Harnessing Radical Relay Strategies for the Difunctionalization of Unsaturated Hydrocarbons Using FGTRs

Inaugural dissertation
of the Faculty of Science,
University of Bern

presented by

Subrata Patra

From India

Supervisor of the doctoral thesis:
Prof. Dr. Dmitry Katayev
Department of Chemistry, Biochemistry, and Pharmaceutical Sciences
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Accepted by the Faculty of Science.

Bern, 06.12.2024

The Dean
Prof. Dr. Jean-Louis Reymond

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to my family

"It is better to live your own destiny imperfectly than to live an imitation of somebody else's life with perfection."

-Krishna

Acknowledgments

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Abstract

This thesis centers on the development and application of functional group transfer reagents (FGTRs) for the radical-mediated difunctionalization of alkenes, utilizing either radical-polar crossover (RPC) or radical ligand transfer (RLT) mechanisms. To promote green and sustainable synthesis, techniques such as photoredox catalysis, electrochemistry, and mechanochemistry are employed to generate reactive radical species under mild conditions. Here's a concise overview of each chapter's content in the thesis:

Chapter 1 introduces alkene reactivity, functionalization, and key synthetic strategies, highlighting mechanisms such as Markovnikov and anti-Markovnikov addition, as well as the importance of functional group transfer reagents (FGTRs). The chapter also outlines foundational tools for transformations, including photochemistry, electrochemistry, and mechanochemistry.

Chapter 2 narrows in on organic nitrating reagents, discussing their properties, reactivity, and applications for targeted functionalization in synthesis.

Chapter 3 details a dual photoredox-cobalt catalyst system for difunctionalizing unsaturated hydrocarbons, focusing on the challenging synthesis of 1,2-halonitroalkanes using N-nitrosuccinimide as a nitryl radical source in radical ligand transfer (RLT) reactions. A cobalt-free, net-neutral radical/polar crossover approach further broadens nucleophile compatibility.

Chapter 4 builds on the previous chapter, introducing a strategy for carbo-heterofunctionalizing alkenes via radical-polar crossover, using geminal bromonitroalkanes with O-centered nucleophiles to synthesize a variety of 1,3-nitro-functionalized products.

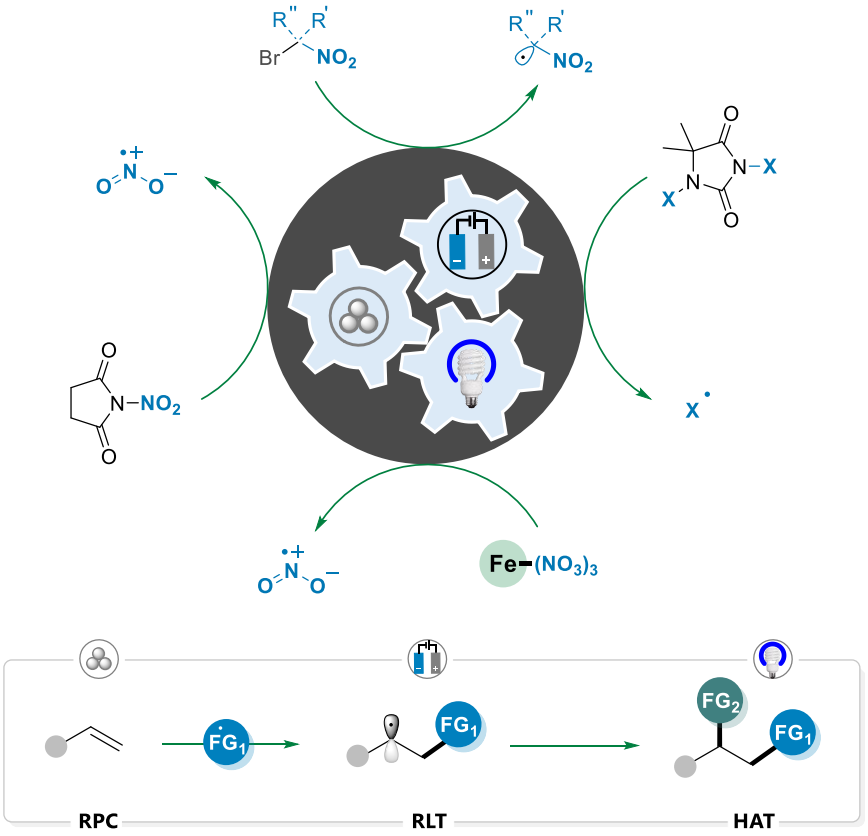
Chapter 5 presents an efficient anti-Markovnikov hydronitration approach for synthesizing terminal nitroalkanes. Using N-nitrosuccinimide and a hydrogen atom transfer (HAT) mediator, this photoredox method achieves regioselective addition, also enabling chain extension using bromonitroalkanes.

Chapter 6 introduces an electrochemical method for generating nitryl radicals from ferric nitrate using simple, cost-effective electrodes, facilitating broad nitration protocols compatible with various substrates. This scalable, electricity-driven approach underscores its sustainable synthesis potential.

Chapter 7 builds on electron catalysis from Chapter 6 by introducing a mechanochemical protocol for alkene difunctionalization using ferric nitrate and catalytic TEMPO. This method achieves selective 1,2-nitronitrooxylation of alkenes under solvent-free conditions, highlighting mechanochemistry's role in radical-driven transformations.

Chapter 8 utilizes ball-milling for solvent-free synthesis of halogenated compounds. Through iron-mediated RLT catalysis, it enables selective dihalogenation of alkenes, producing vicinal dihalides with high selectivity and substrate compatibility, demonstrating mechanochemistry's utility in functionalizing unsaturated hydrocarbons.

This compressed summary captures each chapter's focus, emphasizing advancements in sustainable, radical-based methodologies for alkene functionalization.



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Publications

1. Organic Nitrating Reagents" **S. Patra**, I. Mosiagin, R. Giri, D. Katayev*, *Synthesis* **2022**, *54*, 3432–3472.

2. "Solvent-Controlled Switchable Synthesis of gem-Difluoro Compounds from Anhydrides under Photoredox Catalysis" R. Giri, I. Mosiagin, I. Franzoni, N. Y. Nötel, **S. Patra**, D. Katayev*, *Angew. Chem. Int. Ed*. **2022**, *61*, e2022091.

3. "Nitryl Radical-Triggered Semipinacol-Type Rearrangement, Lactonization, and Cycloetherification of Olefins" R. Giri[†], **S. Patra**[†], D. Katayev*, *ChemCatChem* **2023**, *15*, e202201427. ([†]equally contributed).

4. "Electron-Driven Nitration of Unsaturated Hydrocarbons" **S. Patra**, I. Mosiagin; R. Giri; T. Nauser; D. Katayev*, *Angew. Chem. Int. Ed*. **2023**, *62*, e202300533.

5. "Nitrative Difunctionalization of Alkenes via Cobalt-Mediated Radical Ligand Transfer and Radical-Polar Crossover Photoredox Catalysis" **S. Patra**[†], R. Giri[†], D. Katayev*, *ACS Catalysis*, **2023**, *13*, 16136−16147. ([†]equally contributed).

6. "Simplifying Nitration Chemistry with Bench-stable Organic Nitrating Reagents" **S. Patra**, V. Valsamidou, D. Katayev*, *CHIMIA*, **2024**, *28*, 32–39.

7. "Mechanochemistry Accelerates Alkene Difunctionalization via Radical Ligand Transfer and Electron Catalysis" **S. Patra**, B. N. Nandasana, V. Valsamidou; D. Katayev*, *Adv. Sci.*, **2024**, *11*, 2402970.

8. "Merging Iron-Mediated Radical Ligand Transfer (RLT) Catalysis and Mechanochemistry for Facile Dihalogenation of Alkenes" **S. Patra**, V. Valsamidou, B. N. Nandasana, D. Katayev*, *ACS Catalysis*, **2024**, *14*, 13747–13758.

9. "Facile Access to Terminal Nitroalkanes via Anti-Markovnikov Hydronitration and Hydronitroalkylation of Alkenes Using Photoredox Catalysis" **S. Patra**, D. Katayev*, *Chem. Eur. J.* **2024**, e202403654.

10. "*N*-Nitrosaccharin" V. Valsamidou, **S. Patra**, D. Katayev*, In *e-EROS Encyclopedia of Reagents for Organic Synthesis (EROS)*, **2024**.

11. "*N*-Nitrosuccinimide" **S. Patra**, D. Katayev*, In *e-EROS Encyclopedia of Reagents for Organic Synthesis (EROS)*, **2024**.

12. "Visible-Light-Mediated Vicinal Dihalogenation of Unsaturated C−C Bonds Using Dual-Functional Group Transfer Reagents" R. Giri, [†] E. Zhilin, [†] M. Kissling, **S. Patra**, A. J. Fernandes, D. Katayev*, *J. Am. Chem. Soc.* **2024**, *accepted*. ([†]equally contributed)

13. "Carbo-Heterofunctionalization of Alkenes via Radical-Polar Crossover Photoredox Catalysis: Facile Access to 1,3-Difunctionalized Nitro Compounds" **S. Patra**, V. Valsamidou, B. N. Nandasana, D. Katayev*, *Submitted*, **2024**.

Conference Presentations

1. "Visible Light-Mediated Regio-Selective De Novo Nitrative Difunctionalization of Alkenes Using Bench-Stable Organic Nitrating Reagent." Swiss Photochemistry Symposium **2022**, June 17, 2022, HEIA Fribourg, Switzerland. *(3 min talk & poster)*

2. "A Practical, Versatile Nitration Protocol: Electrocatalytic Activation of Ferric Nitrate." Swiss Catalysis Symposium 2022, June 30, **2022**, University of Bern, Switzerland. *(oral)*

3. "Electrocatalytic Activation of Ferric Nitrate." 17th Belgian Organic Synthesis Symposium (BOSS XVII), July 3–8, **2022**, Namur, Belgium. *(poster)*

4. "A Practical, Versatile Nitration Protocol: Electrocatalytic Activation of Ferric Nitrate." SCS Fall Meeting 2022, September 9, **2022**, Universität Zürich, Switzerland. *(poster)*

5. "Electrocatalytic and Photochemical Nitration: Safe, Sustainable, Selective, Controllable." 4th Swiss Industrial Chemistry Symposium 2023 (SICS 2023), January 27, **2023**, University of Basel, Switzerland. *(poster)*

6. "*N*-Nitrosuccinimide: A Powerful Reagent for the Installation of Nitro Group." 27th International symposium: Synthesis in organic chemistry, July 24-27, **2023**, Oxford, United Kingdom. *(1 min talk & poster)*

7. "Electrochemically Catalyzed Nitration of Unsaturated Hydrocarbons." SCS Fall Meeting **2023**, August 24-25, 2023, University of Bern, Switzerland. *(oral)*

8. "Nitrative Difunctionalization via Radical Ligand Transfer and Radical-Polar Crossover Photoredox Catalysis." School of Photochemistry: from Photocatalysis to Photobiology (photocat24), June 2-7, **2024** Padova, Italy. (poster)

9. "*N*-Nitrosuccinimide: Versatile Organic Reagent for Radical Nitration." 1st Bern Symposium on Radical Chemistry (Bern-SRC-1), June 27- 28, **2024**, University of Bern, Switzerland. *(poster)*

10. "Mechanochemistry Drives Alkene Difunctionalization via Radical Ligand Transfer and Electron Catalysis." SCS Fall Meeting 2024, September 5, **2024**, University of Fribourg, Switzerland. *(poster)*

11. "Molecular Design Using Catalytic Radical Nitration." Hochschule Trifft Industrie 2024, September 25- 27, **2024**, Stein, Switzerland. *(oral)*

Chapter 1:

General Introduction

Parts of this Chapter is adapted from the following publication in peer reviewed journal:

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1. Alkenes and availability

Alkenes are a fundamental class of hydrocarbons defined by the presence of at least one carbon-carbon double bond (C=C).[1] The carbons in this bond are sp^2 hybridized, meaning each carbon combines one s-orbital with two p-orbitals, leaving one unhybridized p-orbital perpendicular to the plane. The sp^2 orbitals overlap to form a C–C σ-bond, while the p orbitals overlap to form a weaker C–C π-bond, resulting in a double bond (Figure 1A). The weaker π-bond makes alkenes highly reactive with a range of reagents, making them versatile intermediates in organic synthesis. In nature, alkenes often exist as parts of more complex molecules, such as unsaturated fatty acids like oleic and linoleic acids, which are found in plant oils and animal fats (Figure 1B).[2] Terpenes, another class of natural compounds with multiple alkene units, are responsible for the aromas of many plants and have significant biological roles (Figure 1C).[3] Industrially, alkenes are primarily derived from the refining of petroleum and natural gas. Ethylene and propylene, the simplest alkenes, are produced in large quantities via steam cracking, where larger hydrocarbons are broken down at high temperatures.[4] In addition to natural sources, alkenes can be synthesized through various methods, including dehydrohalogenation of alkyl halides, dehydration of alcohols, and the Wittig reaction, which transforms carbonyl compounds into alkenes.[5-11] Alkenes also play important roles in biological systems, such as forming the structure of unsaturated fatty acids that are critical for cell membranes and metabolic pathways.[12]

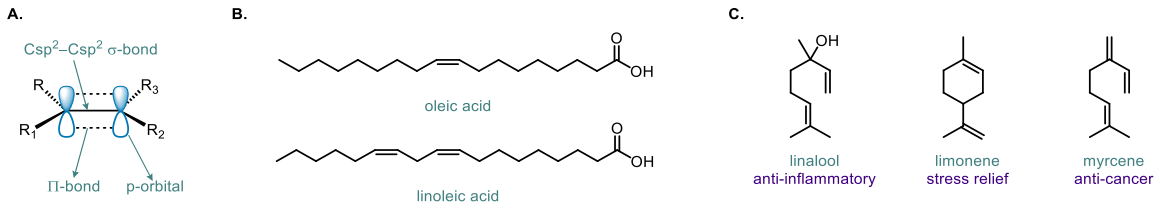

Figure 1. Alkene's reactivity and its presence in natural products.

2. Reactivity of alkenes

Alkenes, though relatively stable, are more reactive than alkanes due to their carbon–carbon π-bond, which is highly accessible and susceptible to addition reactions.[13-15] This reactivity enables a wide range of transformations, including addition, oxidation, polymerization, and cycloaddition, making alkenes essential in organic synthesis and industrial applications.[16] They serve as key feedstocks for manufacturing plastics like polyethylene and polypropylene and are pivotal in reactions such as hydroboration-oxidation, ozonolysis, and the Heck reaction, contributing to the development of pharmaceuticals and fine chemicals.[17-25] Their reactivity is influenced by substitution patterns, with terminal alkenes being more reactive than internal ones, and electron-withdrawing or donating groups further modulating their behavior. While challenges like regioselectivity and stereoselectivity persist, the availability, versatility, and reactivity of alkenes make them indispensable in chemistry.

This thesis focuses on the development and application of catalytic strategies for difunctionalization of alkenes through the introduction of key functional groups. Although alkenes are highly versatile in reactivity, the first chapter will specifically explore various addition reactions to alkenes, with an emphasis on radical-mediated processes.

2.1. Difunctionalization strategies of alkenes

The addition of electrophile-nucleophile (E−Nu) pairs across carbon–carbon multiple bonds is one of the most widely utilized and versatile chemical transformations. These addition reactions are particularly well-suited to meet the current demands of "green chemistry"[26] because they can achieve 100% atom economy[27,28] or atom efficiency,[29] making them highly efficient and sustainable processes. The alkene difunctionalization process can be broadly divided into two major categories: classical two-electron methods and single-electron transfer (SET) methods for olefin functionalization.

2.1.1. Electrophilic addition or classical 2e− methods

In classical two-electron difunctionalization, both electrons from the π-bond of the alkene are involved in the formation of new bonds. These methods typically proceed via ionic or polar mechanisms, where an electrophile adds to the electron-rich π-bond of the alkene, followed by nucleophilic attack (Figure 2). Common examples include hydrohalogenation, halogenation, hydration, and dihydroxylation reactions. These reactions are highly efficient and reliable for introducing two different functional groups across the double bond in a single step, allowing for the rapid transformation of simple alkenes into more complex, functionalized molecules.

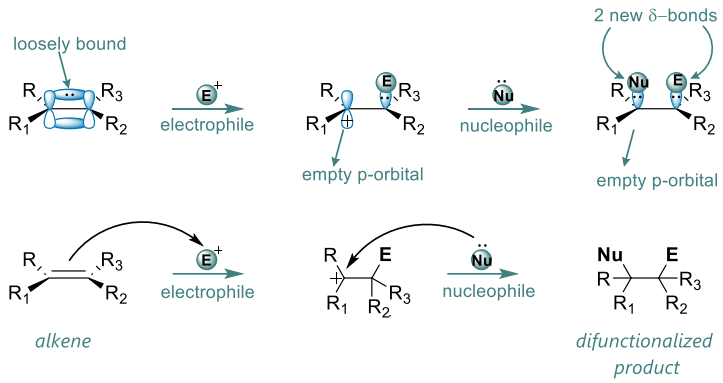

Figure 2. Electrophilic difunctionalization of alkenes.

When the electrophile (E) is hydrogen (H), reactions typically follow Markovnikov addition, where hydrogen attaches to the less substituted carbon, and the electrophile binds to the more substituted (Figure 3). In contrast, in anti-Markovnikov addition, the process is reversed. In H–Nu addition reactions with aliphatic olefins, protonation of the double bond forms a carbocation intermediate. For unsymmetrical alkenes, this can lead to two pathways—Markovnikov or anti-Markovnikov—depending on which carbon is protonated. Often, anti-Markovnikov additions occur via radical mechanisms (Figure 3).

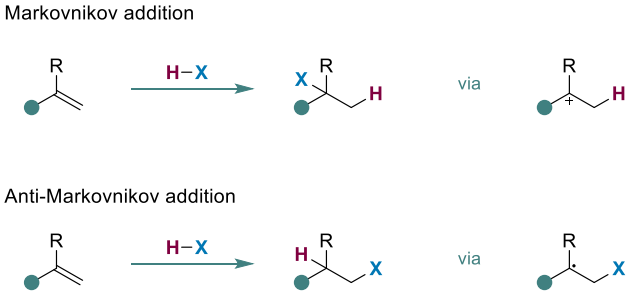

Figure 3. General concept of Markovnikov vs anti-Markovnikov addition.

Markovnikov addition

Markovnikov addition refers to a principle in organic chemistry that governs the regioselectivity of electrophilic addition reactions to alkenes. Formulated by Vladimir Markovnikov in 1869, the rule states: "When a hydrocarbon of unsymmetrical structure combines with a halogen hydroacid, the halogen adds itself to the less hydrogenated carbon atom, that is, to the carbon atom which is more under the influence of other carbon atoms".[30,31] This preference arises because the intermediate carbocation that forms during the reaction is more stable when it is located on the more substituted carbon atom, which can better stabilize the positive charge. Markovnikov's rule is widely applied in the synthesis of various organic compounds, particularly in the formation of alcohols, alkyl halides, and other functionalized hydrocarbons, and plays a crucial role in guiding the outcome of addition reactions in organic chemistry. The key factor in determining which carbocation is formed lies in the stability of the

intermediates. Carbocations can be classified based on the number of alkyl groups attached to the positively charged carbon atom, where tertiary carbocations (three alkyl groups) are more stable than secondary carbocations, and secondary carbocations are more stable than primary carbocations (Figure 4). This effect arises from the electron-donating nature of alkyl groups, which help to stabilize the positive charge on the carbon atom.

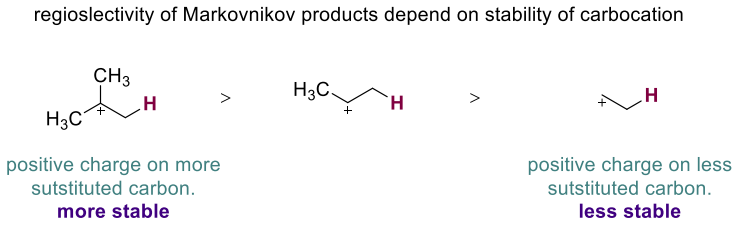

Figure 4. Stability of carbocations.

According to Markovnikov's rule, in electrophilic addition reactions, the proton attaches to the carbon with more hydrogen atoms, forming a more stable carbocation intermediate. In the case of an unsymmetrical alkene like butene, protonation occurs at the terminal carbon, resulting in a secondary carbocation ($CH_3CH_2CH^+CH_3$) rather than a less stable primary one ($CH_3CH_2CH_2^+$). The formation of this secondary carbocation happens with a lower activation energy (ΔE_1) than the formation of the primary carbocation, making it the preferred pathway. This is shown in the energy diagram (Figure 5), where the protonation step (the rate-determining step) has a lower energy barrier for the formation of the secondary carbocation and reacts rapidly with the nucleophile, leading to the final, more stable product.[32] The reaction's outcome is controlled by both kinetic factors (faster intermediate formation) and thermodynamic factors (stability of the final product). Understanding these factors is crucial in predicting regioselectivity in unsymmetrical alkene reactions. This dual control highlights the importance of understanding the energy profiles and transition states in electrophilic addition reactions, particularly when dealing with unsymmetrical alkenes.

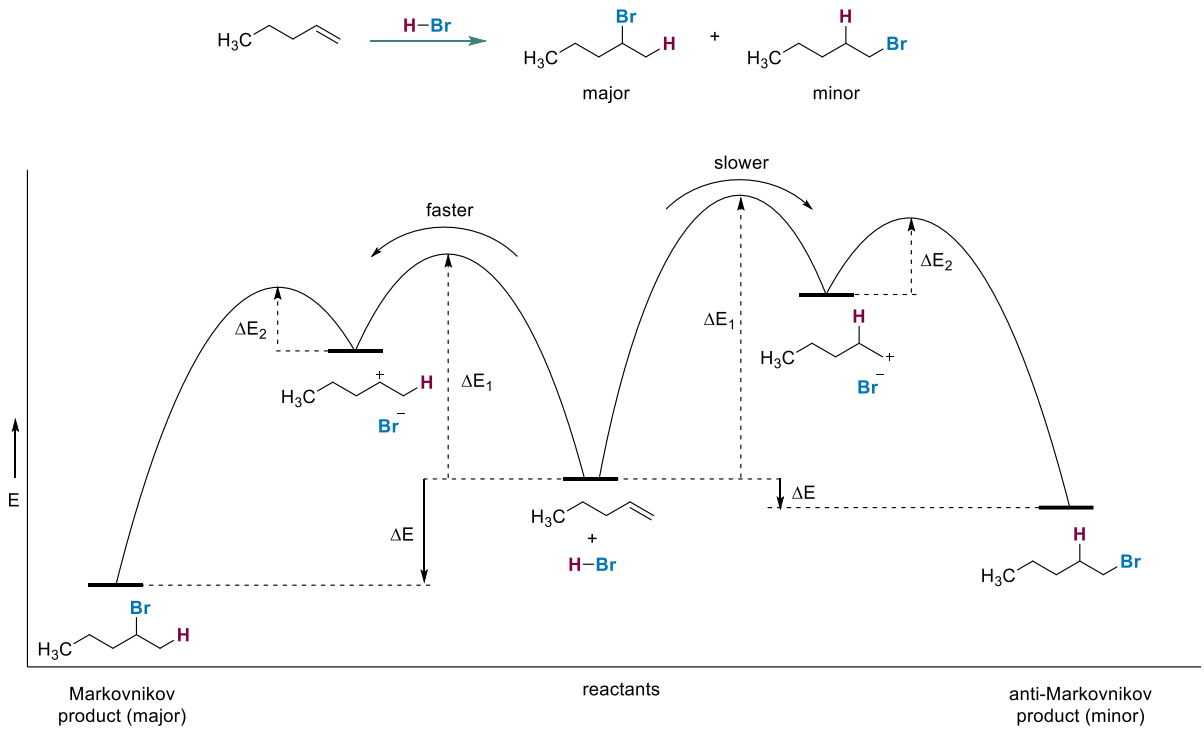

Figure 5. Energy diagram of the Markovnikov addition reaction.

Anti-Markovnikov addition

Anti-Markovnikov addition refers to a regioselective reaction where, in contrast to Markovnikov's rule, the hydrogen atom (H^+) in an electrophilic addition attaches to the carbon of the alkene with fewer hydrogen atoms, while the electrophile (e.g., a halogen or hydroxyl group) bonds to the carbon with more hydrogen atoms. This behavior is often seen in reactions involving radical mechanisms or specific catalysts. A well-known example is hydroboration-oxidation, where boron initially adds to the less substituted carbon, and subsequent oxidation produces alcohols (Figure 6A). Although Markovnikov's original rule applies to hydrogen halides, it has since been expanded to describe polar additions more generally. When E ≠ H, the modern interpretation is that "the electrophile tends to add to the least substituted carbon (primary > secondary > tertiary)."[33] Therefore, in reactions like hydroboration, hydrosilylation, or hydrostannation—where H acts as the nucleophile—an anti-Markovnikov product is formed. Another key example is the radical addition of hydrogen bromide (HBr) to alkenes in the presence of peroxides, which proceeds through a radical mechanism, leading to the attachment of the bromine to the less substituted carbon (Figure 6B). Anti-Markovnikov additions are valuable in synthetic organic chemistry as they allow for the formation of products with different regioselectivity than traditional Markovnikov processes, expanding the scope of possible functional group transformations.

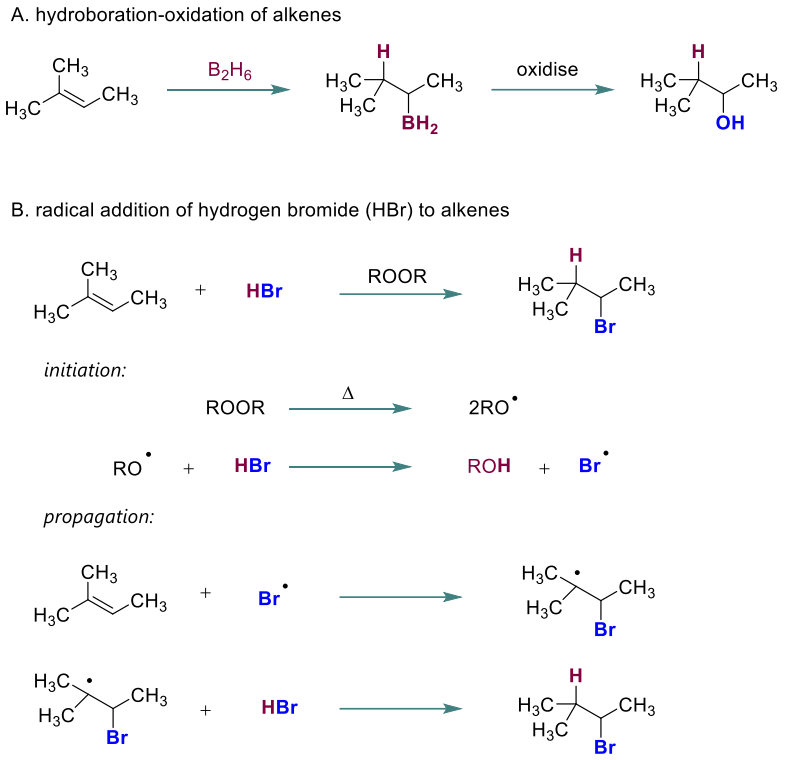

Figure 6. Examples of anti-Markovnikov addition reactions.

2.1.2. Radical addition or 1e⁻ methods

Radical, or one-electron, addition to alkenes is a powerful and versatile method in organic synthesis, especially for radical difunctionalization (Figure 7).[34-40] Unlike traditional two-electron mechanisms that involve electron pair transfers, radical addition proceeds via single-electron transfer (SET), creating reactive radical intermediates. In this process, a radical species adds to one of the carbon atoms in the alkene's π-bond, forming a carbon-centered radical ***Int-1***, which can then undergo further reactions, such as coupling with a second reagent or atom transfer. This enables the introduction of two functional groups across the double bond in a single transformation. One-electron addition to alkenes can follow two key pathways: oxidation, where the alkene forms a radical cation (often through photochemical or electrochemical oxidation), or reduction, where the alkene is reduced to form a radical anion. The radical cation is highly reactive and can react with nucleophiles, while the radical anion reacts with electrophiles to introduce functional groups. These processes offer unique advantages, such as exceptional regio- and stereoselectivity, often producing products that are difficult to obtain through classical two-electron methods. Radical-mediated reactions also proceed under mild conditions and tolerate a wide range of functional groups, making them valuable in constructing complex molecular architectures and indispensable in modern organic synthesis.

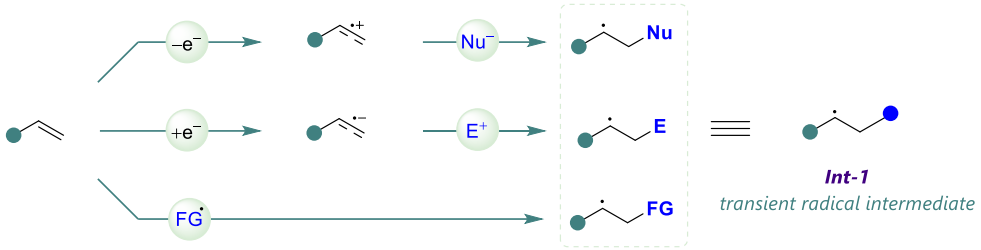

Figure 7. General methods for 1e⁻ addition to alkenes.

Upon forming the transient alkyl radical intermediate (***Int-1***), three possible pathways can deliver the desired difunctionalized products: radical-polar crossover (oxidative or reductive), radical-radical coupling, or transition-metal-mediated coupling. Radical-polar crossover (RPC) is a key concept that merges radical and ionic chemistry (Figure 8).[41-44] In oxidative RPC, a radical is oxidized to a cation, which then undergoes ionic reactions like nucleophilic attack, often driven by photoredox catalysis. Reductive RPC involves the reduction of a radical to form an anion, leading to ionic processes such as electrophilic trapping. RPC enhances synthetic flexibility, enabling reactions like alkene functionalization and nitration. Radical-radical coupling involves the direct bonding of two radicals to form covalent bonds.[45,46,] This method is highly efficient, often occurring under mild conditions with minimal byproducts, and is valuable in polymerization and natural product synthesis, offering broad versatility for complex molecule construction. Transition-metal-mediated or catalyzed coupling in radical functionalization of alkenes enables selective addition of functional groups.[47-50] Metals like copper, iron, or nickel facilitate radical generation and control bond formation. This approach, especially in photoredox catalysis, offers high selectivity and mild conditions, expanding applications in pharmaceuticals and material science.

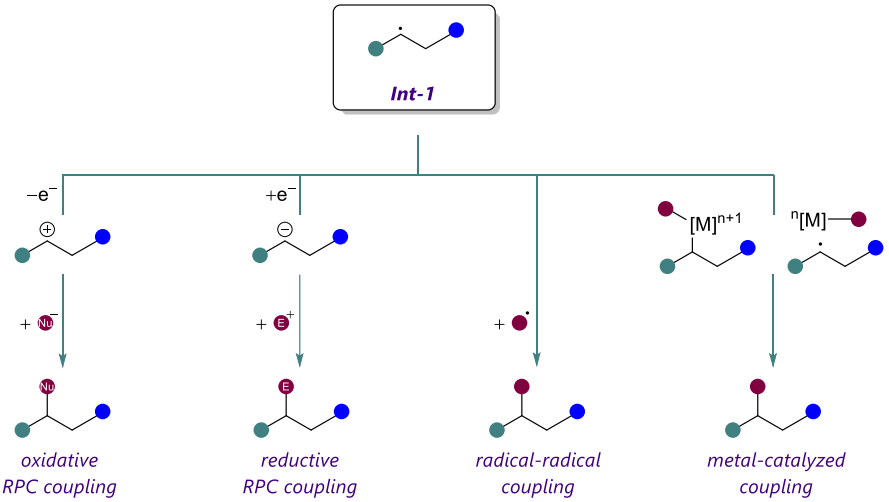

Figure 8. Possible difunctionalization strategies for alkyl radical intermediate (***Int-1***).

3. Functional group transferring reagents (FGTRs)

3.1. Functional groups and their importance

Functional groups are specific atoms or groups of atoms within a molecule that dictate its characteristic chemical reactions. They play a fundamental role in determining a compound's reactivity, polarity, and behavior. Common functional groups include hydroxyl (-OH), carbonyl (-C=O), amino (-NH_2), and nitro (-NO_2), each imparting unique properties. Modifying or introducing functional groups is a core strategy in organic synthesis, allowing chemists to design complex molecules. These groups define molecular properties, influencing aspects like physical characteristics and chemical reactivity (Figure 9). For instance, adding a carboxyl group (-COOH) to hexane transforms it from a nonpolar hydrocarbon to hexanoic acid, a water-soluble, acidic molecule. Similarly, introducing a nitro group (-NO_2) to toluene increases the molecule's electron-withdrawing character, reducing the reactivity of the aromatic ring toward electrophilic substitution and making it more reactive in nucleophilic substitution reactions. When acetic acid is reacted with methanol to form methyl acetate, the transition from a carboxylic acid to an ester result in a less polar, less water-soluble compound, with lower boiling points—properties valuable in applications such as solvents and fragrances. In each case, the functional group profoundly impacts the molecule's reactivity and utility in industrial or biological processes.

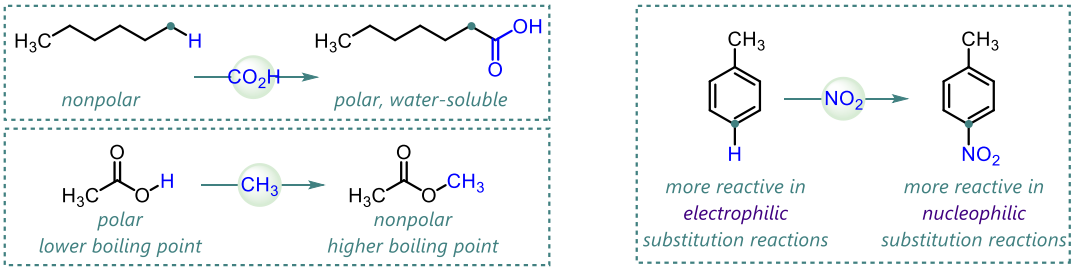

Figure 9. Representative effects of functional groups in small molecules.

Introducing or modifying functional groups (FGs) can dramatically influence a molecule's properties, particularly in fields like pharmacology, where they affect potency and selectivity (Figure 10). Functional groups play a critical role in dictating how compounds behave in both chemical reactions and biological systems, impacting everything from reactivity to physical attributes. In medicinal chemistry, they determine how drugs interact with biological targets, affecting efficacy, selectivity, and stability. For example, the "magic methyl effect" refers to the addition of a methyl group, which often enhances a molecule's potency and binding affinity compared to its unmethylated counterpart. Similarly, the trifluoromethyl (-CF_3) group can transform a molecule's bioactivity. In fluoxetine (Prozac), a commonly used SSRI, the trifluoromethyl group boosts its ability to cross the blood-brain barrier, increases lipophilicity, and enhances metabolic stability, making the drug more effective with fewer doses.

Fluorine also plays a crucial role in drug design. In fluorouracil (5-FU), a chemotherapeutic drug, the replacement of hydrogen with fluorine in uracil transforms the molecule into an antimetabolite that disrupts DNA synthesis in cancer cells, inhibiting their growth. This small fluorine substitution prevents normal cell division by interfering with enzymatic processes.

Nitro groups can similarly drive biological activity. For instance, nitrofurantoin, used to treat urinary tract infections, derives its potency from the nitro group, which generates reactive intermediates that damage bacterial DNA. Nifurtimox, an antiparasitic drug for treating Chagas disease, relies on the nitro group to produce toxic radicals that inhibit Trypanosoma parasites. Chloramphenicol, an antibiotic, also depends on its nitro group to bind to bacterial ribosomes and impede protein synthesis. Without the nitro group, these compounds would lose much of their therapeutic efficacy, highlighting the essential role of functional groups in drug design and activity.

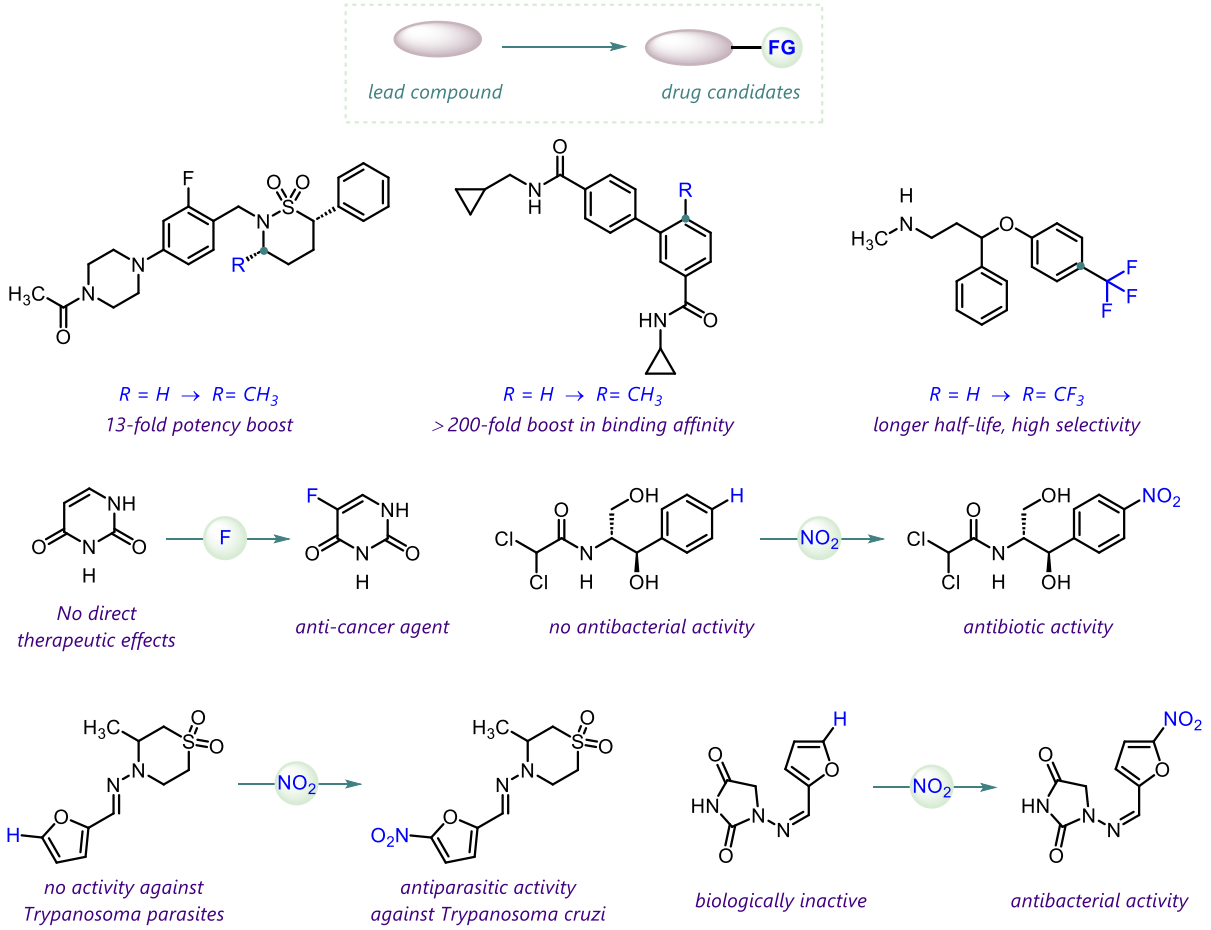

Figure 10. Effect of functional groups in drug molecules.[51,52]

3.2. Functional group transfer reagents

Functional group transfer reagents are indispensable tools in organic chemistry, allowing for the selective addition, modification, or exchange of functional groups within a molecule. Reagents like Grignard reagents, organolithiums, and boron-based compounds (e.g., boranes) enable the efficient introduction of functional groups such as hydroxyl, halides, or alkyl chains. Oxidizing agents such as permanganate or chromate can add oxygen-containing groups, while reducing agents like lithium aluminum hydride can remove or convert functional groups to less oxidized states. The precise control over functional group modifications is especially critical in pharmaceuticals, where little changes in the structure can dramatically impact a drug's efficacy. FGTRs enhance synthesis efficiency by reducing steps and optimizing processes, making them vital in the development of new compounds across industries such as medicine, agrochemicals, and material science.

In functional group transfer reagents, the second component, aside from the functional group itself, is typically called the leaving group, carrier group, or redox auxiliary (Figure 11). This part helps to deliver the functional group to the target substrate and is often discarded or transformed during the reaction. For instance, in organolithium reagents (R-Li), the alkyl or aryl group (R) is the functional group, while lithium acts as the carrier. The carrier group is crucial for the reagent's reactivity and selectivity during functionalization. Depending on the activation energy source and the functional group transfer reagent (FGTR) used, three types of reactive functional groups can typically be generated: radical, electrophilic, and nucleophilic species (Figure 11). However, this thesis specifically focuses on the generation of active radical functional groups through various energy-efficient and sustainable methods. These radical species are then employed in radical relay difunctionalization of alkenes, enabling the selective introduction of multiple functional groups in a single process. By concentrating on radical chemistry, this work aims to explore novel reactivity patterns and expand the scope of difunctionalization strategies in a more environmentally friendly and resource-efficient manner.

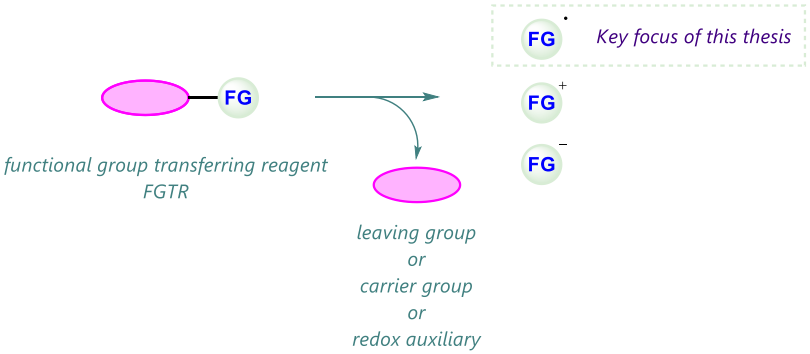

Figure 11. Types of reactive functional groups.

3.3. Toolboxes for radical relay functional group transfer

Radical relay functional group transfer has emerged as a powerful and versatile strategy in modern synthetic chemistry, enabling the efficient construction of complex molecular architectures. This process involves the generation of reactive radical intermediates that mediate the transfer of functional groups in a controlled manner. Unlike traditional two-electron pathways, radical-based methods offer distinct advantages, including mild reaction conditions, tolerance of diverse functional groups, and the ability to engage otherwise inert bonds. To harness the full potential of radical relay for functional group transfer, several advanced toolboxes have been developed, particularly in the areas of photochemistry, electrochemistry, and mechanochemistry. These approaches provide chemists with a diverse set of techniques for generating and manipulating radicals, thus expanding the scope of radical-mediated reactions in organic synthesis.

3.3.1. Photochemistry

Photochemistry, which involves the use of light to initiate chemical reactions, has become one of the most prominent and widely used tools for radical relay functional group transfer.[53-57] The key advantage of photochemistry lies in its ability to generate radical species under mild, energy-efficient conditions by harnessing the power of photons. The use of visible light to drive organic transformations has grown significantly over the past decade due to several key advancements. Increased emphasis on energy-efficient reactions has made visible light an ideal reaction component. The development of affordable, high-intensity LEDs and advances in flow chemistry with transparent reactors have improved scalability and reproducibility, making photocatalysis more accessible. Classical photochemistry, using ultraviolet light for direct excitation of organic compounds, has been a well-established field for over a century. However, it was often viewed by many researchers as a specialized and challenging technique. This perception has shifted with the advent of visible light, photoredox catalysts, and sensitizers. Reaction setups for visible light photochemistry are similar to traditional thermal chemistry, differing mainly in the light source. Visible light, with lower energy than UV, often leads to more selective, predictable, and controllable reactions. This has renewed interest in radical and radical ion intermediates, making visible-light-mediated photoredox reactions a powerful tool in organic synthesis. The use of visible light to drive organic transformations dates back over a century. Italian chemist Giacomo Ciamician, alongside Paul Silber, pioneered photochemical reactions with visible light in the early 1900s (Figure 12).[58] By the 1980s and 1990s, photoredox catalysis was being explored further in organic synthesis. Alain Deronzier demonstrated the first visible-light Pschorr cyclization,[59] while Ganesh Pandey[60] developed near-visible light photocatalytic cycloadditions. Researchers like Angelo Albini, Vincenzo Balzani, Janine Cossy, and Frederick Lewis also contributed significantly to the study of photoinduced electron-transfer steps in organic chemistry.

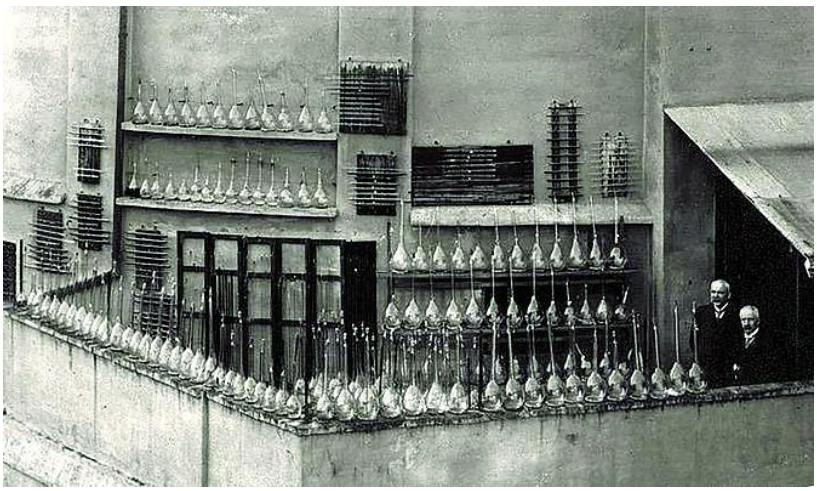

Figure 12. Use visible light for chemical reactions with the help of sunlight on the balcony of the Chemical Institute of the University of Bologna, Italy.[61]

Photochemical reactions can be categorized in various ways, depending on parameters such as reactivity, catalytic activity, conceptual framework, or even practical application (Figure 13). One approach is to classify them by reactivity, where reactions are grouped based on the type of intermediates formed or the nature of the reactivity. For example, radical-based reactions involve free radicals, while radical ion-based reactions feature radical cations or anions, often seen in photoredox catalysis. Reactions can also involve pericyclic mechanisms such as [2+2] cycloadditions, or proceed through energy transfer between a photocatalyst and a substrate. Another way to categorize photochemical reactions is by catalytic activity, which distinguishes between catalyzed and non-catalyzed processes. In photocatalytic reactions, light-absorbing catalysts facilitate the transformations; these include organometallic catalysis, where metal complexes like ruthenium or iridium play a key role, and organic photocatalysis, where organic dyes such as eosin Y act as catalysts. Conversely, non-catalytic photochemical reactions involve direct light excitation of the substrate, like UV-induced photodimerization. Reactions can also be classified by conceptual frameworks, including photoredox reactions that rely on light-induced electron transfer, energy transfer reactions, where excited-state energy is transferred to the substrate, and atom transfer reactions, in which excitation leads to the transfer of atoms such as hydrogen or halogen. Other notable categories include photoisomerization, where light induces changes between different isomers, and photocycloadditions, where unsaturated molecules form cyclic products under light exposure. Classifications can also be based on the source of light used in the reactions. For example, UV-induced reactions rely on ultraviolet light for direct molecular excitation, whereas visible-light photocatalysis uses photosensitizers or catalysts activated by visible light. Additionally, photochemical reactions can be grouped by reaction type, distinguishing between processes like bond formation (e.g., C–C bond formation via radical addition) and bond cleavage (e.g., photooxidation or decarboxylation), as well as functional group transformations like photohalogenation or photoreduction. Photochemical reactions can also be categorized by the nature of the substrates, such as organic photochemistry involving organic molecules, inorganic photochemistry involving metal complexes, and biomolecular photochemistry as

seen in DNA photodamage or photosynthesis. Lastly, a practical classification can be based on industrial or practical applications, including environmental photochemistry for pollutant degradation, synthetic organic photochemistry for complex molecule synthesis, and materials science, where photochemistry plays a role in creating polymers, semiconductors, or photoresponsive materials.

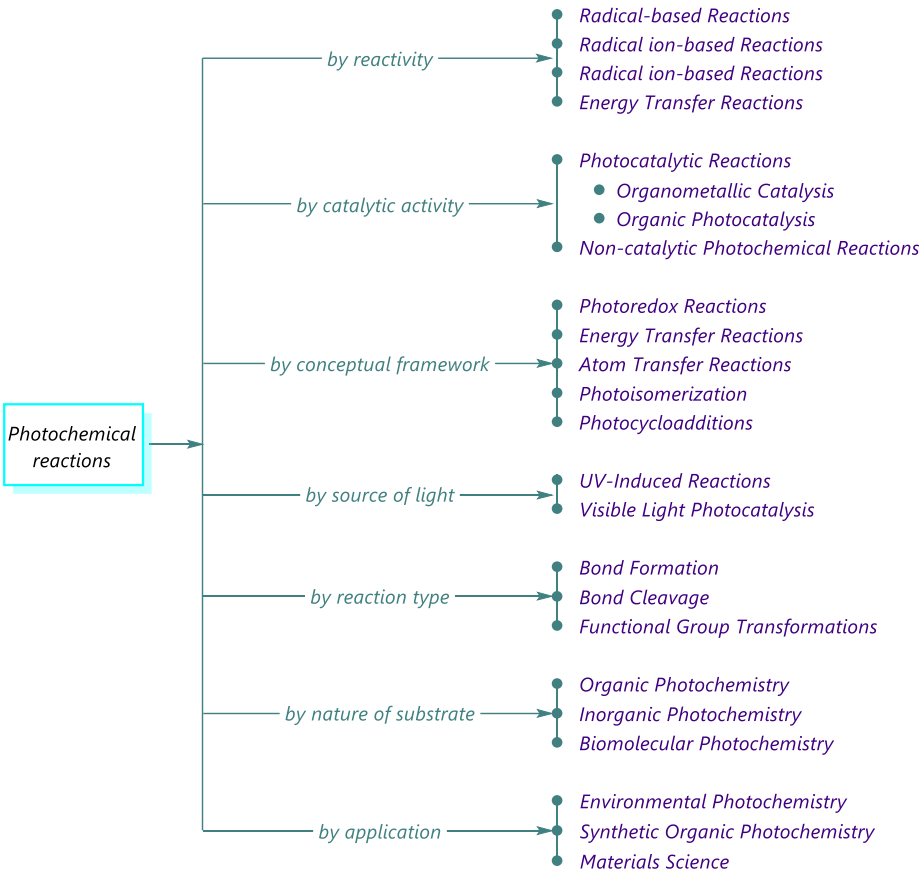

Figure 13. Types of photochemical reactions.

Each of these mechanisms plays a crucial role in converting photon energy into chemical reactivity, driving selective molecular transformations that expand the toolkit of modern synthetic chemistry.

3.3.1.1. Visible-light Photoredox catalysis

Among the categories discussed, visible-light photocatalysis is a powerful and environmentally friendly approach in organic chemistry that harnesses visible light to drive chemical reactions and is applied in Chapters 3, 4, and 5.

Unlike traditional photochemical processes that require high-energy ultraviolet (UV) light, visible-light photocatalysis harnesses lower-energy light, which is both more abundant and safer. Photoredox catalysis is a technique in synthetic chemistry where light, through the action of a photocatalyst, drives chemical reactions by promoting electron transfer events. The term "photoredox" combines "photo" (light) and "redox" (reduction-oxidation), highlighting the light-induced electron transfer mechanism.[62,63] When a photocatalyst like $Ir(ppy)_3$ (tris(2-phenylpyridine)iridium(III)) absorbs visible light, it enters an excited state, allowing it to either donate or accept electrons. This electron transfer generates reactive intermediates—such as radicals, cations, or anions—which then participate in subsequent chemical transformations. $Ir(ppy)_3$ is particularly favored for its excellent photophysical properties, making it a highly efficient and versatile tool in visible-light-driven synthetic reactions. Understanding its molecular orbital (MO) transitions is key to grasping how it mediates these transformations. (Figure 14).[64]

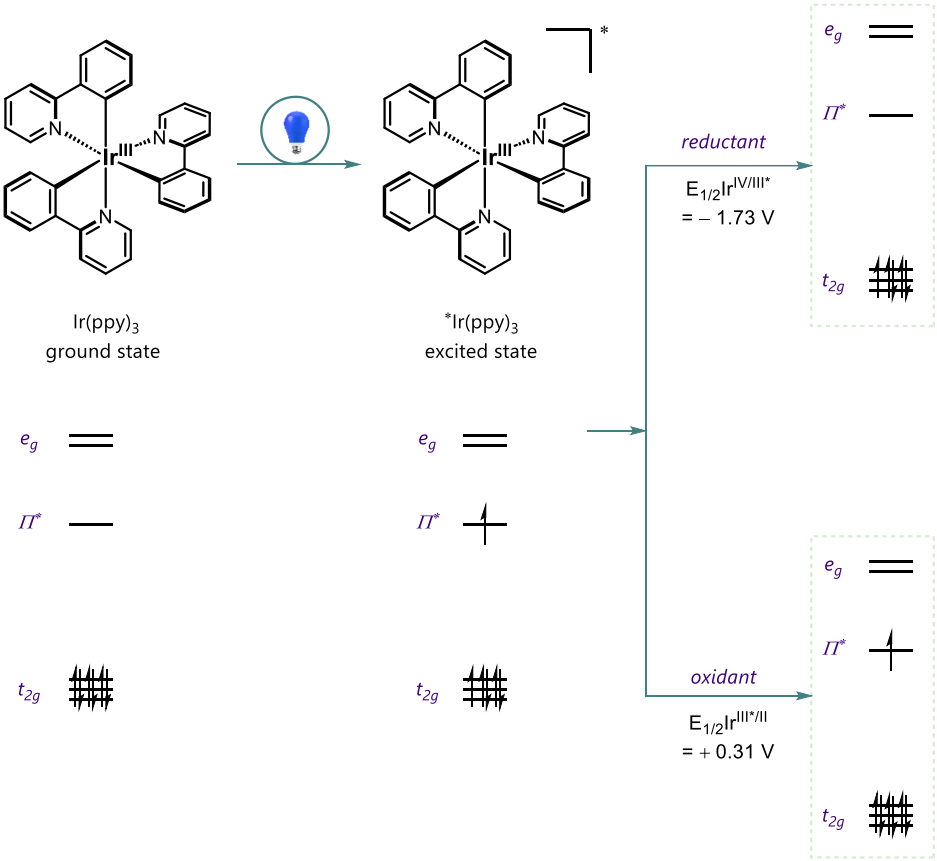

Figure 14. Molecular orbital depiction of $Ir(ppy)_3$ photocatalyst.

The photocatalyst $Ir(ppy)_3$, or tris(2-phenylpyridine)iridium(III), is a widely used organometallic complex in photoredox catalysis due to its excellent photophysical properties, governed by its molecular orbitals (MOs) and electronic transitions. The iridium (Ir^{3+}) center is coordinated to three phenylpyridine (ppy) ligands, creating a molecular orbital arrangement where the metal d-orbitals form the HOMO and the ligands' π-orbitals form the LUMO. When irradiated with visible light (around 450 nm), an electron from the Ir 5d HOMO is excited to the ligands' π LUMO, undergoing a metal-to-ligand charge transfer (MLCT), which generates a long-lived excited state. In this state, $Ir(ppy)_3$ can act as either a reductant by donating an electron (becoming oxidized to $Ir(ppy)_3^+$) or as an oxidant by accepting an electron and returning to its ground state. This redox versatility enables $Ir(ppy)_3$ to participate in both oxidative and reductive radical generation. After redox reactions, the complex returns to its ground state via interaction with a donor or acceptor. Its strong redox potentials—reductive (~ −1.73 V vs SCE) and oxidative (~ +0.31 V vs SCE)—make $Ir(ppy)_3$ an effective photocatalyst for a wide range of photoredox transformations in organic synthesis (Figure 14).

Photoredox catalytic reactions typically proceed via one of two main pathways: oxidative or reductive quenching cycle (Figure 15). In the oxidative quenching pathway, the excited photocatalyst ($[PC^n]^*$) donates an electron to an oxidant or substrate, resulting in its oxidation to $[PC^{n+1}]$. The photocatalyst then returns to its ground state by accepting an electron from a reductant. Conversely, in the reductive quenching pathway, the excited photocatalyst accepts an electron from a reductant or electron-rich substrate, forming $[PC^{n-1}]$, and is restored to its ground state by donating an electron to an oxidant. These alternating redox states enable a wide range of chemical transformations, including bond formation and radical reactions. In photoredox catalysis, substrates can experience one of three general redox outcomes, whether the electron transfer (ET) occurs in the photoinduced electron transfer (PET) step or the catalyst turnover step: net oxidative, net reductive, or net redox-neutral. In a net oxidative reaction, an external oxidant accepts electrons during either the PET or turnover step. Conversely, net reductive reactions involve an external reductant donating electrons at these stages. Net redox-neutral reactions are more complex, typically involving return electron transfer with the oxidized or reduced catalyst, sometimes aided by a redox-active co-catalyst.

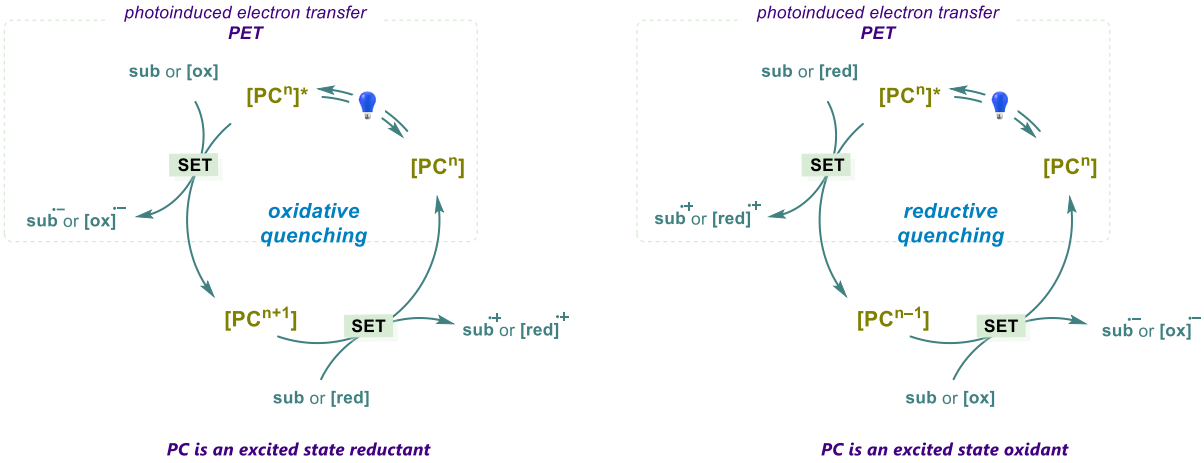

Figure 15. Oxidative and reductive quenching cycles.

These intermediates can then participate in selective bond formation or cleavage reactions. Visible-light photocatalysis has gained significant attention for its ability to facilitate various transformations, including C–C bond formation, oxidation, reduction, and functionalization of alkenes. Its advantages include mild reaction conditions, high selectivity, and the potential to design more sustainable, energy-efficient chemical processes. Due to its broad applicability, visible-light photocatalysis has become a crucial tool in modern synthetic chemistry, as reflected in its use in cutting-edge research and industrial applications.

In radical relay functional group transfer, photochemical approaches enable the selective activation of specific bonds, allowing for precise functionalization of alkenes, alkynes, and other unsaturated systems.[65] Photocatalysts, such as iridium and ruthenium complexes, are frequently employed to mediate the transfer of functional groups, including halogens, nitro, and trifluoromethyl groups.[66] Additionally, photochemical methods allow for dual catalytic systems, where a photocatalyst works in tandem with another catalyst (e.g., metal catalysis) to perform complex transformations. The tunability of light and photocatalyst design has made photochemistry a crucial toolbox in the radical relay functionalization landscape.

3.3.1.2. Electron donor-acceptor (EDA) complex

Recently, a photochemical approach distinct from traditional photoredox catalysis has emerged, focusing on the intrinsic interaction between an electron acceptor substrate and a donor molecule, which leads to the formation of an electron donor-acceptor (EDA) complexes capable of light absorption.[67-69] This interaction can trigger an intramolecular single-electron-transfer (SET) event, generating radical intermediates under mild conditions. Although the photophysics of EDA complexes have been extensively studied since the 1950s, their application in chemical synthesis has been limited until recently, with growing interest among chemists opening new avenues in synthetic chemistry.

An EDA complex, or charge-transfer complex, is formed through the interaction between an electron-rich donor and an electron-deficient acceptor, leading to partial electron transfer and stabilization via electrostatic attraction. When excited by visible or ultraviolet light, these complexes can produce radical ion pairs, facilitating challenging reactions through a process known as photoinduced electron transfer. This mechanism is essential in modern synthetic chemistry, allowing for reactions such as oxidation, cycloaddition, and radical formation under milder conditions, thereby minimizing the need for external catalysts.

EDA complexes are increasingly recognized in green chemistry, photoredox catalysis, polymer synthesis, and organic photovoltaic materials. They may show photolytic reactivity even without a photoredox catalyst, often indicated by a color change upon mixing reactants. Pioneering work by Kochi[70-73] laid the groundwork for further advancements by researchers like Melchiorre,[74-77] who have utilized EDA complexes for catalyst-free photolytic transformations with visible light, taking advantage of these complexes' ability to absorb lower-energy photons.

3.3.2. Electrochemistry

The term "electricus" was first coined by William Gilbert in 1600, marking the beginnings of electrochemistry (Figure 16).[78,79] In 1786, Luigi Galvani's experiment with frog legs led to Alessandro Volta's development of the first electric battery.[80] Michael Faraday's 1834 laws of electrolysis and Hermann Kolbe's first organic electrosynthesis in 1848 laid the groundwork for electrochemical applications in chemical reactions.[81-85] Over the following century, electrosynthesis advanced, giving rise to industrial processes like the Monsanto adiponitrile process and key reactions such as Shono oxidation and electrofluorination.[86-90] In the late 20th century, Yoshida introduced electro auxiliaries to selectively lower the electrochemical potential of substrates, and the concept of using redox mediators for indirect electrolysis was formalized by Steckhan in the 1980s.[91-93]

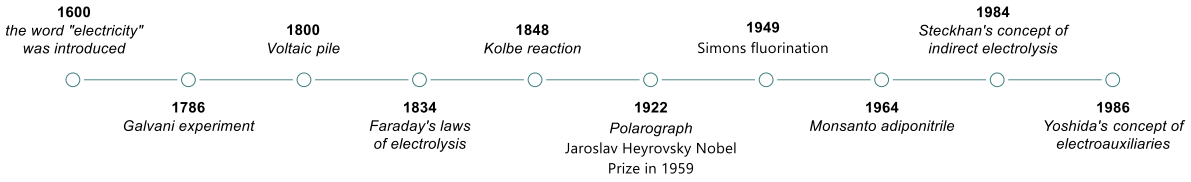

Figure 16. Selective milestones of electrochemistry in organic synthesis.

Pioneering researchers like Little,[94-97] Schäfer,[98,99] Lund,[100,101] Moeller,[102-104] Amatore,[105] Jutand,[106] and Yoshida[107,108] played a crucial role in advancing electrosynthesis as a sustainable and powerful method in organic chemistry. The resurgence of electrosynthesis is driven by its unique ability to enable highly selective reactions through electrochemical or photoelectrochemical mechanisms, bypassing the need for stoichiometric redox reagents and minimizing byproducts (Figure 17).[109-112] The development of commercial electrochemical equipment has made this approach more accessible, while its mild conditions, often using protic solvents, enhance environmental sustainability.[113,114] Electrochemistry also offers precise control over reactivity and chemoselectivity via applied potential, unlocking new reaction pathways and enabling resource-efficient transformations, especially in pharmaceuticals and materials science.[115]

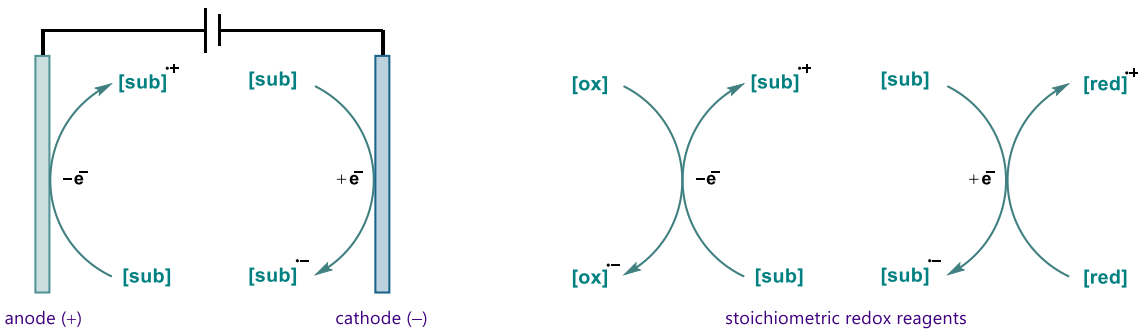

Figure 17. Electricity replacing stoichiometric redox reagents.

Direct electrolysis enables molecules to undergo electron transfer directly at the electrode surface (Figure 18).[116] In contrast indirect electrolysis, utilizing redox mediators, can further enhance efficiency and selectivity, avoiding unwanted side reactions and enabling better control over reaction processes (Figure 18). The combination of electrosynthesis with other catalytic methods, such as transition metal catalysis or electrophotochemistry, has led to novel reaction pathways and bond functionalizations, expanding the scope of modern organic synthesis. Indirect electrosynthesis, in particular, improves reaction outcomes by using a redox mediator to facilitate electron transfer, providing advantages in reaction efficiency and selectivity.[117] Common redox mediators such as N-hydroxyphthalimide (NHPI), quinuclidine, quinones, TEMPO (2,2,6,6-tetramethylpiperidinyl-1-oxy), potassium ferrocyanide, and ferrocene ($FeCp_2$) have proven to be highly effective in facilitating various organic transformations, particularly alkene functionalizations (Figure 18). These mediators act as electron carriers, enabling smoother electron transfers and improving reaction efficiency. Their use has been integral in the synthesis of complex molecules, helping to achieve greater selectivity and control over reaction conditions and minimizing byproduct formation, while also promoting desired transformations.

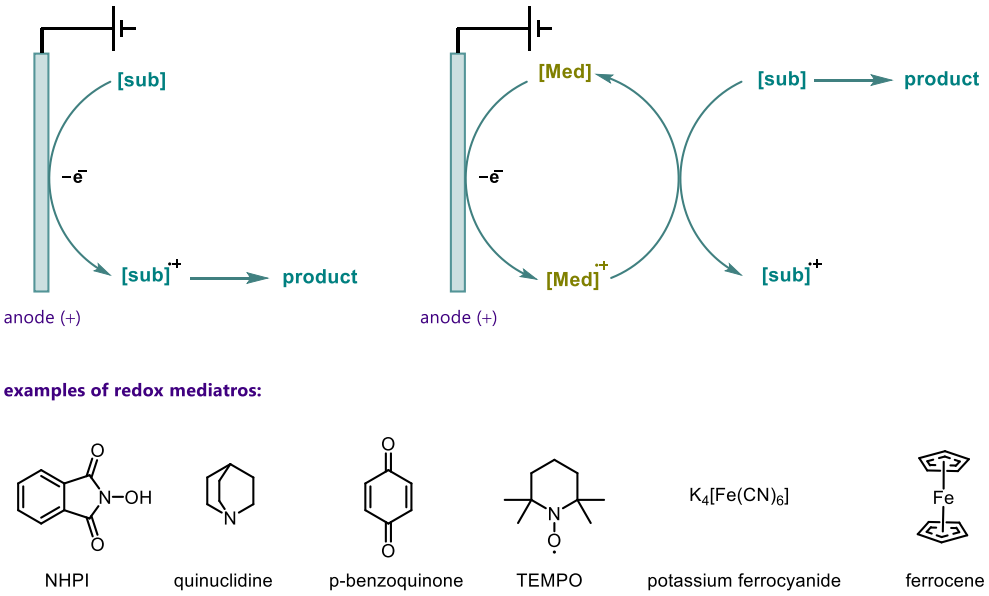

Figure 18. Electricity replacing stoichiometric redox reagents.

Electrochemically driven radical relay difunctionalization of alkenes is an emerging and sustainable strategy for constructing complex molecules.[118,119] This method utilizes electrochemical setups to generate radicals directly at the electrode surface, bypassing the need for traditional chemical oxidants or reductants, and thus minimizing the formation of waste byproducts. In this process, the electric current serves as the primary reagent, enabling precise control over radical generation and transfer. The radical is initially formed at one position of the alkene, which then "relays" to a different site, facilitating the introduction of two distinct functional groups across the alkene in a highly controlled manner. Lin and colleagues made significant strides in the electrochemically driven radical relay difunctionalization of alkenes with their innovative approach to diazidation, yielding vicinal diazides (Figure 19).[120] In this

method, the azidyl radical (N_3•) is anodically generated from sodium azide (NaN_3) and subsequently adds across the alkene's C=C bond, forming two new C–N bonds and releasing hydrogen gas and sodium acetate as byproducts. The reaction is catalyzed by manganese(II) bromide ($MnBr_2$) in combination with electrochemical conditions. This technique showcases broad substrate versatility and excellent functional group tolerance, making it applicable to terminal, internal, and cyclic alkenes. It also demonstrates compatibility with various functional groups, including alcohols, aldehydes, enolizable ketones, carboxylic acids, amines, sulfides, and alkynes, whose oxidation potentials exceed the catalytic voltage of Mn(II)–N_3, thus preventing interference. The reaction mechanism involves anodically coupled electrolysis, where the azido anion reacts with Mn^{II} to form a Mn^{II}–N_3 intermediate. This is oxidized to Mn^{III}–N_3, which selectively reacts with the alkene, ensuring controlled radical generation and preventing undesirable side reactions such as azide radical dimerization. This method has proved effective for synthesizing vicinal diazides across a wide range of substrates.

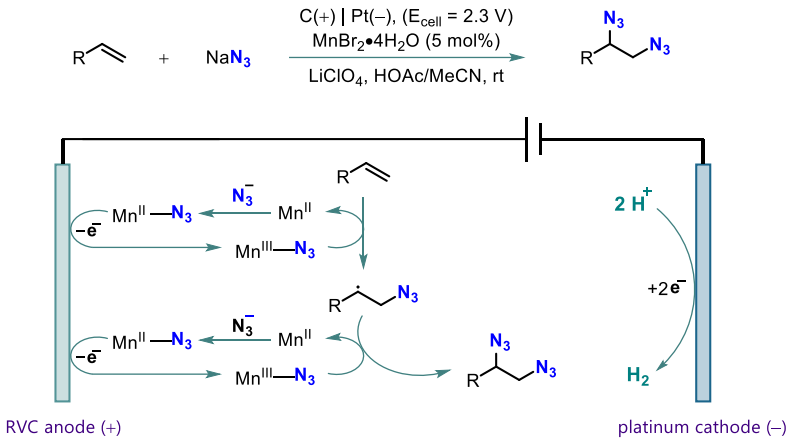

Figure 19. Example of electrochemical diazidation of alkenes.

Several electrochemical radical-mediated difunctionalization reactions of alkenes have since been developed, including silyl-oxygenation, azidooxygenation, chlorotrifluoromethylation, heteroaryltrifluoromethylation, and dichlorination.[121-125] In Chapter 6 of this thesis, we explore a unified, modular protocol for the electrochemical conversion of unsaturated hydrocarbons into nitro group-containing building blocks. This process employs inexpensive ferric nitrate as a nitrating reagent under electrochemically induced conditions, providing an efficient method for the functionalization of alkenes with nitro groups, and expanding the toolbox of radical-mediated alkene transformations.

3.3.3. Mechanochemistry

The earliest recorded instance of mechanochemistry dates back to 314 B.C., when Theophrastus, a student of Aristotle, described the grinding of cinnabar with acetic acid in a copper mortar to produce elemental mercury (Figure 20).[126] Although records are sparse, mortars were a staple in alchemists' and early chemists' labs until they were replaced by glassware. Mechanochemistry began gaining systematic attention in the 19th century. In 1820, Michael Faraday observed silver production when grinding zinc and silver chloride.[127] Later, Walther Spring and Matthew Carey Lea explored mechanochemical processes, demonstrating that poor solubility in reactants like barium sulfate could be overcome by grinding solid-state reactants.[128] In 1893, Ling and Baker synthesized halogen derivatives of quinhydrone using grinding with liquid assistance, a method now called liquid-assisted grinding (LAG).[129] The term "mechanochemistry" was officially introduced by Wilhelm Ostwald in 1919, and further defined by G. Heinicke in 1984, recognizing it as a distinct branch of chemistry alongside thermochemistry, photochemistry, and electrochemistry.[130,131]

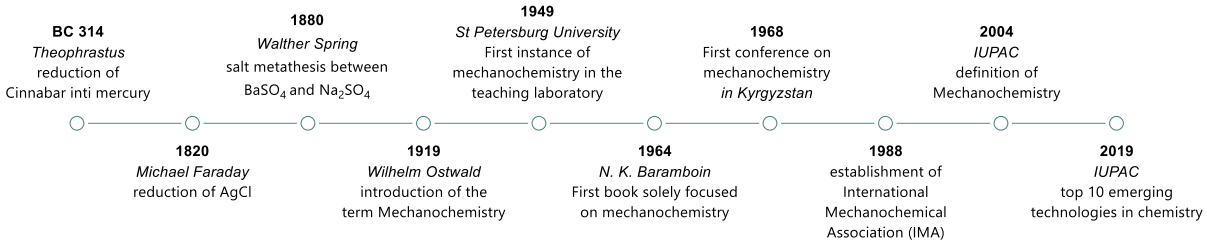

Figure 20. Timeline of mechanochemistry.

The shift from fossil fuels to cleaner energy sources is accelerating due to the depletion of fossil fuels and their environmental impact.[132] Renewable energy options like hydropower, wind, solar, biomass, ocean, and geothermal energy are sustainable and eco-friendly, but their intermittent nature poses challenges.[133,134] Mechanochemistry, which uses mechanical energy for chemical reactions, is a promising method for synthesizing energy conversion materials.[135] Techniques include using mortar and pestle, ball mills, and extruders (Figure 21). Automated ball mills, such as planetary and mixer mills, offer better reproducibility and control, making mechanochemistry a valuable tool in energy conversion research.

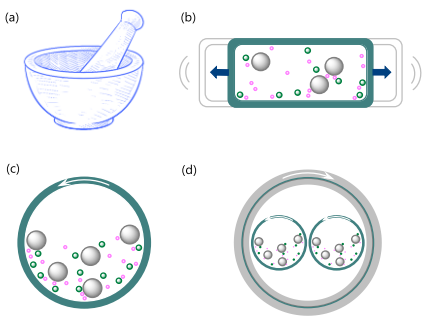

Figure 21. Schematic representations of the three main modes of mechanical activation: (a) grinding with mortar and pestle; (b) vibration milling; (c) & (d) planetary ball milling.

In ball mills, mechanochemistry transfers energy to reactants through the collision of milling balls, offering a solvent-free and sustainable method. By eliminating the need for solvents, it reduces waste and improves energy efficiency, as no heating, cooling, or pumping is required.[136] Additionally, the lack of solubility constraints allows for a broader range of reactants, enabling reactions that would otherwise be limited by solvent requirements. Although mechanochemistry typically involves solid-state reactions, it can also be applied to gas and liquid reactants, further expanding its versatility and environmental benefits.[137] Key parameters affecting reactions include milling time, frequency, filling degree, ball size and quantity, ball material, and reaction temperature.[138-142] Longer milling times increase yield but risk product degradation and equipment abrasion. Higher milling frequencies accelerate reactions but raise vessel temperatures and wear. Optimizing the filling degree, ball size, and number of balls improves reaction efficiency, while controlling the temperature can alter product outcomes.

A mechanochemical reaction occurs when mechanical energy directly triggers a chemical transformation. This energy, generated by methods such as ball milling, grinding, and extrusion, induces phase changes, structural alterations, crystalline transformations, and surface activation, ultimately leading to chemical reactions. The kinetic energy involved promotes material wear, fracture, and refinement, increasing specific surface areas and enhancing component interactions at surfaces or boundaries, where most reactions occur. Due to the unpredictable nature of mechanochemical outcomes, it is a promising field for discovering novel chemical reactions. Ball milling has been widely studied in various reactions, including olefin metathesis,[143] Suzuki-Miyaura coupling,[144,145] Negishi coupling,[146] Friedel-Crafts,[147] Sonogashira coupling,[148] C-H activation,[149] and Buchwald-Hartwig.[150]

Recent advances suggest that mechanochemistry can offer alternative selectivity and withstand conditions that are difficult in traditional solution-based methods, making it both an eco-friendly and innovative approach for exploring new chemical transformations. Among the many advantages—such as reduced solvent use, better yields, shorter reaction times, the ability to use insoluble starting materials, and improved safety—two standout benefits are distinct reactivity and the potential for discovering new reaction pathways. Certain chemical transformations are achievable through mechanochemical processes that cannot occur in traditional solution-based methods. For instance, when β-enaminones react with chalcones in the presence of $AlCl_3$ under mechanochemical conditions, they produce 1,4,6-triaryl-1,4-dihydropyridine derivatives, whereas the same reaction in solution leads to the formation of carbocycles (Figure 22).[151]

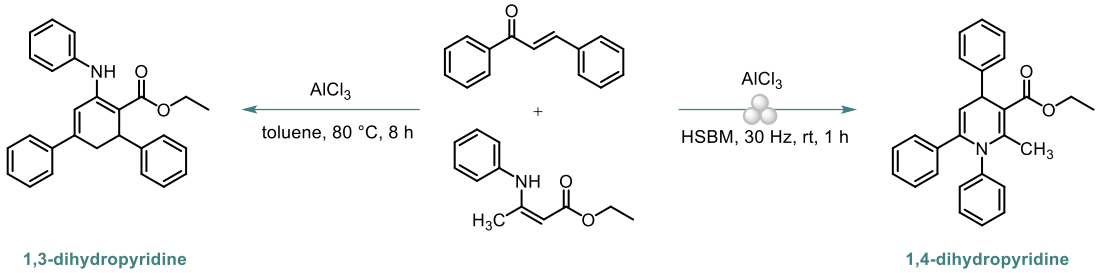

Figure 22. Difference in reactivity between solid and solution phase chemistry.

Another example is the synthesis of N-(thiocarbamoyl)benzotriazoles, where anilines react with bis(benzotriazolyl)methanethione . While these triazoles were initially thought to be intermediates, they exhibited high reactivity in organic solvents, rapidly converting into isothiocyanates and benzotriazole. However, using the liquid-assisted grinding (LAG) method allowed for the successful production of N-(thiocarbamoyl)benzotriazoles in high yields with minimal milling time (Figure 23).[152] These compounds are important in organic synthesis due to their stability in solid form, even after a year of storage, making them valuable precursors for the synthesis of symmetric and asymmetric thioureas. This highlights mechanochemistry's unique capability to synthesize and stabilize highly reactive molecules that are challenging to obtain via conventional methods.

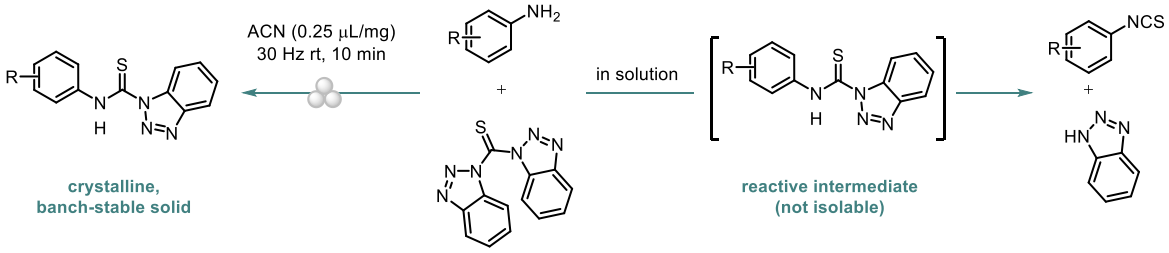

Figure 23. Difference in reactivity between solid and solution phase chemistry.

Over the past two decades, mechanochemistry has garnered renewed interest from synthetic chemists, resulting in a significant increase in mechanochemical reactions. By utilizing ball milling or grinding techniques, radical generation and functionalization can be achieved in solvent-free or low-solvent environments, making mechanochemistry an appealing approach for sustainable chemistry. The ability to conduct reactions under ambient conditions, without the need for extreme temperatures or pressures, further enhances its appeal. Its growing application in radical relay functional group transfers demonstrates its potential to unlock new reactivity, particularly in heterocyclic, polymeric, and organometallic compounds. Despite these advantages, mechanochemical radical reactions for alkene difunctionalization remain relatively rare, with only a handful of examples documented. One notable case involves the activation of piezoelectric materials through ball milling, where the material mediates electron transfer to and from small organic molecules. This innovative mechano-redox process serves as a cost-effective and environmentally friendly alternative to photocatalytic chemistry for the oxidation

of organic substrates. By fine-tuning milling parameters, optimal conditions for Atom Transfer Radical Cyclization (ATRC) were discovered, leading to the efficient conversion of monobromoacetamides into lactams with high yields (Figure 24A). This straightforward approach has expanded the applications of mechanochemistry significantly.[153] In 2023, the Browne group reported a mechanochemical nickel-catalyzed intramolecular difunctionalization of alkene-tethered aryl halides with alkyl halides (Figure 24B). This method enables the synthesis of 3,3-disubstituted heterocycles, specifically oxindoles, with significantly shorter reaction times compared to traditional solution-phase methods. The process is largely solvent-free, utilizing only minimal quantities of DMA in liquid-assisted grinding (LAG), and eliminates the need for chemical activation of the terminal reductant (manganese) through mechanical grinding. The reaction is scalable, producing over a gram of product, and achieves modest enantioinduction when using a chiral PyrOx ligand.[154]

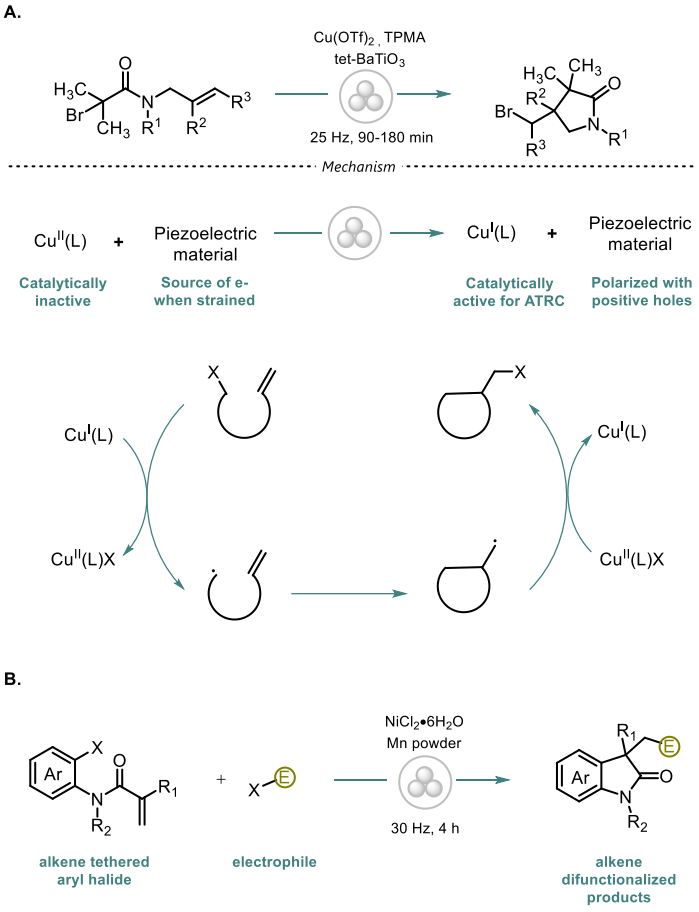

Figure 24. A. Copper-catalyzed ATRC. B. Nickel-catalyzed intramolecular alkene difunctionalization.

Photochemistry, electrochemistry, and mechanochemistry each represent a unique and complementary approach to radical relay functional group transfer. By leveraging the specific advantages of each method—whether through light-induced catalysis, electrical redox control, or mechanical force—these toolboxes expand the versatility and scope of radical chemistry in organic synthesis. Together, they

provide chemists with powerful, efficient, and sustainable strategies for the precise functionalization of complex molecules, driving advancements in fields ranging from pharmaceuticals to materials science.

4. Nitration

Nitro compounds are indispensable in synthesizing nitrogen-containing molecules and are widely used across various chemical sectors, including pharmaceuticals, dyes, energetic materials, and fertilizers (Figure 1A provides selected examples). In synthetic chemistry, the nitro group serves as a critical precursor for the formation of numerous compounds such as amines, hydroxylamines, aldehydes, carboxylic acids, isocyanates, and various heterocycles.[155] Advances in organometallic chemistry have further enabled the use of the nitro group as a leaving entity in cross-coupling reactions, broadening its applications. In recent years, nitro compounds have also become valuable in drug development, forming the backbone of a range of biologically active molecules, including agents targeting anti-infective diseases and parasitic infections like trypanosomatids.[156]

The exploration of nitro compounds has extended beyond classical redox transformations, now incorporating denitrative cross-coupling reactions, radical processes, and asymmetric organocatalytic transformations.[157-159] Research is increasingly focused on developing nitration processes that are more efficient and environmentally sustainable. Key innovations include continuous-flow nitration, transition metal-catalyzed C(sp²)–H nitration, ipso-nitration reactions, and nitrative difunctionalizations.[160-169] Comprehensive reviews on the synthesis of nitro compounds, especially through the nitration of aliphatic and (hetero)aromatic compounds, offer valuable synthetic strategies for constructing C–C, C–N, C–O, and C–S bonds as alternatives to traditional methods.[170]

Despite nearly two centuries of nitration research, there remains significant potential for developing selective, mild, and sustainable nitration techniques. Research continues to prioritize innovations in nitrating reagents, which fall into two main categories: inorganic (e.g., nitric acid) and organic reagents. Although inorganic nitrating reagents have seen considerable advancement, the exploration of organic nitrating reagents—despite a history spanning over 120 years—remains relatively limited.[171] This account summarizes our group's recent progress in designing and synthesizing organic nitrating reagents and highlights their applications in catalytic nitration processes for unsaturated hydrocarbons, aromatic, and (hetero)aromatic compounds.

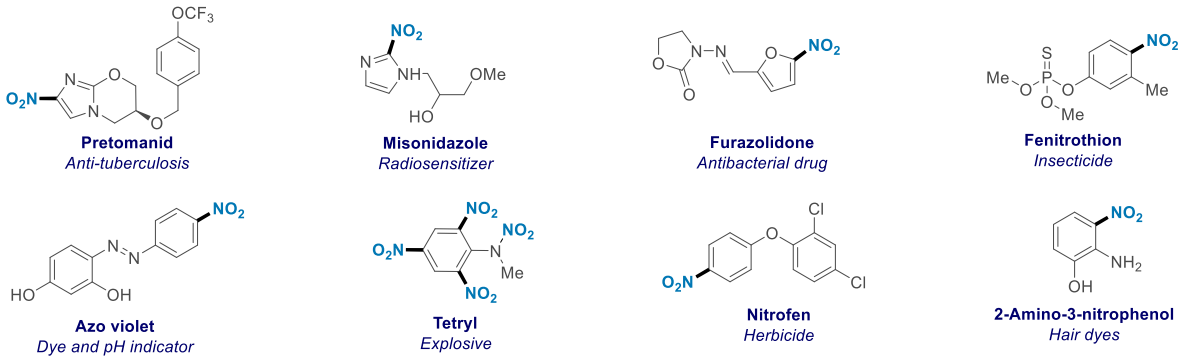

Figure 25. Importance of nitro compounds.

Nitration reactions, which involve the introduction of a nitro group (-NO_2) into organic compounds, can be broadly categorized into three mechanistic classes: electrophilic nitration, radical nitration, and nucleophilic nitration. Each class represents a unique pathway defined by the nature of the reactive species involved and the specific mechanism by which the nitro group is transferred. Electrophilic nitration typically involves nitronium ions (NO_2^+) that react with electron-rich substrates, often in acidic conditions. Radical nitration operates through radical intermediates and is commonly initiated by oxidative conditions. Lastly, nucleophilic nitration involves negatively charged nitro species that selectively react with electron-deficient substrates. These distinct mechanisms result in different intermediate species and allow nitration to be tailored to a range of substrates and conditions, enhancing the versatility of nitration processes.

4.1. Electrophilic nitration

Electrophilic nitration is one of the most common and widely studied nitration reactions, especially for aromatic compounds (Figure 26). It involves the nitronium ion (NO_2^+) acting as the electrophile, which attacks electron-rich substrates like benzene. The nitronium ion is typically generated from a mixture of concentrated nitric acid (HNO_3) and sulfuric acid (H_2SO_4). This ion facilitates a substitution reaction on the aromatic ring, preserving its stability and resulting in the formation of nitroaromatic compounds, which are valuable intermediates in pharmaceuticals, dyes, and explosives. The reactivity of substrates depends on their electron density, with electron-rich rings being more susceptible to nitration. Historically, the first nitration of benzene was reported by Mitscherlich in 1834 using fuming nitric acid, a method later improved by Sobrero in 1847 with a "mixed acid" (HNO_3 + H_2SO_4), which remains a standard in both industrial and academic settings. In recent advancements, nitronium ion carriers like nitronium tetrafluoroborate have been used to nitrate nitropyrroles under mild conditions. Additionally, the Martin D. Eastgate group developed a novel heterogeneous pyrrole nitration method, using sodium nitrate activated by SO_3-pyridine in acetonitrile to form an insoluble nitronium sulfate intermediate (Figure 26C).

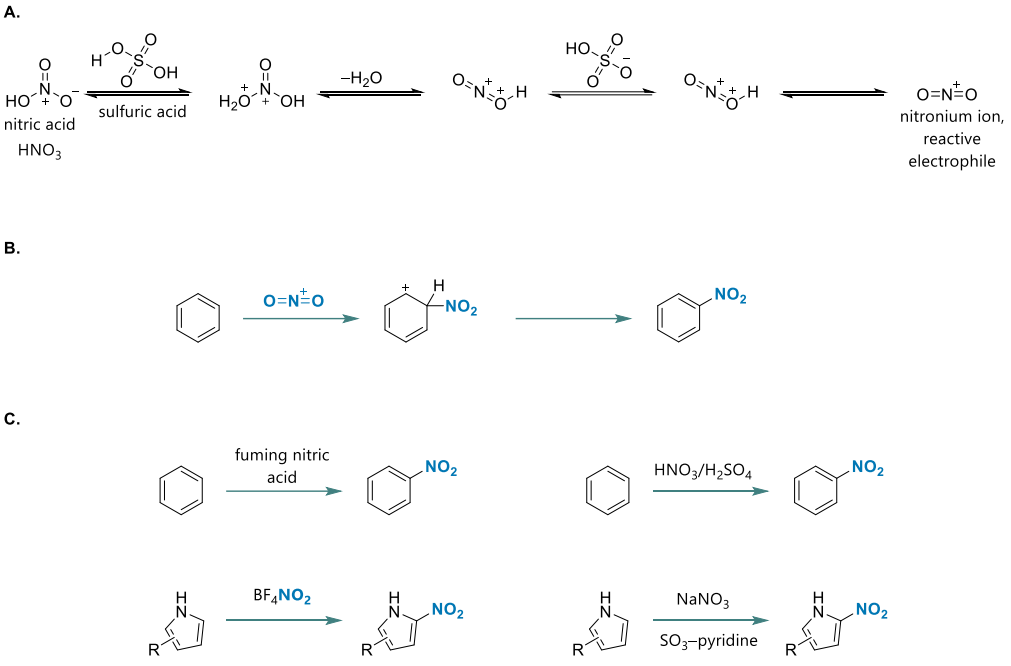

Figure 26. A. Generation of nitronium ion. B. Aromatic nitration. C. Examples of electrophilic nitration.

4.2. Radical nitration

Radical nitration involves the formation of nitroalkyl radicals that react with aliphatic or unsaturated hydrocarbons, such as alkenes or alkynes (Figure 27). Unlike electrophilic nitration, which primarily targets aromatic systems, radical nitration is more effective for non-aromatic, aliphatic substrates. Common nitrating agents like nitrogen dioxide (NO_2) or nitric oxide (NO) generate reactive radicals, initiating a radical chain reaction. This process often requires light or heat to drive radical formation and is commonly used to produce nitroalkanes, valuable intermediates in organic synthesis. Radical nitration is particularly useful for nitrating alkanes and other inert molecules that resist electrophilic attack. The approach gained prominence with the first nitration of paraffinic substrates proposed by A.I. Titov in 1937, using an NO_2/N_2O_4 mixture with hydrocarbons.[172] Later, the Yasutaka Ishii group successfully nitrated alkanes and aromatic compounds using NO_2 and HNO_3 under mild conditions, employing N-hydroxyphthalimide (NHPI) as a catalyst.[173] Taniguchi and Maiti introduced synthetically viable methods for radical nitration of alkenes, utilizing various reagents and decomposition techniques.[174-177] They demonstrated that the thermal decomposition of iron(III) nitrate ($Fe(NO_3)_3$) could efficiently generate nitroalkenes, highlighting the role of iron salts in initiating radical pathways. Additionally, they explored the use of metal ions such as silver (Ag^+), which facilitated the nitration process by promoting the formation of nitro radicals. Another notable approach involves the use of nitrites or tert-butyl nitrite as radical sources, which successfully led to the nitration of alkenes under mild conditions.[178-180] Recent advances in radical nitration have broadened its application in organic synthesis, offering both metal-catalyzed and metal-free methods to efficiently introduce nitro group. These methods provide high regioselectivity for substrates like alkenes, yielding nitroalkanes, and aromatics, enhancing their

reactivity for pharmaceutical and material applications. For alkynes, nitration leads to valuable nitroalkenes, while 1,n-enynes produce multifunctional products. Additionally, selective C–H nitration of alkanes has expanded the scope of hydrocarbon functionalization. These innovations make radical nitration a versatile tool in drug development and materials science.

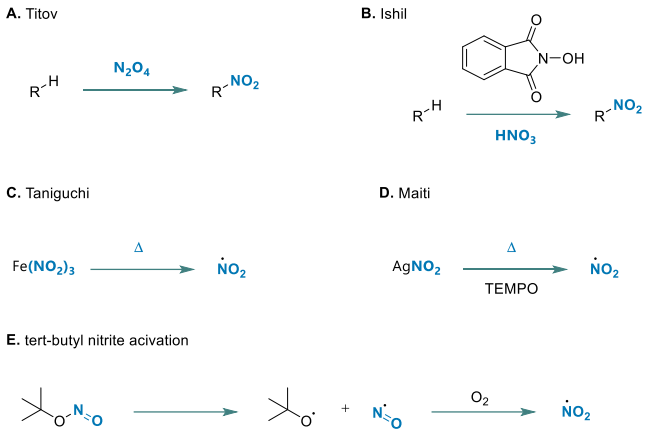

Figure 27. Examples of radical nitration and generation of nitryl radical.

4.3. Nucleophilic nitration

Nucleophilic nitration, though less common than electrophilic or radical nitration, plays an important role, particularly in heterocyclic chemistry. In this process, a nucleophile, such as a nitrite ion (NO_2^-), attacks an electron-deficient substrate, often through nucleophilic substitution or addition (Figure 28). This reaction is particularly relevant for halogenated compounds or activated alkyl halides, where the nitrite anion can replace a halide group to form nitroalkanes. Nucleophilic nitration usually occurs under milder conditions compared to electrophilic nitration and is useful for synthesizing nitro compounds with specific regioselectivity and functional group tolerance. One of the most common methods for preparing nitroalkanes involves converting alkyl halides using metal nitrites. In 1872, Meyer and Stuber first reported the Victor-Meyer reaction, where amyl iodide and silver nitrite under reflux produced a mixture of nitroalkane and alkyl nitrite.[181] Herbert E. Ungnade later developed a simple procedure for synthesizing nitroparaffins using silver nitrite and primary alkyl halides.[182] Another widely used method, the Kornblum reaction, employs sodium nitrite as the nitrating reagent.[183]

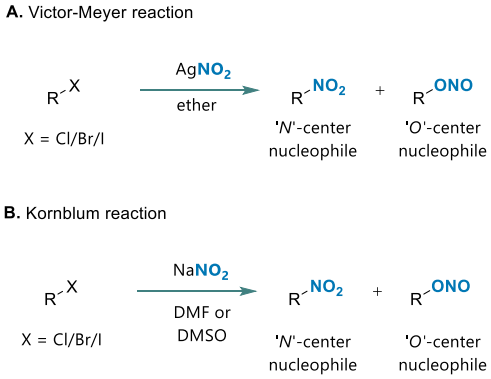

Figure 28. Examples of nucleophilic nitration.

4.4. Classification of nitrating reagents

Nitrating reagents can be broadly classified into two categories: inorganic and organic nitrating agents, as outlined below.

4.4.1. Organic nitrating reagent

Despite nearly 200 years of research in nitration chemistry, there remain areas ripe for further refinement. There is an ongoing need for more selective nitrating methodologies and notable improvements in the sustainability of these processes. The behavior of nitrating reagents in specific transformations often hinges on the nature of the NO_2 species involved, yet many reagents display dual characteristics that vary based on factors like reaction conditions, activation method, and catalyst type.

Organic nitrating reagents have substantially advanced the field by shifting from early inorganic approaches toward selective, functional nitration in organic synthesis. Originally, nitration relied heavily on nitric and sulfuric acids, which were effective for large-scale industrial applications (e.g., in the production of TNT and nitrobenzene) but were unsuitable for sensitive or complex substrates. Over time, the development of milder organic nitrating agents met the demand for controlled nitration, enabling chemists to target delicate functional groups and intricate molecular structures that conventional inorganic methods could not address. This evolution has significantly broadened the scope and utility of nitration in synthetic chemistry.

The following chapter provides an in-depth exploration of various organic nitrating agents and their applications.

4.4.2. Inorganic nitrating reagent

Inorganic nitrating reagents have been integral to nitration chemistry since the mid-19th century, primarily through the "mixed acid" system that combines nitric and sulfuric acids to generate nitronium ions (NO_2^+) for nitrating aromatic compounds. This method, essential in industrial synthesis for products like TNT and nitrobenzene, operates under rigorous conditions and produces a substantial amount of acidic waste. To address these limitations, milder options such as nitronium salts (e.g., NO_2BF_4, NO_2PF_6) and reagents like NO_2 and N_2O_4 were developed, providing more controlled conditions and selectivity for nitration.

In recent years, sustainable nitration strategies have emerged, focusing on reducing waste and improving environmental compatibility. Techniques using solid acid catalysts, as well as electrochemical and photochemical methods, have gained prominence for their potential to offer milder conditions, enhanced

selectivity, and reduced environmental impact. These newer methods reflect the shift towards greener and more efficient nitration approaches in synthetic chemistry.

4.4.3. New type of organic nitrating reagents

Between the 1960s and 1980s, a range of *N*-nitropyridinium and *N*-nitroquinolinium salts were explored as nitrating agents, demonstrating effectiveness for synthesizing nitroaromatic compounds. Although these reagents showed promise as sources of NO_2, their application was largely limited to simple arenes, offering a restricted substrate range. A key limitation was their sensitivity to moisture and hygroscopic nature, which required storage in dry, inert conditions or in situ generation.

Recently, the Katayev group developed a new class of nitro heterocyclic compounds to address these challenges. These compounds are derived from core structures such as pyrrolidinone (**I**), succinimide (**II**), phthalimide (**III**), and saccharin (**IV**, **V**), as well as a hypervalent iodine-based nitrooxylating reagent (**VI**) (Figure 29). This advancement presents an improved approach for selective nitro-functionalization under controlled conditions, broadening the scope and stability of nitrating reagents.

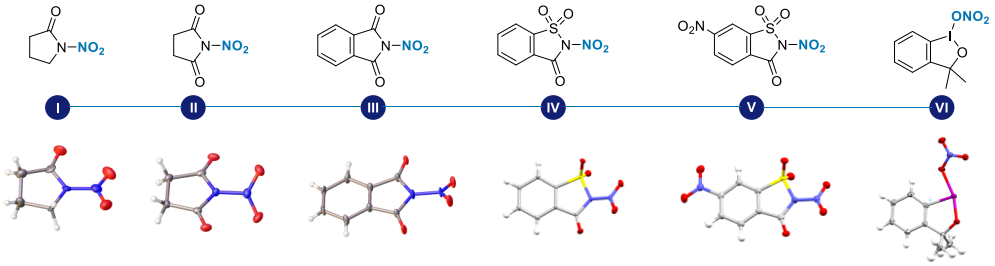

Figure 29. Organic nitrating reagents developed in the Katayev group.

5. Halogenation

Halogenation is a key reaction in organic chemistry, where one or more halogen atoms (fluorine, chlorine, bromine, or iodine) are incorporated into an organic compound. This reaction significantly alters the chemical and physical properties of the molecule, making it essential for organic synthesis. Depending on the substrate and reaction conditions, halogenation can occur through various mechanisms, such as free radical halogenation, electrophilic addition, or nucleophilic substitution. For example, in radical halogenation of alkanes, a halogen atom replaces a hydrogen atom via a chain reaction triggered by heat or light. In contrast, alkenes and alkynes typically undergo electrophilic halogenation, where halogens like chlorine or bromine add across a double or triple bond, producing vicinal dihalides. This transformation is widely applied in industrial chemistry, particularly in the production of pharmaceuticals, agrochemicals, and polymers, as halogenated compounds often exhibit increased bioactivity, stability, and reactivity.[184] For instance, halogenated aromatics are critical intermediates in the synthesis of dyes, solvents, and pharmaceuticals, facilitating further functionalization and structural diversification.[185]

5.1. Dihalogenation of alkenes

In classical dihalogenation of alkenes, halogens like Cl_2 or Br_2 add across the C=C bond.[186-188] The reaction begins with the alkene attacking the halogen, forming a cyclic halonium ion (e.g., bromonium or chloronium). This reactive intermediate is then opened by a nucleophilic attack from the halide ion on the opposite side of the initial halogen bond, leading to the formation of a vicinal dihalide through anti-addition (Figure 30). This ensures the halogens are added to opposite faces of the alkene, yielding a trans product with anti-stereoselectivity. While the reaction doesn't generally show regioselectivity, in cases of unsymmetrical alkenes or substituents, the halonium ion may form at the more electron-rich carbon, affecting the product's structure.

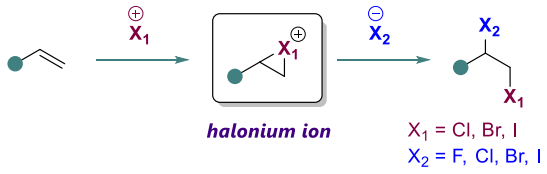

Figure 30. Classical dihalogenation of alkenes *via* halonium ion.

The solvent choice in dihalogenation reactions significantly impacts the outcome. Polar solvents like water or alcohols can act as nucleophiles, leading to halohydrin formation instead of dihalogenation (Figure 31).[189] For example, water can attack a halonium ion, forming a halohydrin (with one halogen and one hydroxyl group added across the alkene). In contrast, nonpolar solvents such as carbon tetrachloride promote selective dihalogenation by avoiding competing nucleophilic attacks.[190-192]

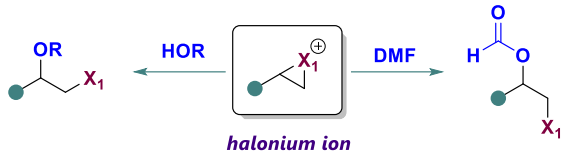

Figure 31. Solvents as nucleophiles.

Dihalogenation offers broad utility in organic synthesis, providing vicinal dihalides that are key intermediates in further transformations like elimination to alkynes or nucleophilic substitutions (Figure 32).[193-197] These products are crucial in synthesizing natural products, pharmaceuticals, and materials. Despite its advantages, over-halogenation and challenges with regioselectivity, especially with electron-withdrawing substituents, can complicate the reaction. Careful tuning of conditions is necessary to prevent unwanted side products, like halohydrins.

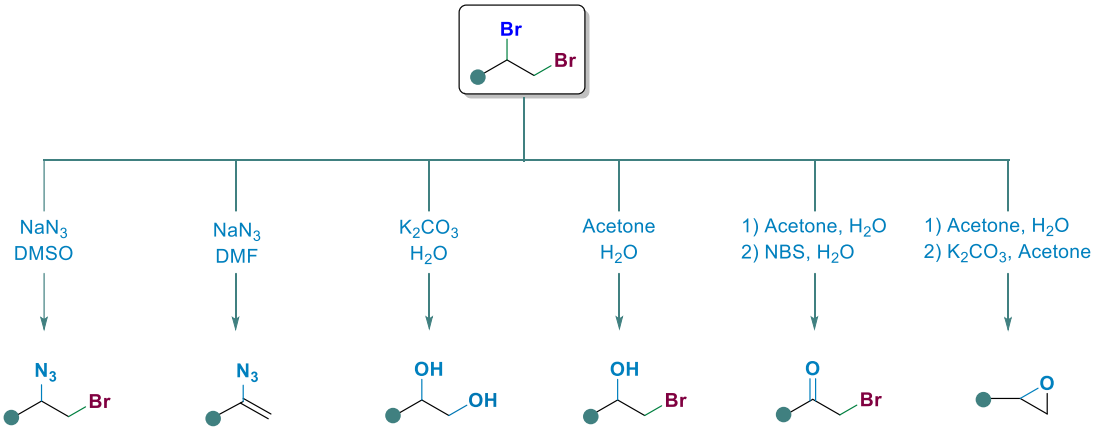

Figure 32. Dihalides as key intermediates.

5.2. Radical-mediated dihalogenation of alkenes

Recent advancements in alkene dihalogenation have focused on catalytic methods and greener reaction conditions. Metal-catalyzed approaches using transition metals like palladium, copper, and iron have improved reaction efficiency and selectivity, reducing the need for excess halogenating agents and minimizing environmental impact. Radical-mediated dihalogenation has also gained attention due to its broader substrate scope and tolerance of varied conditions. In this mechanism, halogen radicals (X•) are generated via heat, light, or radical initiators, adding to the alkene to form vicinal dihalides. Radical pathways allow for better regio- and stereoselective control, especially with bromine. Advances in photoredox catalysis and electrochemistry now offer even greater precision in controlling reaction conditions.

In 2017, Lin and co-workers developed a highly diastereoselective Mn-catalyzed dichlorination of olefins, utilizing $MgCl_2$ as the chlorine source under electrochemical conditions (Figure 38).[198] This method showcased the power of electrochemical catalysis for efficient and selective olefin

functionalization. Furthermore, photochemistry has been explored as a means of achieving dihalogenation under milder and more sustainable conditions. Recently, the West group introduced a versatile strategy for the photocatalytic difunctionalization of a broad spectrum of alkenes (Figure 33).[199] Their approach, based on iron-catalyzed ligand-to-metal charge transfer and radical ligand transfer, allows the use of inexpensive, safe nucleophiles to produce vicinal dichlorides. This method addresses the limitations of substrate scope, harsh reaction conditions, and complex setups often encountered in traditional thermal and electrochemical difunctionalization approaches.

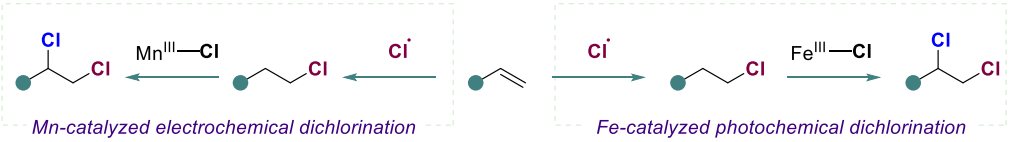

Figure 33. Lin's electrochemical and West's photochemical dichlorination.

5.3. Halogenating reagents

Late-stage halogenation of bioactive compounds faces challenges due to functional group interference, suboptimal selectivity in chemical methods, and complications from electron-withdrawing groups like nitro and carboxyl. To address these issues, several strategies have been developed (Figure 34). The Barluenga group introduced Py_2IBF_4, a reagent enabling efficient, stereoselective iodofunctionalization of alkenes. The Snyder group developed $Et_2SX{\cdot}SbCl_5X$ and IDSI for halenium-induced polyene cyclization. Yang's group introduced CFBSA for aromatic chlorination, while the Baran group developed Palau'chlor and N–X anomeric amides for efficient late-stage halogenation. Additionally, reagents like tert-butyl hypochlorite, which is inexpensive and easily prepared, have shown good performance in chlorination reactions. Common reagents like NXS and DXDMH, while more accessible, suffer from lower reactivity and selectivity. Thus, activation strategies have been explored. Protonation of the carbonyl group in NXS using Brønsted acids or hydrogen-bond donors has been a popular approach. For example, Olah's group employed $BF_3{\cdot}H_2O$ as an activator for electron-deficient arenes, and HFIP has been utilized by various groups to promote halogenation reactions.

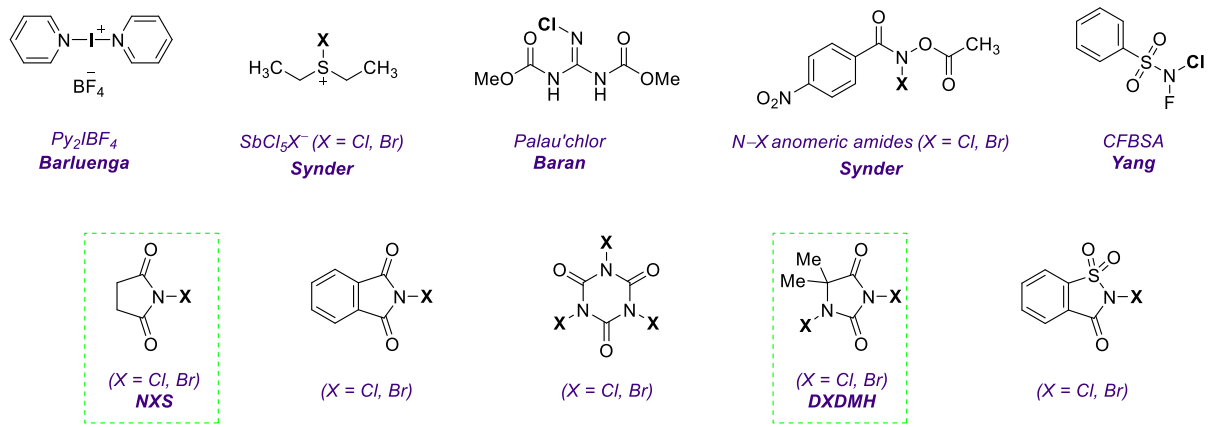

Figure 34. Common halogenating reagents.

The reagents NXS (N-halosuccinimides, where X = Cl, Br) and DXDMH (1,3-dihalo-5,5-dimethylhydantoins, X = Cl, Br) are widely recognized as electrophilic halogenating agents in organic synthesis. These reagents generate electrophilic halogen species, which are key intermediates in many halogenation reactions. However, the efficiency of these reactions is significantly influenced by the solvent system used. In polar solvents or with appropriate additives, NXS and DXDMH release halogens through heterolytic cleavage of the N–X bond, leading to electrophilic halogenation of substrates. Under different reaction conditions—particularly when exposed to photochemical activation, heating, or nonpolar solvents like diethyl ether—these reagents can undergo homolytic cleavage of the N–X bond (Figure 35).[200] This process generates halogen radicals (X•), enabling radical-mediated halogenation pathways. Such conditions allow for distinct reactivity patterns, broadening the versatility of these reagents. Photochemically or thermally induced radical halogenation, for example, is useful for more challenging transformations where traditional electrophilic pathways might fail, offering selectivity and control in functionalization of substrates.

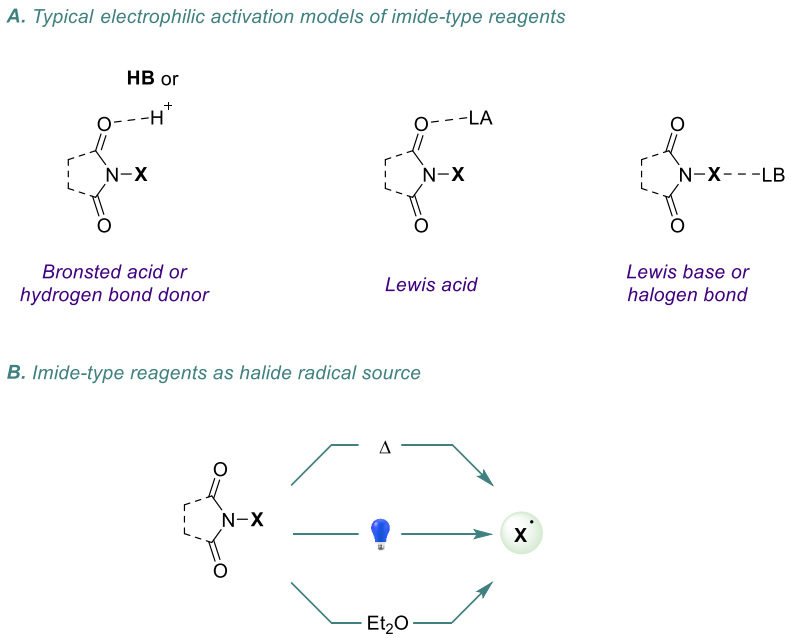

Figure 35. Imide-type reagents as electrophilic and radical source of halogen.

The selection of solvents, additives, and reaction conditions plays a crucial role in directing NXS and DXDMH toward either electrophilic or radical halogenation pathways. Precise optimization of these variables can greatly affect the reaction outcomes, making these reagents adaptable tools for achieving specific synthetic objectives. The dual-mode reactivity of NXS and DXDMH enhances their utility in various halogenation methods, where they can be strategically applied based on desired pathways.

Chapter 8 introduces a novel, solvent-free approach to activating these imide-based reagents through mechanochemical conditions, generating halogen radicals (Cl• or Br•). These radicals add to alkenes,

yielding new alkyl radicals that are subsequently trapped by high-valent Fe–Nu species, resulting in homo- or heterodifunctionalized products. This innovative method offers an alternative route for selective radical addition and functionalization, expanding the application scope of NXS and DXDMH in organic synthesis.

6. Conclusion

This chapter provided a comprehensive overview of the reactivity and functionalization of alkenes, focusing on key mechanisms and modern strategies in organic synthesis. It explores the importance of two-electron and single-electron addition reactions, particularly in determining regioselectivity in Markovnikov and anti-Markovnikov transformations. These mechanisms are crucial for understanding the behavior of alkenes in electrophilic and nucleophilic reactions, helping to predict and control the formation of new C–C and C–heteroatom bonds.

Functional group transfer reagents and difunctionalization strategies, especially through radical relay methods, were emphasized for their versatility in introducing multiple functional groups simultaneously. This approach proves invaluable in synthesizing complex molecules with high selectivity. Novel reagents and catalysts developed for controlling radical intermediates were also discussed, expanding the scope of these transformations.

Photochemical and electrochemical methods were analyzed for their ability to enable selective difunctionalization of alkenes under mild conditions. Photochemistry leverages light energy, while electrochemistry uses electric current to drive redox reactions, both offering green alternatives and control in radical-mediated reactions like C–H activation and C–C bond formation.

Nitration chemistry was reviewed, covering electrophilic, nucleophilic, and radical nitration, with special attention to novel reagents developed for radical nitration in our lab, which broaden the scope of nitration beyond traditional approaches. Additionally, dihalogenation of alkenes, known for forming vicinal dihalides, was highlighted as a fundamental reaction, particularly in recent advances using catalytic, photochemical, and electrochemical methods to improve efficiency and selectivity.

Overall, the chapter illustrates significant advancements in radical-mediated processes and electrochemical techniques, offering greener, more sustainable methods for alkene functionalization and the construction of complex molecules. These developments underscore the evolving landscape of organic synthesis, where innovation continues to enhance both efficiency and selectivity in chemical transformations

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Chapter 2:

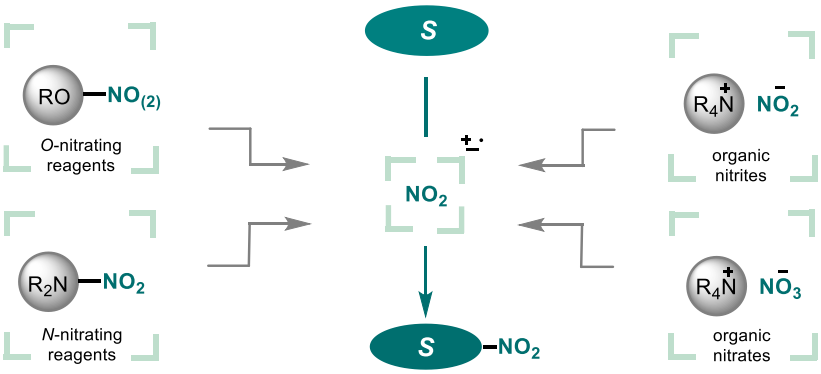
Organic Nitrating Reagents

This Chapter is adapted from the following publication in peer reviewed journal:

S. Patra, I. Mosiagin, R. Giri, D. Katayev, "Organic Nitrating Reagents", *Synthesis* **2022**, *54*, 3432–3472. DOI:10.1055/s-0040-1719905.

1. Abstract

Nitro compounds are vital raw chemicals that are widely used in academic laboratories and industries for the preparation of various drugs, agrochemicals, and materials. Thus, nitrating reactions are of great importance for chemists and are even being taught at schools as one of the fundamental transformations in organic synthesis. Since the discovery of the very first nitrating reactions in the XIX century, progress in this field has never stopped. Yet, for many years a classical electrophilic nitration approach using a mixture of strong mineral acids was dominated in the field. However, in recent decades, significant attention of researchers was dragged to new reactivity and new reagents that can provide access to nitro compounds in a practical and straightforward way under mild reaction conditions. Organic nitrating reagents have played a special role in this field since they open up enhanced reactivity. They also allow nitration to be carried out in an eco-friendly and sustainable manner. This review provides the state of the art in the development and application of organic nitrating reagents.



2. Introduction

Nitro compounds are a keystone in the synthesis of nitrogen-containing molecules, which are essential for all areas of the chemical industry: pharmaceuticals, dyes, explosives, herbicides, fertilizers, etc. (for selected examples see Figure 1). In the context of synthetic chemistry, nitro group can serve as precursors to amines, hydroxylamines, aldehydes, carboxylic acids, isocyanates, various heterocycles, and as a leaving group in cross-coupling reactions.[1] In the recent decades, nitro compounds have also found extensive applications as biologically active molecules present in living organisms.[2] They are being used as anti-infective drugs[3] and for the treatment of trypanosomatid diseases,[4] among many others.[5] Their metabolic pathways are also of great interest,[6] as well as nitration of biomolecules in *vivo*.[7] Improvement in recent years is also related to novel synthetic applications of nitro group that go beyond classical red-ox transformations, including but not limited to denitrative cross-couplings,[8] radical reactions,[9] and asymmetric organocatalytic transformations.[10]

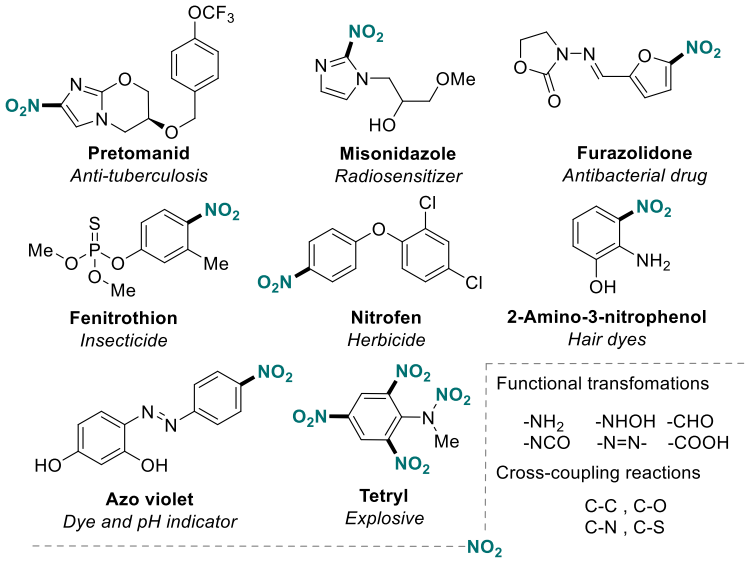


Figure 1. Importance of nitro compounds and nitro functional group.

Thus, with no surprise, many researchers around the globe are constantly contributing to the development of nitration chemistry. Recent advances in the field have been documented,[11] including the progress on continuous flow nitration,[12] decarboxylative nitration,[13] safe and sustainable nitration,[14] transition-metal (TM) catalysed C(sp^2)–H nitration,[15] *ipso*-nitration reactions,[16] and nitrative difunctionalizations.[17] In addition, several reviews cover the synthesis of nitro compounds of distinct structures, such as aliphatic[18] and aromatic[19] compounds, alkenes,[20] alkynes,[21] and porphyrins.[22] These reports provide a comprehensive understanding of synthetic tools available in the field up to date. However, despite nearly 200 years of history of nitration reactions,[23] there is still room for improvement. Synthetic chemistry is still in need of selective nitrating strategies and significant advances in the sustainability of nitration processes.

To support the evolution in the development of new synthetic methods, it is equally important to have a summary of those compounds that make nitration possible – nitrating reagents. They can be roughly divided into two groups – inorganic and organic. Inorganic reagents, such as nitric acid,[24] nitrogen oxides (N_xO_y),[25] nitronium[26] and nitrosonium salts,[27] as well as metal nitrates and nitrites[28] are already well-established with a decent number of publications highlighting their properties.[29] However, progress in the field of organic nitrating reagents has not been addressed to date, despite their 120 years history. Thus, given that the development of organic nitrating reagents is a rapidly growing field, which constantly opens new horizons in nitration chemistry, herein, we would like to provide a summary and analysis of this research topic.

While the reactivity of nitrating reagents, in a particular transformation, can be determined by the nature of NO_2 species, some reagents exhibit mixed properties, which highly depend on the reaction conditions, activation type, or the catalyst nature (Figure 2). This is especially common for organic nitrating reagents.

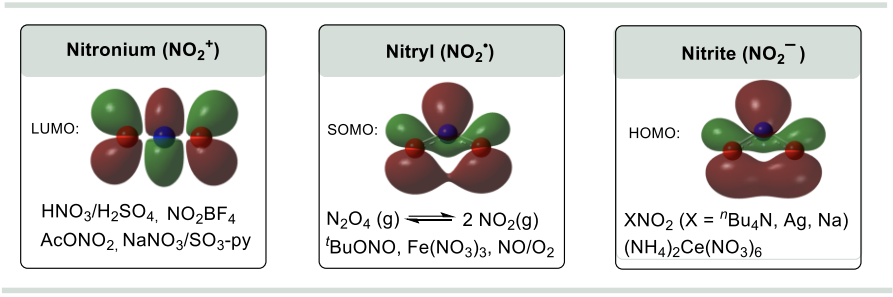


Figure 2. Molecular orbitals of active NO_2 species. Adapted with permission from ref. 30. [Copyright (2019) Wiley].

This review is divided based on the type of reagents and subdivided based on their structures and consists of four main chapters. section 3 and 4 are dedicated to the organic molecules bearing a covalent bond between nitrogen functionality and organic scaffold. They are subdivided as bench-stable organic nitrating reagents and those which are being prepared in situ. Two subsequent chapters are dedicated to ionic organic nitrating reagents. The relatively underdeveloped field of organic nitronium and nitrosonium salts (compounds bearing organic anion) is discussed in section 5. Section 6 describes reagents based on organic nitrates and nitrites (compounds bearing organic cation).

As it can be seen from the timeline containing the first applications of the common organic nitrating reagents (Figure 3), there were three periods of interest related to these reagents. After the discovery of acyl nitrates as nitrating reagents at the beginning of the XIX century, the main attention was given to their use in the synthesis. These reagents were utilized as the first mild nitrating reagents to expand the scope of nitration reactions. The second period of interest spanned between the ‘60s and ‘80s and was related to the understanding of the nature of nitration processes. Based on these studies, specifically

designed nitrating reagents were introduced. The current wave of interest in organic nitrating reagents can be attributed to the use of tertbutylnitrite (TBN) as an indirect origin of the nitro group for the preparation of nitro compounds, which had led to a foundation for the design of selective organic nitrating reagents with unique reactivity.

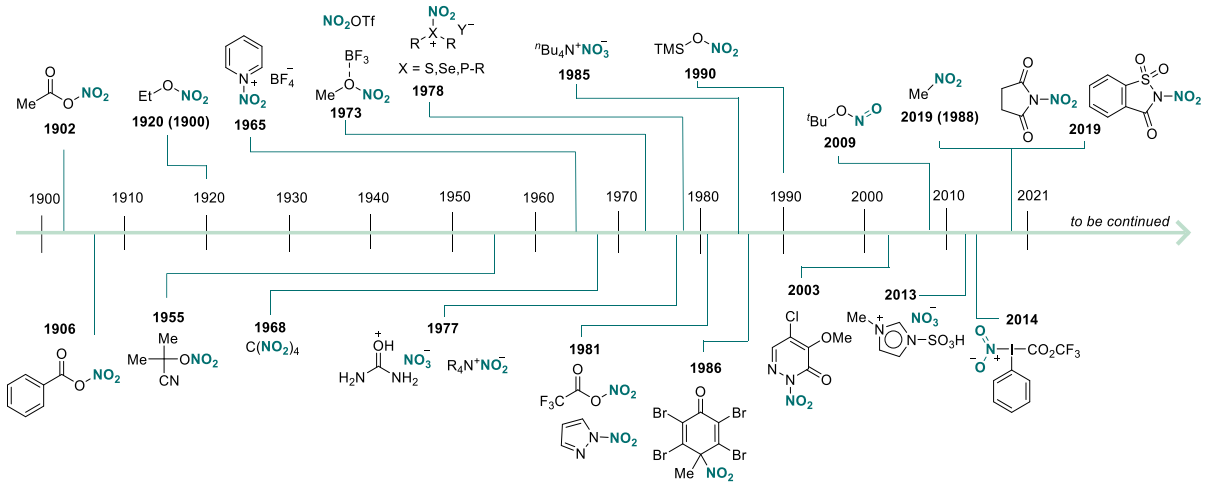


Figure 3. Summary of common organic nitrating reagents. Indicated years show the first use of the molecule as a nitrating reagent.

3. Organic nitrating reagents

Apart from inorganic nitrating reagents, organic compounds in which the nitro or nitroso group is covalently bound to carbon or heteroatom centres, have been extensively used as the source of nitro group over the past several decades. It has been shown that these reagents exhibit diverse reactivity under very mild reaction conditions and can deliver active species such as nitronium ion (NO_2^+), nitryl radical ($NO_2^{\bullet}$), and nitric oxide ($NO^{\bullet}$). The formation of these intermediates depends not only on the structure of the reagent but also on the reaction conditions. In addition, this class of reagents possesses several advantages, including but not limited to enhanced stability, excellent solubility, and potential recyclability of their organic scaffold. Finally, organic nitrating reagents generate less chemical waste compared to inorganic ones. The type of reagents discussed in this chapter are presented in Figure 4.

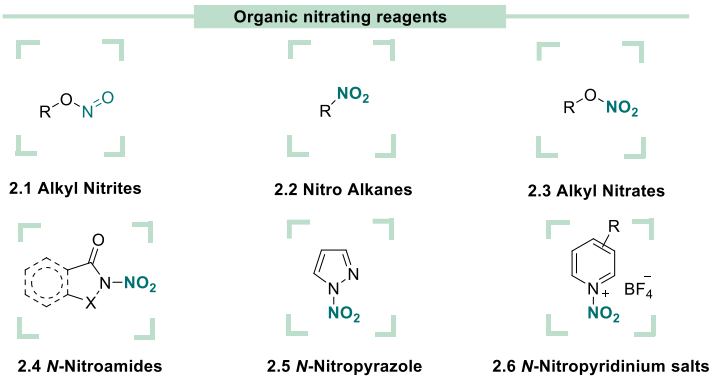
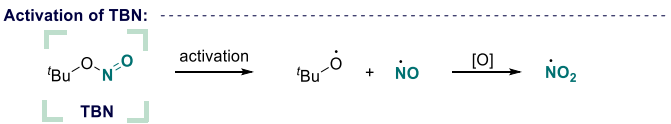


Figure 4. Organic nitrating reagents discussed in this section.

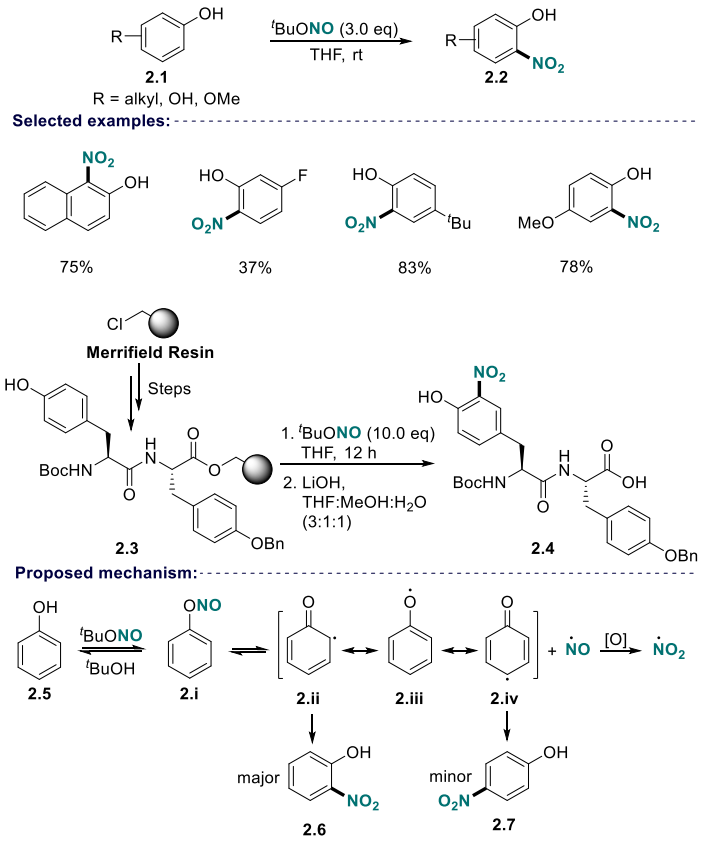
3.1. Alkyl nitrites

Alkyl nitrites are commercially available compounds, that are widely used in various synthetic transformations for the preparation of N-containing structures.[31] Among them, tert-butyl nitrite (**TBN**, Scheme 1) is the most popular over the past 15 years. It is a versatile reagent and the least toxic among other alkyl nitrites.[32] **TBN** is a yellow, highly flammable and toxic liquid, which has great solubility in most organic solvents and is commercially available (~ 100 mL – 50 $). **TBN**-mediated transformations commonly proceed via radical pathways initiated by thermal, or aerobic conditions, as well as irradiation. Therefore, in past years **TBN** has been used for numerous purposes in the field of synthetic organic chemistry: in oxidation, nitrosation, oximation, diazotization, and nitration reactions.[33] However, in the present review only **TBN**-involved nitration processes will be discussed.



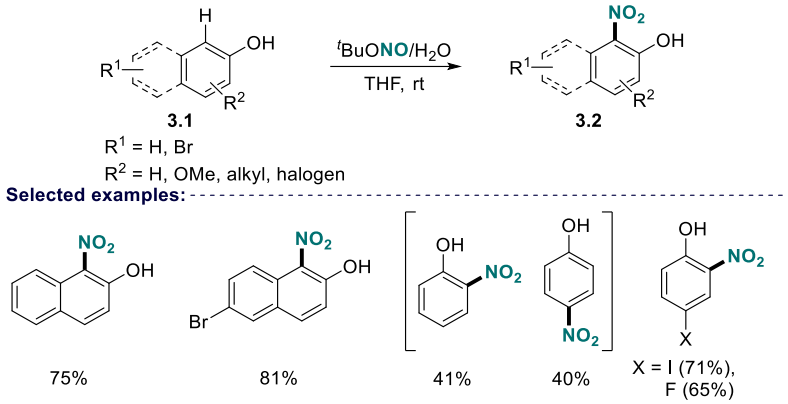
Scheme 1. General activation of **TBN**.

Efficient chemoselective nitration of phenols with **TBN** was reported by Savinov and co-workers in 2009 (Scheme 2).[34] This reaction preferentially provided mono-nitro derivatives of substituted phenols in solution and on a solid support. Owing to the mild reaction conditions, the method demonstrated high functional group tolerance. Although, polymer-supported substrates (**2.3**) can selectively be nitrated, it is difficult to achieve such selectivity levels with other existing nitration methods. The proposed mechanism for this transformation involves the reaction of the phenol derivative with **TBN** to form **2.i.** Follow up homolytic cleavage produces phenoxyl radical species which goes through resonance stabilization to give **2.ii-2.iv**. The coupling reaction with NO radical and subsequent oxidation gives **2.6** as the major product.



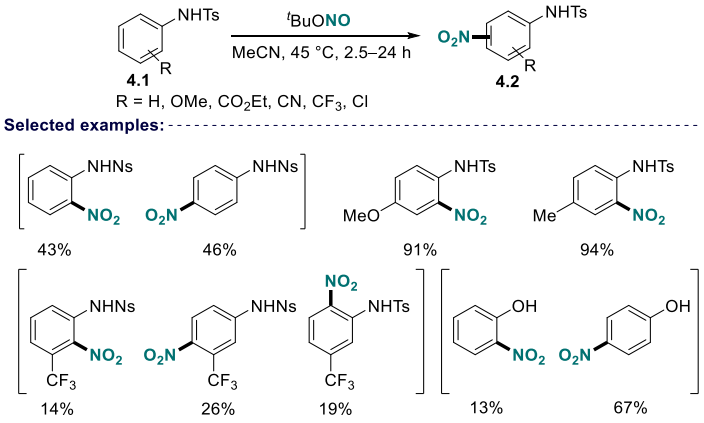
Scheme 2. Chemoselective nitration of polymer-supported substrate **2.3** and phenol derivatives.

In 2017, Liang and co-workers developed a similar water-promoted, radical-coupling process of phenols **3.1** with **TBN** at room temperature (Scheme 3).[35] This reaction required H_2O as an additive to improve the product yield. A variety of phenols and naphthols provided the desired *o*-nitro products in good to excellent yields. The proposed mechanism involves the generation of ^{t}BuO radical directly from ^{t}BuONO under aerobic conditions or by reaction with H_2O. The subsequent reaction with phenol derivative results in a phenoxyl radical formation. Finally, the radical-radical cross-coupling with NO_2 takes place, leading to the formation of a C−N bond.



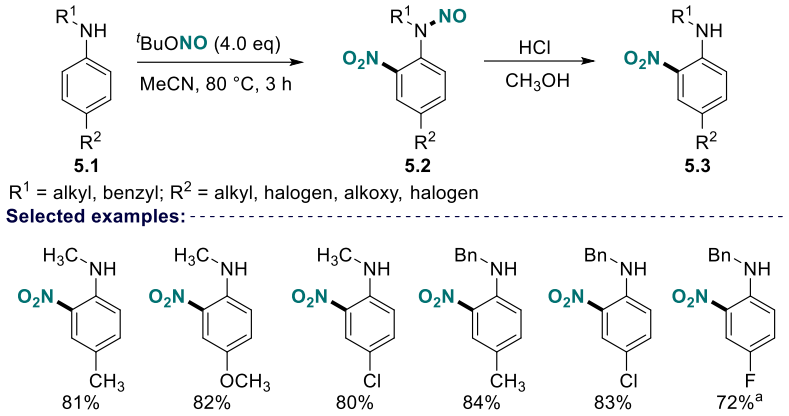
Scheme 3. Water-promoted nitration of phenols.

Mono-nitration of aromatic sulfonamides (**4.1**) was achieved with **TBN** in acetonitrile by Arns and co-workers (Scheme 4).[36] This method offered nitroarenes in high yield even in presence of other potentially reactive functionalities. The developed reaction conditions were further extended to phenols, but other functionalized or unprotected anilines failed to give the corresponding nitro adducts.



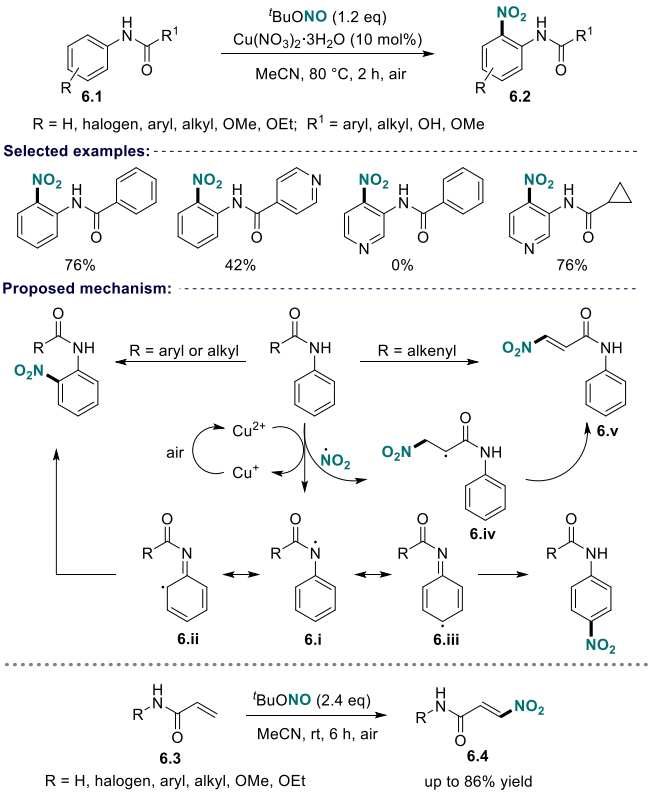
Scheme 4. Water-promoted nitration of phenols.

Following a similar strategy, Kandasamy and co-workers introduced a protocol for **TBN**-mediated nitration of *N*-alkyl anilines (**5.1**, Scheme 5).[37] In this transformation, **TBN** played a dual role as a nitrosating agent for amines and as a nitrating agent for the arene moiety. The subsequent denitrosation of *N*-nitroso-*N*-alkyl nitroanilines (**5.2**) in acidic media resulted in the selective formation of *N*-alkyl nitroanilines (**5.3**).



Scheme 5. Nitration of N-alkyl amines. [a]6 h.

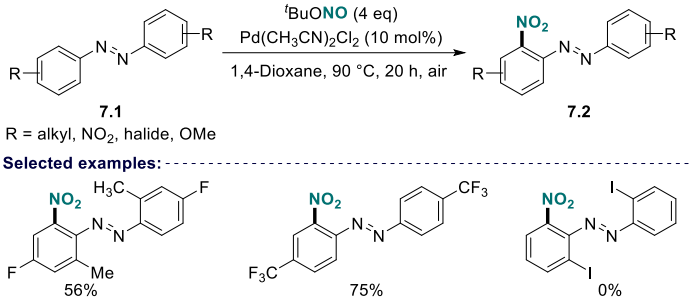
Later, the Jiang group modified Arns's original protocol and applied it for aromatic amides (**6.1**, Scheme 6).[38] The combination of **TBN** and substoichiometric amounts of $Cu(NO_3)_2{\cdot}3H_2O$ allowed to overcome the previous limitations and exhibited efficient nitration of arylamides (Scheme 6, top part). A high level of chemoselectivity was found regardless of steric and electronic effects of the substituents. Interestingly, in the absence of copper salt, alkenyl nitration of acrylamides **6.3** occurred at room temperature using 2.4 equivalents of **TBN** reagent (Scheme 6, bottom part).



Scheme 6. Nitration of arylamides and acrylamides.

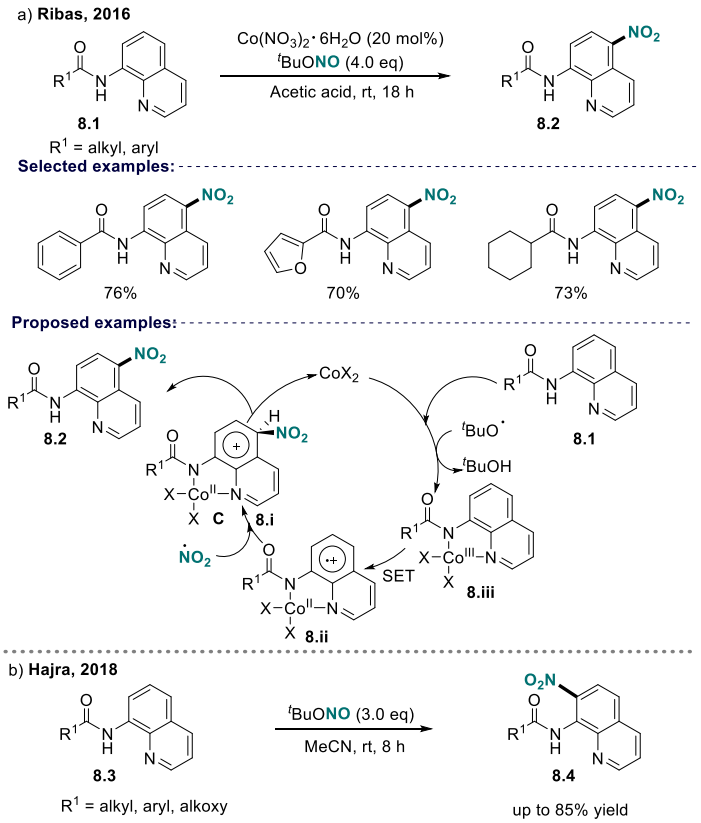
Functionalized azoarenes are versatile synthetic intermediates, in particular for the preparation of pharmaceuticals, dyes, and photochemical switchers. Ranu group disclosed a palladium-catalysed

nitration of *E*-azoarenes (**7.1**) through C−H activation strategy, which allowed the selective formation of *o*-mononitration products **7.2** in presence of both electron-withdrawing and electron-donating groups on the aromatic ring (Scheme 7).[39] *p*-Substituted azoarenes resulted in yield's decrease with an increase in electronegativity (I>Br>Cl>F), while an opposite trend was found for *o*-substituted derivatives (F>Cl>Br>I).



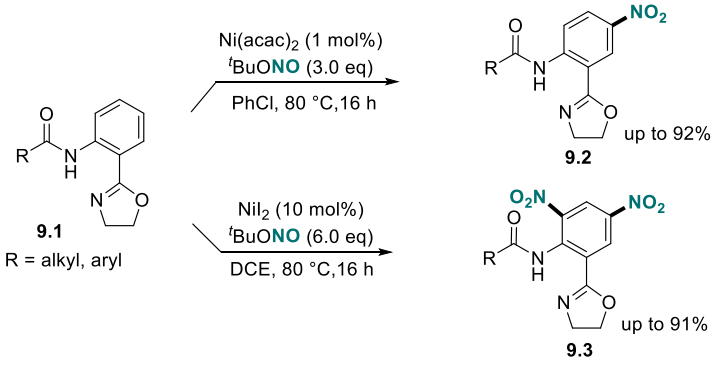
Scheme 7. Pd-Catalysed nitration of azoarenes.

In 2016, Ribas and co-workers introduced the first cobalt-catalysed remote C−H nitration of 8-aminoquinolines **8.1** (Scheme 8, a).[40] The reaction required 4 equivalents of **TBN** and unexpected 5-nitro-8-aminquinolines **8.2** as the major nitro products were obtained, while 7-nitro-8-aminoquinolines were formed as by-products in most cases. The authors proposed a single electron transfer (SET) based mechanism where interconversion of species **8.ii** to **8.iii** occurs intermolecularly. Tandem radical-radical coupling with NO_2 followed by a concerted proton transfer/demetallation led to the formation of the desired product. Later, the Hajra group showed a metal-free regioselective nitration of 8-aminoquinoline amides (**8.3**), in which nitration afforded mainly C-7 nitro adducts **8.4** using 3 equivalents of TBN at ambient temperature (Scheme 8, b).[41]



Scheme 8. Nitration of 8-aminoquinolines.

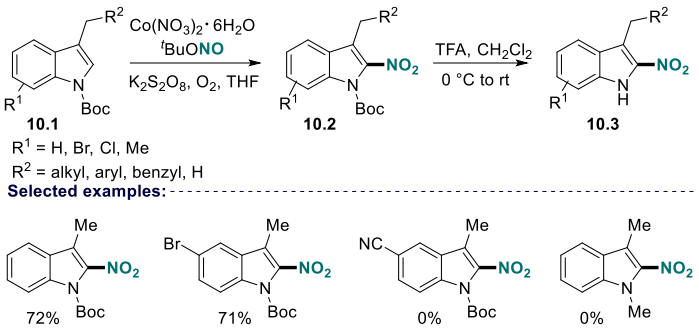
In 2017, Guo and co-workers developed an improved nickel-catalysed protocol for controlled regioselective *mono*- and *bis*-nitration of aryloxazolines **9.1** (Scheme 9). *Mono*-nitration product **9.2** was formed exclusively when $Ni(acac)_2$ was used as the catalyst in PhCl, whereas, in the presence of substoichiometric amounts of NiI_2 in DCE, *bis*-nitration **9.3** was observed.[42] This phenomenon can be explained by the enhanced coordination ability of NiI_2 to the substrate and the increased solubility of a *mono*-nitration product **9.2** in DCE. Similar to previous reports, a SET between 2-aryloxazoline moiety and highly oxidative Ni(III) species was postulated.



Scheme 9. Nickel-catalysed mono- and bis-nitration of aryloxazolines.

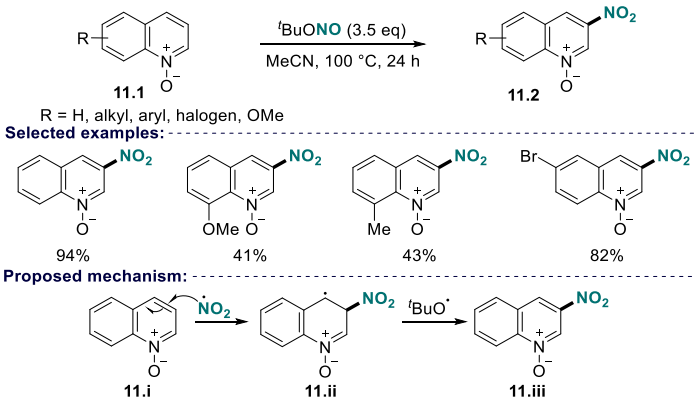
Later, a cobalt-catalysed site-selective C−H nitration of indoles **10.1** was reported by Kapur group (Scheme 10).[43] This is an efficient method for the selective incorporation of amino group at the C-2

position of indoles occurring by reduction of their corresponding nitro adducts **10.3**. The present method involves easily detachable directing group (*tert*-butyl carboxylate) and demonstrates excellent functional group tolerance. On the other hand, this protocol was unsuccessful with strong electron-withdrawing groups such as CN, NO_2 and other *N*-protecting groups.



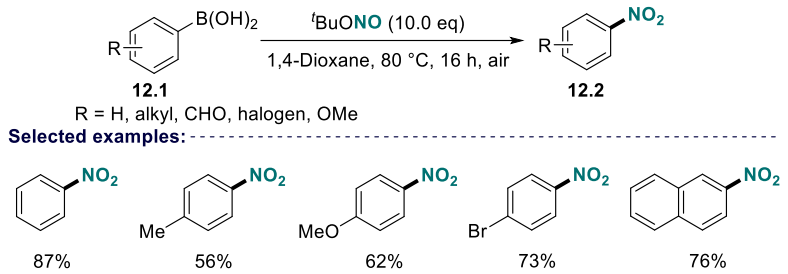
Scheme 10. Cobalt-catalysed nitration of azoarenes.

Zhao et al. extended **TBN**-mediated arylnitration approach through the development of regioselective C-3 nitration of quinoline *N*-oxides (**11.1**, Scheme 11).[44] The regioselectivity of this reaction was determined by the enhanced stability of radical at C-4 position of quinoline *N*-oxide.



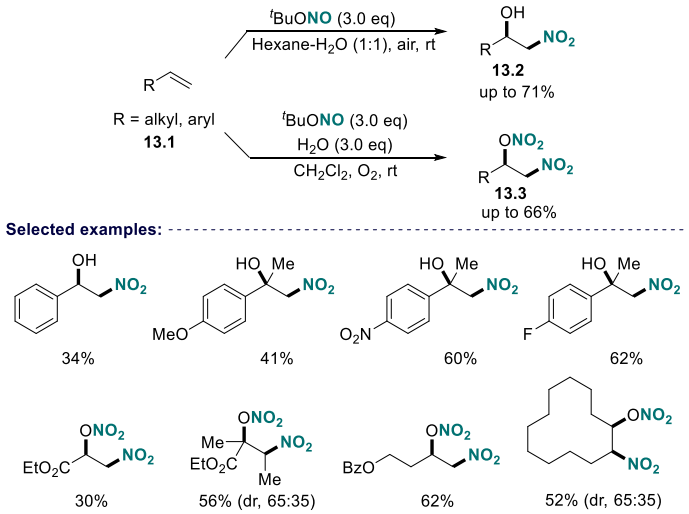
Scheme 11. Nitration of quinoline *N*-oxides.

Metal-free synthesis of nitroarenes from arylboronic acids (**12.1**) using **TBN** as nitrating reagent was first reported by Beller's group (Scheme 12).[45] The reaction proceeds through a nitrosation step followed by oxidation to the corresponding nitroarenes (**12.2**). Notably, the presence of aryl electron-withdrawing substituents requires the addition of one equivalent of $B(OH)_3$ to obtain satisfying yields. Unfortunately, this nitration protocol could not be extended to the *ipso*-nitration of aryl heteroaromatic derivatives.



Scheme 12. *Ipso*-Nitration of arylboronic acids.

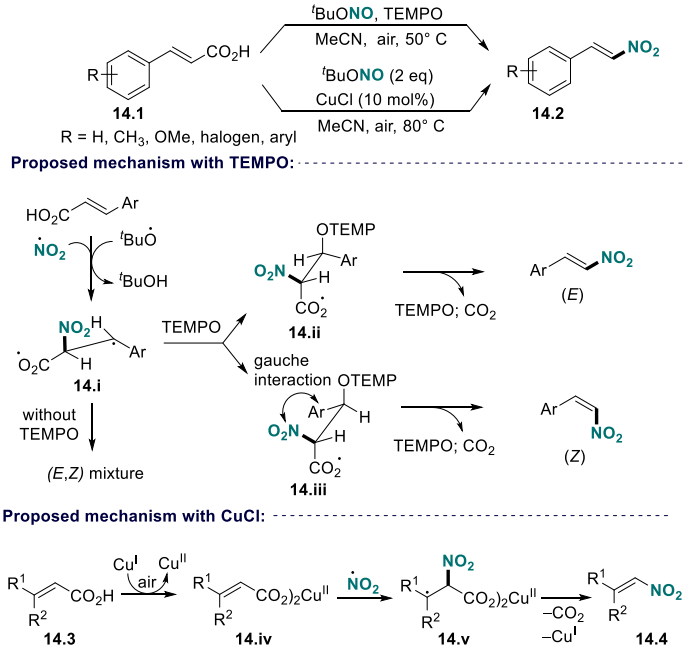
Soon after, the Taniguchi group used *tert*-butyl nitrite and oxygen to access nitrohydrins directly from olefins (**13.1**, Scheme 13).[46] In the presence of water, *tert*-butyl nitrite is quickly hydrolyzed to nitrous acid (HNO_2), which further decomposes to NO_2 and NO radical species. On the other hand, nitro radicals can be generated by direct oxidation of *tert*-butyl nitrite *via* peroxynitrite radical in presence of oxygen. Based on the choice of the solvent, two different types of products could be observed. *β*-Nitro alcohols (**13.2**) were formed as a major product in the mixed solvent system of hexane and water (1:1, v:v), while in dichloromethane their nitrate esters (**13.3**) were obtained.



Scheme 13. Oxidative radical nitration of alkenes.

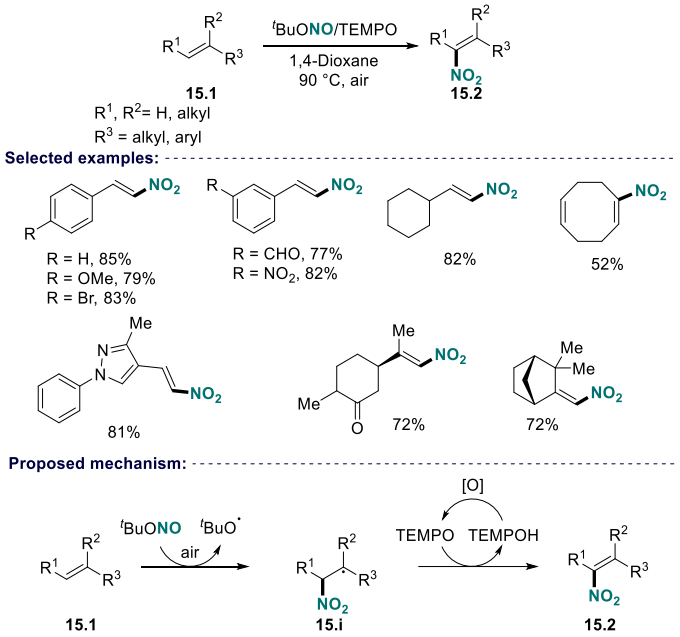
A metal-free decarboxylative nitroolefin synthesis protocol was reported by Maiti group in 2013 (Scheme 14).[47] In this method, *α*,*β*-unsaturated carboxylic acids **14.1** bearing *β*-(hetero)aromatic substituents can be converted to the corresponding nitro-adducts in good to excellent yields under mild conditions using a mixture of **TBN** and 2,2,6,6-tetramethylpiperidin-1-yl)oxyl (TEMPO). According to the proposed mechanism, homolytic cleavage of the O−NO bond of **TBN** reagent leads to the generation of nitroso radical, which further, in the presence of oxygen, can be oxidized to the corresponding nitryl radical. Upon addition of NO_2 radical to the olefin, the benzylic radical intermediate **14.i** can react with TEMPO in two possible pathways to form radicals **14.ii** and **14.iii**. However, DFT studies showed that intermediate **14.ii** formation is more favourable by 5.0 kcal/mol when compared to **14.iii**. Finally, anti-elimination from species **14.ii** exclusively yields *E*-isomer as a major product. A mixture of *E* and *Z*

products is generated in the absence of TEMPO, which supports the plausibility of the mechanism. Aliphatic carboxylic acids, e.g., cyclohex-1-enecarboxylic acid, unfortunately, failed to give the desired product by Maiti's protocol. In the same year, an improved copper-catalysed nitrodecarboxylation of unsaturated carboxylic acids (**14.3**) was reported by Prabhu's group.[48] Apart from excellent functional group tolerance, this method was found to be well compatible with heteroarene-derived α,β-unsaturated carboxylic acids. Notably, in the presence of TEMPO, yields of the reaction drastically decreased, while no product formation was found with butylated hydroxytoluene BHT (butylated hydroxytoluene). It was suggested, that the reaction occurs through the formation of Cu(II)-carboxylate salt **14.iv**, which further reacts with nitro radical. The subsequent decarboxylation resulted in the formation of *E*-nitroolefin (**14.4**, Scheme 14).



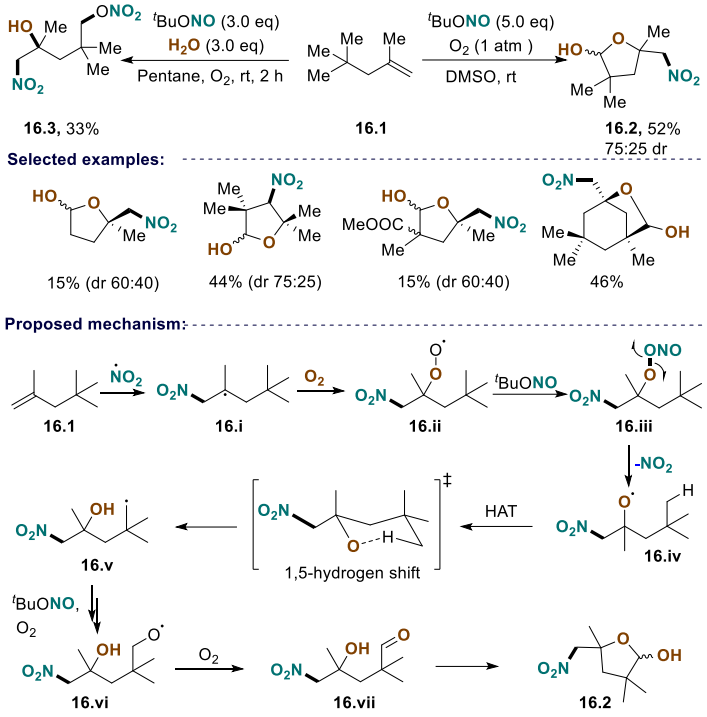
Scheme 14. Nitration of cinnamic acid derivatives.

A significant progress in the synthesis of nitro olefins was disclosed by Maiti and co-workers in 2013.[49] The authors developed a stereoselective mono-nitration of olefins (**15.1**), which proceeds in the presence of a mixture of **TBN** and TEMPO. A wide range of *E*-nitroolefins (**15.2**) with diverse functionalities regardless of steric and electronic effects could be obtained in synthetically useful yields. In addition, the protocol is amenable to the synthesis on a gram-scale without a significant decrease in product yield. Unlike previous advances in the synthesis of nitro alkenes, this reaction condition tolerates various aliphatic and heteroaromatic unsaturated molecules. It was postulated that TEMPO is likely responsible for the radical abstraction of the hydrogen atom from the species **15.i**, which is generated upon the addition of a nitro radical to an olefin (Scheme 15).



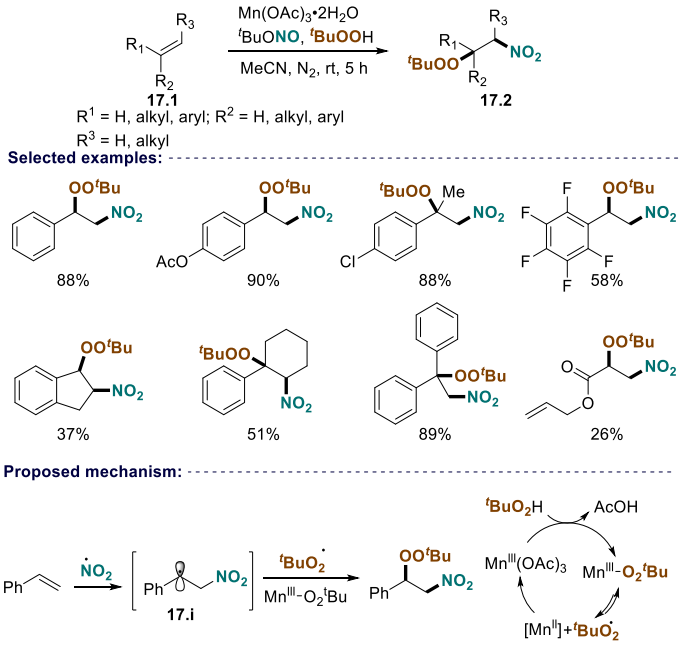
Scheme 15. Metal-free olefin nitration.

TBN can also act as an intermediate to facilitate the formation of new bonds in chemical transformations. In 2013, Taniguchi and co-workers reported a protocol for triple functionalization of alkenes using *tert*-butyl nitrite and molecular oxygen.[50] The reaction proceeded through the sequence of radical processes and involved a direct C(sp^3)–H oxidation of aliphatic alkenes **16.1** to give *γ*-lactols **16.2** in a single step (Scheme 16). The turnover point was the formation of alkoxy radical intermediate **16.iv**, which evoked the subsequent 1,5-hydrogen shift to form intermediate **16.iv**. In turn, the alkoxy radical **16.vi** was formed from intermediate **16.v** through a similar pathway, previously proposed in Barton reaction.[51] Oxidation of the alkoxy radical **16.vi** in presence of molecular oxygen to aldehyde **16.vii** and a following rapid intramolecular hemiacetalization led to the formation of the desired *γ*-lactol. The same group also reported an analogous multifunctionalization reaction of alkene using **TBN** and water to form nitrate esters **16.3**.[52]



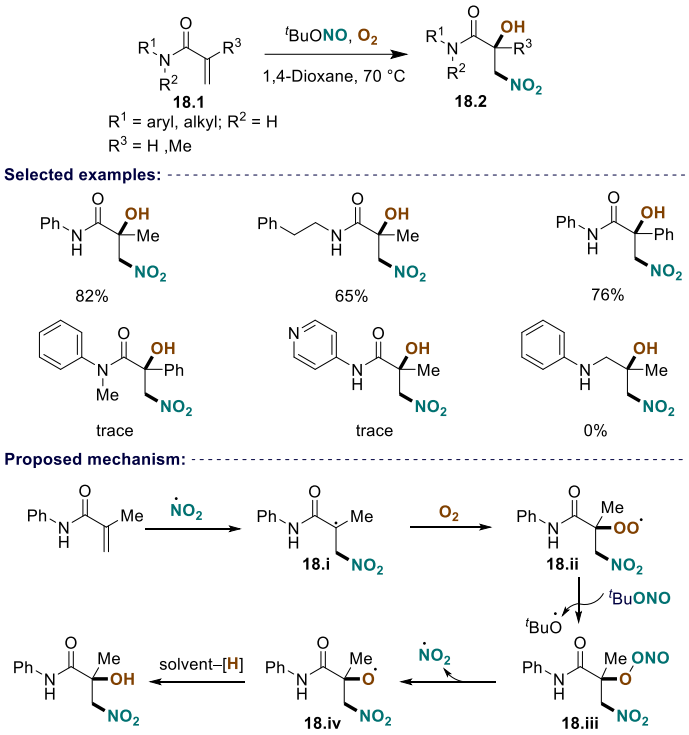
Scheme 16. Multifunctionalization of alkenes.

Another example of nitrative difunctionalization process has been developed by Li and co-workers for the synthesis of *β*-peroxyl nitroalkanes (**17.2**). The reaction is carried out in the presence of **TBN** and *tert*-butyl hydroperoxide and is catalysed with manganese(III) acetate.[53] Similar to Taniguchi's work, this protocol represents a selective and simultaneous introduction of a nitro group and a peroxyl group under mild conditions. Control experiments showed that the product formation is completely suppressed in the presence of radical scavengers such as TEMPO and BHT. Based on DFT calculations and various key experiments, a possible radical mechanism was postulated and is outlined in Scheme 17.



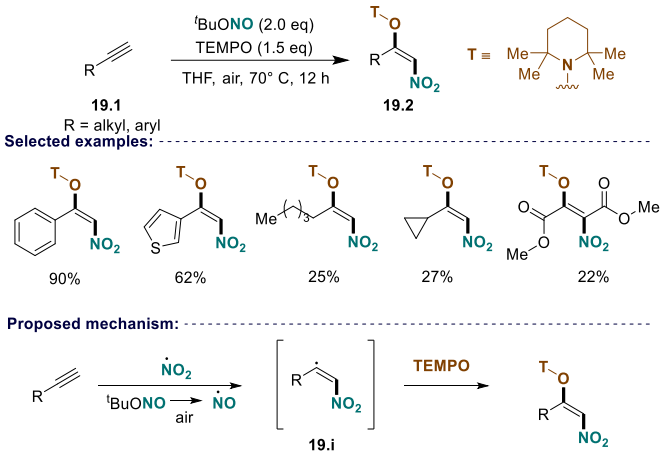
Scheme 17. Manganese-catalysed nitration−peroxidation of alkenes.

In 2019, Liu and co-workers developed the oxynitration of acrylamides (**18.1**) under aerobic oxidation.[54] Unlike Jiao's nitro-carbocyclization reaction of acrylamide, this method is compatible with unsubstituted amines, while aerobic oxygen quenched the radical intermediate before possible C−H functionalization. However, heteroaryl-substituted amides did not react under the standard conditions. Unactivated alkenes also failed to produce the desired product, and instead, the starting material was recovered. The yield of nitrohydrine **18.2** decreased to 8% when anhydrous solvent was used, which suggests that water is essential for this reaction. In the presence of various radical scavengers, no reaction took place. From these results, a radical-based mechanism was postulated (Scheme 18).



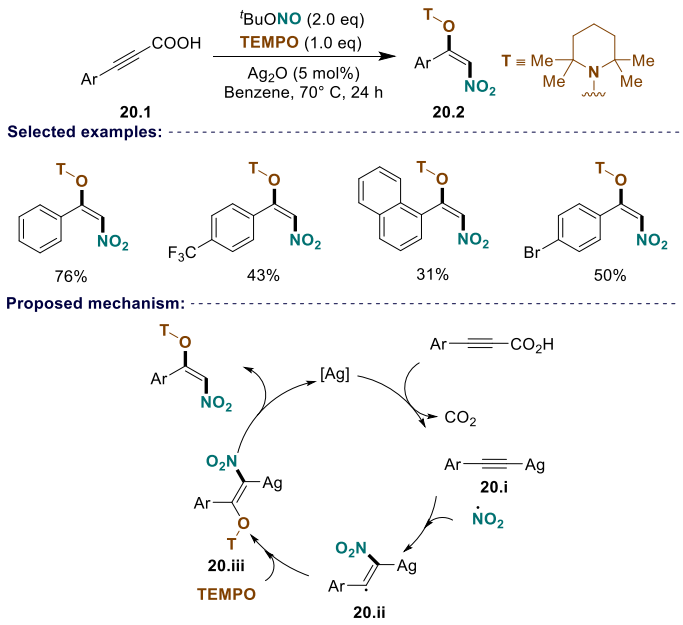
Scheme 18. Oxynitration of acrylamides.

The group of Maiti has also contributed to the development of the stereoselective oxynitration reaction of alkynes (**19.1**, Scheme 19).[55] This protocol can be used for a broad range of substrates and has an exceptional functional group tolerance, delivering the corresponding products in good to excellent chemical yields. Aliphatic terminal alkynes demonstrated poor reactivity, and diphenyl acetylene and other aliphatic internal alkynes were unsuccessful under these reaction conditions. The formation of an intermediate vinyl radical **19.i** was suggested which, upon the reaction with TEMPO, gave the final oxynitration product **19.2**. These nitroaminooxylation products can be further converted to synthetically important α-nitroketones in a single step.



Scheme 19. Oxinitration of alkynes.

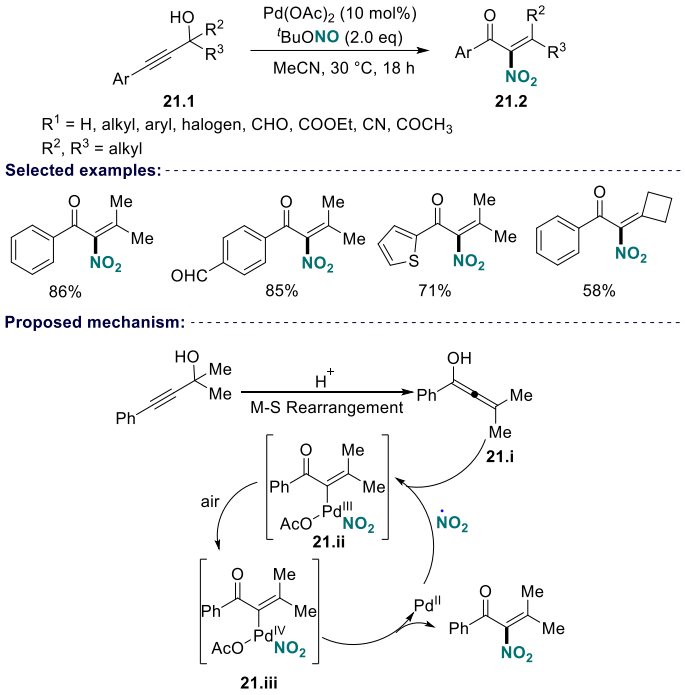
Almost at the same time, Mao and co-workers reported a similar intermolecular nitroaminoxylation of terminal aromatic alkynes.[56] A year later, the authors introduced a decarboxylative formation of *E*-□-nitroolefinic alkoxyamines **20.2** from phenylpropiolic acids (**20.1,** Scheme 20).[57] According to the proposed mechanism, the reaction is initiated by the formation of silver carbonate followed by the decarboxylation step. Subsequent reaction of Ag-acetylide **20.i** with nitryl radical results in the formation of benzylic radical intermediate **20.ii** which is further trapped by TEMPO to **20.iii**. After protonation, the desired nitroaminoxylative product **20.2** is formed, regenerating the silver catalyst.



Scheme 20. Decarboxylative nitroaminoxylation of arylpropiolic acids.

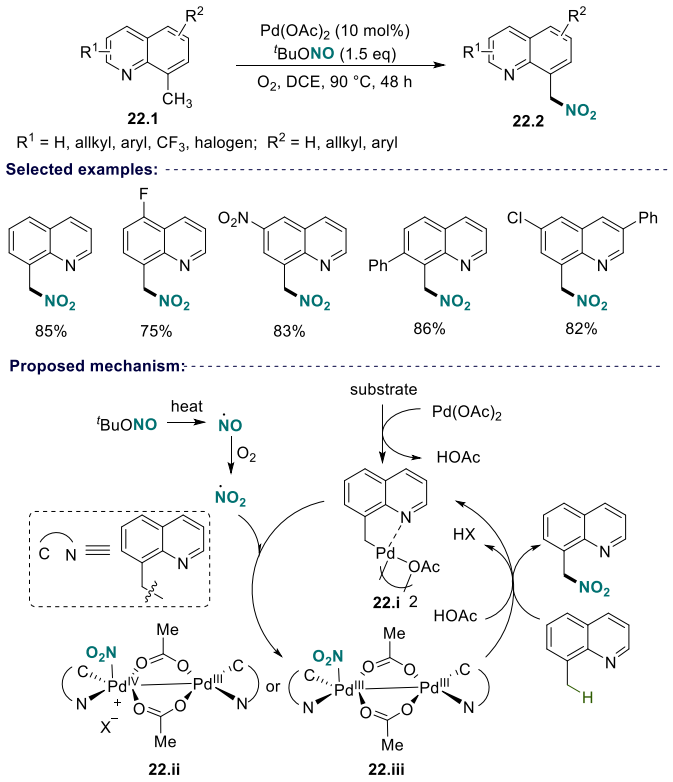
Song and co-workers designed a novel domino palladium-catalysed nitration of Meyer-Schuster intermediates which were formed *in situ* from propargylic alcohols **21.1** under mild conditions (Scheme 21).[58] This approach has a very broad scope and is insensitive to the electronic nature of substituted propargylic alcohols. Besides, the protocol can be scaled up to 1.1 g without efficiency loss. The

proposed mechanism includes the formation of HNO_2 from ^tBuONO and H_2O, which further promotes the Meyer-Schuster rearrangement to generate the allene type intermediate **21.i**. In presence of NO_2 radical, allene intermediate converts into Pd(III) species **21.ii** and are subsequently oxidizes to Pd(IV) **21.iii**. The reductive elimination leads to the formation of α-nitro enones **21.2** in good to excellent yields.



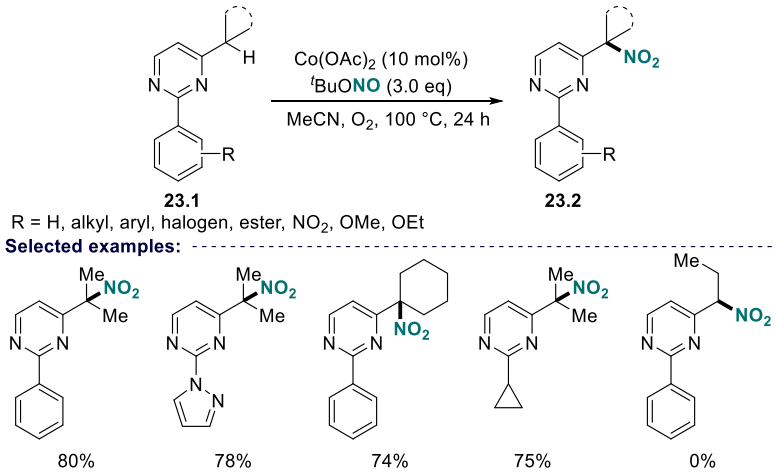
Scheme 21. Palladium-catalysed nitration of Meyer–Schuster intermediates.

Regioselective nitration of C(sp^3)−H generally requires a higher temperature than C(sp^2)−H nitration. Therefore, the development of regio- and chemoselective nitration of aliphatic C−H bond is a very challenging and attractive research area for synthetic chemists. In 2015, the Liu group has investigated transition metal-catalysed C(sp^3)−H functionalization of 8-methylquinolines (**22.1**).[59] The reaction occurs under oxygen atmosphere in the presence of palladium acetate catalyst and **TBN** as the nitrating agent (Scheme 22). The first C(sp^3)−H nitration was reported by the same group in 2014, using $AgNO_3$ as a nitro source.[60]The nitration can be performed at gram-scale and was applied to the synthesis of tetrahydroquinolin derivatives based on selective reduction of nitro group. According to the postulated mechanism, the formation of binuclear palladacycle is assumed to proceed *via* the reaction of the substrate, $Pd(OAc)_2$ and NO radical under aerobic conditions. The direct addition of NO_2 to the palladium center leads to the formation of Pd(III)-Pd(III) and/or Pd(III)-Pd(IV) species (**22.iii** and **22.iv**, respectively). Subsequent reductive elimination assisted by another molecule of the substrate gives nitrated product **22.2** and regenerates a binuclear palladacycle **22.i**.



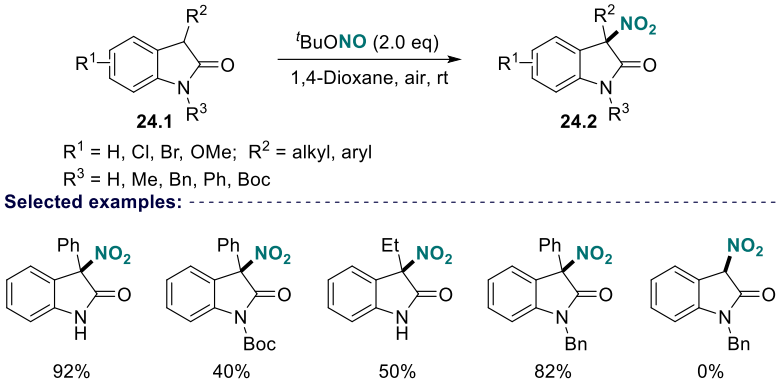
Scheme 22. Palladium-catalysed C(sp3)−H nitration of 8-methylquinolines.

Later, Song and co-workers reported cobalt-catalysed *chemo*- and regioselective C(sp^3)−H nitration using **TBN**.[61] With the optimized reaction conditions, a variety of 4-isopropyl-2-phenylpyridine derivatives (**23.1**), regardless of both the position and electronic properties of the substituents, afforded the desired C(sp^3)−H nitration products **23.2** in good chemical yields (Scheme 23). Exceptions were 4-methyl-2-phenylpyridine and 4-butyl-2-phenylpyrimidine, which did not undergo nitration under standard conditions. Notably, a site-selective C(sp^3)−H nitration was observed only in presence of tertiary alkane chain adjusted to the pyrimidine ring. This selectivity can be interpreted by the corresponding BDEs of C−H bonds.



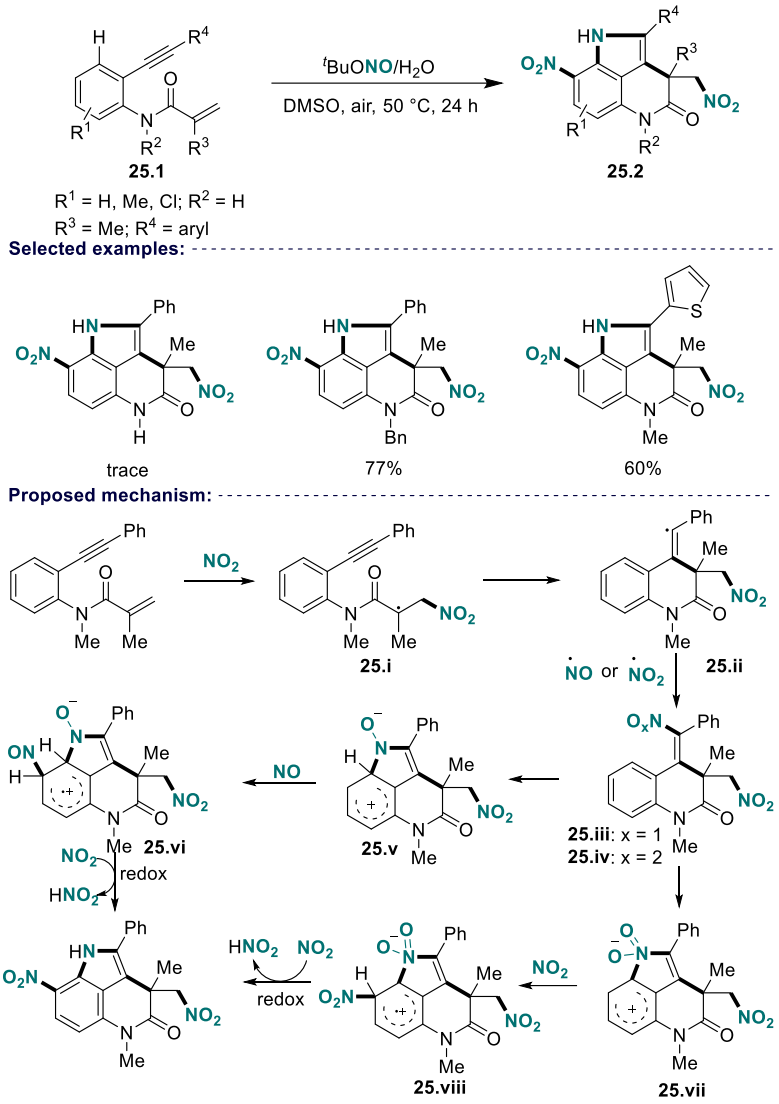
Scheme 23. Cobalt-catalysed C(sp^3)−H nitration.

Soon after, Wei and co-workers disclosed an effective metal-free method for the nitration of C(sp^3)−H bond of 2-oxindoles **24.1**.[62] The reaction proceeds through a radical coupling pathway at ambient temperature. A variety of 2-oxindoles bearing different functional groups smoothly undergo nitration reaction in good to excellent yields (Scheme 24). Only traces of desired product was detected when the reaction was carried out under nitrogen atmosphere. The reaction was also unsuccessful for unsubstituted oxindoles at the C-3 position.



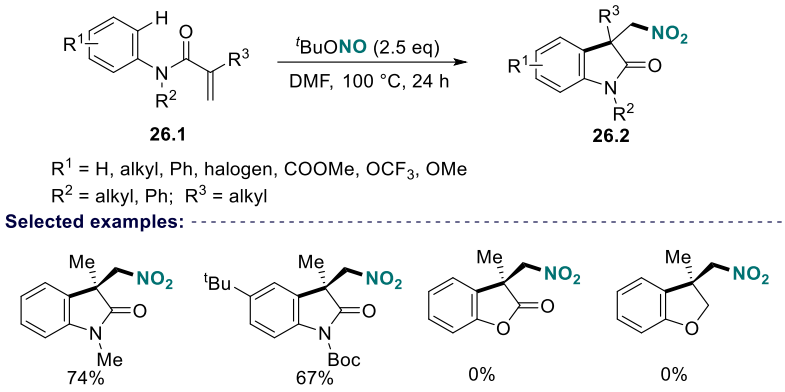
Scheme 24. Metal-free nitration of C(sp^3)−H bonds of 2-oxindoles.

Cascade reactions are a powerful tool for synthetic organic chemists to make complex ring systems in atom and step-economic ways. A cascade nitration/cyclization of 1,7-enynes **25.1** to quinolinone derivatives was introduced by the Li group.[63] This transformation represents the first example of one-pot synthesis of pyrrolo[4,3,2-de]quinolinone motif **25.2** which proceeds *via* alkene nitration, 1,7-enyne 6-exo-trig cyclization, C−H nitration and redox cyclization sequence, demonstrating remarkable functional group tolerance (Scheme 25). It was suggested that intermediate **25.i**, formed after the sequential addition of nitro radical to the olefin and carbocyclization step **25.ii**, can further react with either NO or NO_2 radicals, leading to the formation of the corresponding species **25.iii** and **25.iv**. These intermediates were detected by HRMS analysis. Subsequent reaction of the cationic intermediates **25.v** and **25.vii** with nitroso or nitro radicals provides intermediates **25.vi** and **25.viii**, the redox reaction of which affords the desired product **25.2**. This mechanistic scenario was supported with radical quenching and ^{18}O-labeling experiments.



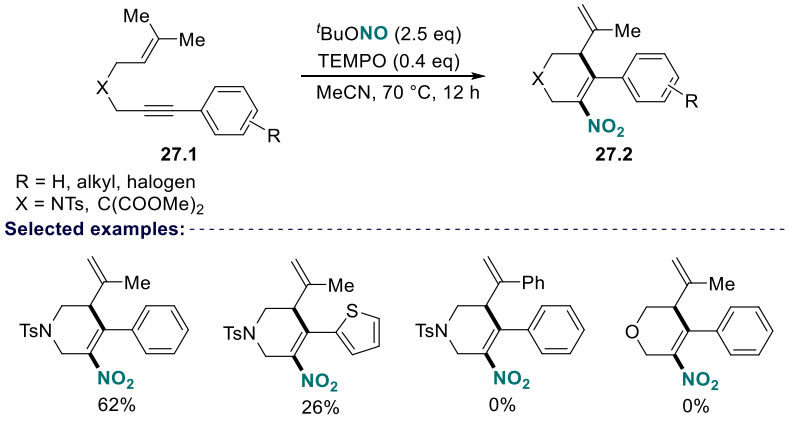
Scheme 25. Cascade nitration/cyclization of 1,7-enynes **25.1** with **TBN** and H_2O.

Subsequently, C−C and C−N cascade bond formation reactions using **TBN** have been reported by Jiao and co-workers (Scheme 26).[64] This metal-free nitro-carbocylization of activated alkenes **26.1** delivered nitro-containing oxindoles **26.2** through aryl C−H functionalization. Substrates with both electron-donating and electron-withdrawing groups at the aryl ring were well tolerated under these reaction conditions. However, in the case of phenyl methacrylates or allylphenyl ethers, no desired products were observed. Mechanistic studies indicated that the reaction occurs *via* the addition of NO_2, followed by the intramolecular cyclization steps.



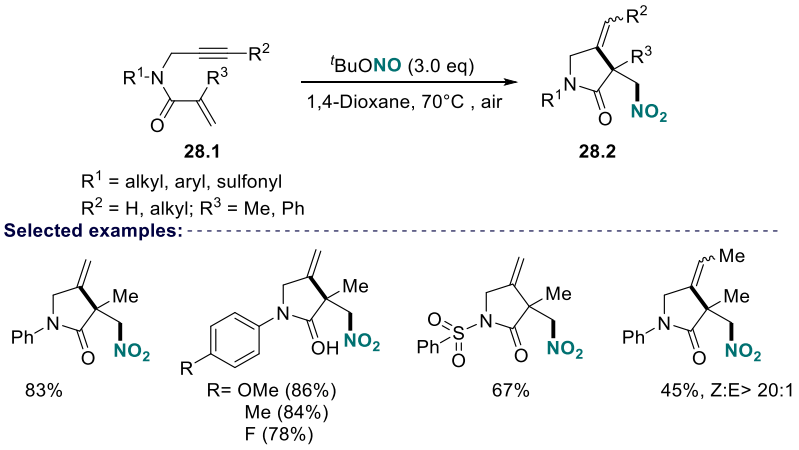
Scheme 26. Metal-free nitro-carbocyclization.

In 2015, Liang and co-workers developed metal-free tandem nitration, cyclization of 1,6-enynes **27.1** to form nitro substituted tetrahydropyridines **27.2**. The reaction proceeded in the presence of **TBN** reagent and TEMPO, involving the formation of two C−C and one C−N bond in a single chemical step.[65] The transformation has shown relatively good functional group compatibility and can be scaled up to gram synthesis (Scheme 27). Based on experimental results and previous reports on nitrative cascade reactions, the authors suggested a radical-based mechanism, in which the addition of NO_2 radical to an alkyne followed by an intramolecular carbocylization and oxidative dehydrogenation yields the corresponding nitrocarbocyclized product.



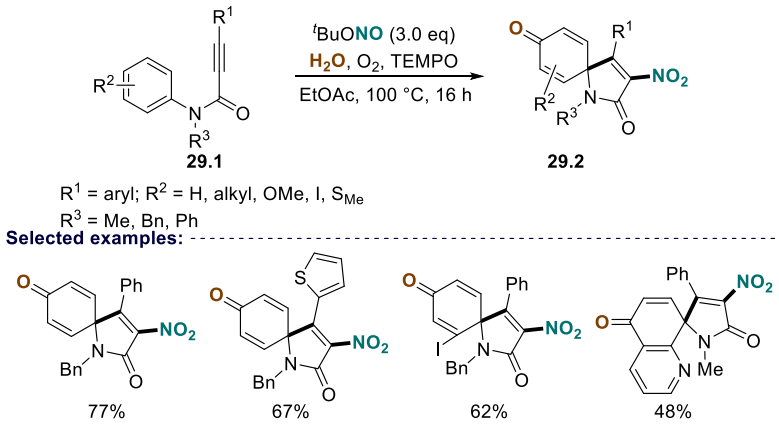
Scheme 27. Nitro-carbocyclization of 1,6-enynes.

In 2018, Qiang Li and co-workers reported an interesting nitrative cyclization reaction of 1,6-enynes **28.1** with ^{t}BuONO that proceeds under metal-free conditions and leads to the construction of 2-pyrrolidinone **28.2** derivatives in a highly controlled manner (Scheme 28).[66] Based on various mechanistic studies, it was postulated that the reaction involves the addition of NO_2 radical towards an alkenyl group followed by 5-exo-dig cyclization/H abstraction sequence. The transformation demonstrated a great functional group tolerance irrespective of steric and electronic effects and was successfully used on a gram scale.



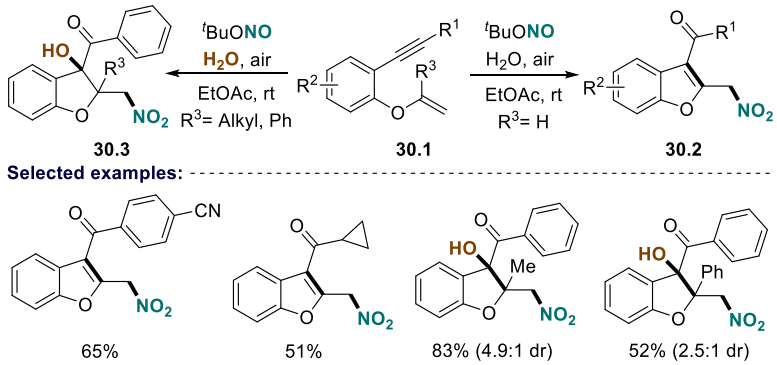
Scheme 28. Regioselective nitrative cyclization of 1,6-enynes with ^{t}BuONO.

Nitrative spirocyclization was introduced by Li and co-workers in 2015, using ^{t}BuONO with water as nitro source and TEMPO as the initiator (Scheme 29).[67] This work represents a new example of oxidative alkyne difunctionalization *via* a formation of C−N/C−C bonds for the synthesis of nitroalkene containing spiro cycles **29.2**.



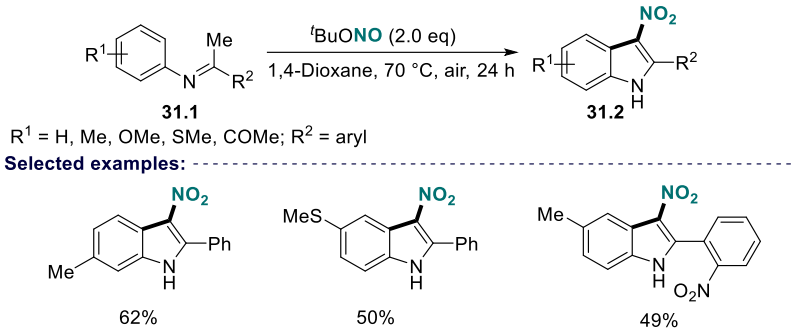
Scheme 29. TEMPO-mediated nitrative spirocylization.

Nitrative cyclization of 1-ethynyl-2-(vinyloxy)benzenes (**30.1**) to access benzofuran derivatives was further developed by the same group (Scheme 30).[68] This reaction incorporated an oxygen atom from dioxygen into the product and resulted in the synthesis of highly functionalized benzofuran ketones **30.2** and **30.3** through 1,6-enyne nitrative cyclization and dioxygen activation.



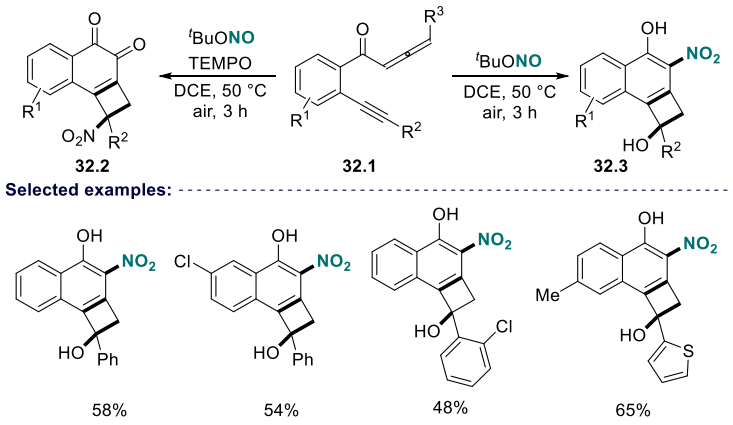
Scheme 30. Nitrative cyclization of 1-ethynyl-2-(vinyloxy)benzenes through.

In the same year, Li group reported another example of nitrative cyclization of *N*-aryl imines (**31.1**) with ^{t}BuONO to access 3-nitro indoles (**31.2**, Scheme 31).[69] The reaction sequence was proposed to undergo through oxidative cleavage of multi C–H bonds, a nitration, a cyclization and an isomerization cascade. The formation of NO_2 radicals *via* reaction of nitroso radicals with water was strengthened by the ^{18}O-labeled experiment using $H_2{}^{18}O$.



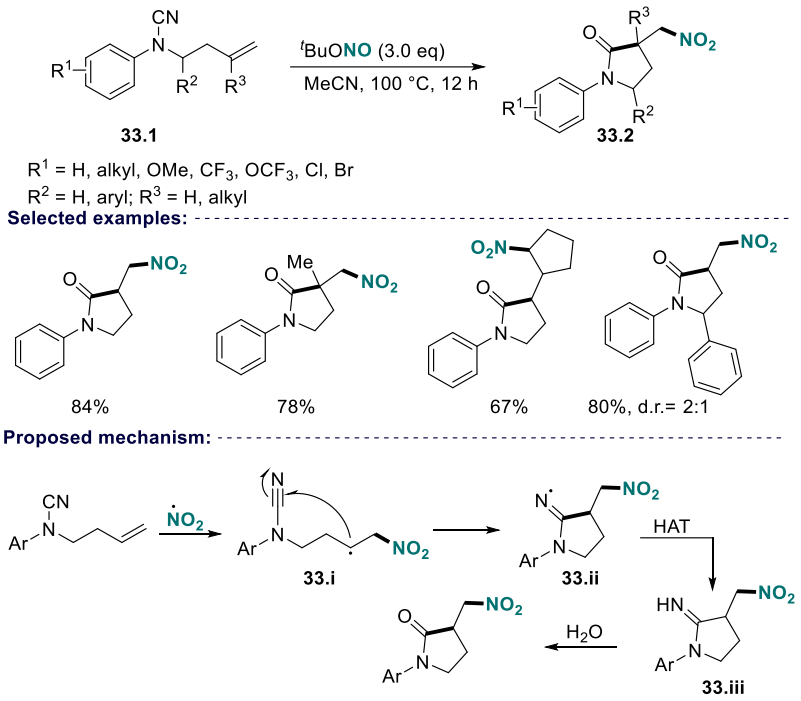
Scheme 31. Metal-free nitrative cyclization of *N*-aryl imines.

Synthesis of functionalized cyclobutene-fused napthalene derivatives **32.2** and **32.3** *via* a cascade reaction of allenynes **32.1** with **TBN** was presented by the Fan group in 2019.[70] This is the first example for the synthesis of nitro containing (6:6:4) fused cycles in a rapid, mild, and one-pot manner (Scheme 32).



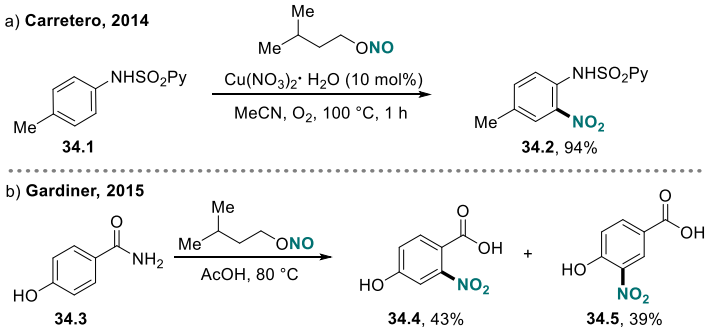
Scheme 32. Metal-free nitrative cyclization of *N*-aryl imines with **TBN**.

γ-Lactams are important structural motifs in organic chemistry as this moiety constitutes the core of many natural drugs, alkaloids, agrochemicals, and bioactive molecules. In 2019, Zhu group reported a metal-free approach for *γ*-lactams synthesis, that involves intramolecular nitration-aminocarbonylation of unactivated olefins **33.1** (Scheme 33).[71] Under the reaction conditions, unexpected *γ*-lactams were formed instead of cyano-migrated products. According to the experimental results and mechanistic investigations, the transformation involves the addition of nitro radical to alkene **33.1** followed by an intramolecular capture of alkyl radical **33.i** by cyano-group to afford five-membered cyclic intermediate **33.ii**. Hydrogen abstraction and hydrolysis steps afford the final product. The utility of the protocol was further demonstrated through the reduction of *γ*-lactam adduct to the corresponding 3-substituted nitro-derived pyrrolidine **33.2**.



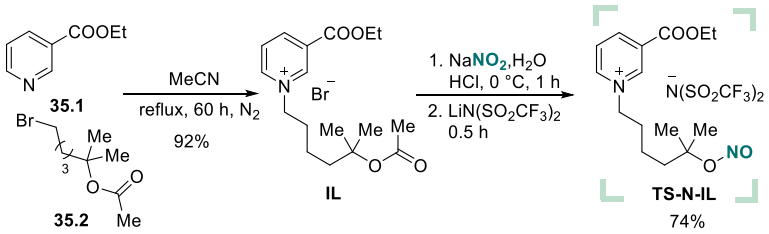
Scheme 33. Intramolecular nitration-aminocarbonylation of olefins.

Other alkyl nitroso nitrating reagents are much less explored. Thus, amyl nitrite, was used a nitrating agent in organic synthesis. In 2014, Carretero and co-workers utilized amyl nitrite during their optimization studies in the nitration of protected anilines **34.1**, and the desired aromatic nitration product **34.2** was formed in excellent yields (Scheme 34, a).[72] Later, the group of Gardiner used amyl nitrite for the conversion of aromatic primary amides to the corresponding carboxylic acids (Scheme 34, b).[73] However, along with the desired transformation, aromatic nitration also occurred, resulting in a mixture of nitro-aromatic carboxylic acids **34.4** and **34.5**.



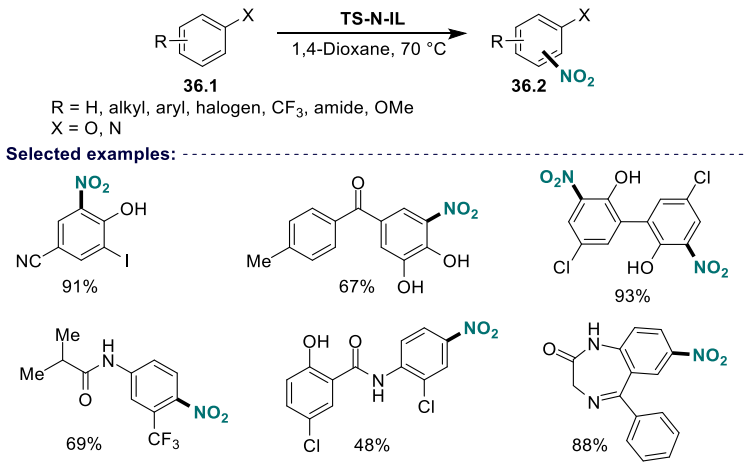
Scheme 34. Aromatic nitration using amyl nitrite.

Recently, Natarajan group has developed a new nitrite reagent, 3-(ethoxycarbonyl)-1-(5-methyl-5 (nitrosooxy)hexyl)pyridin-1-ium bistriflimide (**TS-N-IL**), a greener alternative to *tert*-butyl nitrite.[74] Moreover, it is less flammable and stable up to 150 °C. **TS-N-IL** is an ionic liquid, that can be prepared from ethyl nicotinate (**35.1**) and 6-bromo-2-methylhexan-2-yl acetate (**35.2**) in three steps as shown in Scheme 35.



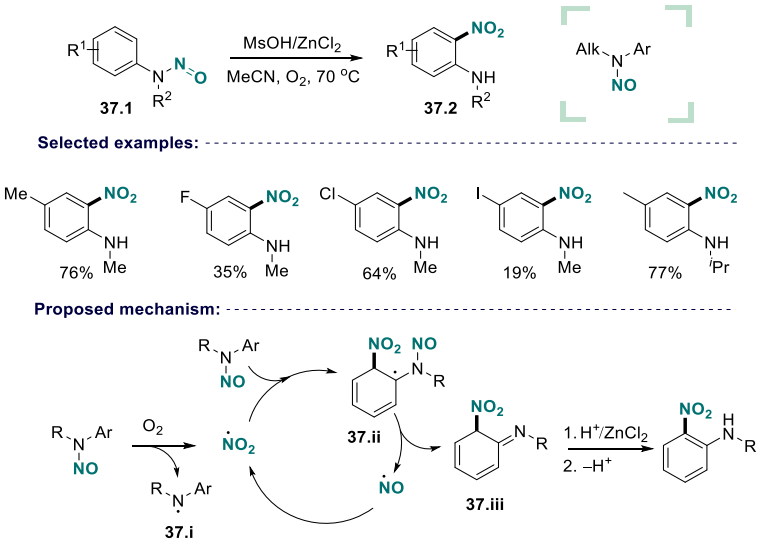
Scheme 35. Preparation of **TS-N-IL**.

A series of electron-rich aromatic compounds **36.1** such as phenols and amines gave an excellent yield of corresponding nitroarenes **36.2** when treated with **TS-N-IL** at room temperature (Scheme 36). Different functional groups such as halides, ethers, amides, and carbonyls are well tolerated under established reaction conditions.



Scheme 36. Aromatic nitration of **36.1** with **TS-N-IL**.

Similar to alkyl nitroso reagents, *N*-nitroso compounds have also recently been used as nitrating agents. In 2019, Jua and co-workers demonstrated that in the presence of dioxygen, direct intramolecular nitration of *N*-nitrosoanilines (**37.1**) to the corresponding nitro-anilines takes place.[75] Based on the results of mechanistic studies, the formation of aniline radical and nitro radical species under aerobic conditions was proposed. Addition of NO_2 to the substrate and □-fragmentation leads to the formation of the desired *o*-nitro anilines (**37.2**) derivative in a highly regioselective fashion (Scheme 37).



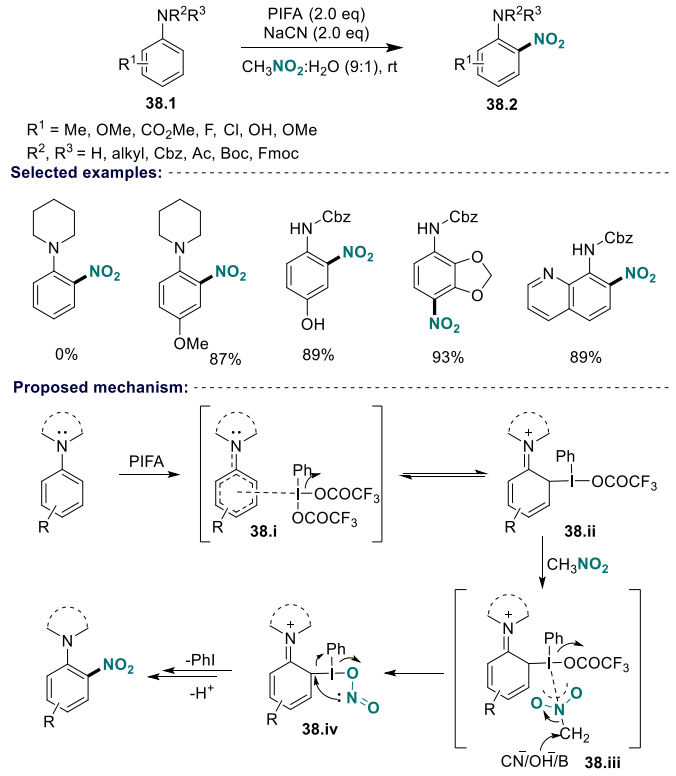
Scheme 37. Nitration of *N*-alkylanilines.

3.2. Nitro Alkanes

Nitroalkanes have found diverse functions in organic synthesis[76] over the past decades, however, their application as nitrating agents is rather limited. As such, the use of nitromethane in nitration reactions that occur through the direct cleavage of the C–N bond is quite rare in the literature.[77] The first reported example of the use of nitromethane as nitrating reagent was shown by Klemm and co-workers in 1988 during the sulfonylation of polyaromatics.[78] However, a 20 year old bottle of nitromethane was utilized for this transformation, making it is difficult to conclude whether the nitromethane was the real source of NO_2.

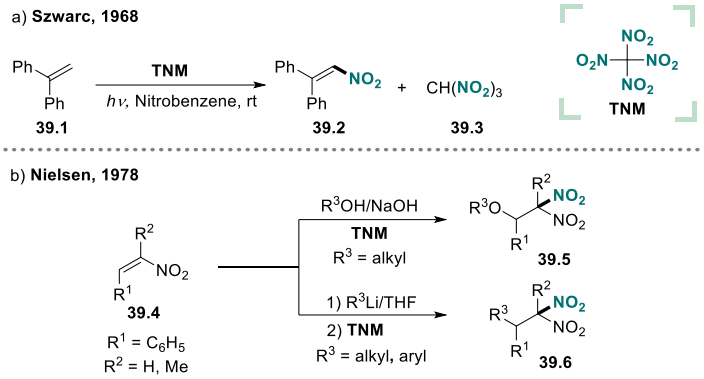
In 2019, Kim group reported a metal-free PIFA-promoted nitration of arylamines mediated by nitromethane (Scheme 38).[79] The reaction demonstrated excellent compatibility with various functional groups. However, the scope of this method was limited to arylamines (**38.1**) and could not be prolonged to phenols and derivatives. According to the proposed mechanism, PIFA coordinates with the substrate *via* halogen–π interactions, and the subsequent elimination of CF_3COO^- generates intermediate **38.ii**. While the nitro (I-N) or nitrite (I-O) transfer from CH_3NO_2 can be assumed, I–O intermediate **38.iii** was chosen on the basis of literature precedence (other nitroiodonium(III) species are discussed in Chapter 3.3). The final nitro product is formed through four-membered transition state **38.iv** followed by

aromatization. The DFT calculations further supported the proposed mechanism. In addition, in a control reaction when NaCN was replaced by NaOPh, the formation of PhOMe was detected by crude NMR and LC−MS.



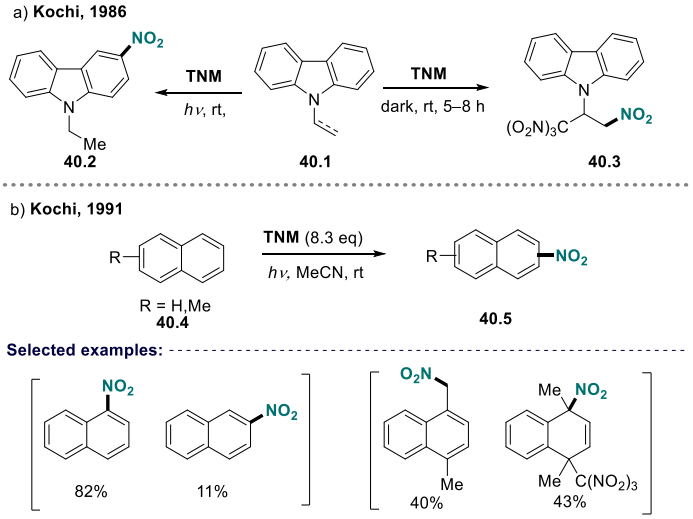
Scheme 38. PIFA promoted nitration of arylamines **38.1** using nitromethane.

While breaking C−N bond in nitromethane is not a trivial task, other nitro alkanes with lower BDEs found more extensive applications in nitration. One of them is tetranitromethane (**TNM**), a common organic oxidizing agent, that is also used as a nitro donor in nitration reactions. It is a highly explosive and toxic liquid that is being prepared in one step from acetic anhydride and nitric acid.[80] In 1968, Szwarc and co-workers found during their studies on the formation of a carbonium ion that the addition of tetranitromethane to 1,1-diphenylethylene (**39.1**) in nitrobenzene produced 1,1-diphenyl-2-nitroethylene (**39.2**, Scheme 39, a).[81] A synthetic route for the preparation of *gem*-dinitroethers **39.5** and *gem*-dinitroalkanes **39.6** using **TNM** was reported by Bedford and Nielsen.[82] Nitro olefins (**39.4**) in the presence of **TNM**, when treated with alkoxide or alkyllithium, yielded the corresponding *gem*-dinitroethers and *gem*-dinitroalkanes (Scheme 39, b). Nitration of vinylsilanes with **TNM** was later demonstrated by Rathore and Kochi.[83]



Scheme 39. TNM-mediated alkene nitration reactions.

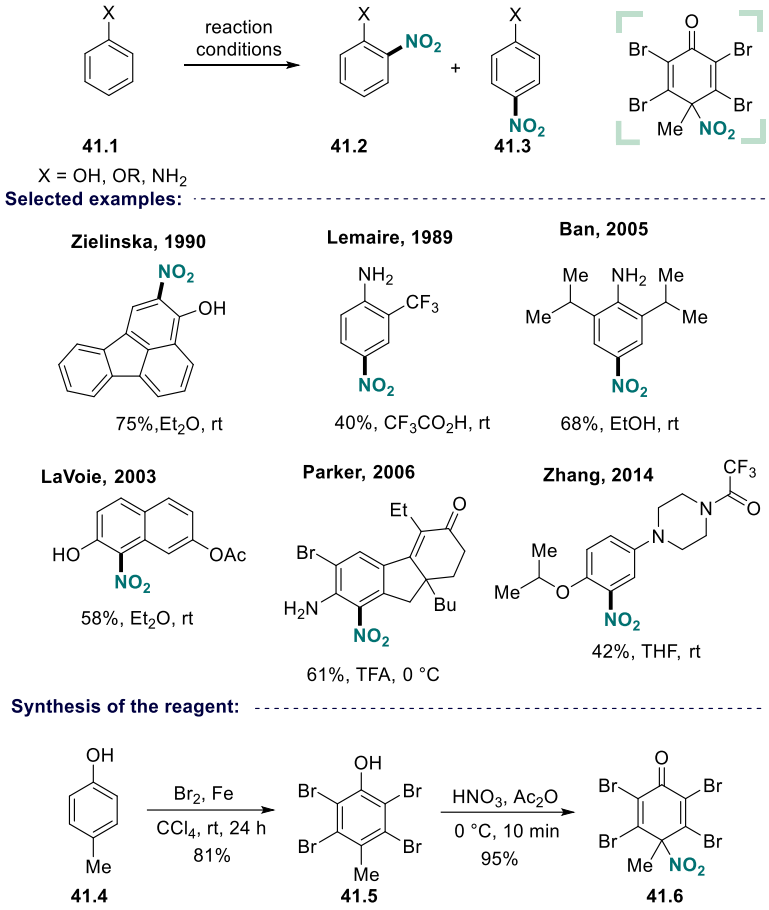
Thermal nitration of *N*-vinylcarbazole (**40.1**) using tetranitromethane was also observed by the Kochi group. 1,2-Adduct **40.3** was formed at room temperature in dark, while in the presence of irradiation nitration of *N*-ethylcarbazole to form 3-nitro derivative **40.2** took place (Scheme 40, a).[84] Later, the same authors found that irradiation of a solution of naphthalene (**40.4**) and **TNM** with visible light for 17 h led to the formation of 1-nitronaphthalene (82%) and 2-nitronaphthalene (11%), respectively (Scheme 40, b).[85]



Scheme 40. TNM-mediated aryl nitration reactions.

Another example of this class of reagents is 4-nitro-cyclohexa-2,5-dienone derivative, which was introduced by Lemaire et al. in 1986.[86] It was successfully applied for the nitration of electron-rich aromatic compounds **41.1**, namely phenols and anilines, including highly substituted molecules (Scheme 41).[87] Few years later, it was shown that this molecule can act as a brominating reagent for the synthesis of aryl bromides under similar reaction conditions.[88] The selectivity between these two processes (nitration and bromination) remains unclear, yet it depends both on solvent and substrate structure.[89] As for the mechanism of nitration, originally, an ionic pathway was postulated. However, evidence for the formation of radical species was also observed,[90] yet it may be possible that the mechanism of the transformation significantly depends on solvent, activation method and the substrate

nature. The synthesis of the reagent was recently improved using an *in situ* generated acetyl nitrate as a nitro source (Scheme 41).[91]



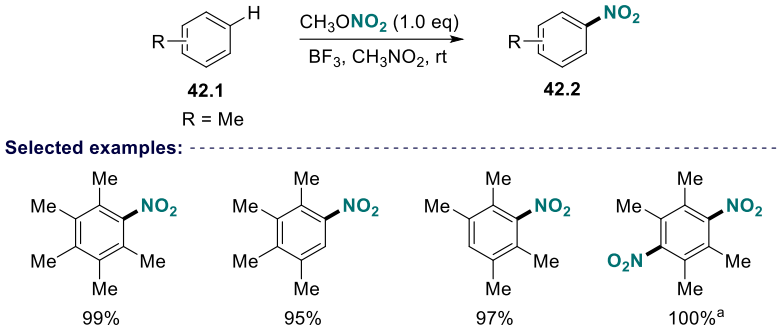
Scheme 41. Nitration of electron-rich aromatic compounds with 4-nitro-cyclohexa-2,5-dienones.

3.3. Alkyl Nitrates

Alkyl nitrates (ANs) are a class of organic molecules in which nitrogen is stabilized in the structure of R-O-NO_2. In nature, ANs are intermediate products of photochemical reactions which regulate ozone formation. From a synthetic point of view, they serve as a source of electrophilic nitro species. Alkyl nitrates can directly react with strong nucleophiles, although they are often chemically inert without additional activation.

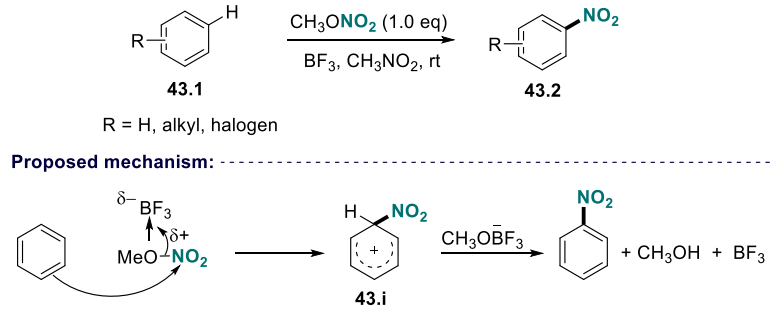
Traditional mineral acids-based processes in aromatic nitration usually lead to the formation of exclusively dinitro products or a complex mixture. A significant improvement over this limitation was realized by using a nitrating system consisting of methyl nitrate and boron trifluoride in nitromethane and was presented by Olah and co-workers in 1973 (Scheme 42).[92] Mononitro aromatic compounds were obtained in excellent yields when equimolar amounts of polymethylbenzene (**42.1**) and methyl nitrate were used. With an excess of methyl nitrate in the solution, only dinitro products were isolated. It is

worth mentioning, that other catalyst systems such as aluminium trichloride and titanium(IV) chloride provided significant product was generated in the presence of sulfuric acid.



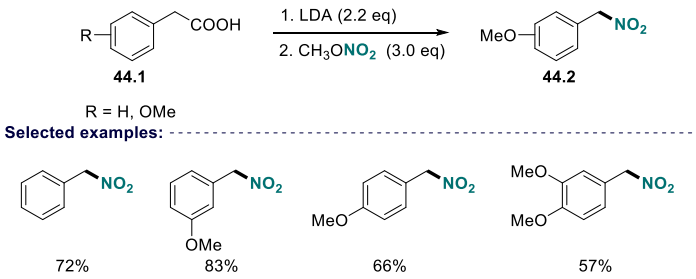
Scheme 42. Nitration of polymethylbenzenes. [a]3.0 eq of methylnitrate.

A year later, Olah and Lin reported a detailed study on the nitration processes of alkylbenzenes and halobenzenes (**43.1**) in order to understand the mechanism and the nature of the nitrating agent in methyl nitrate and boron trifluoride system.[93] The nitration of aromatics with CH_3ONO_2–BF_3 was more selective as compared to $NO_2^+BF_4^-$, indicating the unlikelihood of the direct involvement of nitronium ion **43.i**. In addition, nitronium ion was not detected by IR or Raman spectroscopy. A polarized boron trifluoride complex is likely the nitrating agent which undergoes the reaction with aromatic substrates (Scheme 43).



Scheme 43. Proposed mechanism for boron trifluoride-catalysed nitration.

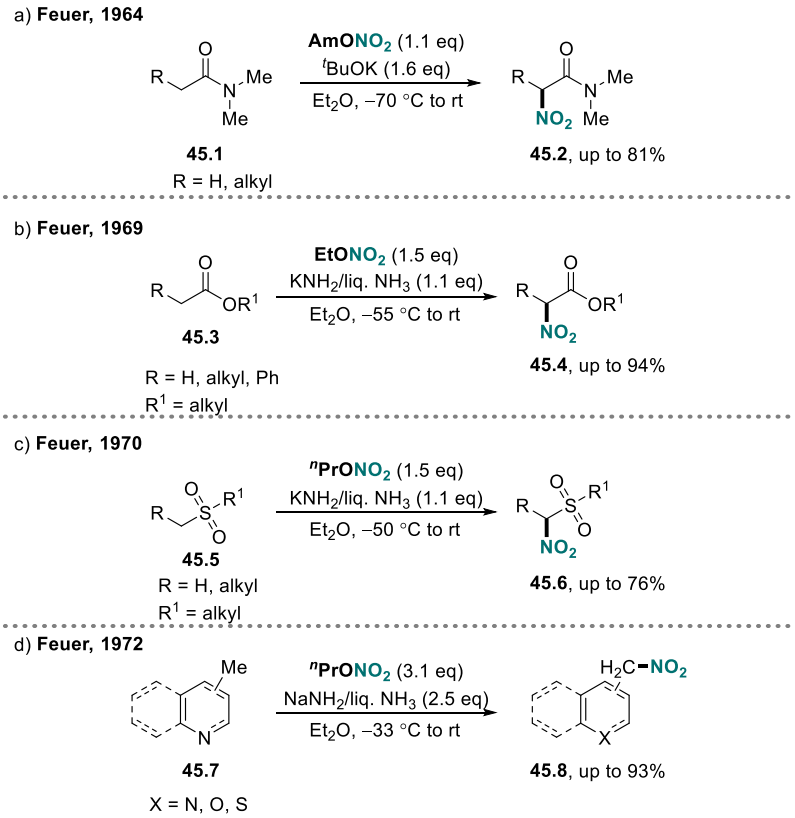
In 1988, Hauser and Baghdanov presented the synthesis of ring-methoxylated phenylnitromethanes (**44.2**) from the corresponding phenylacetic acids (**44.1**) using LDA and methyl nitrate in presence of hexamethylphosphoramide (HMPA) (Scheme 44).[94] The reaction proceeds *via* condensation of the dianions of methoxylated phenyl acetic acids with methyl nitrates.



Scheme 44. Preparation of methoxylated phenylnitromethanes.

Apart from methyl nitrates, the reactivity of other simple alkyl nitrates such as ethyl, propyl, and amyl nitrates was also explored by different research groups.[95] Ethyl nitrate was first applied for the synthesis of nitro compounds in 1900, and after 1902, for the nitration of *in situ* generated carbanions.[95d,e] However, in those transformations, the corresponding azinate salts were isolated as products. Thus, usage of ethyl nitrate for the direct nitration began later.

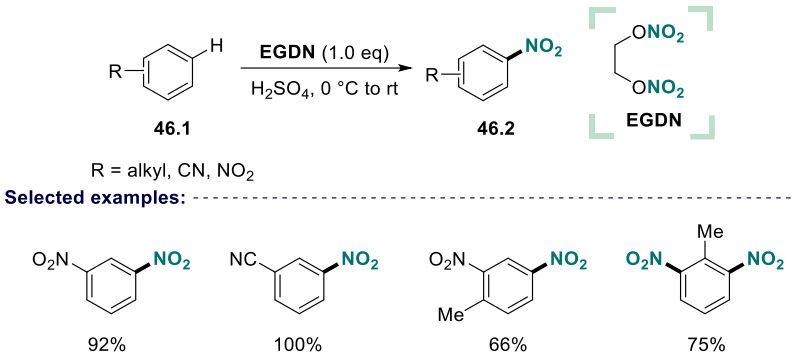
In 1928, Wieland et al. used ethyl nitrate and potassium ethoxide in ethanol/diethyl ether mixture for the nitration of cyclopentanone.[96] Despite the fact that the reaction yield was only 7%, this was one of the first attempts to access α-nitrocarbonyl compounds. Later in 1956 Feuer and co-workers improved the yield of the reaction up to 72% by using amyl nitrate as source of nitro group and potassium *tert*-butoxide as base in tetrahydrofuran.[97] Several alkyl nitrate-mediated nitration of active methylene compounds such as amides **45.1**, esters **45.3**, sulfonates **45.5**, arylidene/alkyllidenes, phosphonates, aldimines, and alicyclic ketimines were reported by Feuer and co-workers (Scheme 45, a-c).[98] At the same time, they also discovered nitration of alkyl-substituted heterocyclic compounds **45.7** using a mixture of alkali metal amide and alkyl nitrate (Scheme 45, d).[99]



Scheme 45. Nitration of activated methylene compounds.

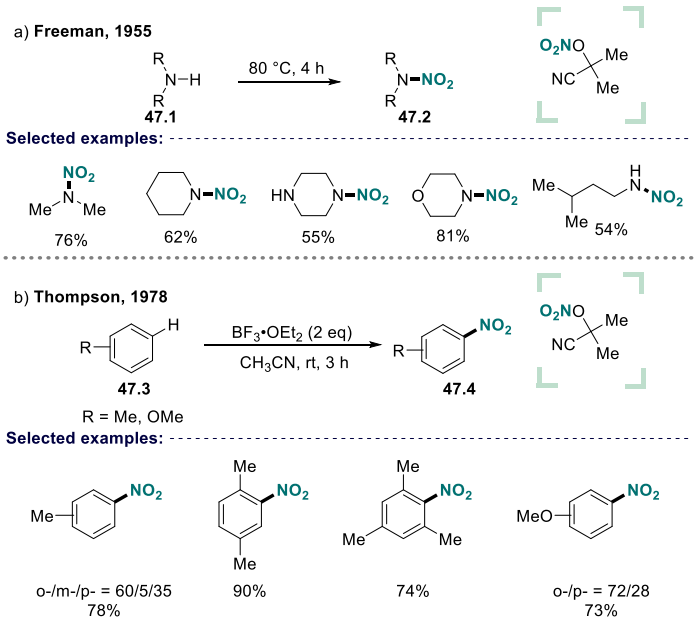
Oxley and co-workers found that ethylene glycol dinitrate (**EGDN**) can act as an effective nitrating reagent for aryl nitration in the presence of sulfuric acid (Scheme 46).[100] This liquid nitrating reagent

provided a very similar nitrating capacity compared to other reagents such as guanidium nitrate, nitroguanidine, urea nitrate, nitro urea, and ammonium nitrate.



Scheme 46. EGDN-mediated aryl nitration.

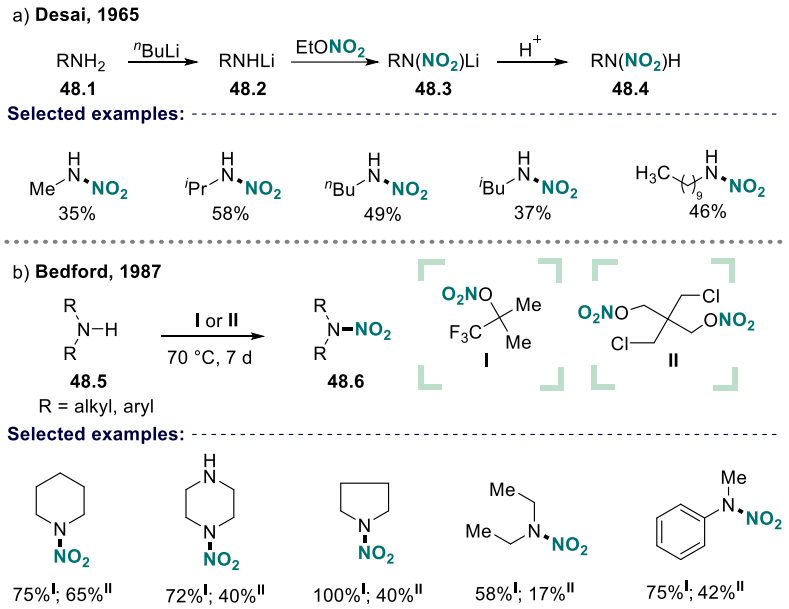
In 1955, Emmons and Freeman used cyanohydrin nitrate to synthesize both primary and secondary aliphatic nitroamines (**47.2**) from the corresponding amine derivatives (Scheme 47, a).[101] Later, acetone cyanohydrin nitrate was also exploited by Narang and Thompson in Friedel-Crafts type electrophilic nitration of activated aromatic systems (**47.3**, Scheme 47, b).[102] In the latter case, the authors replaced BF_3 gas with substoichiometric amounts of boron trifluoride etherate. With a mechanism similar to that the one described by olah, the authors concluded that the formation of free nitronium ion is unlikely, and instead, a nucleophilic attack by the aromatic hydrocarbon is the preferred pathway for this transformation.



Scheme 47. Cyanohydrin nitrate-mediated nitration.

Alkaline nitration of aromatic and aliphatic amines (**48.1**) to nitramines (**48.4**) is another heteroatom nitration example using organic nitrates known in the literature. In 1920, Bamberger developed a convenient method for alkaline nitration using ethyl nitrate as a nitrating reagent and potassium ethoxide

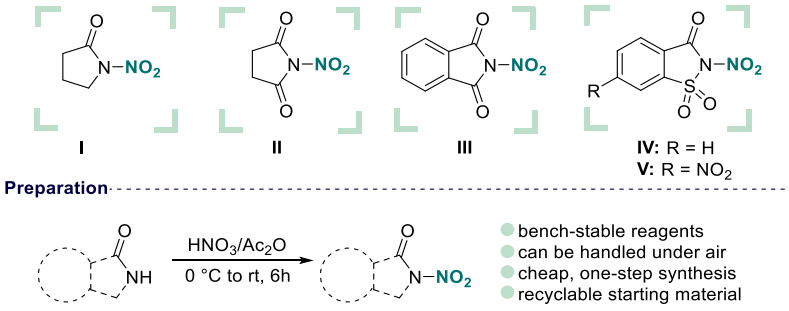
in ethanol/ether solvent.[103] Later, Lazdins and co-workers made use of amyl nitrate as the nitrating agent and phenyllithium as a base to access aromatic nitramines.[104] Few years later, Desai and co-workers demonstrated that ethyl nitrate also can deliver aliphatic nitramines *via* a reaction of the conjugated base of the corresponding amine (Scheme 48, a).[105] In 1987, and Bedford and co-workers introduced two nitrates 2-(trifluoromethyl)-2-propyl nitrate **I** and 2,2-bis(chloromethyl)propane-l,3-diol dinitrate **II** as the potential reagents (Scheme 48, b).[106] It was shown that these compounds are very effective for the acid-free nitration of secondary amines (**48.5**), however, a long reaction time is required to achieve acceptable conversion.



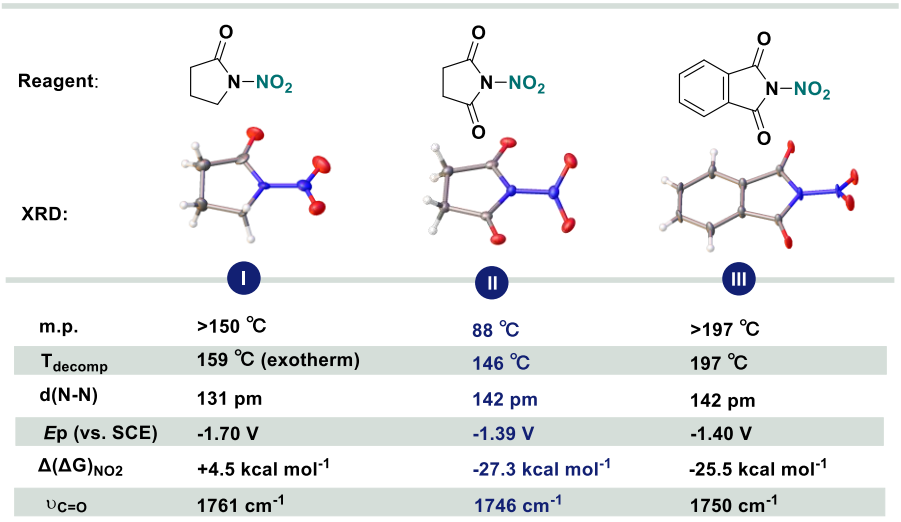
Scheme 48. *N*-Nitration with different alkylnitrates.

3.4. *N*-Nitroamides

Recently, our group has introduced various organic bench-stable, inexpensive, and recyclable nitrating reagents based on heterocyclic scaffold (Scheme 49 and Figure 5). *N*-Nitrosucinimide **I** was firstly prepared by Coburn and Ungnade in 1965, whereas Kauffmann and Burger synthesized reagents **II** and **III** in 1954. However, the reactivity of these nitrating reagents has remained unexplored until recently.



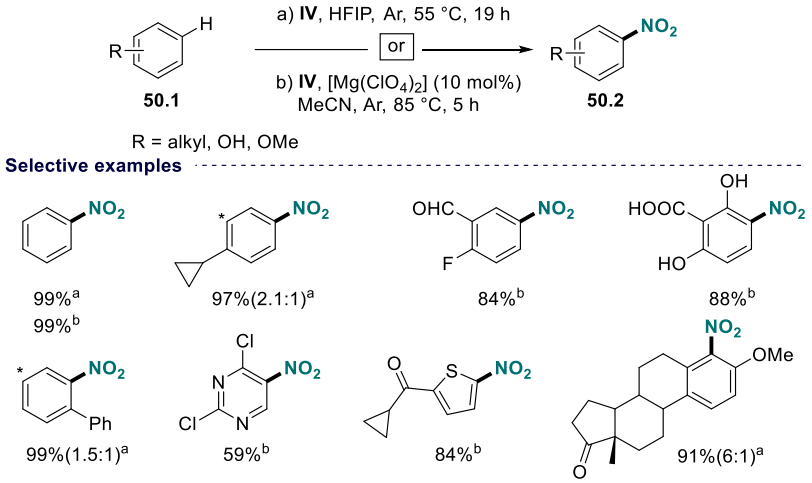
Scheme 49. Different amide-based nitrating reagents.



	I	II	III
m.p.	>150 ℃	88 ℃	>197 ℃
T_{decomp}	159 ℃ (exotherm)	146 ℃	197 ℃
d(N-N)	131 pm	142 pm	142 pm
Ep (vs. SCE)	-1.70 V	-1.39 V	-1.40 V
$\Delta(\Delta G)_{NO2}$	+4.5 kcal mol^{-1}	-27.3 kcal mol^{-1}	-25.5 kcal mol^{-1}
$\upsilon_{C=O}$	1761 cm^{-1}	1746 cm^{-1}	1750 cm^{-1}

Figure 5. Bench-stable organic nitrating reagents. Reproduced with permission from ref. 30. [Copyright (2019) Wiley]

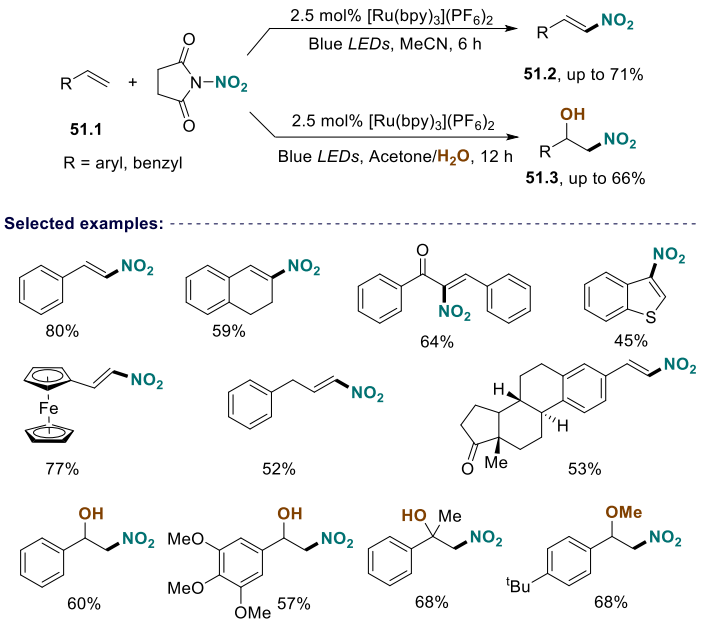
In 2019, we reported a novel protocol to access nitroarenes and nitroheteroarenes (**50.2**) using *N*-nitrosaccharin reagent **IV**, which acts as a controllable source of nitronium ion.[107] Formation of a broad range of nitroarenes, heteroarenes, and late-stage C−H functionalization was demonstrated with an exceptional functional group tolerance under mild reaction conditions (Scheme 50). Inhibition of reaction was not observed in the presence of various radical scavengers. Intermolecular competitive experiments showed that C−N bond formation is likely the rate-determining step. Other experimental mechanistic studies in combination with DFT analysis supported that this reaction proceeds through an electrophilic aromatic pathway and involves the formation of a highly ordered transition state.



Scheme 50. Nitration of arenes and heteroarenes using *N*-nitrosaccharin.

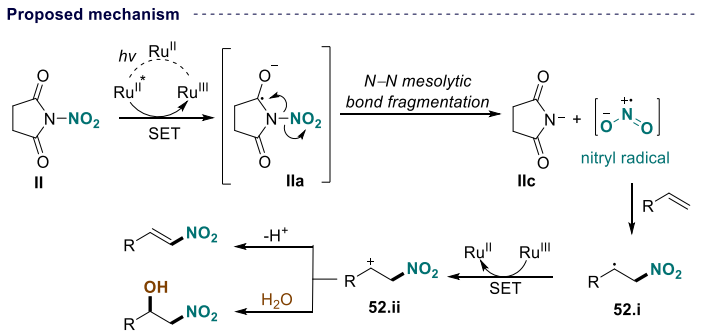
Later, we have demonstrated a photo-induced C−H diversification of alkenes and alkynes. *N*-Nitrosuccinimide (II) slowly releases nitryl radical species under very mild photochemical reaction conditions to form *β*-nitro alkenes (**51.2**, Scheme 51). Besides terminal olefines, highly substituted

alkenes also can be selectively nitrated. If the reaction is performed in the presence of water, nitrohydrins **51.2** could be generated in a single chemical step.



Scheme 51. Alkene nitration using *N*-nitrosuccimide.

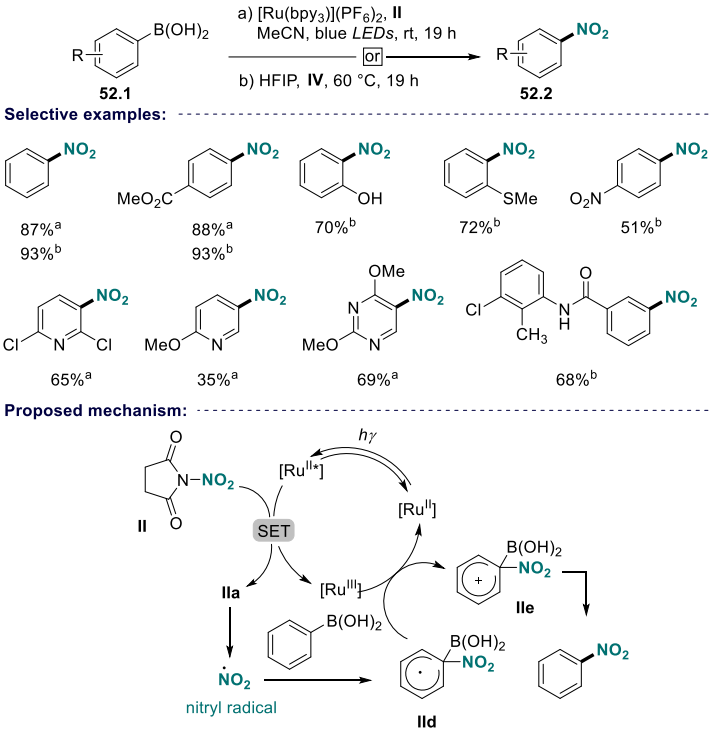
A proposed mechanism is depicted in Scheme 52. First, *N*-nitrosuccimide undergoes an exergonic, irreversible, and reductive SET process, generating NO_2 radical species. The addition of NO_2 to the styrene molecule followed by oxidation step with the photosynthesizer leads to the formation of cationic intermediate **52.ii**. *β*-Elemination from the latter intermediate results in nitroalkene formation, while in the presence of nucleophile, such as water or alcohol, gives nitrohydrines or nitro ethers, respectively.



Scheme 52. Proposed mechanism for C(sp^2)–H nitration.

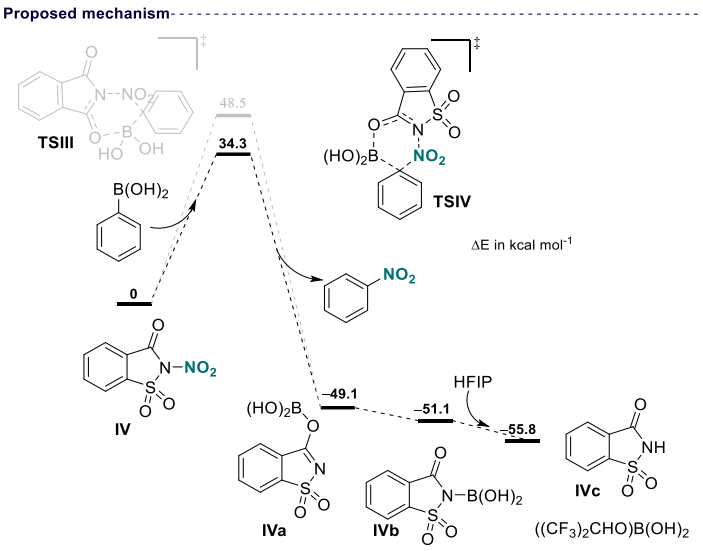
To improve the regioselectivity in the nitration of aromatic compounds using these organic reagents, our group has developed photochemical *ipso*-nitration of aryl and heteroarylboronic acids.[108] In this protocol we have disclosed two general methodologies to overcome the *ipso*-nitration challenge of boronic acids. Photocatalytic activation of *N*-nitosuccinimide **IV** as nitrating reagent rapidly provided selective *ipso*-nitration product. Whereas, *N*-nitrosaccharin can be activated at 60 °C, allowing to access a broad range of nitro(hetero)arenes in synthetically useful yields. The proposed pathway for visible-

light-mediated radical nitration is shown in Scheme 53. Initial excitation of the photocatalyst followed by oxidative quenching with **II** generates NO_2 radical *via* mesolytic N–N bond cleavage. Follow-up addition to the *ipso*-carbon of phenylboronic acid (**53.1**) and the subsequent oxidation/deprotonation steps of the cyclohexadienyl radical **53.i** affords the final nitro product **53.2**.



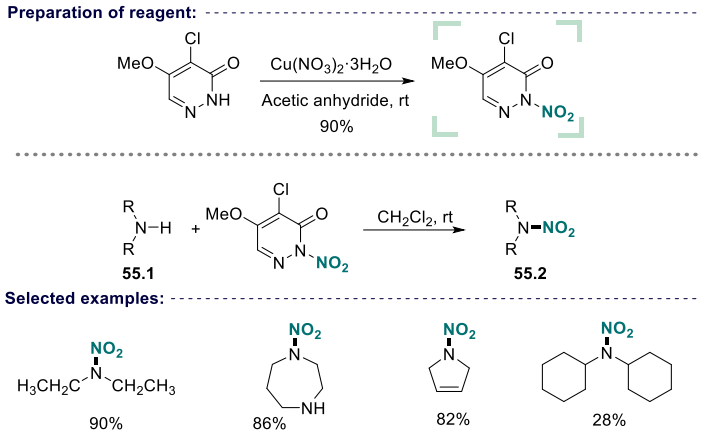
Scheme 53. *Ipso*-Nitration of aryl- and heteroarylboronic acids.

A plausible mechanism for electrophilic nitration with *N*-nitrosaccharin in HFIP was also proposed based on DFT studies and control experiments (Scheme 54). According to outlined mechanism, this electrophilic nitration reaction proceeds *via* a concerted and strongly asynchronous mechanism, where the C–N bond formation is found to be the rate-determining step. The reaction worked equally well for the large-scale nitration reaction of *p*-bromo-phenylboronic acid. A similar activation action of HFIP was previously reported using nitric acid in aromatic nitration.[109]



Scheme 54. Proposed electrophilic mechanism in HFIP.

In 2003, Park et al. reported *N*-nitration of aliphatic secondary amines (**55.1**) using 4-chloro-5-methoxy-2-nitropyridazin-3-one as nitrating agent.[110] This pyridazine nitro-transfer reagent was prepared from 4-chloro-5-methoxypyridazin-3-one with $Cu(NO_3)_2{\cdot}3H_2O$ in acetic anhydride at room temperature (Scheme 55). More hindered dicyclohexylamine yielded the corresponding *N*-nitro compound only in 28%. In the case of homopiperazine, *mono*-nitramine product could be obtained in 86% yield using one equivalent of nitrating reagent, whereas dinitramine can be obtained in 82% with two equivalents of reagent. However, this reaction was limited to secondary amines only, and derivatives such as primary aliphatic amines, anilines, and amides did not provide the desired product.

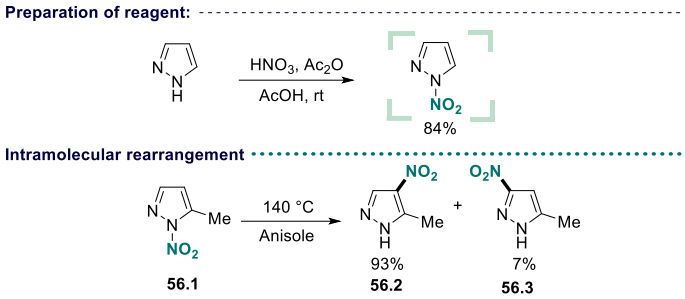


Scheme 55. *N*-Nitration of aliphatic secondary amines **55.1**.

3.5. *N*-Nitropyrazole

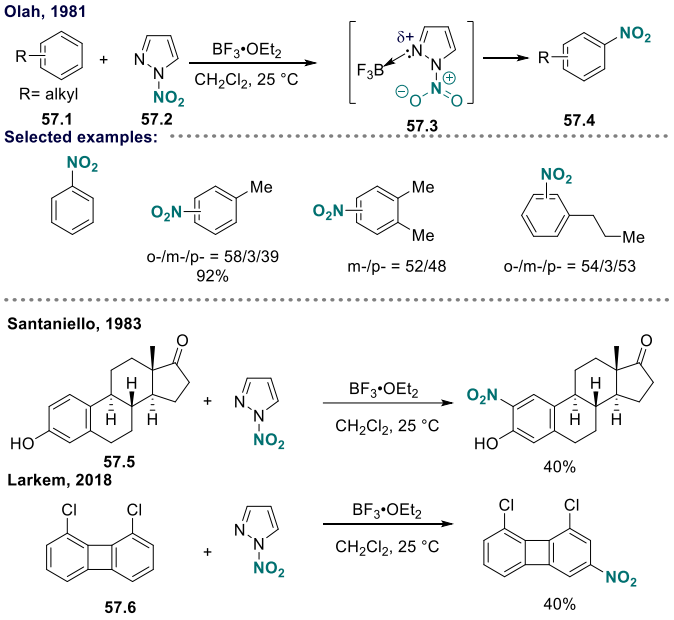
Another known reported organic nitrating reagent with $N{-}NO_2$ bond is *N*-nitropyrazole. It is a stable, crystalline compound (m.p = 92−93 °C) which can be stored for prolonged periods of time at ambient temperature. Several substituted *N*-nitropyrazoles, including 1-nitropyrazole, have been synthesized and

characterized by Hüttel and Büchele in 1955.[111] In 1971 Habrakenand and co-workers showed that *N*-nitropyrazole can undergo an intramolecular thermal rearrangement at 140 °C to form nitro-pyrazoles **56.2** and **56.3** (Scheme 56).[112] According to XRD of N-nitropyrazole, the nitro group is essentially coplanar with the heterocyclic ring.[113]



Scheme 56. Preparation and intramolecular rearrangement of *N*- nitropyrazole.

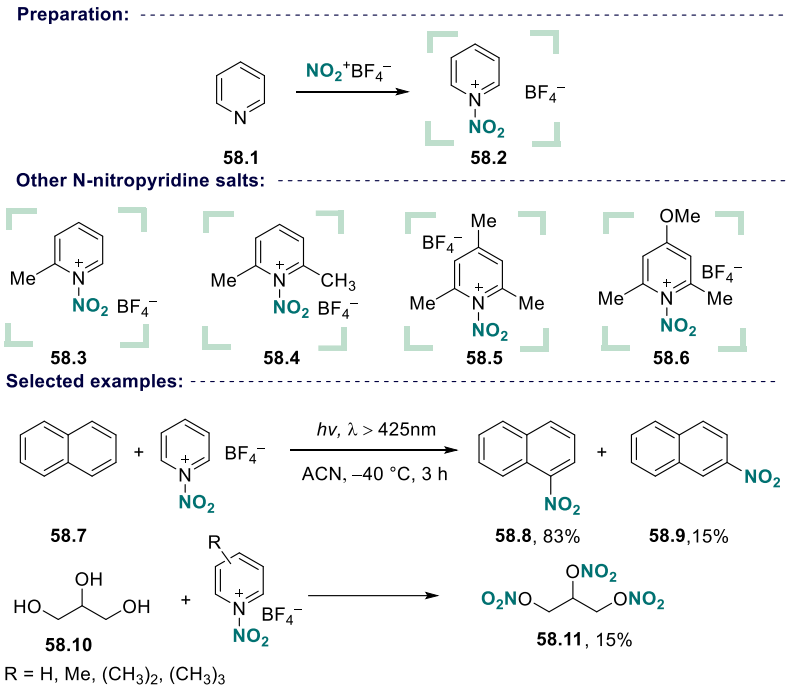
Later, in 1981, Olah and co-workers introduced *N*-nitropyrazole as a suitable new transfer nitrating agent.[114] It was found to be an effective nitrating agent when reacted with aromatic hydrocarbons in the presence of a Lewis or Brønsted acid catalysts (**57.3**). For further optimization several acid catalysts were investigated but the most active catalyst was found to be boron trifluoride etherate. In 1983, Santaniello group[115] developed one of the first nitration protocol of esterone (**57.5**) using *N*-nitropyrazole, however moderate level of chemo- and regioselectivity was observed. Very recently Larkem group has used *N*-nitropyrazole for the nitration of strained molecules such as biphenylene derivatives **57.6**.[116]



Scheme 57. *N*-nitropyrazole as nitrating reagent.

3.6. *N*-Nitropyridinium Salts

Olah and co-workers found that addition of an excess of nitronium or nitrosonium salts to pyridine in different solvents such as tetramethylene sulfone, acetonitrile, nitromethane, or sulfur dioxide solution yielded *N*-nitro- and *N*-nitrosopyridinium tetrafluoborates (**58.2** to **58.6**) in almost quantitative yield.[117] Isolated products were characterized as a colourless crystalline compounds stable under an inert atmosphere. During these studies, authors also observed that ring cleavage products were formed when nitronium or nitrosonium salt was mixed with an excess of pyridine. Few years later, Cupus and Pearson found that under identical reaction conditions electron-releasing *N*-nitropyridine substituents led to a significant increase in the selectivity of aromatic nitration.[118] This result can be interpreted on the basis of both the steric environment around the N−N bond and the basicity of the amine. Greater level of reactivity towards aromatic compounds was observed in case of *N*-nitroquinoline **58.8**, possibly due to the *peri* interaction, which weakens the N−N bond. This observation further supported that base strength is essential in determining the reactivity of *N*-nitro compounds. Using these nitro transfer reagents, C−nitration, as well as heteroatom nitration, were further introduced (Scheme 58).[119] After the completion of the nitration reaction, a pyridinium salt is generated as a by-product, while metal salts produce strong mineral acid in the reaction media.



Scheme 58. Preparation *N*-nitropyridinium salts and their applications as nitrating agents.

4. Organic nitrating reagents generated in situ

In addition to the above-discussed isolated and stable organic reagents, there are other systems that are being used for nitration processes. In particular, in this chapter unstable and *in situ* generated nitrating reagents will be presented (Figure 6).

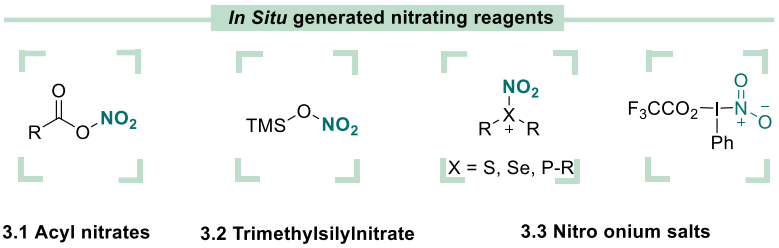


Figure 6. *In situ* generated nitrating reagents.

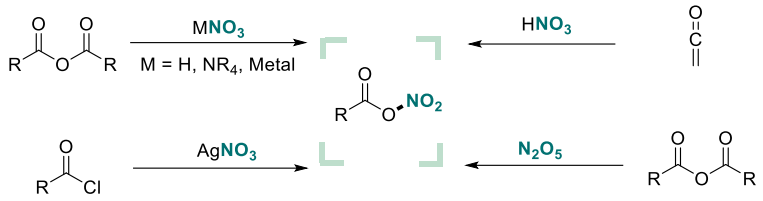
4.1. Acyl nitrates

The most important and widely used type of *in situ* prepared organic nitrating reagents is acyl nitrates. Despite more than 100 years of history of these compounds, up to date only 3 of them have found synthetic applications: acetyl nitrate, trifluoroacetyl nitrate, and nitronium triflate.

The character of the bond between nitro group and acid part is covalent for weak organic acids, like acetyl nitrate or benzoyl nitrate, and ionic for very strong acids such as nitronium triflate. As for the mild acids, their reactivity is mixed and strongly depend on the conditions. Regardless of the increasing polarization of the O−NO_2 bond in the presence of EWG substituents, the formation of nitronium cation species could not be demonstrated.[120]

A mixture of acetic anhydride and nitric acid has been studied for nitration since 1902.[121] However, the nature of the reagent was left aside. The firstly proposed formula in 1902 was $(AcO)_2N(OH)_3$,[122] yet in 1907 $AcONO_2$ structure was suggested.[123] In the first half of the previous century, it was relatively common to use acetyl nitrate in isolated form. It is a colorless liquid that can be distilled at room temperature under reduced pressure. However, it is highly explosive,[124] and therefore, nowadays, acetyl nitrate is being used mostly as *in situ* prepared reagent or as a stock solution. Other compounds from this reagent class are even less stable. Still, this does not prevent the widespread use of acetyl nitrate solutions on a large scale.[125]

Common approaches for the synthesis of acyl nitrates are shown in Scheme 59.[126] Among the mentioned methodologies, an *in situ* formation through the reaction of the corresponding acid anhydride with nitric acid or nitrate is the most commonly handled approach. It is noteworthy, that an excess of nitric acid leads to the formation of N_2O_5.[127] In the case of stock solution of acyl nitrate, it is generally obtained with the reaction of silver nitrate and acyl chloride.

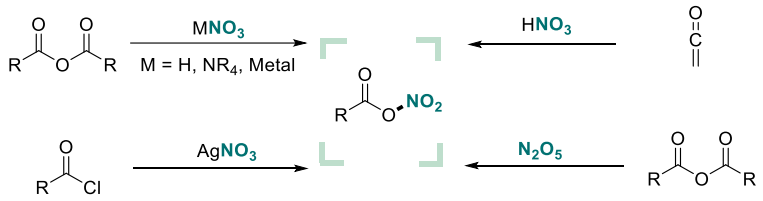


Scheme 59. Preparation of acyl nitrates.

In 1955 Burton and Praill,[128] and later Bordwell and Garbish,[129] reported a comprehensive summary of their studies on nitration of olefins and aromatic compounds using acetic anhydride-nitric acid solution. On the basis of various mechanistic experiments, the authors were able to demonstrate that the key nitrating agent is acetyl nitrate or its protonated form.

The reactivity of acetyl nitrate could be explained by its electrophilic properties. It readily reacts with different nucleophiles and π bonds and previously reported nitration procedures can be classified into several general groups based on the substrate structure: nucleophilic nitration of aromatic and heteroaromatic compounds, nitroacylation of alkenes, nitration of alcohols and amines, as well as *α*-nitration of carbonyl compounds.

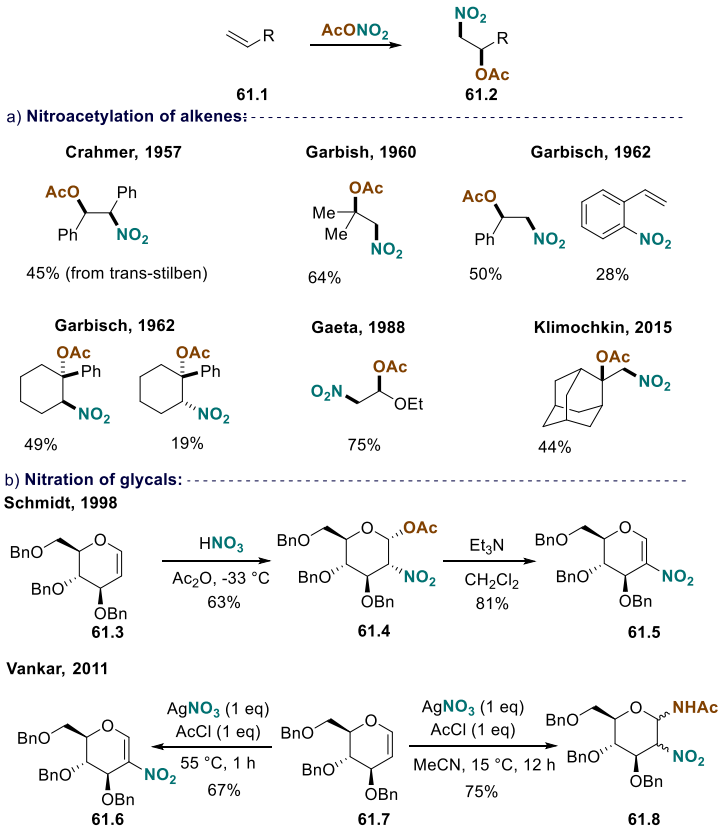
Nitration of aromatic compounds **60.1** using acyl nitrate (mostly as *in situ* prepared reagent from acetic anhydride and nitric acid) has a long history, and numerous publications cover a broad scope of different substrates showing milder reactivity than nitration using a mixture of mineral acids (HNO_3 in H_2SO_4). Scheme 60 illustrates several representative works highlighting the efficiency of acyl nitrate in the nitration of structurally complex aromatic compounds.[130] From the mechanistic point of view, it is widely believed that the nitronium ion is the active species. The classical S_EAr mechanism was further supported with a series of ^{14}N and ^{15}N NMR studies using freshly generated $AcONO_2$ from different sources.[131]



Scheme 60. Nitration of (hetero)aromatic compounds with acetyl nitrate. [a]$AcONO_2$ preformed from HNO_3 and Ac_2O; [b]$AcONO_2$ formed *in situ* from HNO_3 and Ac_2O; [c]$AcONO_2$ preformed from $Cu(NO_3)_3{\cdot}3H_2O$ and AcCl; [d]$AcONO_2$ preformed from $Bi(NO_3)_3{\cdot}5H_2O$ and Ac_2O.

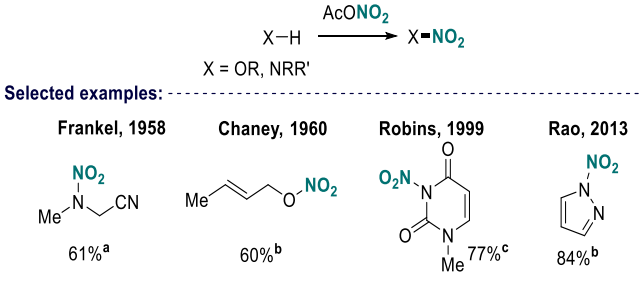
Nitration of alkenes (**61.1**) has also been performed using acyl nitrate reagent. It mostly occurs in accordance with Markovnikov's rule *via* the formation of *β*-nitro acetates (**61.2**), which in the presence of a base, can be easily deacylated to the corresponding nitro-alkene derivatives. A series of work dedicated to this transformation was published in the late '50s and early '60s (Scheme 61, a).[132] Nitration

of cyclic vinyl silanes with acyl nitrate led to different products and was highly depended on the structure of the substance.[133] Garbisch and co-workers in 1962 demonstrated that nitroacetylation of olefins occurs in a non-stereospecific fashion. This observation suggested that the nitration proceeds through a carbocationic intermediate. Acyl nitrate was also applied to the nitration of glycals (Scheme 61, b).[134] It is noteworthy that furan derivatives react with acetyl nitrate in the same way, delivering 2-acetoxy-5-nitro-2,5-dihydrofurans (**61.4**), which can be converted into 2-nitrofurnas (**61.5**) in the presence of a mild base.[135]



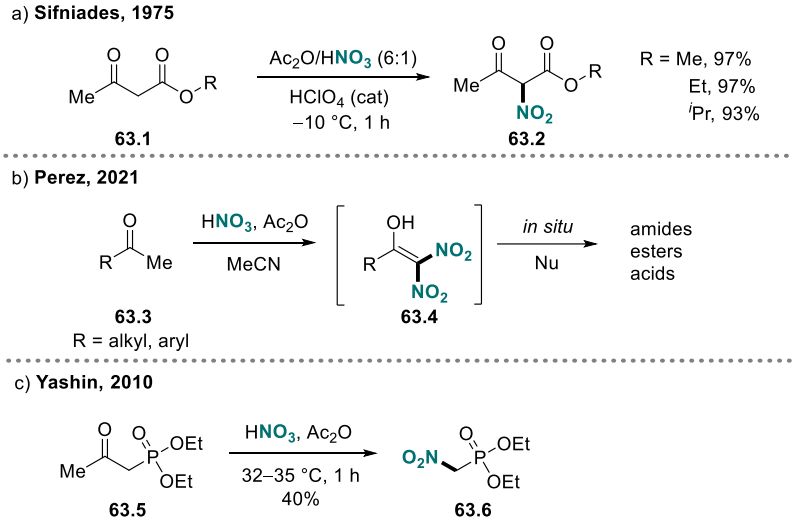
Scheme 61. Application of acetyl nitrate for nitration of alkenes. $AcONO_2$ preformed from HNO_3 and Ac_2O.

Another important application of acyl nitrate reagent was exhibited in the nitration of alcohols and amines **62.1** to obtain nitrate esters and *N*-nitramines, respectively (Scheme 62, only a few selected examples are presented).[136] Nitration of heteroatoms was usually performed at lower temperatures and a greater level of selectivity was observed than in carbon nitration reactions.



Scheme 62. Nitration of alcohols and amines using acetyl nitrate. [a]$AcONO_2$ *in situ* from HNO_3 and Ac_2O; [b]$AcONO_2$ preformed from HNO_3 and Ac_2O in AcOH; [c]$Cu(NO_3)_2,3H_2O/Ac_2O$

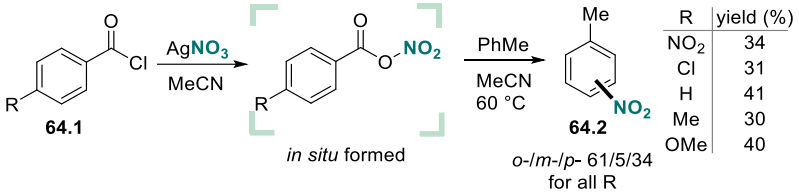
In 1975 Sifniades reported *α*-nitration of *β*-ketoesters (**63.1**) using an *in situ* generated acetyl nitrate from acetic anhydride and nitric acid (Scheme 63, a).[137] Very recently, in 2021, this method found application in one-pot acetyl nitrate-mediated oxidative conversion of methyl ketones (**63.3**) into carboxylic acid derivatives and heterocycles (Scheme 63, b).[138] Under more severe reaction conditions, the deacetylation process may occur (Scheme 63, c),[139] although such reactivity is more typical for the nitration in a mixture of sulfuric and nitric acids.[140]



Scheme 63. Selected examples of nitration of carbonyl compounds using acetyl nitrate reagent.

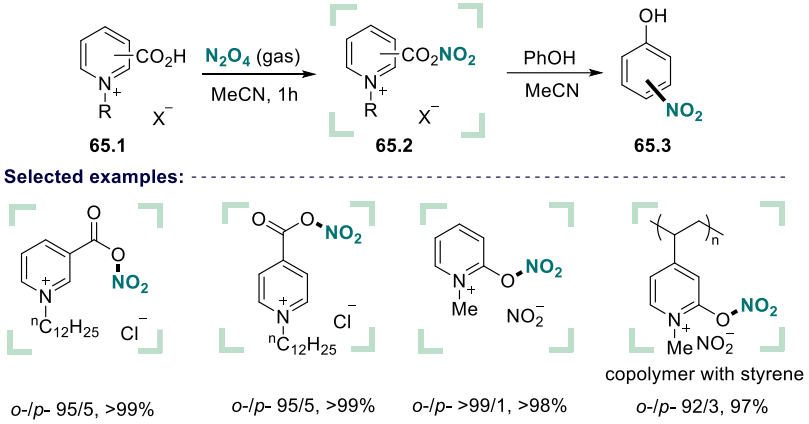
Of note that acyl nitrate can react with saturated aliphatic compounds, although this is not a nitration reaction.[141] In the presence of chlorotrimethylsilane-acetyl nitrate mixture, nitryl chloride can be generated and used in a one-pot synthesis of *gem*-chloronitro compounds from oximes.[142] Besides the above-discussed application, acyl nitrates are also used in oxidation of sulfides[143] and tertiary amines.[144] However, these applications are beyond the scope of the review.

Benzoyl nitrate has properties similar to acyl nitrate, set aside the stability. Owing to the higher cost and complexity of preparation, this compound has found much less applications as a reagent. It was first used in 1906, when Francis introduced its ability to nitrate aromatic compounds **64.1**.[145] It was further shown, that the reaction proceeds *via* an ionic mechanism, without radical formation at elevated temperatures (Scheme 64).[146] However, the equilibrium reaction that leads to the formation of N_2O_5[147] along with other side reactions, significantly complicates the reactivity of the reagent. The use of zeolite catalysis for aromatic nitration also prompted an ionic mechanism.[148]



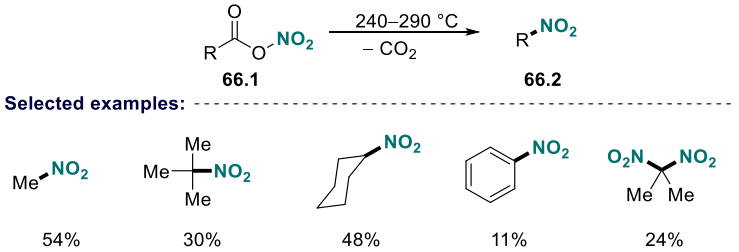
Scheme 64. Application of various benzoyl nitrates for nitration of toluene.

Various pyridine derivatives **65.2** carrying a transferable nitro group have been shown to mediate a selective *ortho*-nitration of phenol in quantitative yield in aprotic solvents (Scheme 65).[149] The nitration reaction can also be carried out on a polymeric support **65.3**. Spectroscopic studies revealed a possible intermolecular association between the phenols and pyridinium salts, as well as a hydrogen bonding between the hydroxyl group and acceptor groups on the pyridine ring.



Scheme 65. Nitration of phenol with nicotinic acid nitrate and related reagents.

In 1970, Bachman and Biermann found that acetyl nitrates (**66.1**) undergo gradual thermolysis at 240–290 °C with the formation of carbon dioxide and the corresponding nitroalkanes (**66.2**, Scheme 66).[150]

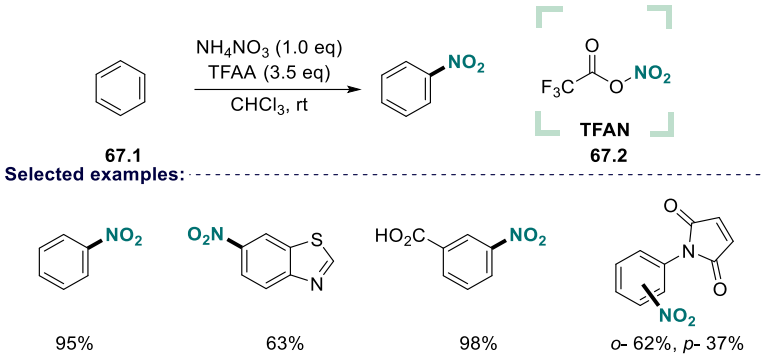


Scheme 66. Decarboxylative nitration of acyl nitrates.

Nitration reactions with trifluoroacetyl nitrate (**TFAN**) is relatively common in organic synthesis. Unlike acetyl nitrate, it is difficult to isolate it in a pure form, so it has always been prepared *in situ*. However, small amounts of a comparatively pure molecule have been isolated by Zelenov and co-workers and successfully characterized by physicochemical studies.[151] In a series of comparative experiments on the nitration of deactivated mono-substituted benzenes (with series of halogen-

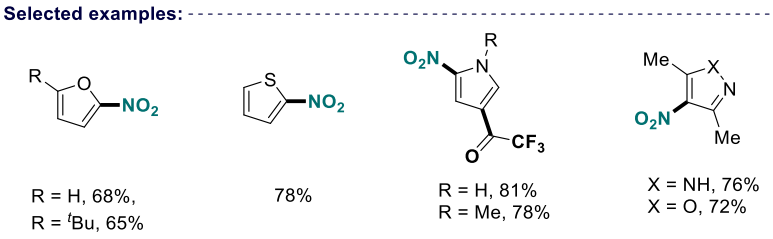
substituted acyl nitrates), Smith and Ajarim clearly demonstrated the improved nitrating ability of trifluoroacetyl nitrate over acetyl nitrate.[152]

In 1981, Crivello reported an effective system for aromatic nitration that can be generated from inorganic nitrate salts and trifluoroacetic anhydride (TFAA).[153] This fundamental work included a comparison of the reactivity of nitrating mixtures, formed between various halogen-substituted acetic acids and nitrate salts, in the nitration of aromatic compounds **67.1**, including polymers. Notably, these nitration systems are milder than the system based on a mixture of nitric and sulfuric acids, as concluded from the aromatic nitration of sensitive compounds (Scheme 67).



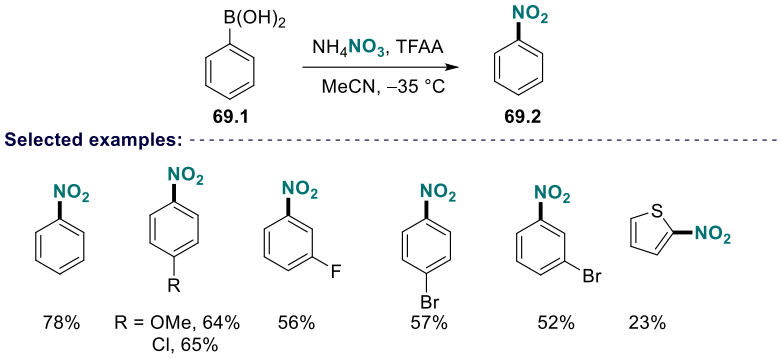
Scheme 67. Original report on nitration of aromatic compounds with **TFAN**.

The seminal work to this field was further made by Katrizky et. al. in 2005, where the authors described the use of trifluoroacetyl nitrate for the nitration of 5-member heterocycles (Scheme 68).[154] The yields were generally higher than for previously published procedures, albeit for heterocycles with two heteroatoms a mixture of regioisomers was often generated.



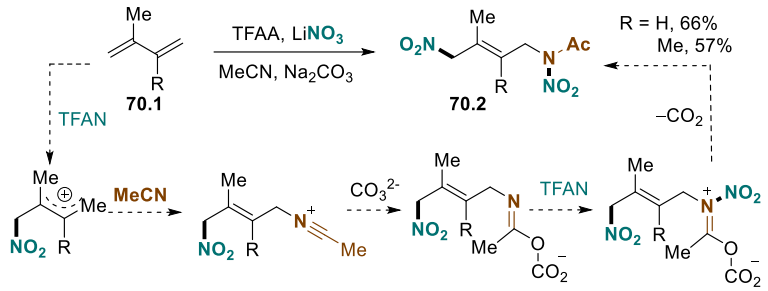
Scheme 68. Nitration of 5-member heterocycles using **TFAN**.

A nitrating mixture consisting of TFAA, Ac_2O, and HNO_3 was also successfully used in the case of the nitration of deactivated aromatic compounds[155] In addition, **TFAN** offers the opportunity to perform *ipso*-nitration of arylboronic acids (**69.1**) under transition metal-free conditions as it was described by Olah group (Scheme 69).[156] The slow addition of a slight excess of nitrating mixture at −35 ºC gave better yields, while the increase in its amount resulted in polynitration.



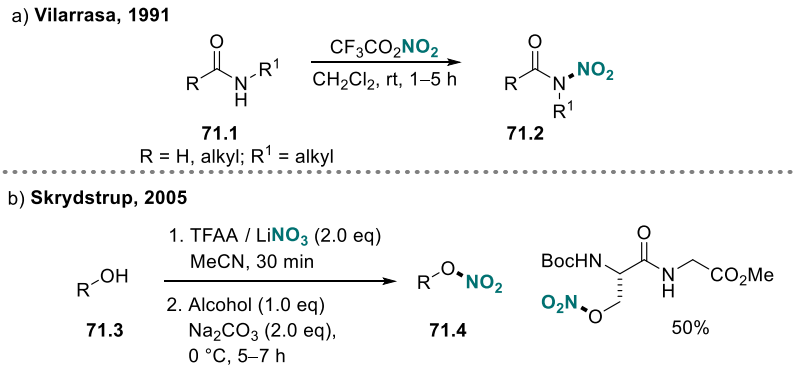
Scheme 69. *Ispo*-Nitration of arylboronic acids with **TFAN**.

Like acetyl nitrate, **TFAN** has also been used for the nitration of olefins. For example, in 2019, Costa and co-workers presented an interesting tandem nitration and Ritter reaction of three conjugated dienes **70.1** using **TFAN** reagent in acetonitrile, that led to 1,4-addition products and concomitant *N*-nitration. The major dinitro products **70.2** were obtained in 57−70% yield (Scheme 70).[157]



Scheme 70. Nitration reactions of conjugated compounds with **TFAN**.

A convenient and simple procedure for the preparation of nitramines[158] and nitrate esters[159] from the corresponding amides and alcohol (**71.1** and **71.3**, respectively) has also been developed using an *in situ* generated trifluoroacetic anhydride (Scheme 71). In the work of Vilarrasa, Hrdlicka and others, the authors made use of trifluoroaceyl nitrate to access ^{15}N-labeled nucleosides, enabling automated synthesis of isotopically labeled RNA for their use in structural studies.

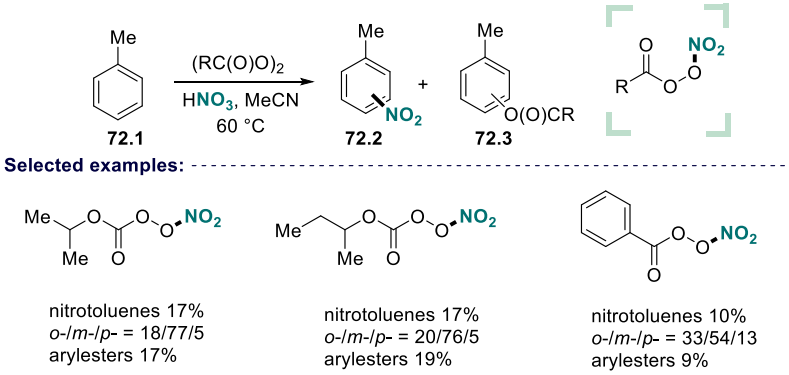


Scheme 71. Nitration of N–H and O–H with **TFAN**.

One of the most typical methods to generate **TFAN** involves the use of tetrabutylammonium nitrate, allowing to perform transformations in nonpolar solvents. Since $^{n}Bu_4NO_3$ is classified in different group of organic nitrating reagents, organic nitrates and organic nitrites, its use for the **TFAN** formation will be discussed in Section 6.1.

Oxalic acid has also been used for the generation of nitrating reagents from nitrates.[160] However, in this case the authors suggested the formation of nitrous acid as an active species.

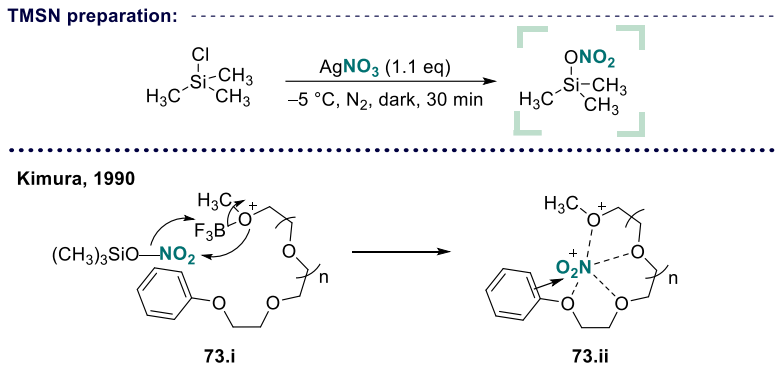
In addition to acyl nitrates, peroxyacetyl nitrates (**PANs**) are well known as relatively unstable intermediates.[161] Since they are implicated in air pollution, these molecules are being intensively studied by the scientific community.[162] Moreover, they are broadly used in oxidative transformations.[163] Nitration of toluene (**72.1**) with peroxyacetyl nitrates was also reported, even though it proceeds with low yields and the nature of nitrating species is not fully elucidated (Scheme 72).[164]



Scheme 72. Nitration of toluene with peroxyacetyl nitrates.

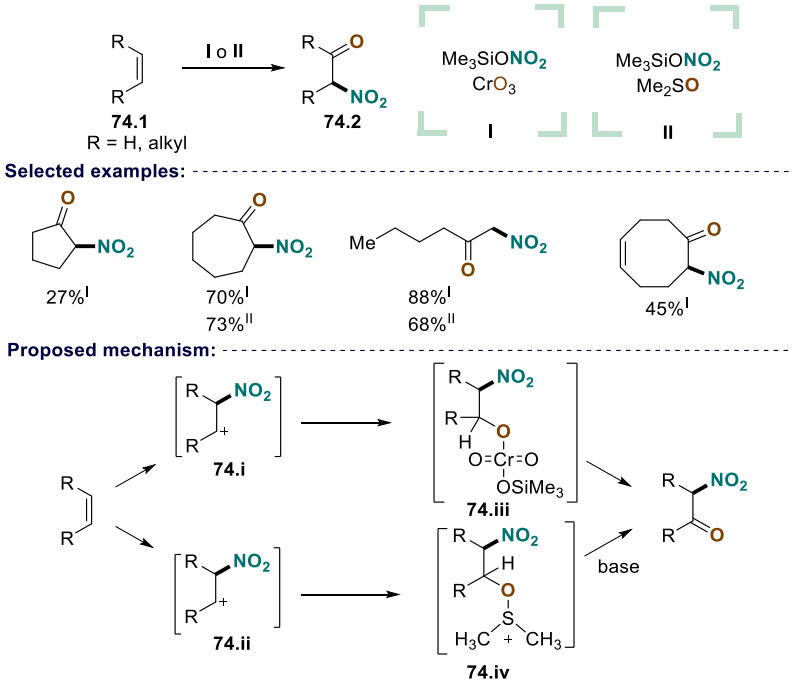
4.2. Trimethylsilylnitrate

While alkyl nitrates (Chapter 2.3) are rather stable compounds, silyl nitrates can exclusively be operated *in situ* in solutions. Trimethylsilylnitrate (**TMSN**) is the only molecule of this class of compounds, which has been used for nitration purposes. It was invented by Kimura and co-workers in 1990,[165] where the authors found that the selectivity and reactivity of nitration reaction increase in the presence of $BF_3{\cdot}OEt_2$ in CCl_4 (Scheme 73). Experimental results showed that the *ortho* selectivity for the nitration of podands (**73.1**, noncyclic crown type compounds) is greater with **TMSN** compared to other nitrating reagents, such as NO_2BF_4, $AcONO_2$, HNO_3/H_2SO_4, and the order of selectivity (*o*-/*p*-) in acetonitrile is as follows: **TMSN**-BF_3OEt_2 > NO_2BF_4 > acetyl nitrate > H_2SO_4-HNO_3. Mechanistically, the authors considered the generation of the ‘’naked’’ form of nitronium ion, which is intercepted by the surrounded oxygen atoms of podand. Therefore, the *ortho* selectivity of the arene ring was achieved through properly arranged oxygen bridges (Scheme 73).



Scheme 73. Preparation and first application of **TMSN**.

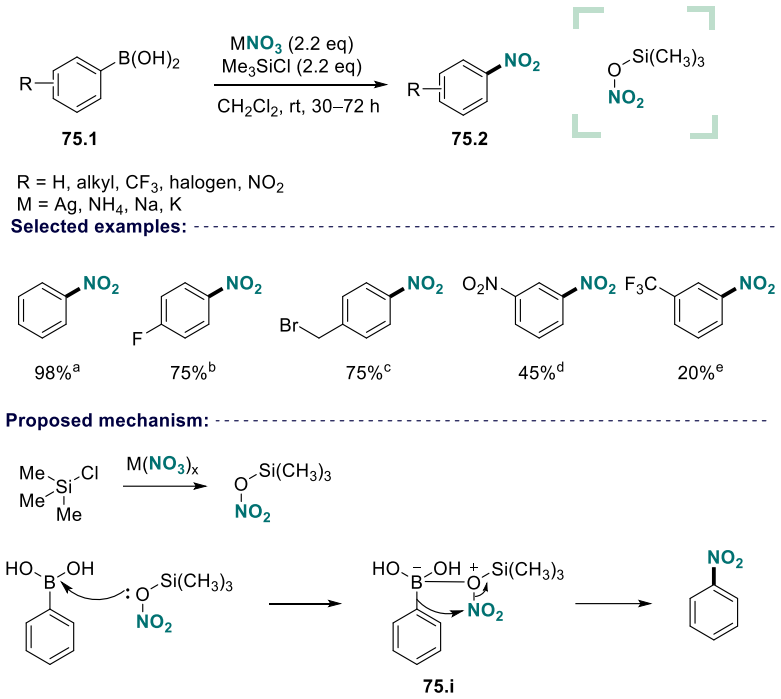
α-Nitro ketones are versatile intermediates in the field of organic chemistry. Functionalization of the *α* proton in presence of nitro group is easier and permits C–C bond formation under mild conditions. Vankar group reported two reagent systems, trimethylsilylnitrate-CrO_3 and trimethylsilylnitrate-DMSO, for a one-step conversion of olefins into *α*-nitro ketones.[166] Both cyclic and acyclic olefins gave the desired products in good yields. A proposed mechanism is shown in Scheme 74 and is believed to proceed through the formation of intermediates **74iii** and **74iv**. Yet the exact course of these reactions is not clear.



Scheme 74. *α*-Nitro ketones formation using **TMSN**.

Functionalization of boronic acids is a challenging and a very important chemical step in multicomponent reactions to build up complex molecules. Olah and Prakash presented a **TMSN**-mediated protocol for *ipso* nitration of arylboronic acids.[167] The reagent was generated using different nitrate salts in combination with chlorotrimethylsilane. The method worked well with a variety of functionalized arylboronic acids (**75.1**) (Scheme 75). Since no dinitro product formation was observed

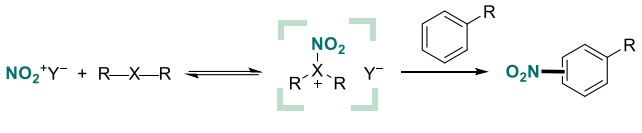
in any case, it is likely that there is a significant electronic interaction between the boronic acid group and the intermediate active nitrating agent TMS-O-NO_2 **75.i**.



Scheme 75. *Ipso*-Nitration of arylboronic acids using **TMSN**. [a]$AgNO_3$, 30 h; [b]NH_4NO_3, 48 h; [c]NH_4NO_3, 30 h; [d]$AgNO_3$, 18 h, 50 °C; [e]$AgNO_3$, 72 h.

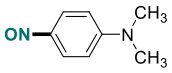
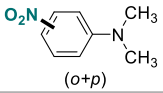
4.3. Nitro onium salts

Several other and relatively rare examples of organic nitrating reagents are summarized in this chapter. These nitro transfer reagents mainly consist of nitro onium salts. In 1976 Olah and co-workers presented the preparation and the use of dimethylnitritosulfonium ion as a powerful reagent for electrophilic nitration of benzene and toluene. The reagent can be easily generated *in situ* in nitroethane at −78 ºC from the corresponding dimethylsulfide and NO_2PF_6.[168] Later, the authors studied the nitration and oxidation properties of nitronium ions prepared from other organic molecules, such as dialkyl(aryl) sulfides, dialkyl(aryl) selenides and trialkyl(aryl)phosphines.[169] *N*,*N*-Dimethylaniline was selected as a trapping agent for nitronium species. Based on these experiments, it was shown, that both nitronium and nitrosonium ions are present in the reaction mixture (Scheme 76). Sulfides and selenides gave similar results, whereas the data obtained from phosphines were different. This is due to the fact that *p*-nitroso-*N*,*N*-di-methylanilines can further react in the presence of triphenylphosphine, affording phosphine oxide and 4,4-bis(N,N-dimethylamino)-azoxybenzene in good yield.



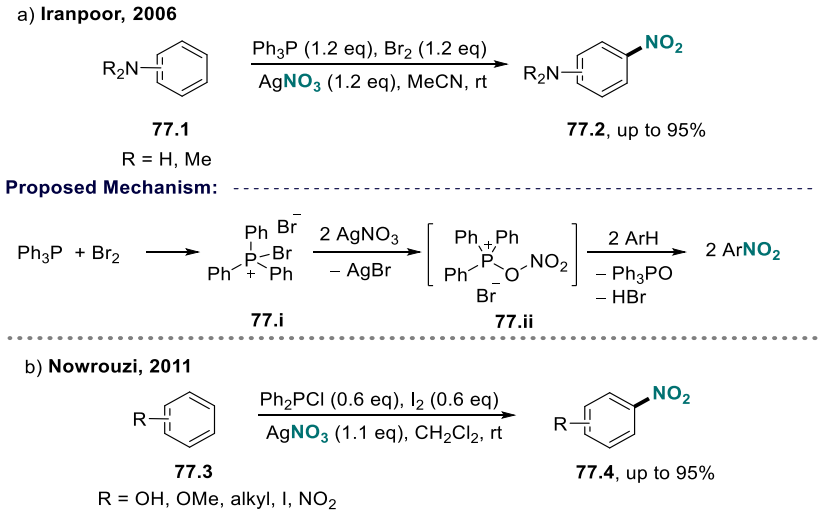
Y = PF_6^-, BF_4^-; X = S, Se, P; R = alkyl, aryl

Selected examples:

substrate		 (*o*+*p*)
$(CH_3)_2S$	66%	34%
$(C_2H_5)_2S$	60%	37%
$(C_6H_5)_2S$	30%	70%
$C_6H_5SCH_3$	60%	40%
$(p\text{-}ClC_6H_4)_2S$	30%	70%
$(CH_3)_2Se$	55%	45%
$(C_6H_5)_2Se$	64%	36%
$(C_6H_5)_3P$	14%	56%

Scheme 76. Trans-nitrosation and nitration with nitro onium ions.

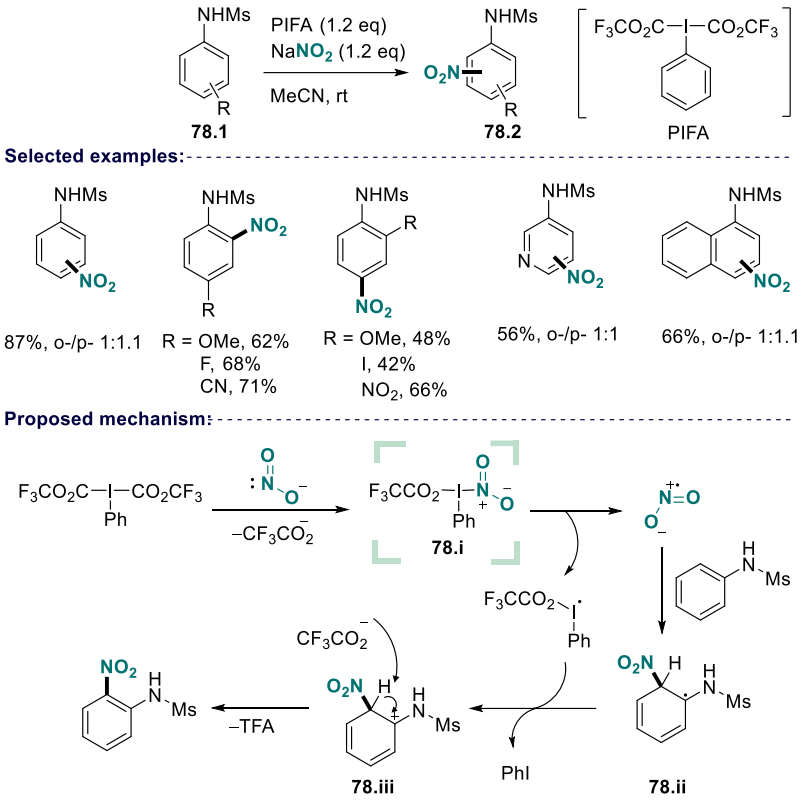
In 2006, Iranpoor group revealed a reagent system consisting of $Ph_3P/Br_2/AgNO_3$ for the nitration of aromatic amines (**77.1**). The authors postulated an initial reaction between nitrate ions and triphenylphosphine with the formation of the phosphorus complex **77.ii**, which further acts as an active nitrating agent in this transformation (Scheme 77, a).[170] Later, Nowrouzi and Jonaghani used a similar reagent system consisting of $Ph_2PCl/I_2/AgNO_3$ for the nitration of aromatic compounds (**77.3**, Scheme 77, b).[171] The authors assumed the presence of $[Ph_2P(ONO_2)_2]^+$ as nitrating reagent obtained *in situ*.



Scheme 77. Phenylphosphine-mediated aryl nitration.

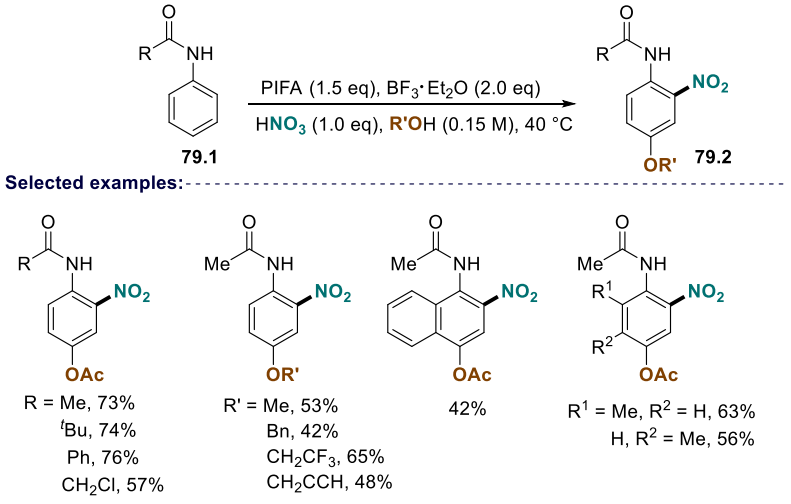
A series of iodonium-based nitrating reagents was developed in the last decade. Even though they have never been isolated, their presence in the reaction mixture was presumed, thus these contributions to the field are presented in section. Pioneering work in this field was reported in 2014 by the group of Nachtsheim.[172] Under very mild reaction conditions, nitration of *N*-aryl sulfonamides (**78.1**) can be achieved using a nitrating system consisting of sodium nitrite and hypervalent iodine reagent PIFA (Scheme **78**). The reaction was initiated through a ligand exchange of nitrite anion at the iodine center

of PIFA, generating reactive species **78.i**, that subsequently decomposed to give nitrogen dioxide. A radical reaction of NO_2 with arene moiety followed by oxidation/elimination sequence resulted in the desired product **78.2**.



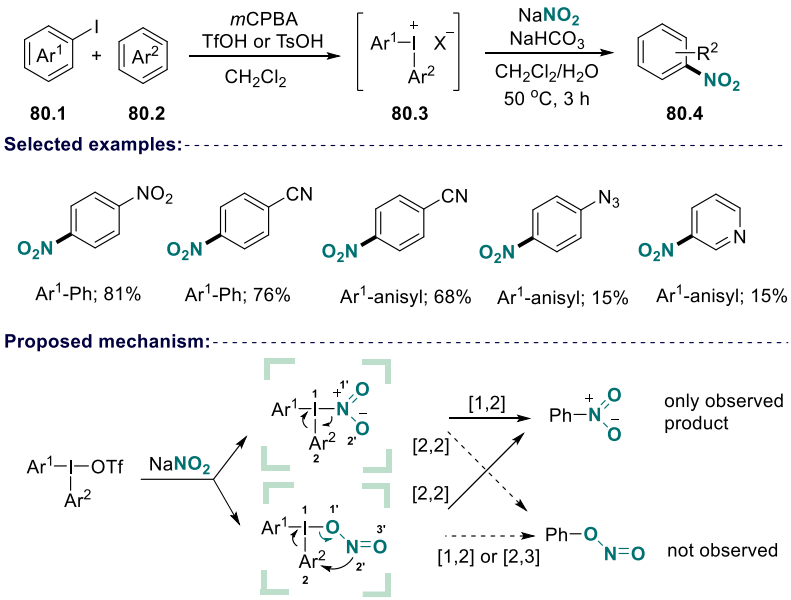
Scheme 78. First application of iodonium-based nitrating reagent.

Later, a similar reagent system was used for *ipso* nitration of aryl boronic acids [173] and regioselective *ortho*-nitration of *N*-acyl protected anilines (**79.1**, Scheme 79).[174] In the latter case, the authors did not propose the formation of nitro-iodonium intermediate, yet its presence can not be neglected.



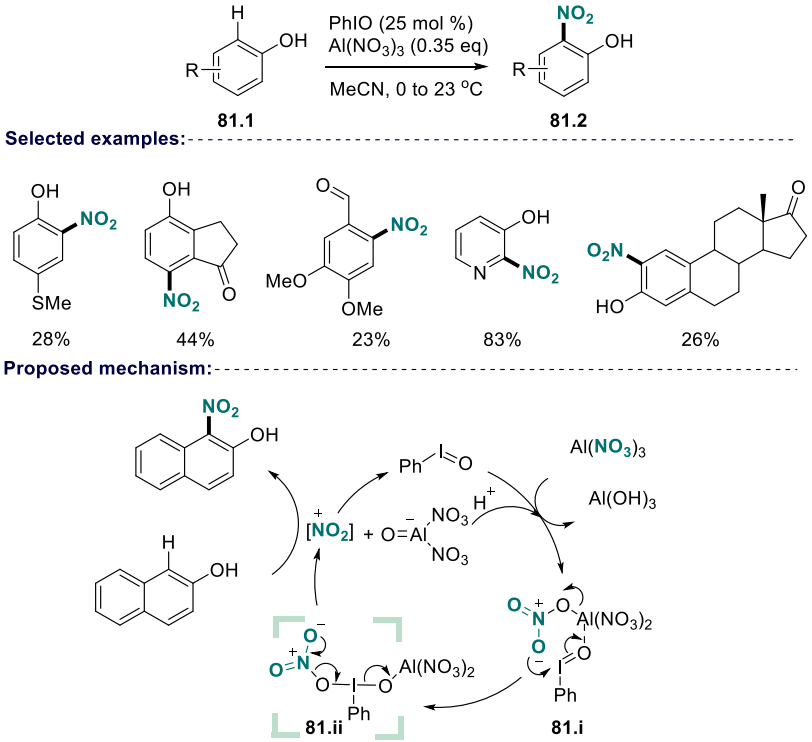
Scheme 79. *Ortho*-Nitration followed by para-functionalization.

In 2016, Olofsson group introduced a highly regioselective method for the synthesis of nitroarenes **80.4** through the sequential one-pot process by nitration of iodine(III) reagents (diaryliodonium salts), which are generated *in situ* from iodine (I) (Scheme 80).[175] Based on computational and experimental mechanistic studies, the authors suggested, that the reaction proceeds through a non-radical process involving the formation of N–I or O−I intermediates (**80.i** and **80.ii**, respectively) followed by an intramolecular [2,2] or [1,2] ligand coupling, respectively.



Scheme 80. *Ipso*-Nitration of aryl iodonium salts *via* nitroiodonium(III) intermediate.

In 2019, Solorio-Alvardo, Maruoka, and co-workers developed the first catalytic procedure for the electrophilic nitration of phenols **81.1** using iodosylbenzene as organocatalyst and aluminum nitrate as nitro source (Scheme 81).[176a] The reaction proceeded under very mild conditions in acetonitrile in the presence of air, tolerating a broad range of functionalities, including several heterocycles. Based on various experimental studies and DFT calculations, the authors postulated that the reaction proceeds *via in situ* generation of iodine(III)-nitrate intermediate **81.ii** followed by the formation of nitronium ion. A year later, the Maiti group reported PIFA-mediated *meta* selective nitration of phenols. Despite the fact that the presence of iodonitronium species was not initially assumed, the possibility of their existence in the reaction mixture can not be neglected.[176b]

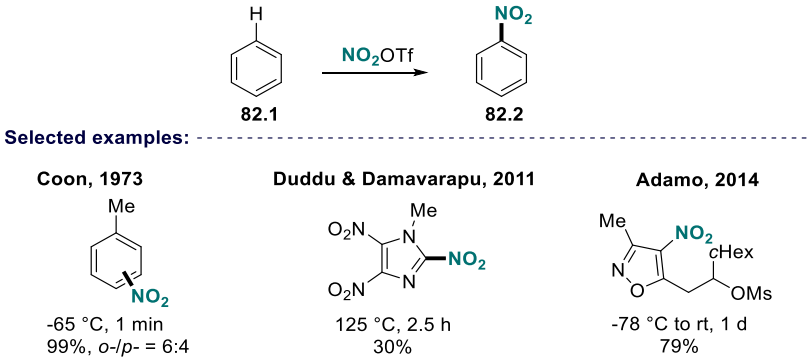


Scheme 81. Catalytic electrophilic aromatic nitration with nitroiodonium(III) species.

5. Organic nitronium salts

Organic nitronium salts represent a separate type of organic nitrating reagents. At the current state of the field, only two compounds, nitronium triflate (NO_2OTf) and nitronium ethyl sulfonate (NO_2SO_3OEt), were applied for nitration purposes. They have properties similar to those of inorganic nitronium salts, yet a very important advantage of these reagents is the ease of in situ preparation. Nitronium triflate found relatively broad application in nitration chemistry. It can be generated *in situ* by the reaction of triflic and nitric acids, which is a very similar process to the formation of nitronium species by the reaction of nitric and sulfuric acids.[177] However, in this chapter only transformations using stoichiometric amounts of reagents are discussed.

In the ’70s, nitronium triflate was isolated in pure form, and it is a white, highly hygroscopic compound.[178] In 1973, Coon and co-workers reported its use as nitrating agent in nitration of aromatic compounds **82.1**.[179] This application remains an important process, especially for the nitration of electron-poor substrates (Scheme 82).[180]

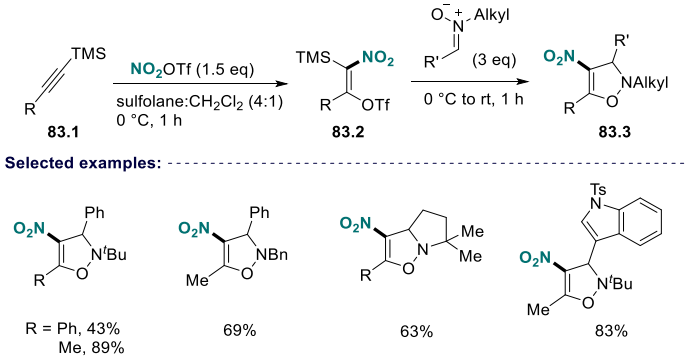


Scheme 82. Selected examples of aromatic nitration with nitronium triflate.

A series of studies was conducted to examine the reaction mechanism, and it was shown that the rate of the reaction is one of the key differences in aromatic nitration with nitronium triflate and other nitronium salts such as NO_2BF_4 and NO_2PF_6. Whether such difference can be attributed to the solubility distinction of the NO_2^+-containing species, the formation of a reactive complex with inorganic salts, or the inherent reactivity of nitronium triflate, it remains unclear. Yet it is solidly known that nitronium triflate is an ionic compound.[181] Nitronium triflate was also used as reagent for direct C(sp^3)–H nitration of adamantane.[182] Several other applications, including the nitration of alkenes and amines, are discussed in Chapter 5.1 since one of the most common methods for its preparation is based on the use of organic nitrates. It can also be used in cascade reactions, leading to the formation of nitrogen-containing heterocycles.[183]

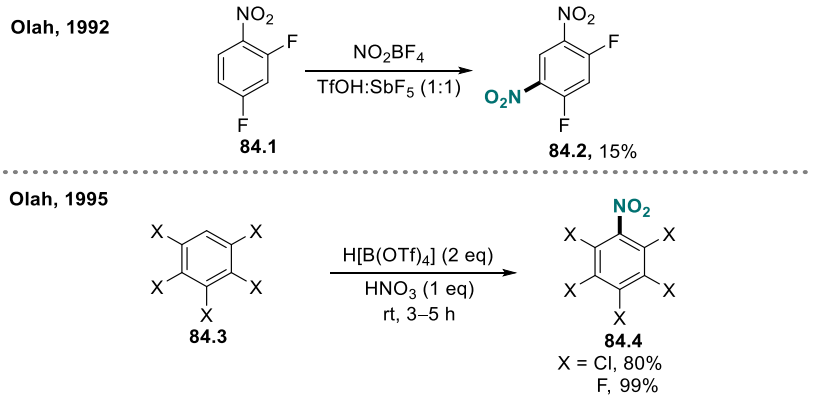
A recent contribution to the use of nitronium triflate as a reagent was presented in 2017 by Morse and Jamison.[184] The authors implemented batch- and flow-chemistry technics for the nitration of TMS-acetylenes (**83.1**) with nitronium triflate to provide synthetic equivalents of alkyne nitrates − silyltriflates

(Scheme 83). Follow-up dipolar cycloaddition reactions with nitrones led to the formation of highly substituted 4-nitro-4-isoxazolines (**83.3**) in high yields.



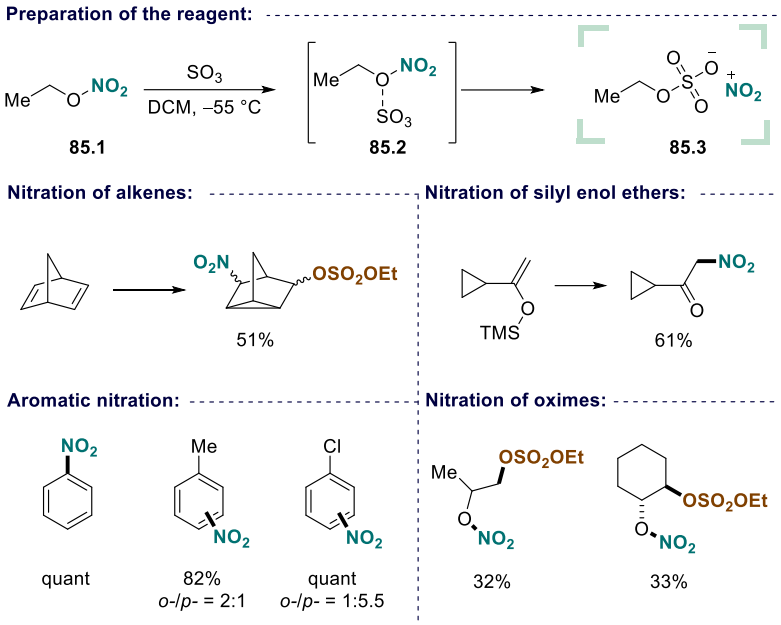
Scheme 83. Synthesis of 4-nitro-4-isoxazolines.

Nitronium triflate in combination with strong Lewis acids such as SbF_5[185] and $B(OTf)_3$[186] results in an even more powerful nitrating mixture. These complex reagent systems were applied for the nitration of highly electron-deficient aromatic compounds **84.1** and **84.3** (Scheme 84).



Scheme 84. Nitration with complex of nitronium triflate and Lewis acid.

Another example of this class of reagents is nitronium ethyl sulfate (NO_2SO_3OEt) and was reported in 1995. In pure form nitronium ethyl sulfate is a white and highly hygroscopic compound, therefore, it has always been generated *in situ* for nitration purposes. For example, it found excellent application for the nitration of alkenes, oxiranes, and aromatic compounds as presented in Scheme 85.[187] ^{15}N-Labeled reagent was also synthesized *via* nitration of ethanol with $H^{15}NO_3$.



Scheme 85. Application of nitronium ethyl sulphate for nitration.

Several other sulfur-based organic acids can also be used for nitration. For example, nitrating systems consisting of *p*-toluenesulfonic acid and nickel (II) nitrate[188] or pyridine-SO_3 complex and sodium nitrate[189] were successfully applied in aromatic nitration. Although, the formation of nitronium ions in the reaction mixture can be postulated, no attempts have been made to isolate or characterize potential novel nitronium salts. Organic nitronium salts are also known compounds,[190] yet to the best of our knowledge, they have not been used for direct nitration of organic frameworks.

6. Organic nitrates and nitrites

While the reagents described in the previous sections generally provide novel reactivity, the use of the reagents discussed in this chapter is in most cases related to the convenience of their synthetic applications. It is especially true for ammonium nitrates and nitrites (5.1, 5.4), yet sometimes different for other types of reagents (5.2, 5.3) (Figure 7).

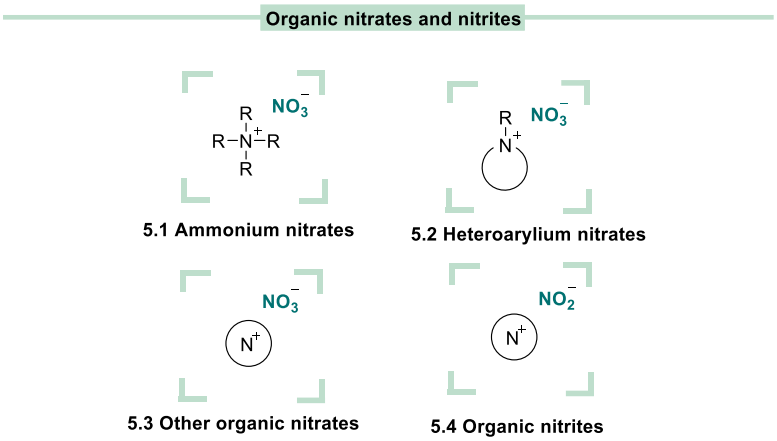
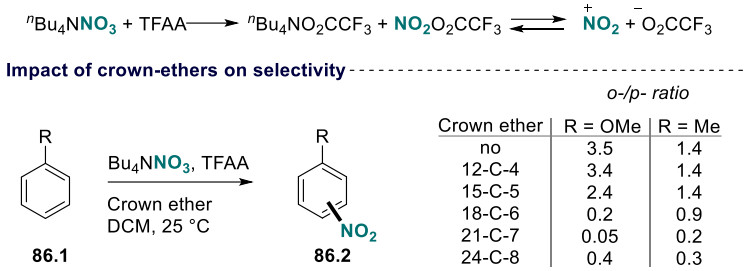


Figure 7. Classification of organic nitrates and organic nitrites.

6.1. Ammonium nitrates

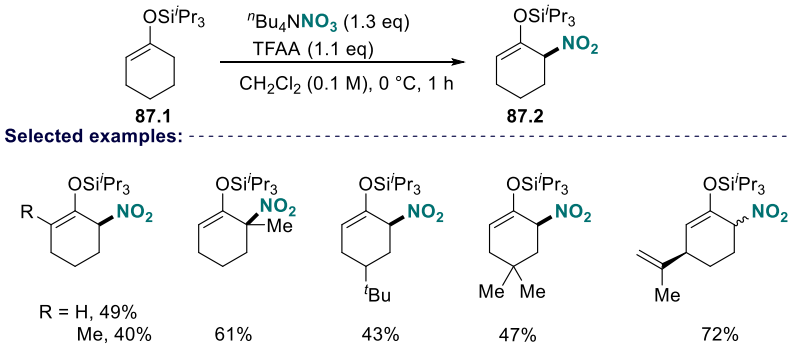
Ammonium nitrate is perhaps one of the most famous inorganic substances in synthesis. It has also been widely used for nitration processes since the pioneering works of Crivello and co-workers described in Chapter 3.1. However, due to the classification, this salt is out of the scope of the current review. Similar to ammonium nitrate, tetraalkylammonium salts are in most cases are used as analogs of metal nitrates, which greatly simplifies experimental procedures. *n*-Tetrabutylammonium nitrate (**TBAN**) is another widely used reagent in synthesis. It is a crystalline compound and is well soluble in most organic solvents. In addition, **TBAN** is a commercially available and inexpensive substance available in large quantities (~ 10 g – 50 $).[191]

TBAN was first utilized in nitration of aromatic substrates in 1985.[192] Its application was related to the need for a non-coordinating cation during the mechanistic studies of aromatic nitration. Formation of nitronium cation was demonstrated by the comparison of kinetic rates and regioisomers distribution in the presence of different crown-ethers during an *in situ* formation of trifluoroacetyl nitrate (Scheme 86). It was also shown that crown-ethers have a strong impact on the regioselectivity outcome when suitable for the complexation of nitronium cation.



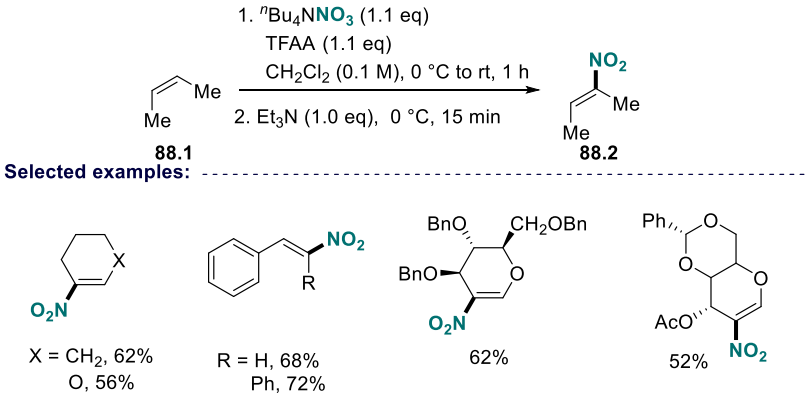
Scheme 86. First example of **TBAN** application for *in situ* synthesis of nitronium trifluoroacetate.

Application for an *in situ* formation of various reactive acyl nitrates or nitronium salts is up to date the most important for **TBAN**. In 1993, Evans and Longmire developed the first example of the □-nitration of silyl enol ethers (**87.1**) where the enol ether functionality remains in the final product (**87.2**, Scheme 87).[193] It was postulated that the reaction occurs *via* a radical pathway since $NO_2O_2CCF_3$ can undergo homolytic cleavage to afford nitronium radicals.



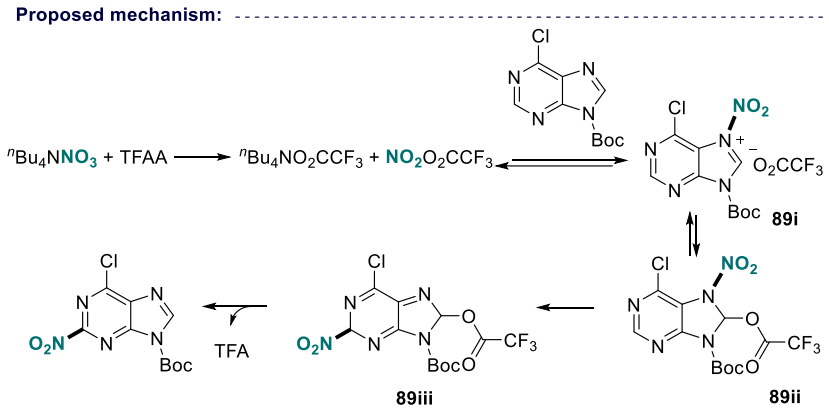
Scheme 87. *α*-Nitration of silyl enol ethers with **TFAN**.

It was also used for direct nitration of unactivated alkenes and vinyl ethers (**88.1**, Scheme 88).[194] According to the suggested mechanism, the use of Et_3N is essential for this transformation as it facilitates the elimination step of the trifluoroacetate moiety from adduct to form nitroolefins **88.2**.



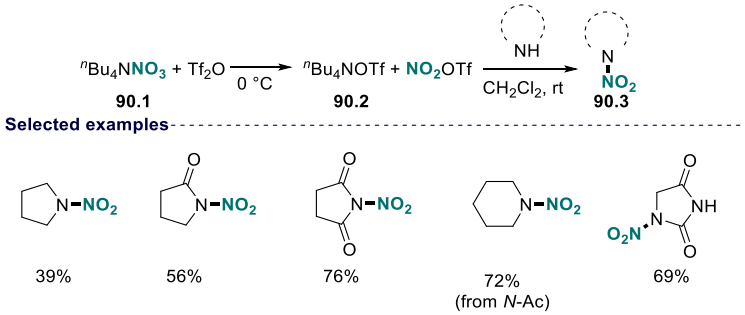
Scheme 88. Nitration of olefins with **TBAN**.

As for aromatic nitration, a series of works on nitration of nucleobases[195] and solid-state supported adenosine nitration[196] were published. Detailed mechanistic studies of this transformation were later tackled.[197] It has been proven, that the reaction primarily proceeds by an ionic mechanism with the formation of a stable adduct of nitronium trifluoroacetate with the substrate (**89.ii**, Scheme 89). However, as it was shown by CIDNP NMR spectroscopy of ^{15}N enriched nitrate, the migration of nitro group from *N* to *C* occurs through a radical process. Required for mechanistic studies, $^{n}NBu_4{}^{15}NO_3$ was also prepared in this work in one step from commercially available sodium nitrate ^{15}N in high yield (85% on 8.4 mmol scale).



Scheme 89. Mechanism of adenine nitration with **TBAN**.

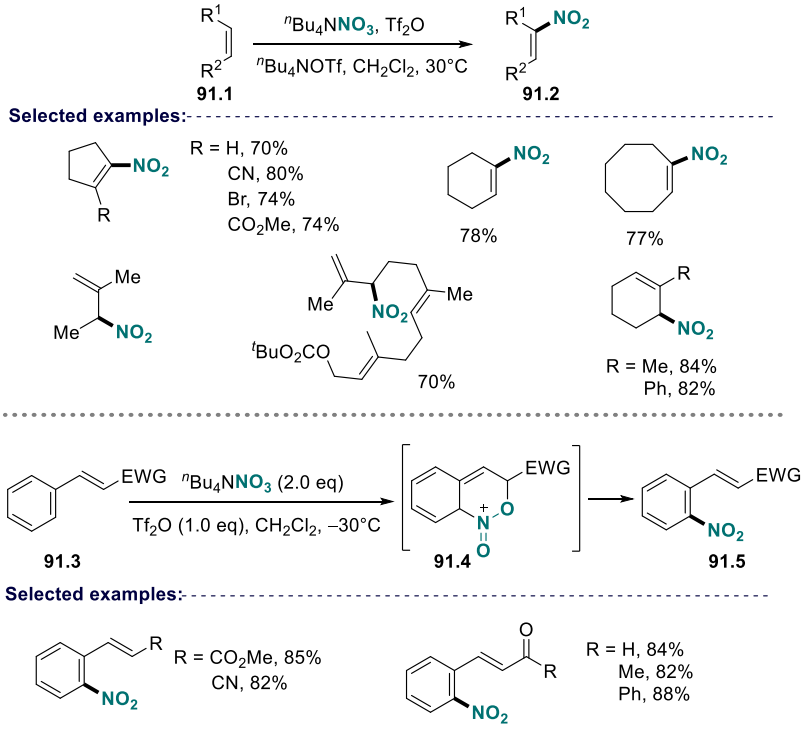
In 1993, Adams and Shackelford also used **TBAN** for the generation of nitronium triflate (**90.2**).[198] In this work, organic cation was required to proceed with nitration reaction in dichloromethane, as a less polar alternative of acetonitrile, where ammonium nitrate is commonly being used (Scheme 90). There, authors were able to successfully nitrate a wide range of secondary amines and amides, delivering the corresponding *N*-nitro products **90.3** in good to excellent yields.



Scheme 90. First example of **TBAN** application for *in situ* synthesis of nitronium triflate.

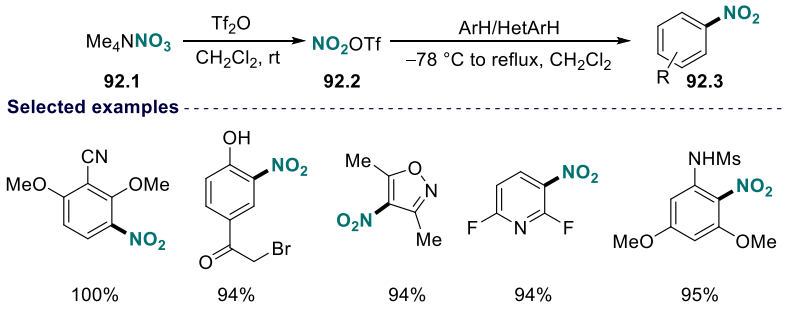
The most recent application of **TBAN** for the synthesis of nitronium triflate has been reported in 2021 by Corey and co-workers.[199a] In this article, aside from the nitration of alkenes, which sometimes proceeds with migration of double bond, selective *ortho*-nitration of cinnamonic aldehyde-type compounds **91.3** was demonstrated. The latter reaction was proposed to occur through the formation of

the bicyclic cationic intermediate, which then releases a proton to yield the *ortho*-substituted product (Scheme 91). The authors further used this step in the preparation of 1-nitrocyclopentene, a key building block for the synthesis of C_2-symmetric *anti*-azatetraquinane.[199b]



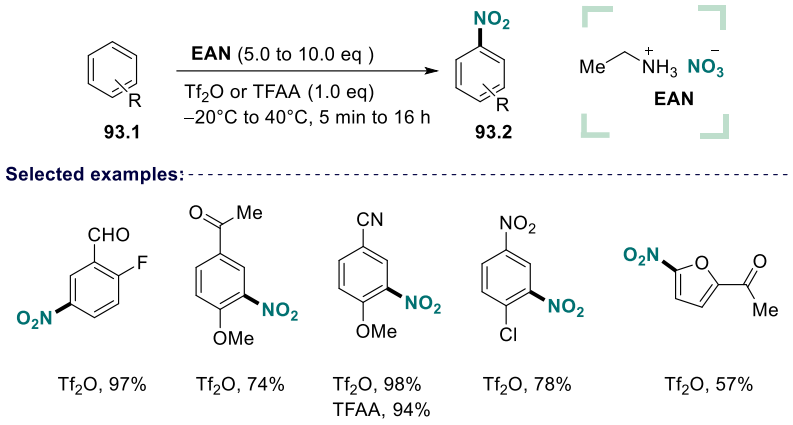
Scheme 91. Application of **TBAN** for *in situ* synthesis of nitronium triflate.

While **TBAN** is the most common organic nitrate, tetramethylammonium nitrate is not yet widely used in nitration reactions. An important difference from **TBAN** is its high solubility in water, which makes extraction an easy and convenient way to separate it after the reaction is complete. It is a commercially available (~ 10g – 35 $) and bench-stable compound at room temperature. In 2003, the Scackelford group reported aromatic nitration through *in situ* formation of nitronium triflate (**92.2**) from tetramethylammonium nitrate (**92.1**) and trifluoromethane sulfonic anhydride in DCM (Scheme 85).[200] Microwave-assisted conditions allowed to perform nitration of aromatic and heteroaromatic compounds with excellent chemo- and regioselectivity. Noteworthy, the authors demonstrated nitration reaction on a 1 to 500 g scale.



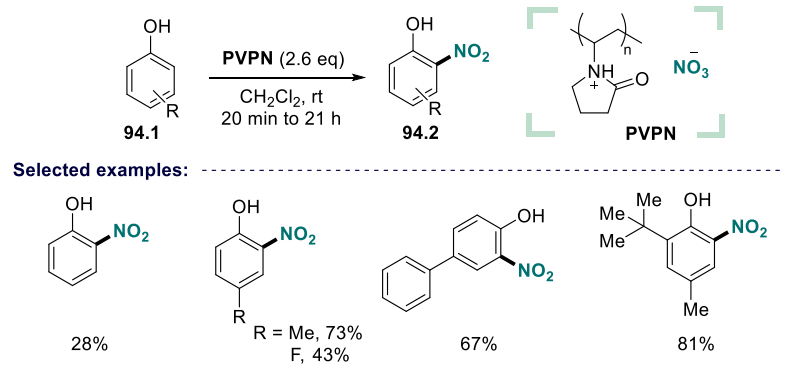
Scheme 92. Aromatic nitration with tetramethylammonium nitrate.

In addition to the use of tertiary ammonium nitrates, ethylammonium nitrate (**EAN**), which is an ionic liquid, has also found application as reagent for the nitration of aromatic and heteroaromatic compounds (Scheme 93).[201] Acting as both solvent and source of nitrate for *in situ* formation of nitronium triflate or trifluoroacetyl nitrate, it seems to be an interesting green alternative to existing methods, although there is a common issue of polynitration for this system.



Scheme 93. Nitration of aromatic compounds with **EAN**.

Supported nitric acid on an organic polymer is another example of organic nitrates that was found to be an efficient, environmentally friendly, and mild nitrating agent (poly-*N*-vinylpyrrolidone nitrate (**PVPN**) (Scheme 94).[202] The reagent was prepared in one step from polyvinylpolypyrrolidone and nitric acid and was used for catalyst-free, selective *ortho*-nitration of phenols **94.1**.

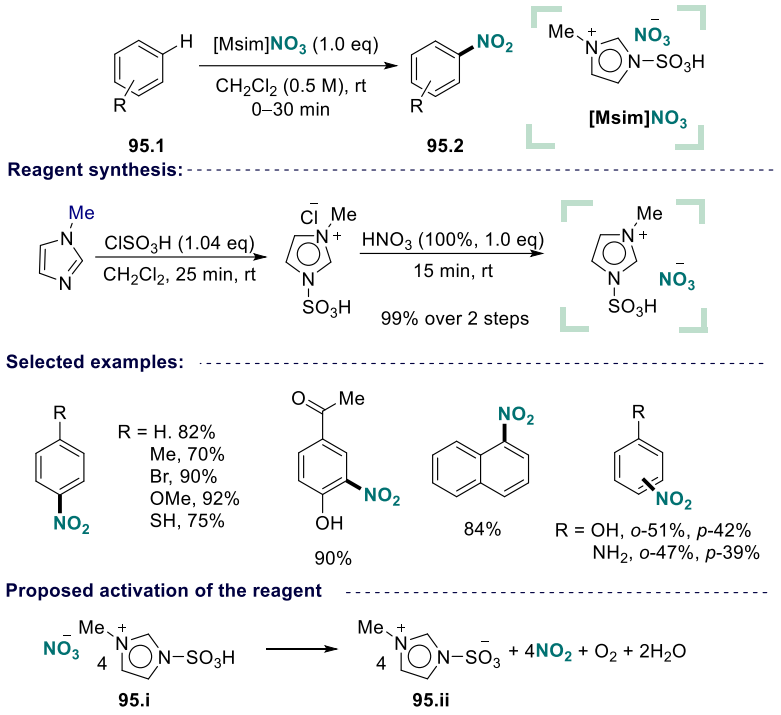


Scheme 94. Nitration of phenols **94.1** with polymer-based nitrating agent.

6.2. Heteroarylium nitrates

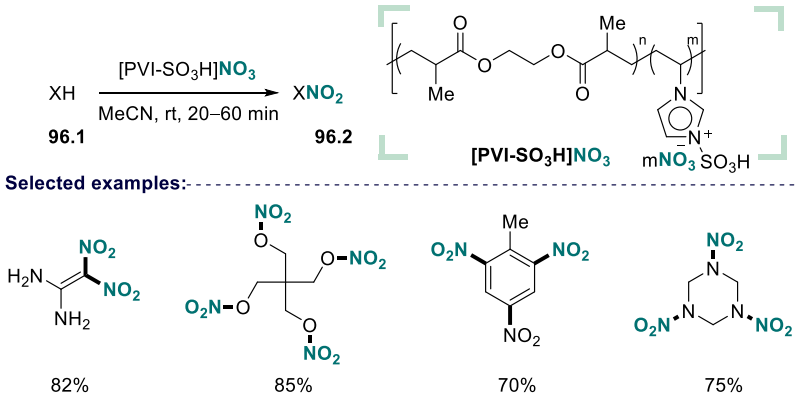
Heteroaromatic ammonium salts entered the field of nitration chemistry only in the last decade. The dominating molecules are *N*-sulfohetarylium salts, where pioneering work has been presented in 2012 by Zolfigol group.[203] The authors reported the synthesis and application of 3-methyl-1-sulfonic acid imidazolium nitrate (**[Msim]−NO_3**) as a new Brønsted acidic ionic liquid and nitrating agent (Scheme 95). Its role as a source of nitro group has been demonstrated by nitration of a limited scope of aromatic

compounds, however, with good chemical yields. The reagent can be prepared in two steps with an overall isolated yield of 99% from commercially available *N*-methylimidazole. A radical pathway through the generation of nitryl radicals has been proposed based on several experiments, including radical trapping with TEMPO and BHT, as well as an experiment with copper powder, where the formation of copper nitrate was observed.



Scheme 95. Nitration of aromatic compounds with **[Msim]NO$_3$**.

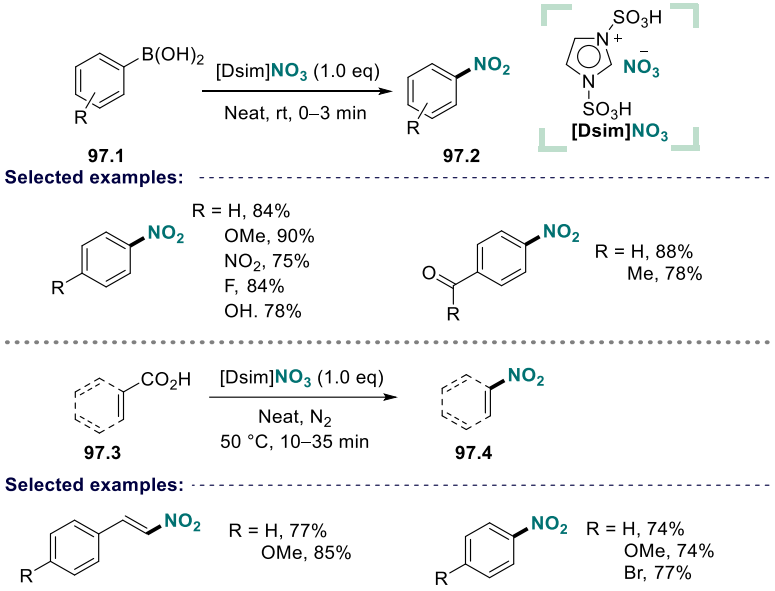
It was further shown by the authors, that *N*-sulfoimidazolium nitrate can be incorporated in a polymer matrix.[204] The synthetic utility of this polymer was further exploited on four structurally different substrates (Scheme 96).



Scheme 96. Nitration of aromatic compounds using polymer-supported **[Msim]NO$_3$**.

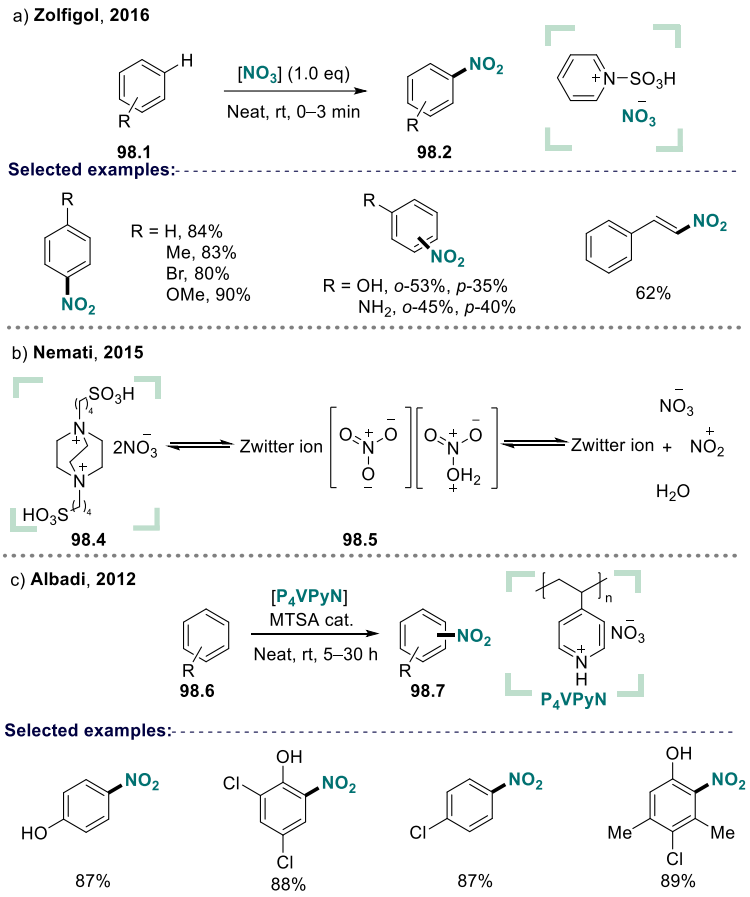
After the initial success, the same group developed another imidazole-based reagent 1,3-disulfonic acid imidazolium nitrate (**[Dsim]NO$_3$**) (Scheme 97).[205] It can be obtained by the same reaction sequence, yet,

starting from imidazole. During the study of the activation pathways through various mechanistic experiments, the reagent displayed a behavior very similar to the one of **[Msim]NO$_3$**. Thus, a radical pathway *via* the generation of nitrogen dioxide radicals was postulated. The reagent was extensively used for *ipso*-nitration of various aryl boronic acids (**97.1**) and nitro Hunsdiecker reaction of different α,β-unsaturated acids **97.3** as well as benzoic acid derivatives (Scheme 97). Postulating the spontaneous decomposition of the reagents in the reaction mixture, no comments on the bench stability of the reagents was reported by the authors. It is however known that they can be isolated and characterized as individual material. Based on DTG experiments, a significant mass loss for **[Dsim]NO$_3$** was detected after 75 °C, while nitrating reactions can already occur at room temperature.



Scheme 97. Nitration of aromatic compounds using **[Dsim]NO$_3$**.

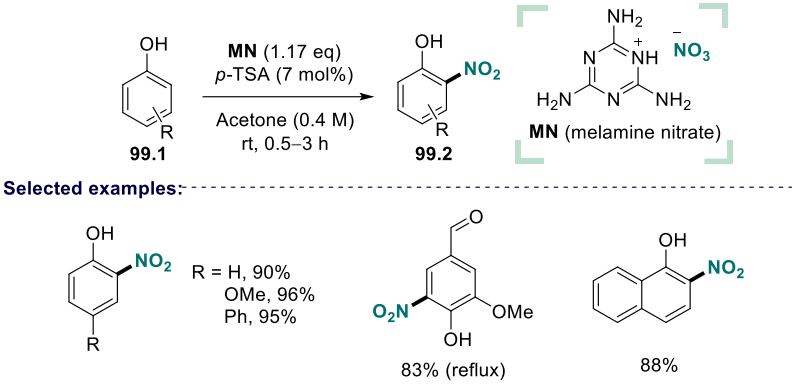
1-Sulfopyridinium nitrate (**98.3**) is another representative example of this class of nitrating reagents, which can be directly synthesized from pyridine with the same reaction sequence as imidazolium derivatives (Scheme 98).[206] The decomposition of this reagent, according to TGA measurements was initiated at 60 °C, yet the authors did not provide detailed information about the stability of the reagent at room temperature. The reagent was further used for the nitration of aromatic compounds and styrene derivatives. To confirm the existence of nitro radicals, the reaction was performed in the presence of radical scavengers such as iodine and BHT. As expected, a significant drop in product formation was observed in both experiments.



Scheme 98. Nitration with pyridinium-based organic nitrating reagents.

In 2015, Nemati and Pour reported a novel bi-SO_3H functional DABCO-derived ionic liquid (**98.4**) based on nitrate ion reagent for rapid mono-nitration of phenols and naphthols (Scheme 98, b).[207]In this case, the authors proposed the initial formation of an equilibrium between a zwitterion and nitronium cation species, followed by the classical electrophilic substitution pathway. Heteroaromatic nitrates, such as poly(4-vinylpyridinium nitrate), can also be used as a source of nitrate as it was demonstrated by Albadi group in melamine trisulfunic acid-catalysed (MTSA) aromatic nitration (Scheme 98, c).[208]

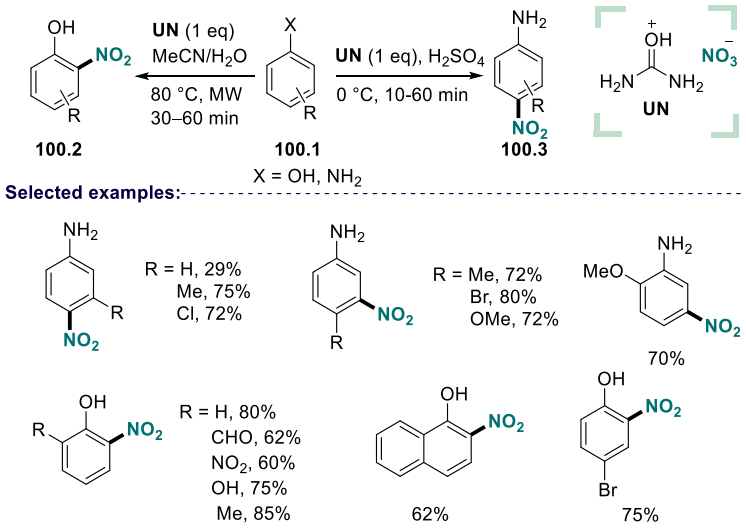
Another example of nitrating reagent containing heteroaromatic cation based on melamine scaffold was developed by Chen and Jiang (Scheme 99).[209] It can be obtained in one step starting from commercially available melamine (~ 1 kg – 70 $) and nitric acid. Simple filtration of the precipitate formed during the reaction yielded an analytically pure compound. The reagent was used for the nitration of phenols (**99.1**) with excellent *ortho* selectivity, possibly due to the hydrogen bonding arising between the reagent and the hydroxyl group of phenol.



Scheme 99. *Ortho*-Nitration of phenols **99.1** by melamine nitrate.

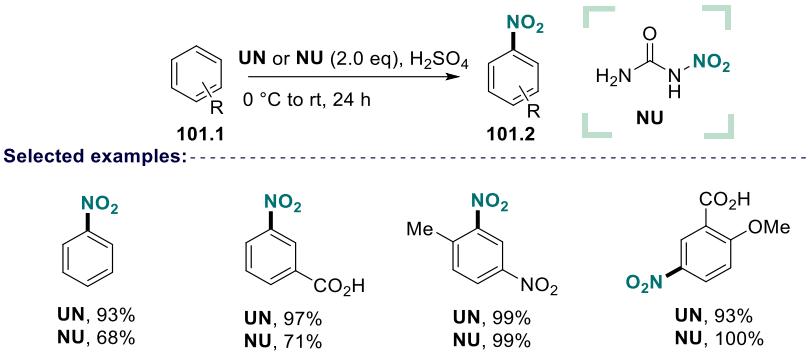
6.3. Other organic nitrates

Several additional organic nitrates with large organic cations were applied for nitration processes. Urea nitrate (**UN**) was the first example of this class of reagents and has a long history of application in nitration of organic molecules. It is a commercially available compound (~ 25 g – 80 $) and can easily be prepared from the reaction of urea and nitric acid under cooling conditions. **UN** was first applied in acid-catalysed aromatic nitration in 1976 by Kudav and co-workers.[210] In recent years, several other methodologies have been introduced, including the nitration of carbazoles,[211] regioselective nitration of anilines,[212] and phenols.[213] For example, the nitration of aniline derivatives **100.1** can be performed with **UN** in the presence of sulfuric acid, delivering exclusively *p*-isomers **100.3**. When the *para* position is blocked with substituent, the nitration occurred to give *m*-nitroanilines in good to excellent yields (Scheme 100). Changing the reaction conditions to non-acidic, while carrying out the reaction under microwave irradiation, allowed to proceed with selective *ortho*-nitration of phenols (**100.2**, Scheme 100). Moreover, when both *ortho* positions were occupied, the reaction in the *para* position did not take place, as demonstrated for 2,5-dimethyl phenol.



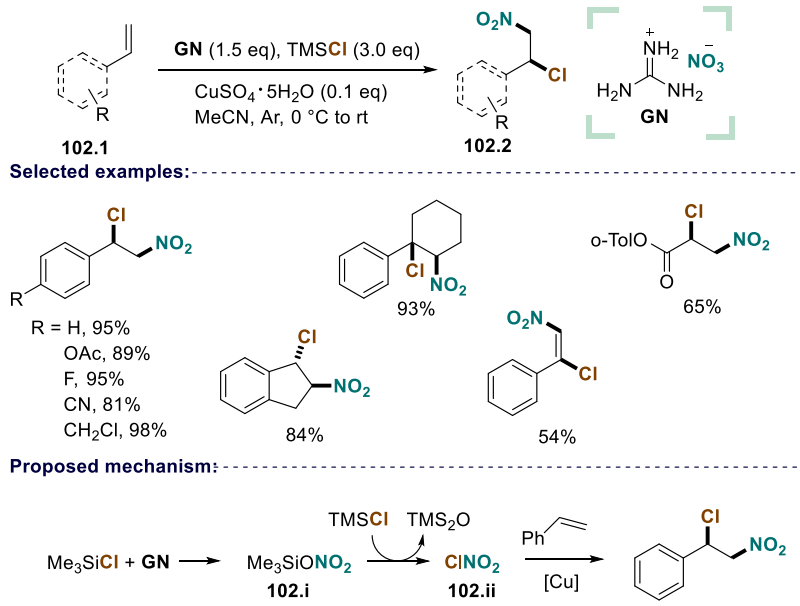
Scheme 100. *Para*-Nitration of anilines with **UN**.

Nitrourea can serve as an alternative to urea nitrate for aromatic nitration in acidic conditions as shown by Almog et al. (Scheme 101).[214] The performance of the two reagents was found to be quite similar, indicating that **NU** is possible an active intermediate in the **UN** nitration processes.



Scheme 101. Aromatic nitration with nitrourea.

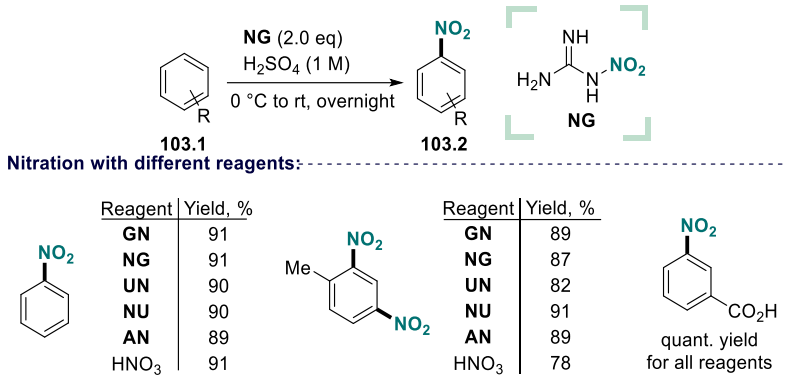
Guanidine nitrate (**GN**) is a bench-stable solid compound, that is less moisture sensitive and less explosive than ammonium nitrate. The average price on the market is estimated at ~ 80 $ per 1 kg. Being extensively used in industry, **GN** has found only few applications as nitrating reagent. Very recently, in 2020, the Deng group reported a practical chloronitration of alkenes, that proceeds in the presence of TMSCl and guanidine nitrate under copper catalysis (Scheme 102).[215] A variety of vicinal chloronitro compounds were directly prepared in good to excellent yields on up to 100 mmol scale using this nitrating system. According to the proposed mechanism, the active nitrating reagent in the reaction mixture is an *in situ* generated NO_2Cl.



Scheme 102. Chloronitration of olefins with guanidine nitrate.

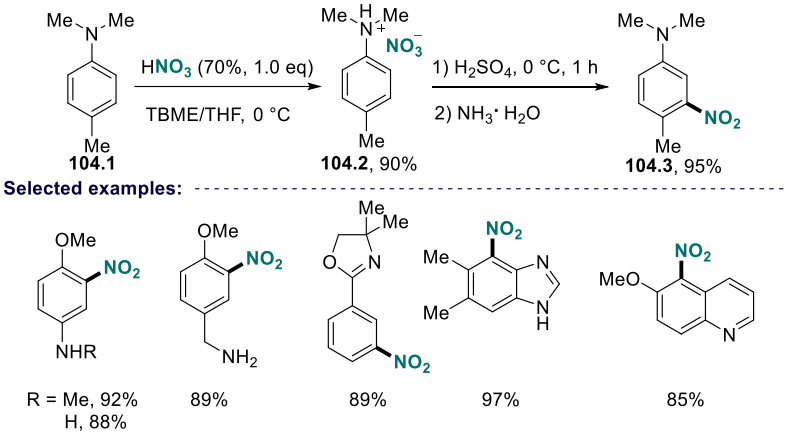
It is interesting to compare the performance of the aforementioned reagents, in particular with the reactivity of ammonium nitrate (**AN**) and nitric acid. As it can be seen from the reported data in Scheme

103, there is no drastic difference between those reagents used in concentrated acid media. This indicates, that the active species is nitronium ion, and the cation which was originally introduced in the reaction mixture does not impact the outcome of the process. While the solubility of these reagents in different organic solvents may differ, this factor can be regulated by the reaction temperature.



Scheme 103. Application of guanidine nitrate for aromatic nitration.

Aromatic compounds bearing basic nitrogen **104.1** can be easily converted to the corresponding nitric acid salts **104.2**, and under acidic medium can further be nitrated resulting in the formation of nitroanilines (**104.3**, Scheme 104).[216] In several cases, a two-step procedure described by Zang and co-workers provided better yields than the classical nitration using a mixture of nitric and sulfuric acids. In general, yields of this transformation are very high, if only one regioisomer can be obtained.

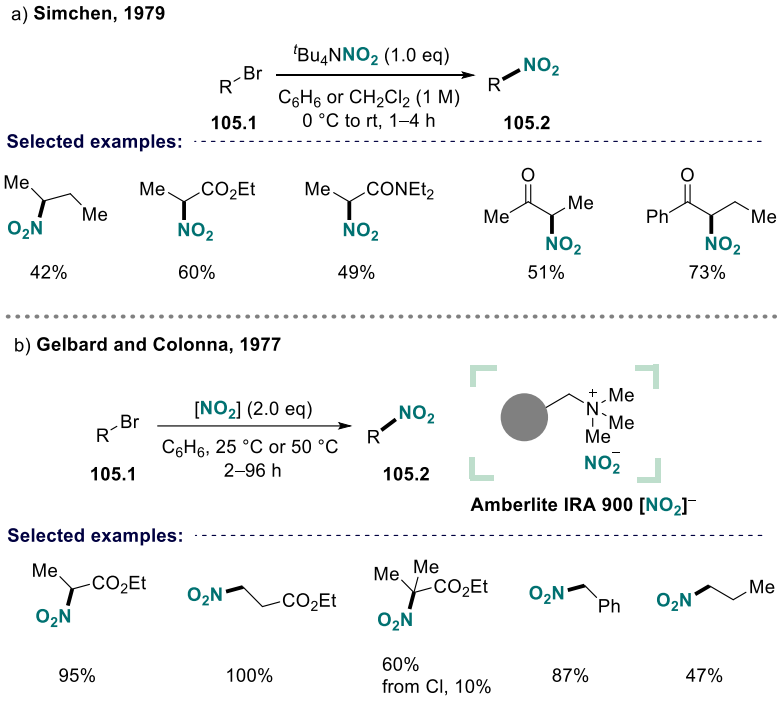


Scheme 104. Self-nitration of aromatic compounds *via* their nitric acid salts.

6.4. Organic nitrites

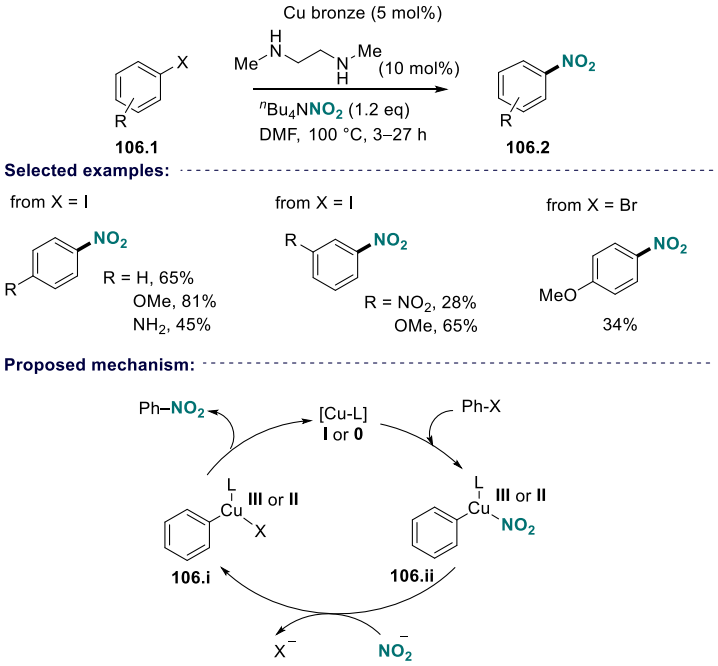
While organic nitrates require additional activation to provide nitronium ion or its surrogate, nitrites often serve as the nitro source without the need for a catalyst or mediator. Yet, they found only limited applications, which can be attributed to the high synthetic utility of inorganic nitrites in such transformations.[217]The most widely used compound of this organic reagents type is *n*-tetrabutylammonium nitrite (**TBAN**). It is a commercially available (~ 10 g – 120 $) hygroscopic solid.

The reaction of **TBAN** with organic halides has been examined in order to determine its potential reactivity in the synthesis of nitro derivatives. It came out, that under very mild reaction conditions, □-halocarbonyl compounds and even simple unactivated haloalkanes (**105.1**) smoothly underwent nitration reaction, delivering the corresponding adducts in moderate to excellent yields (Scheme 105, a).[218] The use of polymer-supported reagents often simplifies the separation of products. As such, an anionic exchange resin with nitrite Amberlit IRA 900 (Scheme 105, b)[219] and poly(4-vinyl-*N*-ethylpyridinium nitrite)[220]have been successfully used in similar type of transformations.



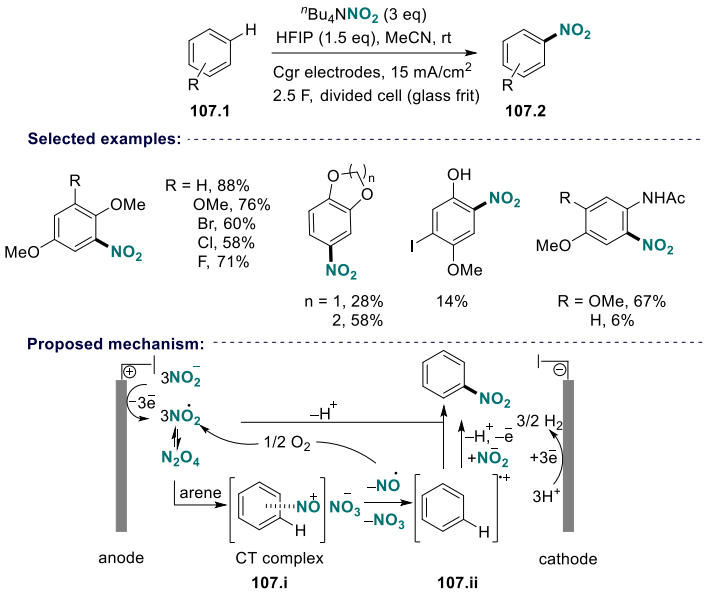
Scheme 105. Nitration of alkyl halides.

In 2005, Saito and co-workers demonstrated the *ipso*-nitration of aromatic halides (**106.1**) that proceeds in the presence of substoichiometric amounts of copper bronze and *N*,*N*-dimethylethylenediamine in DMF (Scheme 106).[221]It was postulated that this copper-catalysed ionic reaction occurs *via* a mechanism similar to Ullmann-type coupling. Few years later, Jones et al. further extended this methodology through the development of microwave-accelerated copper-catalysed nitrodehalogenation of 5-bromo indoles.[222]



Scheme 106. *Ipso*-Nitration of aryl halides with tetrabutylammonium nitrite.

n-Tetrabutylammonium nitrite can also be used as a safe NO_2 source in electrochemical nitration of aromatic compounds **107.1**, as recently demonstrated by the Waldvogel group (Scheme 107).[223]The reaction proceeded mainly for electron-rich aromatics, while the yields were significantly dependent on the nature of the substrate. According to the postulated mechanism, initial anodic oxidation of nitrite to NO_2, which is in equilibrium with N_2O_4, takes place. Upon ionic dissociation of N_2O_4, the formation of charge-transfer (CT) complex **107.i** is suggested, which, in the presence of oxidant, leads to arene radical cations **107.ii**. The subsequent reaction of arene radicals with another molecule of NO_2 affords the desired product **107.2**. On the other hand, the authors also proposed a nucleophilic attack to arene radical cation, followed by oxidation step and H^+ abstraction. In the absence of HFIP, the yields of nitro compounds dropped sharply, which could be explained by the favorable process of ionic dissociation of N_2O_4 under polar reaction conditions.



Scheme 107. Electrochemical nitration with tetrabutylammonium nitrite.

Finally, in 2010, Akhlaghinia and Pourali reported that bromodimethylsulfonium bromide and tetrabutylammonium nitrite can promote the electrophilic nitration of phenols *via* oxidation of nitrite ion.[224] It was postulated that the formation of thionitronium intermediate takes place, a species similar to that described in section 4.3 (Scheme 76). While the authors did not provide evidence to support this mechanistic assumption, the presence of NO_2 or NO_2Br in the reaction mixture cannot be neglected.

7. Conclusion

Main organic nitrating reagents discussed in the review are summarized in Figure 8. As it can be deduced, reagents bearing a covalent bond between nitrogen functionality and organic scaffold in most cases provide novel reactivity, and recent progress in nitration was related to their applications, especially with the use of **TBN,** in organic synthesis. At the same time, organic nitrates, nitrites, and nitronium salts mostly ensure comfortable and sustainable ways to obtain old reactivity, with a few exceptions.

At the current state of the field, electrophilic, nucleophilic, and radical species can be generated using organic-based nitrating reagents. In addition, this reactivity can be promoted by using different activation modes: thermal, Lewis or Brønsted acid catalysis, or light irradiation. Relatively less explored chemical tools with organic nitrating reagents, yet applied are photoredox catalysis, electrochemical activation, and metal-catalysed nitration.

Despite impressive advances in the field, much of the progress in organic nitrating reagents, has been made mainly within the past two decades, and is now accelerating. Thus, the design of new reagents precisely for their usage as nitrating molecules that began in recent years may lead to the discovery of many new bench-stable organic nitrating reagents with unique properties. It is also possible that they could solve the biggest challenge of nitrating chemistry of the last hundred years – selective nitration of aliphatic compounds. Indeed, while demonstrating an extremely important role in the transformation of aromatic compounds, aliphatic nitro compounds play minor role, mainly due to limited number of methods to access such molecules.

Thus, we believe in the rapid development of this field, the progress of which will have a significant impact on the preparation of nitro-derived molecules both in the laboratory and in industry.

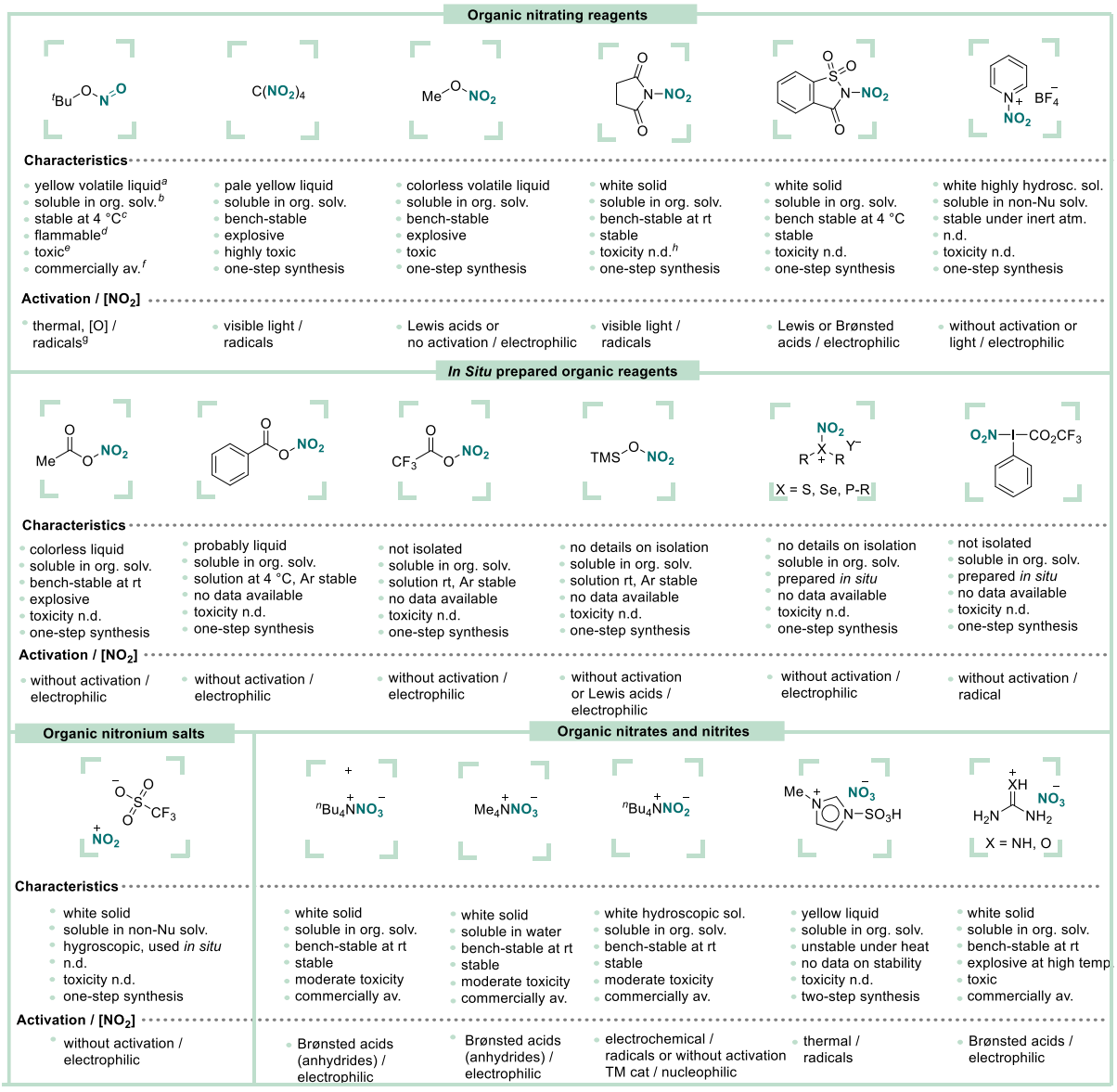


Figure 8. Summary of common organic nitrating reagents. [a]Physical appearance; [b]Solubility; [c]Storage recommendations; [d]Danger; [e]Toxicity; [f]Availability; [g]Common activation pathways and active nitro species. [h]n.d.-not determined.

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Chapter 3:

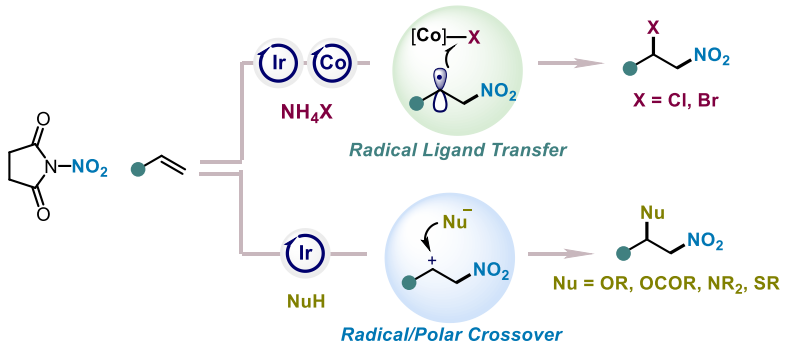
Nitrative Difunctionalization of Alkenes via Cobalt-Mediated Radical Ligand Transfer and Radical-Polar Crossover Photoredox Catalysis

This Chapter is adapted from the following publication in peer reviewed journal:

S. Patra, R. Giri, D. Katayev, "Nitrative Difunctionalization of Alkenes via Cobalt-Mediated Radical Ligand Transfer and Radical-Polar Crossover Photoredox Catalysis", *ACS Catal*. **2023**, *13*, 16136–16147. DOI:org/10.1021/acscatal.3c04899.

1. Abstract

Herein, we report the rational design of a modular dual photoredox and cobalt catalysis paradigm for difunctionalization of unsaturated hydrocarbons unlocking the synthesis of valuable but challenging 1,2-halonitroalkane substrate class. The protocol relies on the use of the redox-active organic nitrating reagent N-nitrosuccinimide as source of nitryl radicals for the cobalt-mediated radical ligand transfer (RLT) methodology to form a carbon–halogen bond. This synergistic cooperation between a photocatalyst and high-valent cobalt metal center occurs under mild reaction conditions and is capable of delivering 1,2-chloronitro- and 1,2-bromonitroalkanes in a single chemical operation, while exhibiting high functional group tolerance and exclusive regioselectivity for a variety of olefins. Mechanistic studies based on both experimental and spectroscopic analysis provided valuable insights into the radical nature of this dual catalytic halo-nitration process, including evidence for cobalt as radical halogen transfer catalyst. Furthermore, employing a net-neutral radical/polar crossover (RPC) approach under cobalt-free reaction conditions allowed to accommodate a variety of external protic nucleophiles, including thiols, alcohols, acids, and, notably, substituted amines. Highly functionalized olefin scaffolds also successfully underwent nitrative difunctionalization, demonstrating the viability of these protocols for the late-stage functionalization of bioactive molecules.



2. Introduction

Alkenes and their derivatives are ideal intermediates for organic synthesis given their readily availability in bulk quantities from renewable feedstocks. Thanks to their remarkable adaptability, alkenes play a key role as building blocks in the production of a multitude of vital industrial products, including detergents, polymers, textiles, and various value-added chemicals.[1] Furthermore, olefin molecules have found a widespread application as structural components in pharmaceuticals, including anticancer drugs, antiviral agents, and enzyme inhibitors.[2] The selective difunctionalization of alkenes, which allows the incorporation of two functionalities across a π bond of an alkene molecule has gained considerable attention in recent years. In particular, the intermolecular two- or three-component radical di-functionalization processes offer an innovative pathway to create molecular complexity rapidly and efficiently.[3] For example, recent advancements in photocatalysis[4] and electrochemical synthesis[5] have significantly simplified radical-based reactions with fine-tuned selectivity and swiftly introduced two crucial functional groups, extending the chemical space of previously distant transformations in synthetic chemistry. Such reactions can be accomplished either by a sequential approach involving redox-active reagents or nucleophiles/electrophiles/radicals or by simultaneous bond-forming reactions using bifunctional reagents (Figure 1).[6]

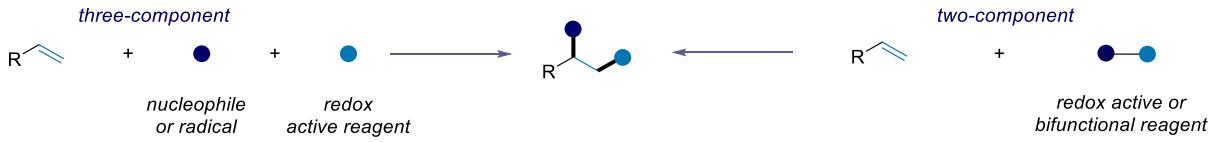


Figure 1. Radical-mediated and catalytic difunctionalization of alkenes

Since the pioneering work of Kharasch et al., atom transfer radical addition (ATRA) stands as a potent method for the radical-based difunctionalization of both activated and unactivated alkenes, typically through the use of radical initiators or transition metal catalysis,[7] while the use of visible light-mediated catalysts as initiators allowed to significantly improve and diversify ATRA processes, making them proceed under milder reaction conditions with minimal side reactivity (Figure 2A).[8] A limitation of this original concept arises if a group different from an already pre-existing one, e.g., a (pseudo-) halide moiety on the original atom transfer reagent, has to be introduced into an olefin molecule in a single chemical operation.[9] However, methods that can efficiently circumvent the rapid halogen atom transfer (XAT)[10] step remain challenging. Very recently, biologically inspired[11] radical ligand transfer (RLT) reactions[12] have been introduced and emerged as a promising chemical tool to intercept alkyl radical species under catalytic conditions and to form diverse C–X, C–N, and C–S bonds (Figure 2B). Mechanistically, this toolbox involves the outer sphere shuttle of a ligand located at a redox-active metal center to a radical intermediate, affording the formation of a new carbon-ligand chemical bond, while the metal is being reduced via a single electron transfer (SET). In the presence of a stochiometric anionic

atom transfer ligand, the sequential reoxidation of a metal center takes place, regenerating the active species for the RLT step and making this approach catalytic. These innovative radical functionalization methods in cooperation with electrochemical or photochemical functionalization approaches have very recently demonstrated on reduced examples the seamless attachment of two functionalities from orthogonal reagents across an unsaturated bond.[13]

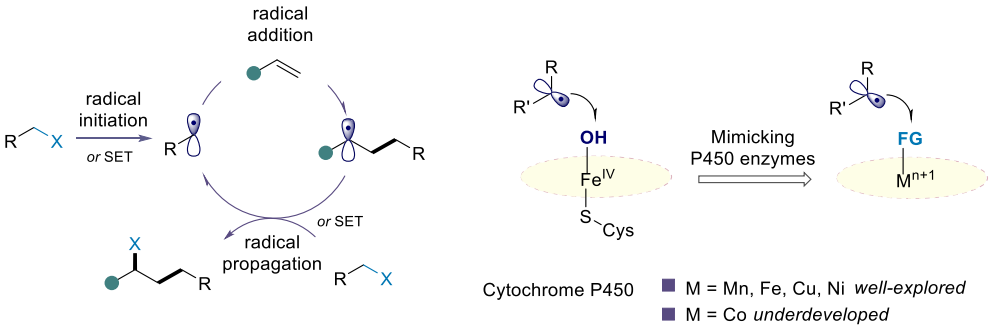


Figure 2. (A) Atom transfer radical addition (ATRA). (B) Biomimetic radical ligand transfer (RLT).

Following the success in radical-mediated transformations, the exploration of photoredox catalysis in transition-metal catalyzed reactions, so-called metallophotoredox catalysis, began to develop intensively and has now become a rising technology in organic synthesis to construct various chemical connections, including 1,2-difunctionalization of unsaturated compounds.[14] With photoredox catalysis, reactive functional radical species can be accessed under mild conditions using numerous reagents, and upon merging with complexes based on 3d-, 4d-, and 5d-transition metals, direct couplings of unconventional nucleophiles can harvest organic molecules in regio- and stereoselective manner by forging concurrent C–C and C–heteroatom bonds in a single step.[15] Among various transition-metal photoredox catalysis, the combination of visible-light-driven photocatalysts with cobalt complexes has been a subject of extensive exploration in the field of inorganic chemistry, particularly in the realm of artificial photosynthesis.[16] Such as the use of cooperative photoredox catalysis with vitamin B_{12} and its derivatives has greatly contributed to biomimetic organic synthesis.[17] The dual catalytic strategy involving cobalt and photoredox paradigm has recently found applications in several organic transformations, including asymmetric catalysis, cross-coupling reactions, C–H functionalizations, etc.[18] In such transformations the photoredox catalyst contributes to the generation of reactive radical intermediates, while cobalt often plays multiple roles, including the promotion of a catalytic cycle by one-electron redox processes. However, the utilization of synergistic cobalt and photoredox catalysis in this domain has not kept up with the rapid development observed in e.g., cooperative nickel/photoredox[4c,19] and cop-per/photoredox[20] catalysis (Figure 3).

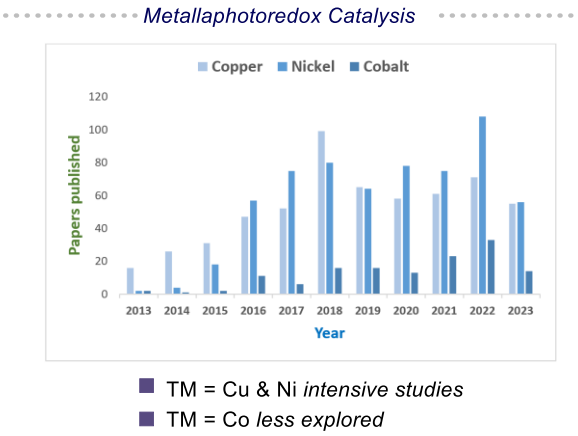


Figure 3. Merger of photoredox and first-row transition-metal catalysis.

Our research group has a keen interest in the development of nitration concepts of organic scaffolds which occur under mild, sustainable, catalytic, and nitric acid-free reaction conditions. In recent works, we introduced a series of bench-stable and easily accessible organic NO_2-transfer reagents derived from pyrrolidinone (**I**), succinimide (**II**), phthalimide (**III**), and saccharin (**IV-V**) core structures (Table 1).[21] Because of their structural uniqueness, the N–N bond cleavage of these molecules can be promoted using various catalytic manifolds, accessing either electrophilic nitronium or nitryl radical species. For example, in 2019, we developed the first photoredox-mediated net-neutral radical-polar crossover (RPC) process for the synthesis of nitro olefines.[22] Shortly after, we observed nitryl radical-triggered semipinacol-type rearrangement, leading to nitrative lactonization/etherification transformations.[23] In both cases, N-nitrosuccinimide was used as a controllable source of nitryl radicals and the reactions proceeded through a nitro-induced transient alkyl radical intermediate. Spurred by these initial results and by the remarkable reactivity of N-nitrosuccinimide reagents under photocatalytic conditions, we set out to design challenging and yet underdeveloped nitrative difunctionalization strategies of unsaturated compounds. Prompted by the versatility of installing di-verse functional groups via RLT processes involving environmentally benign transition metals, we hypothesized that the merger of photocatalysis and cobalt catalysis could provide a platform for the selective introduction of nitryl radical onto olefins, while the generated transient alkyl radical species could be intercepted via RLT with an in situ generated higher-valent cobalt halide species, delivering synthetically valuable 1,2-halonitroalkanes.

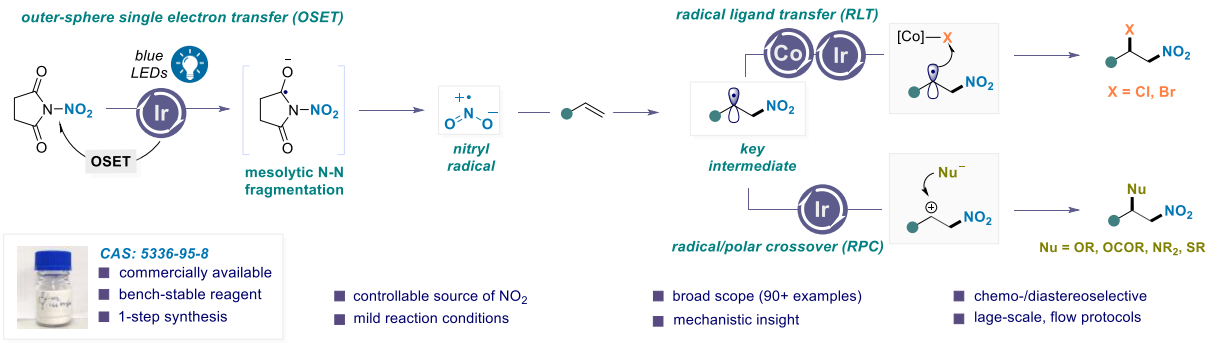


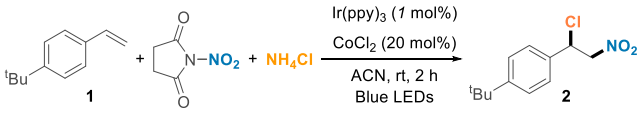
Figure 4. This work: dual cobalt-photoredox induced nitrative difunctionalization via RLT and RPC.

Focusing on these challenges, herein, we report an efficient dual cobalt-photoredox-induced nitrative difunctionalization system of alkenes for the preparation of 1,2-halonitro derivatives involving a unique cobalt-catalyzed RLT step and utilizing N-nitrosuccinimide as the organic nitrating reagent and ammonium salts as cost-effective halogen sources (Figure 4). In contrast to previous reports on bio-inspired manganese- and iron-mediated RLT concepts, the radical rebound step with earth-abundant cobalt metal[24] does not rely on the use of complex polydentate N-based ligands, making this process readily available. Mild and redox-neutral conditions allowed this method to have a broad scope with excellent regioselectivity for a variety of olefins. An in situ generated nitroalkyl carbocation intermediate under cobalt-free reaction conditions can also be captured with different S-, N-, and O-centered nucleophiles, granting access to a novel class of compounds for organic synthesis. Both reaction platforms showcased exceptional functional group tolerance and promising efficiency in the late-stage diversification of molecules containing drug/natural product frameworks.

3. Results and discussion

3.1. Reaction optimization

We commenced our investigations on the development of dual photoredox and cobalt catalytic system for halo-nitration of alkenes using 4-tert-butyl styrene 1 as a model substrate, N-nitrosuccinimide **II** as redox-active organic nitrating reagent ($E_{1/2}^{red} = -1.39$ V vs. SCE) and ammonium chloride NH_4Cl as the chlorine source. After extensive screening of reaction conditions, we observed a smooth progression of chloronitration reaction of **1** in the presence of 1 mol% of photocatalyst **PC1** and 20 mol% of $CoCl_2$ in acetonitrile (0.5 mL) under the irradiation of 350 W blue LEDs for 2 hours, affording the desired product **2** in 89% isolated yield with an excellent level of regioselectivity.



Entry	Deviation from standard conditions[a]	Yield (%)[b]
1	none	92 (89)[c]
2	2.0 eq $CoCl_2$	91
3	LiCl	22
4	NaCl	13
5	KCl	66
6	$MgCl_2{\cdot}6H_2O$	82
7	$Co(OTf)_2$	11
8	$Co(OAc)_2$	7
9	$MnCl_2$	15
10	THF	3
11	EtOAc	6
12	DMF	-

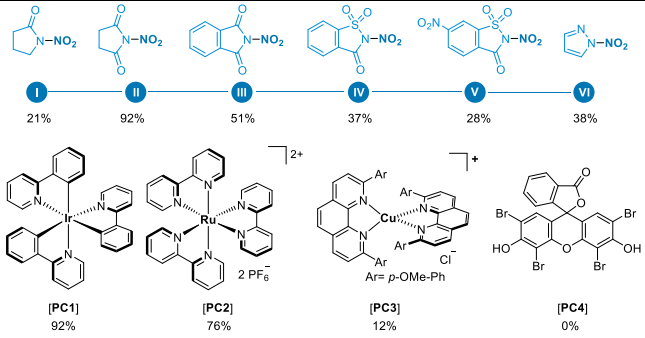


Table 1. [a]**Standard reaction conditions**: **1** (0.5 mmol, 1.0 eq), **PC1** (1 mol%), N-nitrosuccinimide **II** (1.5 eq), NH_4Cl (1.1 eq), $CoCl_2$ (20 mol%) and ACN (0.5 mL), 350 W blue LEDs, rt, 2 h. [b]GC-MS yield using n-decane as an internal standard. [c]Isolated yield in the parenthesis.

For comparison, various other organic nitrating reagents (**I**, **III**-**VI**) have been shown to be less effective as nitryl radical precursors, highlighting the superior application of reagent **II**. PC1 ($E_0(Ir^{IV/III*}) = -1.73$V (vs. SCE)) which has recently been found to be an excellent mediator for the activation of reagent **II** (−1.39 V vs. SCE) under visible light, was chosen as the photocatalyst for reaction development. Many attempts with different photocatalysts, including both metal- and organic-based photocatalysts, were unsuccessful in improving the yield (see Supporting Information for details). When over stoichiometric amounts of $CoCl_2$ were applied instead of NH_4Cl, **2** was furnished in 94% yield, suggesting $CoCl_2$ is the responsible chlorinating reagent in this transformation (Table 1, entry 2). Additionally, we assessed the outcome of this transformation with other chloride sources, and lower yields were observed (Table 1, entries 3-6). The dichlorination adduct of **1** was often formed as a major side product that most probably forms through known ligand-to-metal charge transfer methodology (LMCT).[25] We then probed the effect of other transition-metal catalysts (Table 1, entries 7-9), and also tested a range of solvents on the reaction outcome (Table 1, entries 7-12). However, lower yields and poor selectivity were obtained (see Supporting Information for details).

3.2. Investigation of substrate scope

Substrate scope for halo-nitration of unsaturated hydrocarbons under a dual cobalt-photoredox catalytic system

With the optimized reaction conditions in hand, the generality of this dual catalytic system in the halonitration of various olefin molecules was evaluated (Figure 5). Electron-neutral (**3**) electron-rich (**2**, **4-7**), and electron-deficient (**8-17**) functional groups in ortho-, meta-, and para-positions of the benzene ring were well tolerated under our photoredox protocol. Chloronitration adducts bearing a polysubstituted aromatic ring **7** or naphthalene moiety (**19**) were also formed in 72% and 83% yield, respectively. Essential functional groups at para-position such as ester (**14**), aldehyde (**15**), trifluoro-methyl (**16**), nitro (**17**), and oxirane (**18**), remained untouched and olefins underwent the desired transformation successfully, giving the corresponding chloro-nitration products. Moreover, this protocol was also compatible with α-substituted styrene, including methyl (**20**, **21**) and cyclohexyl (**22**) derivatives. Also, internal alkenes such as indene provided the difunctionalized product with a decent yield (**23**). In our previous studies on photoredox nitration strategies, the scope was restricted to aryl-substituted olefins. To our delight, less activated olefins also underwent the desired transformation with this catalytic cobalt method (**24-26**). Interestingly, electron-deficient alkenes such as 1-morpholinoprop-2-en-1-one (**27a**) and N-methyl-N-phenylacrylamide (**28a**) were found to be compatible with the reaction conditions, resulting in the formation of the corresponding adducts **27** and **28** respectively in good yields. Whereas **28** experienced partial decomposition under the reaction conditions and yielded the terminal nitration product **29**. This general process can also be applied in the late-stage functionalization of architecturally complex molecules **32**, **33**, and **34**, exhibiting excellent chemo- and regioselectivity.

Having explored the chemical space of chloronitration, we moved to the challenging bromonitration protocol (Figure 5). This methodology was equally successful in the nitrative bromination of aryl substituted olefines containing electron-neutral (**35**, **48**), electron-donating (**36-37**), and electron-withdrawing (**39-46**) common functional groups at ortho-, meta- and para-positions utilizing NH_4Br as the bro-mine source and catalytic $CoBr_2$ as RLT mediator. Remarkable functional group compatibility was exhibited during the selective alkene difunctionalization process, enabling the preservation of sensitive functional groups without any major side products (**40-48**).

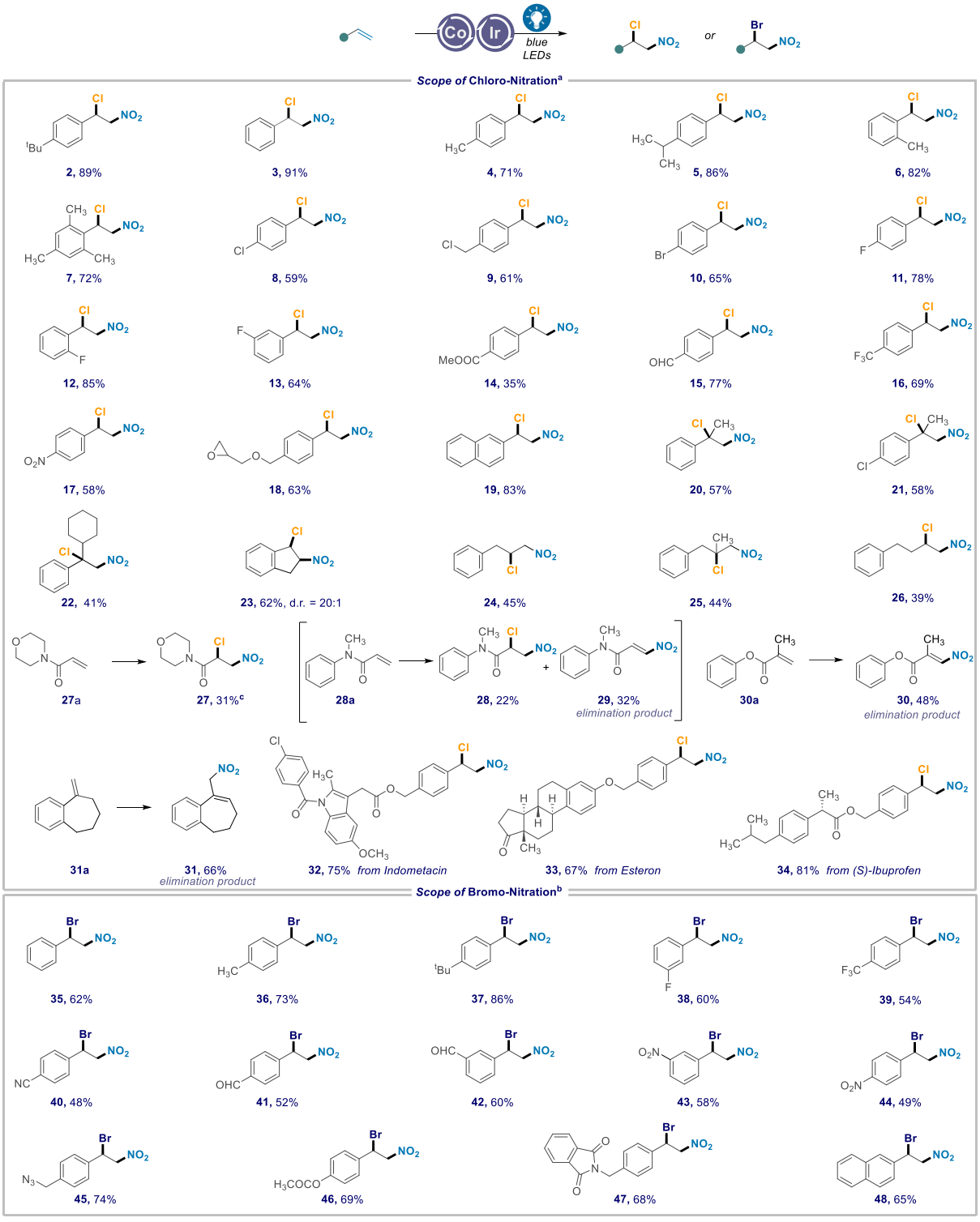


Figure 5. Substrate scope of chloronitration and bromonitration reactions. Standard conditions: [a]alkene (0.5 mmol, 1.0 eq), *fac*-Ir(ppy)$_3$ (1 mol%), reagent **II** (1.5 eq), $CoCl_2$ (20 mol%), NH_4Cl (1.1 eq) and ACN (0.5 mL), 350 W blue LEDs, rt, 2 h. [b]Alkene (0.5 mmol, 1.0 eq), *fac*-Ir(ppy)$_3$ (1 mol%), reagent **II** (1.5 eq), $CoBr_2$ (20 mol%), NH_4Br (1.1 eq) and ACN (0.5 mL), 350 W blue LEDs, rt, 2 h. Isolated yields are reported. [c]Product partially decomposed.

3.3. Mechanistic investigations of dual cobalt-photoredox catalysis

Next, we focused our attention on investigating the reaction mechanism using combined experimental and spectroscopic approaches, and the summary of these studies is outlined in Figure 6. Lack of reaction progression without visible light or photocatalyst implies the photosensitization nature of the reaction. Furthermore, in the absence of a cobalt catalyst, no product formation was observed whereas 15% of **2** was furnished without NH_4Cl addition, suggesting that cobalt chloride is a key intermediate for halogen atom transfer. The yield of the product was marginally affected when the reaction was carried out in the presence of air under established conditions. In addition, product **2** was not detected at elevated temperatures (70 °C) (Figure 6A). Driven by the wide scope and competence of the dual catalytic protocol, we then endeavored to gain a deeper understanding of the mechanism. Based on our previous results, we speculated that in the presence of photocatalyst **PC1** (operating under oxidative quenching), the reagent **II** undergoes an irreversible, exergonic, and reductive SET process to afford the radical ion intermediate, which subsequently generates nitryl radical via a mesolytic N–N bond fragmentation. Experimentally, this hypothesis is fully consistent with Stern–Volmer quenching studies indicating a highly efficient quenching of the excited T1-state of Ir^{III} by the reagent **II** (K = 7.0 × 108 M−1s−1, Figure 6B). Generated nitryl radical further undergoes a Giese-type addition[26] to the β-position of olefin to form the stabilized benzyl radical intermediate **Int-1**. A Hammett study was carried out with styrenes having distinct electronic properties, and styrenes bearing electron-rich substituents reacted significantly faster than their electron-withdrawing counterparts. The resulting Hammett plot provided a slightly negative reaction rate constant (ρ = – 0.74 in MeCN), indicating the formation of an electrophilic species during the course of the reaction (Figure 6D). While the reaction smoothly progressed under blue LED irradiation, it stopped abruptly in the absence of visible light. This outcome strongly suggests that the reaction adheres to a photoredox catalytic pathway instead of depending on radical chain propagation (Figure 6E). The validity of this catalytic pathway was additionally substantiated by a measured quantum yield of Φ = 0.02.[27,28] Next, the designed molecules **49** and **51** were examined in radical clock experiments to explore the probability of oxidation of an in situ generated alkyl radical **Int-1** into a carbocation by either Ir^{IV} or a higher-valent cobalt salt followed by S_N1 type halogen addition (Figure 6C). Firstly, under the standard conditions, cyclopropane alkene **49** yielded **50** via a facile ring-opening, and secondly, 5-exo-trig cyclization product **52** was formed exclusively with **51**. In both cases, 1,2 vicinal chloronitration products were not observed, which suggests that the final chlorination step takes place after migrational ring-opening/closing events, therefore excluding the possibility of a domino-like pathway (oxidation to carbocation and S_N1). These results corroborate the fact that an unactivated alkyl radical has a higher oxidation potential, which negates its subsequent one-electron oxidation under these conditions.[29] Generation of **Int-1** was also supported by chloronitration of (Z)- and (E)-β-methyl styrene, yielding the corresponding product **50** with similar d.r. values (Figure 6G-a). Similarly, radical scavenging experiments with CCl_3CN, and CCl_4 reagents led to the formation of **2** in 19% and 5%,

respectively, confirming both the presence of **Int-1** and its sequential reactivity via the halogen atom transfer (XAT) process. When (E)-(2-nitrovinyl)benzene was subjected to the standard conditions in the absence of nitrating reagent **II**, product **2** was not observed, indicating that the reaction does not proceed through Michael-type addition. Based on the above-mentioned experimental results, we speculate that the alkyl radical intermediate **Int-1** most likely undergoes a cobalt-assisted radical ligand transfer step with the concurrent formation of the product and regeneration of a low-valent cobalt catalyst. Instantaneously, the low-valent cobalt intermediate can undergo thermodynamically favorable[30] one-electron oxidation in the presence of an external nucleophile (Cl and Br) by the oxidized form of a photocatalyst to regenerate the ground-state Ir^{III} ($E_{1/2}(Ir^{IV/III})$ = 0.77 V vs. SCE),[31] closing the photocatalytic cycle, while regenerating the key high-valent cobalt salt in the reaction mixture for the next dual catalytic cycle.

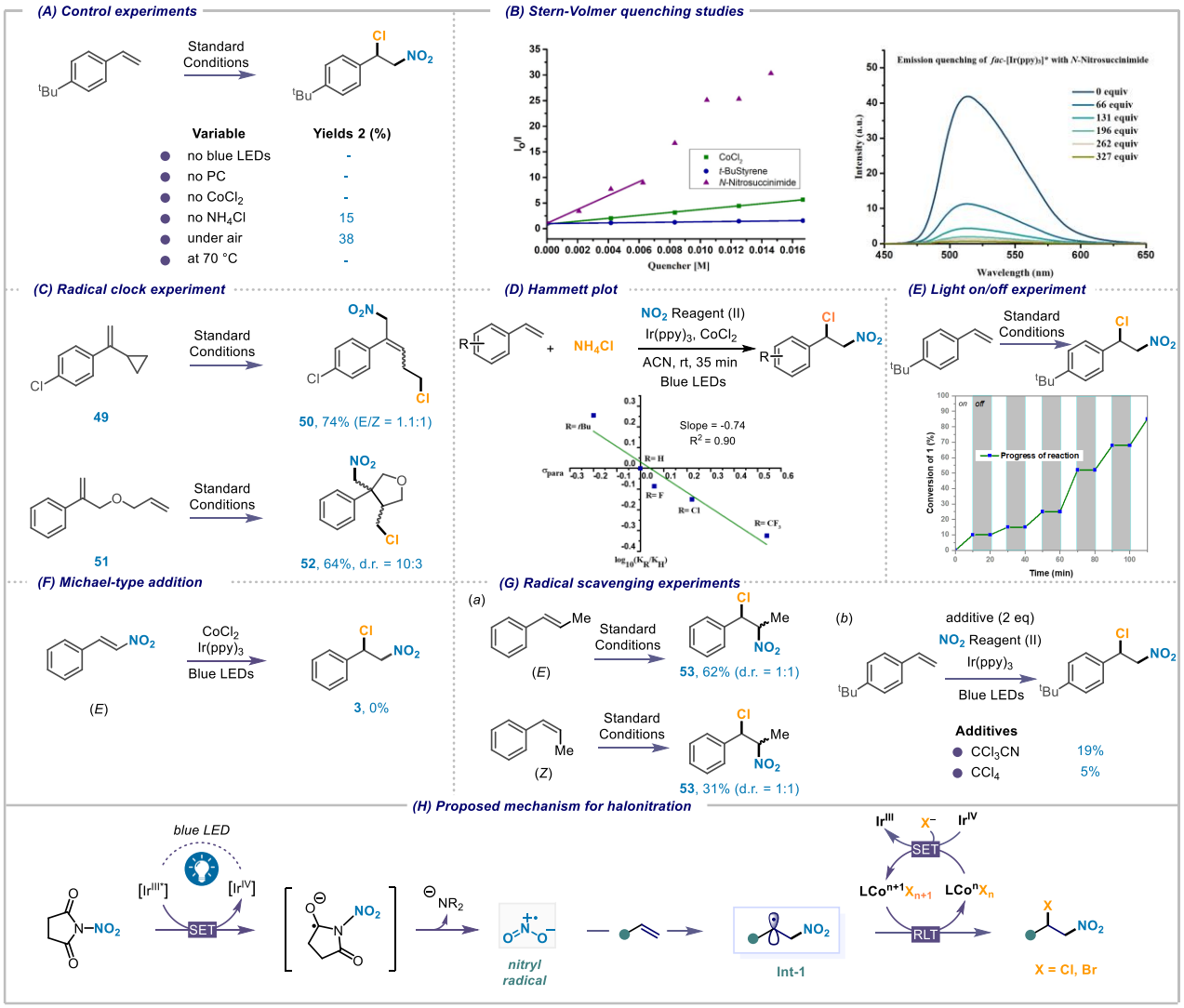


Figure 6. Mechanistic studies. (A) Control experiments. (B) Stern-Volmer quenching experiments. (C) Radical clock experiments. (D) Hammett studies. (E) Light-dark experiments. (F) Control experiment for Michael-type addition process. (G) Radical probe and radical trapping experiments. (H) Proposed mechanism for photoredox-mediated and cobalt-catalyzed RLT alkene halonitration.

3.4. Nitrative difunctionalization via net-neutral radical/polar crossover reaction

Encouraged by the successful application of the dual photoredox and cobalt-catalyzed radical ligand transfer paradigm, we next attempted to adopt this system to other readily available nucleophiles (Figure 7). However, when protic nucleophiles were used as reagents for ligand transfer, this system was not applicable and often resulted in the formation of the desired products in traceless amounts along with many by-products. At this stage, we decided to explore the net-neutral radical/polar crossover pathway to achieve diverse nitrative difunctionalization of alkenes. We began our studies by exploring visible-light mediated nitro- difunctionalization using thiols as S-centered nucleophiles. While aliphatic thiols exhibit pronounced nucleophilic characteristics, often leading to the side reactions such as hydrothiolation of alkenes, we have pleasantly observed in our mild protocol an efficient nitrothiolation reaction with high yields.[32] The process was robust when treated the alkene with catalytic amounts of *fac*-Ir(ppy)$_3$ (1 mol%), N-nitrosuccinimide (1.5 eq), and thiol (2.0 eq) in acetonitrile under blue LED irradiation. Of note, our method showcased an impressive tolerance toward aliphatic thiols that are relatively underexplored in photocatalytic difunctionalization reactions (**54**, **60-63**).[33] This transformation worked equally well with electronically dissimilar alkenes (**54-59**).

The difunctionalization of alkenes with simultaneous introduction of an amino group using unprotected amines under photoredox conditions is a challenging transformation due to the competitive and rapid redox processes. Nitrative-amination has been a longstanding challenge in our group, and through various optimization studies, we found that increasing the nucleophilicity of amines allows us to suppress side processes and carry out the first nitroamination reaction of alkenes in moderate to good yields (**64-69**). The significance of this transformation lies in the fact that the resulting molecule serves as an excellent precursor for the preparation of vicinal diamines. This promising outcome opens new possibilities for the synthesis of valuable molecules with potential applications in various fields.

In addition to introducing halogen, sulfur, and nitrogen functionalities onto alkenes, we were also interested in exploring the reactivity of oxygen-centered nucleophiles. Our investigations revealed that alcohols exhibited exceptional performance in the studied chemical reaction affording the corresponding 1,2-nitroether derivatives in good to excellent chemical yields (**70-78**). In addition, it was intriguing to observe that fluorinated alcohol could also be successfully introduced into an alkene molecule (**80**). When we subjected alcohols having alkene or alkyne moieties in their structures, these functional characteristics, fortunately, did not lead to any adverse reactions, but instead rather contributed with high efficiency to the desired results (**81-85**) including architecturally complex alkenes derived from (−)-Nopol (**95**), Geraniol (**96**) and (S)-Ibuprofen (**97**). The utilization of deuterated methanol also yielded the corresponding product **76** with high efficiency. Other essential functional groups including oxirane (**77**), sulfur moieties (**86**, **87**), or less deactivated terminal olefin (**89**) remained intact. Moreover,

we observed that β-substituted olefin was also reactive forming **88** in 64% yield. The reaction was further extended to heterocycles (**89**), demonstrating a wide applicability and tolerance of the process to various chemical functionalities. On the other hand, acetic and 2-ethylbutyric acids as nucleophiles likewise underwent efficiently nitrative difunctionalization reactions to provide nitroesters **91-94** in yields up to 90%.

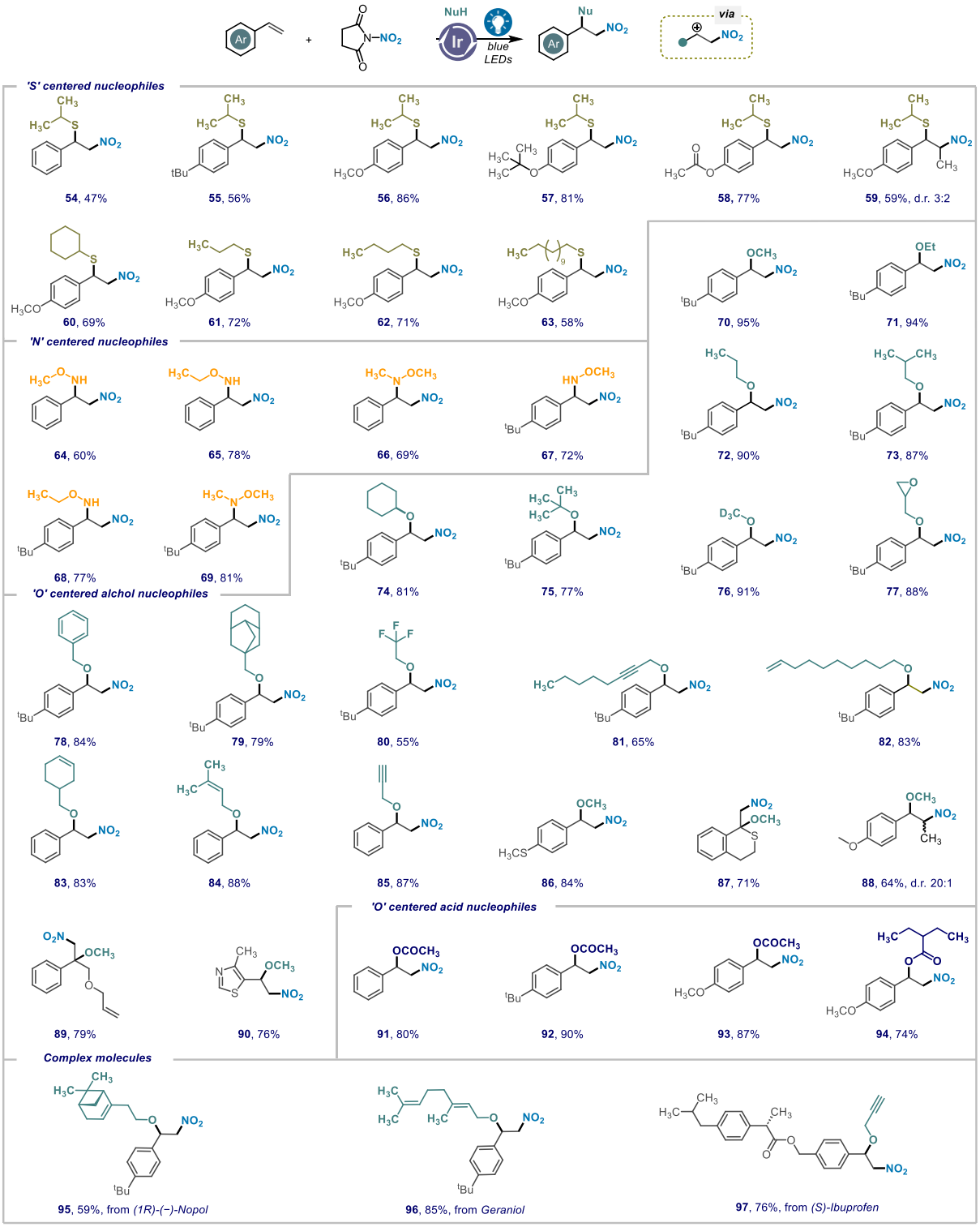


Figure 7. Intermolecular nitrative difunctionalization of alkenes with 'S'-, 'N'-, and 'O'- centered nucleophiles. Standard reaction conditions: alkene (0.5 mmol, 1.0 eq), *fac*-Ir(ppy)$_3$ (1.0 mol%), N-

nitrosuccinimide **II** (1.5 eq), nucleophile (2.0-3.0 eq), and acetonitrile (0.5 mL), 350 W blue LEDs, rt, 10 h. Isolated yields are reported. See the supporting information for detailed reaction conditions.

3.5. Mechanistic understanding for nitrative difunctionalization via net-neutral radical/polar crossover

To gain insights into the mechanistic aspects of this RPC assisted nitrative difunctionalization reaction, we performed key experiments. When (E)-β-methyl styrene was subjected to our reaction conditions, the corresponding product **98** was isolated in 72% with a d.r. value of 1.4:1 in the presence of methanol as an intermolecular nucleophile while only 1,2-vicinal addition product **89** in reaction with olefin **51** was isolated (Figure 8A). These results suggest that the nitryl radical first undergoes addition to the olefin to produce a benzylic radical intermediate, which is next oxidized to a cationic intermediate followed by nucleophilic addition. The absence of 5-exo-trig cyclization product **99** indicates a higher oxidation potential of the non-stabilized alkyl radical species, which is consistent with our previous observation (formation of **52**). As an alternative to our original mechanistic proposal, we considered the scenario that the photocatalytic reaction could generate a nitroalkene, which then interacts with the nucleophile via a Michael-type addition pathway, leading to similar differentiated compounds. To this goal, a series of experiments were conducted using (E)-(2-nitrovinyl)benzene in combination with various nucleophiles (Figure 8B). Notably, no products were found in the case of O-centered nucleophiles, whereas in the reaction with thiols and amines, it was possible to isolate some of the difunctionalized products, suggesting that a rather minor but competitive pathway may occur.

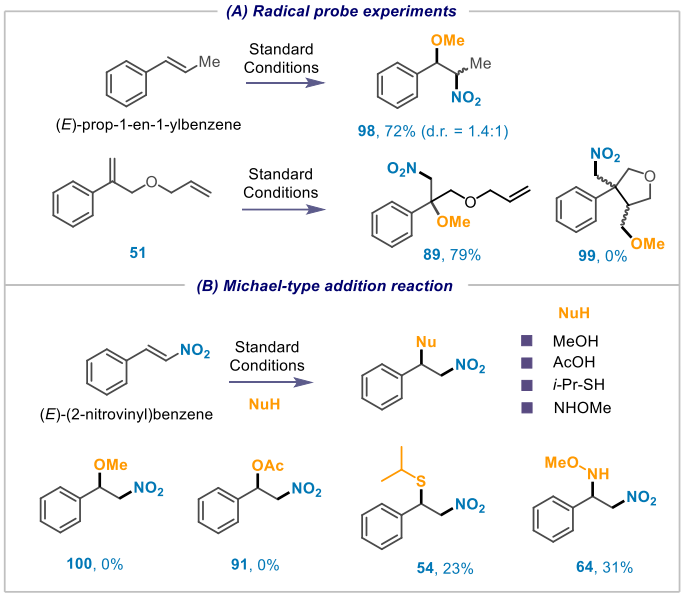


Figure 8. Standard reaction conditions: alkene (0.5 mmol, 1.0 eq), *fac*-Ir(ppy)$_3$ (1.0 mol%), N-nitrosuccinimide **II** (1.5 eq), methanol (3.0 eq), and acetonitrile (0.5 mL), 350 W blue LEDs, rt, 10 h. (A) Radical probe experiments (B) Evaluation of the possibility of Michael-type addition reactions.

3.6. Scale-up synthesis in flow and post-synthetic modifications

To demonstrate the operational simplicity and scalability of the protocol, the process was applied to a 10.0 mmol scale in a continuous flow, and under standard conditions, the corresponding product **101** was isolated in 74% (Figure 9A). Because of the essential importance of nitro compounds, we investigated the synthetic value of 1,2-halonitro derivatives by a series of derivatizations utilizing judicious choices of nucleophiles to access valuable building blocks (Figure 9B). For example, the newly formed carbon-halogen bond can sequentially be substituted with diethylmalonate to access compound **102** in 85%, while basic conditions mediate an elimination reaction releasing **103** in almost quantitative yield. Utilizing an organometallic zinc reagent, a new C(sp^3)−C(sp^3) bond can be generated with high chemoselectivity (**104**). Halonitro alkane **3** was converted to 1-methyl-3-(2-nitro-1-phenylethyl)-1H-indole **105** in 61%, using N-methyl protected indole as carbon nucleophile. The nitro group was also exposed to the installation of triazole (**106**) fragment.

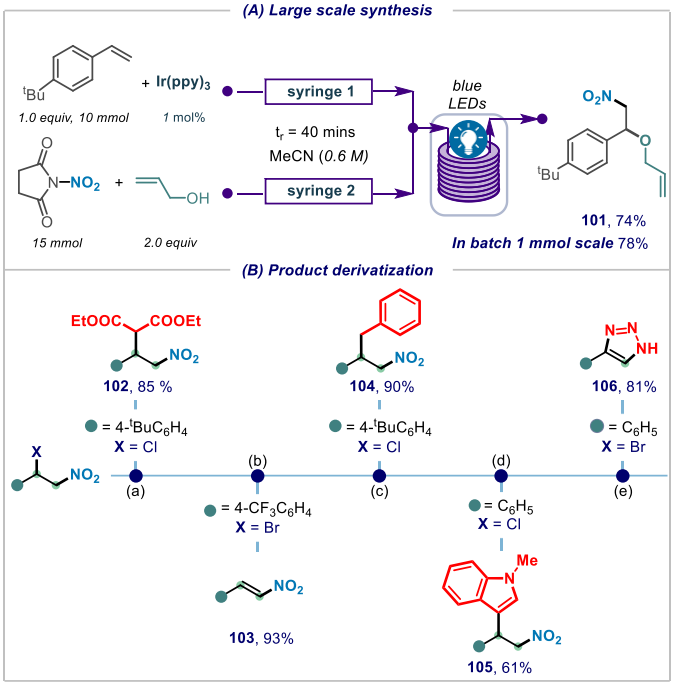


Figure 9. (A) Large-scale synthesis both in flow and batch set-ups. (B) Post-synthetic modifications. (a) 2 (0.5 mmol), diethylmalonate (1.1 eq), NEt_3 (1.0 eq), rt, 6 h. (b) 39 (0.5 mmol), Na_2CO_3 (1.5 eq), THF (2 mL), rt, 6 h. (c) 2 (0.5 mmol), benzylzinc bromide (0.5 M in THF, 1.5 eq), THF (2 mL), 0 °C, 6 h. (d) 3 (0.5 mmol), 1-methyl-1H-indole (1.5 eq), $Sc(OTf)_3$ (20 mol%), ACN/H_2O (1:1) (2 mL), rt, 16 h. (e) 3 (0.5 mmol), NaN_3 (4.0 eq), DMF (2 mL), 60 °C, 12 h.

4. Conclusion

In summary, we have developed a novel dual photoredox and cobalt catalysis platform to unravel the synthesis of halonitroalkanes. This concept possesses a unique mechanistic pathway, which complements existing synthetic approaches. Through a series of control experiments, we recognized a pivotal role played by cobalt-assisted radical ligand transfer (RLT) in the efficient conversion of transient alkyl radical intermediates into the corresponding halo-nitration products. The synergistic cooperation of two efficient systems provides a versatile route to a wide array of nitro compounds, utilizing an organic bench-stable nitrating reagent as a source of nitro group and cost-effective ammonium salts as a source of halogens. The method is characterized by its mildness, catalytic efficiency, and exceptional functional group tolerance. Furthermore, we explored a net-neutral radical/polar crossover (RPC) approach to perform diverse nitrative difunctionalization reactions using readily available O-, S-, and N-centered nucleophiles as coupling reagents. A broad spectrum of over 90 examples, including 1,2-difunctionalization of structurally complex olefins, were demonstrated with consistent and high chemoselectivity. Further investigations of employing ATRA, RLT, and RPC concepts driven by sustainable energy sources to access nitro-derived molecules are currently underway in our laboratory.

5. Experimental section

Material and methods

All reactions were conducted within flame-dried glassware under an argon atmosphere, utilizing Teflon-coated stirring bars and dry septa. Before usage, glassware was dried at 120 °C overnight. Initial materials were commercially obtained from Thermoscientific – Acros, Sigma Aldrich, Apollo Scientific, Fluorochem, and TCI, unless stated otherwise. Commercially available olefins underwent preliminary analysis *via* ^{1}H NMR spectroscopy prior to their application. Anhydrous acetonitrile was stored over pre-conditioned 3 Å molecular sieves for a minimum of 12 hours prior to use. Analytical thin-layer chromatography (TLC) was executed on Merck silica gel 60 F254 TLC glass plates, visualized through 254 nm light and potassium permanganate staining solutions, followed by heating. Purification of reaction products was performed via flash chromatography using Brunschwig silica 32-63, 60Å at an overpressure of 0.3-0.5 bar. Medium pressure liquid chromatography (MPLC) was carried out using a Teledyne ISCO CombiFlash Rf200 System with an in-built UV-detector and fraction collector, or manually using silica gel SilicaFlash P60, 40-63 µm. Teledyne ISCO RediSep Rf flash columns were utilized, featuring particle sizes of 0.035–0.070 mm and mesh sizes of 230–400.

^{1}H- and ^{13}C-NMR spectra were recorded on Bruker Ultrashield 300 (300.1 MHz and 75.5 MHz, respectively), Bruker Ascend 400 (400.1 MHz and 100.6 MHz, respectively), Bruker AVANCE III 500 (500.1 MHz and 125.6 MHz, respectively), and Bruker Ascend LH 600 (600.1 MHz and 151.6 MHz, respectively). ^{19}F-NMR spectra were recorded on Bruker DPX-300 and Bruker Ultrashield 300 (at 282 MHz) and Bruker DPX-400 and Bruker Ascend 400 (at 376 MHz), Bruker DPX-500 and Bruker AVANCE III 500 (at 477 MHz). Chemical shifts are expressed in parts per million (ppm) and coupling constants (*J*) in Hertz (Hz). ^{1}H-NMR spectra are reported with the solvent resonance as the reference unless otherwise specified ($CDCl_3$ at 7.26 ppm). Peaks are designated as (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet or unresolved, coupled constants in Hz, integration). *13*C-NMR spectra were obtained with ^{1}H-decoupling and are reported with the solvent resonance as the reference, unless otherwise indicated ($CDCl_3$ at 77.16 ppm). ^{19}F-NMR spectra were acquired with ^{1}H-decoupling, unless stated otherwise. Infrared spectra were recorded via a Bruker Tensor III spectrometer equipped with a golden gate.

High-resolution mass spectra (ESI+) were measured on a Bruker FTMS 4.7T BioAPEX II and Thermo Scientific LTQ Orbitrap XL, equipped with a static nanospray ion source. Electron impact ionization mass spectra (EI-MS) were conducted on an Agilent 8890 series GC system and Aglient 5977B GC/MSD. Single crystals for X-ray diffraction were measured on a XtaLAB Synergy, Dualflex, Pilatus 300K diffractometer using CuKα radiation (λ = 1.54184 Å) at 100 K. Structures were solved using SHELXS.1, SHELXT51, or Superflip1, and refined through full-matrix least-squares analysis (SHELXL) using OLEX2.2, with non-hydrogen atoms refined anisotropically and hydrogen atoms constrained to ideal geometries (a riding model). Solid-state structures were visualized using the

ORTEP3 program. Additional specifics and CCDC numbers for solid-state structures can be found in Section 14 (X-Ray Diffraction Data) of the Supporting Information. UV-vis absorption spectra were recorded on a Perkin Elmer Lambda 35 UV/VIS spectrometer. Cyclic voltammetry was measured utilizing the Osilla potentiostat, Ag^+ (0.01M $AgNO_3$)/Ag reference electrode, platinum disc working electrode, and platinum counter electrode in MeCN (0.1 M NBu_4PF_6), unless otherwise stated. Fluorescence spectroscopy was performed on a JASCO FP-6200 spectrofluorometer.

5.2. High intensity photoreactors

The photoreactor was custom designed and built in coordination with the mechanical workshop in the Department of Chemistry and Applied Biosciences at ETH Zürich having blue LEDs, equally spaced in a circular design, powered by a 10.3 A power supply, emitting 350 W of light with the measured UV-Vis spectrum (Figure 1). The LEDs are water-cooled and further cooled by built-in fans to maintain an ambient temperature.

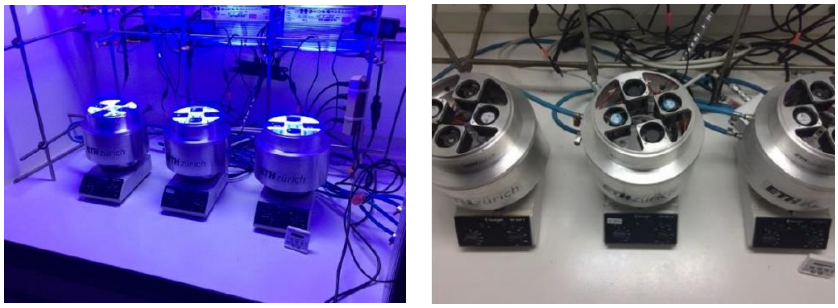


Figure 5.2.1. Custom high-intensity, blue LED photoreactors for photocatalytic reactions.

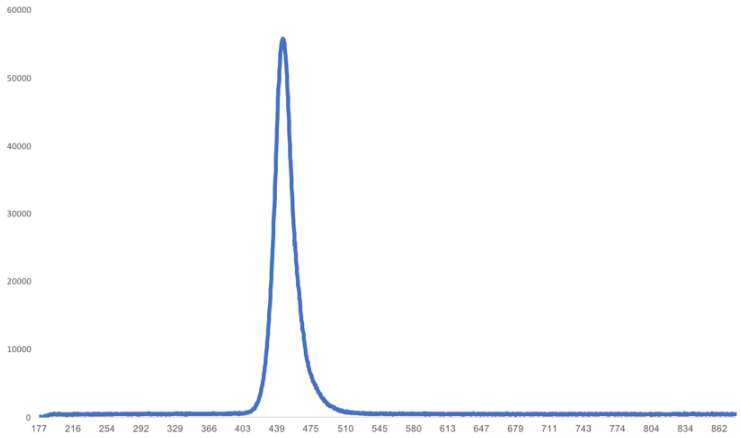
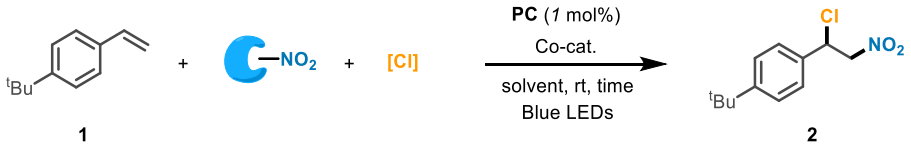


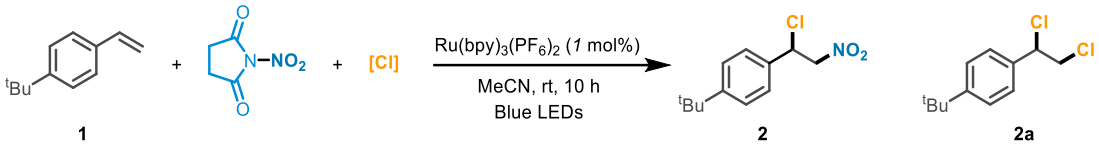
Figure 5.2.2. UV-Vis emission spectrum of high-intensity, blue LED photoreactor (λ_{max} = 446 nm, FWHM = 20 nm).

5.2. Development of the Reaction Conditions



A flame dried 5 mL crimp cap vial was charged with photocatalyst (*x* mol%), nitrating reagent (*x* eq), chloride source (*x* eq), catalyst (*x mol%*) and equipped with a magnetic bar. The contents of the vial were then subject to three vacuum-nitrogen cycles. Anhydrous solvent (*x* mL) and 4-*tert*-butylstyrene **1** (0.1 mmol, 1.0 eq) were introduced to the solution *via* syringes under nitrogen atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 10 h. After that, *n*-decane as an internal standard was added with a micro syringe. An aliquot was taken and analysed by GC-MS to obtain the calibrated yields for the product.

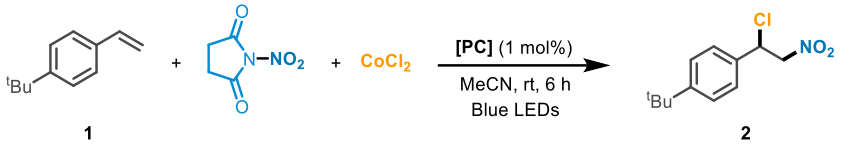
5.2.1. Initial Optimization



Entry[a]	Halide Sources (3.0 eq)	Yield of 2 [%][b]	Yield of 2a [%][b]
1	NaCl	-	-
2	KCl	traces	-
3	LiCl	traces	-
4	NH_4Cl	-	-
5	$CuCl_2$	6	60
6	$MnCl_2$	27	13
7	$FeCl_2•4H_2O$	-	9
8	$MgCl_2•6H_2O$	-	-
9	$CoCl_2$	35	14

Table 5.2.1. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 eq), reagent **II** (1.0 mmol, 2.0 eq), $Ru(bpy)_3(PF_6)_2$ (1.0 mol%), [Cl]-source (1.5 mmol, 3.0 eq), MeCN (0.5 mL). [b]Determined by GC against an internal standard of *n*-decane.

5.2.2. Survey of Photocatalysts



1 2

Entry[a]	**PC** (1 mol%)	**Yield of 2** [%][b]
1	PC-1	80
2	PC-2	35
3	PC-3	12
4	PC-4	-
5	PC-5	36
6	PC-6	17
7	PC-7	5
8	PC-8	25
9	PC-9	-
10	PC-10	-
11	PC-11	-

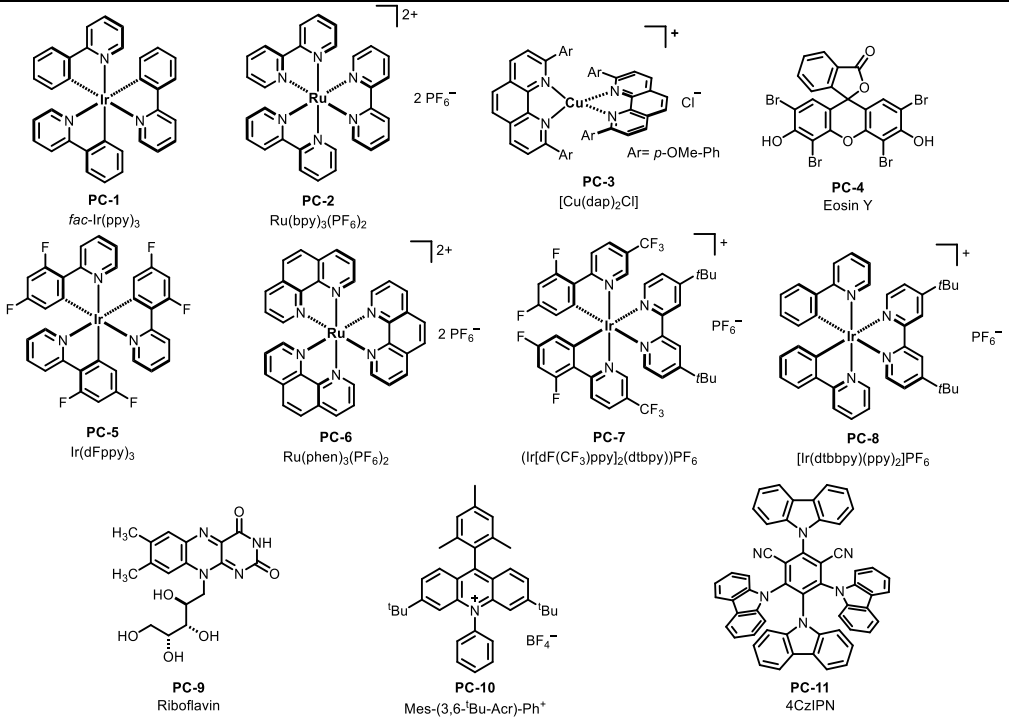
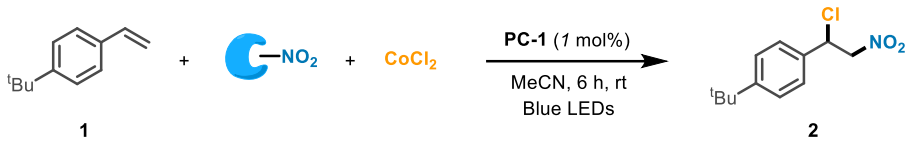


Table 5.2.2. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 eq), reagent **II** (1.0 mmol, 2.0 eq), **PC** (1.0 mol%), $CoCl_2$ (1.5 mmol, 3.0 eq), MeCN (0.5 mL). [b]Determined by GC against an internal standard of *n*-decane.

5.2.3. Survey of Nitrating Reagents



1 2

Entry[a]	Reagent [2.0 eq]	Yield [%][b]
1	**I**	21
2	**II**	87
3	**III**	51
4	**IV**	37
5	**V**	28
6	**VI**	38
7	**II** (1.5 eq)	92
8	**II** (3.0 eq)	80

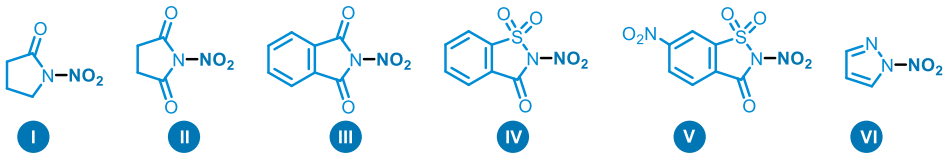
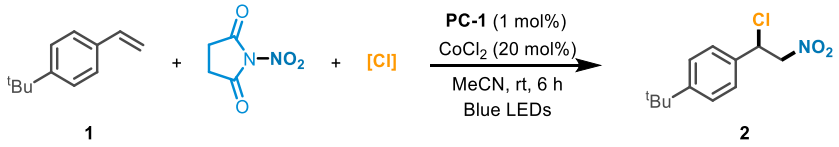


Table 5.2.3. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 eq), reagent (*x* eq) **PC-1** (1.0 mol%), $CoCl_2$ (0.75 mmol, 3.0 eq), MeCN (0.5 mL). [b]Determined by GC against an internal standard of *n*-decane.

5.2.4. Survey of Chloride Source and Metal Co-Catalyst

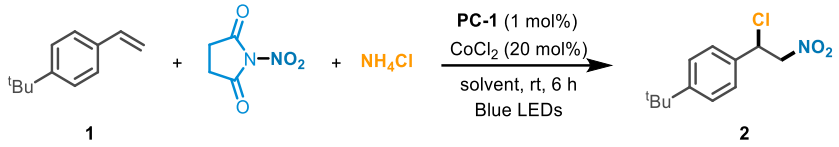


1 2

Entry[a]	Reagent [2 eq]	Co-catalyst (20 mol%)	Yield [%][b]
1	LiCl	$CoCl_2$	22
2	NaCl	$CoCl_2$	13
3	KCl	$CoCl_2$	66
4	$MgCl_2$•$6H_2O$	$CoCl_2$	82
5	$CaCl_2$	$CoCl_2$	61
6	$ZnCl_2$	$CoCl_2$	76
7	NH_4Cl	$CoCl_2$	92
8	NH_4Cl	$Co(OTf)_2$	11
9	NH_4Cl	$Co(OAc)_2$	2

Table 5.2.4. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 eq), reagent **II** (0.75 mmol, 1.5 eq), **PC-1** (1.0 mol%), $CoCl_2$ (20 mol%), chloride salt (*x* eq) MeCN (0.5 mL). [b]Determined by GC against an internal standard of *n*-decane.

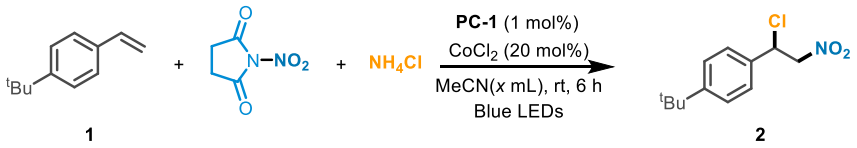
5.2.5. Survey of Survey of Solvents



Entry[a]	Solvent (1.0 M)	Yield of 2 [%][b]
1	EtOAc	6
2	DMF	-
3	THF	3
4	$CHCl_3$	56
5	1,4-Dioxane	7
6	Toluene	4
7	MeCN	92

Table 5.2.5. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 eq), reagent **II** (0.75 mmol, 2.0 eq), **PC** (1.0 mol%), NH_4Cl (0.55 mmol, 1.1 eq), $CoCl_2$ (20 mol%), solvent (*x* mL). [b]Determined by GC against an internal standard of *n*-decane.

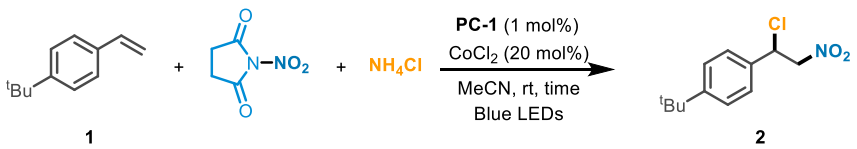
5.2.6. Survey of Concentration Effect



Entry[a]	Substrate [M]	Yield of 2 [%][b]
1	0.5	68
2	1.0	92
5	2.0	81

Table 5.2.6. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 eq), reagent **II** (0.75 mmol, 1.5 eq), **PC** (1.0 mol%), NH_4Cl (0.55 mmol, 1.1 eq), $CoCl_2$ (20 mol%), MeCN (*x* mL). [b]Determined by GC against an internal standard of *n*-decane.

5.2.7. Survey of Reaction Time

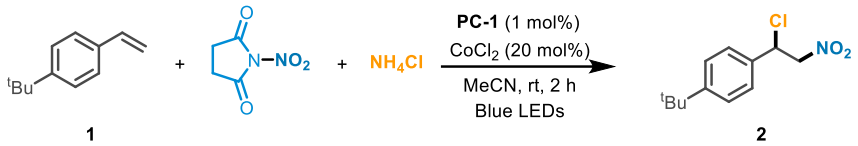


Entry[a]	Reaction Time	Conversion of 1 [%][b]
1	2 h	92

2	30 mins	78

Table 5.2.7. [a]Reaction conditions: 4-*tert*-butylstyrene (0.1 mmol, 1.0 eq), reagent **II** (0.75 mmol, 1.5 eq), **PC-1** (1.0 mol%), NH_4Cl (0.55 mmol, 1.1 eq), $CoCl_2$ (20 mol%), MeCN (0.1 mL). [b]Determined by GC against an internal standard of *n*-decane.

5.2.8. Control Experiments

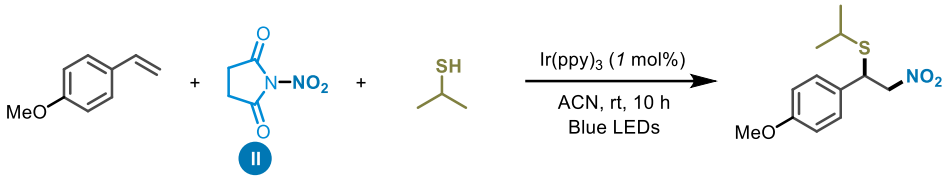


1 2

Entry	Variables	Yield of 2 [%][b]
1	Standard conditions[a]	92 (89)[c]
2	Under air	38
3	Without LEDs	-
4	Without **PC-1**	-
5	Without $CoCl_2$	-
6	Without NH_4Cl	15
7	Heating at 70 ˚C without light	-

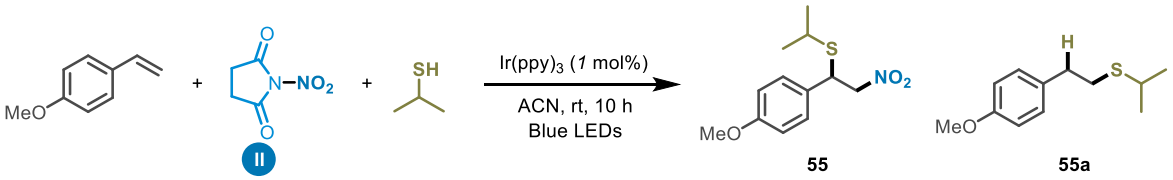
Table 5.2.8. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 eq), reagent **II** (0.75 mmol, 1.5 eq), **PC** (1.0 mol%), $CoCl_2$ (20 mol%), MeCN (0.5 mL). [b]Determined by GC against an internal standard of *n*-decane. [c]Isolated yield.

5.2. **Optimisation of Thionitration**



A flame dried 5 mL crimp cap vial was charged with **PC-1** (*1* mol%), reagent **II** (*1.5* eq), and equipped with a magnetic bar. The contents of the vial were then subject to three vacuum-nitrogen cycles. Anhydrous MeCN (*x* mL), propane-2-thiol (*x* eq), and 4-*tert*-butylstyrene **1** (0.2 mmol, 1.0 eq) were introduced to the solution *via* syringes under nitrogen atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 10 h. After that, *n*-decane as an internal standard was added with a micro syringe. An aliquot was taken and analysed by GC-MS to obtain the calibrated yields for the product.

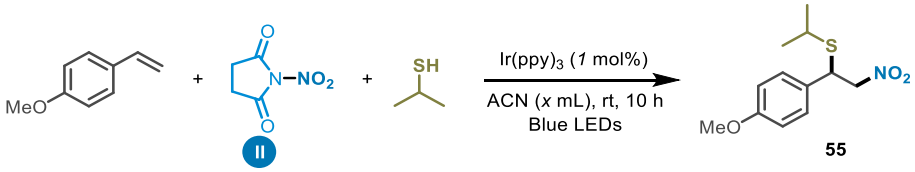
5.3.1. *Survey of Thiol Loading*



Entry[a]	Propane-2-thiol	Yield of 55 [%][b]	Yield of 55a [%][b]
1	1.0 eq	55	traces
2	2.0 eq	91 (86)[c]	traces
3	3.0 eq	65	30
4	4.0 eq	23	75

Table 5.3.1. [a]Reaction conditions: 4-*tert*-butylstyrene (0.2 mmol, 1.0 eq), reagent **II** (0.3 mmol, 1.5 eq), **PC-1** (1.0 mol%), propane-2-thiol (*x* eq), MeCN (0.2 mL). [b]Determined by GC against an internal standard of *n*-decane. [c]Isolated yield.

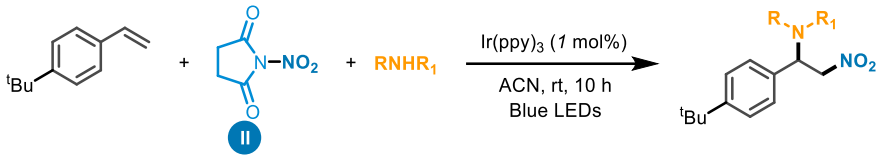
5.3.2. *Concentration Effect*



Entry[a]	Substrate [M]	Yield of 55 [%][b]
1	2.0	89
2	1.0	91 (86)[c]
3	0.5	65
4	0.4	51

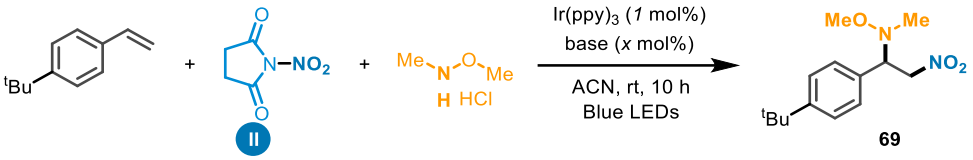
Table 5.3.2. [a]Reaction conditions: 4-*tert*-butylstyrene (0.2 mmol, 1.0 eq), reagent **II** (0.3 mmol, 1.5 eq), **PC-1** (1.0 mol%), propane-2-thiol (0.4 mmol, 2.0 eq), MeCN (*x* mL). [b]Determined by GC against an internal standard of *n*-decane. [c]Isolated yield.

5.3. **Optimisation of Aminonitration**



A flame dried 5 mL crimp cap vial was charged with **PC-1** (*1* mol%), reagent **II** (*1.5* eq), N,O-dimethylhydroxylamine hydrochloride (0.75 mmol, 1.5 eq), base (*x* eq), and equipped with a magnetic bar. The contents of the vial were then subject to three vacuum-nitrogen cycles. Anhydrous MeCN (*x* mL), and 4-*tert*-butylstyrene **1** (0.2 mmol, 1.0 eq) were introduced to the solution *via* syringes under nitrogen atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 10 h. After that, *n*-decane as an internal standard was added with a micro syringe. An aliquot was taken and analysed by GC-MS to obtain the calibrated yields for the product.

5.4.1. **Survey of Bases**

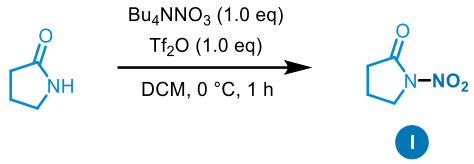


Entry[a]	Base (eq)	Yield of **69** [%][b]
1	Cs_2CO_3 (3)	15
2	Na_2CO_3 (3)	51
3	$NaHCO_3$ (3)	-
4	K_2CO_3 (3)	-
5	$KHCO_3$ (3)	-
6	Na_2CO_3 (2)	85 (81)[c]
7	Na_2CO_3 (1)	57
8	Na_2CO_3 (2)	23[d]
9	Na_2CO_3 (2)	11[e]
10	Na_2CO_3 (2)	20[f]

Table 5.4.1. [a]Reaction conditions: 4-*tert*-butylstyrene **1** (0.5 mmol, 1.0 eq), reagent **II** (0.75 mmol, 1.5 eq), **PC-1** (1.0 mol%), N,O-dimethylhydroxylamine hydrochloride (0.75 mmol, 1.5 eq), base (*x* eq), MeCN (1.0 mL). [b]Determined by GC against an internal standard of *n*-decane. [c]Isolated yield. [d]Acetone as solvent. [e]MeCN (4 mL). [f]N,O-dimethylhydroxylamine hydrochloride (5.0 mmol, 10.0 eq), base (*10* eq).

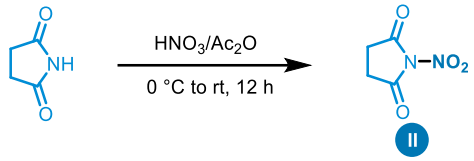
5.5. Synthesis of NO_2-transfer Reagents I-VI

5.5.1. *N*-Nitropyrrolidinone (I)



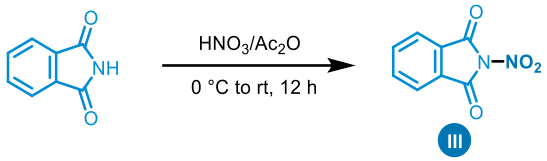
According to previously described procedure, Bu_4NNO_3 1.52 grams (5 mmol) and 30 mL of anhydrous DCM were sequentially introduced into a 100 mL three-necked round bottom flask equipped with a dropping funnel and nitrogen outlet, and the reaction mixture was cooled to 0 °C using an ice bath. The dropping funnel was loaded with 1.411 grams (5 mmol) of triflic anhydride, which was then added dropwise to the reaction mixture over 10 minutes. The final mixture was stirred for an additional one hour at 0 °C. Pyrrolidin-2-one 400 mg (5 mmol) in 10 mL DCM was injected via syringe over a period of 10 minutes, and the reaction mixture was then gradually warmed to room temperature and kept for 12 hours. After completion of the reaction, 25 mL of 5% $NaHCO_3$ was added and stirred for 30 minutes to neutralize the system. Final mixture was extracted with DCM (3×30 mL), the organic solvent was combined and evaporated. The crude was purified by column chromatography on silica gel, yielding 61% of **I** as a yellow solid.

5.5.2. *N*–Nitrosuccinimide (II)



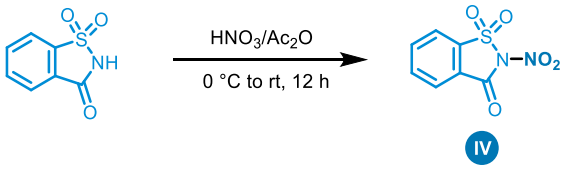
This procedure represents a modification of a previously reported method. A three-necked round-bottom flask 250 mL was equipped with a dropping funnel and a gas outlet connected to a trap containing an aqueous sodium hydroxide solution. The flask was then charged with 15 grams (0.15 mol) of succinimide and 57 mL of acetic anhydride, and the solution was cooled to 0 °C. Fuming nitric acid (98-99%) was slowly introduced via a dropping funnel (the flask was positioned behind a blast shield) over a duration of 20-30 minutes. It should be noted that dry air was rapidly blown through the reaction mixture to eliminate nitrogen oxide emissions. The reaction was subsequently allowed to warm to room temperature and vigorously stirred for 12 hours. Once the reaction was completed, the mixture was cooled again to 0 °C, and a combination of 150 grams of ice and 200 mL of ice-water were incrementally added. This step involved stirring for an additional 15 minutes, resulting in the formation of a white precipitate. The precipitate was separated by filtration, washed with 100 mL of ice-water, and subsequently dried under high vacuum. The overall yield consisted of glistening colourless crystalline plates (12.7 grams, 59% yield).

5.5.3. *N*–Nitrophthalimide (III)



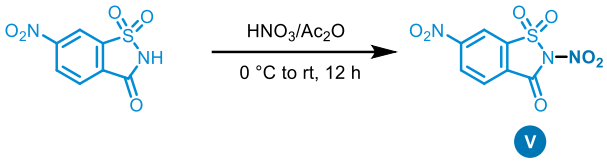
Following the described procedure, 12.5 grams (0.085 mol) of phthalimide and 40 mL of acetic anhydride were introduced to a 250 mL three-necked round-bottom flask, equipped with a dropping funnel and a gas outlet connected to a trap containing an aqueous sodium hydroxide solution. The mixture was then cooled to 0 °C and fuming nitric acid (98-99%) (50 mL) was cautiously added through a dropping funnel, positioned behind a protective blast shield. Off note, that dry air was swiftly passed through the reaction mixture to effectively eliminate any excess of nitrogen oxide. The reaction mixture was allowed to slowly reach room temperature over a span of 12 hours. Upon completion of the reaction, the mixture was transferred to a freezer set at 4 °C for 12 hours. The resulting precipitate was collected and subjected to recrystallization, utilizing chloroform as the solvent. This process yielded *N*-nitrophthalimide as a white solid, achieving a 50% yield (8.16 g).

5.5.4. 2-Nitrobenzo[d]isothiazol-3(2H)-one 1,1-dioxide (IV)



Following the described procedure, into a 250 mL three-necked round-bottom flask, complete with a dropping funnel, an air outlet, and a stirring bar, a solution of 10.0 grams (54.64 mmol) of *N*-saccharin in 25.7 mL of acetic anhydride (0.27 mol) was introduced. The reaction temperature was cooled to 0-5°C using an ice bath. Over a 30-minute duration, fuming concentrated nitric acid (98-99%) (25.1 mL, 0.61 mol) was added dropwise over a period of 30 minutes. Off note, that dry air was swiftly passed through the reaction mixture to effectively eliminate any excess of nitrogen oxide. With the addition of the nitric acid, the *N*-saccharin completely dissolved. Subsequently, the ice bath was removed and stirring was continued at room temperature for a minimum of 4 hours, ensuring that a continuous stream of air passed through the liquid. As the reaction progressed, a precipitate began to form, which was later gathered using a sintered glass filter. The precipitate then underwent meticulous drying under high vacuum until it reached a state of complete dryness, yielding 11.8 grams of final product, constituting a remarkable 95% yield. For further refinement, the material is amenable to purification through recrystallization, a procedure that entails dissolving it in either hot chloroform or acetonitrile. This process yields a final product in the form of a white crystalline compound, poised for subsequent utilization or analysis.

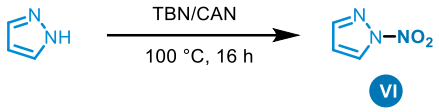
5.5.5. 2,6-dinitrobenzo[d]isothiazol-3(2H)-one 1,1-dioxide (V)



V

Following the described procedure, 10.0 grams (36.63 mmol) of 6-nitrosaccharin and 28.2 mL of acetic anhydride (0.30 mol) were added to a 250 mL three-necked round-bottom flask, equipped with a dropping funnel, an air outlet, and a stirring bar. To achieve the desired reaction temperature 5-10 °C, an ice bath was utilized. Concentrated fuming nitric acid (98-99%) (28.2 mL, 0.67 mol) was added dropwise into the solution over 30 minutes, while ensuring that dry air was rapidly bubbled through the mixture to effectively eliminate any excess nitrogen oxides. The 6-nitrosaccharin completely dissolved once all the nitric acid had been added. Subsequently, the reaction mixture was stirred at the 5-10 °C range for a duration of 4 hours, maintaining a continuous flow of dry air through the liquid. As the reaction proceeded, the solution was placed in a freezer for a period of 10 hours to facilitate the complete precipitation of the product. Following this, the resulting precipitate was collected using a sintered glass filter, washed with cold chloroform, and subjected to a thorough drying process under high vacuum until complete dryness, yielding 9.6 grams of off-white crystalline product (96% yield).

5.5.6. 1-Nitro-1*H*-pyrazole (VI)



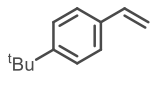
VI

Following the described procedure, pyrazole (3.0 mmol, 1.0 eq), TBN (0.31 g, 3.0 mmol, 1.0 eq), CAN (3.2 g, 6.0 mmol, 2.0 eq), and MeCN (20.0 mL) were added into a tube of a volume of 100 mL under oxygen atmosphere. The tube was hermetically sealed, after which the reaction mixture was heated to 100 °C with vigorous stirring for 16 hours. After completion of the reaction, it was cooled to room temperature and filtered through a thin pad of celite, while washing with ethyl acetate. The combined filtrate was concentrated in vacuo, and the resulting residue was subjected to direct purification by column chromatography on silica gel (petroleum ether (PE) and ethyl acetate (EtOAc) in a 5:1 ratio) yielding the desired product **VI**.

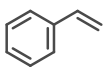
5.6. Availability of Starting Materials

5.6.1. Commercially available starting materials

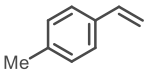
Starting materials which are commercially available are mostly purchased from Apollo Scintific, Sigma Aldrich, Thermoscientific – Acros, TCI and Fluorochem.



CAS 1746-23-2



CAS 100-42-5



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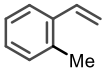

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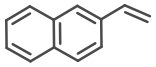

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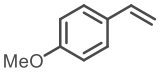

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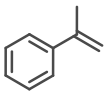
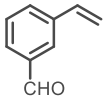


CAS 98-83-9



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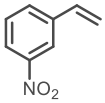
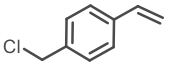


CAS 586-39-0



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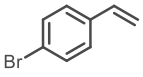

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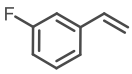

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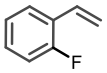

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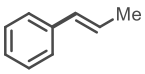
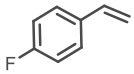


CAS 873-66-5



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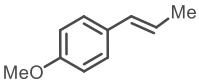

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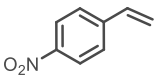
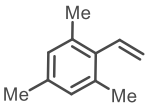


CAS 100-13-0



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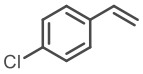

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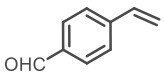

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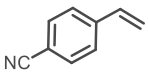

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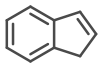

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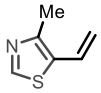

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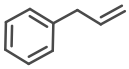

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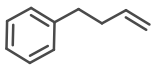

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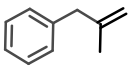

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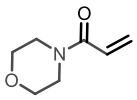

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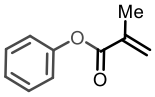

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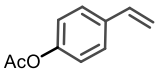

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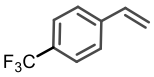
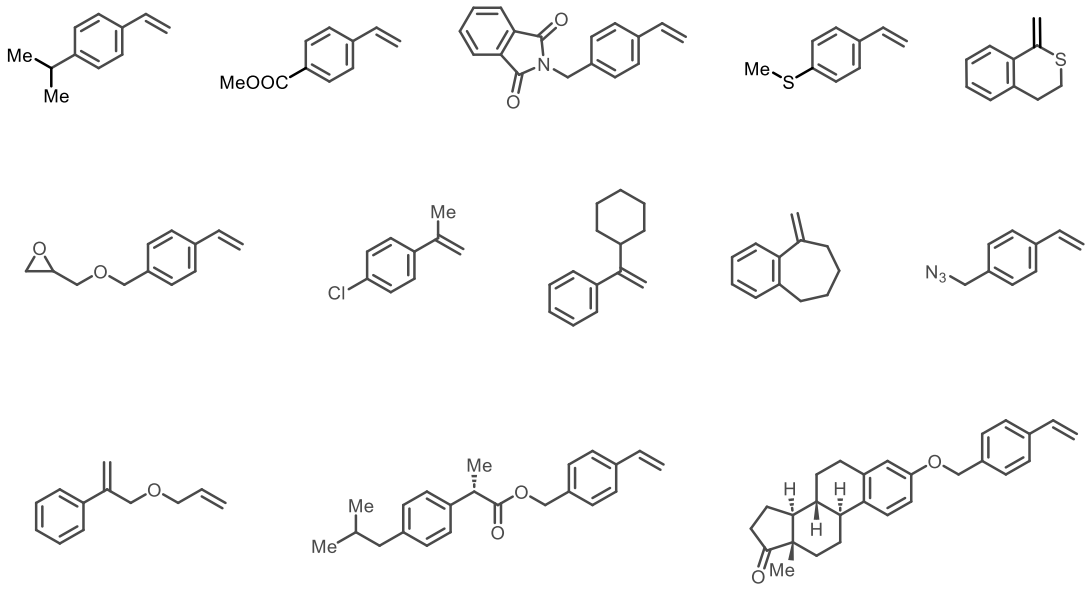


CAS 402-50-6

5.6.2. Prepared starting materials

The following starting materials were prepared according to reported literature procedures.

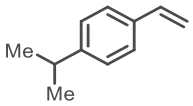


5.6.3. Synthesis of starting materials

General procedure A

Methyltriphenylphosphonium bromide (3 eq) was suspended in dry tetrahydrofuran (THF) at a concentration of 0.2 M and chilled to 0°C. In one step, *tert*-BuOK (3 eq) was introduced, and the reaction mixture was stirred at 0°C for 30 minutes. Subsequently, the ketone or aldehyde (1 eq) was added, and the reaction was allowed to warm to room temperature (RT), continuing to stir until completion was confirmed by thin-layer chromatography (TLC) (a period ranging from 2 to 16 hours). The reaction was terminated by the addition of water and subjected to extraction with ethyl acetate (EtOAc) in three portions of 50 mL each. The combined organic layers were further washed with water, dried using sodium sulfate (Na_2SO_4), filtered, and concentrated under reduced pressure. The resulting crude product underwent purification through flash column chromatography on silica gel, affording the pure alkene.

1-isopropyl-4-vinylbenzene (A1)

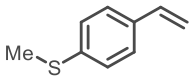


The titled compound was obtained as light-yellow oil (85% yield, 5% ethyl acetate in hexane as eluent) according to a general procedure A. The characterisation data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.35 (d, *J* = 8.1 Hz, 2H), 7.20 (d, *J* = 8.2 Hz, 2H), 6.71 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.71 (dd, *J* = 17.6, 1.0 Hz, 1H), 5.20 (dd, *J* = 10.9, 1.0 Hz, 1H), 2.91 (p, *J* = 6.9 Hz, 1H), 1.27 (s, 3H), 1.25 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 148.8, 136.9, 135.4, 126.7, 126.3, 113.0, 34.0, 24.1.

Methyl(4-vinylphenyl)sulfane (A2)

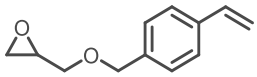


The titled compound was obtained as yellow oil (78% yield, 5% ethyl acetate in hexane as eluent) according to a general procedure A. The characterisation data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.34 (d, *J* = 8.3 Hz, 2H), 7.22 (d, *J* = 8.4 Hz, 2H), 6.67 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.71 (dd, *J* = 17.6, 0.9 Hz, 1H), 5.21 (dd, *J* = 10.9, 0.9 Hz, 1H), 2.49 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.1, 136.3, 134.7, 126.8, 126.7, 113.4, 16.0.

2-(((4-Vinylbenzyl)oxy)methyl)oxirane (A3)

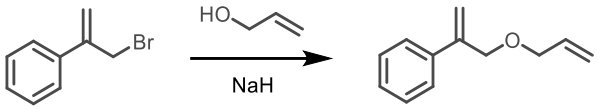


Sodium hydride (60% in mineral oil, 50.0 mmol, 2.00 eq) was dispersed in 50 mL of dimethylformamide (DMF). Then, glycidol (62.5 mmol, 2.5 eq) and 1-(chloromethyl)-4-vinylbenzene (25.0 mmol, 1.00 eq) were introduced at 0 °C. After an additional 4 hours of stirring, the mixture was diluted with 60 mL of ethyl acetate. To quench the reaction, saturated aqueous ammonium chloride was added, and the aqueous layer was subsequently extracted with ethyl acetate (3 x 100 mL). The combined organic layers were dried using sodium sulphate, and the solvent was removed under vacuum. The resulting residue underwent purification via flash chromatography, yielding 4-Vinylbenzyl glycidyl ether (81% yield). The characterisation data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.40 (d, *J* = 8.2 Hz, 2H), 7.31 (d, *J* = 8.2 Hz, 2H), 6.72 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.75 (dd, *J* = 17.6, 0.9 Hz, 1H), 5.24 (dd, *J* = 10.9, 0.9 Hz, 1H), 4.57 (q, *J* = 12.0 Hz, 2H), 3.76 (dd, *J* = 11.4, 3.0 Hz, 1H), 3.43 (dd, *J* = 11.4, 5.9 Hz, 1H), 3.18 (ddt, *J* = 5.7, 4.2, 2.8 Hz, 1H), 2.80 (dd, *J* = 5.0, 4.1 Hz, 1H), 2.61 (dd, *J* = 5.0, 2.7 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 137.6, 137.2, 136.6, 128.0, 126.4, 114.0, 73.1, 70.9, 50.9, 44.3.

(3-(allyloxy)prop-1-en-2-yl)benzene (A4)



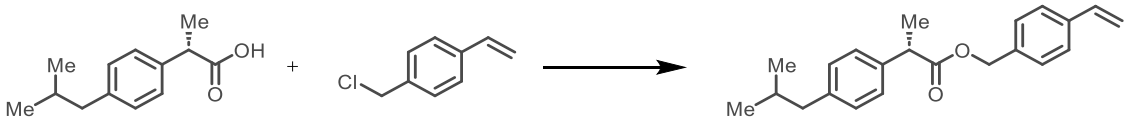
At 0°C, sodium hydride (60% suspension in oil, 6.0 mmol, 1.0 eq) was introduced to a stirred solution of allylic alcohol (6.0 mmol, 1.0 eq) in 12 ml of tetrahydrofuran (THF). The reaction was allowed to gradually reach room temperature, and then, a solution of 3-bromo-2-phenyl-1-propene (6.0 mmol, 1.0 eq) in 6 ml of THF was added dropwise to the reaction mixture. After stirring for 6 hours, the resulting mixture was subjected to hydrolysis using 16 ml saturated solution of ammonium chloride, followed by extraction with diethyl ether (3 × 10 ml). The organic layers were subsequently dried with magnesium sulphate, filtered, and concentrated under vacuum. The titled compound was isolated as colourless oil

(65% yield) after purification by flash column chromatography on silica (hexane/EA=20:1). The characterisation data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.52 – 7.43 (m, 2H), 7.39 – 7.28 (m, 3H), 5.95 (ddt, *J* = 17.2, 10.3, 5.6 Hz, 1H), 5.61 – 5.14 (m, 4H), 4.39 (dd, *J* = 1.4, 0.7 Hz, 2H), 4.06 (dt, *J* = 5.6, 1.4 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 144.4, 139.0, 134.9, 128.5, 127.9, 126.2, 117.3, 114.4, 72.1, 71.2.

4-vinylbenzyl (*S*)-2-(4-isobutylphenyl)propanoate (A5)

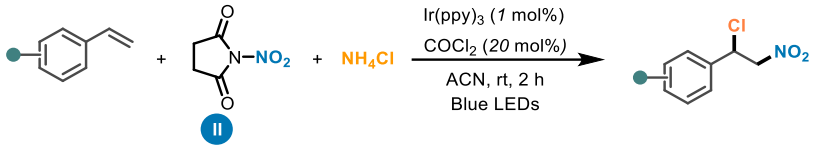


Following the described procedure, (S)-(+)-Ibuprofen (3 mmol) was dissolved in 10 mL of DMF. A mixture consisting of K_2CO_3 (621 mg, 4.5 mmol) and KI (747 mg, 4.5 mmol) was then added to the solution and the mixture was vigorously stirred. To this stirring suspension, 4-vinylbenzyl chloride (503.4 mg, 3.3 mmol) was introduced, and the mixture was allowed to stir for 12 hours at room temperature. Upon the completion of the reaction, a solution of 20 mL of ethyl acetate (EtOAc) and 12 mL of water was added. Subsequently, the mixture underwent extraction and was washed three times with water. The combined organic phases were then dried over anhydrous Na_2SO_4, and the solvent was removed under vacuum. To refine the product, a flash column chromatography was employed, utilizing a 5% EtOAc/PE (petroleum ether) mixture as the eluent. This purification process yielded the product A5 as a colourless oil.

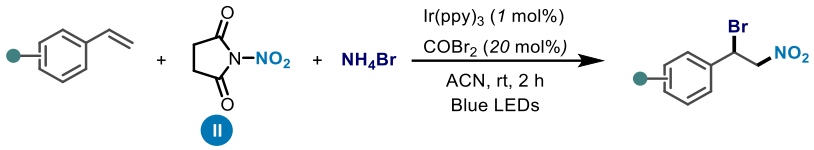
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.23 (d, *J* = 8.2 Hz, 2H), 7.14 – 7.04 (m, 4H), 6.99 (d, *J* = 8.1 Hz, 2H), 6.59 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.63 (dd, *J* = 17.6, 1.0 Hz, 1H), 5.14 (dd, *J* = 10.9, 0.9 Hz, 1H), 4.99 (s, 2H), 3.65 (q, *J* = 7.2 Hz, 1H), 2.36 (d, *J* = 7.2 Hz, 2H), 1.76 (dp, *J* = 13.5, 6.7 Hz, 1H), 1.41 (d, *J* = 7.2 Hz, 3H), 0.81 (d, *J* = 6.6 Hz, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 174.6, 140.7, 137.7, 137.5, 136.5, 135.7, 129.4, 128.1, 127.3, 126.4, 114.2, 66.1, 45.3, 45.1, 30.3, 22.5, 18.5.

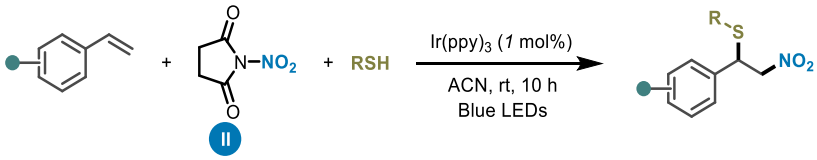
5.7. General Procedures for the Nitrative Difunctionalization



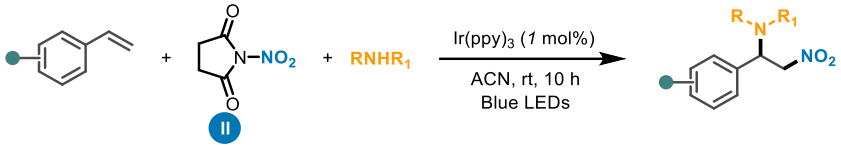
GP 1: A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), NH_4Cl (29.0 mg, 0.55 mmol, 1.1 eq), $CoCl_2$ (13.0 mg, 0.10 mmol, 0.2 eq) and equipped with a magnetic bar. The vial was then subject to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene[a] (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 2 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography.



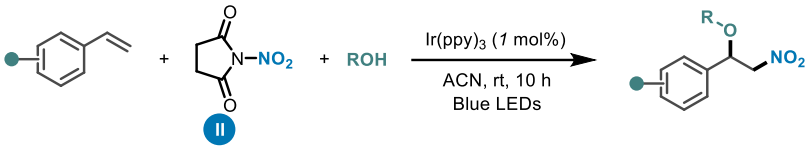
GP 2: A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), NH_4Br (54.0 mg, 0.55 mmol, 1.1 eq), $CoBr_2$ (22.0 mg, 0.10 mmol, 0.2 eq) and equipped with a magnetic bar. The vial was then subject to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene[a] (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 2 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography.



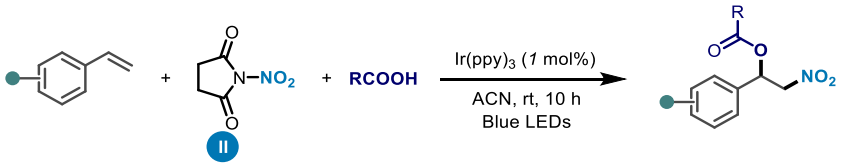
GP 3: A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), and equipped with a magnetic bar. The vial was then subject to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) and thioalcohol (1.5 mmol, 3.0 eq) were added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene[a] (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 10 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography.



GP 4: A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), amine (1.5 mmol, 3.0 eq), Na_2CO_3 (1.5 mmol, 3.0 eq) and equipped with a magnetic bar. The vial was then subject to three vacuum-nitrogen cycles. Anhydrous ACN (1.0 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene[a] (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 10 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography.



GP 5: A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), and equipped with a magnetic bar. The vial was then subject to three vacuum-nitrogen cycles. Anhydrous ACN (1.0 mL) and alcohol (1.5 mmol, 3.0 eq) were added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene[a] (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 10 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography.



GP 6: A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 mol, 1 mol%) and equipped with a magnetic bar. The vial was then subject to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) and carboxylic acid (1.5 mmol, 3.0 eq) were added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene[a] (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 10 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography.

[a] The solid substrates were added to the vial prior to vacuum/argon cycling.

5.8. Mechanistic Investigations

5.8.1 Stern-Volmer quenching studies

To investigate the dynamics of the excited state in more detail, Stern-Volmer quenching studies were carried out. The quenching efficiency can be defined as the following which has been deduced by Stern and Volmer.

$(I_0 \div I) - 1 = k_q \tau_0$ [quencher]

Where I_0 is the luminescence intensity in the absence of any quencher, I is the luminescence intensity in the presence of a predefined quencher concentration while τ_0 is the excited state lifetime of photocatalyst which has been previously reported as 1.90 x 10^{-6} s for *fac*-[Ir(ppy)$_3$] in acetonitrile at 25 °C.

Preparation of stock solutions for Stern-Volmer measurements

A stock solution of photocatalyst was prepared by dissolving *fac*-Ir(ppy)$_3$ (0.33 mg, 0.499 µmol, 50 µM) in oxygen- and water-free acetonitrile (10 mL) under argon. A stock solution of *N*-Nitrosuccinimide was prepared by dissolving 36.5 mg (25.4 µmol, 25.0 mM) compound in 10 mL acetonitrile. A stock solution of Anh. $CoCl_2$ was prepared by dissolving 32.8 mg (25.4 µmol, 25.0 mM) compound in 10 mL acetonitrile. A stock solution of 4-*tert*-butylstyrene was prepared by dissolving 34 µL (24.0 µmol, 24.0 mM) in 10 mL acetonitrile.

For evaluation of the quenching ability of *N*-Nitrosuccinimide and 4-*tert*-butylstyrenerene, samples of *fac*-[Ir(ppy)$_3$] and the reagent were prepared under argon in dark. Quartz cuvettes (3.5 mL, 10 mm x 4 mm, PTFE cap) were filled with photocatalyst stock solution (0.5 mL), the relevant amount of the reagent stock solution (or pure reagent), and acetonitrile to obtain a total volume of 1.5 mL. The samples were further put into a secondary container (Schott wide screw cap bottle or a screwcap Falcon). All samples have been kept in the dark and were only taken out of the secondary container directly before mounting the samples on the spectrometer under the exclusion of light. Fluorescence Emission spectra were acquired as fast as possible after sample preparation (excitation at 430 ± 2 nm, 1 nm steps, excitation slit, and emission slit: 2 nm).

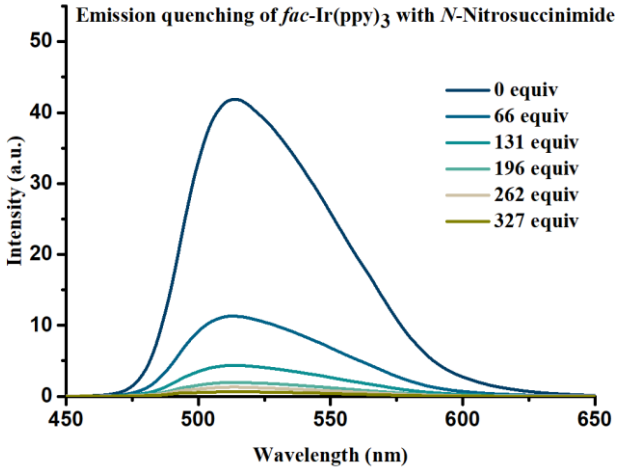


Figure 5.8.1.1. Emission quenching of *fac*-[Ir(ppy)$_3$] with *N*-Nitrosuccinimide in acetonitrile (acetonitrile, 50 µM *fac*-[Ir(ppy)$_3$]. 20 °C, d_{em} = 2 nm, d_{ex} = 2 nm, λ_{ex} = 430 nm).

First, the influence on the emission of the catalyst by *N*-Nitrosuccinimide was investigated. The emission quenching data clearly show that quenching of the excited state of the catalyst by *N*-Nitrosuccinimide is highly efficient and happening with a calculated quenching constant of $k_q = 7.0 \times 10^8$ $M^{-1}s^{-1}$ (Figures 8.1.1 and 8.1.2). Calculation of the quenching constants was performed for *N*-Nitrosuccinimide according to the following equation:

$(I_0 \div I) - 1 = k_q \tau_0$ [quencher]

Where $\tau_0 = 1.90 \times 10^{-6}$ s

Thus $k_q \tau_0 = 1351$

$k_q = 7 \times 10^8$ M^{-1} s^{-1}

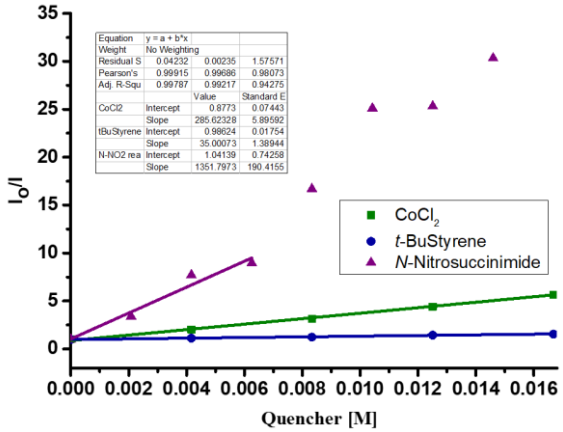


Figure 5.8.1.2. Correlation between emission intensity and concentration of *N*-Nitrosuccinimide **II,** $CoCl_2$ and styrene

Next, the same quenching experiment was carried out in the presence of 4-*tert*-butylstyrenerene and $CoCl_2$ as a quencher. In the presence of these substrates, a weak level of quenching of the excited state of the catalyst was observed when compared with the efficient quenching of *N*-Nitrosuccinimide (Figure 8.1.3).

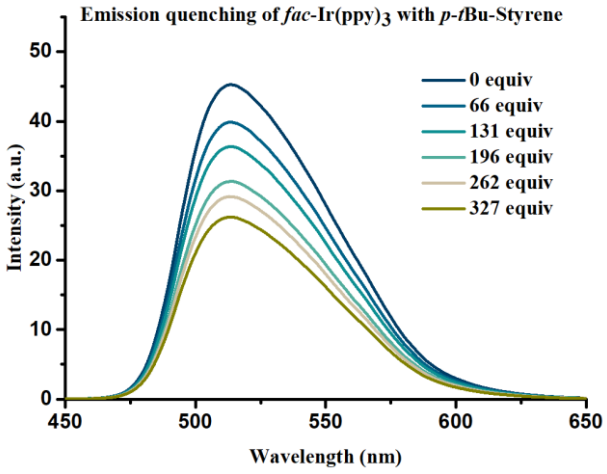


Figure 5.8.1.3. Emission quenching of *fac*-[$Ir(ppy)_3$] with 4-*tert*-butylstyrene **1** in acetonitrile (acetonitrile, 50 µM *fac*-[$Ir(ppy)_3$]. 20°C, d_{em} = 2 nm, d_{ex} = 2 nm, λ_{ex} = 430 nm).

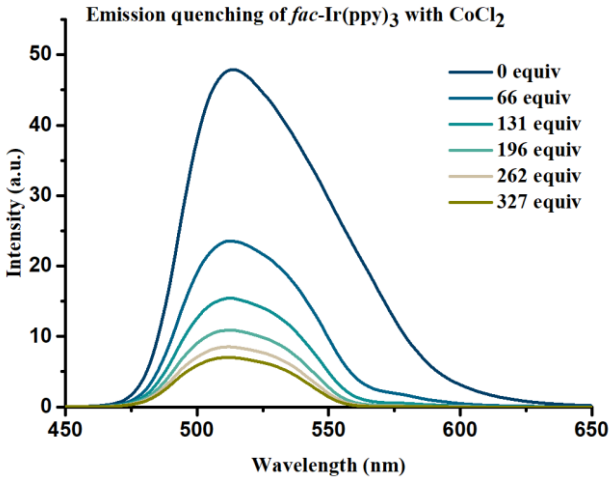
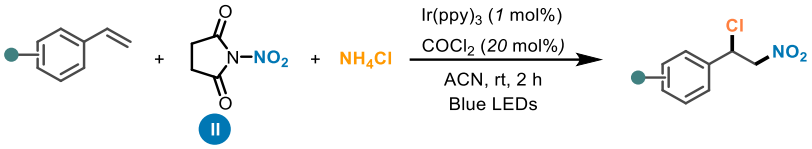


Figure 5.8.1.4. Emission quenching of *fac*-[Ir(ppy)$_3$] with $CoCl_2$ in acetonitrile (acetonitrile, 50 µM *fac*-[Ir(ppy)$_3$].

5.8.2. Light ON-OFF experiment



A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), NH_4Cl (29.0 mg, 0.55 mmol, 1.1 eq), $CoCl_2$ (13.0 mg, 0.10 mmol, 0.2 eq). The vial was then subjected to three vacuum-nitrogen cycles. Anhydrous MeCN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The 4-*tert*-butyl styrene **1** (0.5 mmol, 1.0 eq) was introduced to the solution via a micro syringe. The reaction mixture was stirred under 350 W blue LEDs irradiation for the indicated time at room temperature and samples were analyzed by GC-MS (Figure 8.2.1).

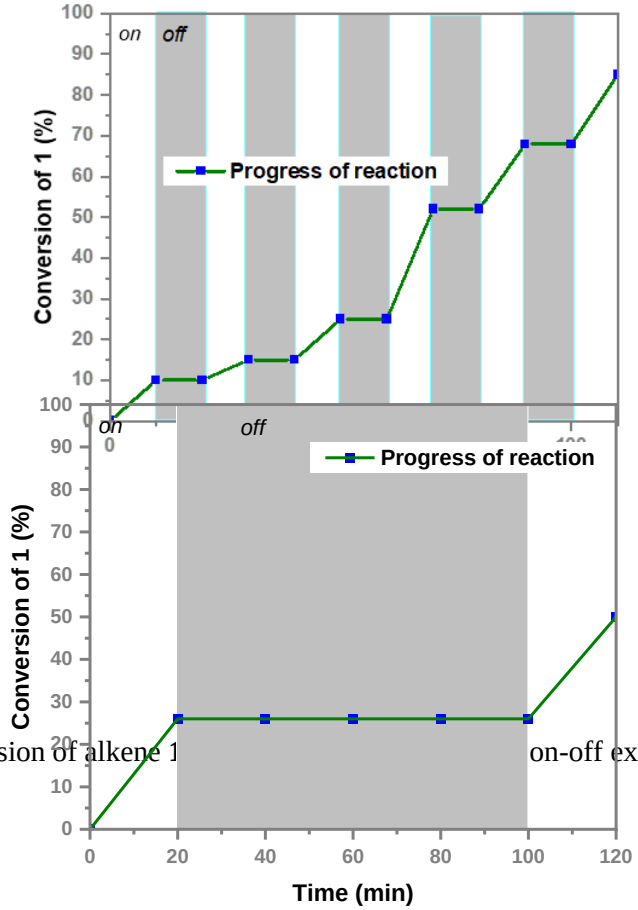
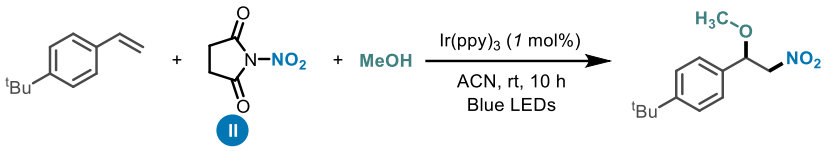


Figure 5.8.2.1. Conversion of alkene 1 on-off experiment.



A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 μmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), and equipped with a magnetic bar. The vial was then subject to three vacuum-nitrogen cycles. Anhydrous ACN (1.0 mL) and methanol (1.5 mmol, 3.0 eq) were added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene **1** (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under 350 W blue LEDs irradiation for the indicated time at room temperature and the samples were analyzed by GC-MS (Figure 8.2.2).

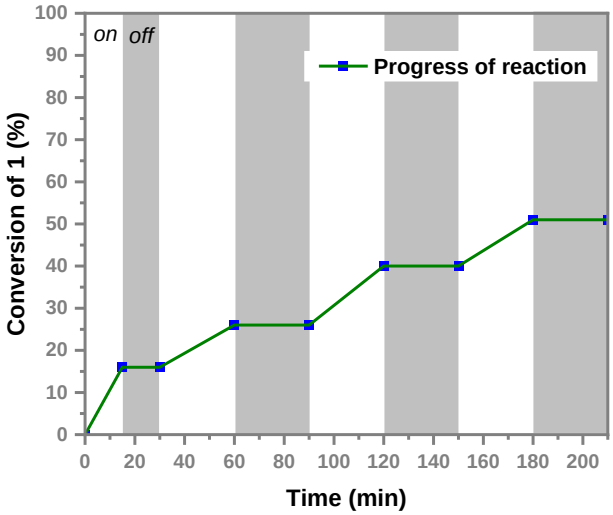


Figure 5.8.2.2. Conversion of alkene **1** vs reaction time for the light on-off experiment.

Under the influence of blue LED irradiation, the reaction proceeded seamlessly. However, in the absence of blue LED light, the reaction stopped. This result strongly indicates that the reaction follows a photoredox catalytic pathway rather than via radical chain propagation.

5.8.3. Cyclic voltammetry

NBu_4PF_6 5.81 g (15.0 mmol, 0.1 M) was dissolved in 150 mL anhydrous acetonitrile in a volumetric flask and the solution was degassed for 20 min with Ar. For each measurement, 10 mL of the solution was taken to the cell and analyte was added. The resulting solution was stirred for 1 min to ensure homogeneity. Before each measurement, the solution was purged with Ar and the glassy carbon electrode was rotated to homogenize the probe solution. During the measurement, the solution was protected by a positive Ar stream.

The cyclovoltammetry setup was built from a Pt-counter electrode and Ag^+ (0.01 M $AgNO_3$ in 0.1 M NBu_4PF_6)/Ag reference electrode. The working electrode was chosen as Pt disc electrode (2 mm diameter). A short introduction to cyclic voltammetry was taken from the following references. Generally, a scan rate of 100 mV/s was applied to measure the reaction components. However, more detailed measurements using scan rates, ranging from 50 mV/s to 400mV/s were also carried out.

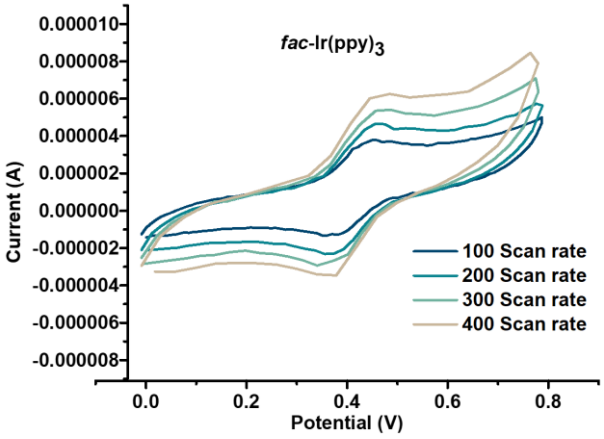


Figure 5.8.3.1. Cyclic voltammogram of *fac*-[$Ir(ppy)_3$] (3.3 mg, 0.005 mmol), recorded in 10 mL 0.1 M NBu_4PF_6 MeCN solution at different scan rates. The cyclovoltammetry setup was built from a Pt-counter electrode and an Ag^+/Ag (0.01 M) reference electrode. The working electrode was chosen as Pt electrode (2 mm diameter).

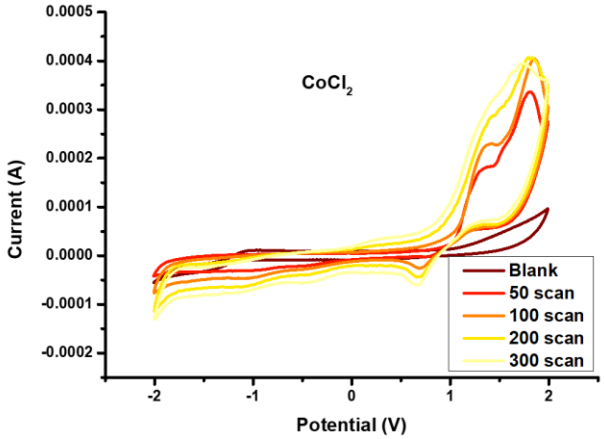


Figure 5.8.3.2. Cyclic voltammogram of $CoCl_2$ (12.9 mg, 0.1 mmol), recorded in 10 mL 0.1 M NBu_4PF_6 MeCN solution at different scan rates. The cyclovoltammetry setup was built from a Pt-counter electrode

and an Ag^+/Ag (0.01 M) reference electrode. The working electrode was chosen as Pt electrode (2 mm diameter).

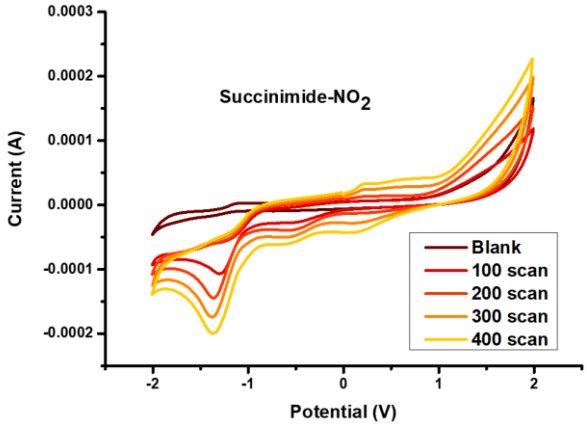


Figure 5.8.3.3. Cyclic voltammogram of *N*-Nitrosuccinimide **II** (14.4 mg, 0.1 mmol), recorded in 10 mL 0.1 M NBu_4PF_6 MeCN solution at different scan rates. The cyclovoltammetry setup was built from a Pt-counter electrode and an Ag^+/Ag (0.01 M) reference electrode. The working electrode was chosen as Pt electrode (2 mm diameter).

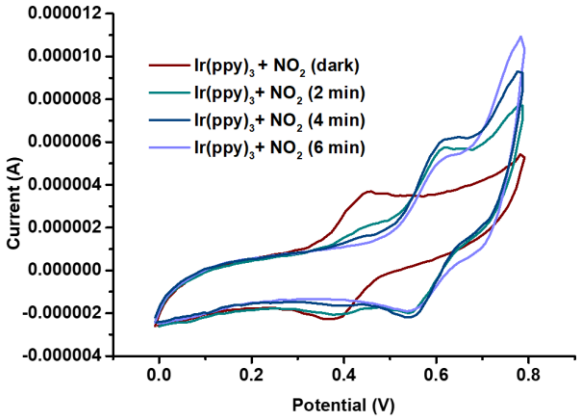


Figure 5.8.3.4. Cyclic voltammogram of *fac*-[Ir(ppy)$_3$] (5.5 mg, 0.008 mmol) and *N*-Nitrosuccinimide **II** (NO_2, 0.1 mmol) in 10 mL 0.1 M NBu_4PF_6 MeCN solution was recorded for the specified time period, and the solution was irradiated with 350 W Blue LEDs. The cyclovoltammetry setup was built from a Pt-counter electrode and an Ag^+/Ag (0.01 M) reference electrode. The working electrode was chosen as Pt electrode (2 mm diameter).

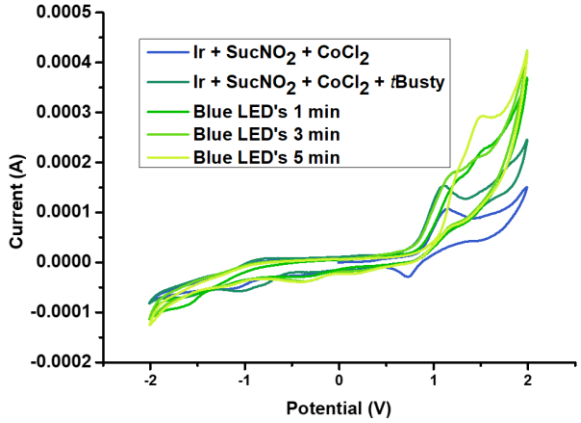


Figure 5.8.3.4. Cyclic voltammogram of reaction mixture containing *fac*-[Ir(ppy)$_3$] (5.5 mg, 0.008 mmol), *N*-Nitrosuccinimide **II** ($SucNO_2$, 14.4 mg, 0.1 mmol), $CoCl_2$ (12.9 mg, 0.1 mmol) and *t*Busty **1**

(16 mg, 0.1 mmol) in 10 mL 0.1 M NBu_4PF_6 MeCN solution was recorded for the specified time period, and the solution was irradiated with 350 W Blue LEDs. The cyclovoltammetry setup was built from a Pt-counter electrode and an Ag^+/Ag (0.01 M) reference electrode. The working electrode was chosen as Pt electrode (2 mm diameter).

5.8.4. Quantum yield measurements

Procedure: In a glovebox, a flame-dried 5 mL crimp cap vial containing a stir bar was prepared. The vial was charged with *fac*-Ir(ppy)$_3$ (0.7 mg, 1 µmol, 1 mol%), nitrating reagent **II** (23 mg, 0.16 mmol, 0.15 eq), NH_4Cl (6.2 mg, 0.12 mmol, 1.1 eq), and $CoCl_2$ (1.5 mg, 0.10 mmol, 0.1 eq). The vial was sealed with a crimp cap, taken out of the glovebox, and then anhydrous pre-degassed MeCN (5 mL) and styrene (17 µL, 0.11 mmol, 0.1 eq) were added using a syringe.

The resulting mixture was transferred to a standard 1 cm quartz cuvette with a stirring bar, set up on a custom-built irradiation device assembled using components provided by ThorLabs (refer to Figure 8.4.1). The device was equipped with a diode emitting light at a wavelength of 455 nm (ThorLabs M455F3).

The photon flux (f) of the diode was calibrated using a Pyroelectric Energy Sensor (Thorlabs ES120C) and measured to be 1.4 x 10^{-7} Einstein s^{-1} (equivalent to 3.75 mW). The reaction mixture was irradiated, and absorbance spectra were recorded at specific time intervals. The conversion of the starting material was assessed through absorption changes at 616 nm, corresponding to the consumption of $CoCl_2$. The absorbance of the solution irradiated for 15.3 hours was considered the point of full conversion (as shown in Figure 8.4.2).

Result: The quantum yield was calculated as slope in coordinates (conversion to f*time). The determined quantum yield for the reaction was **Φ = 0.02.**

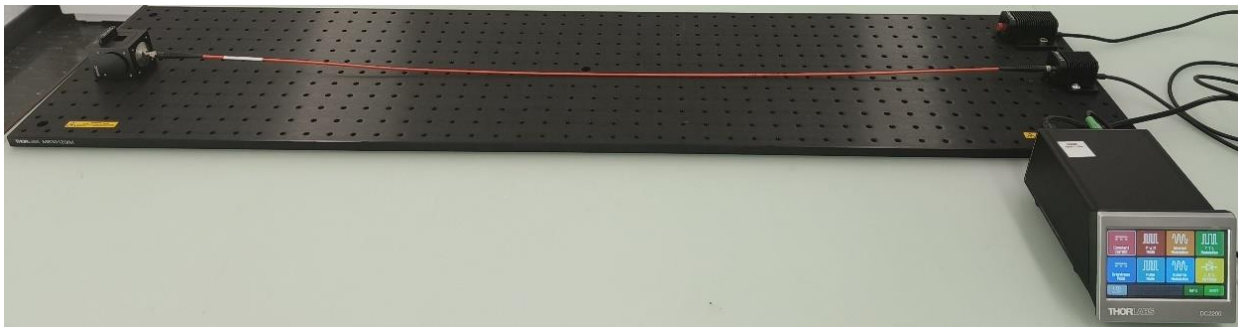


Figure 5.8.4.1. Setup for the measurement of quantum yield.

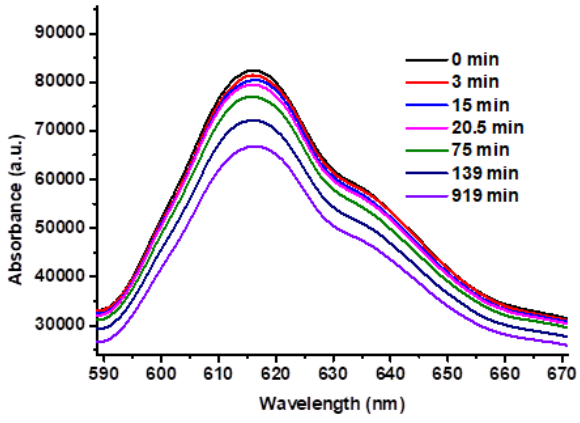


Figure 5.8.4.2. Relative absorbance changes over the course of irradiation.

5.8.5. UV-Vis studies

For a more detailed understanding of the reaction mechanism, its further investigation was carried out by absorption spectroscopy in the UV-Vis region. Therefore, the absorption spectra of the starting substances in acetonitrile were measured first (Fig. 8.5.1).

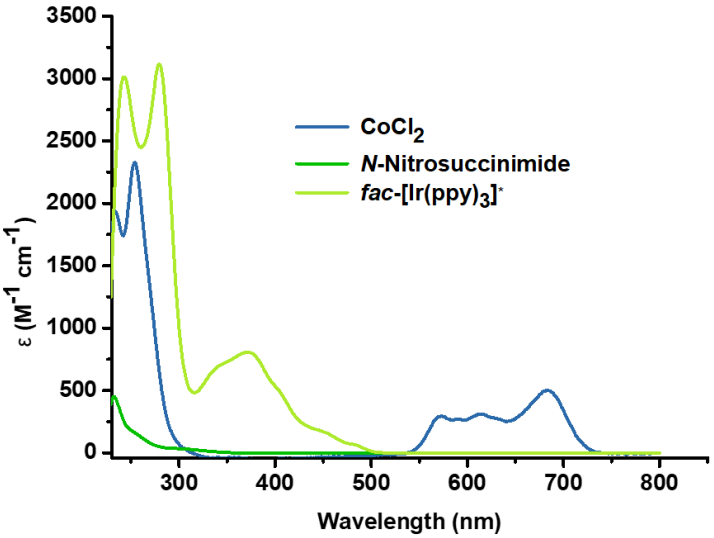


Figure 5.8.5.1. UV-Vis spectra of starting materials in MeCN. *Note: extinction coefficients for *fac*-[Ir(ppy)$_3$] is divided by 10 for representation reasons.

For further monitoring and analysis of the reaction components, several solutions of mixed starting substances were prepared in UV-Vis cuvettes with screw cap under argon. During irradiation, the progress of the reaction was observed, and it can be seen that the absorbance changes over time as the reaction proceeds.

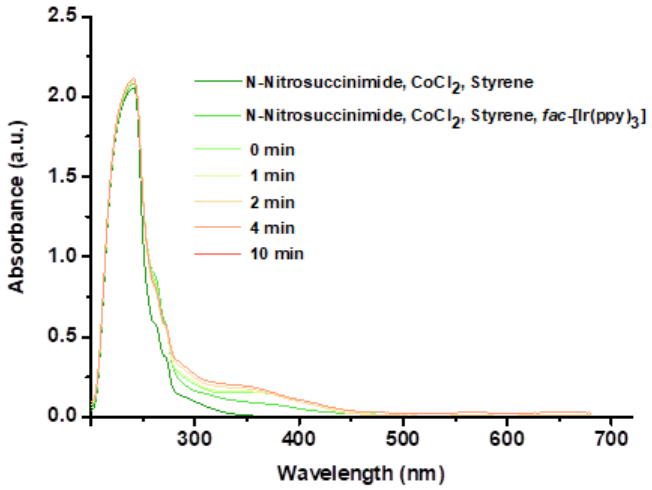


Figure 5.8.5.2. UV-Vis spectra of solution of *fac*-[Ir(ppy)$_3$], CDFAA and 4-*tert*-bustylstyrene in MeCN (0.032, 0.064 and 0.064 mM respectively) in MeCN upon irradiation in the photoreactor.

5.8.6. Hammett studies

The radical nature of initial addition of reactive species to the olefin was also indicated by Hammett studies The experiments were performed in accordance with the method described by the method described by Harper and co-workers and coworkers. To determine the feasibility of using GC-MS techniques in these experiments, stepwise additions of each styrene derivative in MeCN with *n*-decane were used to determine the signal resolution on GC-MS for the corresponding peaks. There was no substantial overlap between the signals of all components of the reaction mixture. A round flame-dried vial 8 mL was charged with *fac*-[Ir(ppy)$_3$] (1.0 mol%, 3.3 mg, 0.005 mmol) and the vial was sealed under argon atmosphere. It was further subjected to 3 argon/vacuum cycles. Anhydrous MeCN (4 mL) was added under Ar. Finally, five styrene derivatives (0.1 mmol *p*-tBu, 0.1 mmol *p*-H, 0.1 mmol *p*-F, 0.1 mmol *p*-Cl, 0.1 mmol *p*-CF_3) (total amount of styrene derivatives = 0.5 mmol), *N*-Nitrosuccinimide reagent (1.5 eq, 0.75 mmol, 108 mg), NH_4Cl (29.0 mg, 0.55 mmol, 1.1 eq), $CoCl_2$ (13.0 mg, 0.10 mmol, 0.2 eq). and *n*-decane (0.1 mmol, 12 μL) were subsequently introduced to the reaction mixture *via* microsyringe. The obtained yellow solution was irradiated at room temperature (440 nm) over 35 min. The amount of the corresponding styrenes were determined by GC-MS analysis with respect to *n*-decane.

Data analysis for *para*-substituted styrene derivatives

Name	T_{peak} (GC-MS)	Initial area (S_o)	Final area (S)	S/S_o	$\ln_{(S/S0)}$	$\ln(S/S_0)/\ln(S_H/S_{H_0}) = K_{rel}$	log10 (K_{rel})	σ_{para}
t-Bu	7.24	51753837	3326293	0.064271428	-2.74464	1.800996	-0.2	0.255513
H	4.22	19398879	4226010	0.217848155	-1.52396	1	0	0
F	4.28	18418145	5287002	0.287053989	-1.24808	0.818976	0.06	-0.08673
Cl	6.03	28096290	9530352	0.339203219	-1.08116	0.70944	0.22	-0.14908
CF_3	4.55	28274923	13750662	0.486320051	-0.72089	0.473037	0.54	-0.3251

Table 5.8.6. Relative rate constants determined from the relative integrations of GC-MS diagrams for the competitive *chloronitration* reactions between various *para*-substituted styrene, *N*-Nitrosuccinimide, and $CoCl_2$ under general photoredox reaction condition **GP1**.

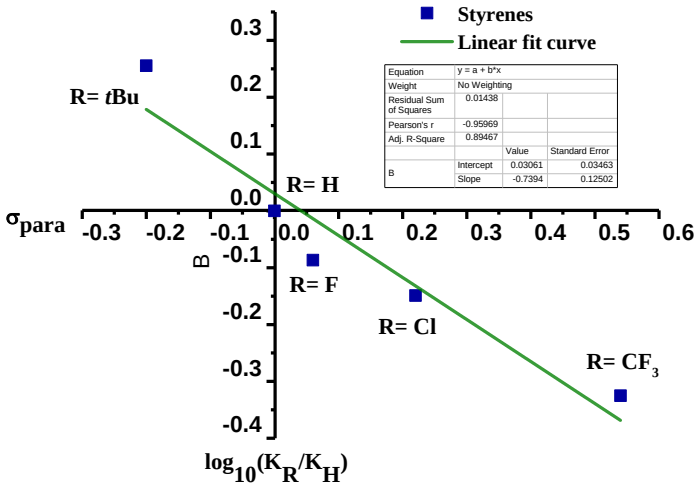
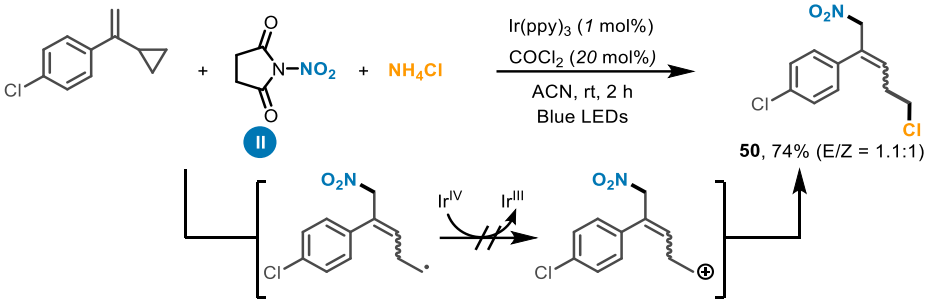


Figure 5.8.6.1. Values of $\log_{10}(K_R/K_H)$ vs σ_x for the *cholonitration* reaction of styrenes using *N*-Nitrosuccinimide **II**.

5.8.7. Radical clock experiment



A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), NH_4Cl (29.0 mg, 0.55 mmol, 1.1 eq), $CoCl_2$ (13.0 mg, 0.10 mmol, 0.2 eq), and equipped with a magnetic bar. The vial was then subjected to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene 1-chloro-4-(1-cyclopropylvinyl)benzene (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LED irradiation at room temperature for 2 h. The crude product was analysed by NMR.

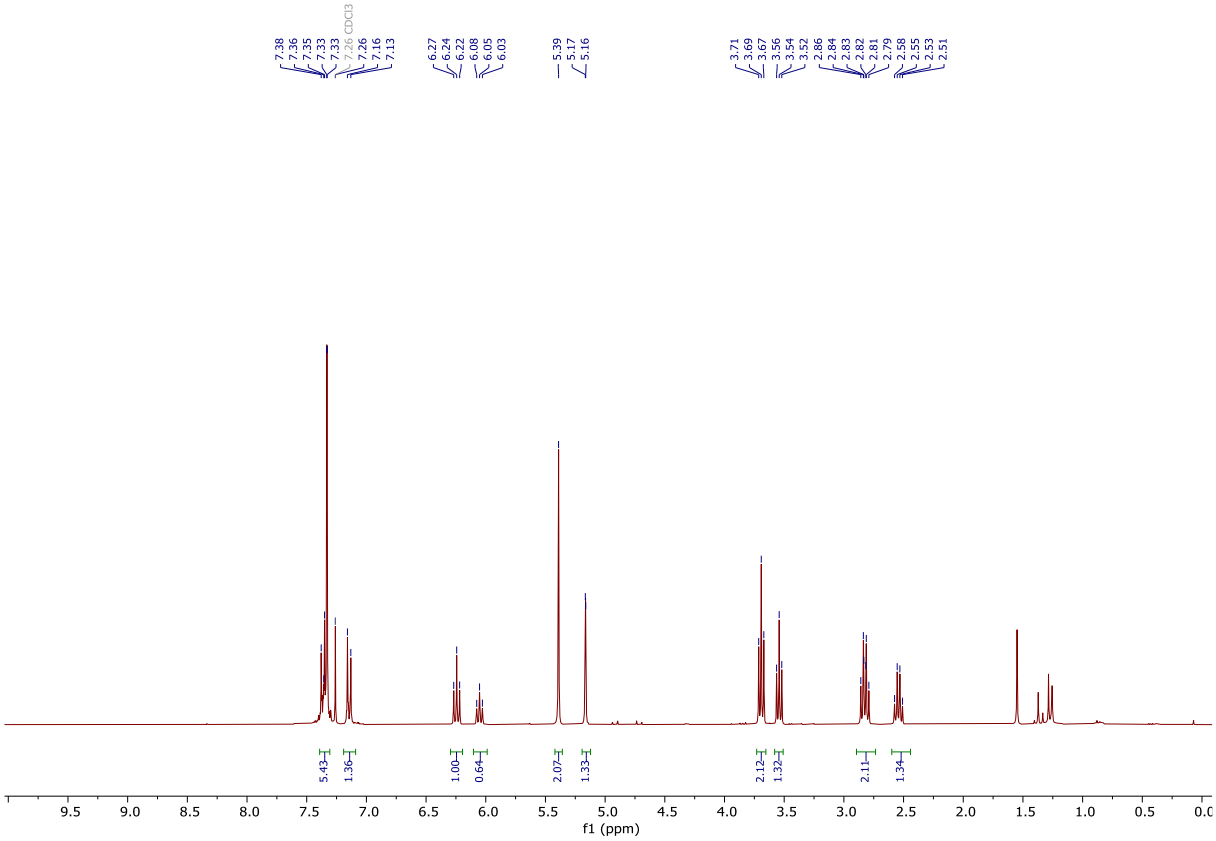
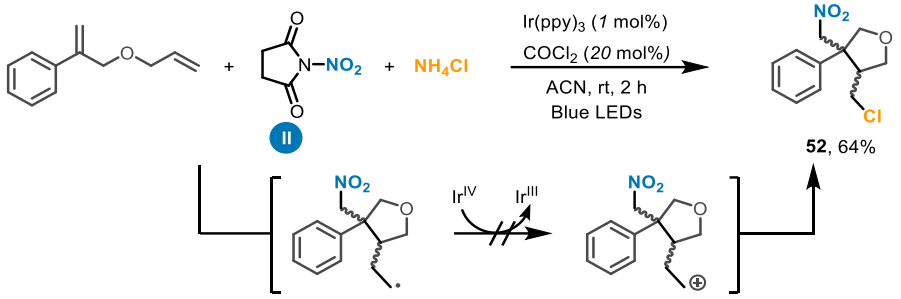


Figure 5.8.7.1. Crude ^1H-NMR of **50**.



A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), NH_4Cl (29.0 mg, 0.55 mmol, 1.1 eq), $CoCl_2$ (13.0 mg, 0.10 mmol, 0.2 eq), and equipped with a magnetic bar. The vial was then subjected to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene (3-(allyloxy)prop-1-en-2-yl)benzene (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 2 h. Crude product was analysed by GC-MS and NMR.

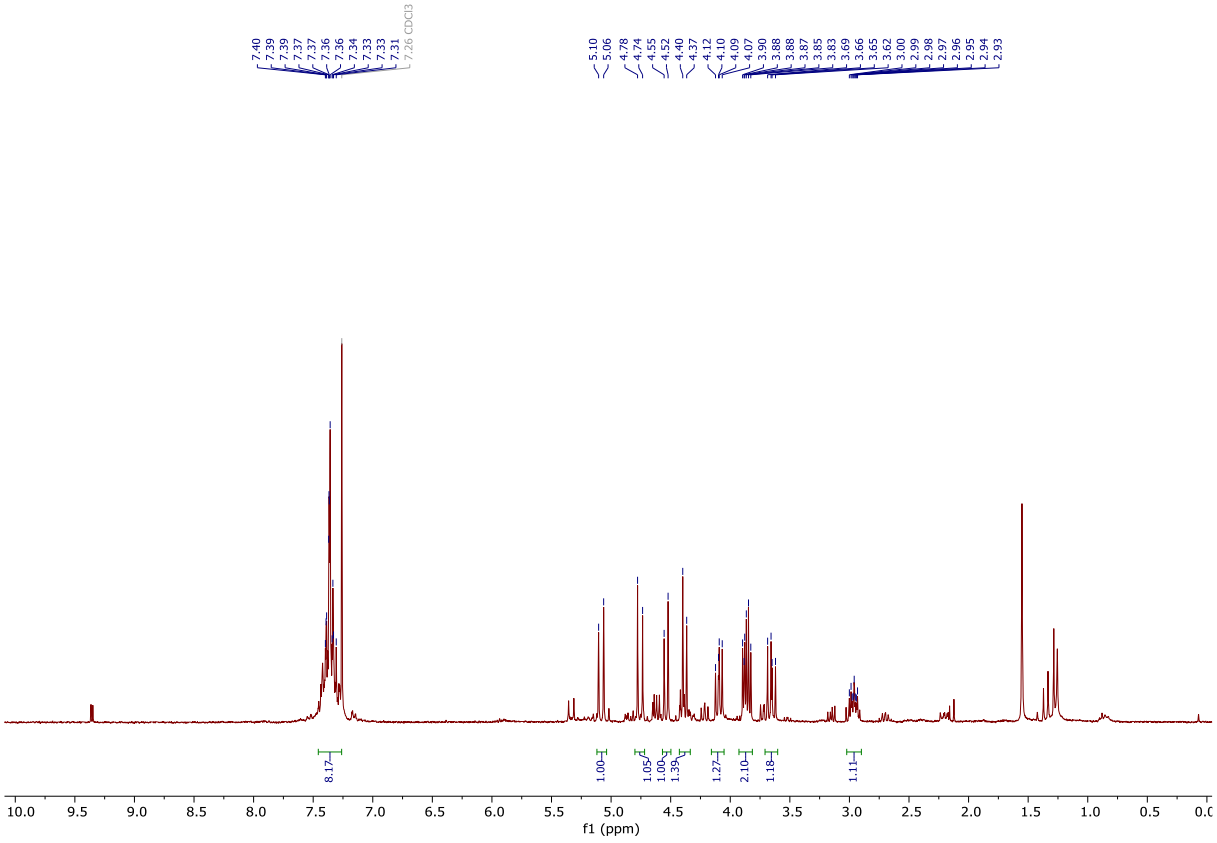
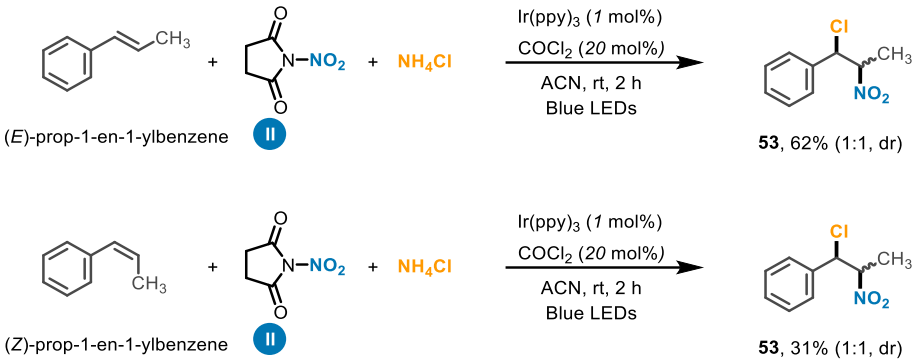


Figure 5.8.7.2. Crude ^{1}*H*-NMR of **52**.



A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), NH_4Cl (29.0 mg, 0.55 mmol, 1.1 eq), $CoCl_2$ (13.0 mg, 0.10 mmol, 0.2 eq), and equipped with a magnetic bar. The vial was then subjected to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene either (*E*)-prop-1-en-1-ylbenxene or (*Z*)-prop-1-en-1-ylbenxene (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 2 h. Crude product was analysed by NMR.

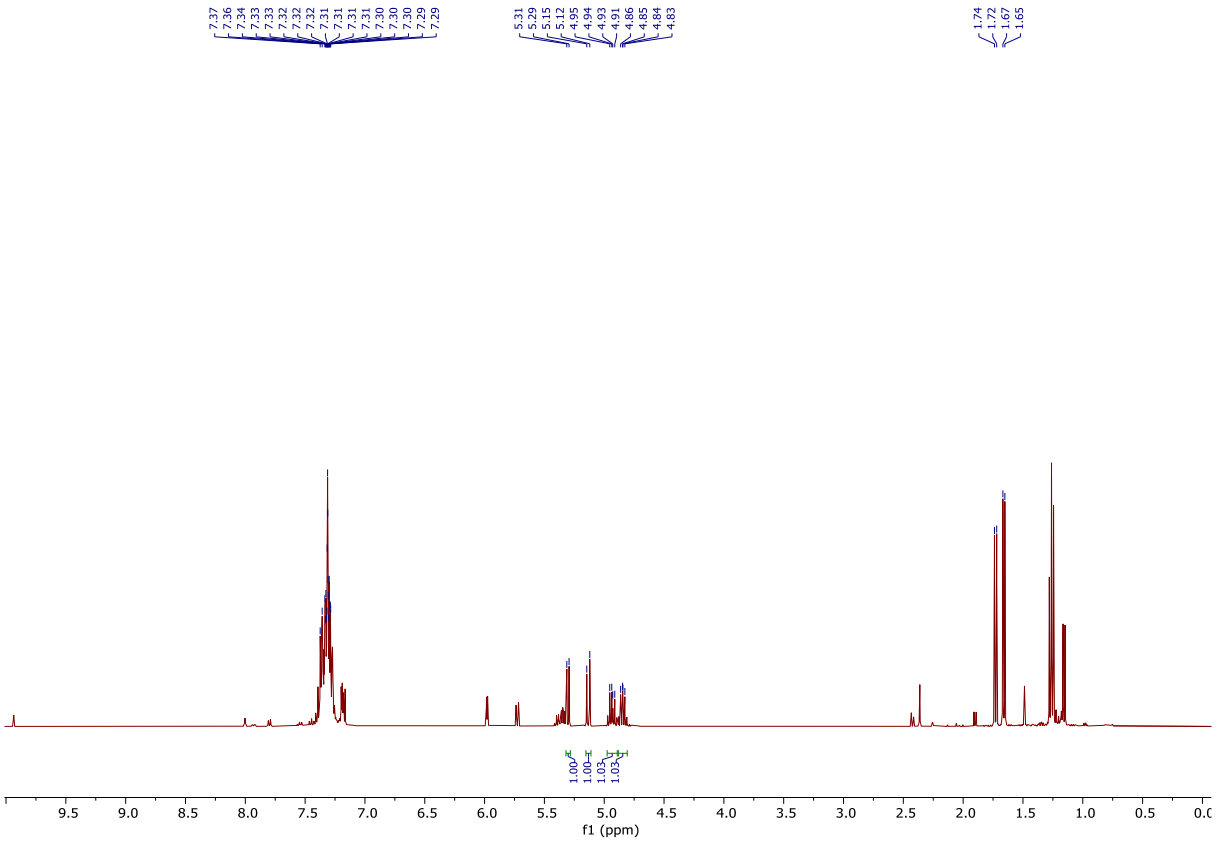


Figure 5.8.7.3. Crude ^{1}*H*-NMR of **53**.

A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), NH_4Cl (29.0 mg, 0.55 mmol, 1.1 eq), $CoCl_2$ (13.0 mg, 0.10 mmol, 0.2 eq), and equipped with a magnetic bar. The vial was then subjected to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene either (*E*)-prop-1-en-1-ylbenxene or (*Z*)-prop-1-en-1-ylbenxene (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 2 h. Crude product was analysed by NMR.

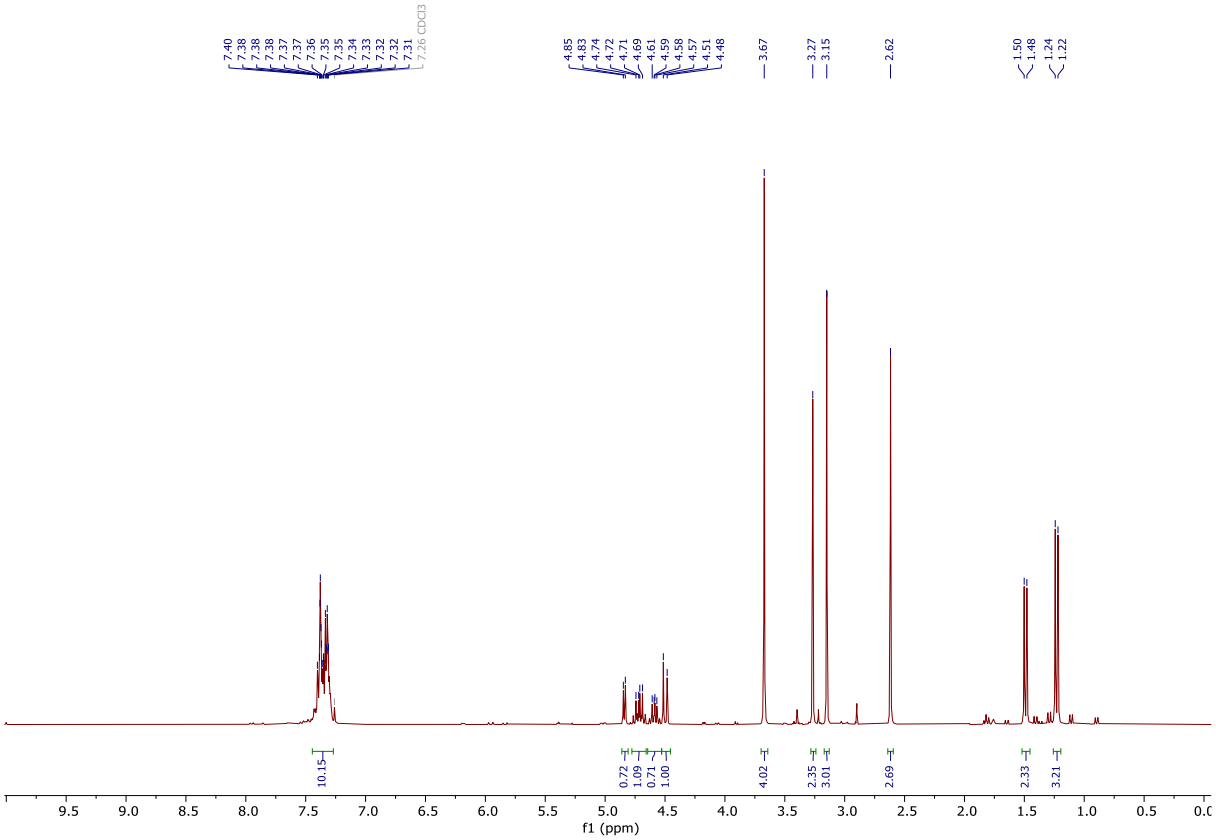
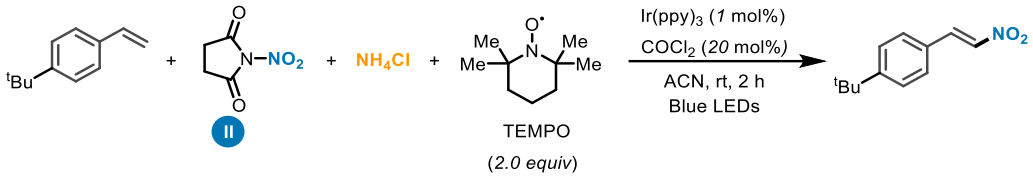


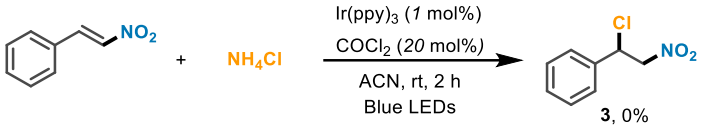
Figure 5.8.7.5. Crude ^1H-NMR of **98**.

5.8.8. Reaction in presence of radical scavenger

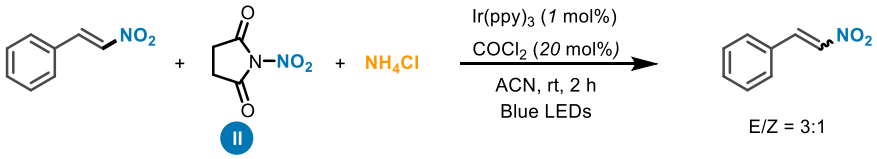


A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), NH_4Cl (29.0 mg, 0.55 mmol, 1.1 eq), $CoCl_2$ (13.0 mg, 0.10 mmol, 0.2 eq), 2,2,6,6-tetramethylpiperidin-1-yl)oxidanyl (TEMPO) (157.0 mg, 1.0 mmol, 2 eq) and equipped with a magnetic bar. The vial was then subjected to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene **1** (0.5 mmol, 1.0 eq) was introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs irradiation at room temperature for 2 h. Crude product was analysed by GC-MS and NMR.

5.8.9. Michael addition type reaction

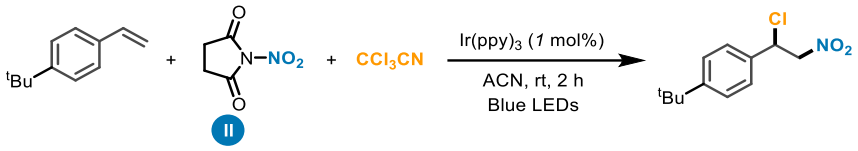


A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), NH_4Cl (29.0 mg, 0.55 mmol, 1.1 eq), $CoCl_2$ (13.0 mg, 0.10 mmol, 0.2 eq), nitrostyrene (0.5 mmol, 1.0 eq) and equipped with a magnetic bar. The vial was then subjected to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 2 h. Crude product was analysed by GC-MS and NMR.

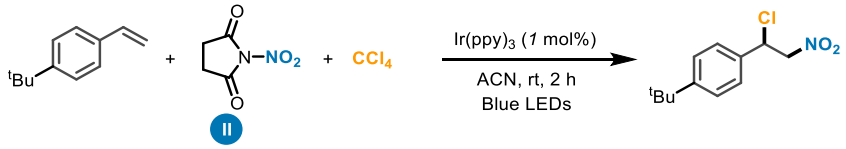


A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), NH_4Cl (29.0 mg, 0.55 mmol, 1.1 eq), $CoCl_2$ (13.0 mg, 0.10 mmol, 0.2 eq), nitrostyrene (0.5 mmol, 1.0 eq) and equipped with a magnetic bar. The vial was then subjected to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 2 h. Crude product was analysed by GC-MS and NMR.

5.8.10. Radical trapping experiments



A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), and equipped with a magnetic bar. The vial was then subjected to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene (0.5 mmol, 1.0 eq) and CCl_3CN (1.5 mmol, 1.5 eq) were introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 2 h. Crude product was analysed by GC-MS.



A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (3.3 mg, 5 µmol, 1 mol%), nitrating reagent **II** (108.0 mg, 0.75 mmol, 1.5 eq), and equipped with a magnetic bar. The vial was then subjected to three vacuum-nitrogen cycles. Anhydrous ACN (0.5 mL) was added under a nitrogen atmosphere, and the solution was sparged for 3 min. The alkene (0.5 mmol, 1.0 eq) and CCl_4 (1.5 mmol, 1.5 eq) were introduced to the solution *via* a micro syringe. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 2 h. Crude product was analysed by GC-MS.

5.9. Scale-Up Synthesis

Flow set-up

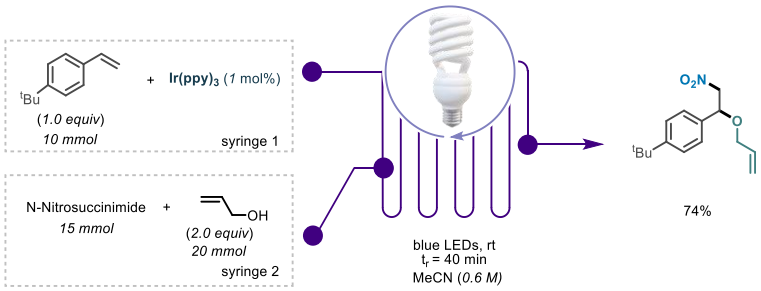


Figure 9.1.1. Pictorial representation of flow setup.

Components of flow reactor.

Syringe pump: Fusion 4000 syringe pump

Tubing components:

1. Tubing PFA 1/16″ OD (1 mm ID) [Item #: 1507L], length =50ft
2. Nut PEEK 1/16″ [LT-115X]
3. Ferrule SF [P-250X]
4. SS Ring 1/16″ [included with P-250X]
5. Y Assembly PEEK ¼-28 0.20” [P-512]

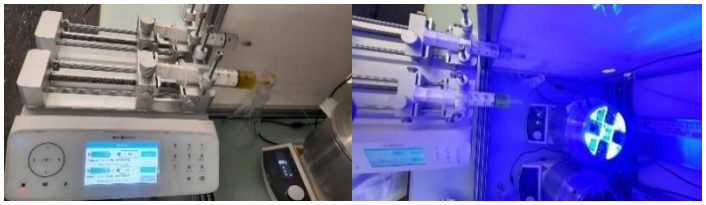
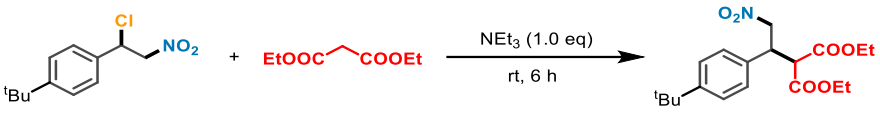


Figure 5.9.1.2. Flow setup for scale-up.

Procedure for reaction in flow: In an oven dried flask, 4-*tert*-butylstyrene, (94%, stab. with 50 ppm 4-*tert*-butylcatechol commercially available at Thermoscientific - Alfa Aesar, 1.6 gram, 10.0 mmol, 1.0 eq) and *fac*-[Ir(ppy)$_3$] (65.0 mg, 0.1 mmol, 1.0 mol%) were dissolved in 10 mL MeCN while in another flask *N*-Nitrosuccinimide (15.0 mmol) was dissolved in 30 mL DMF. Both liquids were taken up with a syringe and mounted on a syringe pump. The syringes were connected to a 50 mL flow coil tubing (PFA tubing, 1/16” outer diameter and 1 mm inner diameter, [1507L]) *via* a PEEK Y-mixer (Y Assembly PEEK [P-512]), the volume of the tube is 12 mL. Stock solutions were pumped into the flow reactor with a flow rate of 0.3 mL/min through each syringe (corresponding to 40 min residence time). When the syringe was fully empty, again stock solution was loaded into a syringe and injected to collect all product at the end of the reactor in a flask. The reaction mixture was concentrated under reduced pressure. The residue was purified by flash column chromatography over silica gel as indicated to afford 1-(1-(allyloxy)-2-nitroethyl)-4-(*tert*-butyl)benzene as a pale-yellow solid (1.95 g, 7.4 mmol, 74% yield).

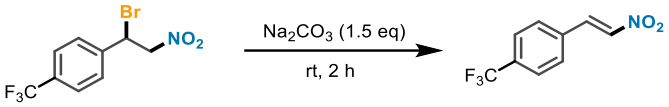
5.10. Post-synthetic Modifications

Diethyl 2-(1-(4-(*tert*-butyl)phenyl)-2-nitroethyl)malonate (102)



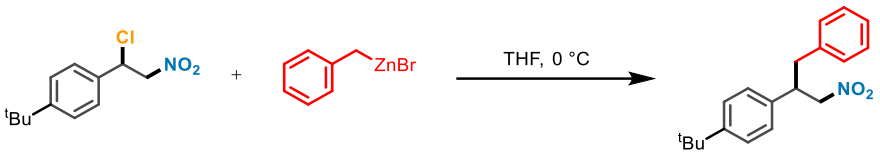
1-(1-Chloro-2-nitroethyl)-4-(*tert*-butyl)benzene **2** (0.5 mmol, 1.0 eq), diethyl malonate (0.55 mmol, 1.1 eq), and NEt_3 (0.5 mmol, 1.0 eq) were stirred at room temperature for 6 h. Then volatiles were removed under vacuum, and extracted with dichloromethane, the organic layer was washed with water, brine, dried over anhydrous magnesium sulfate, filtered and concentrated under vacuum. After column chromatography on silica the titled compound was isolated as yellow solid (85% yield, 5% ethyl acetate in hexane as eluent).

(*E*)-1-(2-Nitrovinyl)-4-(trifluoromethyl)benzene (103)



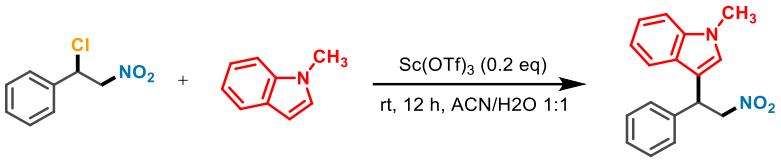
1-(1-Bromo-2-nitroethyl)-4-(trifluoromethyl)benzene (0.5 mmol, 1.0 eq), Na_2CO_3 (1.5 mmol, 1.5 eq), were stirred at room temperature for 6 h in THF (2 mL). Then volatiles were removed under vacuum, and extracted with dichloromethane, the organic layer was washed with water, brine, dried over anhydrous magnesium sulfate, filtered, and concentrated under vacuum. After column chromatography on silica the titled compound was isolated as light orange solid (93% yield, 5% ethyl acetate in hexane as eluent).

(*E*)-1-(2-Nitrovinyl)-4-(trifluoromethyl)benzene (104)



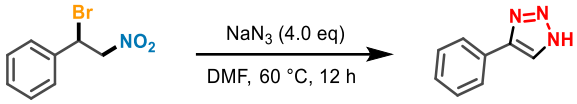
1-(1-Chloro-2-nitroethyl)-4-(*tert*-butyl)benzene **2** (0.5 mmol, 1.0 eq), benzylzinc bromide (0.5 M in THF, 1.5 mmol, 1.5 eq), were stirred at 0 °C under N_2 atmosphere for 6 h in THF (2 mL). Then volatiles were removed under vacuum, and extracted with dichloromethane, the organic layer was washed with water, brine, dried over anhydrous magnesium sulfate, filtered, and concentrated under vacuum. After column chromatography on silica the titled compound was isolated as light-yellow solid (90% yield, 5% ethyl acetate in hexane as eluent).

1-Methyl-3-(2-nitro-1-phenylethyl)-1*H*-indole (105)



(1-Chloro-2-nitroethyl)benzene (0.5 mmol, 1.0 eq), 1-methyl-1*H*-indole (1.5 mmol, 1.5 eq), and $Sc(OTf)_3$ (20 mol%) were stirred at room temperature for 16 h in ACN/H_2O (1:1) (2 mL). Then volatiles were removed under vacuum, and extracted with dichloromethane, the organic layer was washed with water, brine, dried over anhydrous magnesium sulfate, filtered, and concentrated under vacuum. After column chromatography on silica the titled compound was isolated as yellow oil (61% yield, 10% ethyl acetate in hexane as eluent).

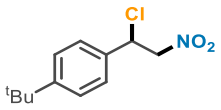
4-Phenyl-1*H*-1,2,3-triazole (106)



(1-Bromo-2-nitroethyl)benzene (0.5 mmol, 1.0 eq), NaN_3 (2.0 mmol, 4.0 eq), were stirred at 60 °C for 12 h in DMF (2 mL). After completion, the reaction mixture was washed with saturated Na_2CO_3 (2 mL) and extracted with Et_2O (3 × 5 mL). The organic layer was washed with water, brine, dried over anhydrous magnesium sulfate, filtered, and concentrated under vacuum. After column chromatography on silica the titled compound was isolated as white solid (81% yield, 20% ethyl acetate in hexane as eluent).

5.11. NMR Data

1-(*tert*-Butyl)-4-(1-chloro-2-nitroethyl)benzene (2)

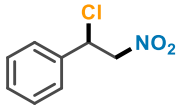


Compound **2** was obtained according to general procedure **GP1** as a colorless liquid (91% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.43 (d, *J* = 8.5 Hz, 2H), 7.36 (d, *J* = 8.5 Hz, 2H), 5.56 (dd, *J* = 9.2, 5.5 Hz, 1H), 4.91 (dd, *J* = 13.4, 9.2 Hz, 1H), 4.78 (dd, *J* = 13.4, 5.5 Hz, 1H), 1.33 (s, 9H).

The characterisation data match the literature.

(1-Chloro-2-nitroethyl)benzene (3)



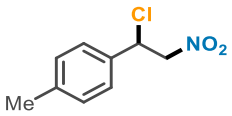
Compound **3** was obtained according to general procedure **GP1** as a yellow liquid (89% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44 – 7.39 (m, 5H), 5.57 (dd, *J* = 9.1, 5.6 Hz, 1H), 4.91 (dd, *J* = 13.4, 9.1 Hz, 1H), 4.78 (dd, *J* = 13.4, 5.6 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 136.0, 129.9, 129.4, 127.3, 81.0, 57.0.

The characterisation data match the literature.

1-(1-Chloro-2-nitroethyl)-4-methylbenzene (4)



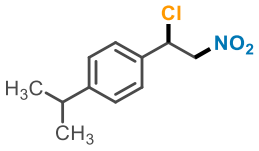
Compound **4** was obtained according to general procedure **GP1** as a yellow oil (71% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.31 (d, *J* = 8.2 Hz, 2H), 7.22 (d, *J* = 8.2 Hz, 2H), 5.54 (dd, *J* = 9.1, 5.6 Hz, 1H), 4.90 (dd, *J* = 13.4, 9.1 Hz, 1H), 4.77 (dd, *J* = 13.4, 5.6 Hz, 1H), 2.37 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 140.0, 133.0, 130.0, 127.2, 81.0, 57.0, 21.3.

The characterisation data match the literature.

1-(1-Chloro-2-nitroethyl)-4-isopropylbenzene (5)



Compound **5** was obtained according to general procedure **GP1** as a yellow oil (71% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

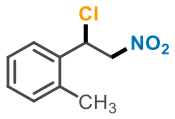
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.35 (d, *J* = 8.2 Hz, 2H), 7.27 (d, *J* = 8.2 Hz, 2H), 5.56 (dd, *J* = 9.2, 5.5 Hz, 1H), 4.90 (dd, *J* = 13.4, 9.2 Hz, 1H), 4.77 (dd, *J* = 13.4, 5.6 Hz, 1H), 2.92 (p, *J* = 6.9 Hz, 1H), 1.25 (d, J = 6.9 Hz, 6H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 150.9, 133.3, 127.5, 127.3, 81.0, 57.0, 34.0, 23.9.

FT-IR (ATR, neat; cm^{-1}): 3034, 1554, 1516, 1315, 1204.

HRMS (ESI) *m/z* calcd for $C_{11}H_{14}ClNO_2$: 227.0713; found 227.0715.

1-(1-Chloro-2-nitroethyl)-2-methylbenzene (6)



Compound **6** was obtained according to general procedure **GP1** as a yellow oil (82% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

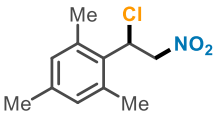
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.48 – 7.42 (m, 1H), 7.29 (dt, *J* = 11.4, 4.2 Hz, 3H), 5.87 (dd, *J* = 9.1, 5.2 Hz, 1H), 4.99 (dd, *J* = 13.6, 9.1 Hz, 1H), 4.84 (dd, J = 13.6, 5.2 Hz, 1H), 2.51 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.0, 134.1, 131.3, 129.7, 127.2, 126.6, 80.1, 53.4, 19.2.

FT-IR (ATR, neat; cm^{-1}): 3011, 1558, 1522, 1376, 1345.

HRMS (ESI) *m/z* calcd for $C_9H_{10}ClNO_2$: 199.0400; found 199.0401.

2-(1-Chloro-2-nitroethyl)-1,3,5-trimethylbenzene (7)



Compound **7** was obtained according to general procedure **GP1** as a yellow oil (72% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

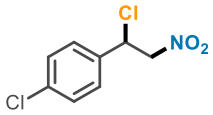
^{1}H-NMR (400 MHz, $CDCl_3$): δ 6.90 (s, 2H), 6.15 (dd, *J* = 9.3, 5.2 Hz, 1H), 5.20 (dd, *J* = 13.6, 9.3 Hz, 1H), 4.83 (dd, *J* = 13.6, 5.1 Hz, 1H), 2.50 (s, 6H), 2.28 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 139.5, 135.6, 131.9, 129.9, 129.1, 128.4, 79.3, 53.2, 20.9, 20.7.

FT-IR (ATR, neat; cm^{-1}): 3014, 1556, 1520, 1374, 1342.

HRMS (ESI) *m/z* calcd for $C_{11}H_{14}ClNO_2$: 227.0713; found 227.0711.

1-Chloro-4-(1-chloro-2-nitroethyl)benzene (8)



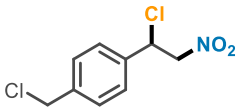
Compound **8** was obtained according to general procedure **GP1** as a white solid (59% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.41 – 7.36 (m, 4H), 5.53 (dd, *J* = 8.8, 6.0 Hz, 1H), 4.89 (dd, *J* = 13.5, 8.8 Hz, 1H), 4.76 (dd, *J* = 13.5, 6.0 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 136.0, 134.5, 129.7, 128.8, 80.7, 56.1.

The characterisation data match the literature.

1-(1-Chloro-2-nitroethyl)-4-(chloromethyl)benzene (9)



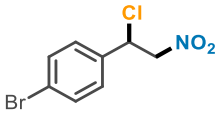
Compound **9** was obtained according to general procedure **GP1** as a yellow liquid (61% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44 (m, 4H), 5.56 (dd, *J* = 9.0, 5.8 Hz, 1H), 4.90 (dd, *J* = 13.5, 9.0 Hz, 1H), 4.77 (dd, *J* = 13.5, 5.8 Hz, 1H), 4.58 (s, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 139.3, 136.1, 129.5, 127.8, 80.8, 56.4, 45.4.

The characterisation data match the literature.

1-Bromo-4-(1-chloro-2-nitroethyl)benzene (10)



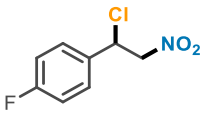
Compound **10** was obtained according to general procedure **GP1** as a white solid (65% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.55 (d, *J* = 8.4 Hz, 2H), 7.31 (d, *J* = 8.4 Hz, 2H), 5.52 (dd, *J* = 8.8, 6.0 Hz, 1H), 4.88 (dd, *J* = 13.5, 8.8 Hz, 1H), 4.76 (dd, *J* = 13.5, 6.0 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 135.0, 132.6, 129.0, 124.1, 80.6, 56.1.

The characterisation data match the literature.

1-(1-Chloro-2-nitroethyl)-4-fluorobenzene (11)



Compound **11** was obtained according to general procedure **GP1** as a yellow oil (78% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

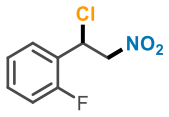
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.42 (dd, *J* = 8.6, 5.1 Hz, 2H), 7.10 (t, *J* = 8.6 Hz, 2H), 5.55 (dd, *J* = 8.7, 6.0 Hz, 1H), 4.90 (dd, *J* = 13.4, 8.8 Hz, 1H), 4.76 (dd, *J* = 13.4, 6.1 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 163.4 (d, *J* = 250.1 Hz), 129.3 (d, *J* = 8.6 Hz), 116.5 (d, *J* = 22.0 Hz), 80.8, 56.1.

^{19}F-NMR (282 MHz, $CDCl_3$): δ -110.8.

The characterisation data match the literature.

1-(1-Chloro-2-nitroethyl)-2-fluorobenzene (12)



Compound **12** was obtained according to general procedure **GP1** as a yellow liquid (85% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.49 (td, *J* = 7.6, 1.8 Hz, 1H), 7.43 – 7.36 (m, 1H), 7.22 (td, *J* = 7.6, 1.2 Hz, 1H), 7.13 (ddd, *J* = 10.5, 8.3, 1.2 Hz, 1H), 5.85 (dd, *J* = 9.1, 5.3 Hz, 1H), 4.96 (ddd, *J* = 13.7, 9.1, 0.6 Hz, 1H), 4.86 (dd, *J* = 13.7, 5.3 Hz, 1H).

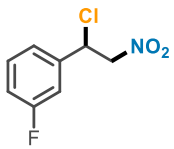
^{13}C-NMR (101 MHz, $CDCl_3$): δ 159.9 (d, *J* = 249.9 Hz), 131.7 (d, *J* = 8.5 Hz), 129.1 (d, *J* = 2.8 Hz), 125.1 (d, *J* = 3.7 Hz), 116.4 (d, *J* = 21.4 Hz), 79.5 (d, *J* = 2.9 Hz), 51.0 (d, *J* = 3.6 Hz).

^{19}F-NMR (282 MHz, $CDCl_3$): δ -116.1.

FT-IR (ATR, neat; cm^{-1}): 3001, 2980, 1561, 1384, 1263, 1151.

HRMS (ESI) *m/z* calcd for $C_8H_7ClFNO_2$: 203.0149; found 203.0148.

1-(1-Chloro-2-nitroethyl)-3-fluorobenzene (13)



Compound **13** was obtained according to general procedure **GP1** as a colorless oil (64% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

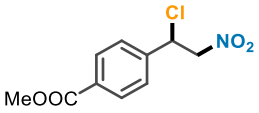
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.39 (td, J = 8.0, 5.7 Hz, 1H), 7.23 – 7.05 (m, 4H), 5.54 (dd, J = 8.8, 5.9 Hz, 1H), 4.89 (dd, J = 13.5, 8.8 Hz, 1H), 4.77 (dd, J = 13.5, 5.9 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 163.0 (d, *J* = 248.5 Hz), 138.3 (d, *J* = 7.4 Hz), 131.1 (d, *J* = 8.3 Hz), 123.0 (d, *J* = 3.2 Hz), 117.0 (d, *J* = 21.1 Hz), 114.6 (d, *J* = 23.0 Hz), 80.7, 56.0 (d, *J* = 2.2 Hz).

^{19}F-NMR (282 MHz, $CDCl_3$): δ -111.0.

The characterisation data match the literature.

Methyl 4-(1-chloro-2-nitroethyl)benzoate (14)



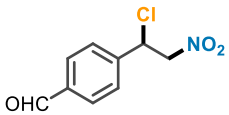
Compound **14** was obtained according to general procedure **GP1** as a white solid (35% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.83 (d, *J* = 8.4 Hz, 2H), 7.27 (d, *J* = 8.4 Hz, 2H), 5.36 (dd, *J* = 8.9, 5.8 Hz, 1H), 4.68 (dd, *J* = 13.6, 8.9 Hz, 1H), 4.57 (dd, *J* = 13.6, 5.8 Hz, 1H), 3.68 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 166.2, 140.5, 131.5, 130.5, 127.4, 80.5, 56.2, 52.5.

The characterisation data match the literature.

4-(1-Chloro-2-nitroethyl)benzaldehyde (15)



Compound **15** was obtained according to general procedure **GP1** as a yellow liquid (77% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

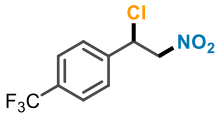
^{1}H-NMR (300 MHz, $CDCl_3$): δ 10.03 (s, 1H), 7.93 (d, J = 8.3 Hz, 2H), 7.62 (d, J = 8.2 Hz, 2H), 5.61 (dd, J = 8.7, 6.0 Hz, 1H), 4.93 (dd, J = 13.6, 8.7 Hz, 1H), 4.82 (dd, J = 13.6, 6.0 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 191.3, 142.0, 137.3, 130.6, 128.2, 80.4, 56.0.

FT-IR (ATR, neat; cm^{-1}): 3021, 2844, 2731, 1691, 1558, 1377, 1145.

HRMS (ESI) *m/z*, calcd for $C_9H_8ClNO_3$: 213.0193; found 213.0191.

1-(1-Chloro-2-nitroethyl)-4-(trifluoromethyl)benzene (16)



Compound **16** was obtained according to general procedure **GP1** as an orange liquid (69% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.69 (d, *J* = 8.2 Hz, 2H), 7.58 (d, *J* = 8.2 Hz, 2H), 5.61 (dd, *J* = 8.7, 6.0 Hz, 1H), 4.92 (dd, *J* = 13.6, 8.7 Hz, 1H), 4.80 (dd, *J* = 13.6, 6.0 Hz, 1H).

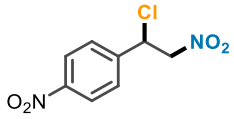
^{13}C-NMR (101 MHz, $CDCl_3$): δ 139.8 (d, *J* = 1.5 Hz), 132.1 (q, *J* = 33.0 Hz), 129.4, 127.9, 127.8, 126.5 (q, *J* = 3.7 Hz), 123.7 (q, *J* = 273.7 Hz), 80.5, 55.8.

^{19}F-NMR (377 MHz, $CDCl_3$): δ - 62.9.

FT-IR (ATR, neat; cm^{-1}): 3013, 1559, 1527, 1367, 1353.

HRMS (ESI) *m/z*, calcd for $C_9H_7ClF_3NO_2$: 253.0117; found 253.0114.

1-(1-Chloro-2-nitroethyl)-4-nitrobenzene (17)



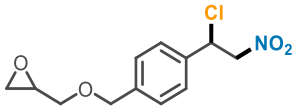
Compound **17** was obtained according to general procedure **GP1** as a yellow oil (58% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.26 (d, *J* = 8.8 Hz, 2H), 7.65 (d, *J* = 8.8 Hz, 2H), 5.64 (dd, *J* = 8.6, 6.2 Hz, 1H), 4.95 (dd, *J* = 13.7, 8.6 Hz, 1H), 4.84 (dd, *J* = 13.7, 6.2 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 148.6, 142.7, 128.6, 124.5, 80.1, 55.3.

The characterisation data match the literature.

2-(((4-(1-Chloro-2-nitroethyl)benzyl)oxy)methyl)oxirane (18)



Compound **18** was obtained according to general procedure **GP1** as a yellow liquid (63% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

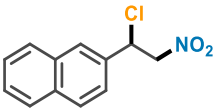
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44 – 7.40 (m, 2H), 7.36 (d, *J* = 8.3 Hz, 2H), 5.55 (dd, *J* = 9.0, 5.7 Hz, 1H), 4.90 (dd, *J* = 13.5, 9.0 Hz, 1H), 4.78 (dd, *J* = 13.5, 5.7 Hz, 1H), 4.56 (s, 2H), 4.53 (dd, *J* = 5.4, 4.0 Hz, 2H), 4.15 – 4.06 (m, 1H), 3.62 – 3.52 (m, 2H), 2.78 (s, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 139.3, 135.7, 128.5, 127.6, 80.8, 73.5, 73.0, 70.8, 67.5, 56.6.

FT-IR (ATR, neat; cm^{-1}): 3002, 1562, 1520, 1374, 1342, 1157.

HRMS (ESI) *m/z*, calcd for $C_{12}H_{14}ClNO_4$: 271.0611; found 271.0609.

2-(1-Chloro-2-nitroethyl)naphthalene (19)



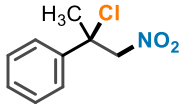
Compound **19** was obtained according to general procedure **GP1** as a white solid (83% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.95 – 7.81 (m, 4H), 7.60 – 7.48 (m, 3H), 5.74 (dd, *J* = 9.0, 5.7 Hz, 1H), 5.02 (dd, *J* = 13.4, 9.0 Hz, 1H), 4.88 (dd, *J* = 13.4, 5.7 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 133.8, 133.1, 129.6, 128.3, 128.0, 127.4, 127.2, 127.2, 124.0, 80.9, 57.3.

The characterisation data match the literature.

(2-Chloro-1-nitropropan-2-yl)benzene (20)



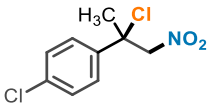
Compound **20** was obtained according to general procedure **GP1** as a yellow oil (57% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.63 – 7.51 (m, 2H), 7.47 – 7.28 (m, 3H), 4.93 (d, *J* = 1.7 Hz, 2H), 2.23 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 140.2, 129.1, 128.9, 126.2, 86.1, 67.1, 29.2.

The characterisation data match the literature.

1-Chloro-4-(2-chloro-1-nitropropan-2-yl)benzene (21)



Compound **21** was obtained according to general procedure **GP1** as a yellow oil (58% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

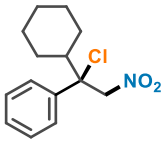
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.50 (d, *J* = 8.8 Hz, 2H), 7.38 (d, *J* = 8.8 Hz, 2H), 4.91 (d, *J* = 3.7 Hz, 2H), 2.20 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.8, 135.2, 129.1, 127.8, 85.8, 66.4, 29.2.

FT-IR (ATR, neat; cm^{-1}): 3007, 2945, 1551, 1487, 1387, 1062.

HRMS (ESI) *m/z*, calcd for $C_9H_9Cl_2NO_2$: 233.0010; found 233.0007.

(1-Chloro-1-cyclohexyl-2-nitroethyl)benzene (22)



Compound **22** was obtained according to general procedure **GP1** as a yellow oil (41% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

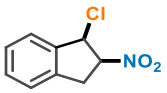
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.55 – 7.46 (m, 2H), 7.44 – 7.29 (m, 3H), 5.11 (d, *J* = 12.4 Hz, 1H), 5.01 (d, *J* = 12.4 Hz, 1H), 2.28 – 2.09 (m, 1H), 2.01 – 1.80 (m, 2H), 1.77 – 1.60 (m, 2H), 1.51 – 1.07 (m, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.3, 128.5, 128.4, 126.9, 83.8, 47.8, 27.8, 27.8, 26.2, 26.0.

FT-IR (ATR, neat; cm^{-1}): 3008, 1561, 1492, 1333, 1012.

HRMS (ESI) *m/z*, calcd for $C_{14}H_{18}ClNO_2$: 267.1026; found 267.1024.

1-Chloro-2-nitro-2,3-dihydro-1H-indene (23)



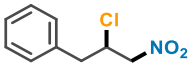
Compound **23** was obtained according to general procedure **GP1** as a yellow oil (62% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.38 – 7.33 (m, 1H), 7.28 (dd, *J* = 6.2, 2.7 Hz, 2H), 7.21 – 7.15 (m, 1H), 5.84 (d, *J* = 4.4 Hz, 1H), 5.25 (dt, *J* = 8.1, 4.9 Hz, 1H), 3.65 (dd, *J* = 16.8, 8.1 Hz, 1H), 3.50 (dd, *J* = 16.8, 5.4 Hz, 1H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 138.9, 137.7, 130.2, 128.7, 125.4, 124.9, 92.5, 62.5, 36.4.

The characterisation data match the literature.

(2-Chloro-3-nitropropyl)benzene (24)



Compound **24** was obtained according to general procedure **GP1** as a yellow oil (45% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

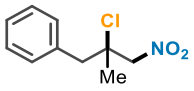
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.27 – 7.15 (m, 3H), 7.17 – 7.08 (m, 2H), 4.69 – 4.57 (m, 1H), 4.51 – 4.36 (m, 2H), 3.05 (qd, *J* = 14.2, 7.1 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.3, 129.4, 129.1, 127.9, 79.6, 56.2, 41.7.

FT-IR (ATR, neat; cm^{-1}): 3023, 2965, 1553, 1462, 1380, 1278.

HRMS (ESI) *m/z*, $C_9H_{10}ClNO_2$: 199.0400; found 199.0438.

(2-Chloro-2-methyl-3-nitropropyl)benzene (25)



Compound **25** was obtained according to general procedure **GP1** as a yellow oil (44% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

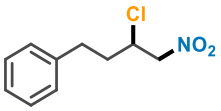
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.33 (d, *J* = 1.8 Hz, 5H), 4.59 (d, *J* = 2.6 Hz, 2H), 3.28 (s, 2H), 1.74 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 134.6, 131.1, 128.6, 127.8, 83.4, 66.6, 47.5, 28.5.

FT-IR (ATR, neat; cm^{-1}): 3023, 2965, 1553, 1462, 1380, 1278.

HRMS (ESI) *m/z*, $C_{10}H_{12}ClNO_2$: 213.0557; found 213.0553.

(3-Chloro-4-nitrobutyl)benzene (26)



Compound **26** was obtained according to general procedure **GP1** as a yellow oil (39% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

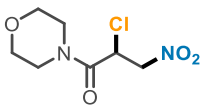
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.30 – 7.20 (m, 2H), 7.19 – 7.09 (m, 3H), 4.59 – 4.30 (m, 3H), 2.87 (ddd, *J* = 13.9, 8.2, 5.7 Hz, 1H), 2.72 (dt, *J* = 13.9, 8.0 Hz, 1H), 2.11 – 1.90 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.7, 128.9, 128.6, 126.8, 80.6, 55.5, 36.8, 32.1.

FT-IR (ATR, neat; cm^{-1}): 2975, 2943, 1556, 1321, 1283, 1191.

HRMS (ESI) *m/z*, $C_{10}H_{12}ClNO_2$: 213.0557; found 213.0554.

2-Chloro-1-morpholino-3-nitropropan-1-one (27)



Compound **27** was obtained according to general procedure **GP1** as a yellow oil (31% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

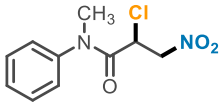
^{1}H-NMR (300 MHz, $CDCl_3$): δ 5.18 – 4.98 (m, 2H), 4.72 (dd, *J* = 14.1, 5.5 Hz, 1H), 3.84 – 3.48 (m, 8H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 164.0, 75.4, 66.7, 66.5, 46.6, 43.0.

FT-IR (ATR, neat; cm^{-1}): 3033, 2936, 2932, 1785, 1691, 1654, 1273, 1211.

HRMS (ESI) *m/z*, $C_7H_{11}ClN_2O_4$: 222.0407; found 222.0405.

2-Chloro-N-methyl-3-nitro-N-phenylpropanamide (28)



Compound **28** was obtained according to general procedure **GP1** as a yellow oil (22% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

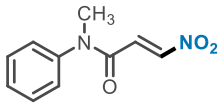
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.52 – 7.42 (m, 5H), 5.17 (dd, *J* = 14.8, 9.4 Hz, 1H), 4.70 – 4.61 (m, 1H), 4.53 (dd, *J* = 14.8, 4.7 Hz, 1H), 3.34 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 161.6, 141.9, 130.3, 129.2, 127.6, 74.8, 46.0, 38.3.

FT-IR (ATR, neat; cm^{-1}): 3012, 2926, 1791, 1696, 1278.

HRMS (EI) *m/z*, calcd for $C_{10}H_{11}ClN_2O_3$: 242.0458; found 242.0454.

(*E*)-*N*-Methyl-3-nitro-N-phenylacrylamide (29)



Compound **29** was obtained according to general procedure **GP1** as a yellow oil (31% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

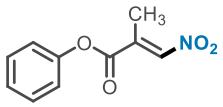
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.68 (d, *J* = 13.0 Hz, 1H), 7.55 – 7.39 (m, 3H), 7.19 (dd, *J* = 8.0, 1.6 Hz, 2H), 7.07 (d, *J* = 13.0 Hz, 1H), 3.42 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 164.5, 147.6, 138.4, 130.4, 129.0, 128.5, 127.0, 38.0.

FT-IR (ATR, neat; cm^{-1}): 3031, 2979, 1761, 1715, 1554, 1436, 1389, 1337.

HRMS (EI) *m/z*, calcd for $C_{10}H_{10}N_2O_3$: 206.0691; found 206.069189.

Phenyl (*E*)-2-methyl-3-nitroacrylate (30)



Compound **30** was obtained according to general procedure **GP1** as a yellow oil (48% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

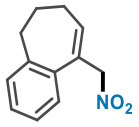
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.93 (q, *J* = 1.7 Hz, 1H), 7.48 – 7.40 (m, 2H), 7.34 – 7.27 (m, 1H), 7.15 (dd, *J* = 8.6, 1.2 Hz, 2H), 2.42 (d, *J* = 1.7 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 164.1, 150.2, 144.9, 136.1, 129.8, 126.7, 121.2, 13.9.

FT-IR (ATR, neat; cm^{-1}): 3024, 2989, 1767, 1712, 1549, 1328.

HRMS (EI) *m/z*, calcd for $C_{10}H_9NO_4$: 207.0526; found 207.0527.

9-(Nitromethyl)-6,7-dihydro-5H-benzo[7]annulene (31)



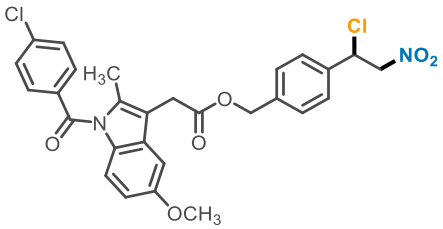
Compound **31** was obtained according to general procedure **GP1** as a yellow solid (66% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.20 – 7.12 (m, 4H), 6.39 (t, *J* = 7.2 Hz, 1H), 5.21 (s, 2H), 2.58 (t, *J* = 7.1 Hz, 2H), 2.18 – 2.07 (m, 2H), 1.89 (t, *J* = 7.2 Hz, 2H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 142.1, 137.9, 136.9, 131.6, 129.5, 128.0, 126.4, 125.6, 80.9, 35.0, 32.2, 25.2.

The characterisation data match the literature.

(8R,9S,13S,14S)-3-((4-((R)-1-Chloro-2-nitroethyl)benzyl)oxy)-13-methyl-6,7,8,9,11,12,13,14,15,16-decahydro-17H-cyclopenta[a]phenanthren-17-one (32)



Compound **32** was obtained according to general procedure **GP1** as a orange solid (75% yield) after purification by column chromatography (SiO_2, hexane/EA=3:1).

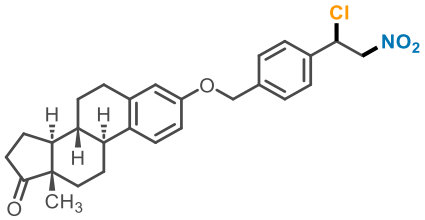
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.65 (d, *J* = 8.5 Hz, 2H), 7.49 (d, *J* = 8.5 Hz, 2H), 7.41 (s, 4H), 7.30 – 7.20 (m, 2H), 6.83 (d, *J* = 9.2 Hz, 1H), 5.56 (dd, *J* = 9.1, 5.6 Hz, 1H), 5.14 (s, 2H), 4.90 (dd, *J* = 13.5, 9.1 Hz, 1H), 4.77 (dd, *J* = 13.5, 5.6 Hz, 1H), 3.90 (s, 3H), 3.68 (s, 2H), 2.30 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 170.5, 168.1, 147.9, 140.5, 139.6, 137.7, 135.8, 133.1, 131.8, 131.5, 129.6, 129.1, 127.5, 122.1, 117.0, 109.4, 108.7, 80.9, 66.3, 57.5, 56.7, 29.8, 13.5.

FT-IR (ATR, neat; cm^{-1}): 3029, 1758, 1716, 1517, 1263, 1051.

HRMS (ESI) *m/z*, $C_{28}H_{24}Cl_2N_2O_6$: 554.1011; found 554.1008.

(8R,9S,13S,14S)-3-((4-(1-Chloro-2-nitroethyl)benzyl)oxy)-13-methyl-6,7,8,9,11,12,13,14,15,16-decahydro-17H-cyclopenta[a]phenanthren-17-one (33)



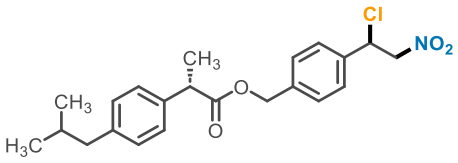
Compound **33** was obtained according to general procedure **GP1** as a white solid (67% yield) after purification by column chromatography (SiO_2, hexane/EA=3:1).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.51 – 7.39 (m, 3H), 7.21 (d, *J* = 8.6 Hz, 1H), 6.80 – 6.74 (m, 1H), 6.73 – 6.69 (m, 1H), 5.63 – 5.52 (m, 1H), 5.05 (s, 2H), 4.96 – 4.72 (m, 2H), 2.93 – 2.84 (m, 2H), 2.58 – 2.45 (m, 1H), 2.44 – 2.35 (m, 1H), 2.26 (s, 1H), 2.19 – 2.03 (m, 2H), 1.99 – 1.92 (m, 1H), 1.58 – 1.54 (m, 3H), 1.54 – 1.45 (m, 3H), 1.29 – 1.24 (m, 1H), 0.91 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 221.1, 156.8, 138.1, 132.7, 128.2, 126.6, 126.3, 115.0, 112.5, 81.4, 70.9, 69.6, 50.6, 48.2, 44.8, 44.1, 38.5, 36.0, 31.7, 29.8, 26.7, 26.1, 22.8, 21.7, 14.0.

FT-IR (ATR, neat; cm^{-1}): 2986, 2894, 1757, 1576, 1449, 1375.

4-(1-Chloro-2-nitroethyl)benzyl (2S)-2-(4-isobutylphenyl)propanoate (34)



Compound **34** was obtained according to general procedure **GP1** as a white solid (81% yield) after purification by column chromatography (SiO_2, hexane/EA=3:1).

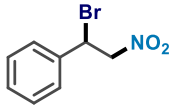
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.36 (d, *J* = 8.3 Hz, 2H), 7.28 – 7.19 (m, 5H), 7.12 (d, *J* = 8.2 Hz, 2H), 5.54 (dd, *J* = 9.0, 5.6 Hz, 1H), 5.12 (s, 2H), 4.88 (dd, *J* = 13.5, 9.0 Hz, 1H), 4.74 (dd, *J* = 13.5, 5.6 Hz, 1H), 3.78 (q, *J* = 7.2 Hz, 1H), 2.48 (d, *J* = 7.2 Hz, 2H), 1.88 (dt, *J* = 13.5, 6.8 Hz, 1H), 1.53 (d, *J* = 7.2 Hz, 3H), 0.93 (d, *J* = 6.6 Hz, 7H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 174.4, 140.73, 138.0, 137.5, 135.5, 129.4, 128.4, 127.4, 127.3, 80.7, 65.4, 56.6, 45.1, 45.1, 30.3, 22.4, 18.4.

FT-IR (ATR, neat; cm^{-1}): 3019, 2947, 1711, 1655, 1554, 1174.

HRMS (ESI) *m/z*, $C_{22}H_{26}ClNO_4$: 403.1550; found 403.1546.

(1-Bromo-2-nitroethyl)benzene (35)



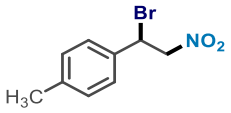
Compound **35** was obtained according to general procedure **GP2** as a pale-yellow liquid (62% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.46 – 7.34 (m, 5H), 5.56 (dd, *J* = 8.2, 7.2 Hz, 1H), 5.04 (dd, *J* = 13.7, 8.2 Hz, 1H), 4.96 (dd, *J* = 13.6, 7.2 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 136.6, 129.9, 129.4, 127.6, 80.7, 45.4.

The characterisation data match the literature.

1-(1-Bromo-2-nitroethyl)-4-methylbenzene (36)



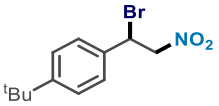
Compound **36** was obtained according to general procedure **GP2** as a pale-yellow liquid (73% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.32 (d, *J* = 8.2 Hz, 2H), 7.22 – 7.17 (m, 2H), 5.60 – 5.49 (m, 1H), 5.02 (dd, *J* = 13.6, 8.1 Hz, 1H), 4.94 (dd, *J* = 13.6, 7.3 Hz, 1H), 2.36 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 140.1, 133.6, 130.1, 127.5, 80.7, 45.5, 21.4.

The characterisation data match the literature.

1-(1-Bromo-2-nitroethyl)-4-(*tert*-butyl)benzene (37)



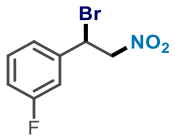
Compound **37** was obtained according to general procedure **GP2** as a colorless liquid (86% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.40 (d, *J* = 8.6 Hz, 2H), 7.35 (d, *J* = 8.6 Hz, 2H), 5.57 (dd, *J* = 8.2, 7.1 Hz, 1H), 5.03 (dd, *J* = 13.6, 8.2 Hz, 1H), 4.95 (dd, *J* = 13.6, 7.1 Hz, 1H), 1.31 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 153.2, 133.5, 127.3, 126.4, 80.8, 45.5, 34.9, 31.3.

The characterisation data match the literature.

1-(1-Bromo-2-nitroethyl)-3-fluorobenzene (38)



Compound **38** was obtained according to general procedure **GP2** as a colorless liquid (60% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

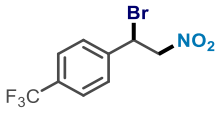
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.36 (td, *J* = 8.0, 5.8 Hz, 1H), 7.24 – 7.19 (m, 1H), 7.18 – 7.13 (m, 1H), 7.11 – 7.02 (m, 1H), 5.53 (t, *J* = 7.7 Hz, 1H), 5.01 (dd, *J* = 13.8, 7.6 Hz, 1H), 4.94 (dd, *J* = 13.8, 7.6 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 162.9 (d, *J* = 248.4 Hz), 131.1 (d, *J* = 8.3 Hz), 123.33 (d, *J* = 3.1 Hz), 116.97 (d, *J* = 21.0 Hz), 114.88 (d, *J* = 22.8 Hz), 80.35, 44.10 (d, *J* = 2.2 Hz).

^{19}F-NMR (377 MHz, $CDCl_3$): δ -110.8.

The characterisation data match the literature.

1-(1-Bromo-2-nitroethyl)-4-(trifluoromethyl)benzene (39)



Compound **39** was obtained according to general procedure **GP2** as a yellow liquid (54% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.66 (d, *J* = 8.2 Hz, 2H), 7.57 (d, *J* = 8.2 Hz, 2H), 5.58 (t, *J* = 7.7 Hz, 1H), 5.05 (dd, *J* = 13.8, 7.8 Hz, 1H), 4.97 (dd, *J* = 13.8, 7.8 Hz, 1H).

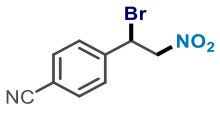
^{13}C-NMR (101 MHz, $CDCl_3$): δ 140.5 (d, *J* = 1.4 Hz), 132.0 (q, *J* = 32.9 Hz), 128.2, 126.45 (q, *J* = 3.8 Hz), 123.67 (q, *J* = 272.3 Hz), 80.16, 43.68.

^{19}F-NMR (377 MHz, $CDCl_3$): δ -62.9.

FT-IR (ATR, neat; cm^{-1}): 3022, 2932, 1586, 1379, 1163.

HRMS (ESI) *m/z*, $C_9H_7BrF_3NO_2$: 296.9612; found 296.9611.

4-(1-Bromo-2-nitroethyl)benzonitrile (40)



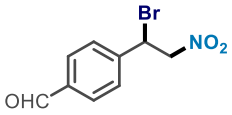
Compound **40** was obtained according to general procedure **GP2** as a colorless liquid (48% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.70 (d, *J* = 8.4 Hz, 2H), 7.56 (d, *J* = 8.4 Hz, 2H), 5.54 (t, *J* = 7.7 Hz, 1H), 5.04 (dd, *J* = 13.9, 7.5 Hz, 1H), 4.97 (dd, *J* = 13.9, 8.0 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 141.6, 133.2, 128.6, 117.9, 113.9, 79.9, 43.2.

The characterisation data match the literature.

4-(1-Bromo-2-nitroethyl)benzaldehyde (41)



Compound **41** was obtained according to general procedure **GP2** as a colorless liquid (52% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

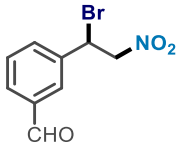
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.92 – 7.81 (m, 4H), 7.58 – 7.49 (m, 3H), 5.75 (t, *J* = 7.7 Hz, 1H), 5.14 (dd, *J* = 13.6, 8.0 Hz, 1H), 5.07 (dd, *J* = 13.6, 7.4 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 191.2, 142.7, 137.2, 130.6, 128.4, 80.0, 43.8.

FT-IR (ATR, neat; cm^{-1}): 3024, 2862, 2738, 1689, 1556, 1164.

HRMS (ESI) *m/z*, $C_9H_8BrNO_3$: 256.9688; found 256.9686.

3-(1-Bromo-2-nitroethyl)benzaldehyde (42)



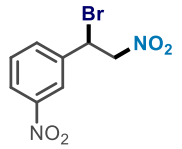
Compound **42** was obtained according to general procedure **GP2** as a yellow liquid (60% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 10.01 (s, 1H), 7.95 (t, *J* = 1.8 Hz, 1H), 7.87 (dt, *J* = 7.6, 1.4 Hz, 1H), 7.74 – 7.68 (m, 1H), 7.58 (t, *J* = 7.6 Hz, 1H), 5.61 (t, *J* = 7.7 Hz, 1H), 5.08 (dd, *J* = 13.8, 7.8 Hz, 1H), 5.01 (dd, *J* = 13.8, 7.8 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 191.3, 138.0, 137.2, 133.5, 131.2, 130.2, 128.2, 80.1, 44.0.

The characterisation data match the literature.

1-(1-Bromo-2-nitroethyl)-3-nitrobenzene (43)



Compound **43** was obtained according to general procedure **GP2** as a yellow oil (58% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

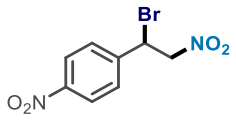
^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.31 (t, *J* = 2.0 Hz, 1H), 8.21 (ddd, *J* = 8.2, 2.2, 1.0 Hz, 1H), 7.79 (ddd, *J* = 7.8, 1.9, 1.1 Hz, 1H), 7.60 (t, *J* = 8.0 Hz, 1H), 5.62 (t, *J* = 7.7 Hz, 1H), 5.15 – 4.97 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 148.6, 138.8, 133.7, 130.6, 124.6, 122.8, 79.9, 43.0.

FT-IR (ATR, neat; cm^{-1}): 3013, 1558, 1532, 1388, 1349.

HRMS (ESI) *m/z*, $C_8H_7BrN_2O_4$: 273.9589; found 273.9587.

1-(1-Bromo-2-nitroethyl)-4-nitrobenzene (44)



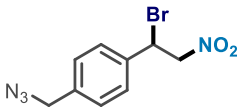
Compound **44** was obtained according to general procedure **GP2** as a yellow liquid (49% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.26 (d, *J* = 8.7 Hz, 2H), 7.64 (d, *J* = 8.8 Hz, 2H), 5.60 (t, *J* = 7.8 Hz, 1H), 5.07 (dd, *J* = 13.9, 7.4 Hz, 1H), 5.00 (dd, *J* = 13.9, 8.1 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 148.6, 143.4, 128.9, 124.6, 79.9, 42.7.

The characterisation data match the literature.

1-(Azidomethyl)-4-(1-bromo-2-nitroethyl)benzene (45)



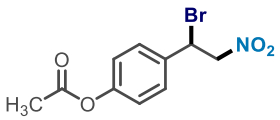
Compound **45** was obtained according to general procedure **GP2** as a yellow liquid (74% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 10.01 (s, 1H), 7.95 (t, *J* = 1.8 Hz, 1H), 7.87 (dt, *J* = 7.6, 1.4 Hz, 1H), 7.74 – 7.68 (m, 1H), 7.58 (t, *J* = 7.6 Hz, 1H), 5.61 (t, *J* = 7.7 Hz, 1H), 5.08 (dd, *J* = 13.8, 7.8 Hz, 1H), 5.01 (dd, *J* = 13.8, 7.8 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 191.3, 138.0, 137.2, 133.5, 131.2, 130.2, 128.2, 80.1, 44.0.

The characterisation data match the literature.

4-(1-Bromo-2-nitroethyl)phenyl acetate (46)



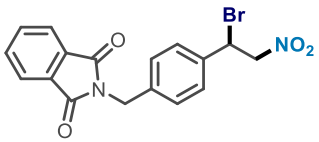
Compound **46** was obtained according to general procedure **GP2** as a yellow liquid (69% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.45 (d, *J* = 8.6 Hz, 2H), 7.13 (d, *J* = 8.6 Hz, 2H), 5.56 (dd, *J* = 8.2, 7.1 Hz, 1H), 5.02 (dd, J = 13.8, 8.2 Hz, 1H), 4.93 (dd, J = 13.8, 7.1 Hz, 1H), 2.31 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 169.2, 151.6, 134.1, 128.9, 122.6, 80.7, 44.6, 21.3.

The characterisation data match the literature.

2-(4-(1-Bromo-2-nitroethyl)benzyl)isoindoline-1,3-dione (47)



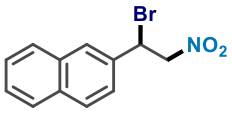
Compound **47** was obtained according to general procedure **GP2** as a white solid (68% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.84 (dd, *J* = 5.4, 3.1 Hz, 2H), 7.71 (dd, *J* = 5.5, 3.1 Hz, 2H), 7.45 (d, *J* = 8.3 Hz, 2H), 7.37 (d, *J* = 8.3 Hz, 2H), 5.52 (t, *J* = 7.7 Hz, 1H), 4.99 (dd, *J* = 13.7, 8.1 Hz, 1H), 4.90 (dd, *J* = 13.8, 7.3 Hz, 2H), 4.83 (s, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 168.1, 138.2, 136.2, 134.3, 132.1, 129.7, 128.0, 123.6, 80.5, 44.9, 41.2.

The characterisation data match the literature.

2-(1-Bromo-2-nitroethyl)naphthalene (48)



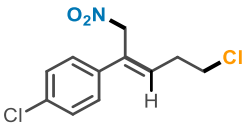
Compound **48** was obtained according to general procedure **GP2** as a yellow solid (65% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.92 – 7.81 (m, 4H), 7.58 – 7.49 (m, 3H), 5.75 (t, *J* = 7.7 Hz, 1H), 5.14 (dd, *J* = 13.6, 8.0 Hz, 1H), 5.07 (dd, *J* = 13.6, 7.4 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 133.8, 133.7, 133.1, 129.7, 128.3, 128.0, 127.5, 127.2, 127.2, 124.5, 80.6, 45.9.

The characterisation data match the literature.

(*Z*)-1-Chloro-4-(5-chloro-1-nitropent-2-en-2-yl)benzene (49a)



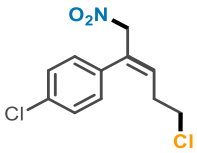
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.38 – 7.29 (m, 4H), 6.24 (t, *J* = 7.5 Hz, 1H), 5.39 (s, 2H), 3.69 (t, *J* = 6.4 Hz, 2H), 2.82 (dt, *J* = 7.4, 6.4 Hz, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 137.7, 134.8, 134.4, 131.7, 129.1, 127.6, 74.6, 43.3, 32.3.

FT-IR (ATR, neat; cm^{-1}): 3011, 2976, 1551, 1489, 1376.

HRMS (ESI) *m/z*, $C_{11}H_{11}Cl_2NO_2$: 259.0167; found 259.0166.

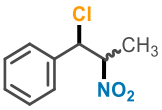
(*E*)-1-Chloro-4-(5-chloro-1-nitropent-2-en-2-yl)benzene (49b)



^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.36 (d, *J* = 8.5 Hz, 2H), 7.14 (d, *J* = 8.5 Hz, 2H), 6.09 – 6.01 (m, 1H), 5.16 (s, 2H), 3.54 (t, *J* = 6.5 Hz, 2H), 2.59 – 2.50 (m, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 135.5, 134.6, 133.0, 130.0, 129.2, 82.6, 43.4, 32.2.

(1-Chloro-2-nitropropyl)benzene (53)



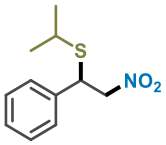
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44 – 7.34 (m, 5H), 5.38 (d, *J* = 7.6 Hz, 1H), 4.93 (dq, *J* = 7.6, 6.6 Hz, 1H), 1.76 (d, *J* = 6.6 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 136.4, 129.6, 129.1, 127.6, 87.7, 62.8, 16.0.

FT-IR (ATR, neat; cm^{-1}): 3015, 2948, 1416, 1246, 1043.

HRMS (ESI) *m/z*, $C_9H_{10}ClNO_2$: 199.0400; found 199.0498.

Isopropyl(2-nitro-1-phenylethyl)sulfane (54)



Compound **54** was obtained according to general procedure **GP3** as a yellow liquid (47% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

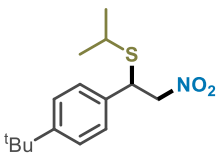
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.39 – 7.27 (m, 5H), 4.72 (dd, *J* = 7.8, 1.0 Hz, 2H), 4.60 (dd, *J* = 8.8, 6.8 Hz, 1H), 2.80 (hept, *J* = 6.7 Hz, 1H), 1.27 (d, *J* = 6.6 Hz, 3H), 1.22 (d, *J* = 6.7 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.1, 129.1, 128.5, 127.8, 79.9, 45.8, 35.6, 23.4, 23.3.

FT-IR (ATR, neat; cm^{-1}): 3031, 2991, 2858, 1555.

HRMS (ESI) *m/z*, $C_{11}H_{15}NO_2S$: 225.0823; found 225.0825.

(1-(4-(*tert*-Butyl)phenyl)-2-nitroethyl)(isopropyl)sulfane (55)



Compound **55** was obtained according to general procedure **GP3** as a yellow liquid (56% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

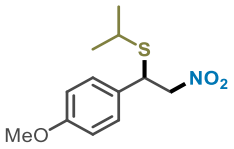
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.35 (d, *J* = 8.6 Hz, 2H), 7.26 (d, *J* = 8.6 Hz, 3H), 4.72 (d, *J* = 3.0 Hz, 1H), 4.70 (d, *J* = 0.7 Hz, 1H), 4.57 (dd, *J* = 8.9, 6.7 Hz, 1H), 2.82 (p, *J* = 6.7 Hz, 1H), 1.30 (s, 9H), 1.27 (d, *J* = 6.7 Hz, 4H), 1.23 (d, *J* = 6.8 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 151.5, 134.8, 127.3, 126.1, 79.9, 45.4, 35.5, 34.7, 31.4, 23.4, 23.3.

FT-IR (ATR, neat; cm^{-1}): 3022, 2985, 2857, 1562, 1248.

HRMS (ESI) *m/z*, $C_{15}H_{23}NO_2S$: 281.1450; found 281.1452.

Isopropyl(1-(4-methoxyphenyl)-2-nitroethyl)sulfane (56)



Compound **56** was obtained according to general procedure **GP3** as a yellow liquid (86% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

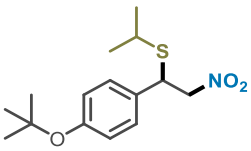
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.27 (d, *J* = 8.7 Hz, 2H), 6.87 (d, *J* = 8.7 Hz, 2H), 4.71 – 4.65 (m, 2H), 4.56 (dd, *J* = 8.3, 7.3 Hz, 1H), 3.79 (s, 3H), 2.78 (p, *J* = 6.7 Hz, 1H), 1.26 (d, *J* = 6.7 Hz, 3H), 1.22 (d, *J* = 6.7 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 159.6, 129.8, 128.9, 114.5, 80.0, 55.4, 45.3, 35.4, 23.4, 23.3.

FT-IR (ATR, neat; cm^{-1}): 3002, 2975, 1552, 1264, 1043.

HRMS (ESI) *m/z*, $C_{12}H_{17}NO_3S$: 255.0929; found 255.0928.

(1-(4-(*tert*-Butoxy)phenyl)-2-nitroethyl)(isopropyl)sulfane (57)



Compound **57** was obtained according to general procedure **GP3** as a yellow liquid (81% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

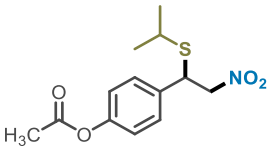
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.23 (d, *J* = 8.6 Hz, 2H), 6.94 (d, *J* = 8.6 Hz, 2H), 4.72 – 4.65 (m, 2H), 4.57 (dd, *J* = 8.7, 6.8 Hz, 1H), 2.79 (p, *J* = 6.7 Hz, 1H), 1.33 (s, 9H), 1.24 (d, *J* = 6.7 Hz, 3H), 1.21 (d, *J* = 6.7 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 159.6, 129.8, 128.9, 114.5, 80.0, 55.4, 45.3, 35.4, 23.4, 23.3.

FT-IR (ATR, neat; cm^{-1}): 3017, 2984, 1559, 1166, 1063.

HRMS (ESI) *m/z*, calcd for $[C_{15}H_{23}NO_3S–CH_3]^+$: 282.1164; found 282.1162.

4-(1-(Isopropylthio)-2-nitroethyl)phenyl acetate (58)



Compound **58** was obtained according to general procedure **GP3** as a yellow liquid (77% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

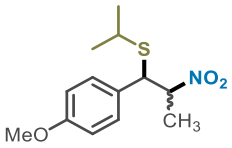
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.37 (d, *J* = 8.6 Hz, 2H), 7.09 (d, *J* = 8.6 Hz, 2H), 4.72 – 4.65 (m, 2H), 4.60 (dd, *J* = 8.7, 6.6 Hz, 1H), 2.79 (p, *J* = 6.7 Hz, 1H), 2.29 (s, 3H), 1.26 (d, *J* = 6.6 Hz, 3H), 1.21 (d, *J* = 6.8 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 169.3, 150.6, 135.6, 128.9, 122.3, 79.8, 45.2, 35.6, 23.4, 23.3, 21.3.

FT-IR (ATR, neat; cm^{-1}): 3037, 1754, 1716, 1317, 1206, 1066, 754.

HRMS (ESI) *m/z*, $C_{13}H_{17}NO_4S$ Exact Mass: 283.0878; found 283.0880.

Isopropyl(1-(4-methoxyphenyl)-2-nitropropyl)sulfane (59)



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Compound **59** was obtained according to general procedure **GP3** as a yellow liquid (59% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

Major isomer:

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.22 (d, *J* = 8.7 Hz, 2H), 6.87 (d, *J* = 8.7 Hz, 2H), 4.78 (dq, *J* = 9.3, 6.7 Hz, 1H), 4.28 (d, *J* = 9.3 Hz, 1H), 3.81 (s, 3H), 2.69 (p, *J* = 6.7 Hz, 1H), 1.35 (d, *J* = 6.7 Hz, 3H), 1.22 (d, *J* = 6.6 Hz, 3H), 1.14 (d, *J* = 6.8 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 159.6, 129.7, 114.4, 87.5, 55.4, 51.4, 35.7, 23.3, 23.2, 17.8.

Minor isomer:

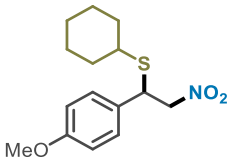
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.31 – 7.22 (m, 3H), 6.84 (d, *J* = 8.7 Hz, 2H), 4.78 (dq, *J* = 9.3, 6.6 Hz, 1H), 4.30 (d, *J* = 9.4 Hz, 1H), 3.79 (s, 3H), 2.60 (p, *J* = 6.7 Hz, 1H), 1.72 (d, *J* = 6.6 Hz, 3H), 1.23 (d, *J* = 6.5 Hz, 3H), 1.14 (d, *J* = 6.9 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 159.5, 130.3, 129.4, 114.3, 88.2, 55.4, 52.0, 35.3, 23.6, 23.1, 17.9.

FT-IR (ATR, neat; cm^{-1}): 3026, 2974, 1517, 1306, 1119.

HRMS (ESI) *m/z*, $C_{13}H_{19}NO_3S$: 269.1086; found 269.1085.

Cyclohexyl(1-(4-methoxyphenyl)-2-nitroethyl)sulfane (60)



Compound **60** was obtained according to general procedure **GP3** as a yellow liquid (69% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

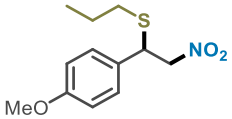
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.28 (d, *J* = 8.7 Hz, 2H), 6.89 (d, *J* = 8.7 Hz, 2H), 4.75 – 4.67 (m, 2H), 4.60 (dd, *J* = 8.5, 7.1 Hz, 1H), 3.81 (s, 3H), 2.65 – 2.52 (m, 1H), 2.02 – 1.83 (m, 2H), 1.81 – 1.67 (m, 2H), 1.65 – 1.52 (m, 1H), 1.40 – 1.20 (m, 5H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 159.5, 130.0, 128.8, 114.5, 80.1, 55.4, 44.7, 43.9, 33.6, 33.5, 25.7.

FT-IR (ATR, neat; cm^{-1}): 3032, 1543, 1417, 1356, 1166.

HRMS (ESI) *m/z*, $C_{15}H_{21}NO_3S$: 295.1242; found 295.1240.

(1-(4-Methoxyphenyl)-2-nitroethyl)(propyl)sulfane (61)



Compound **61** was obtained according to general procedure **GP3** as a yellow liquid (72% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

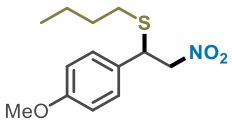
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.28 (d, *J* = 8.7 Hz, 2H), 6.89 (d, *J* = 8.7 Hz, 2H), 4.76 – 4.70 (m, 2H), 4.53 (t, *J* = 7.9 Hz, 1H), 3.82 (s, 3H), 2.43 (t, *J* = 7.3 Hz, 2H), 1.58 (q, *J* = 7.3 Hz, 2H), 0.96 (t, *J* = 7.3 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 159.7, 129.4, 128.9, 114.5, 79.7, 55.4, 46.1, 33.7, 22.7, 13.5.

FT-IR (ATR, neat; cm^{-1}): 3025, 2942, 1537, 1331, 1166.

HRMS (ESI) *m/z*, $C_{12}H_{17}NO_3S$: 255.0929; found 255.0929.

Butyl(1-(4-methoxyphenyl)-2-nitroethyl)sulfane (62)



Compound **62** was obtained according to general procedure **GP3** as a yellow liquid (71% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

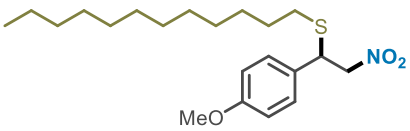
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.28 (d, *J* = 8.7 Hz, 2H), 6.89 (d, *J* = 8.7 Hz, 2H), 4.77 – 4.71 (m, 2H), 4.54 (t, *J* = 7.9 Hz, 1H), 2.49 – 2.41 (m, 2H), 1.60 – 1.48 (m, 2H), 1.43 – 1.27 (m, 2H), 0.89 (t, *J* = 7.3 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 159.7, 129.4, 128.9, 114.5, 79.7, 55.4, 46.1, 31.4, 31.3, 22.0, 13.7.

FT-IR (ATR, neat; cm^{-1}): 3031, 2976, 1566, 1386, 1256.

HRMS (ESI) *m/z*, $C_{13}H_{19}NO_3S$: 269.1086; found 269.1086.

Dodecyl(1-(4-methoxyphenyl)-2-nitroethyl)sulfane (63)



Compound **63** was obtained according to general procedure **GP3** as a yellow liquid (58% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

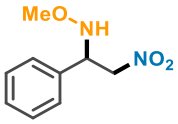
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.25 (d, *J* = 8.7 Hz, 2H), 6.87 (d, *J* = 8.7 Hz, 2H), 4.75 – 4.67 (m, 2H), 4.51 (t, *J* = 7.9 Hz, 1H), 3.79 (s, 3H), 2.47 – 2.38 (m, 2H), 1.51 (d, *J* = 7.3 Hz, 2H), 1.28 – 1.21 (m, 18H), 0.89 (t, *J* = 6.5 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 159.7, 129.4, 128.9, 114.5, 79.7, 55.4, 46.2, 32.0, 31.8, 29.8, 29.7, 29.6, 29.5, 29.3, 29.2, 28.9, 22.8, 14.2.

FT-IR (ATR, neat; cm^{-1}): 3002, 2987, 1547, 1391, 1270.

HRMS (ESI) *m/z*, $C_{21}H_{35}NO_3S$: 381.2338; found 381.2336.

O-Methyl-*N*-(2-nitro-1-phenylethyl)hydroxylamine (64)



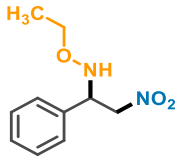
Compound **64** was obtained according to general procedure **GP4** as a yellow liquid (60% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.40 – 7.31 (m, 5H), 5.89 (s, 1H), 4.89 (dd, *J* = 12.4, 7.9 Hz, 1H), 4.78 (dd, *J* = 7.9, 5.1 Hz, 1H), 4.60 (dd, *J* = 12.4, 5.1 Hz, 1H), 3.52 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 135.9, 129.2, 129.2, 127.7, 78.0, 63.1, 62.9.

The characterisation data match the literature.

O-Ethyl-*N*-(2-nitro-1-phenylethyl)hydroxylamine (65)



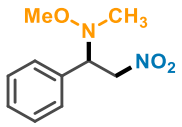
Compound **65** was obtained according to general procedure **GP4** as a yellow liquid (78% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.43 – 7.30 (m, 5H), 5.75 (s, 1H), 4.90 (dd, *J* = 12.4, 7.7 Hz, 1H), 4.79 (dd, J = 7.7, 5.2 Hz, 1H), 4.60 (dd, *J* = 12.4, 5.2 Hz, 1H), 3.71 (q, *J* = 7.0 Hz, 2H), 1.13 (t, *J* = 7.0 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 136.0, 129.2, 129.1, 127.8, 78.2, 70.4, 63.2, 14.0.

The characterisation data match the literature.

N,*O*-Dimethyl-*N*-(2-nitro-1-phenylethyl)hydroxylamine (66)



Compound **66** was obtained according to general procedure **GP4** as a yellow liquid (69% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

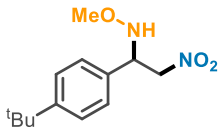
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.35 – 7.25 (m, 5H), 4.96 (dd, *J* = 12.5, 8.4 Hz, 1H), 4.45 (dd, *J* = 12.5, 5.0 Hz, 1H), 4.35 (dd, *J* = 8.4, 5.0 Hz, 1H), 3.49 (s, 3H), 2.38 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 129.0, 129.0, 128.8, 78.7, 70.5, 60.6, 42.4.

FT-IR (ATR, neat; cm^{-1}): 3037, 1754, 1716, 1317, 1206, 1066, 754.

HRMS (ESI) *m/z*, $C_{10}H_{14}N_2O_3$: 210.1004; found 210.1006.

N-(1-(4-(*tert*-Butyl)phenyl)-2-nitroethyl)-*O*-methylhydroxylamine (67)



Compound **67** was obtained according to general procedure **GP4** as a yellow liquid (72% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

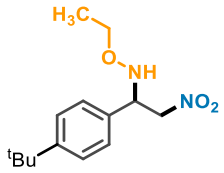
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.37 (d, *J* = 8.6 Hz, 2H), 7.25 (d, *J* = 8.3 Hz, 2H), 5.83 (d, *J* = 4.0 Hz, 1H), 4.87 (dd, *J* = 12.2, 7.9 Hz, 1H), 4.75 (dt, *J* = 8.1, 4.3 Hz, 1H), 4.58 (dd, *J* = 12.2, 5.0 Hz, 1H), 3.50 (s, 3H), 1.29 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 152.2, 132.7, 127.3, 126.0, 78.0, 62.8, 34.7, 31.3.

FT-IR (ATR, neat; cm^{-1}): 3150, 3021, 2964, 1523, 1452, 1285, 1044, 730.

HRMS (ESI) *m/z*, $C_{13}H_{20}N_2O_3$: 252.1474; found 252.1472.

N-(1-(4-(*tert*-Butyl)phenyl)-2-nitroethyl)-*O*-ethylhydroxylamine (68)



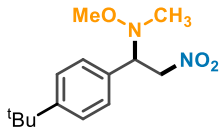
Compound **68** was obtained according to general procedure **GP4** as a yellow liquid (67% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.39 (d, *J* = 8.4 Hz, 2H), 7.27 (d, *J* = 8.4 Hz, 2H), 5.68 (s, 1H), 4.90 (dd, *J* = 12.2, 7.7 Hz, 1H), 4.78 (dd, *J* = 7.7, 5.1 Hz, 1H), 4.59 (dd, *J* = 12.2, 5.1 Hz, 1H), 3.71 (t, *J* = 7.0 Hz, 2H), 1.31 (s, 9H), 1.14 (t, *J* = 7.0 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 152.2, 132.8, 127.4, 126.0, 78.3, 70.3, 62.9, 34.8, 31.4, 14.0.

The characterisation data match the literature.

N-(1-(4-(*tert*-Butyl)phenyl)-2-nitroethyl)-*N*,*O*-dimethylhydroxylamine (69)



Compound **69** was obtained according to general procedure **GP4** as a yellow liquid (81% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

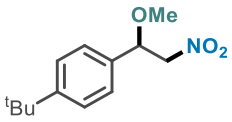
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.37 (d, *J* = 8.4 Hz, 2H), 7.24 (d, *J* = 8.4 Hz, 2H), 5.01 (dd, *J* = 12.5, 8.7 Hz, 1H), 4.49 (dd, *J* = 12.5, 4.8 Hz, 1H), 4.39 (dd, *J* = 8.7, 4.8 Hz, 1H), 3.54 (s, 3H), 2.42 (s, 3H), 1.31 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 152.0, 128.5, 125.8, 125.8, 78.6, 70.0, 60.5, 42.3, 34.7, 31.4.

FT-IR (ATR, neat; cm^{-1}): 3015, 2969, 1553, 1461, 1044.

HRMS (ESI) *m/z*, $C_{14}H_{22}N_2O_3$: 266.1630; found 266.1628.

1-(*tert*-Butyl)-4-(1-methoxy-2-nitroethyl)benzene (70)



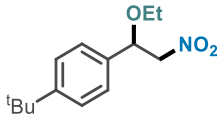
Compound **70** was obtained according to general procedure **GP5** as a yellow liquid (95% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.43 (d, *J* = 8.4 Hz, 2H), 7.28 (d, *J* = 8.3 Hz, 2H), 4.93 (dd, *J* = 10.2, 3.3 Hz, 1H), 4.61 (dd, *J* = 12.7, 10.2 Hz, 1H), 4.38 (dd, *J* = 12.7, 3.3 Hz, 1H), 3.27 (s, 3H), 1.33 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 152.4, 133.0, 126.7, 126.1, 80.6, 80.0, 57.2, 34.8, 31.4.

The characterisation data match the literature.

1-(*tert*-Butyl)-4-(1-ethoxy-2-nitroethyl)benzene (71)



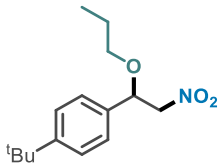
Compound **71** was obtained according to general procedure **GP5** as a yellow liquid (94% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.41 (d, *J* = 8.3 Hz, 2H), 7.29 (d, *J* = 8.3 Hz, 2H), 5.04 (dd, *J* = 10.2, 3.4 Hz, 1H), 4.60 (dd, *J* = 12.7, 10.2 Hz, 1H), 4.37 (dd, *J* = 12.7, 3.4 Hz, H), 3.43 (ddq, *J* = 37.2, 9.3, 7.0 Hz, 2H), 1.33 (s, 9H), 1.16 (t, *J* = 7.0 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 152.2, 133.8, 126.6, 126.0, 80.8, 78.1, 65.0, 34.8, 31.4, 15.1.

The characterisation data match the literature.

1-(*tert*-Butyl)-4-(2-nitro-1-propoxyethyl)benzene (72)



Compound **72** was obtained according to general procedure **GP5** as a yellow liquid (90% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

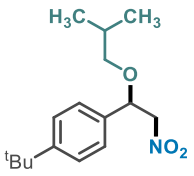
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.41 (d, *J* = 8.4 Hz, 2H), 7.29 (d, *J* = 8.4 Hz, 2H), 5.03 (dd, *J* = 10.2, 3.3 Hz, 1H), 4.60 (dd, *J* = 12.7, 10.2 Hz, 1H), 4.37 (dd, *J* = 12.7, 3.3 Hz, 1H), 3.38 (dt, *J* = 9.1, 6.6 Hz, 1H), 3.27 (dt, *J* = 9.1, 6.6 Hz, 1H), 1.60 – 1.51 (m, 3H), 1.34 – 1.32 (m, 9H), 0.87 (*t*, J = 7.4 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 152.2, 133.8, 126.6, 126.0, 80.8, 78.3, 71.3, 34.8, 31.5, 22.9, 10.6.

FT-IR (ATR, neat; cm^{-1}): 2964, 1633, 1527, 1335, 1262, 1176.

HRMS (ESI) *m/z* $C_{15}H_{23}NO_3$ Exact Mass: 265.1678; found 265.1680.

1-(*tert*-Butyl)-4-(1-isobutoxy-2-nitroethyl)benzene (73)



Compound **73** was obtained according to general procedure **GP5** as a yellow liquid (87% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

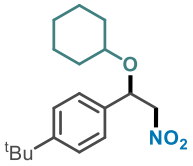
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.42 (d, *J* = 8.4 Hz, 2H), 7.28 (d, *J* = 8.4 Hz, 2H), 5.02 (dd, *J* = 10.3, 3.2 Hz, 1H), 4.60 (dd, *J* = 12.6, 10.3 Hz, 1H), 4.37 (dd, *J* = 12.6, 3.3 Hz, 1H), 3.20 (dd, *J* = 8.8, 6.6 Hz, 1H), 3.05 (dd, *J* = 8.8, 6.6 Hz, 1H), 1.84 (dt, *J* = 13.3, 6.7 Hz, 1H), 1.33 (s, 9H), 0.86 (d, *J* = 6.7 Hz, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 152.1, 133.7, 126.5, 126.0, 80.8, 78.5, 76.3, 34.8, 31.5, 31.4, 28.6, 19.4, 19.3.

FT-IR (ATR, neat; cm^{-1}): 3004, 2954, 1516, 1268, 1074.

HRMS (ESI) *m/z*, $C_{16}H_{25}NO_3$: 279.1834; found 279.1836.

1-(*tert*-Butyl)-4-(1-(cyclohexyloxy)-2-nitroethyl)benzene (74)



Compound **74** was obtained according to general procedure **GP5** as a yellow liquid (81% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

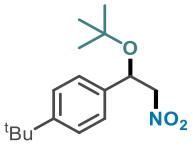
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.41 (d, *J* = 8.4 Hz, 2H), 7.31 (d, *J* = 8.3 Hz, 2H), 5.21 (dd, *J* = 10.3, 3.3 Hz, 1H), 4.56 (dd, *J* = 12.5, 10.3 Hz, 1H), 4.35 (dd, *J* = 12.5, 3.3 Hz, 1H), 3.27 (td, *J* = 9.0, 4.5 Hz, 1H), 1.85 (d, *J* = 14.1 Hz, 1H), 1.74 – 1.57 (m, 4H), 1.49 – 1.41 (m, 1H), 1.33 (s, 9H), 1.22 – 1.10 (m, 4H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 151.9, 134.7, 126.5, 125.9, 81.2, 75.7, 75.5, 34.8, 33.3, 31.4, 25.8, 24.0, 23.7.

FT-IR (ATR, neat; cm^{-1}): 3013, 2936, 1564, 1235, 1056.

HRMS (ESI) *m/z*, $C_{18}H_{27}NO_3$: 305.1991; found 305.1989.

1-(1-(*tert*-Butoxy)-2-nitroethyl)-4-(*tert*-butyl)benzene (75)



Compound **75** was obtained according to general procedure **GP5** as a yellow liquid (77% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

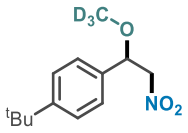
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.37 (d, *J* = 8.5 Hz, 2H), 7.32 (d, *J* = 8.5 Hz, 2H), 5.25 (dd, *J* = 10.0, 3.4 Hz, 1H), 4.48 (dd, *J* = 11.9, 10.0 Hz, 1H), 4.31 (dd, *J* = 11.9, 3.4 Hz, 1H), 1.31 (s, 9H), 1.10 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 151.5, 137.2, 126.1, 125.8, 82.2, 75.5, 72.0, 34.7, 31.5, 31.2, 28.5.

FT-IR (ATR, neat; cm^{-1}): 3025, 2975, 1575, 1387, 1068.

HRMS (ESI) *m/z*, $C_{16}H_{25}NO_3$: 279.1834; found 279.1830.

1-(*tert*-Butyl)-4-(1-(methoxy-d_3)-2-nitroethyl)benzene (76)



Compound **76** was obtained according to general procedure **GP5** as a yellow liquid (91% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

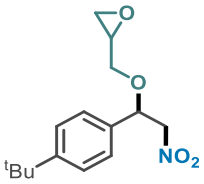
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.34 (d, *J* = 8.4 Hz, 2H), 7.20 (d, *J* = 8.4 Hz, 2H), 4.84 (dd, *J* = 10.2, 3.3 Hz, 1H), 4.51 (dd, *J* = 12.7, 10.2 Hz, 1H), 4.29 (dd, *J* = 12.7, 3.3 Hz, 1H), 1.24 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 152.4, 133.0, 126.7, 126.1, 80.6, 79.9, 34.8, 31.4.

FT-IR (ATR, neat; cm^{-1}): 3117, 3058, 2969, 2864, 1558, 1348, 1165.

HRMS (ESI) *m/z*, $C_{13}H_{16}D_3NO_3$: 240.1553; found 240.1550.

2-((1-(4-(*tert*-Butyl)phenyl)-2-nitroethoxy)methyl)oxirane (77)



Compound **77** was obtained according to general procedure **GP5** as a yellow liquid (88% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

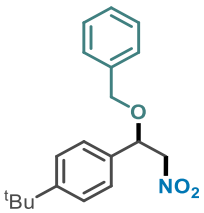
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.42 (dd, *J* = 8.4, 1.6 Hz, 2H), 7.29 (dd, *J* = 8.4, 1.6 Hz, 2H), 5.17 (ddd, *J* = 35.4, 10.1, 3.4 Hz, 1H), 4.64 (ddd, *J* = 13.3, 10.1, 3.4 Hz, 1H), 4.39 (ddd, *J* = 13.3, 4.4, 3.3 Hz, 1H), 3.64 (ddd, *J* = 37.4, 11.5, 3.1 Hz, 1H), 3.35 (ddd, *J* = 34.3, 11.5, 5.8 Hz, 1H), 3.09 (ttd, *J* = 5.8, 2.9, 1.8 Hz, 1H), 2.74 (ddd, *J* = 17.2, 5.0, 4.4 Hz, 1H), 2.51 (ddd, *J* = 18.9, 5.0, 2.9 Hz, 1H), 1.32 (s, 9H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 152.5, 152.5, 132.9, 132.8, 126.8, 126.6, 126.2, 126.1, 126.1, 125.9, 81.4, 80.4, 80.4, 78.8, 78.2, 77.4, 71.0, 70.2, 69.5, 50.7, 50.5, 44.6, 44.0, 34.8, 31.4.

FT-IR (ATR, neat; cm^{-1}): 2967, 1578, 1483, 1375, 1325, 1176, 1053.

HRMS (ESI) *m/z*, $C_{15}H_{21}NO_4$: 279.1471; found 279.1470.

1-(1-(Benzyloxy)-2-nitroethyl)-4-(*tert*-butyl)benzene (78)



Compound **78** was obtained according to general procedure **GP5** as a yellow liquid (84% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

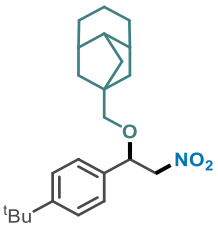
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.47 – 7.41 (m, 2H), 7.37 – 7.28 (m, 5H), 7.27 – 7.22 (m, 2H), 5.14 (dd, *J* = 10.1, 3.3 Hz, 1H), 4.69 (dd, *J* = 12.8, 10.1 Hz, 1H), 4.53 (d, *J* = 11.6 Hz, 1H), 4.40 (dd, *J* = 12.8, 3.3 Hz, 1H), 4.34 (d, *J* = 11.6 Hz, 1H), 1.34 (s, 9H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 152.5, 137.3, 133.1, 128.6, 128.0, 128.0, 126.8, 126.2, 80.5, 77.5, 71.0, 34.9, 31.4.

FT-IR (ATR, neat; cm^{-1}): 3012, 2946, 1575, 1524, 1386, 1296, 1035.

HRMS (ESI) *m/z*, $C_{19}H_{23}NO_3$ Exact Mass: 313.1678; found 313.1676.

2-((1-(4-(*tert*-Butyl)phenyl)-2-nitroethoxy)methyl)octahydro-1H-2,4-methanoindene (79)



Compound **79** was obtained according to general procedure **GP5** as a yellow liquid (79% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

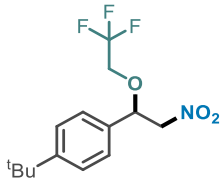
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.43 (d, *J* = 8.1 Hz, 2H), 7.31 – 7.27 (m, 2H), 4.99 (dd, *J* = 10.3, 3.3 Hz, 1H), 4.60 (dd, *J* = 12.5, 10.3 Hz, 1H), 4.39 (dd, *J* = 12.6, 3.3 Hz, 1H), 3.04 (d, *J* = 8.5 Hz, 1H), 2.87 (d, *J* = 8.5 Hz, 1H), 1.99 – 1.95 (m, 3H), 1.77 – 1.63 (m, 8H), 1.55 – 1.51 (m, 4H), 1.35 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 152.0, 133.9, 126.5, 126.0, 80.8, 80.3, 78.7, 39.6, 37.3, 36.7, 36.0, 34.8, 34.2, 31.5, 31.4, 28.3, 27.5.

FT-IR (ATR, neat; cm^{-1}): 3018, 2964, 1534, 1512, 1424, 1337, 1296.

HRMS (ESI) *m/z*, $C_{23}H_{33}NO_3$: 371.2460; found 371.2462.

1-(*tert*-Butyl)-4-(2-nitro-1-(2,2,2-trifluoroethoxy)ethyl)benzene (80)



Compound **80** was obtained according to general procedure **GP5** as a yellow liquid (55% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 (d, *J* = 8.5 Hz, 2H), 7.29 (d, *J* = 8.2 Hz, 2H), 5.23 (dd, *J* = 9.9, 3.3 Hz, 1H), 4.70 (dd, *J* = 13.4, 9.9 Hz, 1H), 4.41 (dd, *J* = 13.4, 3.3 Hz, 1H), 3.74 (qd, *J* = 8.5, 5.4 Hz, 2H), 1.33 (s, 9H).

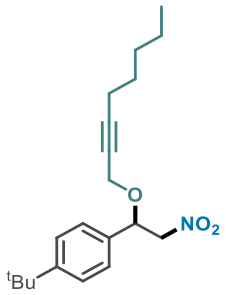
^{13}C-NMR (75 MHz, $CDCl_3$): δ 153.24, 131.29, 126.78, 126.47, 79.83, 79.29, 66.23 (q, *J* = 34.9 Hz), 34.91, 31.36.

^{19}F-NMR (282 MHz, $CDCl_3$): δ -73.97.

FT-IR (ATR, neat; cm^{-1}): 3023, 2985, 1636, 1524, 1436, 1380, 1166.

HRMS (ESI) *m/z*, $C_{14}H_{18}F_3NO_3$: 305.1239; found 305.1237.

1-(*tert*-Butyl)-4-(2-nitro-1-(oct-2-yn-1-yloxy)ethyl)benzene (81)



Compound **81** was obtained according to general procedure **GP5** as a yellow liquid (65% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

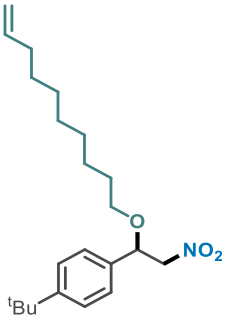
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.42 (d, *J* = 8.5 Hz, 2H), 7.30 (d, *J* = 8.3 Hz, 2H), 5.32 (dd, *J* = 9.9, 3.5 Hz, 1H), 4.67 (dd, *J* = 12.7, 9.9 Hz, 1H), 4.41 (dd, *J* = 12.7, 3.6 Hz, 1H), 4.14 (dt, *J* = 15.3, 2.2 Hz, 1H), 3.92 (dt, *J* = 15.3, 2.2 Hz, 1H), 2.19 (ddt, *J* = 7.2, 4.4, 2.2 Hz, 2H), 1.55 – 1.46 (m, 2H), 1.32 (s, 12H), 0.96 – 0.89 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 152.4, 132.7, 129.2, 126.9, 126.1, 88.2, 80.3, 76.4, 74.8, 56.8, 34.8, 31.4, 28.3, 22.3, 18.8, 14.1.

FT-IR (ATR, neat; cm^{-1}): 3034, 2967, 2623, 1525, 1475, 1326.

HRMS (ESI) *m/z*, $C_{20}H_{29}NO_3$ Exact Mass: 331.2147; found 331.2145.

(R)-1-(*tert*-Butyl)-4-(1-(dec-9-en-1-yloxy)-2-nitroethyl)benzene (82)



Compound **82** was obtained according to general procedure **GP5** as a yellow liquid (83% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

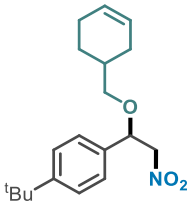
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.42 (d, *J* = 8.4 Hz, 2H), 7.29 (d, *J* = 8.3 Hz, 2H), 5.82 (ddt, *J* = 17.0, 10.2, 6.7 Hz, 2H), 5.05 – 4.90 (m, 4H), 4.60 (dd, *J* = 12.7, 10.2 Hz, 1H), 4.37 (dd, *J* = 12.7, 3.3 Hz, 1H), 3.41 (dt, *J* = 9.1, 6.6 Hz, 1H), 3.30 (dt, *J* = 9.1, 6.5 Hz, 1H), 2.08 – 2.01 (m, 3H), 1.59 – 1.48 (m, 3H), 1.33 (s, 9H), 1.27 (d, *J* = 4.3 Hz, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 152.1, 139.3, 133.8, 126.5, 126.0, 114.2, 80.7, 78.3, 69.6, 34.8, 33.9, 31.4, 29.6, 29.5, 29.4, 29.2, 29.0, 26.0.

FT-IR (ATR, neat; cm^{-1}): 3014, 2946, 1558, 1464, 1386, 1346, 1223.

HRMS (ESI) *m/z*, $C_{22}H_{35}NO_3$: 361.2617; found 361.2615.

1-(*tert*-Butyl)-4-(1-(cyclohex-3-en-1-ylmethoxy)-2-nitroethyl)benzene (83)



Compound **83** was obtained according to general procedure **GP5** as a yellow liquid (83% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

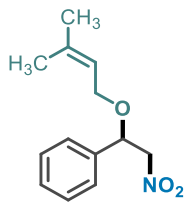
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.42 – 7.30 (m, 5H), 5.69 – 5.58 (m, 2H), 5.04 (dd, *J* = 10.2, 3.3 Hz, 1H), 4.61 (dd, *J* = 12.7, 10.2 Hz, 1H), 4.39 (dd, *J* = 12.7, 3.3 Hz, 1H), 3.30 (ddd, *J* = 9.0, 6.4, 1.1 Hz, 1H), 3.21 (ddd, *J* = 9.0, 6.4, 2.3 Hz, 1H), 2.10 – 1.97 (m, 3H), 1.91 – 1.82 (m, 1H), 1.77 – 1.60 (m, 2H), 1.31 – 1.19 (m, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 136.8, 129.2, 129.1, 127.2, 127.1, 126.9, 126.0, 126.0, 80.7, 78.8, 78.8, 74.5, 74.5, 34.0, 28.5, 28.4, 25.6, 25.5, 24.6.

FT-IR (ATR, neat; cm^{-1}): 3034, 2919, 2889, 1544, 1371, 1063.

HRMS (ESI) *m/z*, $C_{19}H_{27}NO_3$: 317.1991; found 317.1990.

(1-((3-Methylbut-2-en-1-yl)oxy)-2-nitroethyl)benzene (84)



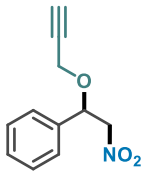
Compound **84** was obtained according to general procedure **GP5** as a colorless liquid (88% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.43 – 7.35 (m, 5H), 5.29 (ddt, *J* = 7.8, 6.4, 1.4 Hz, 1H), 5.10 (dd, *J* = 10.0, 3.5 Hz, 1H), 4.63 (dd, *J* = 12.8, 10.0 Hz, 1H), 4.39 (dd, *J* = 12.8, 3.5 Hz, 1H), 3.93 (dd, *J* = 11.5, 6.6 Hz, 1H), 3.86 (dd, *J* = 11.5, 7.5 Hz, 1H), 1.73 (s, 3H), 1.53 (s, 3H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 138.5, 136.7, 129.0, 129.0, 126.9, 119.9, 80.5, 76.8, 65.5, 25.7, 17.9.

The characterisation data match the literature.

(2-Nitro-1-(prop-2-yn-1-yloxy)ethyl)benzene (85)



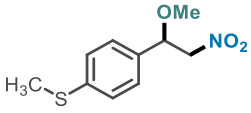
Compound **85** was obtained according to general procedure **GP5** as a yellow liquid (87% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44 – 7.37 (m, 5H), 5.35 (dd, *J* = 9.8, 3.6 Hz, 1H), 4.69 (dd, *J* = 12.8, 9.8 Hz, 1H), 4.44 (dd, *J* = 12.8, 3.6 Hz, 1H), 4.18 (dd, *J* = 15.8, 2.4 Hz, 1H), 3.94 (dd, *J* = 15.8, 2.4 Hz, 1H), 2.45 (s, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 135.2, 129.5, 129.2, 127.1, 80.0, 78.3, 76.8, 75.4, 56.1.

The characterisation data match the literature.

(4-(1-Methoxy-2-nitroethyl)phenyl)(methyl)sulfane (86)



Compound **86** was obtained according to general procedure **GP5** as a yellow liquid (84% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

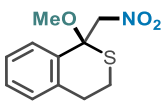
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.28 (br s, 4H), 4.91 (dd, *J* = 10.0, 3.4 Hz, 1H), 4.59 (dd, *J* = 12.7, 10.0 Hz, 1H), 4.36 (dd, *J* = 12.7, 3.4 Hz, 1H), 3.26 (s, 3H), 2.50 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 140.2, 132.7, 127.4, 126.9, 80.4, 79.8, 57.2, 15.7.

FT-IR (ATR, neat; cm^{-1}): 3032, 2972, 1554, 1461, 1378, 1081, 1017.

HRMS (ESI) *m/z*, $C_{10}H_{13}NO_3S$: 227.0616; found 227.0612.

1-Methoxy-1-(nitromethyl)isothiochromane (87)



Compound **87** was obtained according to general procedure **GP5** as a yellow liquid (71% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

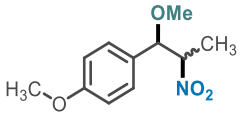
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.48 (dd, *J* = 7.8, 1.5 Hz, 1H), 7.23 – 7.08 (m, 3H), 4.75 (d, *J* = 11.5 Hz, 1H), 4.62 – 4.53 (m, 1H), 3.44 (td, *J* = 12.7, 3.8 Hz, 1H), 3.18 (s, 3H), 3.12 (dt, *J* = 13.2, 4.5 Hz, 1H), 2.58 – 2.44 (m, 2H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 135.5, 131.1, 129.1, 127.2, 127.1, 124.8, 81.2, 76.6, 50.9, 27.0, 23.5.

FT-IR (ATR, neat; cm^{-1}): 3016, 2947, 2895, 1564, 1406, 1395.

HRMS (ESI) *m/z*, $C_{11}H_{13}NO_3S$: 239.0616; found 239.0615.

1-Methoxy-4-(1-methoxy-2-nitropropyl)benzene (88)

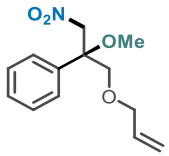


Compound **88** was obtained according to general procedure **GP5** as a yellow liquid (64% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.24 (d, *J* = 8.7 Hz, 2H), 6.92 (d, *J* = 8.7 Hz, 2H), 4.69 (dd, *J* = 9.6, 6.8 Hz, 1H), 4.44 (d, *J* = 9.6 Hz, 1H), 3.80 (s, 3H), 3.12 (s, 3H), 1.22 (d, *J* = 6.9 Hz, 3H).

The characterisation data match the literature.

(1-(Allyloxy)-2-methoxy-3-nitropropan-2-yl)benzene (89)



Compound **89** was obtained according to general procedure **GP5** as a yellow liquid (79% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

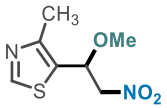
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 – 7.31 (m, 5H), 5.89 (ddt, *J* = 17.3, 10.4, 5.7 Hz, 1H), 5.30 – 5.14 (m, 2H), 5.01 – 4.84 (m, 2H), 4.07 (dd, *J* = 5.7, 1.8 Hz, 2H), 3.95 (s, 2H), 3.21 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 137.8, 134.3, 128.9, 128.7, 126.6, 117.7, 79.6, 78.9, 72.7, 70.8, 51.3.

FT-IR (ATR, neat; cm^{-1}): 3023, 2985, 2847, 1586, 1335, 1096.

HRMS (ESI) *m/z*, $[M+Na]^+$ calcd for $C_{13}H_{17}NO_4+Na^+$: 274.1055; found 274.1048.

5-(1-Methoxy-2-nitroethyl)-4-methylthiazole (90)



Compound **90** was obtained according to general procedure **GP5** as a yellow liquid (76% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

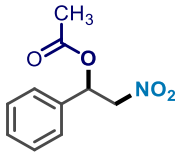
^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.78 (s, 1H), 5.30 (dd, *J* = 9.6, 3.8 Hz, 1H), 4.69 (dd, J = 13.0, 9.6 Hz, 1H), 4.42 (dd, *J* = 13.0, 3.8 Hz, 1H), 3.30 (s, 3H), 2.51 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 153.1, 151.9, 127.4, 79.4, 73.3, 57.3, 29.0, 15.5.

FT-IR (ATR, neat; cm^{-1}): 2986, 1657, 1406, 1345, 1237, 1106, 1067.

HRMS (ESI) *m/z*, $C_7H_{10}N_2O_3S$: 202.0412; found 202.0410.

2-Nitro-1-phenylethyl acetate (91)



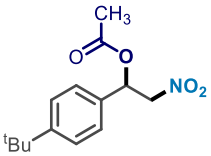
Compound **91** was obtained according to general procedure **GP6** as a yellow liquid (80% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.41 – 7.37 (m, 5H), 6.44 (dd, *J* = 9.9, 3.5 Hz, 1H), 4.81 (dd, *J* = 13.5, 9.9 Hz, 1H), 4.57 (dd, *J* = 13.5, 3.5 Hz, 1H), 2.09 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 169.4, 135.1, 129.5, 129.2, 126.7, 78.3, 71.9, 20.9.

The characterisation data match the literature.

1-(4-(*tert*-Butyl)phenyl)-2-nitroethyl acetate (92)



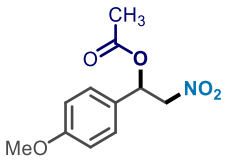
Compound **92** was obtained according to general procedure **GP6** as a yellow liquid (90% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44 – 7.38 (m, 2H), 7.33 – 7.28 (m, 2H), 6.43 (dd, *J* = 10.0, 3.5 Hz, 1H), 4.81 (dd, *J* = 13.5, 10.0 Hz, 1H), 4.55 (dd, *J* = 13.5, 3.5 Hz, 1H), 2.08 (s, 3H), 1.31 (s, 9H).

FT-IR (ATR, neat; cm^{-1}): 3017, 2974, 1716, 1693, 1636, 1548, 1378, 1272.

HRMS (ESI) *m/z*, $C_{14}H_{19}NO_4$: 265.1314; found 265.1314.

1-(4-Methoxyphenyl)-2-nitroethyl acetate (93)



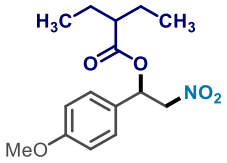
Compound **93** was obtained according to general procedure **GP6** as a yellow liquid (87% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.31 (d, *J* = 8.8 Hz, 2H), 6.91 (d, *J* = 8.8 Hz, 2H), 6.39 (dd, *J* = 9.9, 3.7 Hz, 1H), 4.81 (dd, *J* = 13.4, 9.9 Hz, 1H), 4.54 (dd, *J* = 13.4, 3.7 Hz, 1H), 3.80 (s, 3H), 2.06 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 169.5, 160.5, 128.3, 114.6, 78.3, 71.6, 55.5, 20.9.

The characterisation data match the literature.

1-(4-Methoxyphenyl)-2-nitroethyl 2-ethylbutanoate (94)



Compound **94** was obtained according to general procedure **GP6** as a yellow liquid (74% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

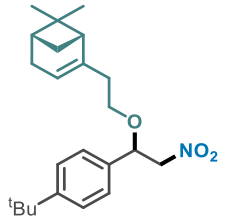
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.31 (d, *J* = 8.8 Hz, 2H), 6.90 (d, *J* = 8.8 Hz, 2H), 6.41 (dd, *J* = 10.2, 3.5 Hz, 1H), 4.82 (dd, *J* = 13.4, 10.2 Hz, 1H), 4.53 (dd, *J* = 13.4, 3.5 Hz, 1H), 3.80 (s, 3H), 2.22 (tt, *J* = 8.5, 5.6 Hz, 1H), 1.65 – 1.40 (m, 4H), 0.79 (dt, *J* = 13.4, 7.4 Hz, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 174.7, 160.4, 128.3, 127.3, 114.5, 78.4, 71.3, 55.4, 49.0, 25.1, 25.1, 11.8, 11.7.

FT-IR (ATR, neat; cm^{-1}): 3026, 2937, 1765, 1717, 1595, 1337, 1276, 1048.

HRMS (ESI) *m/z*, $C_{15}H_{21}NO_5$: 295.1420; found 295.1419.

2-(2-(1-(4-(*tert*-Butyl)phenyl)-2-nitroethoxy)ethyl)-6,6-dimethylbicyclo[3.1.1]hept-2-ene (95)



Compound **95** was obtained according to general procedure **GP5** as a yellow liquid (59% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.42 (d, *J* = 8.4 Hz, 2H), 7.29 (d, *J* = 8.4 Hz, 2H), 5.19 (dd, *J* = 3.0, 1.5 Hz, 1H), 5.04 (dd, *J* = 10.1, 3.3 Hz, 1H), 4.59 (ddd, *J* = 12.7, 10.1, 1.0 Hz, 1H), 4.41 – 4.30 (m, 1H),

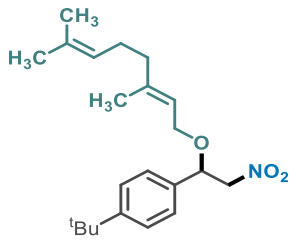
3.49 – 3.27 (m, 2H), 2.36 – 2.28 (m, 1H), 2.22 – 2.15 (m, 3H), 2.04 (d, *J* = 5.4 Hz, 2H), 2.00 – 1.92 (m, 1H), 1.33 (s, 9H), 1.25 (s, 3H), 1.10 (dd, *J* = 8.5, 3.6 Hz, 1H), 0.78 (d, *J* = 1.7 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 152.1, 144.7, 133.7, 126.6, 126.0, 118.2, 80.7, 78.4, 67.9, 45.9, 40.9, 38.1, 37.0, 34.8, 31.7, 31.4, 31.2, 26.4, 21.2.

FT-IR (ATR, neat; cm^{-1}): 3024, 2955, 1559, 1373, 1089.

HRMS (ESI) *m/z*, $C_{23}H_{33}NO_3$: 371.2460; found 371.2462.

(*E*)-1-(*tert*-Butyl)-4-(1-((3,7-dimethylocta-2,6-dien-1-yl)oxy)-2-nitroethyl)benzene (96)



Compound **96** was obtained according to general procedure **GP5** as a yellow liquid (85% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

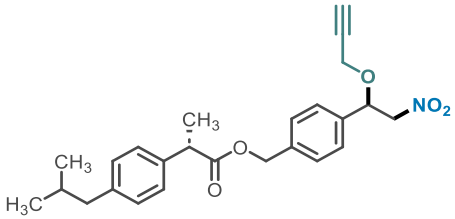
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44 (d, *J* = 8.4 Hz, 2H), 7.32 (d, *J* = 8.3 Hz, 2H), 5.36 – 5.27 (m, 1H), 5.16 – 5.08 (m, 2H), 4.65 (dd, *J* = 12.7, 10.1 Hz, 1H), 4.40 (dd, *J* = 12.7, 3.4 Hz, 1H), 4.04 – 3.95 (m, 1H), 3.90 (dd, *J* = 11.7, 7.4 Hz, 1H), 2.15 – 2.02 (m, 4H), 1.72 (d, *J* = 1.4 Hz, 3H), 1.63 (d, *J* = 1.4 Hz, 3H), 1.55 (d, *J* = 1.4 Hz, 3H), 1.35 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 152.2, 141.7, 133.7, 131.8, 126.7, 126.0, 126.0, 124.1, 119.9, 80.7, 77.0, 65.6, 39.7, 34.8, 31.4, 26.5, 25.8, 17.8, 16.5.

FT-IR (ATR, neat; cm^{-1}): 3021, 2974, 1549, 1262.

HRMS (ESI) *m/z*, $C_{22}H_{33}NO_3$: 359.2460; found 359.2458.

4-(-2-Nitro-1-(prop-2-yn-1-yloxy)ethyl)benzyl 2-(4-isobutylphenyl)propanoate (97)



Compound **97** was obtained according to general procedure **GP5** as a yellow liquid (76% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.37 – 7.17 (m, 6H), 7.10 (d, *J* = 8.2 Hz, 2H), 5.33 (dd, *J* = 9.8, 3.6 Hz, 1H), 5.12 (s, 2H), 4.66 (dd, *J* = 12.9, 9.8 Hz, 1H), 4.40 (dd, *J* = 12.9, 3.6 Hz, 1H), 4.16 (dd, *J* = 15.8,

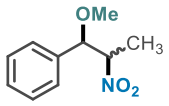
2.5 Hz, 1H), 3.91 (dd, *J* = 15.8, 2.4 Hz, 1H), 3.77 (q, *J* = 7.1 Hz, 1H), 2.50 – 2.41 (m, 3H), 1.86 (dt, *J* = 13.5, 6.8 Hz, 1H), 1.52 (d, *J* = 7.2 Hz, 3H), 0.91 (d, *J* = 6.6 Hz, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 174.5, 140.8, 137.7, 137.6, 135.0, 129.5, 128.4, 127.3, 80.0, 78.3, 76.6, 75.6, 65.7, 56.2, 45.2, 45.1, 30.3, 22.5, 18.5.

FT-IR (ATR, neat; cm^{-1}): 3013, 2924, 2656, 2539, 2346, 1699, 1652, 1557, 1272.

HRMS (ESI) *m/z*, $[M+H]^+$ calcd for $C_{25}H_{29}NO_5+H^+$: 424.2124; found 424.2113.

(1-Methoxy-2-nitropropyl)benzene (98)



Compound **98** was obtained according to general procedure **GP5** as a yellow liquid (72% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

Major isomer:

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.46 – 7.29 (m, 5H), 4.73 (dq, *J* = 9.6, 6.8 Hz, 1H), 4.51 (d, *J* = 9.6 Hz, 1H), 3.17 (s, 3H), 1.25 (d, *J* = 6.8 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.8, 129.23, 129.0, 127.8, 87.6, 85.2, 56.9, 16.3.

Minor isomer:

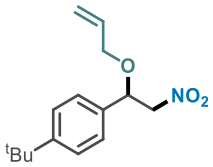
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.46 – 7.29 (m, 5H), 4.85 (d, J = 5.0 Hz, 1H), 4.60 (qd, J = 6.8, 5.0 Hz, 1H), 3.29 (s, 3H), 1.51 (d, *J* = 6.8 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.6, 128.9, 128.8, 127.0, 87.0, 83.8, 57.8, 12.8.

FT-IR (ATR, neat; cm^{-1}): 3007, 1513, 1106, 1062.

HRMS (ESI) *m/z*, $C_{10}H_{13}NO_3$: 195.0895; found 195.0894.

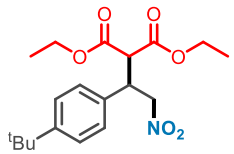
1-(1-(Allyloxy)-2-nitroethyl)-4-(*tert*-butyl)benzene (101)



^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.42 (d, *J* = 8.5 Hz, 2H), 7.29 (d, *J* = 8.3 Hz, 2H), 5.84 (dddd, *J* = 17.2, 10.4, 6.2, 5.1 Hz, 1H), 5.27 – 5.07 (m, 3H), 4.64 (dd, *J* = 12.7, 10.1 Hz, 1H), 4.39 (dd, *J* = 12.7, 3.3 Hz, 1H), 3.99 (ddt, *J* = 12.7, 5.1, 1.6 Hz, 1H), 3.81 (ddt, *J* = 12.7, 6.2, 1.4 Hz, 1H), 1.33 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 152.4, 133.9, 133.3, 126.7, 126.1, 117.8, 80.6, 77.3, 69.9, 34.8, 31.4.

Diethyl 2-(1-(4-(*tert*-butyl)phenyl)-2-nitroethyl)malonate (102)



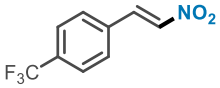
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.31 (d, *J* = 8.4 Hz, 2H), 7.15 (d, *J* = 8.4 Hz, 2H), 4.94 – 4.81 (m, 2H), 4.26 – 4.16 (m, 3H), 4.00 (qd, *J* = 7.1, 2.4 Hz, 2H), 3.80 (d, *J* = 9.2 Hz, 1H), 1.27 (s, 9H), 1.00 (t, *J* = 7.1 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 167.7, 167.1, 151.3, 133.2, 127.8, 125.9, 77.8, 62.2, 61.9, 55.2, 42.7, 34.6, 31.3, 14.1, 13.8.

FT-IR (ATR, neat; cm^{-1}): 3027, 2996, 2831, 1728, 1551.

HRMS (ESI) *m/z*, $C_{19}H_{27}NO_6$: 365.1838; found 365.1834.

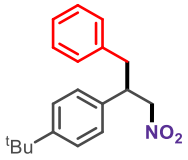
(*E*)-1-(2-Nitrovinyl)-4-(trifluoromethyl)benzene (103)



^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.02 (d, *J* = 13.8 Hz, 1H), 7.72 (d, *J* = 8.5 Hz, 2H), 7.67 (d, *J* = 8.5 Hz, 2H), 7.62 (d, *J* = 13.8 Hz, 1H).

The characterization data match the literature.

1-(*tert*-Butyl)-4-(1-nitro-3-phenylpropan-2-yl)benzene (104)



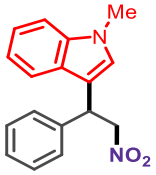
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.38 – 7.18 (m, 6H), 7.14 – 7.08 (m, 4H), 4.63 – 4.50 (m, 2H), 3.75 (tt, *J* = 8.5, 6.7 Hz, 1H), 3.05 (dd, *J* = 13.9, 6.7 Hz, 1H), 2.92 (dd, *J* = 13.9, 8.4 Hz, 1H), 1.30 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 150.7, 138.2, 136.3, 129.2, 128.7, 127.2, 126.9, 125.9, 79.7, 45.5, 40.2, 34.6, 31.4.

FT-IR (ATR, neat; cm^{-1}): 3012, 2954, 1373, 1044.

HRMS (ESI) *m/z*, $C_{19}H_{23}NO_2$: 297.1729; found 297.1726.

1-Methyl-3-(2-nitro-1-phenylethyl)-1*H*-indole (105)

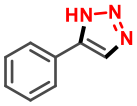


^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.54 – 7.50 (m, 1H), 7.43 – 7.26 (m, 7H), 7.13 (ddd, *J* = 8.0, 6.6, 1.1 Hz, 1H), 6.91 (s, 1H), 5.24 (t, *J* = 8.0 Hz, 1H), 5.10 (dd, *J* = 12.5, 7.5 Hz, 1H), 4.98 (dd, *J* = 12.5, 8.5 Hz, 1H), 3.77 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 139.5, 137.4, 129.0, 127.8, 127.6, 126.7, 126.5, 122.3, 119.6, 119.1, 112.9, 109.6, 79.7, 41.6, 32.9.

The characterization data match the literature.

5-Phenyl-1H-1,2,3-triazole (106)



^{1}H-NMR (300 MHz, DMSO-D_6): δ 15.14 (s, 1H), 8.34 (s, 1H), 7.91 – 7.82 (m, 2H), 7.51 – 7.41 (m, 2H), 7.39 – 7.29 (m, 1H).

The characterization data match the literature.

6. References

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Chapter 4:

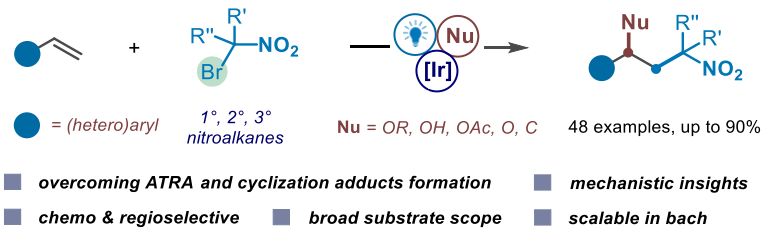
Carbo-Heterofunctionalization of Alkenes via Radical-Polar Crossover Photoredox Catalysis: Facile Access to 1,3-Nitro-difunctionalized Compounds

This Chapter is adapted from the following submitted article:

S. Patra, V. Valsamidou, B. N. Nandasana, D. Katayev, "Carbo-Heterofunctionalization of Alkenes via Radical-Polar Crossover Photoredox Catalysis: Facile Access to 1,3-Nitro-difunctionalized Compounds", *Submitted*. **2024**.

1. Abstract

Herein, we present an efficient and practical method for multicomponent carbo-heterofunctionalization of alkenes via radical-polar crossover photoredox catalysis. Employing geminal bromonitroalkanes as redox-active reagents with a wide range of O-centered nucleophiles allows rapid access to various 1,3-nitro difunctionalized compounds, including β-nitro ketones, β-nitro alcohols as well as cyclic molecules.



2. Introduction

The β-amino ketones and their reduced form, 1,3-amino alcohols, are versatile intermediates in organic synthesis, valued for their dual functional groups that enable diverse transformations, and serve as essential building blocks for chiral ligands, natural products, and pharmaceuticals (Figure 1).[1] Selected methods for their synthesis comprise metal-catalyzed Mannich reactions, Michael addition, condensation reactions, reductive hydroamination of ynones, alkylation of alicyclic imines, carbonylative coupling of unactivated alkenes, and many others including asymmetric transformations.[2] Despite significant progress in this field, these transformations often rely on complex reaction conditions and multistep processes, while being limited to specific classes of compounds, underscoring the need for more efficient and streamlined methods.

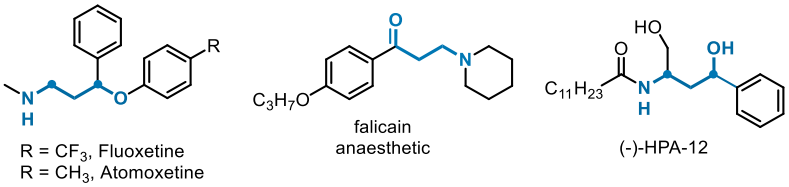


Figure 1. Representative examples of bio-active 1,3-amino alcohol and ketones.

Gem-halonitroalkanes are recognized for their ability to introduce nitro-derived motifs, with their α-acidic protons making them well-suited for various nucleophilic and cycloaddition reactions.[3] On the other hand, recent advancements in photoredox activation of redox-active transfer reagents have allowed to utilize gem-halonitroalkanes in radical functionalization of alkenes, enabling the synthesis of 1,3-nitro- difunctionalized compounds.[4] The Ooi group developed a photocatalytic system for α-bromonitroalkanes with styrene derivatives, yielding either γ-bromo nitroalkanes or isoxazoline-N-oxides, though in moderate yields (Figure 2).[5] The Reiser group subsequently introduced a visible-light-mediated Cu-catalyzed vicinal difunctionalization of olefins with gem-halonitroalkanes, though its scope was limited to bromide addition and intramolecular cyclization.[6] The Jiao group also explored geminal bromonitroalkanes as reagents in photocatalytic nitroalkylation of silyl enol ethers to access β-nitro ketones.[7]

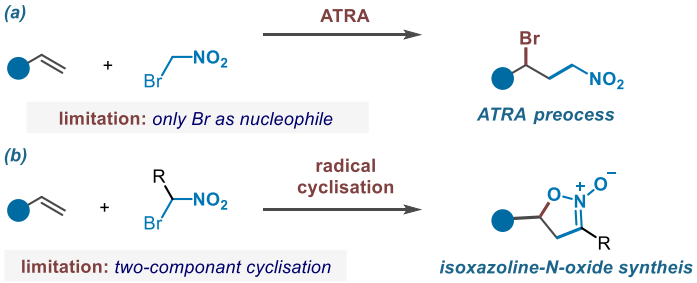


Figure 2. Our previous works on nitration.

Our group has long focused on development mild and sustainable concepts for the nitrative difunctionalization of olefins, and very recently we reported anti-Markovnikov hydronitroalkylation of alkenes to synthesis terminal nitroalkanes.[8] Using thiol-based hydrogen atom donors, we successfully suppressed the formation of ATRA adducts and isoxazoline-N-oxides (Figure 3).[9]

Figure 3. Anti-Markovnikov hydronitroalkylation of alkenes.

Building on this process, we hypothesized that the transient alkyl radical (Giese-type intermediate), generated by the addition of a nitroalkyl radical, could be rapidly oxidized to the corresponding carbocation using an appropriate photocatalyst. Eliminating the bromide ion with a suitable trap would further reduce the formation of ATRA adduct and will enable reactions with diverse O- and C- centred nucleophiles, facilitating the synthesis of previously inaccessible 1,3-nitrodifunctionalized molecules (Figure 4).

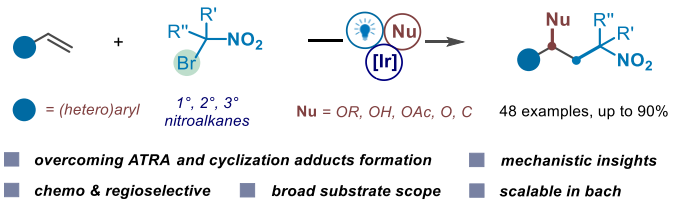
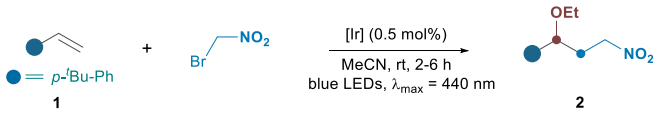


Figure 4. This work: 1,3-nitrodifunctionalized alkane synthesis.

3. Results and discussion

3.1. Reaction optimization

We began the reaction development using 4-tert-butylstyrene **1** as a model substrate, bromonitromethane as a redox-active reagent ($E_{1/2}^{red}$ = -0.87 V vs SCE), and ethanol as nucleophile. After screening of reaction parameters (see SI for details), we observed excellent disubstitution of **1** in the presence of only 0.5% of Ir-based photocatalyst, 1.4 equivalent of reagent, silver carbonate (0.7 eq.), EtOH (5.0 eq) in MeCN under 440 nm visible light irradiation for 8 hours (Table 1, entry 1). Attempts to enhance the reactivity using other inorganic and organic-based photocatalysts have proven unsuccessful (entries 2-3), while MeCN as the solvent provided the highest conversion (entries 4-5). The screening of various alkali metal-based halogen scavengers revealed them to be less efficient than silver salts (entries 6-8). Only in the presence of silver carbonate we were able to achieve smooth net-neutral radical-polar crossover reaction.



Entry	Variation of the optimal conditions[a]	**2** (%)[b]
1	**None**	**91 (87)**[c]
2	[Ru]/[Cu]	88 / 6
3	[Mes-Acr]/[PTH]/[4CzIPN]	23 / 81 / 31
4	DMF/THF	0 / 6
5	DCE/DMC	31 / 25
6	$AgNO_2$/$AgNO_3$	16 / 27
7	CF_3CO_2Ag/$PhCO_2Ag$	57 / 11
8	Na_2CO_3/Cs_2CO_3/K_2CO_3	Up to 42

Table 1. [a]**Standard reaction conditions**: **1** (1.0 equiv), [Ir] (0.5 mol%), Br-CH_2-NO_2 (1.4 equiv), Ag_2CO_3 (0.7 equiv), EtOH (5.0 equiv), MeCN (0.04 M), blue LEDs, rt, 8 h, under N_2; [b] Yields were determined by GC against n-decane as internal standard. [c] Isolated yield. [Ir] = *fac*-Ir(ppy)$_3$; [Ru] = Ru(bpy)$_3$(PF_6)$_2$; [Cu] = [Cu(dap)$_2$Cl]; [Mes-Acr] = 9-mesityl-10-methylacridinium tetrafluoroborate;

3.2. Investigation of Substrate Scope

After identifying optimal reaction conditions, we proceeded to evaluate the substrate scope by testing several styrene derivatives, alcohols, and gem-bromonitroalkanes as reagents. Common functionalities at ortho-, and para-positions were examined, revealing a great level of site-selectivity, with product yields ranging from 81 to 90% (Figure 5A). Notably, the benzylic chlorine in **5** remained intact under our reaction conditions. Naphthalene and thiazole derivatives also exhibited great reactivity, yielding the corresponding products **7** and **10**. Likewise, α,α-disubstituted and α,β-disubstituted olefins provided the corresponding products **8** and **9** in good yields. Varying alcohols, including methanol, deuterated methanol, and isopropanol, did not significantly affect the outcome of the reaction suggesting that both linear and branched alcohols can be employed. We then shifted our focus to utilizing substituted gem-bromonitroalkanes as reagents, obtaining secondary nitroalkanes from 1-bromo-1-nitroethane and tertiary nitroalkanes from 2-bromo-2-nitropropane or 2-bromo-2-nitro-1,3-dioxane. These highly substituted adducts **14-16** were isolated in excellent yields with high site selectivity. To demonstrate the scalability of our protocol, we extended the reaction time for substrate **1** to 24 hours in a batch process (10.0 mmol), achieving an isolated yield of 84% for product **2**.

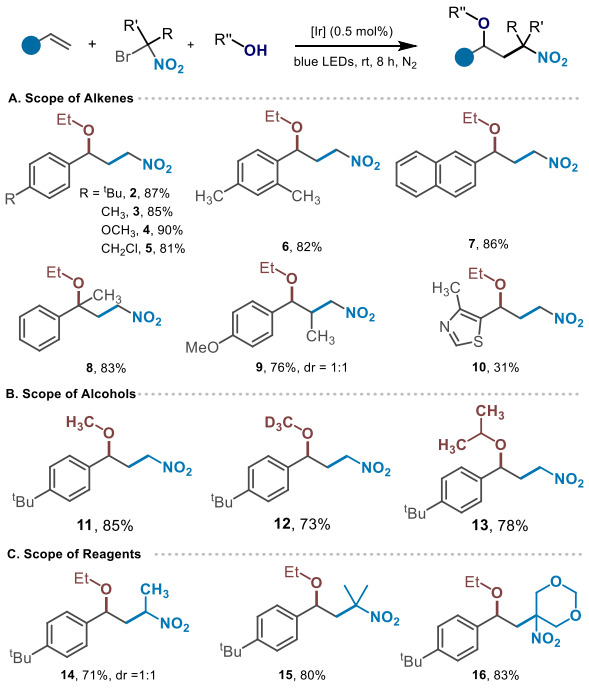


Figure 5. (A-C) Synthesis 1,3-nitroethers. Standard conditions: alkene (0.2 mmol, 1.0 equiv), fac-[Ir(ppy)3] (0.5 mol%), reagent (1.4 equiv), Ag2CO3 (0.7 equiv), ROH (5.0 equiv), MeCN, blue LEDs, rt, 12 h; Isolated yields are reported.

Encouraged by the great reactivity of this multicomponent reaction, we decided to apply our strategy to the intramolecular processes including radical-triggered lactonization and cycloetherification of olefins as well as semipinacol-type rearrangement. For example, unsaturated carboxylic acids and alcohols underwent smooth cycloaddition reactions, yielding the corresponding lactones or substituted furans

bearing nitro groups in their structures, with isolated yields of up to 86% (Figure 6A). Allylic alcohol 1-(1-phenylvinyl)cyclobutan-1-ol underwent a semipinacol-type rearrangement, forming an all-carbon quaternary γ-nitro ketone **22**. Bronopol (2-bromo-2-nitropropane-1,3-diol), a widely used antimicrobial preservative in personal care, pharmaceutical, and industrial products, was also explored as a readily available redox-active reagent.[10] The intriguing property of this molecules is its potential to be used as bifunctional reagent in cycloaddition reactions with unsaturated hydrocarbons using photoredox catalysis. We were pleased to see that a number of highly substituted furan derivatives can be easily generated under our reaction conditions in excellent isolated yields (**23-29**) (Figure 6B).

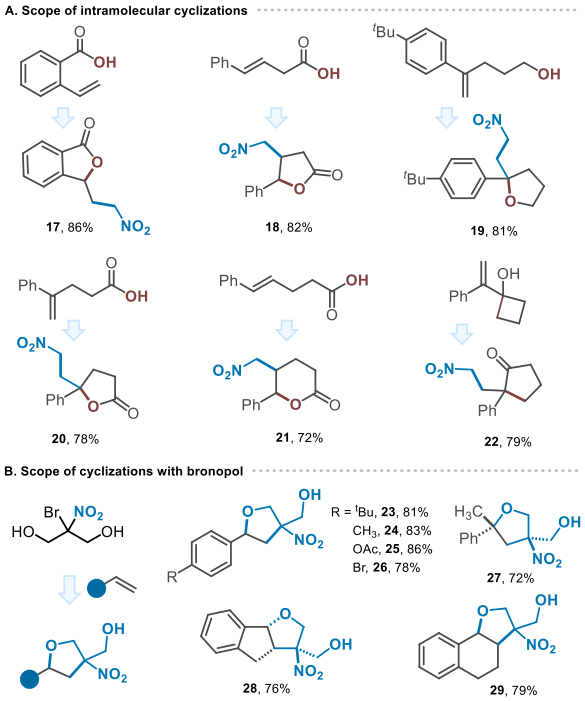


Figure 6. (A-B) Scope of intramolecular cyclizations using bromonitromethane and bronopol as redox active reagents.

We envision that this method will find broad applications in the synthesis of complex polycyclic molecules. Since the protocol generates a carbocation intermediate, we hypothesized that conducting the reaction in the presence of DMSO would facilitate rapid access to biologically important β-nitro ketones. Notably, various styrene derivatives featuring electron-donating and electron-withdrawing aryl substituents at the ortho-, meta-, and para-positions were efficiently difunctionalized, resulting in the corresponding 1,3-nitro ketones (**30**–**39**) with isolated yields of up to 74% (Figure 7A). Varying different gem-bromonitroalkanes in the presence of DMSO has also led to the formation of β-nitro ketones with nitro group located at secondary or tertiary carbon centers (**40**–**42**) (Figure 7A). The direct synthesis of 1,3-nitro alcohols also can be achieved by simply switching the nucleophile to water (**43-45**) (Figure 7B). Notably, when no external nucleophiles were used and silver carbonate was replaced with silver acetate, the latter served as both a trap for halogen ions and a source of nucleophile, resulting in the formation of 1,3-nitroesters **46**–**49** with excellent yields (Figure 7C).

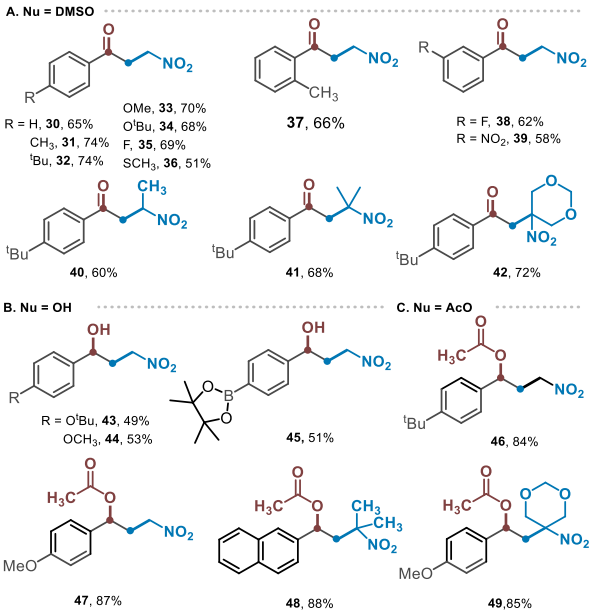


Figure 7. (A-C) Scope of intermolecular difunctionalization of alkenes with various O-centered nucleophiles.

3.3. Mechanistic investigations

Following the successful exploration of the scope over a wide range of nucleophiles and demonstrating the potential of gem-bromonitroalkanes in the synthesis of 1,3-nitrodisubstituted molecules, we next aimed to examine the reaction mechanism and provide evidence for its radical-polar crossover nature. Our investigation began with control experiments, which highlighted the crucial roles of both the photocatalyst and light. No reaction was observed even under heating at 90 °C, regardless of whether the photocatalyst was present (Figure 8A). Adding radical scavengers, such as 2,2,6,6-tetramethylpiperidin-1-yl)oxyl (TEMPO) or butylated hydroxytoluene (BHT), completely inhibited the formation of the desired products, instead, the starting olefin was recovered in both cases, indicating a likely radical pathway (Figure 8B).

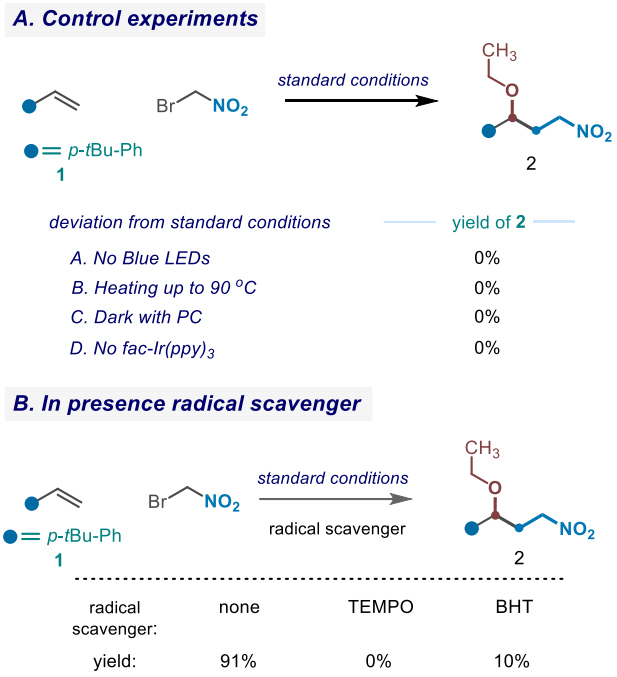


Figure 8. A. Control experiments. B. Radical trapping experiments

The reaction proceeded smoothly under visible light but halted immediately in its absence, as confirmed by on-off experiments, indicating a photoredox catalytic pathway rather than radical chain propagation (Figure 9).

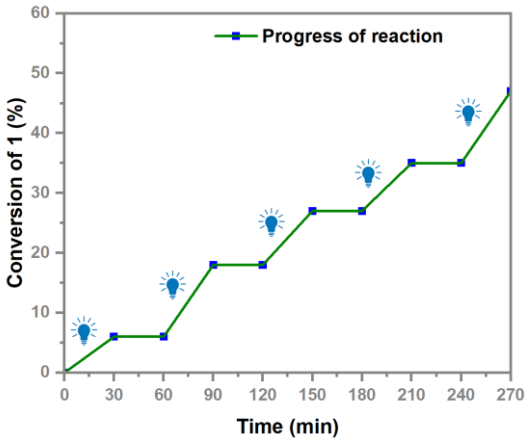


Figure 9. On-off experiment.

To distinguish whether the reaction proceeds via the radical-polar crossover (RPC) pathway or through nucleophilic substitution of the ATRA adduct, we carried out two experiments. First, we tested the reaction with an unactivated alkene, such as 1-decene, which proved to be ineffective under the optimized conditions. This result suggests that the reaction most likely follows an RPC mechanism, as the Ir^{IV} species is not expected to effectively oxidize the alkyl radical intermediate. In the second experiment, the ATRA adduct was subjected to standard reaction conditions, but no product **53** was detected.

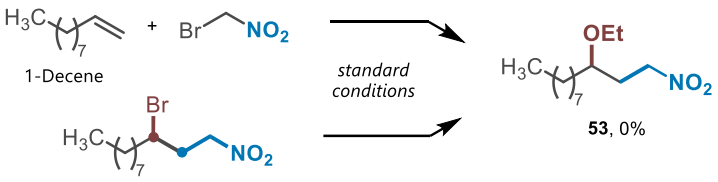


Figure 10. A. Reaction with unactivated alkenes.

Interestingly, a radical clock experiment using dimethyl 2-vinylcyclopropane-1,1-dicarboxylate as substrate did not provide the expected product **50**. However, in the presence of a hydrogen atom transfer (HAT) reagent, the ring-opening product **51** was obtained, supporting the involvement of an alkyl radical intermediate in the reaction mechanism.

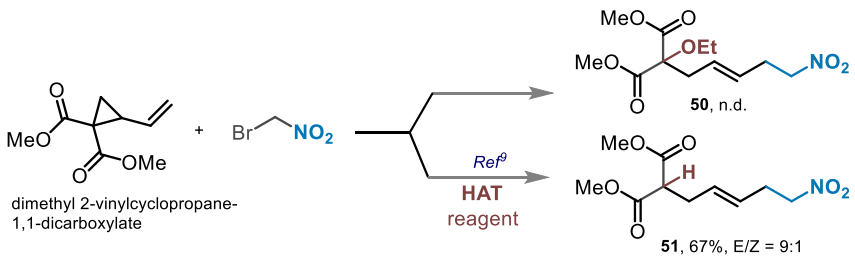


Figure 11. A. Radical-clock experiments.

Further, a competition reaction experiment with increasing amounts of HAT reagent showed that as HAT reagent increases, hydride addition product formation also increases, with 2 equivalents yielding

product **52** exclusively. This suggests that HAT process with Giese-type intermediate outpaces its oxidation to the corresponding carbocation by Ir^{IV}.

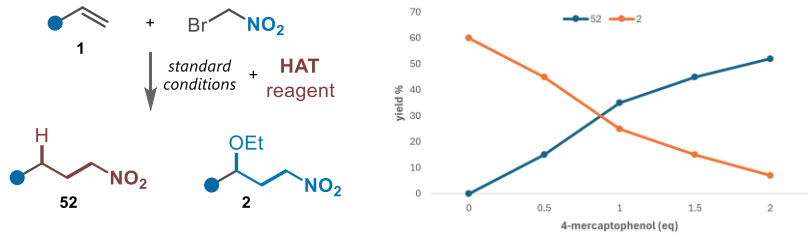


Figure 12. HAT vs RPC pathway.

Building on this experimental evidence and our previous reports on nitryl-triggered alkene difunctionalization reactions, a plausible catalytic cycle is proposed as outlined in Scheme 5F. Under visible-light irradiation and in the presence of fac-Ir(ppy)$_3$ photocatalyst the reagent undergoes a reductive single electron transfer (SET) process to afford α-nitroalkyl radical species (***i***) and bromide ion. In the presence of the silver salt the bromide ion is trapped, preventing its future involvement inside reactions. In the presence of styrene derivative, α-nitroalkyl radical undergoes a Giese-type addition, generating a benzylic alkyl radical intermediate ii. In the absence of a HAT reagent, the catalytic cycle concludes with the oxidation of the radical to the corresponding carbocation ***iii***, while simultaneously regenerating the photocatalyst to its ground state. The presence of various nucleophiles enables control over the reactivity of carbocation ***iii***, allowing rapid access to a range of 1,3-nitrodisubstituted molecules.

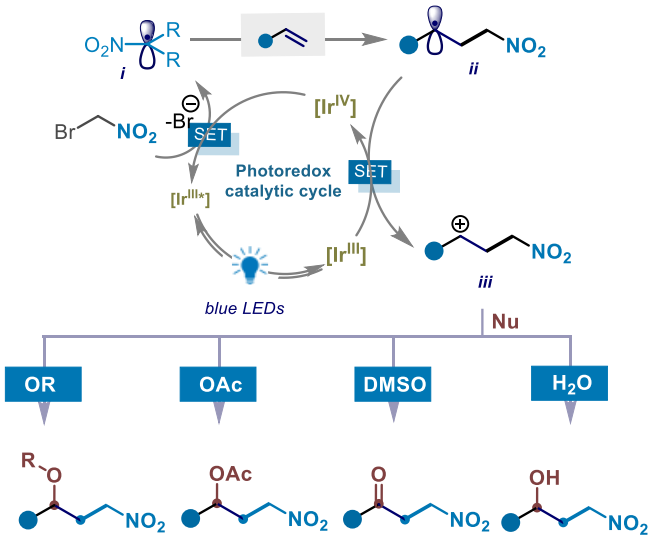


Figure 3. Proposed mechanism.

4. Conclusion

In summary, we successfully activated α-bromo nitroalkanes using visible-light photoredox catalysis, producing an electrophilic radical intermediate that rapidly reacts with olefins. By employing a net-neutral radical-polar crossover (RPC) strategy and using silver carbonate as the additive to prevent ATRA product formation, we achieved diverse nitrative difunctionalization reactions with O-centered nucleophiles as coupling partners. The utility of this concept has been demonstrated across a wide range of over 45 examples, showing excellent levels of chemo- and regioselectivity, as well as functional group tolerance. The ongoing exploration of gem-halonitroalkanes as redox-active, readily available reagents in molecular design using RPC and radical ligand transfer (RLT) mechanisms is currently being investigated by our group.

5. Experimental section

1. General Information

1.1. Material and methods

All reactions were conducted using flame-dried glassware under an inert argon atmosphere, equipped with Teflon-coated magnetic stirring bars and secured with dry septa. Glassware was pre-dried at 120 °C overnight to ensure dryness before use. Starting materials were obtained commercially from Thermo Fisher Scientific (Acros), Sigma-Aldrich, Apollo Scientific, Fluorochem, and TCI unless otherwise specified. To ensure quality, all commercially available olefins were characterized via ^{1}H-NMR spectroscopy prior to use. Anhydrous acetonitrile was stored over preconditioned 3 Å molecular sieves.

Analytical thin-layer chromatography (TLC) was performed on Merck silica gel 60 F254 glass plates, visualized under 254 nm UV light or stained with potassium permanganate solution and heated. Product purification was achieved using flash chromatography on Brunschwig silica gel (32-63 µm, 60 Å) with a pressure of 0.3-0.5 bar. Medium-pressure liquid chromatography (MPLC) was performed on a Teledyne ISCO CombiFlash Rf200 System equipped with UV detection and fraction collection, or manually with SilicaFlash P60, 40-63 µm. Preparative HPLC was done using a Teledyne Isco CombiFlash EZ Prep system fitted with Macherey-Nagel VP 250/21 Nucleosil 50-5 columns.

Nuclear magnetic resonance (NMR) spectra were recorded on Bruker Ultrashield 300 and Bruker Ascend 400 spectrometers, with ^{1}H and ^{13}C-NMR at 300.1 MHz and 75.5 MHz. Fluorine NMR ^{19}F spectra were acquired on Bruker DPX-300, Ultrashield 300. Chemical shifts (δ) are reported in ppm relative to solvent peaks (e.g., $CDCl_3$ at 7.26 ppm for ^{1}H, $CDCl_3$ at 77.16 ppm for ^{13}C). Signals are labeled as singlet (s), doublet (d), triplet (t), quartet (q), multiplet (m), with coupling constants (*J*) in Hz.

High-resolution mass spectrometry (HR-MS) with electrospray ionization (ESI+) was conducted on a Bruker FTMS 4.7T BioAPEX II or Thermo Scientific LTQ Orbitrap XL, including electron impact ionization (EI) on a VG-TRIBRID system. Gas chromatography-mass spectrometry (GC-MS) was performed on an Agilent 8890 series GC coupled with an Agilent 5977B mass selective detector.

1.2. High intensity photoreactors

The photoreactor was custom designed and built by Katayev and co-workers in coordination with the mechanical workshop in the Department of Chemistry and Applied Biosciences at ETH Zürich having blue LEDs, equally spaced in a circular design, powered by a 10.3 A power supply, emitting 350 W of light with the measured UV-Vis spectrum (Figure 1). The LEDs were water-cooled and further cooled by built-in fans to maintain an ambient temperature.

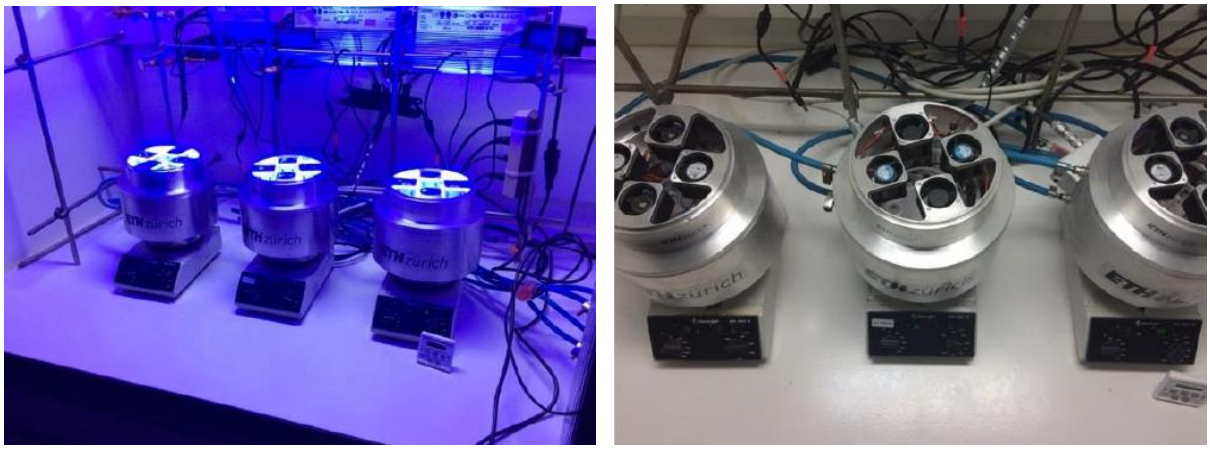


Figure 1.1. Custom high-intensity, blue LED photoreactors for photocatalytic reactions.

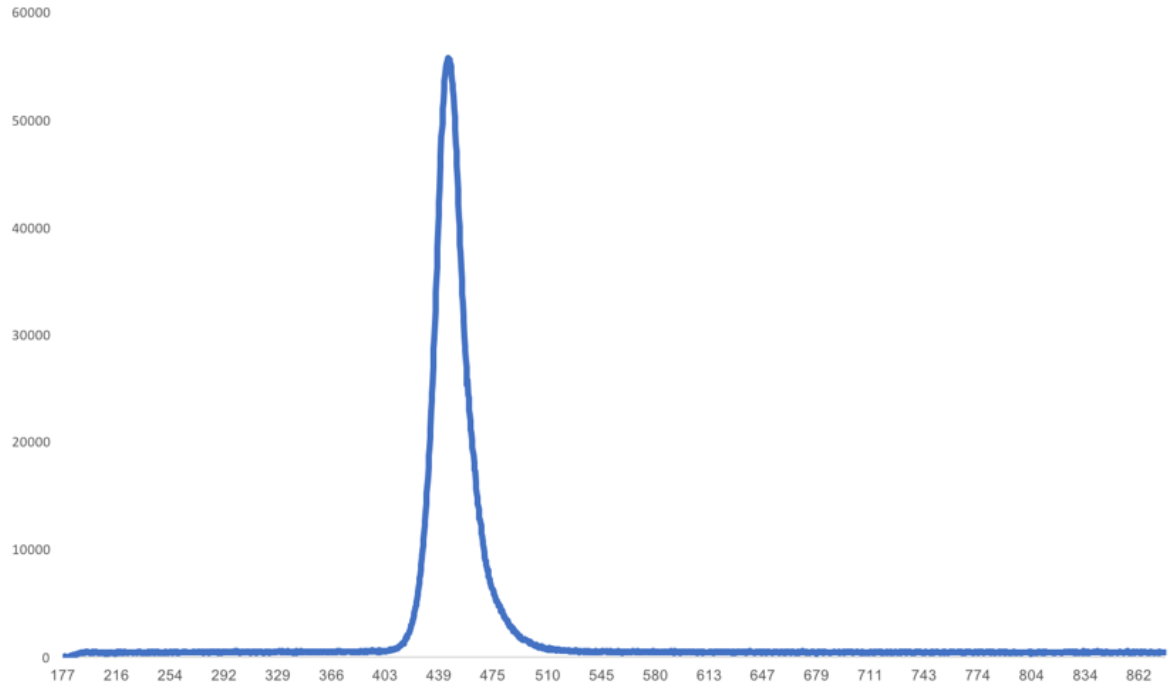
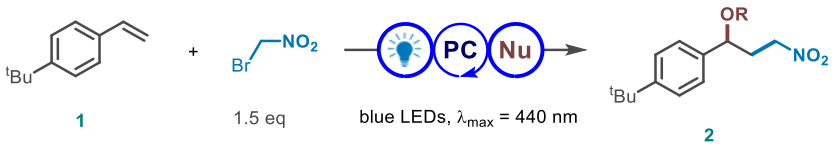


Figure 1.2. UV-Vis emission spectrum of high-intensity, blue LED photoreactor (λ_{max} = 446 nm, FWHM = 20 nm).

2. Development of the Reaction Conditions



A flame-dried 5 mL crimp cap vial was charged with photocatalyst (PC) (*x* mol%), bromo(nitro)methane (*x* equiv), nucleophile (*x* equiv), and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous solvent (*x* mL) and 4-*tert*-butylstyrene **1** (0.5 mmol, 1.0 equiv) were introduced to the solution *via* syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h. After that, *n*-decane as an internal standard was added with a microsyringe. An aliquot was taken and analyzed by GC-MS to obtain the calibrated yields for the desired product.

2.1. *Survey of Photocatalysts*

Entry[a]	**PC** [0.5 mmol]	**Yield of 2** [%][b]
1	PC1	91 (87)
2	PC2	88
3	PC3	3
4	PC4	31
5	PC5	81

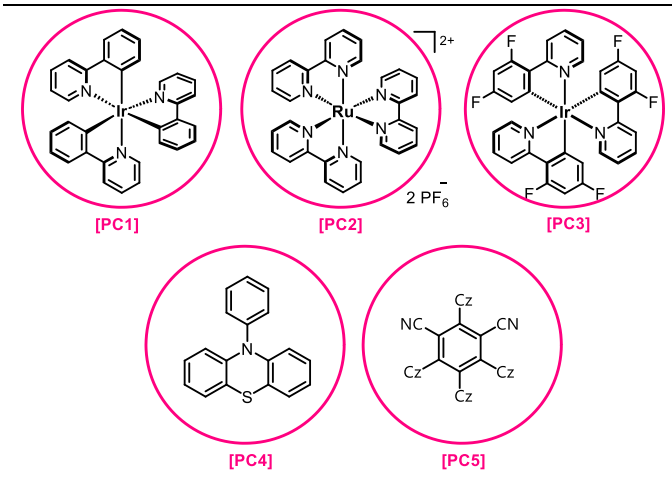


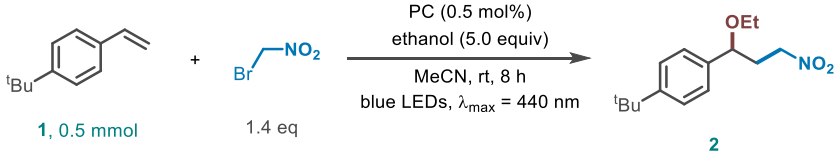
Table 2.1. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 equiv), bromo(nitro)methane (1.4 equiv), *PC* (0.5 mol%), ethanol (5.0 equiv) and MeCN (1.25 mL), 350 W blue LEDs, rt, 8 h. [b]Determined by GC against an internal standard of *n*-decane. [c]Isolated yield. Cz = carbazole.

2.2. *Survey of solvents*

Entry[a]	solvent	yield of 2 [%][b]
1	MeCN	91 (87)[c]
2	THF	6
3	DCE	31
4	$OC(OCH_3)_2$	25
5	DMF	0

Table 2.2. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 equiv), bromo(nitro)methane (1.4 equiv), *fac*-$Ir(ppy)_3$ (0.5 mol%), ethanol (5.0 equiv) and solvent (1.25 mL), 350 W blue LEDs, rt, 12 h. [b]Determined by GC against an internal standard of *n*-decane.

2.3. *Survey of silver salts and bases*



Entry[a]	Base (eq)	yield of 2 [%][b]
1	Ag_2CO_3 (0.7)	91 (87)[c]
2	$AgNO_2$	16
3	$AgNO_3$	27
4	CF_3COOAg	57
5	PhCOOAg	11
6	Na_2CO_3	37
7	K_2CO_3	25
8	Cs_2CO_3	42
9	0.3 eq of Ag_2CO_3 instead of 0.7 equiv	53

Table 2.3. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 equiv), bromo(nitro)methane (1.4 equiv), *fac*-$Ir(ppy)_3$ (0.5 mol%), ethanol (5.0 equiv) and MeCN (1.25 mL), 350 W blue LEDs, rt, 12 h. [b]Determined by GC against an internal standard of *n*-decane.

2.4. Control experiments

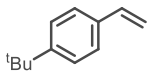
Entry	Variables	Yield of 2 [%][b]
1	Standard conditions[a]	91 (87)[c]
2	Without LEDs	0
3	Without **PC1**	0
4	Without EtOH	30
5	Heating at 90 ˚C without light	0

Table 2.4. [a]Standard reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 equiv), bromo(nitro)methane (1.4 equiv), *fac*-Ir(ppy)$_3$ (0.5 mol%), ethanol (5.0 equiv) and MeCN (1.25 mL), 350 W blue LEDs, rt, 12 h. [b]Determined by GC against an internal standard of *n*-decane.

3. Availability of Starting Materials

3.1. Commercially available starting materials

Starting materials which are commercially available are mostly purchased from Thermoscientific – Acros, Sigma Aldrich, Apollo Scintific, Fluorochem and TCI.



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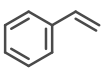

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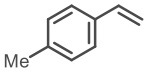

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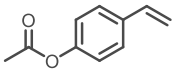

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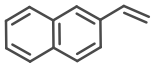

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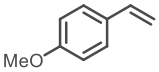

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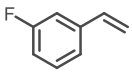

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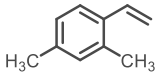

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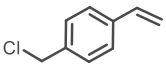

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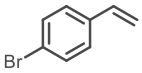

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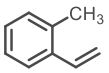

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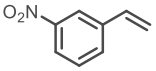

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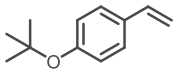

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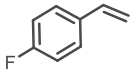
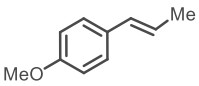
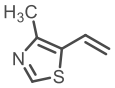


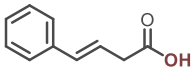
CAS
405-99-2



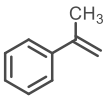
CAS
4180-23-8



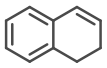
CAS
1759-28-0



CAS
1914-58-5



CAS
98-83-9



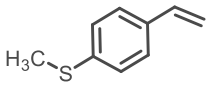
CAS
447-53-0

3.2. Prepared starting materials

General procedure A

To synthesize the desired alkene, methyltriphenylphosphonium bromide (3 equivalents) was first suspended in dry tetrahydrofuran (THF) at a concentration of 0.2 M, with the solution then cooled to 0°C. To this, tert-butoxide potassium (t-BuOK, 3 equivalents) was added in a single step, and the mixture was stirred for 30 minutes at 0°C. Following this, the ketone or aldehyde (1 equivalent) was introduced, and the reaction was gradually warmed to room temperature (RT) while stirring. Progress was monitored by thin-layer chromatography (TLC) and allowed to continue from 2 to 16 hours until completion. Upon completion, the reaction was quenched by adding water, and the resulting solution was extracted with three portions of ethyl acetate (EtOAc, 50 mL each). The organic layers were combined, washed with water, dried over sodium sulfate (Na_2SO_4), filtered, and concentrated under reduced pressure. The crude product was then purified via flash column chromatography on silica gel, yielding the pure alkene.

Methyl(4-vinylphenyl)sulfane

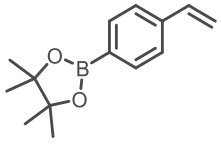


According to a general procedure A, the titled compound was obtained as yellow oil (77% yield, 5% ethyl acetate in hexane as eluent). The characterization data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.34 (d, *J* = 8.3 Hz, 2H), 7.22 (d, *J* = 8.4 Hz, 2H), 6.67 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.71 (dd, *J* = 17.6, 0.9 Hz, 1H), 5.21 (dd, *J* = 10.9, 0.9 Hz, 1H), 2.49 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.1, 136.3, 134.7, 126.8, 126.7, 113.4, 16.0.

4,4,5,5-tetramethyl-2-(4-vinylphenyl)-1,3,2-dioxaborolane

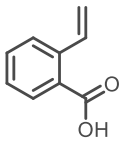


Pinacol (5.5 mmol, 1.1 equiv) was added in one portion to a solution of 4-vinylphenylboronic acid (5.0 mmol, 1.0 equiv) and MgSO4 (10 mol%) in THF (15.0 mL). After stirring the resulting mixture for 2 hours at room temperature, it was filtered and concentrated under a vacuum. The crude product was then purified by column chromatography on silica gel using Hexanes: EtOAc 95:5 (v/v), and the titled compound was obtained as a colorless oil. The characterization data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.79 (d, J = 8.1 Hz, 2H), 7.42 (d, J = 8.0 Hz, 2H), 6.74 (dd, J = 17.6, 10.9 Hz, 1H), 5.82 (dd, J = 17.6, 1.0 Hz, 1H), 5.30 (dd, J = 10.8, 0.9 Hz, 1H), 1.36 (s, 12H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 140.3, 137.0, 135.2, 125.6, 115.0, 83.9, 25.0.

2-vinylbenzoic acid

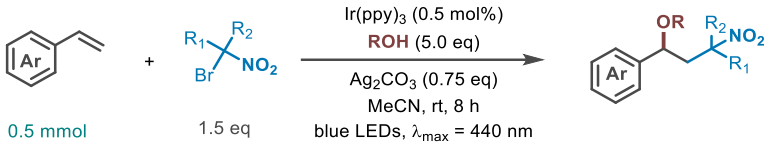


According to a general procedure A, the titled compound was obtained as white solid (88% yield, 10% ethyl acetate in hexane as eluent). The characterization data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 11.78 (br, 1H), 8.05 (dt, *J* = 11.0, 1.3, 1H), 7.66 – 7.52 (m, 3H), 7.42 – 7.33 (m, 1H), 5.68 (dd, *J* = 17.4, 1.3, 1H), 5.39 (dd, *J* = 11.0, 1.3, 1H).

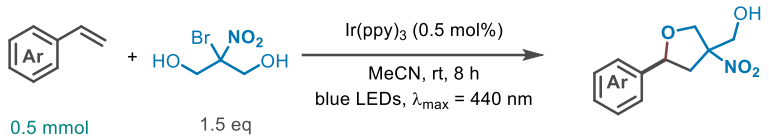
4. General Procedures

4.1. GP1 for the inter-molecular alcohol addition



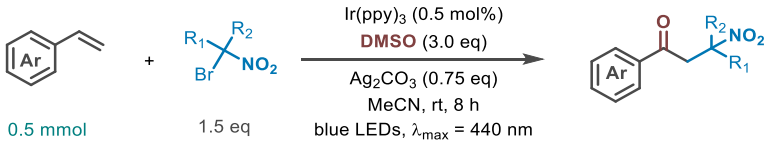
A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), Ag_2CO_3 (0.75 equiv), and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous MeCN (1.25 mL), bromo(nitro)alkane (1.5 equiv), alcohol (5.0 equiv), and alkene (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography over silica gel as indicated to get the desired product.

4.2. GP2 for the cyclization with bronopol reactions



A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), Ag_2CO_3 (0.75 equiv), bronopol (1.5 equiv), and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous MeCN (1.25 mL), and alkene (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography over silica gel as indicated to get the desired product.

4.3. GP3 for the b-nitro ketones synthesis

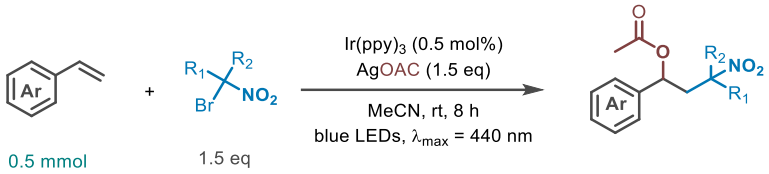


A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), Ag_2CO_3 (0.75 equiv), and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous MeCN (1.25 mL), bromo(nitro)alkane (1.5 equiv), DMSO (3.0 equiv), and alkene (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography over silica gel as indicated to get the desired product.

4.4. GP4 for the b-nitro alcohols synthesis

A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), Ag_2CO_3 (0.75 equiv), and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous MeCN (1.25 mL), bromo(nitro)alkane (1.5 equiv), water (5.0 eq) and alkene (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography over silica gel as indicated to get the desired product.

4.5. GP5 for the acetate addition



A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), AgOAc (1.5 equiv), and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous solvent (1.3 mL), bromo(nitro)alkane (1.5 equiv), and alkene (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography over silica gel as indicated to get the desired product.

5. On-Off Experiment

A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), Ag_2CO_3 (0.75 equiv), and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous MeCN (1.25 mL), bromo(nitro)methane (1.5 equiv), ethanol (5.0 equiv), and 4-tert-butylstyrene **1** (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs as following sequence: reaction mixture was stirred in the presence of blue LEDs for 30 min (interval with bulb) and then stirred at room temperature without LEDs for 30 min (interval without bulb). At the end of each time interval, aliquot of the reaction mixture was taken, filtrated through a short pot of silica gel and subjected to GC-MS analysis. Results of the experiments are presented in Figure 5.1.

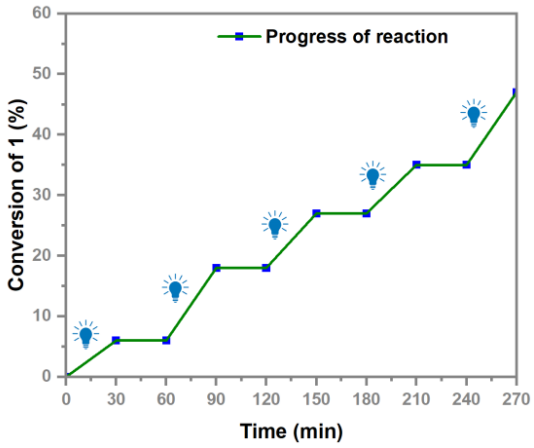


Figure 5.1. Conversion vs reaction time for the light on-off experiment.

6. Radical Trapping Experiment with TEMPO and BHT

A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), Ag_2CO_3 (0.75 equiv), additive TEMPO (2.0 equiv) or BHT (2.0 equiv) and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous MeCN (1.25 mL), bromo(nitro)methane (1.5 equiv), ethanol (5.0 equiv), and 4-tert-butylstyrene **1** (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h. An aliquot of the reaction mixture was taken, filtrated through a short pot of silica gel and subjected to GC-MS analysis. Results of the experiments are presented in Figure 6.1.

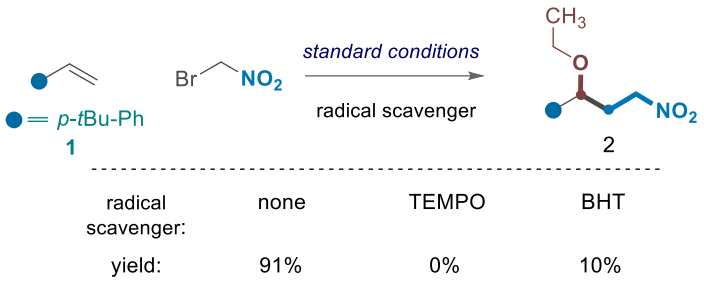
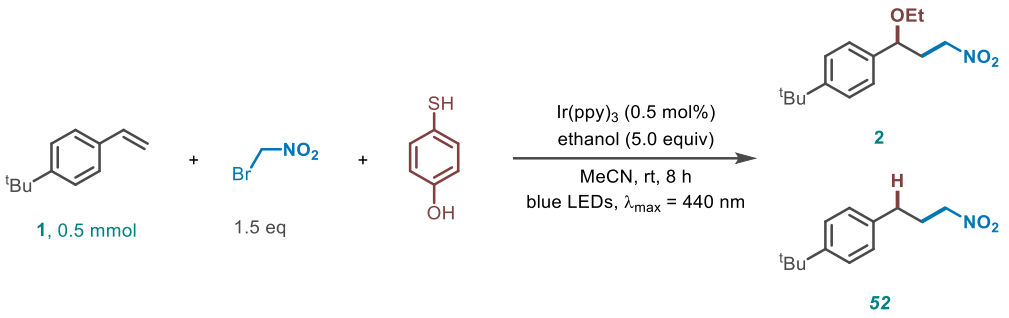


Figure 6.1. Results of trapping experiments with TEMPO and BHT.

7. HAT vs RPC Experiment



A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), Ag_2CO_3 (0.75 equiv), additive 4-hydroxythiophenol (0.0 equiv, 0.5 equiv, 1.0 equiv, 1.5 equiv, 2.0 equiv in separate vials) and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous MeCN (1.25 mL), bromo(nitro)methane (1.5 equiv), ethanol (5.0 equiv), and 4-tert-butylstyrene **1** (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h. An aliquot of the reaction mixture was taken, filtrated through a short pot of silica gel and subjected to GC-MS analysis. Results of the experiments are presented in Figure 7.1.

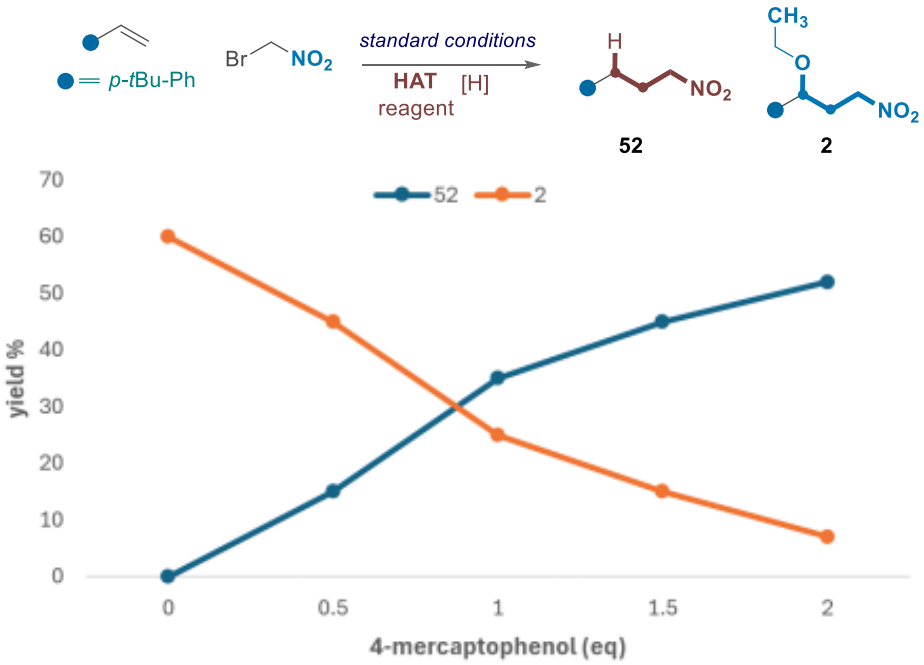
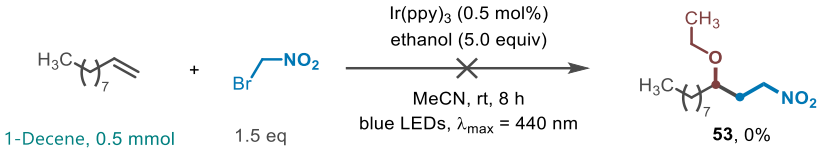
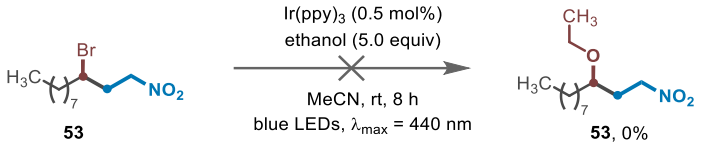


Figure 7.1. HAT vs RPC experiments.

8. Reactivity with Unactivated Alkene

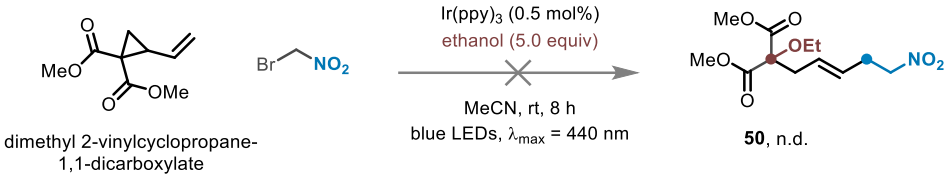


A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), Ag_2CO_3 (0.75 equiv), and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous MeCN (1.25 mL), bromo(nitro)methane (1.5 equiv), ethanol (5.0 equiv), and 1-decene (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h. An aliquot of the reaction mixture was taken, filtrated through a short pot of silica gel and subjected to GC-MS analysis.



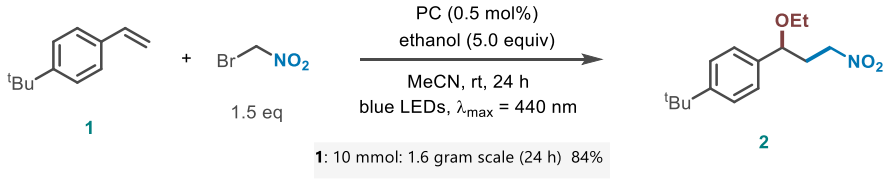
A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), Ag_2CO_3 (0.75 equiv), and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous MeCN (1.25 mL), bromo(nitro)methane (1.5 equiv), ethanol (5.0 equiv), and **54** (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h. An aliquot of the reaction mixture was taken, filtrated through a short pot of silica gel and subjected to GC-MS analysis.

9. Radical-clock Experiment



A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), Ag_2CO_3 (0.75 equiv), and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous MeCN (1.25 mL), bromo(nitro)methane (1.5 equiv), ethanol (5.0 equiv), and dimethyl 2-vinylcyclopropane-1,1-dicarboxylate (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h. An aliquot of the reaction mixture was taken, filtrated through a short pot of silica gel and subjected to GC-MS analysis.

10. Scale-up Synthesis in Batch

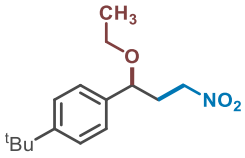


1: 10 mmol: 1.6 gram scale (24 h) 84%

A flame-dried 5 mL crimp cap vial was charged with $Ir(ppy)_3$ (0.5 mol%), Ag_2CO_3 (0.75 equiv), and equipped with a magnetic bar. The vial contents were then subject to three vacuum/N_2 cycles. Anhydrous MeCN (25 mL), bromo(nitro)methane (1.5 equiv), ethanol (5.0 equiv), and 4-tert-butylstyrene **1** (0.5 mmol, 1.0 equiv) were introduced to the solution via syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 8 h.

11. NMR Data

1-(tert-butyl)-4-(1-ethoxy-3-nitropropyl)benzene (2)



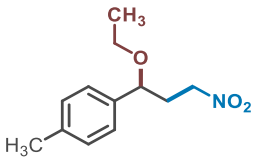
Compound **2** was obtained according to general procedure **GP1** as a colorless oil (87% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.38 (d, *J* = 8.4 Hz, 2H), 7.21 (d, *J* = 8.2 Hz, 2H), 4.60 (dt, *J* = 13.3, 7.2 Hz, 1H), 4.43 (dt, *J* = 13.2, 6.4 Hz, 1H), 4.32 (t, *J* = 6.6 Hz, 1H), 3.41 (dq, *J* = 9.2, 7.0 Hz, 1H), 3.29 (dq, J = 9.2, 7.0 Hz, 1H), 2.34 (q, *J* = 6.7 Hz, 2H), 1.32 (s, 9H), 1.16 (t, *J* = 7.0 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 151.2, 138.1, 126.1, 125.7, 78.2, 72.7, 64.5, 35.8, 34.7, 31.5, 15.3.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{15}H_{23}NO_3^+$: 265.1678; found 265.1676.

1-(1-ethoxy-3-nitropropyl)-4-methylbenzene (3)



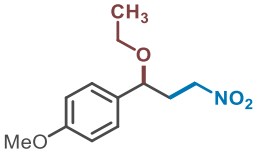
Compound **3** was obtained according to general procedure **GP1** as a colorless oil (85% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.19 (d, *J* = 0.8 Hz, 4H), 4.59 (dt, *J* = 13.3, 7.1 Hz, 1H), 4.43 (dt, *J* = 13.2, 6.4 Hz, 1H), 4.32 (dd, *J* = 7.3, 6.0 Hz, 1H), 3.46 – 3.22 (m, 2H), 2.39 – 2.32 (m, 5H), 1.16 (td, *J* = 7.0, 0.6 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.1, 137.9, 129.5, 126.4, 78.2, 72.6, 64.4, 35.8, 21.2, 15.2.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{12}H_{17}NO_3^+$: 223.1208; found 223.1205.

1-(1-ethoxy-3-nitropropyl)-4-methoxybenzene (4)



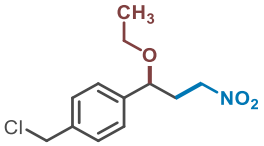
Compound **4** was obtained according to general procedure **GP1** as a light-yellow oil (90% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.22 (d, *J* = 8.7 Hz, 2H), 6.90 (d, *J* = 8.8 Hz, 2H), 4.58 (ddd, *J* = 13.2, 7.5, 6.6 Hz, 1H), 4.42 (dt, *J* = 13.3, 6.5 Hz, 1H), 4.29 (dd, *J* = 8.1, 5.3 Hz, 1H), 3.81 (s, 3H), 3.43 – 3.20 (m, 2H), 2.39 – 2.27 (m, 2H), 1.15 (t, *J* = 7.0 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 159.6, 133.1, 127.7, 114.2, 78.0, 72.7, 64.3, 55.4, 35.8, 15.3.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{12}H_{17}NO_4^+$: 239.1158; found 239.1156.

1-(chloromethyl)-4-(1-ethoxy-3-nitropropyl)benzene (5)



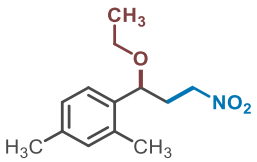
Compound **5** was obtained according to general procedure GP1 as a light-yellow oil (81% yield) after purification by column chromatography (SiO2, hexane/EA=4:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.40 (d, *J* = 8.2 Hz, 2H), 7.30 (d, *J* = 8.0 Hz, 2H), 4.64 – 4.56 (m, 3H), 4.50 – 4.29 (m, 2H), 3.46 – 3.21 (m, 2H), 2.40 – 2.27 (m, 2H), 1.17 (t, *J* = 7.0 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 141.6, 137.5, 129.1, 126.8, 78.1, 72.5, 64.8, 46.0, 35.8, 15.3.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{12}H_{16}NClO_3^+$: 257.0819; found 257.0817.

1-(1-ethoxy-3-nitropropyl)-2,4-dimethylbenzene (6)



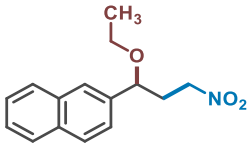
Compound **6** was obtained according to general procedure **GP1** as a colorless oil (82% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.19 (dd, *J* = 12.2, 7.8 Hz, 1H), 6.96 (dd, *J* = 7.8, 1.8 Hz, 1H), 6.89 (d, *J* = 1.8 Hz, 1H), 4.64 – 4.52 (m, 1H), 4.48 (dd, *J* = 9.5, 3.6 Hz, 1H), 4.37 (dt, *J* = 13.5, 5.9 Hz, 1H), 3.37 – 3.09 (m, 3H), 2.22 (s, 3H), 2.20 (s, 3H), 1.08 (t, *J* = 7.0 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 137.3, 136.2, 135.1, 131.6, 127.2, 125.7, 74.8, 72.6, 64.4, 34.5, 21.1, 18.8, 15.3.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{13}H_{19}NO_3^+$: 237.1365; found 237.1363.

2-(1-ethoxy-3-nitropropyl)naphthalene (7)



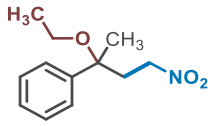
Compound **7** was obtained according to general procedure **GP1** as a light yellow oil (86% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.94 – 7.72 (m, 4H), 7.55 – 7.40 (m, 3H), 4.65 (dt, *J* = 13.3, 7.1 Hz, 1H), 4.56 – 4.41 (m, 2H), 3.53 – 3.30 (m, 2H), 2.44 (ddd, *J* = 7.2, 6.3, 5.3 Hz, 2H), 1.20 (t, *J* = 7.0 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.6, 133.4, 133.3, 128.9, 128.0, 127.9, 126.5, 126.3, 125.7, 123.9, 78.6, 72.6, 64.7, 35.6, 15.3.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{15}H_{17}NO_3^+$: 259.1208; found 259.1206.

(2-ethoxy-4-nitrobutan-2-yl)benzene (8)



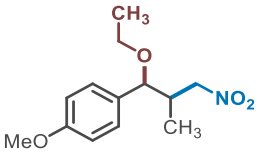
Compound **8** was obtained according to general procedure **GP1** as a light yellow oil (83% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.42 – 7.32 (m, 5H), 4.47 (ddd, *J* = 13.3, 9.5, 6.1 Hz, 1H), 4.28 (ddd, *J* = 13.2, 9.4, 5.9 Hz, 1H), 3.37 (dq, *J* = 8.8, 6.9 Hz, 1H), 3.21 (dq, *J* = 8.8, 7.0 Hz, 1H), 2.58 – 2.34 (m, 2H), 1.61 (s, 3H), 1.19 (t, *J* = 7.0 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 144.1, 128.7, 127.5, 125.7, 72.0, 58.1, 40.6, 31.2, 24.1, 15.6.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{12}H_{17}NO_3^+$: 223.1208; found 223.1206.

1-(1-ethoxy-2-methyl-3-nitropropyl)-4-methoxybenzene (9)



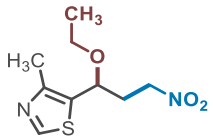
Compound **9** was obtained according to general procedure **GP1** as a light yellow oil (76% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.19 (d, *J* = 8.5 Hz, 2H), 6.89 (d, *J* = 8.8 Hz, 2H), 4.66 (dd, *J* = 12.1, 5.0 Hz, 1H), 4.38 (dd, *J* = 12.2, 8.2 Hz, 1H), 3.98 (d, *J* = 8.3 Hz, 1H), 3.82 (s, 3H), 3.39 – 3.16 (m, 2H), 2.66 – 2.51 (m, 1H), 1.12 (t, *J* = 7.0 Hz, 3H), 0.83 (d, *J* = 6.9 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 159.6, 132.0, 128.5, 114.1, 83.5, 79.1, 64.4, 55.4, 39.6, 15.2, 14.5.

HRMS (ESI) *m/z*, $[M+Na]^+$ calcd for $C_{13}H_{19}NO_4$+Na^+: 276.1212; found 276.1210.

5-(1-ethoxy-3-nitropropyl)-4-methylthiazole (10)



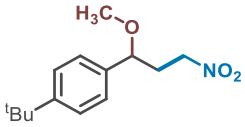
Compound **10** was obtained according to general procedure **GP1** as an orange oil (77% yield) after purification by column chromatography (SiO_2, hexane/EA=1:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.69 (s, 1H), 4.76 – 4.57 (m, 2H), 4.45 (dt, *J* = 13.8, 6.0 Hz, 1H), 3.50 – 3.23 (m, 2H), 2.43 (s, 3H), 2.42 – 2.34 (m, 2H), 1.15 (t, *J* = 7.0 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 151.7, 150.3, 132.8, 72.0, 71.5, 64.8, 35.6, 15.4, 15.1.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_9H_{14}NSO_3^+$: 230.0725; found 230.0722.

1-(tert-butyl)-4-(1-methoxy-3-nitropropyl)benzene (11)



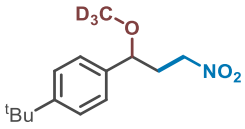
Compound **11** was obtained according to general procedure **GP1** as a light yellow oil (85% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.40 (d, *J* = 8.4 Hz, 2H), 7.21 (d, *J* = 8.2 Hz, 2H), 4.58 (dt, *J* = 13.3, 7.2 Hz, 1H), 4.42 (dt, *J* = 13.2, 6.5 Hz, 1H), 4.22 (t, *J* = 6.6 Hz, 1H), 3.22 (s, 3H), 2.41 – 2.31 (m, 2H), 1.33 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 151.2, 137.2, 126.1, 125.6, 80.0, 72.4, 56.8, 35.5, 34.6, 31.4.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{14}H_{21}NO_3^+$: 251.1521; found 251.1519.

1-(tert-butyl)-4-(1-(methoxy-d3)-3-nitropropyl)benzene (12)



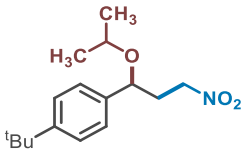
Compound **12** was obtained according to general procedure **GP1** as a light yellow oil (73% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.39 (d, *J* = 8.4 Hz, 2H), 7.21 (d, *J* = 8.1 Hz, 2H), 4.64 – 4.36 (m, 1H), 4.21 (t, *J* = 6.6 Hz, 1H), 2.39 – 2.31 (m, 2H), 1.33 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 151.3, 137.3, 126.2, 125.8, 80.0, 72.6, 35.6, 35.6, 34.7, 31.5.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{14}H_{18}D_3NO_3^+$: 254.1710; found 254.1708.

1-(tert-butyl)-4-(1-isopropoxy-3-nitropropyl)benzene (13)



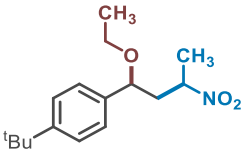
Compound **13** was obtained according to general procedure **GP1** as a light yellow oil (78% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.38 (d, *J* = 8.4 Hz, 3H), 7.23 (d, *J* = 8.3 Hz, 2H), 4.60 (ddd, *J* = 13.4, 7.7, 6.7 Hz, 1H), 4.49 – 4.35 (m, 2H), 3.50 (p, *J* = 6.1 Hz, 1H), 2.30 (dtd, *J* = 8.4, 6.7, 5.4 Hz, 2H), 1.33 (s, 9H), 1.10 (dd, *J* = 10.6, 6.1 Hz, 6H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 151.0, 138.8, 126.1, 125.6, 75.1, 72.7, 69.1, 36.1, 34.7, 31.5, 23.5, 21.1.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{16}H_{25}NO_3^+$: 279.1834; found 279.1832.

1-(tert-butyl)-4-(1-ethoxy-3-nitrobutyl)benzene (14)



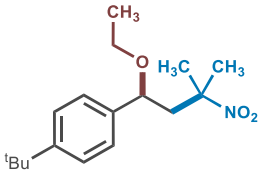
Compound **14** was obtained according to general procedure **GP1** as a light yellow oil (71% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.36 (d, *J* = 8.3 Hz, 2H), 7.19 (d, *J* = 8.4 Hz, 2H), 5.00 (ddd, *J* = 10.1, 6.7, 3.2 Hz, 1H), 4.17 (dd, *J* = 10.5, 2.9 Hz, 1H), 3.41 (dq, *J* = 9.3, 7.0 Hz, 1H), 3.27 (dq, *J* = 9.2, 7.0 Hz, 1H), 2.28 (ddd, *J* = 14.9, 10.3, 2.9 Hz, 1H), 1.99 (ddd, *J* = 14.9, 10.5, 3.2 Hz, 1H), 1.54 (d, *J* = 1.7 Hz, 3H), 1.32 (s, 10H), 1.17 (t, *J* = 7.0 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 151.0, 138.5, 126.0, 125.6, 80.8, 77.8, 64.7, 44.0, 34.7, 31.5, 20.2, 15.3.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{16}H_{25}NO_3^+$: 279.1834; found 279.1832.

1-(tert-butyl)-4-(1-ethoxy-3-methyl-3-nitrobutyl)benzene (15)



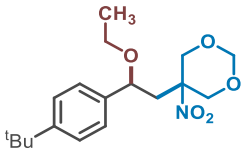
Compound **15** was obtained according to general procedure **GP1** as a light yellow oil (80% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.36 (d, *J* = 8.3 Hz, 2H), 7.21 (d, *J* = 8.3 Hz, 2H), 4.30 (dd, *J* = 10.3, 2.5 Hz, 1H), 3.35 (dq, *J* = 16.2, 6.9 Hz, 1H), 3.20 (dq, *J* = 9.1, 7.0 Hz, 1H), 2.49 (dd, *J* = 15.1, 10.3 Hz, 1H), 2.11 – 2.02 (m, 1H), 1.67 (s, 6H), 1.32 (s, 9H), 1.12 (t, *J* = 7.0 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 150.8, 139.1, 126.0, 125.6, 87.2, 78.3, 64.4, 48.8, 34.7, 31.5, 27.0, 15.1.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{17}H_{27}NO_3^+$: 293.1991; found 293.1989.

5-(2-(4-(tert-butyl)phenyl)-2-ethoxyethyl)-5-nitro-1,3-dioxane (16)



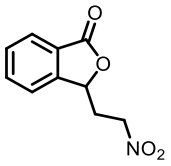
Compound **16** was obtained according to general procedure **GP1** as a yellow oil (83% yield) after purification by column chromatography (SiO_2, hexane/EA=3:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.35 (d, *J* = 8.4 Hz, 2H), 7.14 (d, *J* = 8.3 Hz, 2H), 5.07 – 4.96 (m, 2H), 4.72 (d, *J* = 6.3 Hz, 1H), 4.63 (ddd, *J* = 12.5, 2.7, 0.9 Hz, 1H), 4.19 (dd, *J* = 10.5, 2.3 Hz, 1H), 3.95 (d, *J* = 13.0 Hz, 1H), 3.82 (d, J = 12.5 Hz, 1H), 3.39 – 3.17 (m, 2H), 2.13 (dd, *J* = 15.1, 10.5 Hz, 1H), 1.93 (dd, *J* = 15.2, 2.3 Hz, 1H), 1.31 (s, 9H), 1.14 (d, *J* = 7.0 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 151.2, 137.9, 125.9, 125.7, 93.9, 86.0, 77.1, 71.2, 71.0, 64.4, 42.5, 34.6, 31.4, 15.2.

HRMS (ESI) *m/z*, $[M+Na]^+$ calcd for $C_{16}H_{21}NO_4$+Na^+: 314.1363; found 314.1360.

3-(2-nitroethyl)isobenzofuran-1(3H)-one (17)



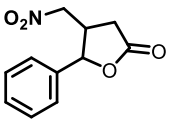
Compound **17** was obtained according to general procedure **GP1** (without adding ethanol) as a colorless oil (86% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.93 (dt, *J* = 7.7, 1.0 Hz, 1H), 7.74 (td, *J* = 7.5, 1.2 Hz, 1H), 7.64 – 7.56 (m, 1H), 7.51 (dq, *J* = 7.7, 0.9 Hz, 1H), 5.59 (dd, *J* = 9.4, 3.1 Hz, 1H), 4.71 (ddd, *J* = 14.5, 8.2, 6.5 Hz, 1H), 4.54 (ddd, *J* = 14.2, 7.0, 5.4 Hz, 1H), 2.90 (dddd, *J* = 15.1, 8.1, 7.0, 3.1 Hz, 1H), 2.27 (dddd, *J* = 14.9, 9.4, 6.5, 5.4 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 169.7, 148.1, 134.7, 130.1, 126.3, 125.9, 122.0, 77.5, 71.1, 32.4.

HRMS (ESI) *m/z*, $[C_{10}H_9O_4N+Na]^+$ calcd: 230.0424; found 230.0419.

3-(2-nitroethyl)isobenzofuran-1(3H)-one (18)



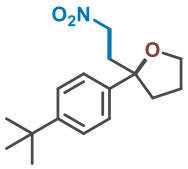
Compound **18** was obtained according to general procedure **GP1** (without adding ethanol) as a yellow oil (82% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.42 (tdd, *J* = 3.8, 2.5, 1.0 Hz, 3H), 7.38 – 7.32 (m, 2H), 5.23 (d, *J* = 7.1 Hz, 1H), 4.65 – 4.45 (m, 2H), 3.29 – 3.12 (m, 1H), 2.98 (dd, *J* = 17.7, 8.4 Hz, 1H), 2.57 (dd, *J* = 17.7, 8.4 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 173.9, 136.6, 129.7, 129.3, 125.9, 82.5, 75.5, 42.6, 32.8.

HRMS (ESI) *m/z*, $[C_{11}H_{11}O_4N]^+$ calcd: 221.0688; found 221.0686.

2-(4-(tert-butyl)phenyl)-2-(2-nitroethyl)tetrahydrofuran (19)



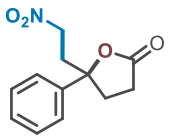
Compound **19** was obtained according to general procedure **GP1** (without adding ethanol) as a light yellow oil (81% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.35 (d, *J* = 8.6 Hz, 2H), 7.25 (d, *J* = 8.5 Hz, 2H), 4.43 (ddd, *J* = 13.4, 8.3, 7.6 Hz, 1H), 4.11 – 3.86 (m, 3H), 2.52 (t, *J* = 7.8 Hz, 2H), 2.26 – 2.05 (m, 2H), 2.04 – 1.75 (m, 2H), 1.32 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 150.1, 141.6, 125.5, 124.8, 84.6, 72.3, 68.1, 39.6, 39.4, 34.6, 31.5, 25.6.

HRMS (ESI) *m/z*, $[C_{16}H_{23}O_3N]^+$ calcd: 277.1678; found 277.1676.

5-(2-nitroethyl)-5-phenyldihydrofuran-2(3*H*)-one (20)



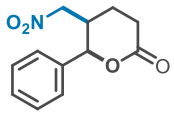
Compound **20** was obtained according to general procedure **GP1** (without adding ethanol) as a yellow oil (78% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 – 7.28 (m, 5H), 4.45 (ddd, *J* = 13.9, 9.5, 6.2 Hz, 1H), 4.05 (ddd, *J* = 13.9, 9.5, 6.0 Hz, 1H), 2.83 – 2.41 (m, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 175.5, 140.5, 129.3, 128.6, 124.4, 86.5, 71.0, 39.0, 36.1, 28.1.

HRMS (ESI) *m/z*, $[C_{12}H_{13}O_4N+Na]^+$ calcd: 258.0742; found 258.0739.

5-(nitromethyl)-6-phenyltetrahydro-2*H*-pyran-2-one (21)



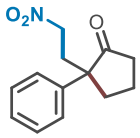
Compound **21** was obtained according to general procedure **GP1** (without adding ethanol) as a yellow oil (72% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.47 – 7.28 (m, 5H), 5.20 (d, *J* = 10.0 Hz, 1H), 4.28 – 4.15 (m, 2H), 2.89 – 2.62 (m, 3H), 2.26 – 2.11 (m, 1H), 2.06 – 1.86 (m, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 170.0, 136.3, 129.9, 129.4, 127.1, 82.4, 76.3, 38.7, 28.6, 22.6.

HRMS (ESI) *m/z*, $[C_{12}H_{14}O_4N]^+$ calcd: 236.0917; found 236.0915.

2-(2-nitroethyl)-2-phenylcyclopentan-1-one (22)



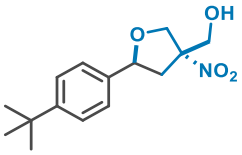
Compound **22** was obtained according to general procedure **GP1** (without adding ethanol) as a yellow oil (79% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.42 – 7.25 (m, 5H), 4.35 (ddd, *J* = 13.4, 9.8, 5.6 Hz, 1H), 4.07 (ddd, *J* = 13.5, 9.8, 6.1 Hz, 1H), 2.61 (ddd, *J* = 14.0, 9.8, 5.5 Hz, 2H), 2.44 – 2.20 (m, 3H), 2.04 – 1.91 (m, 2H), 1.86 – 1.70 (m, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 218.3, 137.1, 129.4, 127.9, 126.7, 72.2, 55.1, 37.08, 35.7, 35.3, 18.7.

HRMS (ESI) *m/z*, $[C_{13}H_{14}O_3N]^+$ calcd: 232.0968; found 232.0971.

5-(4-(tert-butyl)phenyl)-3-nitrotetrahydrofuran-3-yl)methanol (SP-15-184)



Compound **23** was obtained according to general procedure **GP2** (81% yield) after purification by column chromatography (SiO_2, hexane/EA=2:1).

23a: light-yellow oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.40 (d, *J* = 8.5 Hz, 2H), 7.27 (d, *J* = 8.3 Hz, 2H), 5.18 (dd, *J* = 9.7, 6.2 Hz, 1H), 4.35 (q, *J* = 10.7 Hz, 2H), 4.06 (q, *J* = 12.3 Hz, 2H), 3.05 (dd, *J* = 14.3, 6.1 Hz, 1H), 2.65 (s, 1H), 2.12 (dd, *J* = 14.3, 9.7 Hz, 1H), 1.32 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 151.4, 136.6, 125.7, 125.7, 97.8, 81.2, 73.7, 66.1, 42.7, 34.7, 31.4.

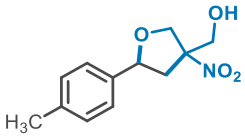
HRMS (ESI) *m/z*, $[C_{15}H_{21}NO_4$+Na$]^+$ calcd for: 302.1363; found 302.1361.

23a: light-yellow solid.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.40 (d, *J* = 8.5 Hz, 2H), 7.31 (d, *J* = 8.4 Hz, 2H), 4.89 (dd, *J* = 9.1, 6.7 Hz, 1H), 4.71 (d, *J* = 11.0 Hz, 1H), 4.25 – 3.92 (m, 4H), 2.98 (s, 1H), 2.82 – 2.58 (m, 2H), 1.32 (s, 9H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 151.6, 136.3, 126.0, 125.7, 98.3, 81.3, 73.8, 65.6, 42.0, 34.7, 31.4.

3-nitro-5-(p-tolyl)tetrahydrofuran-3-yl)methanol (24)



Compound **24** was obtained according to general procedure **GP2** as a light-yellow solid (83% yield) after purification by column chromatography (SiO_2, hexane/EA=2:1).

24a: light-yellow solid.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.21 (q, *J* = 8.2 Hz, 4H), 5.17 (dd, *J* = 9.7, 6.1 Hz, 1H), 4.42 – 4.29 (m, 2H), 4.14 – 3.97 (m, 2H), 3.04 (dd, *J* = 14.3, 6.2 Hz, 1H), 2.63 (s, 1H), 2.35 (s, 3H), 2.10 (dd, *J* = 14.3, 9.7 Hz, 1H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 138.2, 136.6, 129.5, 125.8, 97.8, 81.3, 73.7, 66.1, 42.9, 21.3.

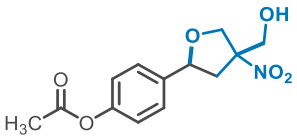
HRMS (ESI) *m/z*, $[M+Na]^+$ calcd for $C_{12}H_{15}NO_4$+Na^+: 260.0893; found 260.0894.

24b: light-yellow solid.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.27 (d, *J* = 8.0 Hz, 2H), 7.21 – 7.14 (d, *J* = 8.0 Hz, 2H), 4.88 (dd, *J* = 9.1, 6.8 Hz, 1H), 4.71 (d, *J* = 11.0 Hz, 1H), 4.25 – 3.93 (m, 3H), 2.80 – 2.57 (m, 3H), 2.35 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 138.3, 136.4, 129.5, 126.2, 98.2, 81.4, 73.9, 65.6, 42.3, 21.3.

4-(4-(hydroxymethyl)-4-nitrotetrahydrofuran-2-yl)phenyl acetate (25)



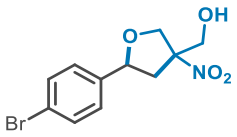
Compound **25** was obtained according to general procedure **GP2** as a light-yellow oil (86% yield) after purification by column chromatography (SiO_2, hexane/EA=2:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.33 (d, *J* = 0.6 Hz, 2H), 7.08 (d, *J* = 8.7 Hz, 2H), 5.17 (dd, *J* = 9.8, 6.1 Hz, 1H), 4.41 – 4.26 (m, 2H), 4.11 – 3.92 (m, 2H), 3.06 (dd, *J* = 14.3, 6.1 Hz, 1H), 2.79 (s, 1H), 2.29 (s, 3H), 2.05 (dd, *J* = 10.0, 4.3 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 169.9, 150.5, 137.5, 126.9, 121.9, 97.8, 80.7, 73.7, 66.1, 65.9, 42.8, 21.2.

HRMS (ESI) *m/z*, $[C_{13}H_{15}NO_6+Na]^+$ calcd for: 304.0797; found 304.0795.

(5-(4-bromophenyl)-3-nitrotetrahydrofuran-3-yl)methanol (26)



Compound **26** was obtained according to general procedure **GP2** (78% yield) after purification by column chromatography (SiO_2, hexane/EA=2:1).

26a: light-yellow oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.49 (d, *J* = 8.5 Hz, 2H), 7.21 (d, *J* = 8.7 Hz, 2H), 5.15 (dd, *J* = 9.8, 6.2 Hz, 1H), 4.43 – 4.26 (m, 2H), 4.11 (d, *J* = 12.4 Hz, 1H), 4.01 (dd, *J* = 12.4, 0.9 Hz, 1H), 3.07 (dd, *J* = 14.3, 6.2 Hz, 1H), 2.63 (s, 1H), 2.04 (dd, *J* = 14.3, 9.7 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.8, 131.9, 127.5, 122.2, 97.7, 80.6, 73.8, 66.0, 42.9.i

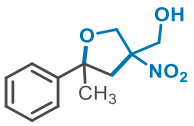
26b: light-yellow solid.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.42 (d, *J* = 8.5 Hz, 2H), 7.17 (d, *J* = 8.3 Hz, 2H), 4.81 (t, *J* = 7.9 Hz, 1H), 4.63 (d, *J* = 11.0 Hz, 1H), 4.34 (d, *J* = 12.7 Hz, 1H), 4.18 (d, *J* = 12.7 Hz, 1H), 3.91 (d, *J* = 11.0 Hz, 1H), 2.61 (d, *J* = 7.9 Hz, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 138.6, 131.9, 127.8, 122.3, 98.2, 80.7, 74.0, 66.3, 65.5, 42.1.

HRMS (ESI) *m/z*, $[C_{11}H_{12}NBrO_4+Na]^+$ calcd for: 323.9847; found 323.9844.

5-methyl-3-nitro-5-phenyltetrahydrofuran-3-yl)methanol (27)



Compound **27** was obtained according to general procedure **GP2** (72% yield) after purification by column chromatography (SiO_2, hexane/EA=2:1).

27a: light-yellow oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.38 (d, *J* = 4.0 Hz, 4H), 7.34 – 7.27 (m, 1H), 4.63 (d, *J* = 10.9 Hz, 1H), 3.97 (d, *J* = 11.0 Hz, 1H), 3.86 – 3.70 (m, 2H), 3.03 (d, *J* = 14.3 Hz, 1H), 2.72 (d, *J* = 14.4 Hz, 1H), 2.63 (s, 1H), 1.63 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 145.7, 128.8, 127.3, 124.4, 99.2, 85.8, 72.1, 65.8, 46.4, 30.6.

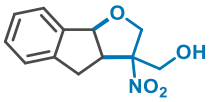
27b: light-yellow solid.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.44 – 7.33 (m, 4H), 7.31 – 7.22 (m, 1H), 4.47 (d, *J* = 10.7 Hz, 1H), 4.22 (d, *J* = 10.6 Hz, 1H), 4.08 (s, 2H), 3.29 (d, *J* = 14.5 Hz, 1H), 2.84 (s, 1H), 2.41 (d, *J* = 14.5 Hz, 1H), 1.58 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 145.1, 128.6, 127.3, 124.6, 98.2, 85.6, 71.0, 67.0, 46.0, 30.6.

HRMS (ESI) *m/z*, $[C_{12}H_{15}NO_4+Na]^+$ calcd for: 260.0899; found 260.0897.

(3-nitro-3,3a,4,8b-tetrahydro-2H-indeno[1,2-b]furan-3-yl)methanol (28)



Compound **28** was obtained according to general procedure **GP2** (76% yield) after purification by column chromatography (SiO_2, hexane/EA=2:1).

28a: light-yellow oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.49 – 7.40 (m, 1H), 7.37 – 7.18 (m, 4H), 5.78 (d, *J* = 6.9 Hz, 1H), 4.51 (dd, *J* = 10.9, 1.1 Hz, 1H), 4.10 (s, 2H), 3.99 – 3.87 (m, 1H), 3.64 (d, *J* = 10.9 Hz, 1H), 3.27 (dd, *J* = 17.4, 9.5 Hz, 1H), 3.11 (dd, *J* = 17.5, 4.3 Hz, 1H), 2.19 (s, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 142.0, 139.9, 129.7, 127.8, 125.8, 124.6, 101.4, 88.4, 72.7, 63.3, 48.5, 32.4.

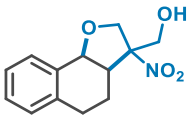
28b: light-yellow solid.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.47 – 7.39 (m, 1H), 7.37 – 7.27 (m, 2H), 7.24 – 7.16 (m, 1H), 5.58 (d, *J* = 6.2 Hz, 1H), 4.34 – 4.22 (m, 1H), 4.19 (d, *J* = 9.8 Hz, 1H), 4.10 – 3.93 (m, 2H), 3.27 – 3.11 (m, 2H), 2.92 (s, 1H), 2.79 – 2.65 (m, 1H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 142.1, 139.5, 129.8, 127.8, 125.7, 124.6, 98.5, 87.3, 67.1, 65.6, 45.9, 34.0.

HRMS (ESI) *m/z*, $[C_{12}H_{13}NO_4+Na]^+$ calcd for: 258.0742; found 258.0740.

(3-nitro-2,3,3a,4,5,9b-hexahydronaphtho[1,2-b]furan-3-yl)methanol (29)



Compound **29** was obtained according to general procedure **GP2** (79% yield) after purification by column chromatography (SiO_2, hexane/EA=2:1).

29a: light-yellow oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.44 – 7.34 (m, 1H), 7.30 – 7.20 (m, 2H), 7.15 (dd, *J* = 5.5, 3.7 Hz, 1H), 5.03 (d, *J* = 5.0 Hz, 1H), 4.52 (d, *J* = 11.0 Hz, 1H), 4.19 – 4.00 (m, 3H), 3.16 (dt, *J* = 13.2, 4.7 Hz, 1H), 2.92 – 2.58 (m, 3H), 2.14 – 1.98 (m, 1H), 1.53 (qd, *J* = 12.7, 4.4 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.7, 132.7, 130.3, 128.5, 126.8, 102.3, 77.9, 72.0, 63.0, 45.1, 29.0, 21.1.

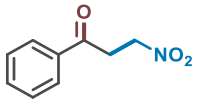
29b: light-yellow solid.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.42 (dd, *J* = 5.5, 3.7 Hz, 1H), 7.30 – 7.20 (m, 2H), 7.14 (dd, *J* = 5.5, 3.7 Hz, 1H), 4.87 – 4.74 (m, 2H), 4.56 – 4.44 (m, 1H), 4.08 (dd, *J* = 20.9, 11.6 Hz, 2H), 2.84 (dt, *J* = 16.4, 3.9 Hz, 1H), 2.74 – 2.55 (m, 2H), 2.46 (s, 1H), 1.78 – 1.45 (m, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 137.0, 132.6, 130.0, 128.5, 128.5, 126.8, 101.0, 77.4, 70.9, 66.4, 44.5, 28.7, 21.2.

HRMS (ESI) *m/z*, $[C_{13}H_{15}NO_4+Na]^+$ calcd for: 272.0899; found 272.0897.

3-nitro-1-phenylpropan-1-one (30)

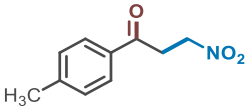


Compound **30** was obtained according to general procedure **GP3** as a colorless oil (65% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.03 – 7.93 (m, 2H), 7.67 – 7.57 (m, 1H), 7.51 (dd, *J* = 8.3, 6.8 Hz, 2H), 4.83 (t, *J* = 6.1 Hz, 2H), 3.66 (t, *J* = 6.1 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 195.1, 135.8, 134.1, 129.0, 128.3, 69.4, 35.0.

3-nitro-1-(p-tolyl)propan-1-one (31)

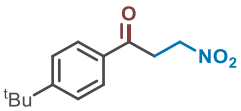


Compound **31** was obtained according to general procedure **GP3** as a colorless oil (74% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.87 (d, *J* = 8.2 Hz, 2H), 7.29 (d, *J* = 7.9 Hz, 2H), 4.81 (t, *J* = 6.1 Hz, 2H), 3.63 (t, *J* = 6.2 Hz, 2H), 2.43 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 195.1, 135.8, 134.1, 129.0, 128.8, 69.4, 35.0.

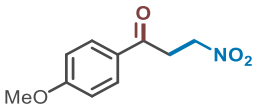
1-(4-(tert-butyl)phenyl)-3-nitropropan-1-one (32)



Compound **32** was obtained according to general procedure **GP3** as a colorless oil (74% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.93 (d, *J* = 8.6 Hz, 2H), 7.52 (d, *J* = 8.6 Hz, 2H), 4.83 (t, *J* = 6.2 Hz, 2H), 3.65 (t, *J* = 6.2 Hz, 2H), 1.35 (s, 9H).

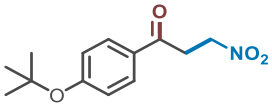
1-(4-methoxyphenyl)-3-nitropropan-1-one (33)



Compound **33** was obtained according to general procedure **GP3** as a colorless oil (70% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.56 (d, *J* = 9.0 Hz, 2H), 6.93 (d, *J* = 8.9 Hz, 3H), 4.70 – 4.59 (m, 2H), 3.84 (s, 3H), 3.53 – 3.44 (m, 2H).

1-(4-(tert-butoxy)phenyl)-3-nitropropan-1-one (34)



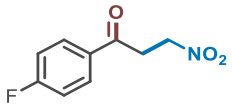
Compound **34** was obtained according to general procedure **GP3** as a colorless oil (68% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.92 (d, *J* = 8.8 Hz, 2H), 7.06 (d, *J* = 8.8 Hz, 2H), 4.82 (t, *J* = 6.2 Hz, 2H), 3.62 (t, *J* = 6.2 Hz, 2H), 1.44 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 193.8, 161.4, 130.2, 129.9, 122.4, 80.1, 69.6, 34.8, 29.1.

HRMS (ESI) *m/z*, $[M+Na]^+$ calcd for $C_{13}H_{17}NO_4$+Na^+: 274.1050; found 274.1048.

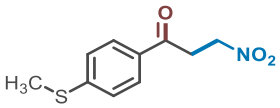
1-(4-fluorophenyl)-3-nitropropan-1-one (35)



Compound **35** was obtained according to general procedure **GP3** as a colorless oil (69% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.07 – 7.96 (m, 2H), 7.22 – 7.14 (m, 2H), 4.83 (t, *J* = 6.1 Hz, 2H), 3.63 (t, *J* = 6.1 Hz, 2H).

1-(4-(methylthio)phenyl)-3-nitropropan-1-one (36)



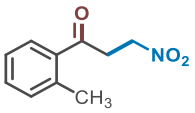
Compound **36** was obtained according to general procedure **GP3** as a colorless oil (51% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.88 (d, *J* = 8.6 Hz, 2H), 7.29 (d, *J* = 8.6 Hz, 2H), 4.82 (t, *J* = 6.2 Hz, 2H), 3.62 (t, *J* = 6.2 Hz, 2H), 2.53 (s, 4H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 194.0, 147.4, 132.1, 128.6, 125.2, 69.5, 34.8, 14.8.

HRMS (ESI) *m/z*, $[M+Na]^+$ calcd for $C_{10}H_{11}SNO_3+Na^+$: 248.0352; found 248.0351.

3-nitro-1-(o-tolyl)propan-1-one (37)

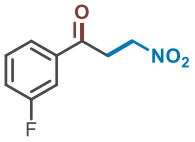


Compound **37** was obtained according to general procedure **GP3** as a colorless oil (66% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.74 (dd, *J* = 7.7, 1.4 Hz, 1H), 7.44 (td, *J* = 7.5, 1.5 Hz, 1H), 7.35 – 7.27 (m, 2H), 4.81 (t, *J* = 6.0 Hz, 2H), 3.58 (t, *J* = 6.0 Hz, 2H), 2.52 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 198.2, 139.4, 136.1, 132.5, 132.4, 129.0, 126.1, 69.6, 37.3, 21.7.

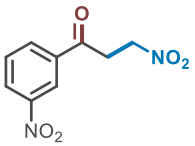
1-(3-fluorophenyl)-3-nitropropan-1-one (38)



Compound **38** was obtained according to general procedure **GP3** as a colorless oil (62% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.77 (dt, *J* = 7.7, 1.3 Hz, 1H), 7.67 (dt, *J* = 9.2, 2.1 Hz, 1H), 7.50 (td, *J* = 8.0, 5.5 Hz, 1H), 7.39 – 7.30 (m, 1H), 4.84 (t, *J* = 6.1 Hz, 2H), 3.64 (t, *J* = 6.1 Hz, 2H).

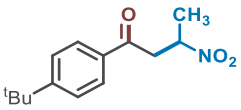
3-nitro-1-(3-nitrophenyl)propan-1-one (39)



Compound **39** was obtained according to general procedure **GP3** as a colorless oil (58% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.82 (s, 1H), 8.54 – 8.46 (m, 1H), 8.33 (dt, *J* = 7.9, 1.3 Hz, 1H), 7.75 (t, *J* = 8.0 Hz, 1H), 4.88 (t, *J* = 5.9 Hz, 2H), 3.71 (t, *J* = 5.9 Hz, 2H).

1-(4-(tert-butyl)phenyl)-3-nitrobutan-1-one (40)



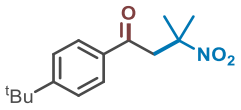
Compound **40** was obtained according to general procedure **GP3** as a colorless oil (60% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.90 (d, *J* = 8.6 Hz, 2H), 7.50 (d, *J* = 8.6 Hz, 2H), 5.26 – 5.12 (m, 1H), 3.89 (dd, *J* = 18.0, 7.7 Hz, 1H), 3.26 (dd, *J* = 18.0, 5.3 Hz, 1H), 1.68 (d, *J* = 6.9 Hz, 3H), 1.35 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 194.8, 157.9, 133.5, 128.2, 125.9, 78.4, 42.5, 35.4, 31.2, 19.8.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{13}H_{16}NO_3^+$: 234.1125; found 234.1128.

1-(4-(tert-butyl)phenyl)-3-methyl-3-nitrobutan-1-one (41)



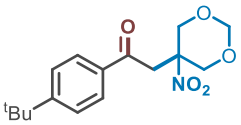
Compound **41** was obtained according to general procedure **GP3** as a colorless oil (68% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.87 (d, *J* = 8.6 Hz, 2H), 7.48 (d, *J* = 8.6 Hz, 2H), 3.66 (s, 2H), 1.75 (s, 6H), 1.34 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 194.7, 157.6, 134.0, 128.0, 125.8, 85.1, 47.1, 35.3, 31.4, 31.1, 26.7.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{15}H_{21}NO_3^+$: 263.1521; found 263.1519.

1-(4-(tert-butyl)phenyl)-2-(5-nitro-1,3-dioxan-5-yl)ethan-1-one (42)



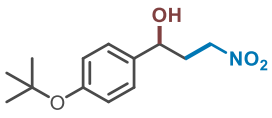
Compound **42** was obtained according to general procedure **GP3** as a colorless oil (72% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.88 (d, *J* = 8.6 Hz, 2H), 7.50 (d, *J* = 8.7 Hz, 2H), 4.95 (d, *J* = 6.1 Hz, 1H), 4.82 (d, *J* = 6.1 Hz, 1H), 4.45 (d, *J* = 11.7 Hz, 2H), 4.30 (d, *J* = 11.7 Hz, 2H), 3.84 (s, 2H), 1.34 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 194.2, 158.2, 133.5, 128.2, 126.0, 94.4, 82.0, 71.1, 40.8, 35.4, 31.2.

HRMS (ESI) *m/z*, $[M+Na]^+$ calcd for $C_{16}H_{21}NO_5$+Na^+: 330.1312; found 330.1310.

1-(4-(tert-butoxy)phenyl)-3-nitropropan-1-ol (43)



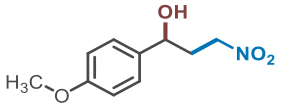
Compound **43** was obtained according to general procedure **GP4** as a colorless iol (49% yield) after purification by column chromatography (SiO_2, hexane/EA=3:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.23 (d, *J* = 8.5 Hz, 2H), 6.97 (d, *J* = 8.5 Hz, 2H), 4.79 (dd, *J* = 7.5, 5.6 Hz, 1H), 4.60 (dt, *J* = 14.0, 7.1 Hz, 1H), 4.46 (dt, *J* = 13.3, 6.5 Hz, 1H), 2.44 – 2.33 (m, 2H), 1.34 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 155.5, 137.8, 126.4, 124.5, 78.9, 72.6, 71.0, 36.1, 29.0.

HRMS (ESI) *m/z*, $[C_{13}H_{19}O_4N+Na]^+$ calcd: 276.1206; found 276.1204.

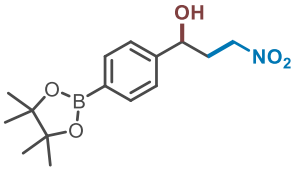
1-(4-methoxyphenyl)-3-nitropropan-1-ol (44)



Compound **44** was obtained according to general procedure **GP4** as a colorless oil (53% yield) after purification by column chromatography (SiO_2, hexane/EA=3:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.27 (d, *J* = 8.5 Hz, 2H), 6.90 (d, *J* = 8.5 Hz, 2H), 4.80 (t, *J* = 6.2 Hz, 1H), 4.58 (dt, *J* = 13.4, 7.2 Hz, 1H), 4.44 (dt, *J* = 13.4, 6.6 Hz, 1H), 3.80 (s, 3H), 3.61 (t, *J* = 6.2 Hz, 1H), 2.38 (q, *J* = 6.6 Hz, 2H), 2.08 (s, 1H).

3-nitro-1-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)propan-1-ol (45)



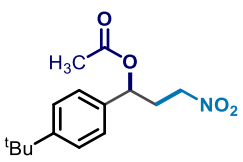
Compound **45** was obtained according to general procedure **GP4** as a colorless iol (51% yield) after purification by column chromatography (SiO_2, hexane/EA=3:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.81 (d, *J* = 8.1 Hz, 2H), 7.35 (d, *J* = 7.9 Hz, 2H), 4.85 (dd, *J* = 8.4, 4.6 Hz, 1H), 4.61 (ddd, *J* = 13.6, 7.6, 6.7 Hz, 1H), 4.44 (dt, *J* = 13.3, 6.4 Hz, 1H), 2.47 – 2.29 (m, 2H), 1.34 (s, 12H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 146.1, 135.4, 125.0, 84.1, 72.4, 71.2, 36.1, 25.0.

HRMS (ESI) *m/z*, $[C_{15}H_{22}O_5NB+Na]^+$ calcd: 330.1483; found 330.1481.

1-(4-(tert-butyl)phenyl)-3-nitropropyl acetate (46)



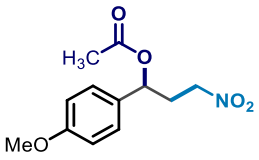
Compound **46** was obtained according to general procedure **GP5** as a yellow oil (84% yield) after purification by column chromatography (SiO_2, hexane/EA=8:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.39 (d, *J* = 8.4 Hz, 2H), 7.25 (d, *J* = 8.3 Hz, 3H), 5.85 (dd, *J* = 7.8, 5.4 Hz, 1H), 4.50 – 4.29 (m, 2H), 2.66 – 2.46 (m, 2H), 2.08 (s, 3H), 1.31 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 170.1, 151.8, 135.7, 126.1, 125.9, 72.7, 72.1, 34.8, 33.7, 31.4, 21.2.

HRMS (ESI) *m/z*, $[M–CH_3]^+$ calcd for $C_{14}H_{18}NO_4$: 264.1230; found 264.1235.

1-(4-methoxyphenyl)-3-nitropropyl acetate (47)



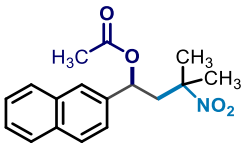
Compound **47** was obtained according to general procedure **GP5** as a yellow oil (87% yield) after purification by column chromatography (SiO_2, hexane/EA=8:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.26 (d, *J* = 8.6 Hz, 2H), 6.89 (d, *J* = 8.7 Hz, 2H), 5.81 (dd, *J* = 8.0, 5.5 Hz, 1H), 4.48 – 4.28 (m, 2H), 3.80 (s, 3H), 2.61 (ddt, *J* = 14.8, 8.1, 6.9 Hz, 1H), 2.48 (ddd, *J* = 14.4, 7.1, 1.6 Hz, 1H), 2.06 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 170.1, 159.9, 130.8, 127.8, 114.3, 72.6, 72.1, 55.4, 33.6, 21.1.

HRMS (ESI) *m/z*, $[M+Na]^+$ calcd for $C_{12}H_{15}NO_5$+Na^+: 276.0842; found 276.0841.

3-methyl-1-(naphthalen-2-yl)-3-nitrobutyl acetate (48)



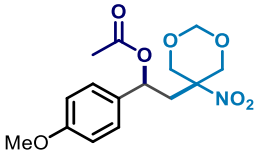
Compound **48** was obtained according to general procedure **GP5** as a yellow oil (88% yield) after purification by column chromatography (SiO_2, hexane/EA=8:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.88 – 7.78 (m, 4H), 7.52 – 7.42 (m, 3H), 6.08 (dd, *J* = 10.7, 3.1 Hz, 1H), 2.96 (dd, *J* = 15.4, 10.7 Hz, 1H), 2.24 (dd, *J* = 15.4, 3.1 Hz, 1H), 2.04 (s, 3H), 1.70 (s, 3H), 1.64 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 170.0, 137.3, 133.2, 133.2, 128.8, 128.1, 127.8, 126.5, 126.4, 125.6, 123.8, 86.2, 72.1, 46.5, 27.9, 24.5, 20.9.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{17}H_{19}NO_4$: 301.1309; found 301.1312.

1-(4-methoxyphenyl)-2-(5-nitro-1,3-dioxan-5-yl)ethyl acetate (49)



Compound **49** was obtained according to general procedure **GP5** as a yellow oil (85% yield) after purification by column chromatography (SiO_2, hexane/EA=8:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.21 (d, *J* = 8.7 Hz, 2H), 6.85 (d, *J* = 8.7 Hz, 2H), 5.73 (dd, *J* = 10.3, 3.5 Hz, 1H), 4.88 (d, *J* = 6.3 Hz, 1H), 4.73 (d, *J* = 6.2 Hz, 1H), 4.54 (d, *J* = 12.4 Hz, 2H), 3.94 – 3.83 (m, 2H), 3.77 (s, 3H), 2.55 (dd, *J* = 15.5, 10.3 Hz, 1H), 2.20 (dd, *J* = 15.4, 3.5 Hz, 1H), 1.97 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 169.7, 159.9, 131.2, 127.7, 114.2, 93.9, 83.5, 71.6, 70.3, 69.5, 55.3, 39.6, 20.8.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{15}H_{19}NO_7^+$: 325.1156; found 325.1161.

6. References

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Chapter 5:

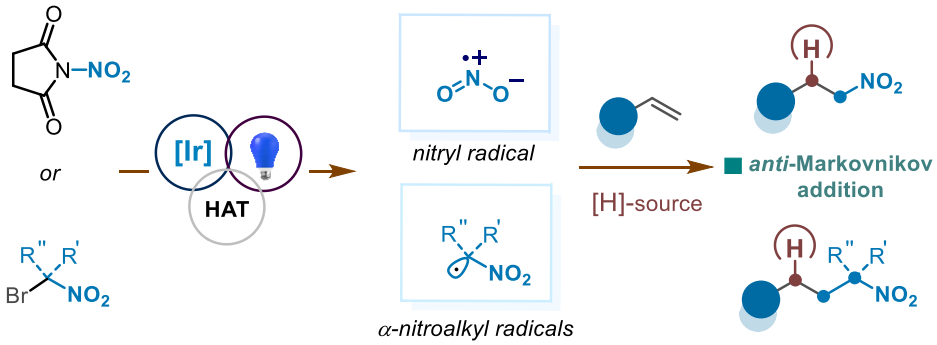
Facile Access to Terminal Nitroalkanes via Anti-Markovnikov Hydronitration and Hydronitroalkylation of Alkenes Using Photoredox Catalysis

This Chapter is adapted from the following publication in peer-reviewed journal:

S. Patra, D. Katayev, "Facile Access to Terminal Nitroalkanes via Anti-Markovnikov Hydronitration and Hydronitroalkylation of Alkenes Using Photoredox Catalysis", *Chem. Eur. J.* **2024**, e202403654. DOI:org/10.1002/chem.202403654.

1. Abstract

The evolution of catalysis and functional group transfer reagents play a significant role in the development of anti-Markovnikov alkene hydrofunctionalization reactions, facilitating the access to value-added molecules. We herein report the first rational design of a modular intermolecular anti-Markovnikov hydronitration of alkenes, enabling the direct synthesis of terminal nitroalkanes under visible light-mediated photoredox catalysis. By employing the redox-active organic nitrating reagent N-nitrosuccinimide, the produced nitryl radicals, in the presence of an olefin and a hydrogen atom transfer (HAT) mediator, lead to an anti-Markovnikov addition with complete regioselectivity. Furthermore, we present results demonstrating the use of this catalytic system for chain expansion via anti-Markovnikov addition, utilizing substituted bromonitroalkanes as commercially available reagents. These transformations effectively address a gap in synthetic chemistry, enabling the direct synthesis of nitroalkanes from a variety of unactivated olefins in both complex molecules and unfunctionalized commodity chemicals.



2. Introduction

The use of redox-active and redox-neutral functional group transfer reagents (FGTRs) in synergy with various catalytic manifolds is a powerful tool for functionalizing bulk chemical feedstock while maintaining high levels of chemo- and regioselectivity.[1] Unsaturated hydrocarbons are ideal materials for chemical synthesis owing to their availability from renewable sources. For example, their versatility makes them essential for producing daily industrial products including detergents, polymers, textiles, and numerous value-added chemicals.[2] The hydrofunctionalization of terminal unsaturated hydrocarbons is a fundamental transformation for accessing branched isomers.[3] This has been extensively demonstrated over the last two centuries in alkene hydrochlorination among others hydrofunctionalizations with well-known Markovnikov selectivity.[4] Synthesizing linear anti-Markovnikov adducts via a similar ionic pathway is challenging due to the instability of the corresponding carbocation intermediate.[5] A two-step redox process was developed to overcome this challenge and has been successfully utilized e.g. for hydrochlorination and hydrooxygenation of α-olefins.[6] With the advancements in catalysis and the growing emphasis on green and sustainable chemistry, recent years have seen significant progress in expanding the scope of anti-Markovnikov addition products using metal-based/metal-free protocols and particularly through the use of radical-based approaches mediated by photochemical or electrochemical synthesis (Figure 1A).[4,7] Two prevalent radical-based methodologies for synthesizing linear adducts with amino, alkoxy, azido, ester, ether, fluoroalkyl, phosphate, and other groups involve either single-electron oxidation of the alkene, followed by nucleophile addition and hydrogen atom transfer (HAT) (Figure 1B, path A), or the catalytic generation of functional group radical synthons, followed by their addition to the alkene and subsequent HAT (path B).[8]

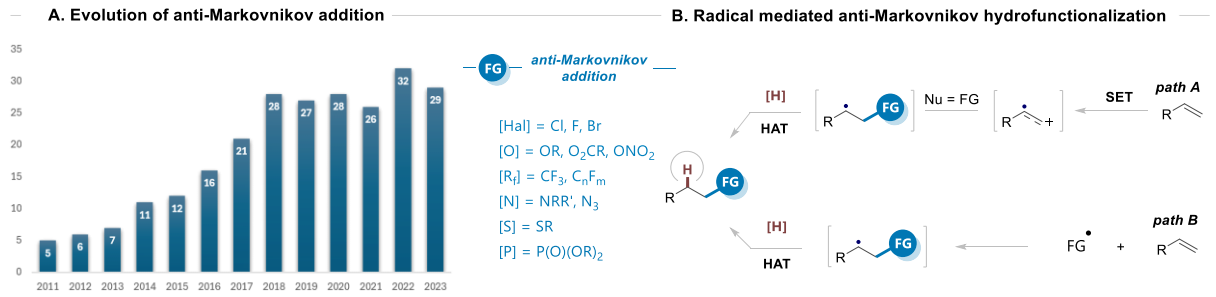


Figure 1. A. Reported number of articles on anti-Markovnikov addition to alkenes (source: web of science, July 2024). B. Radical approaches for anti-Markovnikov hydrofunctionalization reactions.

The widespread application of organic nitroalkanes in chemical synthesis, biology, material sciences, and agrochemistry necessitates methodologies to synthesize them directly from readily available starting materials.[9] As part of our ongoing research on developing catalytic, mild, and efficient methods for the nitration of organic molecules,[10] our laboratory has long been pursuing a method for preparing linear nitroalkanes from olefins using organic nitration reagents. Traditionally, terminal nitroalkanes have been

synthesized via nucleophilic substitution of alkyl halides with metal nitrite in polar solvents known as Victor-Mayer[11] and Kornblum[12] reactions. However, this approach has limitations, including the requirement for pre-functionalized alkyl halides and the occurrence of side reactions that produce significant amounts of alkyl nitrite by-products and over-oxidation to carboxylic acids.[13] Therefore, and especially due to the difficulties in separating these mixtures, the method finds limited applications today. To complement these methods, direct transformations of activated olefins to nitroalkanes via Michael 1,4-addition have also been explored, though this approach is limited only to α,β-unsaturated carbonyl compounds.[14] Despite these advances, the development of a general process to form C(sp^3)–NO_2 bonds from unsaturated hydrocarbons has not received further attention, most likely due to the lack of suitable reagents capable of releasing the nitro group under mild conditions.

The direct anti-Markovnikov hydronitration and hydronitroalkylation of olefins are currently beyond the scope of known reaction chemistry and would be a beneficial chemical transformation for accessing linear nitroalkanes from both activated and unactivated olefins without stoichiometric waste. A promising strategy for directly accessing anti-Markovnikov addition products involves generating controlled amounts of nitryl radicals (•NO_2) under mild reaction conditions.

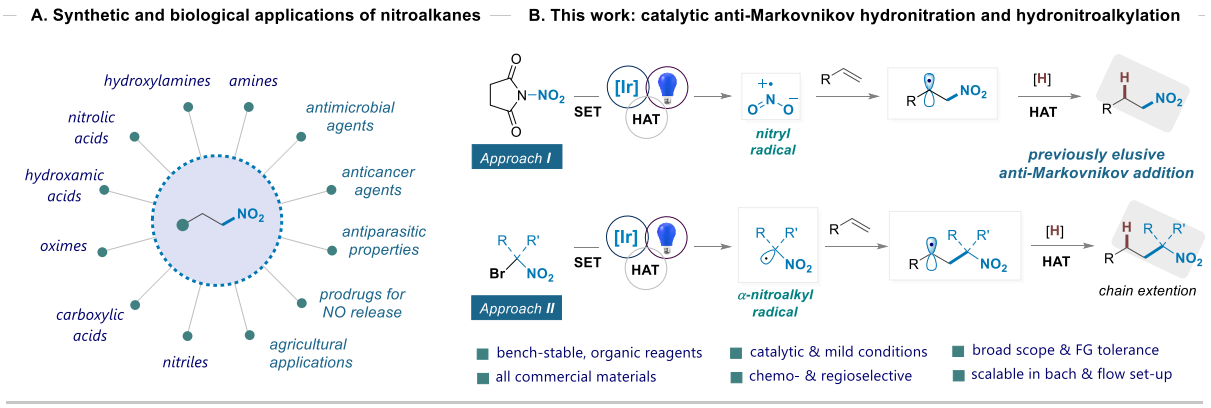


Figure 1. A. Synthetic and biological applications of nitroalkanes. B. This work: direct and catalytic anti-Markovnikov hydronitration and hydronitroalkylation of alkenes.

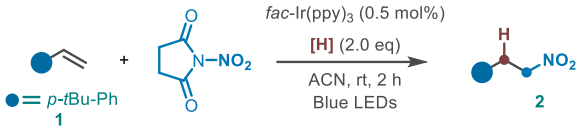
Recently, our research group introduced a series of bench-stable organic NO_2-transfer reagents based on heterocyclic scaffolds.[15] Due to their structural uniqueness, the mesolytic N–N bond cleavage in these molecules can be promoted using various catalytic manifolds, accessing either electrophilic nitronium or nitryl radical reactive species.[16] In this context, a range of nitrative functionalization transformations can be achieved using the principals of radical polar-crossover (RPC) and radical ligand transfer (RLT) catalysis.[17] Herein, we report the first design of a modular visible light-mediated paradigm for synthesizing nitroalkanes from unsaturated hydrocarbons. The protocol employs the redox-active organic nitrating reagent N-nitrosuccinimide as a mild source of nitryl radicals, in conjunction with hydrogen atom abstraction (HAT), to simultaneously construct C–NO_2 and C–H bonds. This transformation expands synthetic possibilities using a bench-stable NO_2 source, tolerates

air and moisture, and proceeds under mild conditions, allowing broad functional group compatibility. Additionally, by generating a variety of nitroalkyl radical intermediates from commercially available organic reagents, we further extended this concept to access a range of longer-chain terminal nitroalkanes as well as molecules that contains NO_2-embeded secondary and tertiary carbon centers.

3. Results and discussion

3.1. Reaction design and reaction optimization for anti-Markovnikov hydronitration

Encouraged by the remarkable reactivity of N-nitrosuccinimide reagent with unsaturated molecules under photocatalytic conditions, we set out to design a challenging yet undeveloped anti-Markovnikov hydronitration transformation. The initial challenge in achieving the desired reactivity was the interception of a transient alkyl radical (Giese-type intermediate) by HAT reagent. We began our research by developing a photo redox catalytic system for alkene nitration using **1** as a model substrate, N-nitrosuccinimide **II** as a redox-active organic nitrating reagent ($E_{1/2}^{red}$ = −1.39 V vs SCE), and thiols as hydrogen atom donors. After an extensive screening of reaction conditions, we observed a smooth progression of the anti-Markovnikov hydronitration reaction of **1** in the presence of 0.5 mol % of photocatalyst **PC-1**, 1.5 equivalent of N-nitrosuccinimide **II** and 2.0 equivalent of 4-mercaptophenol in a mixture of ethanol (2.0 eq) and acetonitrile (0.5 mL) under the irradiation of 350 W blue LEDs for 12 h, affording the desired product **2** in an 89% isolated yield with an excellent level of regioselectivity. For comparison, various other organic nitrating reagents (**I** and **III–VI**) proved less effective as nitryl radical precursors, underscoring the superior performance of reagent **II**. PC1 ($E_0(Ir^{IV/III*})$ = −1.73 V vs SCE) was chosen as the photocatalyst due to its recent success in activating reagent **II** (−1.39 V vs SCE) under visible light. Numerous attempts with different photocatalysts, including both metal- and organic-based options, failed to improve the yield. (see Experimental section for details). Thiol sources were also studied extensively. After various attempts with different electronic aryl thiols as well as alkyl thiols failed to improve the yield. After choosing 4-mercaptophenol as HAT reagent we then focused on thiol loading and we found that the 2.0 equivalent was optimal under the reaction condition. We then tested a range of solvents on the reaction outcome (Table 1, entries 7–12). However, lower yields and poor selectivity were obtained (see the Experimental section for details). In the absence of visible light, no product formation was observed either at room temperature or elevated temperatures (80 °C). The lack of reaction progression without a photocatalyst implies the photosensitization nature of the reaction. Furthermore, the yield of the product was marginally affected when the reaction was carried out in the absence of ethanol. Additionally, we assessed the outcome of this transformation with other reaction conditions reported as a source of nitryl radical keeping the 4-mercaptophenol as HAT reagent (Table 1, entries 3–6). Notably, no deuterium scrambling was observed when the reaction was conducted in the presence of ethanol-d1.



Entry	Variation of reaction conditions[a]	Yield of 2 (%)[b]
1	none	80 (77)[c]
2	Reagent [**I**] instead of [**II**]	n.d.
3	Reagent [**III**] instead of [**II**]	10
4	Reagent [**IV**] instead of [**II**]	5
5	Reagent [**V**] instead of [**II**]	n.d.
6	Reagent [**VI**] instead of [**II**]	n.d.
7	[PC-2] instead of [PC-1]	16
8	[PC-3] instead of [PC-1]	35
9	[PC-4] instead of [PC-1]	0
10	PhSH instead of 4-OHPhSH	0
11	4-OMePhSH instead of 4-OHPhSH	5
12	TRIPSH instead of 4-OHPhSH	55
13	triethylsilane instead of 4-OHPhSH	0
14	phenylsilane instead of 4-OHPhSH	0
15	1.0 eq triethylsilane and 0.1 eq 4-OHPhSH	5
16	THF instead of ACN	12
17	toluene instead of ACN	10
18	No light, rt	n.r.
19	No light, 80 °C	n.r.
20	No [PC-1]	n.r.
21	No EtOH	30

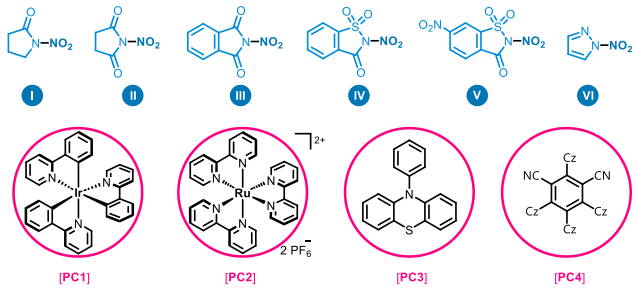


Table 1. [a] Standard conditions: alkene **1** (0.5 mmol, 1.0 equiv), *fac*-Ir(ppy)$_3$ (0.5 mol %), reagent **II** (1.5 equiv), 4-mercaptophenol (2.0 eq), ethanol (2.0 eq) and ACN (0.5 mL), 350 W blue LEDs, rt, 6 h. TBN = tert-butyl nitrite, n.r. = no reaction, n.d. = not detected. PHT = N-phenylphenothiazine,

We were also curious about the feasibility of anti-Markovnikov reactivity using reported platforms for generating nitryl radicals, including TBN/O_2, $NaNO_2$/$K_2S_2O_8$, $AgNO_2$/TEMPO and $Fe(NO_3)_3$•$9H_2O$.[19]

Entry	other reaction conditions	Yield of 1 (%)[b]
1	TBN, 4-OHPhSH, ACN, 80 °C	n.d.
2	TBN, $K_2S_2O_8$, 4-OHPhSH, ACN, 85 °C	n.d.
3	$AgNO_2$, TEMPO, 4-OHPhSH, DCE, 70 °C	n.d.
4	$Fe(NO_3)$•$9H_2O$, 4-OHPhSH, ACN, 80 °C	n.d.

Table 2. [a] Standard conditions: alkene **1** (0.5 mmol, 1.0 equiv), *fac*-$Ir(ppy)_3$ (0.5 mol %), reagent **II** (1.5 equiv), 4-mercaptophenol (2.0 eq), ethanol (2.0 eq) and ACN (0.5 mL), 350 W blue LEDs, rt, 6 h. n.d. = not detected.

3.2. Investigation of substrate scope of hydronitration

With the optimized reaction conditions established, we evaluated the generality of this synergistic catalytic system for the hydronitration of various styrene derivatives (Figure 3). Our protocol tolerated electron-neutral (**4**), electron-rich (**2**, **5**–**9**), and electron-deficient (**16**–**20**) functional groups at o-, m-, and p-positions of the benzene ring. Essential functional groups such as nitro (**16**, **17**), aldehyde (**18**), fluorine (**10**, **11**), chlorine (**12**, **13**, **18**), bromine (**14**, **15**), ester (**20**), and nitrile (**21**), remained intact, and olefins underwent successful transformations, yielding the corresponding nitroalkane products with exclusive anti-Markovnikov selectivity. Hydronitration adducts with polysubstituted aromatic rings such as naphthalene moieties (**22**, **23**) were formed in 69% and 70% yields, respectively. Disubstituted and internal alkenes participated in the reaction and provided the corresponding products **24** and **25** as a single isomer. Less activated olefins have also been subjected to the established reaction conditions but furnished products **26** and **27** in low chemical yields.

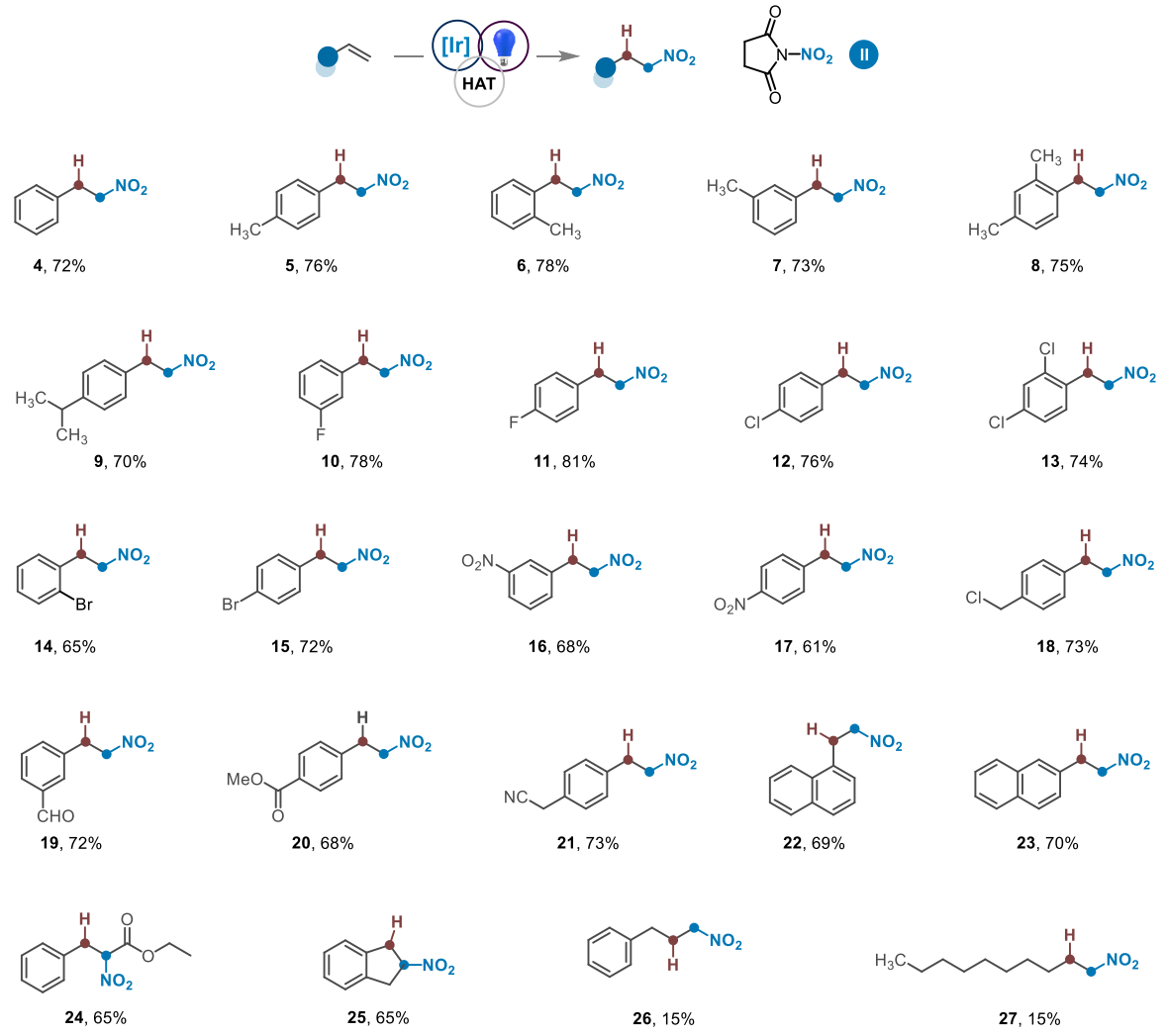
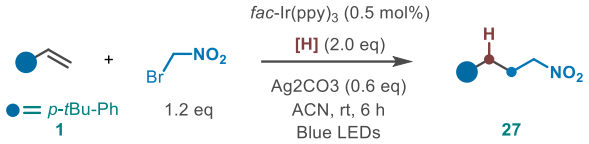


Figure 3. Standard conditions: alkene (0.5 mmol, 1.0 equiv.), *fac*-Ir(ppy)*3* (0.5 mol %), reagent **II** (1.5 equiv.), 4-mercaptophenol (2.0 equiv.), ethanol (2.0 equiv.) and MeCN (0.5 mL), 445 nm, rt, 12 h. Isolated yields are reported.

3.3. Reaction design and reaction optimization

To extend this protocol to unactivated alkenes and broaden the chemical space of terminal nitroalkanes, we turned our focus to anti-Markovnikov nitromethylation to form C−C and C−H bonds simultaneously. Bromo(nitro)methane is an inexpensive, commercially available, and stable reagent. Recently, photoredox activation of bromonitroalkanes has been explored. Ooi and co-workers demonstrated an iridium(III)-catalyzed, photodivergent addition of bromonitroalkanes to styrenes. The reaction proceeds through a single-electron reduction of organobromonitroalkanes by the photoexcited Ir^{III} complex. This reduction is followed by mesolytic cleavage of the C–Br bond, generating an α-nitro alkyl radical and an oxidized Ir^{IV} complex in the form of a bromide salt. The subsequent addition of the alkyl radical to an alkene yields a β-nitro benzylic radical, which undergoes spontaneous cyclization to produce dihydroisoxazoline-N-oxyl (nitroxyl) radical and ultimately isoxazoline-N-oxide. With suitable tuning, the ATRA product γ-bromo nitroalkane can also be achieved. Initially limited to styrenes, this protocol was later expanded by Reiser and co-workers, who developed a copper(I) photocatalyzed bromonitroalkylation of olefins via inner-sphere pathways, broadening the scope to unactivated alkenes. Inspiring by these works and building on our success with the anti-Markovnikov hydronitration protocol, we hypothesized that an α-nitro alkyl radical generated under photoredox conditions could react with alkenes to form a β-nitro alkyl transient radical intermediate. This intermediate can be intercepted to form nitroalkanes in the presence of 4-mercaptophenol as a hydrogen atom transfer (HAT) reagent.

We began our investigation by irradiating bromonitromethane **VII** and 4-tert-butylstyrene **1** in the presence of **PC-I** (0.5 mol%), 4-mercaptophenol (2.0 eq), and acetonitrile (0.5 mL) using 350 W blue LEDs for 4 hours. Adding silver salts reduced ATRA product formation. Silver carbonate was particularly beneficial, giving **26** in good yield. Various other bases, including silver, sodium, potassium, and cesium salts, were tested, but none matched the efficiency of silver carbonate for this transformation (Table 2, entries 2-8). Testing a range of solvents resulted in lower yields and poor selectivity (see Supporting Information for details). Attempting to initiate a radical chain process with AIBN under thermal conditions did not promote the reaction (Table 2, entry 13). Additionally, performing the reaction without a photocatalyst or light yielded no desired product (Table 2, entries 14–15).



Entry	Variation of standard reaction conditions[a]	Yield 1 (%)[b]
1	none	92 (87)[c]
2	AgOAC instead of Ag_2CO_3	88
3	$AgNO_2$ instead of Ag_2CO_3	34
4	AgF instead of Ag_2CO_3	73
5	AgOTf instead of Ag_2CO_3	69
6	Na_2CO_3 instead of Ag_2CO_3	65
7	K_2CO_3 instead of Ag_2CO_3	16
8	Cs_2CO_3 instead of Ag_2CO_3	13
9	0.3 eq of Ag_2CO_3 instead of 0.6 eq	71
10	THF instead of ACN	10
11	ethylbenzene instead of ACN	15
12	Triethylsilane instead of 4-mercaptophenol	n.d.
13	AIBN, 80 °C	n.r.
14	No light	n.r.
15	No PC-**I**	n.r.

Table 3. [a] Standard conditions: alkene **1** (0.5 mmol, 1.0 equiv), *fac*-Ir(ppy)$_3$ (0.5 mol %), bromonitromethane **VII** (1.5 equiv), 4-mercaptophenol (2.0 eq), ethanol (2.0 eq) and ACN (0.5 mL), 350 W blue LEDs, rt, 6 h. n.r. = no reaction, n.d. = not detected.

3.4. Investigation of substrate scope of hydronitromethylation

We next turned our attention to the reactivity evaluation of nitromethyl radical in anti-Markovnikov addition to various activated and unactivated olefins (Figure 4). With the optimal conditions in hand, we first subjected several styrene derivatives. An impressive reactivity and selectivity levels have been observed and the corresponding products **26-30** have been isolated in up to 90%. Variation of electronically different substituents at the para-position of the benzene ring did not affect the yield. Functional groups such as methoxy (**28**), methyl ester (**29**), and Bpin (**30**) remained intact. Less deactivating alkenes such as allylbenzene and 3-butenylbenzene showcased excellent reactivity, delivering the corresponding adducts **31** and **32** in 93% and 90%, respectively. Encouraged by the reactivity of nitromethyl radical under photoredox conditions, we thoroughly explored the functional group tolerance with aliphatic alkenes. Delightedly, several functional groups, such as esters (**33**, **36**), silyl (**34**), epoxide (**35**), hydroxy (**37**), azide (**38**), aldehyde (**39**), and bromine (**41**, **42**, **81**) were all compatible under our reaction conditions. In all cases, no by-product formation has been detected. Notably, various long-chain alkenes such as 1-nonene, 1-decene, 1-undecene, 1-dodecene, and even tridecane resulted in the corresponding formation of exclusively linear products (**27-46**) in up to 91% yield. Since the nitro group can be interconverted into a variety of key functionalities, this method represents an important tool in chemical synthesis to access e.g. long-chain alkyl amines or carboxylic acids. Styrene derivatives with a methyl substituent at the alpha position of the olefin and 2-methylundec-1-ene also demonstrated unequaled regioselectivity (**47-49**). The reactivity of the nitromethyl radical with trisubstituted alkenes also occurred at the least substituted carbon, delivering anti-Markovnikov products in high isolated yields. In the latter case, reactivity towards both internal and terminal olefins was well-tolerated (**50-52**). Tetrasubstituted styrene, such as (3-methylbut-2-en-2-yl)benzene, likewise delivered the anti-Markovnikov adduct **53**, where hydrogen is incorporated at the most stabilized benzylic radical position.

It is noteworthy that this visible light-mediated hydronitromethylation process exhibits excellent chemo- and regioselectivity, as well as broad functional group tolerance. Nitro-derived compounds have garnered significant attention in recent years for their applications in medicinal and agrochemistry, serving as anticancer and antitubercular agents, tranquilizers, and pesticides.[9, 20] Subsequently, we next attempted to perform late-stage functionalization of biologically active compounds and other relevant molecules derived from gemfibrozil, isopulegol, carvone, rotenone, safrole, eugenol and isobonyl acrylate (**54-60**). Besides their structural complexity and diversity, these molecules bear several reactive centers. Nevertheless, high levels of anti-Markovnikov reactivity have been achieved across all complex examples, with product yields in the range of 57-87% (Figure 4).

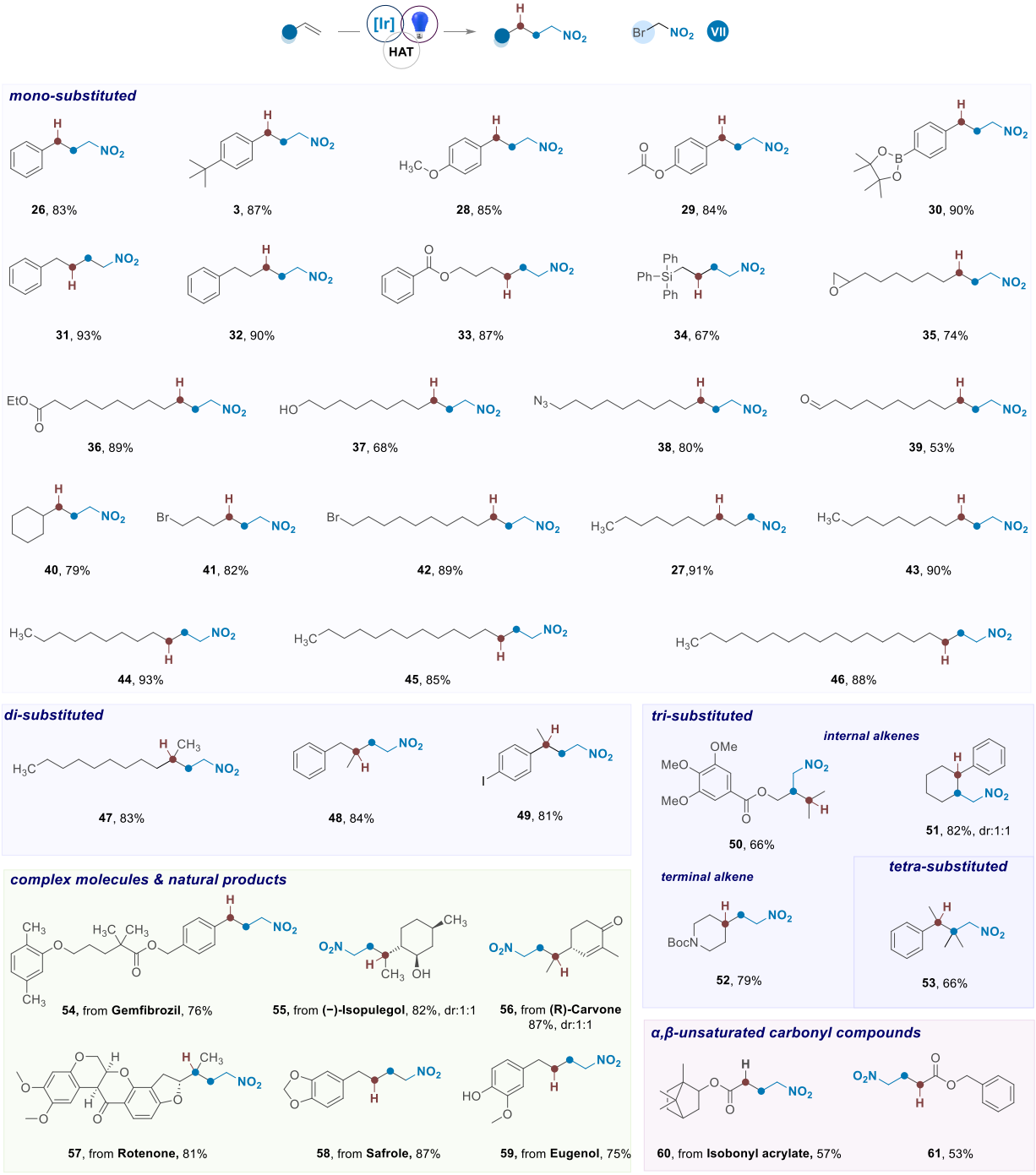


Figure 4. Standard reaction conditions: alkene (0.5 mmol, 1.0 equiv.), *fac*-Ir(ppy)$_3$ (0.5 mol %), bromo(nitro)methane (1.2 equiv.), silver carbonate (0.6 equiv.), 4-mercaptophenol (2.0 equiv.), ethanol (2.0 equiv.) and MeCN (2.5 mL), N_2, 445 nm visible light, rt, 6 h. Isolated yields are reported.

Reactivity evaluation of hydronitroalkylation

Alkyl-substituted bromonitroalkanes with secondary or tertiary carbons are widely commercially available. Therefore, it was fundamentally interesting to explore their reactivity towards olefins (Figure 5). Secondary or tertiary alkyl radicals, generated from bromonitroethane and 2-bromo-2-nitropropane, respectively, under photoredox conditions, exhibited similar reactivity to nitromethyl radical. These radicals efficiently reacted with both activated and unactivated olefins, delivering products (**62-64**) with tertiary and quaternary carbon centers bearing the NO_2 group with entire anti-Markovnikov selectivity. Similarly, tertiary radicals formed from 1-bromo-1-nitro-cyclopentane, -cyclohexane, and -cycloheptane reagents have also been successfully incorporated into olefins (**65-67**). Lastly, Bronidox (5-bromo-5-nitro-1,3-dioxane), known as an antimicrobial compound, was activated under our reaction conditions. Its addition to alkenes, followed by subsequent HAT, led to the formation of the corresponding products with excellent anti-Markovnikov selectivity (**68-70**).

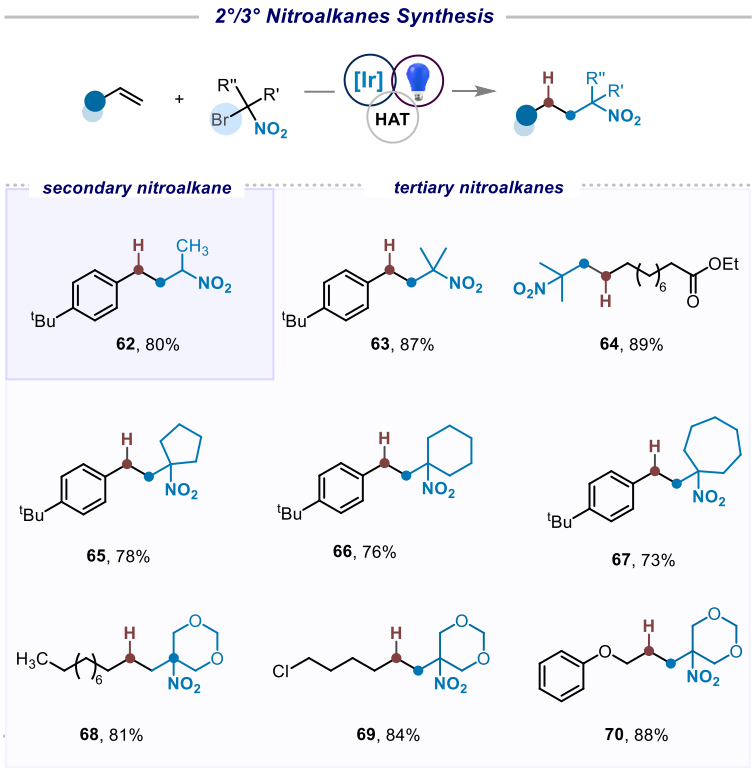


Figure 5. Standard reaction conditions: alkene (0.5 mmol, 1.0 equiv.), *fac*-Ir(ppy)$_3$ (0.5 mol%), alkyl-substituted bromonitroalkane reagent (1.2 equiv.), Ag_2CO_3 (0.6 equiv.), 4-mercaptophenol (2.0 equiv.), ethanol (2.0 equiv.), and MeCN (2.5 mL), N2, 445 nm, rt, 6 h. Isolated yields are reported.

3.5. Mechanistic insights

To gain mechanistic insights into the hydronitration and hydronitroalkylation reactions, we conducted several experiments. Initially, standard trials in the presence of radical scavengers such as TEMPO (2,2,6,6-tetramethylpiperidine 1-oxyl) were examined. Injecting 2.0 equivalents of radical trap completely suppressed the reactivity under optimized conditions, with no anti-Markovnikov product detected by ^{1}H-NMR or HRMS (Figure 6A). Instead, the initial olefin was recovered in both reactions when N-nitrosuccinimide or bromo-nitromethane were used as reagents. While the reaction progressed smoothly under visible light irradiation, it abruptly halted in the absence of visible light as it can be seen from on-off experiments (Figure 6B). This suggests the reaction follows a photoredox catalytic pathway rather than relying on a radical chain propagation process.

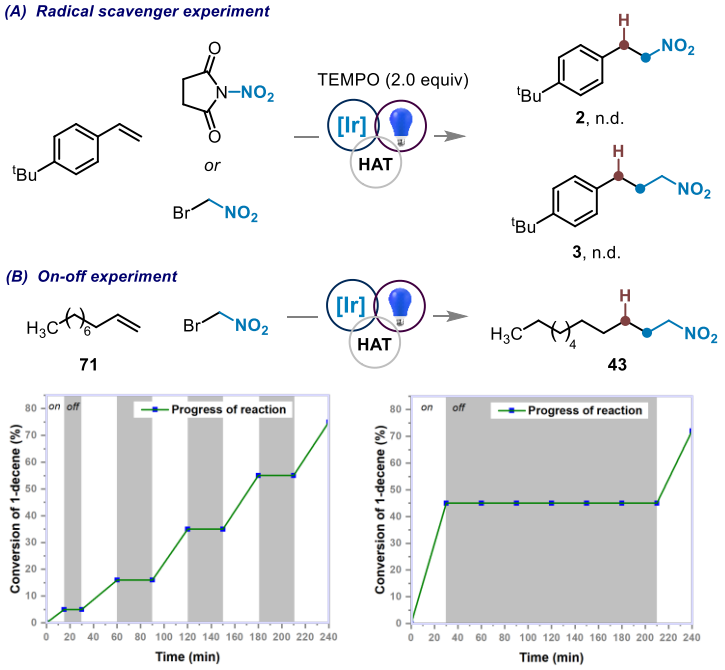


Figure 6. Mechanistic investigations. Standard reaction conditions: alkene (0.5 mmol, 1.0 equiv.), *fac*-Ir(ppy)$_3$ (0.5 mol%), alkyl-substituted bromonitroalkane reagent (1.2 equiv.) with Ag_2CO_3 (0.6 equiv.) or N-nitrosuccinimide (1.5 equiv.), 4-mercaptophenol (2.0 equiv.), ethanol (2.0 equiv.) and MeCN (2.5 mL), 445 nm, rt, 6 h. Isolated yields are reported. n.d. = not detected.

Next, several radical clock experiments have been explored. Due to the poor reactivity of electrophilic nitryl radical with unactivated alkenes to deliver anti-Markovnikov adducts, we selected nitromethyl radical for these studies. Subjecting cyclopropyl-substituted alkenes (**72** & **74**) as shown in Figure 7A resulted in facile ring-opening, delivering the expected products **73** and **75** in 78% and 67%, respectively. This led us to examine substrates **76** and **78**, which could undergo 5-exo-trig cyclization reactions in the presence of radicals (Figure 7B). Indeed, dimethyl diallylmalonate produced cyclopentyl derivative **77**, while N-Boc diallyl amine yielded expected pyrrolidine **79** with a 76% yield. The presence of only cyclization products in the reaction mixture suggests that the quenching step with HAT

reagent is slower than the cyclization event. These observations align with previous studies on the generation of nitryl radicals from N-nitrosuccinimide and α-nitroalkyl radicals from bromonitromethane under photoredox catalysis. Based on literature reports[15, 21] and mechanistic experiments presented in Figure 7, both radical species, the nitryl radical and α-nitroalkyl radical, generated in situ upon single electron transfer, undergo a Giese-type addition to the β-position of an olefin to form a reactive transient carbon-centred radical intermediate. The high anti-Markovnikov regioselectivity would be determined by the thermodynamic stability of this species. This intermediate is ultimately quenched by a thiol-based hydrogen atom donor, producing the desired nitroalkane product (Figure 2B). Based on extensive examination of the substrate scope for hydronitration vs hydronitroalkylation reactions, it is evident that the addition of nitryl radical is much slower and is reversible compared to the addition of carbon-centered radicals with adjacent NO_2 group (less electrophilic species),[22] which explains the sluggish reactivity of $\bullet NO_2$ with simple unactivated alkenes under our reaction conditions.

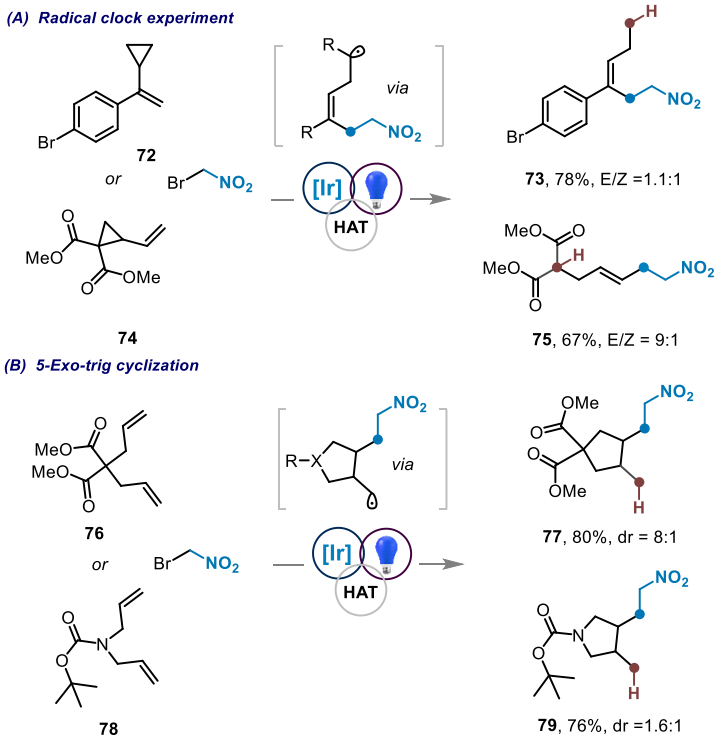


Figure 7. Mechanistic investigations. Standard reaction conditions: alkene (0.5 mmol, 1.0 equiv.), fac-Ir(ppy)3 (0.5 mol%), alkyl-substituted bromonitroalkane reagent **VII** (1.2 equiv.) with Ag_2CO_3 (0.6 equiv.) or N-nitrosuccinimide (1.5 equiv.), 4-mercaptophenol (2.0 equiv.), ethanol (2.0 equiv.) and MeCN (2.5 mL), 445 nm, rt, 6 h. Isolated yields are reported. dr determined by ^{1}H-NMR of the unpurified reaction mixture.

3.6. Synthetic advantages

One of the intriguing applications of aliphatic nitro compounds is their use in inhibition of foodborne bacteria, parasites, and methane production in economic animals.[23] Their synthesis can be accomplished from the corresponding alkyl halides by heating with lithium, potassium, sodium, or silver nitrites. However, because the nitrite ion is an ambident nucleophile, these reactions often result in the formation of various by-products, complicating the separation process of the desired nitroalkane molecule. As demonstrated in Figure 8, employing a conventional method for the nitration of 1,7-dibromoheptane to produce the corresponding nitro adduct **81** results in a yield of only 21%.[24] Notably, using commercially available 7-bromohept-1-ene (**80**) and our anti-Markovnikov addition conditions with bromonitromethane as reagent, the desired compound **81** can be isolated in 88%. In addition, due to the complete conversion of the starting material and the minimal formation of by-products, the separation of the product is facile and straightforward.

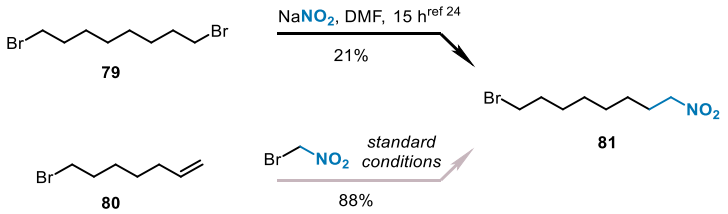


Figure 8. Synthetic advantages of anti-Markovnikov hydronitroalkylation reactions to alkenes vs S_N2 reaction to alkyl halides. Isolated yields are reported.

The Michael addition reactions of nitroalkanes to electron-deficient alkenes are fundamental transformations, with the resulting adducts having a wide range of applications. For example, base-mediated addition of nitromethane to methyl cinnamate results in the formation of **83**, where nitromethylene group is adjacent at the benzylic position.[25] The method has been used for accessing γ-amino acids. In contrast, our approach leads to the formation of adduct **84** with an orthogonal regioselectivity outcome. Subsequently, this switchable selectivity can be used for the preparation of β-amino acids.

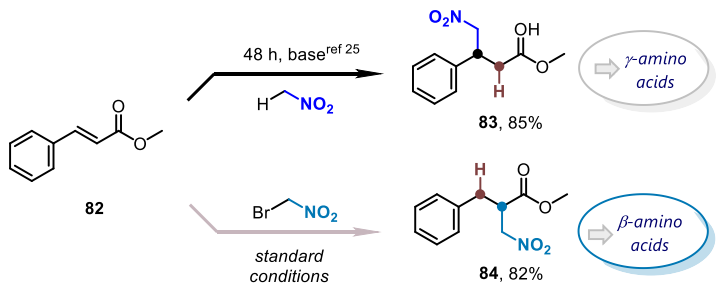


Figure 9. Synthetic advantages of anti-Markovnikov hydronitroalkylation reactions to alkenes vs Michael addition reactions of nitroalkanes.

3.7. Scale-up synthesis

While there are numerous potential applications for anti-Markovnikov hydronitration and hydronitroalkylation processes, we were particularly curious about the scalability of these methods, given that all materials are readily available. At first, we attempted to gram-scale synthesis in batch, and after 6 hours under standard reaction conditions the corresponding product **3** was formed without significant decrease in isolated yield. Next, we realized the synthesis of **43** in continuous flow reactor using automatic syringe pump and a high blue LED photoreactor equipped with a 100 mL tube of an internal diameter 0.101 cm. Carrying out anti-Markovnikov hydronitromethylation of 1-decene on a gram-scale afforded the corresponding adduct in 72% isolated yield. These results indicate that our methodologies can be effectively scaled up, offering promising avenues for further optimization and application in various contexts.

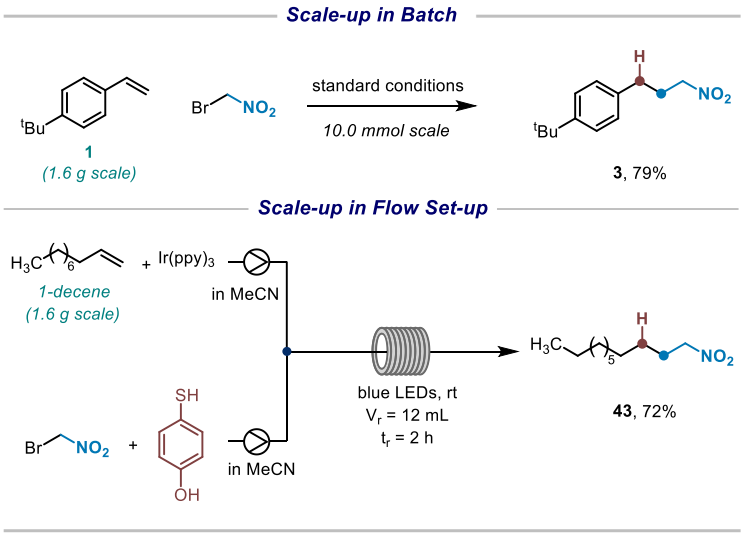


Figure 10. Scale-up in batch and flow set-up using standard reaction conditions. Standard reaction conditions: alkene (10.0 mmol, 1.0 equiv.), *fac*-Ir(ppy)$_3$ (0.5 mol%), bromonitromethane **VII** (1.2 equiv.) with Ag_2CO_3 (0.6 equiv.), 4-mercaptophenol (2.0 equiv.), ethanol (2.0 equiv.) and MeCN (2.5 mL), 445 nm, rt, 6 h. Isolated yields are reported.

4. Conclusion

In summary, we have developed the first anti-Markovnikov hydronitration and hydronitroalkylation of alkenes which proceeds under visible light-mediated photoredox catalysis. This transformation relies on the synergistic cooperation of two systems, where the nitro group is introduced via a photocatalytic cycle with a redox-active organic nitrating reagent N-nitrosuccinimide, and the formed transient nitroalkyl radical is rapidly quenched by a thiol as a hydrogen atom transfer (HAT) reagent, preventing side products formation. The research concept has been successfully expanded towards anti-Markovnikov hydronitroalkylation using readily available and inexpensive bromo(nitro)alkanes as reagents. The latter approach allows to expand alkyl chain within one chemical step while maintaining nitro group at terminal position. The methods are distinguished by their mild conditions, high and consistent catalytic efficiency across over 70 examples including activated and unactivated alkenes, and excellent tolerance towards diverse functional groups. Further investigations on the application of these methodologies to other classes of unsaturated molecules are currently being investigated in our laboratory.

5. Experimental section

1. General Information

All reactions were conducted in flame-dried glassware under an argon atmosphere, using a Teflon-coated stirring bar and dry septum. The glassware was dried overnight at 150°C before use. Starting materials were obtained from Thermo Scientific – Acros, Sigma-Aldrich, Apollo Scientific, Fluorochem, and TCI. Anhydrous acetonitrile was distilled over CaH_2 and stored over pre-conditioned 3 Å molecular sieves for at least 12 hours before use. Analytical TLC was performed on Merck silica gel 60 F254 plates, visualized with 254 nm light and potassium permanganate staining.

Flash chromatography was used for product purification, employing Brunschwig silica 32-63, 60Å under 0.3-0.5 bar overpressure. MPLC was conducted on a CombiFlash Rf200 System with a UV detector and fraction collector, or manually with SilicaFlash P60, 40-63 µm silica gel. Normal-phase preparative HPLC was carried out on a Teledyne Isco CombiFlash EZ Prep system using Macherey-Nagel VP 250/21 Nucleosil 50-5 columns.

^{1}H and ^{13}C NMR spectra were recorded on Bruker Ultrashield 300, Bruker Ascend 400, and Bruker AVANCE III 500 spectrometers. 19F NMR spectra were recorded on Bruker DPX-300, Bruker Ultrashield 300, Bruker DPX-400, and Bruker Ascend 400 spectrometers. Chemical shifts are reported in ppm, with coupling constants (*J*) given in Hertz. Solvent resonance was used as the reference unless otherwise noted ($CDCl_3$ at 7.26 ppm for ^{1}H NMR, $CDCl_3$ at 77.16 ppm for ^{13}C NMR). Peaks are denoted as singlet (s), doublet (d), triplet (t), quartet (q), multiplet (m), or unresolved.

HR-MS (ESI^+) mass spectra were measured on a Bruker FTMS 4.7T BioAPEX II and Thermo Scientific LTQ Orbitrap XL. Electron impact ionization mass spectra (EI-MS) were obtained using an Agilent 8890 series GC system and Agilent 5977B GC/MSD.

1.2. High intensity photoreactors

The photoreactor was custom designed and built by Katayev and co-workers in coordination with the mechanical workshop in the Department of Chemistry and Applied Biosciences at ETH Zürich having blue LEDs, equally spaced in a circular design, powered by a 10.3 A power supply, emitting 350 W of light with the measured UV-Vis spectrum (Figure 1). The LEDs were water-cooled and further cooled by built-in fans to maintain an ambient temperature.

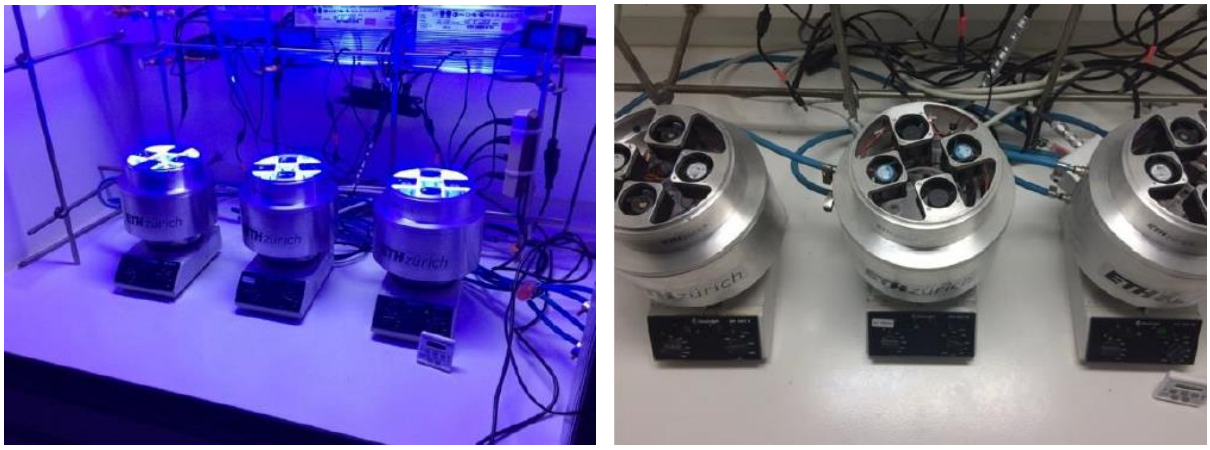


Figure 1.1. Custom high-intensity, blue LED photoreactors for photocatalytic reactions. The figure is taken from.

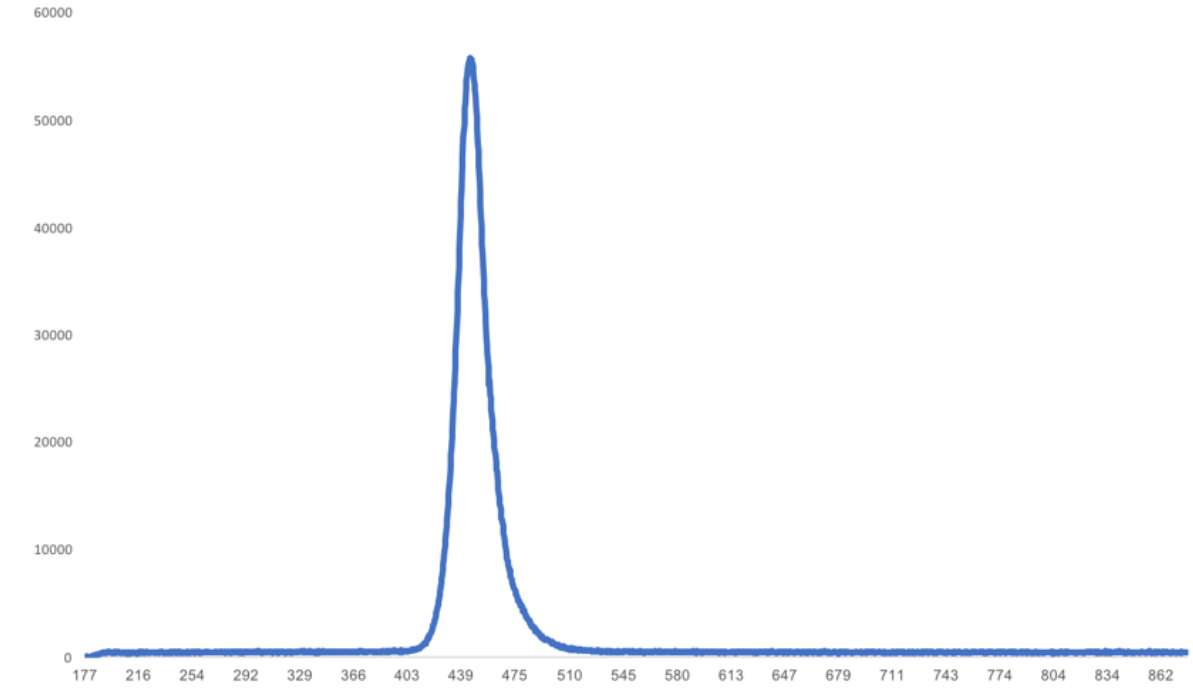
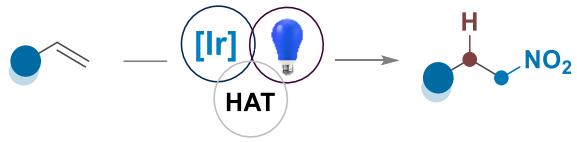


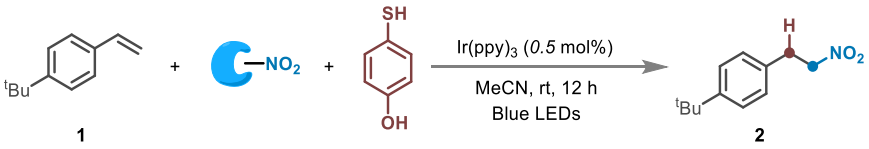
Figure 1.2. UV-Vis emission spectrum of high-intensity, blue LED photoreactor (λ_{max} = 446 nm, FWHM = 20 nm). The figure is taken from.

2. Development of the Hydronitration Reaction Conditions



A flame dried 5 mL crimp cap vial was charged with photocatalyst (*x* mol%), nitrating reagent (*x* equiv), HAT source (*x* equiv) and equipped with a magnetic bar. Anhydrous solvent (*x* mL) and 4-*tert*-butylstyrene (0.1 mmol, 1.0 equiv) were introduced to the solution *via* syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 12 h. After that, *n*-decane as an internal standard was added with a microsyringe. An aliquot was taken and analyzed by GC-MS to obtain the calibrated yields for the desired product.

2.1. *Survey of nitrating reagent*



1 2

entry[a]	nitrating reagents (1.5 eq)	yield of 2 [%][b]
1	Reagent **[I]**	n.d.
2	Reagent **[II]**	80 (77)[c]
3	Reagent **[III]**	10
4	Reagent **[IV]**	5
5	Reagent **[V]**	n.d.
6	Reagent **[VI]**	n.d.

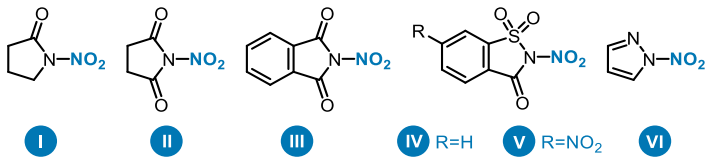
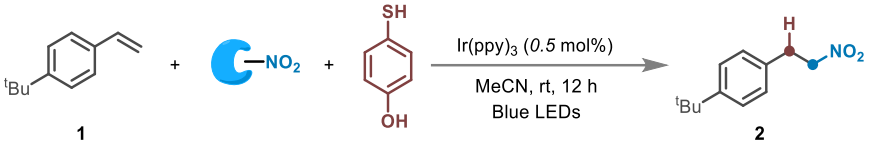


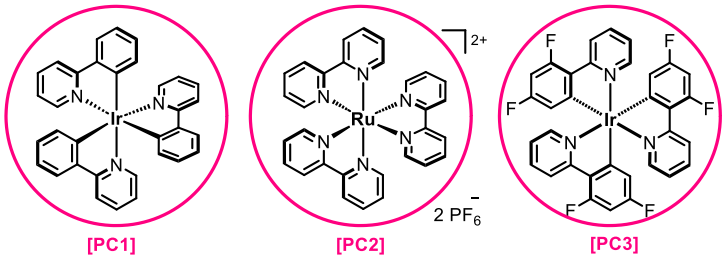
Table 2.1. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 eq), nitrating reagent (1.5 mmol, 2.0 eq), *fac*-Ir(ppy)$_3$ (0.5 mol%), 4-mercaptophenol (2.0 eq), ethanol (2.0 eq) and MeCN (0.5 mL), 350 W blue LEDs, rt, 12 h. [b]Determined by GC against an internal standard of *n*-decane. [c]Isolated yield.

2.2. *Survey of Photocatalysts (PC)*

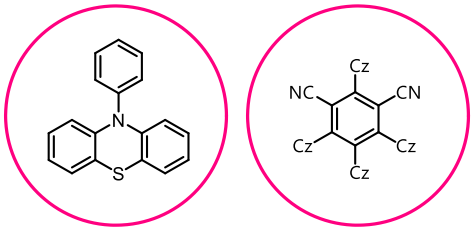


1 2

entry[a]	PC (0.5 mol%)	yield of 2 [%][b]
1	PC1	80 (77)[c]
2	PC2	16
3	PC3	5
4	PC4	35
5	PC5	0



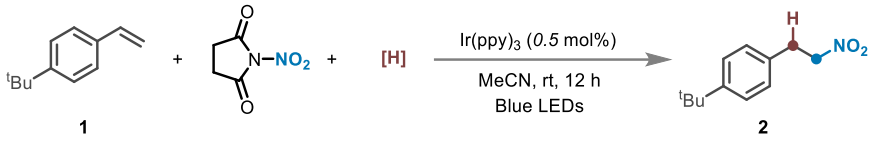
[PC1] [PC2] [PC3]



[PC4] [PC5]

Table 2.2. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 eq), nitrating reagent **II** (1.5 mmol, 2.0 eq), *PC* (0.5 mol%), 4-mercaptophenol (2.0 eq), ethanol (2.0 eq) and MeCN (0.5 mL), 350 W blue LEDs, rt, 12 h. [b]Determined by GC against an internal standard of *n*-decane. [c]Isolated yield. Cz = carbazol.

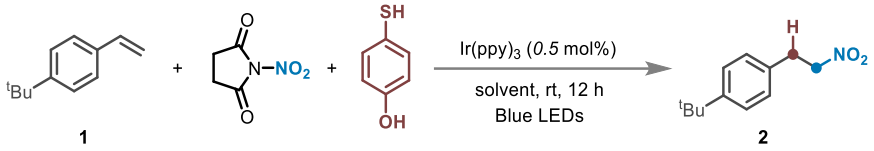
2.3. *Survey of HAT sources*



entry[a]	**HAT source** (2 eq)	**yield of 2** [%][b]
1	4-mercaptophenol	80 (77)[c]
2	2-mercaptophenol	15
3	2-(Trifluoromethyl)thiophenol	0
4	2-Methoxythiophenol	0
5	2,4,6-Triisopropylbenzenethiol	55
6	3-Fluorothiophenol	0
7	4-Fluorobenzenethiol	0
8	4-Bromothiophenol	0
9	4-Chlorothiophenol	0
10	4-Mercaptobenzoic acid	0
11	4-Methoxybenzenethiol	0
12	4-Nitrothiophenol	0
13	Thiosalicylic acid	0
14	Thiophenol	0
15	4-tert-Butylthiophenol	0
16	2-Mercaptoacetic acid	0
17	Methyl thioglycolate	0
18	Triethylsilane	0
19	Tris(trimethylsilyl)silane	0
20	Phenylsilane	0

Table 2.3. [a]Reaction conditions: 4-*tert*-butylstyrene (0.5 mmol, 1.0 eq), nitrating reagent **II** (1.5 mmol, 2.0 eq), *fac*-Ir(ppy)$_3$ (0.5 mol%), HAT source (2.0 eq), ethanol (2.0 eq) and MeCN (0.5 mL), 350 W blue LEDs, rt, 12 h. [b]Determined by GC against an internal standard of *n*-decane. [c]Isolated yield.

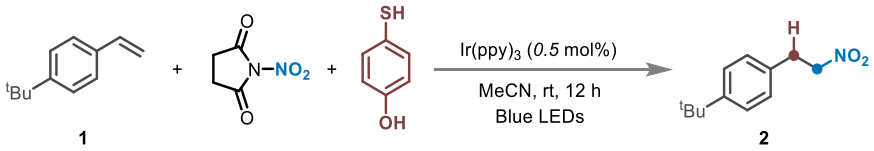
2.4. *Survey of solvents*



entry[a]	solvent	yield of **2** [%][b]
1	MeCN	80 (77)[c]
2	THF	12
3	toluene	10
4	acetone	2
5	DMF	0

Table 2.4. [a]Reaction conditions: 4-*tert*-butylstyrene **1** (0.5 mmol, 1.0 eq), nitrating reagent **II** (1.5 mmol, 2.0 eq), *fac*-Ir(ppy)$_3$ (0.5 mol%), 4-mercaptophenol (2.0 eq), ethanol (2.0 eq) and solvent (0.5 mL), 350 W blue LEDs, rt, 12 h. [b]Determined by GC against an internal standard of *n*-decane. [c]Isolated yield.

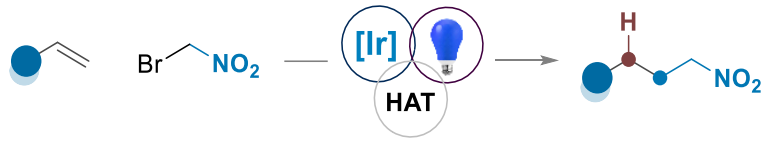
2.5. Control experiments



Entry	Variables	Yield of **2** [%][b]
1	Standard conditions[a]	80 (77)[c]
2	Without LEDs	0
3	Without **PC1**	0
4	Without EtOH	30
5	Heating at 80 ˚C without light	0

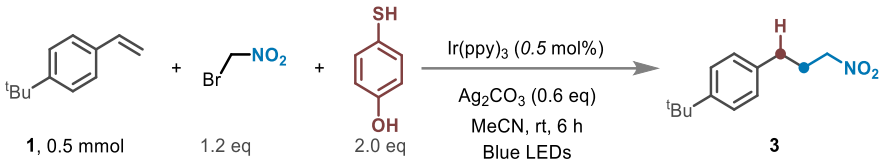
Table 2.5. [a]Standard reaction conditions: 4-*tert*-butylstyrene **1** (0.5 mmol, 1.0 eq), nitrating reagent **II** (1.5 mmol, 2.0 eq), *fac*-Ir(ppy)$_3$ (0.5 mol%), 4-mercaptophenol (2.0 eq), ethanol (2.0 eq) and MeCN (0.5 mL), 350 W blue LEDs, rt, 12 h. [b]Determined by GC against an internal standard of *n*-decane. [c]Isolated yield.

3. **Development of the Nitromethylation Reaction Conditions**



A flame dried 5 mL crimp cap vial was charged with photocatalyst (*x* mol%), nitrating reagent (*x* equiv), HAT source (*x* equiv) and equipped with a magnetic bar. Anhydrous solvent (*x* mL) and 4-*tert*-butylstyrene (0.1 mmol, 1.0 equiv) were introduced to the solution *via* syringes under an N_2 atmosphere. The reaction mixture was irradiated at room temperature under blue LEDs for 12 h. After that, *n*-decane as an internal standard was added with a microsyringe. An aliquot was taken and analyzed by GC-MS to obtain the calibrated yields for the desired product.

3.1. *Reaction development and optimisation*



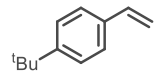
entry	variation of standard reaction conditions[a]	yield of **3** [%][b]
1	none	92 (87)[c]
2	AgOAC instead of Ag_2CO_3	88
3	$AgNO_2$ instead of Ag_2CO_3	34
4	AgF instead of Ag_2CO_3	73
5	AgOTf instead of Ag_2CO_3	69
6	Na_2CO_3 instead of Ag_2CO_3	65
7	K_2CO_3 instead of Ag_2CO_3	16
8	Cs_2CO_3 instead of Ag_2CO_3	13
9	0.3 eq of Ag_2CO_3 instead of 0.6 eq	71
10	THF instead of MeCN	10
11	ethylbenzene instead of MeCN	15
12	Triethylsilane instead of 4-mercaptophenol	0
13	AIBN, 80 °C	0
14	No light	0
15	No *fac*-Ir(ppy)$_3$	0

Table 3.1. [a]Standard reaction conditions: 4-*tert*-butylstyrene **1** (0.5 mmol, 1.0 eq.), *fac*-Ir(ppy)$_3$ (0.5 mol%), bromo(nitro)methane **VII** (1.2 eq.), Silver carbonate (0.6 eq.), 4-mercaptophenol (2.0 eq.), and MeCN (2.5 mL), 350 W blue LEDs, rt, 6 h. [b]Determined by GC against an internal standard of *n*-decane. [c]Isolated yield.

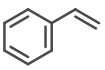
4. Availability of Starting Materials

4.1. Commercially available starting materials

Starting materials which are commercially available are mostly purchased from Thermoscientific – Acros, Sigma Aldrich, Apollo Scintific, Fluorochem and TCI.



CAS 1746-23-2



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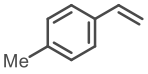

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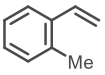

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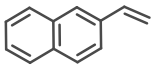
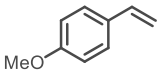


CAS 827-54-3



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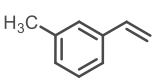

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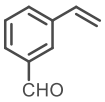

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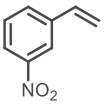

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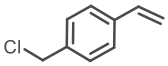
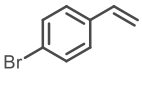
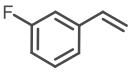


CAS 1592-20-7



CAS 2039-82-9



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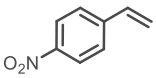

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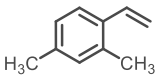

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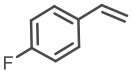
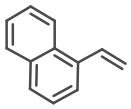
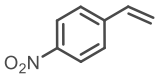


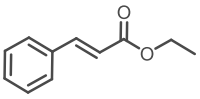
CAS 405-99-2



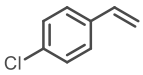
CAS 826-74-4



CAS 100-13-0



CAS 103-36-6



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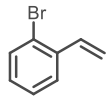

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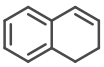
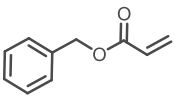


CAS 447-53-0

CAS 95-13-6



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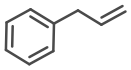

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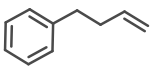

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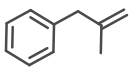
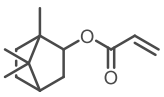
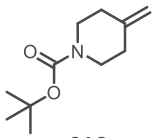


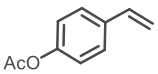
CAS 3290-53-7



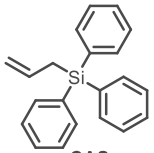
CAS 5888-33-5



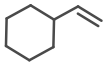
CAS 159635-49-1



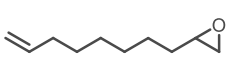
CAS 2628-16-2



CAS 18752-21-1



CAS 695-12-5



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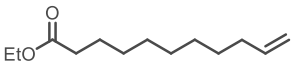
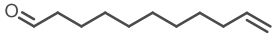
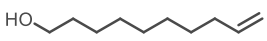


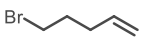
CAS 692-86-4



CAS 112-45-8



CAS
13019-22-2



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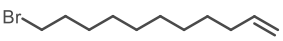
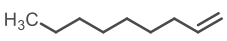
1119-51-3

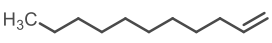


CAS
7766-50-9



CAS
124-11-8

CAS
872-05-9



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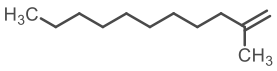

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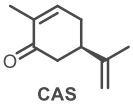
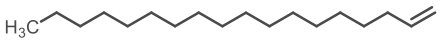


CAS
6485-40-1

CAS
1120-36-1



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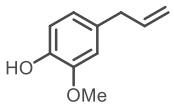
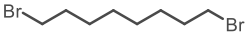


CAS
97-53-0

CAS
928-89-2



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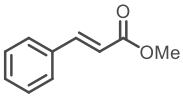
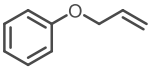
4549-32-0

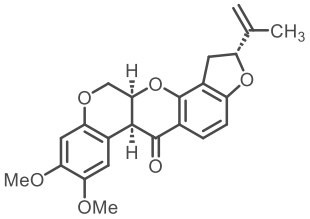


CAS
103-26-4

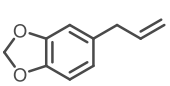


CAS
1746-13-0

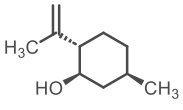
CAS
4117-09-3



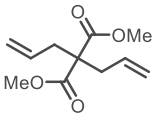
CAS
83-79-4



CAS
94-59-7



CAS
89-79-2



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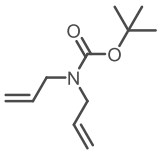
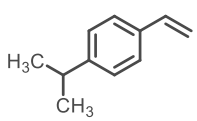
3195-24-2

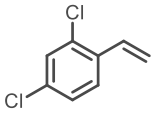


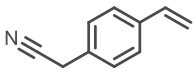
CAS
151259-38-0

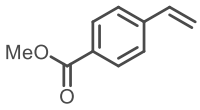
4.2. Prepared starting materials

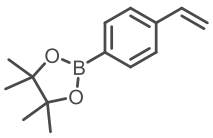
The following starting materials were prepared according to reported literature procedures.

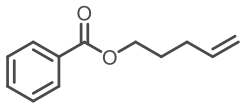


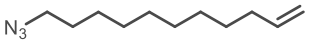


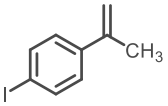


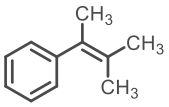


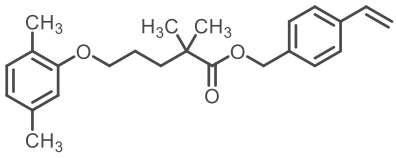


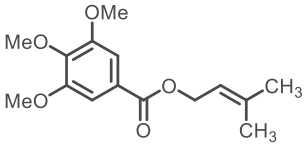


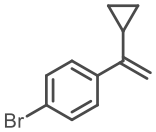


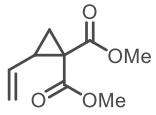






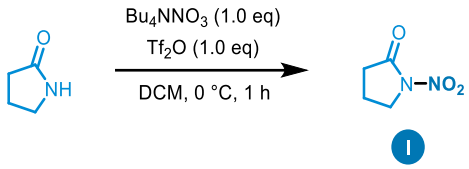






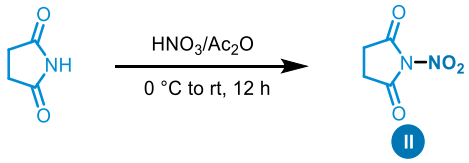
5. Synthesis of NO_2-transfer Reagents

5.1. *N*-Nitropyrrolidinone (I)



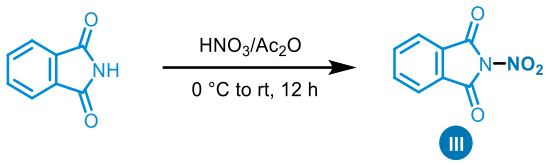
According to previously described procedure, Bu_4NNO_3 1.52 grams (5 mmol) and 30 mL of anhydrous DCM were sequentially introduced into a 100 mL three-necked round bottom flask equipped with a dropping funnel and nitrogen outlet, and the reaction mixture was cooled to 0 °C using an ice bath. The dropping funnel was loaded with 1.411 grams (5 mmol) of triflic anhydride, which was then added dropwise to the reaction mixture over 10 minutes. The final mixture was stirred for an additional one hour at 0 °C. Pyrrolidin-2-one 400 mg (5 mmol) in 10 mL DCM was injected via syringe over a period of 10 minutes, and the reaction mixture was then gradually warmed to room temperature and kept for 12 hours. After completion of the reaction, 25 mL of 5% $NaHCO_3$ was added and stirred for 30 minutes to neutralize the system. Final mixture was extracted with DCM (3×30 mL), the organic solvent was combined and evaporated. The crude was purified by column chromatography on silica gel, yielding 61% of **I** as a yellow solid.

5.2. *N*–Nitrosuccinimide (II)



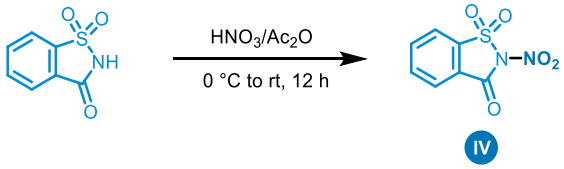
This procedure represents a modification of a previously reported method. A three-necked round-bottom flask 250 mL was equipped with a dropping funnel and a gas outlet connected to a trap containing an aqueous sodium hydroxide solution. The flask was then charged with 15 grams (0.15 mol) of succinimide and 57 mL of acetic anhydride, and the solution was cooled to 0 °C. Fuming nitric acid (98-99%) was slowly introduced via a dropping funnel (the flask was positioned behind a blast shield) over a duration of 20-30 minutes. It should be noted that dry air was rapidly blown through the reaction mixture to eliminate nitrogen oxide emissions. The reaction was subsequently allowed to warm to room temperature and vigorously stirred for 12 hours. Once the reaction was completed, the mixture was cooled again to 0 °C, and a combination of 150 grams of ice and 200 mL of ice-water were incrementally added. This step involved stirring for an additional 15 minutes, resulting in the formation of a white precipitate. The precipitate was separated by filtration, washed with 100 mL of ice-water, and subsequently dried under high vacuum. The overall yield consisted of glistening colourless crystalline plates (12.7 grams, 59% yield).

5.3. *N*–Nitrophthalimide (III)



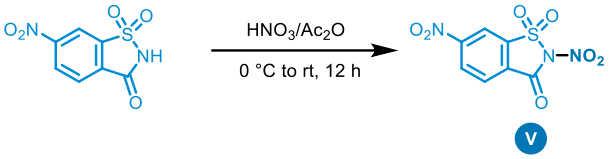
Following the described procedure, 12.5 grams (0.085 mol) of phthalimide and 40 mL of acetic anhydride were introduced to a 250 mL three-necked round-bottom flask, equipped with a dropping funnel and a gas outlet connected to a trap containing an aqueous sodium hydroxide solution. The mixture was then cooled to 0 °C and fuming nitric acid (98-99%) (50 mL) was cautiously added through a dropping funnel, positioned behind a protective blast shield. Off note, that dry air was swiftly passed through the reaction mixture to effectively eliminate any excess of nitrogen oxide. The reaction mixture was allowed to slowly reach room temperature over a span of 12 hours. Upon completion of the reaction, the mixture was transferred to a freezer set at 4 °C for 12 hours. The resulting precipitate was collected and subjected to recrystallization, utilizing chloroform as the solvent. This process yielded *N*-nitrophthalimide as a white solid, achieving a 50% yield (8.16 g).

5.4. 2-Nitrobenzo[d]isothiazol-3(2H)-one 1,1-dioxide (IV)



Following the described procedure, into a 250 mL three-necked round-bottom flask, complete with a dropping funnel, an air outlet, and a stirring bar, a solution of 10.0 grams (54.64 mmol) of *N*-saccharin in 25.7 mL of acetic anhydride (0.27 mol) was introduced. The reaction temperature was cooled to 0-5°C using an ice bath. Over a 30-minute duration, fuming concentrated nitric acid (98-99%) (25.1 mL, 0.61 mol) was added dropwise over a period of 30 minutes. Off note, that dry air was swiftly passed through the reaction mixture to effectively eliminate any excess of nitrogen oxide. With the addition of the nitric acid, the *N*-saccharin completely dissolved. Subsequently, the ice bath was removed and stirring was continued at room temperature for a minimum of 4 hours, ensuring that a continuous stream of air passed through the liquid. As the reaction progressed, a precipitate began to form, which was later gathered using a sintered glass filter. The precipitate then underwent meticulous drying under high vacuum until it reached a state of complete dryness, yielding 11.8 grams of final product, constituting a remarkable 95% yield. For further refinement, the material is amenable to purification through recrystallization, a procedure that entails dissolving it in either hot chloroform or acetonitrile. This process yields a final product in the form of a white crystalline compound, poised for subsequent utilization or analysis.

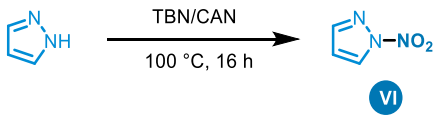
5.5. 2,6-Dinitrobenzo[d]isothiazol-3(2H)-one 1,1-dioxide (V)



V

Following the described procedure, 10.0 grams (36.63 mmol) of 6-nitrosaccharin and 28.2 mL of acetic anhydride (0.30 mol) were added to a 250 mL three-necked round-bottom flask, equipped with a dropping funnel, an air outlet, and a stirring bar. To achieve the desired reaction temperature 5-10 °C, an ice bath was utilized. Concentrated fuming nitric acid (98-99%) (28.2 mL, 0.67 mol) was added dropwise into the solution over 30 minutes, while ensuring that dry air was rapidly bubbled through the mixture to effectively eliminate any excess nitrogen oxides. The 6-nitrosaccharin completely dissolved once all the nitric acid had been added. Subsequently, the reaction mixture was stirred at the 5-10 °C range for a duration of 4 hours, maintaining a continuous flow of dry air through the liquid. As the reaction proceeded, the solution was placed in a freezer for a period of 10 hours to facilitate the complete precipitation of the product. Following this, the resulting precipitate was collected using a sintered glass filter, washed with cold chloroform, and subjected to a thorough drying process under high vacuum until complete dryness, yielding 9.6 grams of off-white crystalline product (96% yield).

5.6. 1-Nitro-1*H*-pyrazole (VI)



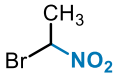
VI

Following the described procedure, pyrazole (3.0 mmol, 1.0 eq), TBN (0.31 g, 3.0 mmol, 1.0 eq), CAN (3.2 g, 6.0 mmol, 2.0 eq), and MeCN (20.0 mL) were added into a tube of a volume of 100 mL under oxygen atmosphere. The tube was hermetically sealed, after which the reaction mixture was heated to 100 °C with vigorous stirring for 16 hours. After completion of the reaction, it was cooled to room temperature and filtered through a thin pad of celite, while washing with ethyl acetate. The combined filtrate was concentrated in vacuo, and the resulting residue was subjected to direct purification by column chromatography on silica gel (petroleum ether (PE) and ethyl acetate (EtOAc) in a 5:1 ratio) yielding the desired product **VI**.

5.7. Bromo(nitro)methane (VII)

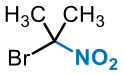
Bromo(nitro)methane **VII** was purchased from Sigma Aldrich and was used as it is.

5.8. 1-Bromo-1-nitroethane (VIII)



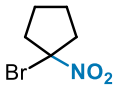
1-Bromo-1-nitroethane **VIII** was prepared following the literature procedure.

5.9. 2-Bromo-2-nitropropane (IX)



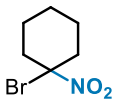
2-Bromo-2-nitropropane **IX** was purchased from Sigma Aldrich and was used as it is.

5.10. 1-Bromo-1-nitrocyclopentane (X)



1-Bromo-1-nitrocyclopentane **X** was prepared following the literature procedure.

5.11. 1-Bromo-1-nitrocyclohexane (XI)

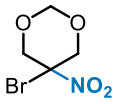


1-Bromo-1-nitrocyclohexane **XI** was prepared following the literature procedure.

5.12. 1-Bromo-1-nitrocyclohexane (XII)

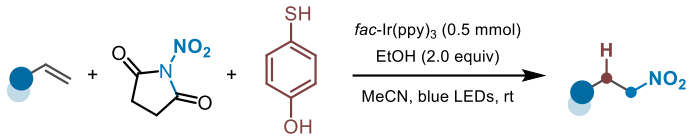
1-Bromo-1-nitrocycloheptane **XII** was prepared following the literature procedure.

5.12. 5-Bromo-5-nitro-1,3-dioxane (XIII)

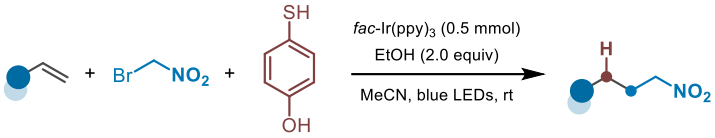


5-Bromo-5-nitro-1,3-dioxane **XIII** was purchased from Sigma Aldrich and was used as it is.

6. General Procedures for the Synthesis of Nitroalkanes



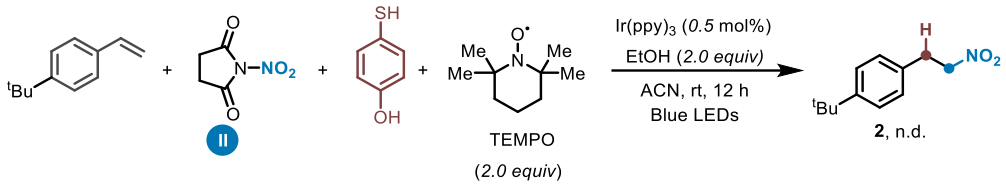
GP1: A flame dried 5 mL crimp cap vial was charged with alkene (0.5 mmol, 1.0 eq), *fac*-Ir(ppy)$_3$ (0.5 mol%), nitrating reagent **II** (0.75 mmol, 1.5 eq), 4-mercaptophenol (1.0 mmol, 2.0 eq), ethanol (1.0 mmol, 2.0 eq), anhydrous ACN (0.5 mL) and equipped with a magnetic bar. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 12 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography.



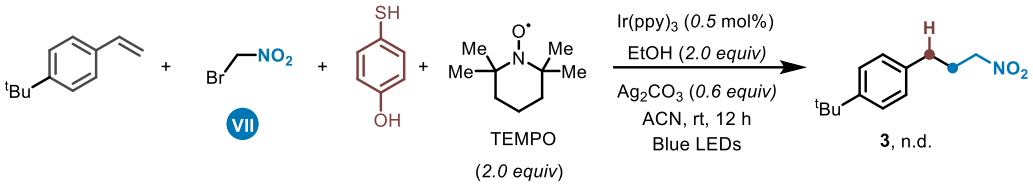
GP2: A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (0.5 mol%), 4-mercaptophenol (1.0 mmol, 2.0 eq), silver carbonate (0.3 mmol, 0.6 eq), nitrating reagent (if solid) (0.6 mmol, 1.2 eq). The vial was then subjected to three vacuum-nitrogen cycles. The alkene (0.5 mmol, 1.0 eq), nitrating reagent (if liquid) (0.6 mmol, 1.2 eq), ethanol (1.0 mmol, 2.0 eq) and anhydrous MeCN (2.5 mL) were added via syringe under a nitrogen atmosphere. The reaction mixture was stirred under 350 W blue LEDs irradiation for the 6 h. The solvent was evaporated under reduced pressure, and the crude product was purified by flash column chromatography.

7. Mechanistic Investigations

7.1. Reactions in presence of radical scavenger

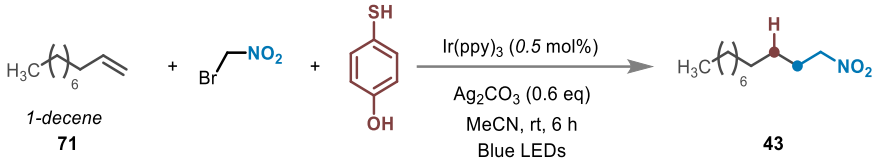


A flame dried 5 mL crimp cap vial was charged with alkene (0.5 mmol, 1.0 eq), *fac*-Ir(ppy)$_3$ (0.5 mol%), nitrating reagent **II** (0.75 mmol, 1.5 eq), 4-mercaptophenol (1.0 mmol, 2.0 eq), ethanol (1.0 mmol, 2.0 eq), anhydrous ACN (0.5 mL) and equipped with a magnetic bar. The reaction mixture was stirred under blue LEDs Irradiation at room temperature for 12 h. The samples was analyzed by GC-MS.



A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (0.5 mol%), 4-mercaptophenol (1.0 mmol, 2.0 eq), silver carbonate (0.3 mmol, 0.6 eq). The vial was then subjected to three vacuum-nitrogen cycles. The alkene (0.5 mmol, 1.0 eq), ethanol (1.0 mmol, 2.0 eq) , nitrating reagent **VII** (0.6 mmol, 1.2 eq) and anhydrous MeCN (2.5 mL) were added via syringe under a nitrogen atmosphere. The reaction mixture was stirred under 350 W blue LEDs irradiation for the 6 h and samples were analyzed by GC-MS.

7.2. Light ON-OFF experiment



1-decene
71

43

A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (0.5 mol%), 4-mercaptophenol (1.0 mmol, 2.0 eq), silver carbonate (0.3 mmol, 0.6 eq). The vial was then subjected to three vacuum-nitrogen cycles. The 1-decene **71** (0.5 mmol, 1.0 eq), ethanol (1.0 mmol, 2.0 eq) , nitrating reagent **VII** (0.6 mmol, 1.2 eq) and anhydrous MeCN (2.5 mL) were added *via* syringe under a nitrogen atmosphere. The reaction mixture was stirred under 350 W blue LEDs irradiation for the 6 h and samples were analyzed by GC-MS (Figure 7.2.1).

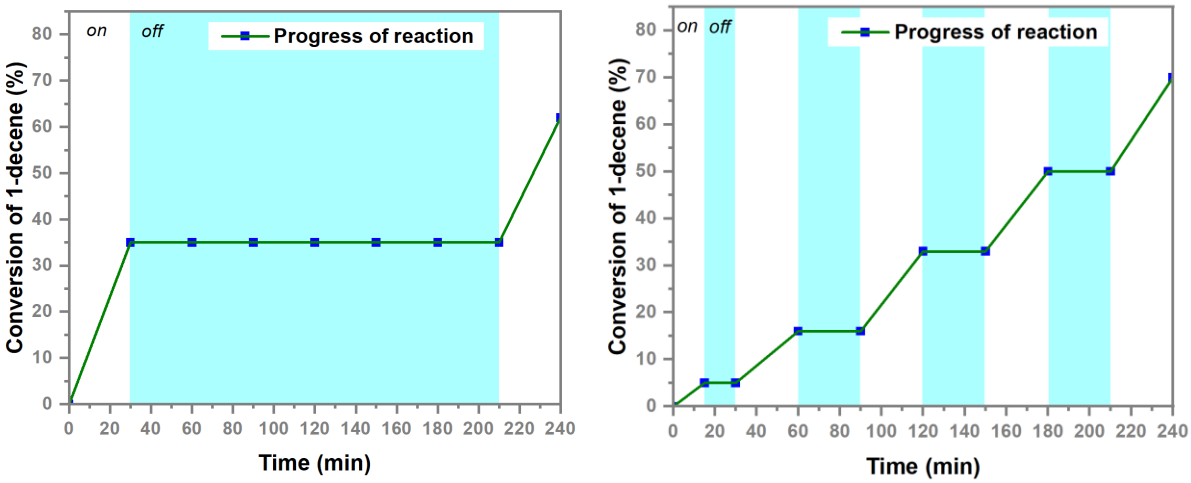
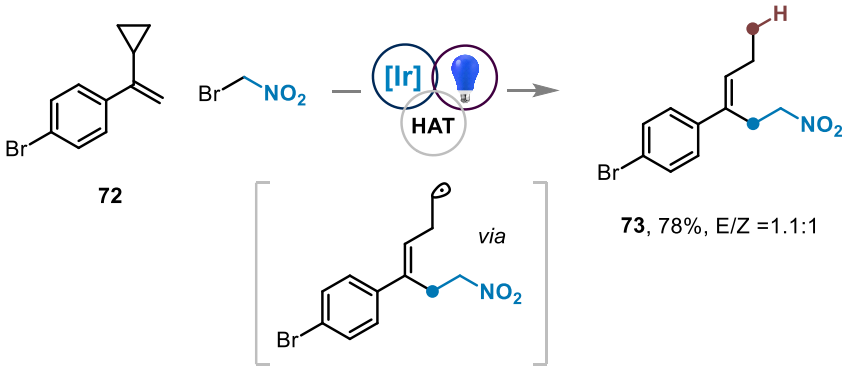


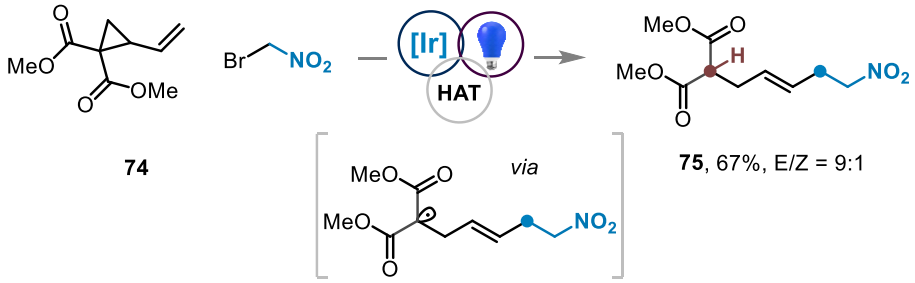
Figure 7.2.1. Conversion of 1-decene *vs* reaction time for the light on-off experiment.

Under the influence of blue LED irradiation, the reaction proceeded seamlessly. However, in the absence of blue LED light, the reaction stopped. This result strongly indicates that the reaction follows a photoredox catalytic pathway rather than via radical chain propagation.

7.3. Radical clock experiment

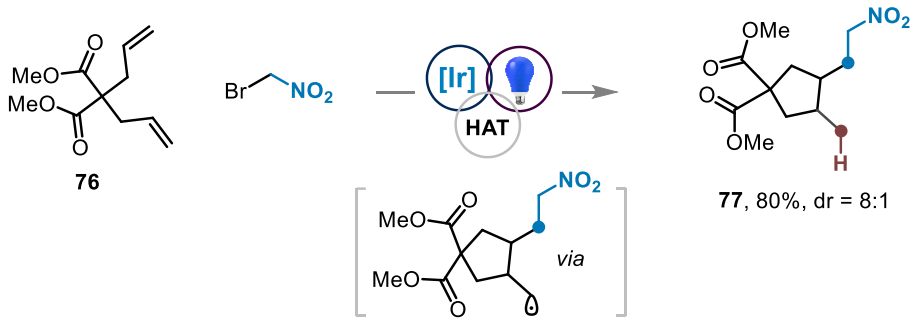


A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (0.5 mol%), 4-mercaptophenol (1.0 mmol, 2.0 eq), silver carbonate (0.3 mmol, 0.6 eq). The vial was then subjected to three vacuum-nitrogen cycles. The 1-bromo-4-(1-cyclopropylvinyl)benzene **72** (0.5 mmol, 1.0 eq), ethanol (1.0 mmol, 2.0 eq) , nitrating reagent **VII** (0.6 mmol, 1.2 eq) and anhydrous MeCN (2.5 mL) were added via syringe under a nitrogen atmosphere. The reaction mixture was stirred under 350 W blue LEDs irradiation for the 6 h. The reaction contents were concentrated under reduced pressure. The residue was purified by flash column chromatography over silica gel, yielding **73** as a colorless oil (78% yield, E/Z = 1.1:1).

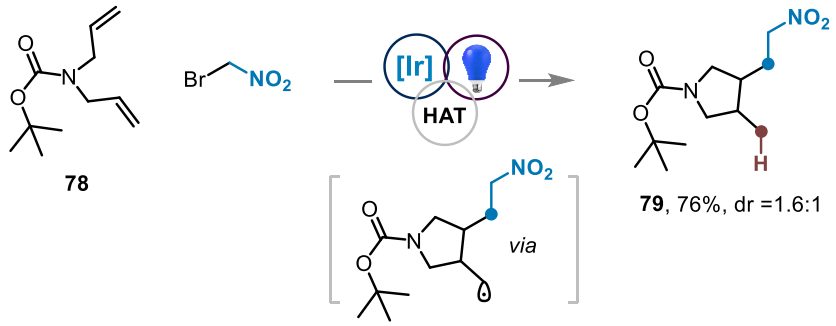


A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (0.5 mol%), 4-mercaptophenol (1.0 mmol, 2.0 eq), silver carbonate (0.3 mmol, 0.6 eq). The vial was then subjected to three vacuum-nitrogen cycles. The dimethyl 2-vinylcyclopropane-1,1-dicarboxylate **74** (0.5 mmol, 1.0 eq), ethanol (1.0 mmol, 2.0 eq) , nitrating reagent **VII** (0.6 mmol, 1.2 eq) and anhydrous MeCN (2.5 mL) were added via syringe under a nitrogen atmosphere. The reaction mixture was stirred under 350 W blue LEDs irradiation for the 6 h. The reaction contents were concentrated under reduced pressure. The residue was purified by flash column chromatography over silica gel, yielding **75** as a colorless oil (67% yield, E/Z = 9:1).

7.4. 5-Exo-trig cyclization



A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (0.5 mol%), 4-mercaptophenol (1.0 mmol, 2.0 eq), silver carbonate (0.3 mmol, 0.6 eq). The vial was then subjected to three vacuum-nitrogen cycles. The dimethyl 2,2-diallylmalonate **76** (0.5 mmol, 1.0 eq), ethanol (1.0 mmol, 2.0 eq) , nitrating reagent **VII** (0.6 mmol, 1.2 eq) and anhydrous MeCN (2.5 mL) were added via syringe under a nitrogen atmosphere. The reaction mixture was stirred under 350 W blue LEDs irradiation for the 6 h. The reaction contents were concentrated under reduced pressure. The residue was purified by flash column chromatography over silica gel, yielding **77** as a colorless oil (80% yield, dr = 8:1).



A flame dried 5 mL crimp cap vial was charged with *fac*-Ir(ppy)$_3$ (0.5 mol%), 4-mercaptophenol (1.0 mmol, 2.0 eq), silver carbonate (0.3 mmol, 0.6 eq). The vial was then subjected to three vacuum-nitrogen cycles. The tert-butyl diallylcarbamate **78** (0.5 mmol, 1.0 eq), ethanol (1.0 mmol, 2.0 eq) , nitrating reagent **VII** (0.6 mmol, 1.2 eq) and anhydrous MeCN (2.5 mL) were added via syringe under a nitrogen atmosphere. The reaction mixture was stirred under 350 W blue LEDs irradiation for the 6 h. The reaction contents were concentrated under reduced pressure. The residue was purified by flash column chromatography over silica gel, yielding **79** as a colorless oil (76% yield, dr = 1.6:1).

8. Proposed Reaction Mechanism

8.1. Reaction mechanism for anti-Markovnikov hydronitration

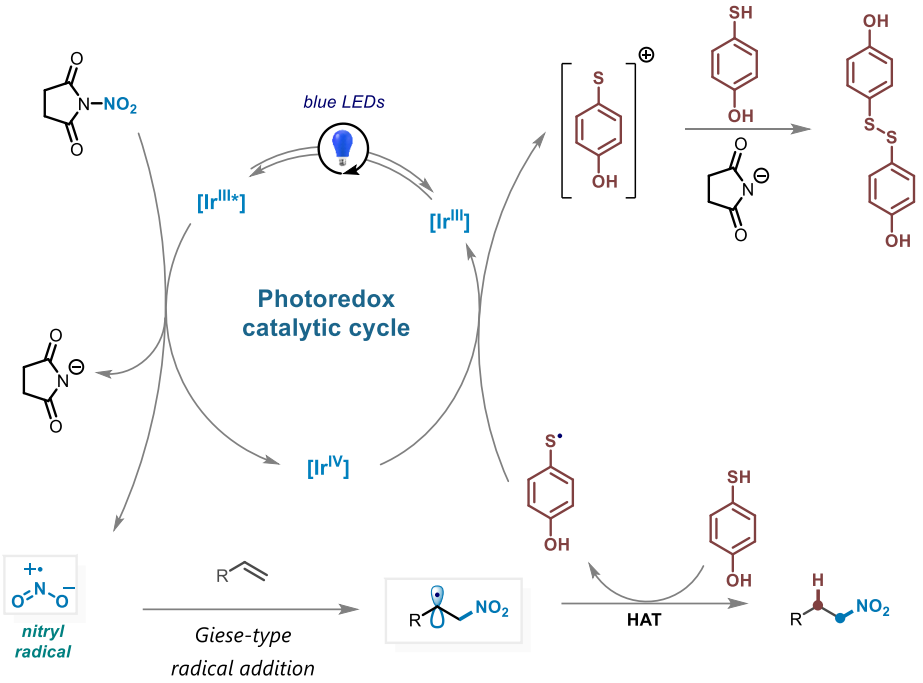


Figure 8.1.1. Proposed mechanism for hydronitration reaction.

8.2. Reaction mechanism for anti-Markovnikov hydronitroalkylation

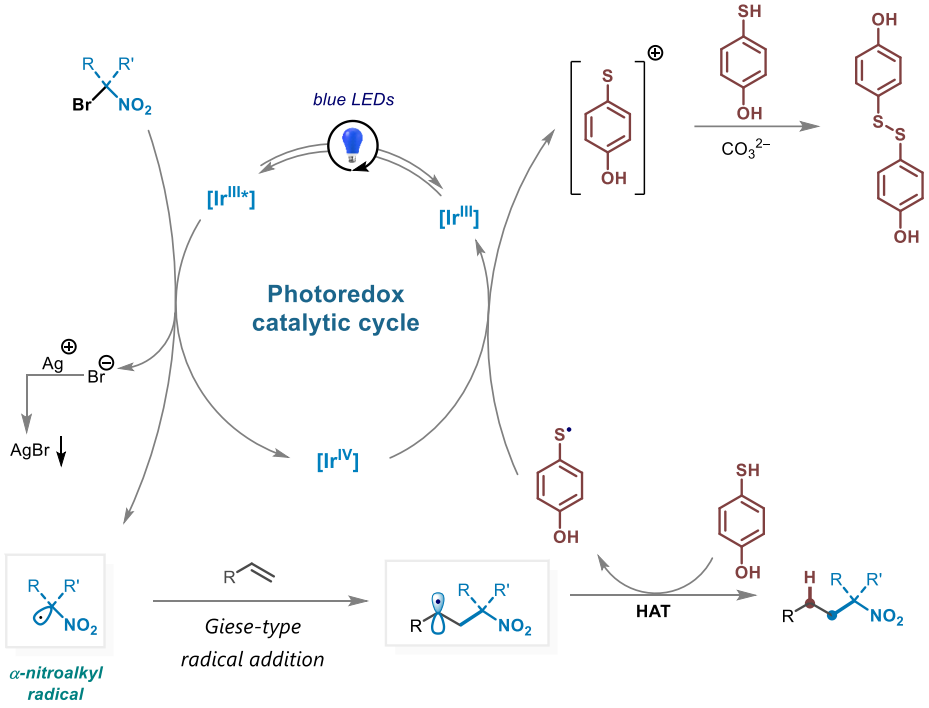
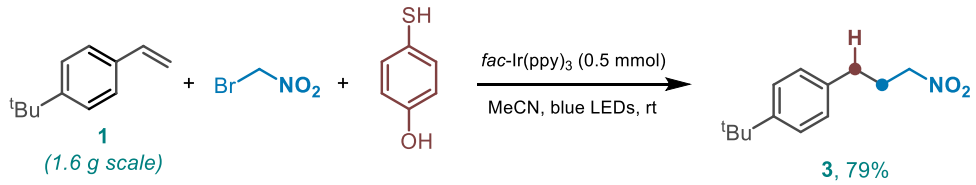


Figure 8.2.1. Proposed mechanism for hydronitroalkylation reaction.

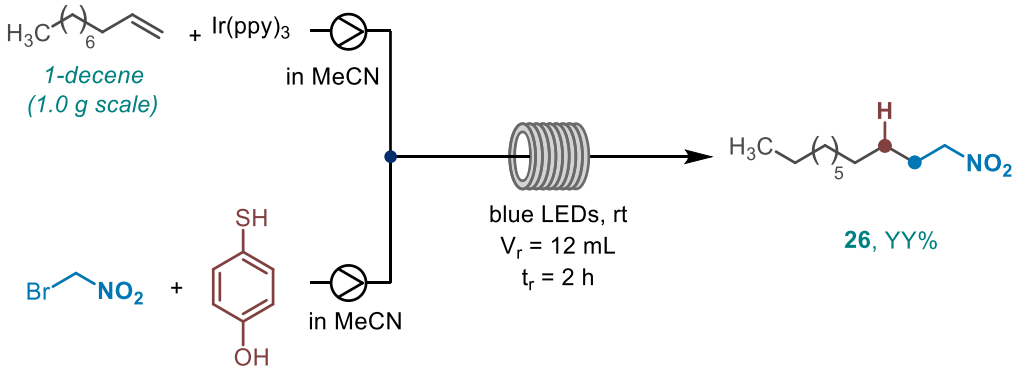
9. Scale-Up Synthesis

9.1. Procedure for batch set-up



A flame dried 100 mL schlenk tube was charged with *fac*-Ir(ppy)$_3$ (0.5 mol%), 4-mercaptophenol (20.0 mmol, 2.0 eq), silver carbonate (6.0 mmol, 0.6 eq). The vial was then subjected to three vacuum-nitrogen cycles. The 4-*tert*-butyl styrene **1** (10 mmol, 1.0 eq), nitrating reagent **VII** (12.0 mmol, 1.2 eq), ethanol (20.0 mmol, 2.0 eq) and anhydrous MeCN (50 mL) were added via syringe under a nitrogen atmosphere. The reaction mixture was stirred under 350 W blue LEDs irradiation for 12 h. The reaction contents were concentrated under reduced pressure. The residue was purified by flash column chromatography over silica gel, yielding **3** as a yellow oil (79% yield).

9.2. Procedure for flow set-up



In an oven-dried flask, 1-decene **71**, (1.6 gram, 10.0 mmol, 1.0 eq) and *fac*-Ir(ppy)$_3$ (0.5 mol%) were dissolved in 25 mL anhydrous MeCN while in another flask nitrating reagent **VII** (15.0 mmol) and 4-mercaptophenol (20.0 mmol, 2.0 eq) was dissolved in 25 mL anhydrous MeCN. Both liquids were taken up with a syringe and mounted on a syringe pump. The syringes were connected to a 12 mL flow coil tubing (PFA tubing, 1/16" outer diameter, and 1 mm inner diameter, [1507L]) *via* a PEEK Y-mixer (Y Assembly PEEK [P-512]), the volume of the tube is 12 mL. Stock solutions were pumped into the flow reactor with a flow rate of 0.1 mL/min through each syringe (corresponding to 120 min residence time). When the syringe was fully empty, again stock solution was loaded into a syringe and injected to collect all product at the end of the reactor in a flask. The reaction mixture was concentrated under reduced pressure. The residue was purified by flash column chromatography over silica gel as indicated to afford 1-nitroundecane as a colorless oil (72% yield).

Components of flow reactor.

Tube volume	**Retention time**
$V_r = \pi r^2 h$ (r = 0.5 mm; h = 15240 mm)	t_r = Tube volume / Flow rate
$V_r = 3.14 \times (0.5)^2 \times (15240)$ mm^3	t_r = 12 mL / 0.1 mL·min^{-1}
V_r = 11969.46 mm^3	t_r = 120 min
V_r = 12 mL	t_r = 2 h

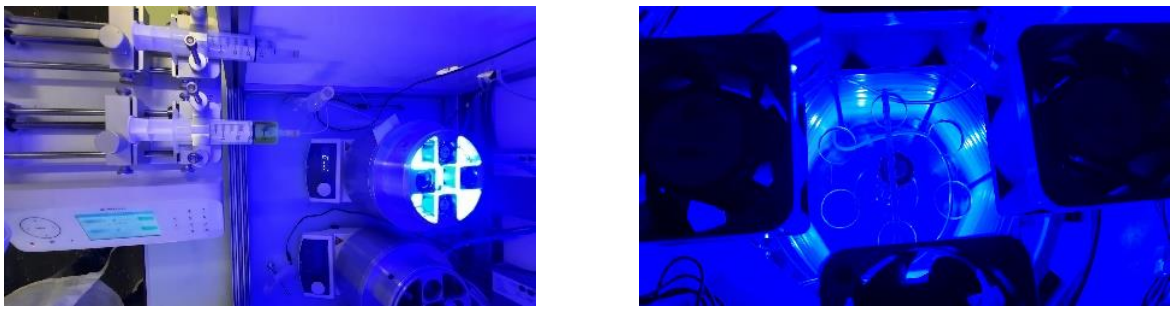
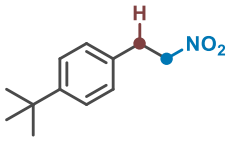


Figure 9.2.1. In-house developed flow setup for scale-up reactions.

10. NMR Data

1-(Tert-butyl)-4-(2-nitroethyl)benzene (2)



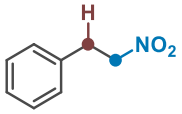
Compound **2** was obtained according to general procedure **GP1** as a yellow oil (77% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.24 (d, *J* = 8.3 Hz, 2H), 7.03 (d, *J* = 8.3 Hz, 2H), 4.48 (t, *J* = 7.5 Hz, 2H), 3.17 (t, *J* = 7.5 Hz, 2H), 1.20 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 150.4, 132.7, 128.4, 126.0, 76.4, 34.6, 33.0, 31.4.

The NMR spectra are in accordance with the literature.

(2-Nitroethyl)benzene (4)



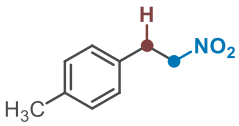
Compound **4** was obtained according to general procedure **GP1** as a yellow oil (72% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.38 – 7.28 (m, 3H), 7.25 – 7.18 (m, 2H), 4.61 (t, *J* = 7.4 Hz, 2H), 3.32 (t, *J* = 7.4 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.8, 129.0, 128.7, 127.5, 76.3, 33.5.

The NMR spectra are in accordance with the literature.

1-Methyl-4-(2-nitroethyl)benzene (5)



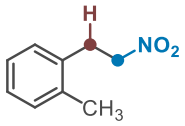
Compound **5** was obtained according to general procedure **GP1** as a yellow oil (76% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.15 (q, *J* = 8.0 Hz, 4H), 4.59 (t, *J* = 7.4 Hz, 2H), 3.28 (t, *J* = 7.4 Hz, 2H), 2.36 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 137.0, 132.6, 129.6, 128.4, 76.4, 33.0, 21.0.

The NMR spectra are in accordance with the literature.

1-Methyl-2-(2-nitroethyl)benzene (6)

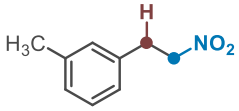


Compound **6** was obtained according to general procedure **GP1** as a yellow oil (73% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.36 – 7.25 (m, 4H), 4.73 – 4.62 (m, 2H), 3.52 – 3.41 (m, 2H), 2.49 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.2, 133.8, 130.7, 129.0, 127.5, 126.5, 75.0, 30.8, 19.1.

1-Methyl-2-(2-nitroethyl)benzene (7)



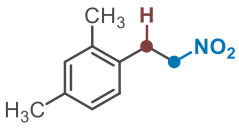
Compound **7** was obtained according to general procedure **GP1** as a yellow oil (73% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.07 (t, *J* = 7.5 Hz, 1H), 6.94 (d, *J* = 7.5 Hz, 1H), 6.90 – 6.82 (m, 2H), 4.41 (t, *J* = 7.4 Hz, 2H), 3.10 (t, *J* = 7.4 Hz, 2H), 2.19 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.5, 135.7, 129.3, 128.7, 128.1, 125.5, 76.2, 33.2, 21.2, 21.2.

HRMS (ESI) *m/z*, $[M-H]^+$ calcd for $C_9H_{10}NO_2$: 164.0706; found 164.0707.

2,4-Dimethyl-1-(2-nitroethyl)benzene (8)



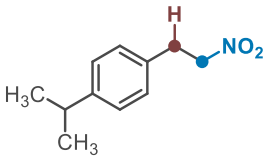
Compound **8** was obtained according to general procedure **GP1** as a yellow oil (75% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.08 – 6.88 (m, 3H), 4.59 – 4.48 (m, 2H), 3.35 – 3.26 (m, 2H), 2.31 (s, 3H), 2.30 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 137.4, 136.1, 131.7, 130.7, 129.2, 127.3, 75.4, 30.8, 21.1, 19.3.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{10}H_{13}NO_3$: 179.0941; found 179.0943.

1-Isopropyl-4-(2-nitroethyl)benzene (9)



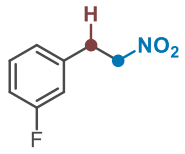
Compound **9** was obtained according to general procedure **GP1** as a yellow oil (70% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.20 (d, *J* = 8.2 Hz, 2H), 7.13 (d, *J* = 8.3 Hz, 2H), 4.60 (t, *J* = 7.5 Hz, 2H), 3.29 (t, *J* = 7.5 Hz, 2H), 2.89 (p, *J* = 6.9 Hz, 1H), 1.25 (s, 3H), 1.23 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 148.2, 133.0, 128.6, 127.1, 76.5, 33.9, 33.2, 24.1.

The NMR spectra are in accordance with the literature.

1-Fluoro-3-(2-nitroethyl)benzene (10)



Compound **10** was obtained according to general procedure **GP1** as a colorless oil (78% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

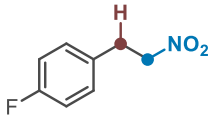
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.33 – 7.27 (m, 1H), 7.02 – 6.90 (m, 3H), 4.61 (t, *J* = 7.3 Hz, 2H), 3.31 (t, *J* = 7.2 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 163.1 (d, *J* = 247.0 Hz), 130.7 (d, *J* = 8.3 Hz), 124.3 (d, *J* = 3.0 Hz), 115.7 (d, *J* = 21.6 Hz), 114.6 (d, *J* = 21.0 Hz), 75.9, 33.1 (d, *J* = 1.9 Hz).

^{19}F-NMR (282 MHz, $CDCl_3$): δ -112.38.

The NMR spectra are in accordance with the literature.

1-Fluoro-4-(2-nitroethyl)benzene (11)

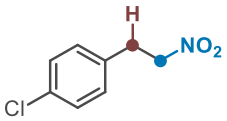


Compound **11** was obtained according to general procedure **GP1** as a colorless oil (81% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.18 (dd, *J* = 8.6, 5.2 Hz, 2H), 7.02 (t, *J* = 8.7 Hz, 2H), 4.59 (t, *J* = 7.2 Hz, 2H), 3.30 (t, *J* = 7.3 Hz, 2H).

The ^{1}H-NMR is in accordance with the literature.

1-Chloro-4-(2-nitroethyl)benzene (12)

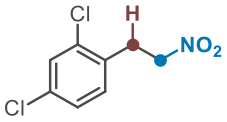


Compound **12** was obtained according to general procedure **GP1** as a colorless oil (76% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.30 (d, *J* = 8.5 Hz, 2H), 7.14 (d, *J* = 8.4 Hz, 2H), 4.59 (t, *J* = 7.2 Hz, 2H), 3.29 (t, *J* = 7.2 Hz, 2H).

The ^{1}H-NMR is in accordance with the literature.

2,4-Dichloro-1-(2-nitroethyl)benzene (13)



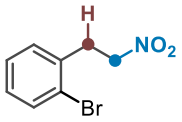
Compound **13** was obtained according to general procedure **GP1** as a pale-yellow oil (73% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.40 (dd, *J* = 1.8, 0.8 Hz, 1H), 7.19 (t, *J* = 1.3 Hz, 2H), 4.62 (t, *J* = 7.1 Hz, 2H), 3.40 (t, *J* = 7.1 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 134.7, 134.3, 132.1, 132.0, 129.8, 127.7, 74.0, 30.9.

The NMR spectra are in accordance with the literature.

1-Bromo-2-(2-nitroethyl)benzene (14)



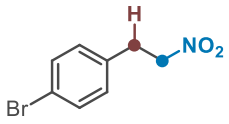
Compound **14** was obtained according to general procedure **GP1** as a colorless oil (65% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.60 – 7.54 (m, 1H), 7.28 – 7.23 (m, 2H), 7.18 – 7.11 (m, 1H), 4.64 (t, *J* = 7.3 Hz, 2H), 3.44 (t, *J* = 7.3 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.1, 133.3, 131.2, 129.4, 128.1, 124.4, 74.4, 33.9.

The NMR spectra are in accordance with the literature.

1-Bromo-4-(2-nitroethyl)benzene (15)

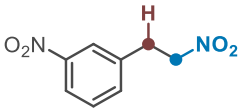


Compound **15** was obtained according to general procedure **GP1** as a white solid (72% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.46 (d, *J* = 8.4 Hz, 2H), 7.09 (d, *J* = 8.4 Hz, 2H), 4.59 (t, *J* = 7.2 Hz, 2H), 3.28 (t, *J* = 7.2 Hz, 2H).

The ^{1}H-NMR is in accordance with the literature.

1-Nitro-3-(2-nitroethyl)benzene (16)

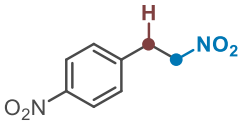


Compound **16** was obtained according to general procedure **GP1** as a white solid (68% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.22 – 8.07 (m, 2H), 7.61 – 7.49 (m, 2H), 4.69 (t, *J* = 7.0 Hz, 2H), 3.44 (t, *J* = 7.0 Hz, 2H).

The ^{1}H-NMR is in accordance with the literature.

1-Nitro-4-(2-nitroethyl)benzene (17)



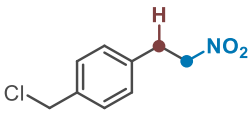
Compound **17** was obtained according to general procedure **GP1** as a yellow oil (61% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.20 (d, *J* = 8.7 Hz, 2H), 7.40 (d, *J* = 8.7 Hz, 2H), 4.68 (t, *J* = 7.0 Hz, 2H), 3.44 (t, *J* = 7.0 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 147.6, 143.3, 129.7, 124.3, 75.4, 33.0.

The NMR spectra are in accordance with the literature.

1-(Chloromethyl)-4-(2-nitroethyl)benzene (18)



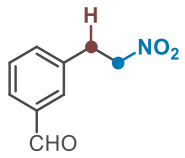
Compound **18** was obtained according to general procedure **GP1** as a colorless oil (73% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.36 (d, *J* = 8.0 Hz, 2H), 7.21 (d, *J* = 7.9 Hz, 2H), 4.61 (t, *J* = 7.3 Hz, 2H), 4.57 (s, 2H), 3.32 (t, *J* = 7.3 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.9, 136.1, 129.3, 129.1, 76.2, 45.9, 33.2.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_9H_{10}ClNO_2$: 199.0400; found 199.0398.

3-(2-Nitroethyl)benzaldehyde (19)



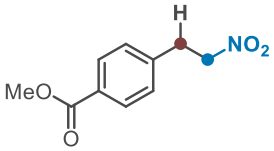
Compound **19** was obtained according to general procedure **GP1** as a colorless oil (72% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 10.01 (s, 1H), 7.84 – 7.70 (m, 2H), 7.56 – 7.43 (m, 2H), 4.67 (t, *J* = 7.2 Hz, 2H), 3.41 (t, *J* = 7.2 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 192.0, 137.1, 137.0, 134.8, 129.9, 129.5, 129.4, 75.9, 33.1.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_9H_9NO_3$: 179.0582; found 179.0536.

Methyl 4-(2-nitroethyl)benzoate (20)



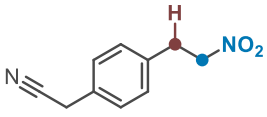
Compound **20** was obtained according to general procedure **GP1** as a colorless oil (68% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.00 (d, *J* = 8.3 Hz, 2H), 7.29 (d, *J* = 8.0 Hz, 2H), 4.64 (t, *J* = 7.3 Hz, 2H), 3.91 (s, 3H), 3.38 (t, *J* = 7.3 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 166.8, 141.0, 130.4, 129.6, 128.8, 75.8, 52.3, 33.4.

The NMR spectra are in accordance with the literature.

2-(4-(2-Nitroethyl)phenyl)acetonitrile (21)



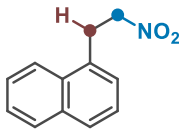
Compound **21** was obtained according to general procedure **GP1** as a yellow oil (73% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.29 (d, *J* = 8.3 Hz, 2H), 7.23 (d, *J* = 8.3 Hz, 2H), 4.61 (t, *J* = 7.2 Hz, 2H), 3.72 (s, 2H), 3.30 (t, *J* = 7.2 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.8, 129.4, 129.3, 128.5, 118.0, 76.1, 32.8, 23.2.

HRMS (ESI) *m/z*, $[M\text{-}O_2]^+$ calcd for $C_{10}H_{10}N_2$: 158.0838; found 158.0840.

1-(2-Nitroethyl)naphthalene (22)



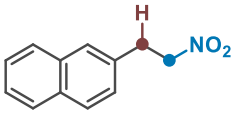
Compound **22** was obtained according to general procedure **GP1** as a colorless oil (69% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.99 (dd, *J* = 8.4, 1.1 Hz, 1H), 7.90 (dd, *J* = 8.2, 1.4 Hz, 1H), 7.85 – 7.76 (m, 1H), 7.62 – 7.50 (m, 2H), 7.48 – 7.33 (m, 2H), 4.80 – 4.68 (m, 2H), 3.86 – 3.77 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 134.1, 131.50 129.3, 128.5, 127.2, 126.9, 126.1, 125.7, 122.7, 75.6, 30.9.

The NMR spectra are in accordance with the literature.

2-(2-Nitroethyl)naphthalene (23)



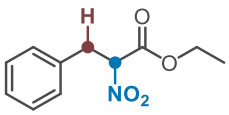
Compound **23** was obtained according to general procedure **GP1** as a colorless oil (70% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.88 – 7.75 (m, 3H), 7.71 – 7.64 (m, 1H), 7.54 – 7.43 (m, 2H), 7.32 (dd, *J* = 8.4, 1.8 Hz, 1H), 4.70 (t, *J* = 7.4 Hz, 2H), 3.49 (t, *J* = 7.4 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 133.6, 133.2, 132.7, 128.9, 127.8, 127.8, 127.5, 126.6, 126.5, 126.2, 76.3, 33.7.

The NMR spectra are in accordance with the literature.

Ethyl 2-nitro-3-phenylpropanoate (24)



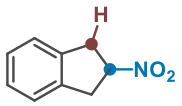
Compound **24** was obtained according to general procedure **GP1** as a colorless solid (65% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.37 – 7.26 (m, 3H), 7.22 (dd, *J* = 7.7, 1.9 Hz, 2H), 5.36 (dd, *J* = 9.3, 6.0 Hz, 1H), 4.27 (q, *J* = 7.2 Hz, 2H), 3.64 – 3.41 (m, 2H), 1.27 (t, *J* = 7.1 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 164.1, 134.2, 129.0, 128.9, 127.8, 89.2, 63.2, 36.3, 13.9.

The NMR spectra are in accordance with the literature.

Ethyl 2-nitro-3-phenylpropanoate (25)



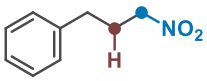
Compound **25** was obtained according to general procedure **GP1** as a colorless oil (65% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.24 (p, *J* = 2.0 Hz, 4H), 5.28 (tt, *J* = 8.0, 4.7 Hz, 1H), 3.69 (dd, *J* = 17.0, 4.7 Hz, 2H), 3.51 (dd, *J* = 17.0, 8.0 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 1 138.7, 127.7, 124.6, 85.1, 38.5.

HRMS (ESI) *m/z*, $[M\text{-}HO_2]^+$ calcd for C_9H_8N: 130.0651; found 130.0654.

(3-Nitropropyl)benzene (26)



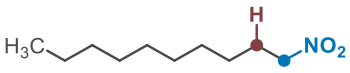
Compound **26** was obtained according to general procedure **GP1** as a colorless oil (15% yield) [83% according to general procedure **GP2**] after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.40 – 7.28 (m, 3H), 7.24 – 7.16 (m, 2H), 4.37 (t, *J* = 6.9 Hz, 2H), 2.73 (t, *J* = 7.5 Hz, 2H), 2.35 (dt, *J* = 8.2, 6.9 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.6, 128.9, 128.6, 126.8, 74.8, 32.4, 29.0.

The NMR spectra are in accordance with the literature.

1-Nitrodecane (27)



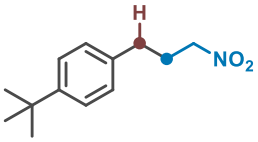
Compound **27** was obtained according to general procedure **GP2** as a colorless oil (68% yield) [91% according to general procedure **GP2**] after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.37 (t, *J* = 7.1 Hz, 2H), 2.00 (p, *J* = 7.1 Hz, 2H), 1.40 – 1.21 (m, 14H), 0.94 – 0.83 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.9, 32.0, 29.6, 29.4, 29.4, 29.0, 27.6, 26.4, 22.8, 14.2.

The NMR spectra are in accordance with the literature.

1-(Tert-butyl)-4-(3-nitropropyl)benzene (3)



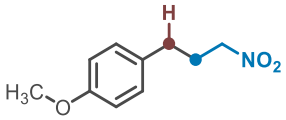
Compound **3** was obtained according to general procedure **GP2** as a colorless oil (87% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.34 (d, *J* = 8.3 Hz, 2H), 7.15 – 7.08 (m, 2H), 4.37 (t, *J* = 6.9 Hz, 2H), 2.70 (t, *J* = 7.4 Hz, 2H), 2.33 (dq, *J* = 8.5, 6.9 Hz, 2H), 1.31 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 149.7, 136.5, 128.3, 125.8, 74.9, 34.6, 31.8, 31.5, 29.0.

HRMS (ESI) *m/z*, $[M]^+$ calcd for $C_{13}H_{19}NO_2$: 221.1410; found 221.1414.

1-Methoxy-4-(3-nitropropyl)benzene (28)



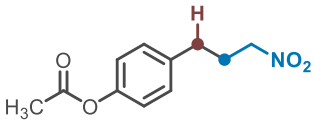
Compound **28** was obtained according to general procedure **GP2** as a colorless oil (85% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.10 (d, *J* = 8.6 Hz, 2H), 6.85 (d, *J* = 8.6 Hz, 2H), 4.35 (t, *J* = 6.9 Hz, 2H), 3.79 (s, 3H), 2.67 (t, *J* = 7.4 Hz, 2H), 2.30 (dt, *J* = 8.1, 6.9 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 58.4, 131.6, 129.5, 114.2, 74.8, 55.4, 31.4, 29.2.

HRMS (ESI) *m/z*, $[C_{10}H_{13}NO_3+Na]^+$ calcd for: 218.0788; found 218.0786.

4-(3-Nitropropyl)phenyl acetate (29)



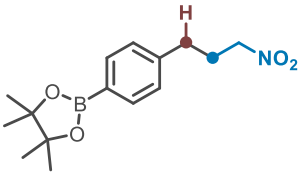
Compound **29** was obtained according to general procedure **GP2** as a colorless oil (84% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.19 (d, *J* = 8.6 Hz, 2H), 7.03 (d, *J* = 8.6 Hz, 2H), 4.37 (t, *J* = 6.8 Hz, 2H), 2.71 (dd, *J* = 8.3, 6.8 Hz, 2H), 2.37 – 2.24 (m, 5H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 169.7, 149.5, 137.2, 129.5, 121.9, 74.7, 31.8, 28.9, 21.2.

HRMS (ESI) *m/z*, $[C_{11}H_{13}NO_4]^+$ calcd for: 223.0839; found 223.0843.

4,4,5,5-Tetramethyl-2-(4-(3-nitropropyl)phenyl)-1,3,2-dioxaborolane (30)



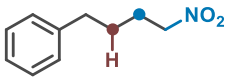
Compound **30** was obtained according to general procedure **GP2** as a colorless oil (90% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.76 (d, *J* = 8.0 Hz, 2H), 7.19 (d, *J* = 8.0 Hz, 2H), 4.35 (t, *J* = 6.9 Hz, 2H), 2.74 (t, *J* = 7.5 Hz, 2H), 2.33 (dq, *J* = 8.5, 6.9 Hz, 2H), 1.34 (s, 12H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 142.9, 135.4, 128.0, 83.9, 74.7, 32.6, 28.8, 25.0.

HRMS (ESI) *m/z*, $[C_{15}H_{22}NBO_4+Na]^+$ calcd for: 314.1534; found 314.1531.

(4-Nitrobutyl)benzene (31)



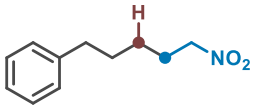
Compound **31** was obtained according to general procedure **GP2** as a colorless oil (93% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.28 (dd, *J* = 8.0, 6.4 Hz, 2H), 7.21 – 7.10 (m, 3H), 4.36 (t, *J* = 7.0 Hz, 2H), 2.66 (t, *J* = 7.5 Hz, 2H), 2.01 (dt, *J* = 8.6, 7.0 Hz, 2H), 1.79 – 1.64 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 141.2, 128.6, 128.5, 126.3, 75.6, 35.1, 28.0, 27.0.

The NMR spectra are in accordance with the literature.

(5-Nitropentyl)benzene (32)



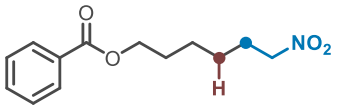
Compound **32** was obtained according to general procedure **GP2** as a colorless oil (90% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.34 – 7.25 (m, 2H), 7.24 – 7.13 (m, 3H), 4.37 (t, *J* = 7.0 Hz, 2H), 2.64 (t, *J* = 7.6 Hz, 2H), 2.10 – 1.96 (m, 2H), 1.69 (dtd, *J* = 8.9, 7.4, 6.2 Hz, 2H), 1.50 – 1.36 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 142.0, 128.5, 128.5, 126.0, 75.7, 35.6, 30.8, 27.4, 26.0.

The NMR spectra are in accordance with the literature.

6-Nitrohexyl benzoate (33)



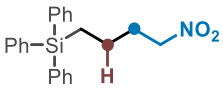
Compound **33** was obtained according to general procedure **GP2** as a colorless oil (87% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.07 – 7.98 (m, 2H), 7.60 – 7.50 (m, 1H), 7.44 (ddt, *J* = 8.3, 6.8, 1.2 Hz, 2H), 4.38 (t, *J* = 7.0 Hz, 2H), 4.31 (t, *J* = 6.5 Hz, 2H), 2.03 (dq, *J* = 8.4, 7.0 Hz, 2H), 1.83 – 1.73 (m, 2H), 1.56 – 1.38 (m, 4H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 166.7, 133.0, 130.4, 129.6, 128.5, 75.6, 64.7, 28.5, 27.3, 26.1, 25.5.

HRMS (ESI) *m/z*, $[C_{13}H_{17}NO_4\text{-}HNOH]^+$ calcd for: 219.1016; found 219.1019.

(4-Nitrobutyl)triphenylsilane (34)

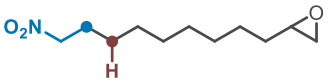


Compound **34** was obtained according to general procedure **GP2** as a colorless oil (67% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.55 – 7.49 (m, 6H), 7.44 – 7.34 (m, 9H), 4.36 (t, *J* = 7.1 Hz, 2H), 2.08 (p, *J* = 7.1 Hz, 2H), 1.59 (tdd, *J* = 8.4, 6.8, 4.1 Hz, 2H), 1.46 – 1.37 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.7, 134.7, 129.8, 128.2, 128.1, 75.3, 31.2, 21.1, 13.0.

2-(9-Nitrononyl)oxirane (35)

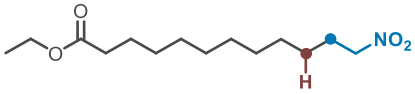


Compound **35** was obtained according to general procedure **GP2** as a colorless oil (74% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.37 (t, *J* = 7.0 Hz, 2H), 2.90 (tdd, *J* = 5.0, 4.0, 2.7 Hz, 1H), 2.74 (dd, *J* = 5.0, 4.0 Hz, 1H), 2.46 (dd, *J* = 5.0, 2.7 Hz, 1H), 2.00 (p, *J* = 7.1 Hz, 2H), 1.54 – 1.27 (m, 14H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.9, 52.5, 47.2, 32.6, 29.5, 29.3, 28.9, 27.5, 26.3, 26.1.

Ethyl 12-nitrododecanoate (36)



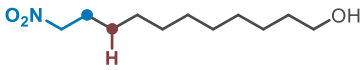
Compound **36** was obtained according to general procedure **GP2** as a colorless oil (89% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.36 (t, *J* = 7.1 Hz, 2H), 4.11 (q, *J* = 7.1 Hz, 2H), 2.27 (t, *J* = 7.5 Hz, 2H), 1.99 (p, *J* = 7.1 Hz, 2H), 1.66 – 1.55 (m, 2H), 1.33 – 1.22 (m, 17H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 174.0, 75.9, 60.3, 34.5, 29.5, 29.5, 29.3, 29.2, 28.9, 27.5, 26.3, 25.1, 14.4.

HRMS (ESI) *m/z*, $[C_{14}H_{27}NO_4+Na]^+$ calcd for: 296.1832; found 296.1825.

11-Nitroundecan-1-ol (37)

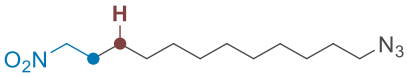


Compound **37** was obtained according to general procedure **GP2** as a colorless oil (68% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.37 (t, *J* = 7.1 Hz, 2H), 3.63 (t, *J* = 6.6 Hz, 2H), 2.05 – 1.94 (m, 2H), 1.56 (t, *J* = 6.8 Hz, 2H), 1.40 – 1.24 (m, 15H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.9, 63.2, 32.9, 29.6, 29.5, 29.5, 29.3, 28.9, 27.5, 26.3, 25.8.

1-Azido-12-nitrododecane (38)



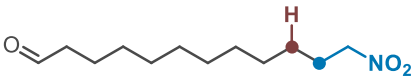
Compound **38** was obtained according to general procedure **GP2** as a colorless oil (80% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.36 (t, *J* = 7.1 Hz, 2H), 3.24 (t, *J* = 6.9 Hz, 2H), 1.99 (p, *J* = 7.0 Hz, 2H), 1.68 – 1.49 (m, 2H), 1.30 (d, *J* = 22.9 Hz, 15H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.8, 51.6, 29.5, 29.5, 29.3, 29.2, 28.9, 28.9, 27.5, 26.8, 26.3.

HRMS (ESI) *m/z*, $[C_{12}H_{24}N_4O_2-HN_2]^+$ calcd for: 227.1754; found 227.1758.

1-Azido-11-nitroundecane (39)



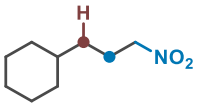
Compound **38** was obtained according to general procedure **GP2** as a colorless oil (53% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 9.76 (d, *J* = 1.9 Hz, 1H), 4.37 (t, *J* = 7.1 Hz, 2H), 2.42 (td, *J* = 7.3, 1.9 Hz, 2H), 2.00 (p, *J* = 7.1 Hz, 2H), 1.63 (t, *J* = 7.3 Hz, 2H), 1.33 – 1.18 (m, 14H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 203.0, 75.9, 44.1, 29.9, 29.5, 29.4, 29.3, 29.3, 28.9, 27.5, 26.4, 22.2.

HRMS (ESI) *m/z*, $[C_{12}H_{23}NO_3-H_2O_2]^+$ calcd for: 194.1539; found 194.1539.

(3-Nitropropyl)cyclohexane (40)



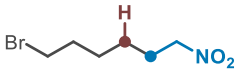
Compound **40** was obtained according to general procedure **GP2** as a colorless oil (79% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.35 (t, *J* = 7.1 Hz, 2H), 2.01 (dtd, *J* = 9.0, 7.1, 3.6 Hz, 2H), 1.74 – 1.63 (m, 5H), 1.28 – 1.16 (m, 6H), 0.92 (dd, *J* = 16.9, 6.5 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 76.2, 37.2, 33.9, 33.2, 26.6, 26.3, 25.1.

HRMS (ESI) *m/z*, $[C_9H_{17}NO_2]^+$ calcd for: 171.1259; found 171.1257.

1-Bromo-6-nitrohexane (41)

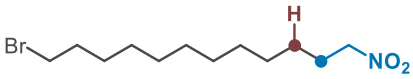


Compound **41** was obtained according to general procedure **GP2** as a colorless oil (82% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.39 (t, *J* = 7.0 Hz, 2H), 3.40 (t, *J* = 6.6 Hz, 2H), 2.08 – 1.96 (m, 2H), 1.87 (dq, *J* = 8.1, 6.6 Hz, 2H), 1.54 – 1.34 (m, 4H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.6, 33.5, 32.4, 27.5, 27.3, 25.6.

1-Bromo-12-nitrododecane (42)



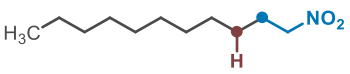
Compound **42** was obtained according to general procedure **GP2** as a white solid (89% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.36 (t, *J* = 7.1 Hz, 2H), 3.39 (t, *J* = 6.9 Hz, 2H), 1.98 (p, *J* = 7.1 Hz, 2H), 1.83 (p, *J* = 6.9 Hz, 2H), 1.43 – 1.23 (m, 16H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.8, 34.1, 32.9, 29.5, 29.5, 29.3, 28.9, 28.8, 28.2, 27.5, 26.3.

HRMS (ESI) *m/z*, $[C_{12}H_{24}BrNO_2+Na]^+$ calcd for: 316.0883; found 316.0878.

1-Nitroundecane (43)

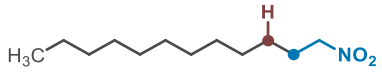


Compound **27** was obtained according to general procedure **GP2** as a colorless oil (90% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.37 (t, *J* = 7.1 Hz, 2H), 2.06 – 1.93 (m, 2H), 1.37 – 1.21 (m, 16H), 0.91 – 0.83 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.9, 32.0, 29.7, 29.6, 29.4, 29.4, 29.0, 27.6, 26.4, 22.8, 14.2.

1-Nitrododecane (44)

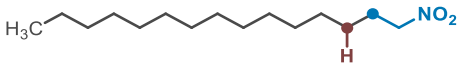


Compound **44** was obtained according to general procedure **GP2** as a colorless oil (93% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.37 (t, *J* = 7.1 Hz, 2H), 2.00 (p, *J* = 7.1 Hz, 2H), 1.36 – 1.22 (m, 18H), 0.92 – 0.83 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.9, 32.0, 29.7, 29.7, 29.6, 29.5, 29.4, 29.0, 27.6, 26.4, 22.8, 14.2.

1-Nitropentadecane (45)

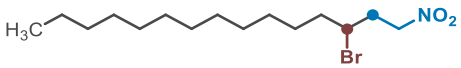


Compound **45** was obtained according to general procedure **GP2** as a colorless oil (85% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.37 (t, *J* = 7.1 Hz, 2H), 2.00 (p, *J* = 7.1 Hz, 2H), 1.26 (s, 24H), 0.92 – 0.84 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.9, 32.1, 29.8, 29.8, 29.8, 29.7, 29.6, 29.5, 29.4, 29.0, 27.6, 26.4, 22.8, 14.3.

3-Bromo-1-nitropentadecane (45a)



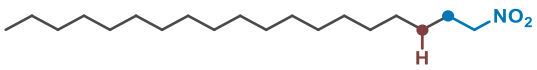
Compound **47** was obtained according to general procedure **GP2** as a white solid (10% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.62 (ddd, *J* = 7.3, 6.0, 3.1 Hz, 2H), 4.04 (dddd, *J* = 10.5, 8.2, 5.5, 3.0 Hz, 1H), 2.61 (dtd, *J* = 15.1, 7.6, 3.1 Hz, 1H), 2.34 (dddd, *J* = 15.3, 10.2, 6.5, 5.6 Hz, 1H), 1.92 – 1.77 (m, 2H), 1.49 – 1.38 (m, 1H), 1.26 (s, 19H), 0.91 – 0.83 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 73.8, 52.8, 39.3, 36.2, 32.1, 29.8, 29.8, 29.7, 29.7, 29.5, 29.5, 29.0, 27.5, 22.8, 14.3.

HRMS (ESI) *m/z*, $[C_{15}H_{30}BrNO_2\text{-}OH]^+$ calcd for: 318.1427; found 318.1434.

1-Nitrononadecane (46)



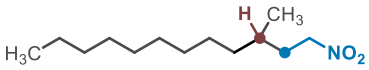
Compound **46** was obtained according to general procedure **GP2** as a white solid (88% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.37 (t, *J* = 7.1 Hz, 2H), 2.01 (dd, *J* = 13.0, 5.9 Hz, 2H), 1.25 (s, 32H), 0.91 – 0.84 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.9, 32.1, 29.8, 29.8, 29.8, 29.7, 29.6, 29.5, 29.4, 29.0, 27.6, 26.4, 22.8, 14.2.

HRMS (ESI) *m/z*, $[C_{19}H_{38}NO_2]^+$ calcd for: 312.2897; found 312.2900.

3-Methyl-1-nitrododecane (47)



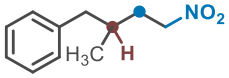
Compound **47** was obtained according to general procedure **GP2** as a colorless oil (83% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.44 – 4.35 (m, 2H), 2.06 (dtd, *J* = 15.4, 7.7, 5.5 Hz, 1H), 1.87 – 1.71 (m, 1H), 1.57 – 1.45 (m, 1H), 1.26 (s, 16H), 0.89 (dd, *J* = 16.5, 6.8 Hz, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 74.3, 36.6, 34.5, 32.0, 30.5, 29.9, 29.7, 29.7, 29.5, 26.9, 22.8, 19.2, 14.2.

HRMS (ESI) *m/z*, $[C_{13}H_{27}NO_2]^+$ calcd for: 229.2042; found 229.2040.

(2-Methyl-4-nitrobutyl)benzene (48)



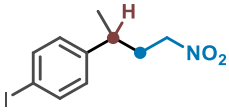
Compound **48** was obtained according to general procedure **GP2** as a colorless oil (84% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.30 (ddd, *J* = 8.2, 6.5, 1.2 Hz, 2H), 7.25 – 7.17 (m, 1H), 7.16 – 7.11 (m, 2H), 4.46 – 4.33 (m, 2H), 2.64 (dd, *J* = 13.5, 6.1 Hz, 1H), 2.50 (dd, *J* = 13.5, 7.2 Hz, 1H), 2.12 (dt, *J* = 8.6, 7.6 Hz, 1H), 1.91 – 1.74 (m, 2H), 0.94 (d, *J* = 6.3 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.9, 129.2, 128.6, 126.4, 74.2, 43.4, 34.0, 32.6, 19.2.

HRMS (ESI) *m/z*, $[C_{11}H_{15}O_2N\text{-}H_3O]^+$ calcd for: 174.0913; found 174.0916.

1-Iodo-4-(4-nitrobutan-2-yl)benzene (49)



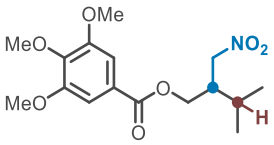
Compound **49** was obtained according to general procedure **GP2** as a colorless oil (81% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.65 (d, *J* = 8.4 Hz, 2H), 6.94 (d, *J* = 8.2 Hz, 2H), 4.23 (ddd, *J* = 7.8, 6.7, 1.4 Hz, 2H), 2.85 – 2.68 (m, 1H), 2.34 (dtd, *J* = 14.3, 7.6, 5.6 Hz, 1H), 2.17 (ddt, *J* = 14.2, 9.5, 6.7 Hz, 1H), 1.30 (d, *J* = 6.9 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 144.3, 138.1, 129.1, 92.1, 73.9, 36.9, 35.4, 22.1.

HRMS (ESI) *m/z*, $[C_{10}H_{12}O_2NI+Na]^+$ calcd for: 327.9805; found 327.9802.

3-Methyl-2-(nitromethyl)butyl 3,4,5-trimethoxybenzoate (50)



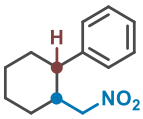
Compound **50** was obtained according to general procedure **GP2** as a light-yellow oil (66% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.21 (s, 2H), 4.56 – 4.42 (m, 3H), 4.24 (dd, *J* = 11.4, 9.0 Hz, 1H), 3.90 (d, *J* = 3.9 Hz, 9H), 2.79 – 2.63 (m, 1H), 1.92 (pd, *J* = 6.9, 5.2 Hz, 1H), 1.05 (dd, *J* = 6.9, 2.9 Hz, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 166.1, 153.1, 142.6, 124.6, 106.9, 65.0, 61.0, 56.4, 43.0, 28.2, 19.8, 19.6.

HRMS (ESI) *m/z*, $[C_{16}H_{23}O_7N+Na]^+$ calcd for: 364.1367; found 364.1364.

(2-(Nitromethyl)cyclohexyl)benzene (51)



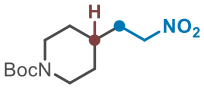
Compound **51** was obtained according to general procedure **GP2** as a colorless oil (82% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.36 – 7.30 (m, 2H), 7.27 – 7.16 (m, 3H), 4.48 (t, *J* = 11.8 Hz, 1H), 3.94 (ddd, *J* = 11.8, 4.2, 0.7 Hz, 1H), 3.05 (dt, *J* = 12.3, 4.2 Hz, 1H), 2.86 (dt, *J* = 11.8, 4.2 Hz, 1H), 2.00 – 1.44 (m, 8H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 143.0, 128.8, 127.3, 126.9, 74.6, 44.4, 39.6, 28.0, 26.1, 25.7, 20.3.

HRMS (ESI) *m/z*, $[C_{13}H_{17}O_2N+Na]^+$ calcd for: 242.1152; found 242.1148.

Tert-butyl 4-(2-nitroethyl)piperidine-1-carboxylate (52)

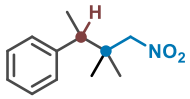


Compound **52** was obtained according to general procedure **GP2** as a white solid (79% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.42 (t, *J* = 7.1 Hz, 2H), 4.23 – 3.97 (m, 2H), 2.66 (t, *J* = 12.8 Hz, 2H), 1.95 (q, *J* = 7.0 Hz, 2H), 1.71 – 1.57 (m, 2H), 1.43 (s, 10H), 1.15 (dtd, *J* = 24.5, 11.7, 5.0 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 154.8, 79.6, 73.4, 43.7, 33.8, 33.4, 31.6, 28.5.

(3,3-dimethyl-4-nitrobutan-2-yl)benzene (53)



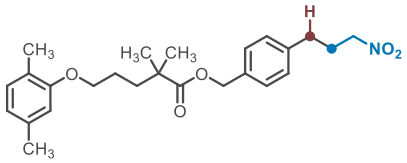
Compound **43** was obtained according to general procedure **GP2** as a light-yellow oil (66% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.29 (dd, *J* = 6.8, 1.4 Hz, 2H), 7.20 – 7.16 (m, 2H), 4.23 (d, *J* = 2.6 Hz, 2H), 2.87 (q, *J* = 7.2 Hz, 1H), 1.34 (d, *J* = 7.2 Hz, 3H), 1.10 (s, 3H), 1.02 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 142.4, 129.2, 128.3, 127.0, 85.2, 46.7, 38.7, 23.2, 22.8, 15.6.

HRMS (ESI) *m/z*, $[C_{12}H_{17}NO_2]^+$ calcd for: 207.1259; found 207.1256.

4-(3-nitropropyl)benzyl 5-(2,5-dimethylphenoxy)-2,2-dimethylpentanoate (54)



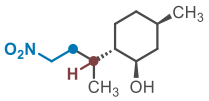
Compound **54** was obtained according to general procedure **GP2** as a colorless oil (76% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.29 (d, *J* = 8.3 Hz, 2H), 7.16 (d, *J* = 8.1 Hz, 2H), 7.00 (d, *J* = 7.5 Hz, 1H), 6.66 (d, *J* = 7.5 Hz, 1H), 6.59 (s, 1H), 5.09 (s, 2H), 4.35 (t, *J* = 6.9 Hz, 2H), 3.88 (t, *J* = 3.5 Hz, 2H), 2.71 (t, *J* = 7.5 Hz, 2H), 2.36 – 2.26 (m, 5H), 2.15 (s, 3H), 1.75 – 1.68 (m, 4H), 1.25 (s, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 177.7, 157.1, 139.5, 136.6, 134.9, 130.4, 128.7, 128.5, 123.7, 120.8, 112.1, 74.8, 68.0, 66.0, 42.3, 37.2, 32.1, 28.9, 25.3, 21.5, 15.9.

HRMS (ESI) *m/z*, $[C_{25}H_{33}NO_5+Na]^+$ calcd for: 450.2251; found 450.2242.

(1R,2S,5R)-5-methyl-2-(4-nitrobutan-2-yl)cyclohexan-1-ol (55)



Compound **55** was obtained according to general procedure **GP2** as a colorless oil (82% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

isomer a

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.51 – 4.31 (m, 2H), 3.47 (td, *J* = 10.4, 4.3 Hz, 1H), 2.23 (dtd, *J* = 13.7, 7.9, 3.6 Hz, 1H), 2.05 – 1.86 (m, 2H), 1.81 – 1.57 (m, 3H), 1.56 – 1.34 (m, 2H), 1.29 – 1.12 (m, 1H), 1.06 – 0.81 (m, 9H).

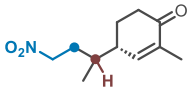
^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.0, 71.0, 49.8, 45.3, 34.6, 31.7, 30.1, 29.9, 25.2, 22.2, 17.1.

isomer b

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.51 – 4.33 (m, 2H), 3.42 (td, *J* = 10.3, 4.3 Hz, 1H), 2.22 – 1.88 (m, 4H), 1.68 (dq, *J* = 12.4, 3.0 Hz, 1H), 1.56 (dq, *J* = 12.6, 2.9 Hz, 1H), 1.50 – 1.35 (m, 1H), 1.33 – 1.23 (m, 1H), 1.23 – 1.10 (m, 1H), 1.08 – 1.01 (m, 1H), 0.99 – 0.80 (m, 8H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 74.8, 71.0, 48.7, 45.3, 34.4, 32.9, 31.7, 28.8, 23.5, 22.2, 13.8.

(4S)-2-methyl-4-(4-nitrobutan-2-yl)cyclohex-2-en-1-one (56)

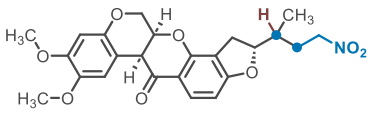


Compound **47** was obtained according to general procedure **GP2** as a colorless oil (87% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 6.73 (dd, *J* = 5.4, 3.2 Hz, 1H), 4.41 (td, *J* = 6.7, 3.7 Hz, 2H), 2.54 – 2.42 (m, 1H), 2.39 – 1.91 (m, 5H), 1.75 (dt, *J* = 2.6, 1.4 Hz, 4H), 1.62 – 1.45 (m, 1H), 0.94 (dd, *J* = 6.8, 2.3 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 199.7, 199.6, 144.7, 144.6, 135.7, 135.7, 74.0, 74.0, 42.0, 40.8, 40.3, 40.2, 34.3, 34.2, 31.4, 31.2, 30.2, 28.7, 15.7, 15.6, 15.6.

(2R,6aS,12aS)-8,9-dimethoxy-2-(4-nitrobutan-2-yl)-1,2,12,12a-tetrahydrochromeno[3,4-b]furo[2,3-h]chromen-6(6aH)-one (57)



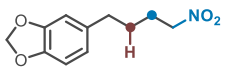
Compound **57** was obtained according to general procedure **GP2** as an off-white solid (57% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.86 – 7.78 (m, 1H), 6.76 (d, *J* = 1.0 Hz, 1H), 6.49 – 6.42 (m, 2H), 4.96 – 4.88 (m, 1H), 4.78 (td, *J* = 9.1, 4.3 Hz, 1H), 4.62 (dd, *J* = 12.1, 3.1 Hz, 1H), 4.56 – 4.44 (m, 2H), 4.23 – 4.16 (m, 1H), 3.85 (d, *J* = 4.1 Hz, 1H), 3.81 (s, 3H), 3.76 (s, 3H), 3.23 (dt, *J* = 16.6, 8.9 Hz, 1H), 2.95 – 2.80 (m, 1H), 2.42 – 2.22 (m, 1H), 1.93 (dd, *J* = 10.8, 4.7 Hz, 2H), 1.03 (dd, *J* = 6.5, 5.4 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 189.2, 167.3, 158.1, 149.6, 147.5, 144.0, 130.2, 113.4, 112.9, 110.5, 105.0, 104.9, 104.9, 101.1, 89.5, 88.1, 73.9, 73.7, 72.3, 66.3, 56.4, 56.0, 44.7, 36.1, 35.3, 30.6, 30.5, 30.1, 29.3, 15.4, 14.3, 13.8.

HRMS (EI) *m/z*, [$C_{24}H_{25}NO_8$] calcd for: 455.1575; found 455.1574.

5-(4-nitrobutyl)benzo[d][1,3]dioxole (58)



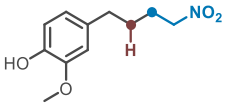
Compound **58** was obtained according to general procedure **GP2** as a colorless oil (87% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 6.73 (d, *J* = 7.8 Hz, 1H), 6.66 – 6.56 (m, 2H), 5.92 (s, 2H), 4.37 (t, *J* = 7.0 Hz, 2H), 2.59 (t, *J* = 7.5 Hz, 2H), 2.01 (dt, *J* = 15.3, 7.1 Hz, 2H), 1.73 – 1.61 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 147.8, 146.0, 135.0, 121.2, 108.8, 108.3, 101.0, 75.6, 34.8, 28.2, 26.8.

HRMS (ESI) *m/z*, $[C_{11}H_{13}NO_4]^+$ calcd for: 223.0845; found 223.0842.

2-methoxy-4-(4-nitrobutyl)phenol (59)



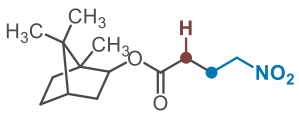
Compound **59** was obtained according to general procedure **GP2** as a colorless oil (75% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 6.83 (d, *J* = 8.5 Hz, 1H), 6.68 – 6.62 (m, 2H), 5.50 (s, 1H), 4.38 (t, *J* = 6.9 Hz, 2H), 3.88 (s, 3H), 2.60 (t, *J* = 7.5 Hz, 2H), 2.08 – 1.97 (m, 2H), 1.74 – 1.61 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 146.6, 144.1, 133.1, 121.1, 114.4, 111.0, 75.7, 56.0, 34.8, 28.3, 26.9.

HRMS (ESI) *m/z*, [$C_{11}H_{15}NO_4$] calcd for: 225.1001; found 225.1000.

(1S,4S)-1,7,7-trimethylbicyclo[2.2.1]heptan-2-yl 4-nitrobutanoate (60)



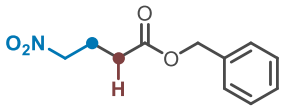
Compound **60** was obtained according to general procedure **GP2** as a colorless oil (57% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.69 (dd, *J* = 7.7, 3.5 Hz, 1H), 4.46 (t, *J* = 6.7 Hz, 2H), 2.48 – 2.39 (m, 2H), 2.36 – 2.24 (m, 2H), 1.82 – 1.66 (m, 4H), 1.58 – 1.49 (m, 1H), 1.17 – 1.04 (m, 2H), 0.95 (s, 3H), 0.83 (d, *J* = 1.3 Hz, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 171.4, 81.8, 74.6, 48.9, 47.1, 45.1, 38.9, 33.8, 31.0, 27.1, 22.6, 20.2, 20.0, 11.6.

HRMS (ESI) *m/z*, [$C_{14}H_{23}NO_4$-CH_3] calcd for: 254.1387; found 254.1392.

benzyl 4-nitrobutanoate (61)

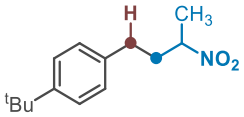


Compound **61** was obtained according to general procedure **GP2** as a colorless oil (53% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 – 7.29 (m, 5H), 5.14 (s, 2H), 4.47 (t, *J* = 6.7 Hz, 2H), 2.52 (td, *J* = 7.0, 0.8 Hz, 2H), 2.33 (pd, *J* = 7.0, 0.8 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 150.9, 133.3, 127.5, 127.3, 81.0, 57.0, 34.0, 23.9.

1-(tert-butyl)-4-(3-nitrobutyl)benzene (62)



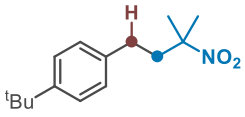
Compound **52** was obtained according to general procedure **GP2** as a colorless oil (80% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.33 (d, *J* = 8.3 Hz, 2H), 7.14 – 7.08 (m, 2H), 4.62 – 4.48 (m, 1H), 2.68 – 2.54 (m, 2H), 2.43 – 2.28 (m, 1H), 1.98 (dddd, *J* = 14.2, 9.1, 7.1, 5.1 Hz, 1H), 1.55 (d, *J* = 6.6 Hz, 3H), 1.31 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 149.5, 136.9, 128.2, 125.7, 82.9, 34.6, 31.5, 31.5, 31.4, 19.5.

HRMS (ESI) *m/z*, $[C_{14}H_{21}NO_2]^+$ calcd for: 235.1567; found 235.1570.

1-(tert-butyl)-4-(3-methyl-3-nitrobutyl)benzene (63)

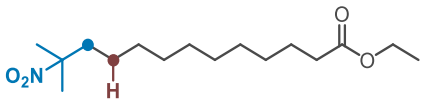


Compound **63** was obtained according to general procedure **GP2** as a yellow solid (87% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.32 (d, *J* = 8.3 Hz, 2H), 7.11 (d, *J* = 8.3 Hz, 2H), 2.60 – 2.49 (m, 2H), 2.25 – 2.15 (m, 2H), 1.65 (s, 6H), 1.31 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 149.3, 137.5, 128.1, 125.6, 88.2, 43.0, 34.5, 31.5, 31.5, 30.1, 26.0.

ethyl 12-methyl-12-nitrotridecanoate (64)



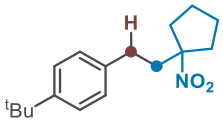
Compound **64** was obtained according to general procedure **GP2** as a light-yellow liquid (89% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.12 (q, J = 7.1 Hz, 2H), 3.93 (ddt, J = 8.3, 6.8, 5.0 Hz, 1H), 2.62 – 2.52 (m, 2H), 2.28 (t, J = 7.5 Hz, 2H), 1.88 – 1.70 (m, 2H), 1.71 – 1.68 (m, 3H), 1.65 (s, 3H), 1.60 (d, J = 7.3 Hz, 2H), 1.37 – 1.21 (m, 14H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 174.0, 87.6, 60.3, 50.2, 49.2, 40.3, 34.5, 29.3, 29.3, 29.2, 28.9, 27.4, 27.2, 25.9, 25.1, 14.4.

HRMS (ESI) *m/z*, $[C_{16}H_{29}O_4N+Na]^+$ calcd for: 322.1989; found 322.1984.

1-(tert-butyl)-4-(2-(1-nitrocyclopentyl)ethyl)benzene (65)



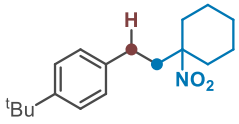
Compound **65** was obtained according to general procedure **GP2** as a light-yellow liquid (78% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.32 (d, *J* = 8.3 Hz, 2H), 7.10 (d, *J* = 8.3 Hz, 2H), 2.68 – 2.59 (m, 2H), 2.58 – 2.49 (m, 2H), 2.31 – 2.23 (m, 2H), 1.88 – 1.73 (m, 6H), 1.31 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 149.3, 137.6, 128.1, 125.6, 100.0, 41.8, 37.4, 34.5, 31.5, 30.8, 24.3.

HRMS (ESI) *m/z*, $[C_{17}H_{25}NO_2+Na]^+$ calcd for: 298.1778; found 298.1772.

1-(tert-butyl)-4-(2-(1-nitrocyclohexyl)ethyl)benzene (66)



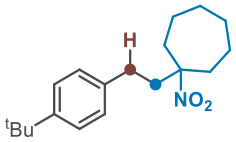
Compound **66** was obtained according to general procedure **GP2** as a light-yellow liquid (76% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.31 (d, *J* = 8.3 Hz, 2H), 7.11 – 7.04 (m, 2H), 2.57 – 2.42 (m, 4H), 2.16 – 2.04 (m, 2H), 1.67 (ddd, *J* = 24.3, 11.0, 4.1 Hz, 4H), 1.52 – 1.41 (m, 2H), 1.31 (d, *J* = 3.2 Hz, 11H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 149.2, 137.6, 128.1, 125.6, 91.5, 34.5, 34.3, 31.5, 29.2, 25.0, 22.5.

HRMS (ESI) *m/z*, $[C_{18}H_{27}NO_2+Na]^+$ calcd for: 312.1934; found 312.1932.

1-(4-(Tert-butyl)phenethyl)-1-nitrocycloheptane (67)



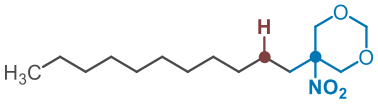
Compound **67** was obtained according to general procedure **GP2** as a light-yellow liquid (73% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.31 (d, *J* = 8.3 Hz, 2H), 7.09 (d, *J* = 8.3 Hz, 2H), 2.60 – 2.42 (m, 4H), 2.25 – 2.10 (m, 2H), 1.92 (dd, *J* = 14.9, 8.4 Hz, 2H), 1.60 (d, *J* = 3.0 Hz, 8H), 1.30 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 149.3, 137.7, 128.1, 125.6, 95.9, 43.6, 37.4, 34.5, 31.5, 29.9, 29.7, 23.3.

HRMS (ESI) *m/z*, $[C_{19}H_{29}NO_2+Na]^+$ calcd for: 326.2091; found 326.2087.

5-Nitro-5-undecyl-1,3-dioxane (68)



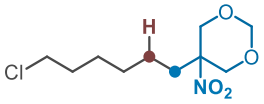
Compound **68** was obtained according to general procedure **GP2** as a light-yellow liquid (81% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.98 – 4.49 (m, 4H), 3.96 (dd, *J* = 24.4, 12.5 Hz, 2H), 3.88 – 3.75 (m, 1H), 2.45 (d, *J* = 6.0 Hz, 2H), 1.85 – 1.61 (m, 2H), 1.24 (d, *J* = 1.9 Hz, 15H), 0.90 – 0.82 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 94.0, 85.2, 70.8, 70.5, 47.6, 42.8, 40.3, 31.9, 29.5, 29.5, 29.3, 28.8, 27.2, 22.7, 14.2.

HRMS (ESI) *m/z*, $[C_{15}H_{29}NO_4+Na]^+$ calcd for: 310.1989; found 310.1987.

5-(6-Chlorohexyl)-5-nitro-1,3-dioxane (69)



Compound **69** was obtained according to general procedure **GP2** as a light-yellow liquid (84% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

Isomer a:

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.95 (d, *J* = 6.1 Hz, 1H), 4.72 (d, *J* = 6.2 Hz, 1H), 4.65 (d, *J* = 12.2 Hz, 2H), 3.82 (d, *J* = 1.4 Hz, 1H), 3.79 (d, *J* = 1.4 Hz, 1H), 3.51 (t, *J* = 6.6 Hz, 2H), 1.74 (ddd, *J* = 12.7, 10.2, 6.4 Hz, 4H), 1.50 – 1.34 (m, 2H), 1.35 – 1.20 (m, 4H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 94.0, 84.9, 70.8, 70.5, 47.0, 44.6, 42.7, 39.5, 31.7, 24.6.

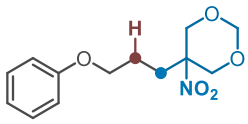
Isomer b:

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.91 (d, *J* = 6.1 Hz, 1H), 4.85 – 4.74 (m, 2H), 4.53 (dd, *J* = 12.4, 2.3 Hz, 1H), 4.08 – 3.81 (m, 3H), 3.52 (t, *J* = 6.4 Hz, 2H), 2.56 – 2.42 (m, 2H), 1.94 – 1.42 (m, 7H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 94.0, 84.9, 70.7, 70.5, 47.0, 44.6, 42.7, 39.4, 31.7, 24.6.

HRMS (ESI) *m/z*, $[C_{10}H_{18}NClO_4+Na]^+$ calcd for: 274.0817; found 274.0816.

5-Nitro-5-(3-phenoxypropyl)-1,3-dioxane (70)



Compound **70** was obtained according to general procedure **GP2** as a light-yellow liquid (88% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

Isomer a:

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.35 – 7.27 (m, 2H), 7.04 – 6.96 (m, 1H), 6.88 (dd, *J* = 8.8, 1.0 Hz, 2H), 4.95 (d, *J* = 6.2 Hz, 1H), 4.88 – 4.75 (m, 2H), 4.60 (dd, *J* = 12.4, 2.4 Hz, 1H), 4.22 (dd, *J* = 9.3, 4.1 Hz, 1H), 4.17 – 3.91 (m, 4H), 2.85 (dd, *J* = 16.2, 2.6 Hz, 1H), 2.49 (dd, *J* = 16.2, 8.9 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 157.7, 129.8, 122.1, 114.9, 94.1, 84.7, 71.7, 70.7, 70.6, 41.7, 39.3.

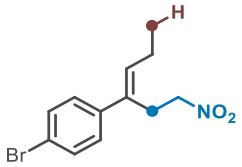
Isomer b:

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.32 – 7.24 (m, 2H), 6.99 – 6.92 (m, 1H), 6.89 – 6.82 (m, 2H), 4.98 (d, *J* = 6.1 Hz, 1H), 4.77 – 4.66 (m, 3H), 3.92 (t, *J* = 5.8 Hz, 2H), 3.87 (d, *J* = 1.2 Hz, 1H), 3.83 (d, *J* = 1.2 Hz, 1H), 2.03 – 1.93 (m, 2H), 1.79 – 1.66 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 158.6, 129.7, 121.2, 114.5, 94.1, 85.7, 70.7, 66.6, 30.7, 22.9.

HRMS (ESI) *m/z*, $[C_{13}H_{17}NO_5+Na]^+$ calcd for: 290.0999; found 290.0990.

(*E*)-1-Bromo-4-(1-nitrohex-3-en-3-yl)benzene (73)



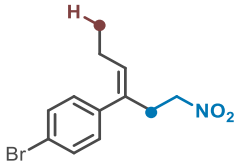
Compound **73** was obtained according to general procedure **GP2** as a colorless oil (78% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.49 (d, *J* = 8.4 Hz, 2H), 7.03 (d, *J* = 8.4 Hz, 2H), 5.63 – 5.54 (m, 1H), 4.30 (t, *J* = 7.0 Hz, 2H), 3.03 – 2.94 (m, 2H), 1.98 – 1.84 (m, 2H), 0.91 (t, *J* = 7.5 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 137.8, 134.4, 133.2, 131.9, 130.4, 100.2, 74.3, 37.1, 22.5, 14.3.

HRMS (ESI) *m/z*, $[C_{12}H_{14}NBrO_2]^+$ calcd for: 283.0202; found 28.0206.

(*Z*)-1-Bromo-4-(1-nitrohex-3-en-3-yl)benzene

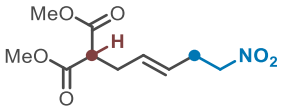


^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.46 (d, *J* = 8.6 Hz, 2H), 7.17 (d, *J* = 8.5 Hz, 2H), 5.80 (t, *J* = 7.4 Hz, 1H), 4.30 (t, *J* = 7.5 Hz, 2H), 3.20 (t, *J* = 7.4 Hz, 2H), 2.22 (p, *J* = 7.5 Hz, 2H), 1.06 (t, *J* = 7.5 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 140.1, 135.9, 132.4, 131.9, 128.2, 121.5, 73.9, 28.0, 22.1, 14.3.

HRMS (ESI) *m/z*, $[C_{12}H_{14}NBrO_2]^+$ calcd for: 283.0202; found 28.0206.

Dimethyl (E)-2-(5-nitropent-2-en-1-yl)malonate (75)



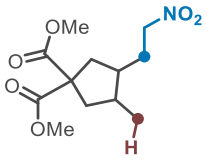
Compound **75** was obtained according to general procedure **GP2** as a colorless oil (67% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 5.66 – 5.44 (m, 2H), 4.37 (t, *J* = 6.9 Hz, 2H), 3.73 (s, 6H), 3.41 (t, *J* = 7.5 Hz, 1H), 2.72 – 2.55 (m, 4H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 169.3, 130.5, 126.9, 75.1, 52.7, 51.6, 31.8, 30.4.

HRMS (ESI) *m/z*, $[C_{10}H_{15}NO_6+Na]^+$ calcd for: 268.0792; found 268.0786.

Dimethyl 3-methyl-4-(2-nitroethyl)cyclopentane-1,1-dicarboxylate (77)



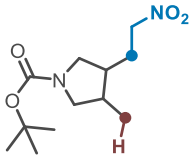
Compound **77** was obtained according to general procedure **GP2** as a colorless oil (80% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.44 – 4.34 (m, 2H), 3.71 (s, 3H), 3.71 (s, 3H), 2.47 (dd, *J* = 13.8, 7.1 Hz, 1H), 2.34 (q, *J* = 5.5 Hz, 1H), 2.22 (ddd, *J* = 12.9, 7.0, 5.6 Hz, 1H), 2.15 – 1.78 (m, 5H), 0.89 (d, *J* = 7.1 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 173.1, 173.1, 74.7, 58.8, 53.0, 53.0, 41.3, 39.7, 37.9, 35.9, 27.7, 14.8.

HRMS (ESI) *m/z*, $[C_{11}H_{16}NO_5]^+$ calcd for: 242.1023; found 242.1028.

Tert-butyl 3-methyl-4-(2-nitroethyl)pyrrolidine-1-carboxylate (79)



Compound **79** was obtained according to general procedure **GP2** as a colorless oil (76% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

Major isomer

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.39 (dd, *J* = 8.1, 5.9 Hz, 2H), 3.45 (ddt, *J* = 22.3, 11.3, 6.4 Hz, 2H), 3.20 – 2.97 (m, 2H), 2.36 – 2.22 (m, 1H), 2.21 – 2.06 (m, 2H), 1.98 (tt, *J* = 13.7, 6.9 Hz, 1H), 1.44 (s, 9H), 0.95 (d, *J* = 7.0 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 154.8, 79.5, 74.4, 53.0, 52.7, 48.9, 48.6, 38.9, 38.2, 35.1, 34.2, 28.6, 26.2, 26.0, 13.4.

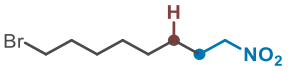
Minor isomer

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.39 (q, *J* = 8.2 Hz, 2H), 3.62 (dq, *J* = 27.3, 9.3 Hz, 2H), 2.91 (dq, *J* = 18.7, 9.3 Hz, 2H), 2.44 – 2.27 (m, 1H), 1.94 – 1.58 (m, 3H), 1.45 (s, 9H), 1.05 (d, *J* = 6.5 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 154.5, 79.6, 74.3, 53.2, 52.7, 51.2, 50.8, 43.1, 42.2, 39.1, 38.3, 29.8, 28.6, 16.2.

HRMS (ESI) *m/z*, $[C_{12}H_{23}N_2O_4]^+$ calcd for: 259.1652; found 259.1656.

1-Bromo-8-nitrooctane (81)



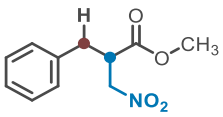
Compound **81** was obtained according to general procedure **GP2** as a colorless oil (88% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.37 (t, *J* = 7.0 Hz, 2H), 3.40 (t, *J* = 6.8 Hz, 2H), 2.00 (p, *J* = 7.1 Hz, 2H), 1.89 – 1.75 (m, 2H), 1.47 – 1.29 (m, 8H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 75.8, 34.0, 32.8, 28.8, 28.5, 28.1, 27.4, 26.2.

HRMS (ESI) *m/z*, $[C_8H_{16}BrNO_2\text{-}OH]^+$ calcd for: 220.0332; found 220.0336.

Methyl 2-benzyl-3-nitropropanoate (84)



Compound **84** was obtained according to general procedure **GP2** as a colorless oil (82% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.38 – 7.23 (m, 3H), 7.20 – 7.13 (m, 2H), 4.69 (dd, *J* = 14.6, 9.0 Hz, 1H), 4.38 (dd, *J* = 14.6, 4.5 Hz, 1H), 3.76 (s, 3H), 3.50 (tdd, *J* = 9.0, 5.9, 4.5 Hz, 1H), 3.17 (dd, *J* = 14.0, 5.9 Hz, 1H), 2.85 (dd, *J* = 14.0, 8.9 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 172.1, 136.5, 129.1, 129.0, 127.5, 74.2, 52.6, 44.6, 35.2.

The NMR spectra are in accordance with the literature.

6. References

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Chapter 6:

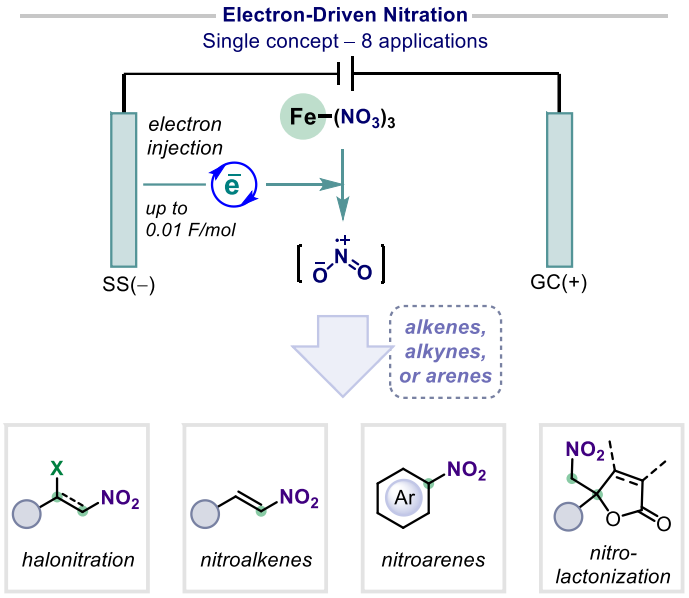
Electron-Driven Nitration of Unsaturated Hydrocarbons

This Chapter is adapted from the following publication in peer reviewed journal:

S. Patra, I. Mosiagin, R. Giri, T. Nauser, D. Katayev, "Electron-Driven Nitration of Unsaturated Hydrocarbons", *Angew. Chem. Int. Ed.* **2023**, *62*, e202300533. DOI:org/10.1002/anie.202300533.

1. Abstract

Herein, we introduce an electrochemically assisted paradigm for the generation of nitryl radicals from ferric nitrate under mild reaction conditions using a simple setup with inexpensive graphite and stainless-steel electrodes. Mechanistic evidence of such a unique reaction mode was supported by detailed spectroscopic and experimental studies. Powered by electricity and driven by electrons, the synthetic diversity of this concept has been demonstrated through the development of highly efficient nitration protocols of various unsaturated hydrocarbons. In addition to a broad application area, these protocols are easy of scaling to decagrams, while exhibiting exceptional substrate generality and functional group compatibility.



2. Introduction

Advancements in synthetic organic chemistry, especially in the last 50 years, are undisputedly linked to the progress of catalysis, which has become an indispensable tool with numerous opportunities for discovery, both in academia and across chemical industries.[1] The catalyst not only facilitates and increases the sustainability of countless processes, but it also often provides novel reactivity and allows previously inaccessible transformations to take place in chemo-, regio- or stereoselective manner. The evolution of this field is nicely illustrated by the emergence of biocatalysis,[2] and homogeneous and heterogeneous catalysis,[3] where common key players are enzymes,[4] transition metals,[5] organocatalysts,[6] Lewis acids and bases,[7] and hydrogen-bonding catalysts.[8] At present, catalysis also plays a substantial role in the production of fine chemicals and fuels from renewable feedstock, making a great contribution to the development of ´Green Chemistry´.[9] Therefore, the introduction of a new catalyst paradigm often results in an exponential growth of novel transformations. Among the concepts developed in the last few decades, the use of electrons as a catalyst or initiator has been underexplored. This activation mode, frequently referred to a single electron transfer (SET), allows to forge various redox-neutral transformations that otherwise require harsh reaction conditions and/or additives, and occurs via generation of radicals or radical anions as reactive intermediates. Currently, a single electron oxidation/reduction sequence in catalytic cycles is one of the exciting strategies and is widely utilized in photoredox catalysis[5a,10] and electro-organic synthesis.[11] The electron as a catalyst or as initiator is identified as inexpensive, traceless, and green, and its use in substoichiometric amounts often results in achieving excellent selectivity of chemical transformations.[12] In addition to having the highest mass efficiency among other mediators, it does not need to be removed from the mixture after the completion of the reaction.

Electrochemical set up is one of the privileged methods to study electron-driven transformations, since it allows a direct count of electrons provided to the reaction mixture. However, there are several ways to merge electrochemistry with catalysis, which should not be confused with each other. One of them is electrocatalysis, where catalytic manifold occurs either heterogeneously on the surface of electrodes or homogeneously and is mediated by an external catalyst (Figure 1A).[13] In both cases, a stoichiometric amount of charge is necessary to complete the reaction. This mode should not be attributed to electron catalysis. The use of electric current in substoichiometric amounts to promote redox-neutral reactions is associated with electrochemical catalysis and is a particular case of electron catalysis.[14] From a generic mechanistic point of view, an electron shuttle between an electrode and a neutral starting material takes place, leading to a radical anion intermediate formation, which upon a single or plural transformation, converts into a product. The final backward electron transfer can either occur at the electrode or with the starting material, closing the catalytic cycle (Figure 1B). This type of catalysis often amplifies thermodynamically favored but kinetically hindered processes. Despite the enormous potential of electron catalysis, real synthetic examples are still scarce in the literature. It is important to highlight

several preconditions for electron catalysis, though most of them have been mentioned in several review articles.[13-15] The number of electrons required for a complete conversion should be substoichiometric. The electron which enters as a catalyst should be transferred within the catalytic cycle, while the oxidation state of the intermediates should be changing over the course of the reaction. Finally, the initiation step should not include atom transfer since this is a major evidence for radical-chain reactions.[16] To differentiate real electron catalysis vs electron-initiation process in radical transformations is highly challenging as formal mechanism can be overlooked by several scenarios. It can be well seen on examples of classical $S_{RN}1$-type[14,17] and base-promoted homolytic aromatic substitution (BHAS)[18] reactions where these mechanisms can be considered as electron-catalyzed processes.[12] At present, only few known transformations can be ascribed to electron catalysis including but not limited to olefin isomerization,[19] radical Heck-type reactions,[20] cross-dehydrogenative couplings,[21] radical arene trifluoromethylations,[22] alkoxycarbonylations[23] and molecular recognition.[24] Notably, these reactions are specific to selective substrates and often lack practicality, versatility, and scalability.

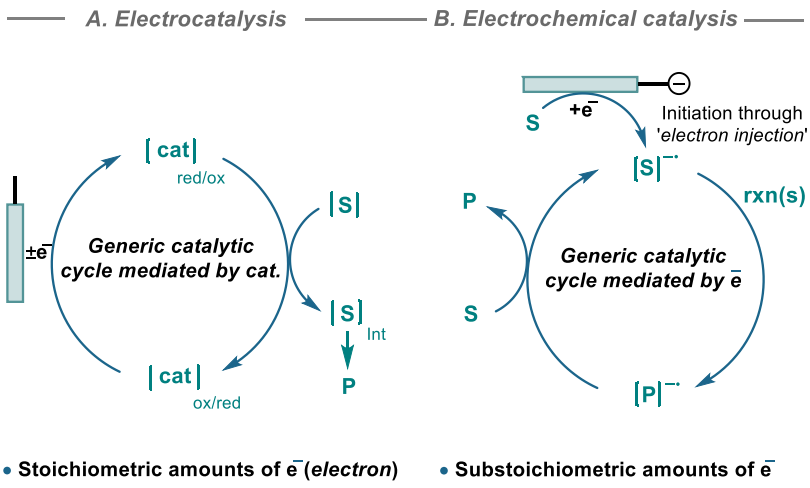


Figure 1. A-B) Concepts of electrocatalysis and electrochemical catalysis.

Thus, we aimed to strengthen the concept and develop a comprehensive example of an electron-driven transformation. In order to design such process, several elementary steps that are of decisive importance should be selected thoroughly (Figure 2). Electron-mediated reactions can in principle be initiated by various setups, while the electrochemical approach allows for precise, external control of chemoselectivity and the flux of electrons into the reaction mixture by regulating the applied potential. Recent studies have demonstrated that earth-abundant metal-based complexes can undergo light-induced homolysis, providing access to various reactive radical species.[25] On the other hand, our research group has a long-term interest in nitration chemistry.[26] The aforementioned considerations led us to choose ferric nitrate as a suitable reagent that can potentially be activated under electrochemically assisted conditions, liberating nitryl radicals through electron transfer mechanism.[27] In addition, iron possesses several stable oxidation states that can interconvert with each other, ensuring the continuous

presence of reactive intermediates. As further outlined in Figure 2, unsaturated hydrocarbons have been opted as model substrates due to their ensuing reactivity towards electron-deficient radicals. The subsequent downstream SET-induced transformation would lead to the formation of the product and restore an electron, completing the catalytic cycle (scenario a). On the other hand, it can be seen that organic radical intermediate will undergo SET with ferric nitrate, delivering the desired product and re-activating ferric nitrate (scenario b). We suspected, therefore, that this electron-driven manifold would be a highly efficient process to generate nitryl radicals under mild and controllable conditions and could be a valuable entry in organic synthesis for the preparation of a broad range of nitro-derived molecules.

Herein, we disclose a unified and modular protocol to access various nitro group-containing building blocks from unsaturated hydrocarbons that proceed under electrochemically induced reaction conditions and utilizes ferric nitrate as an inexpensive nitrating reagent. Detailed mechanistic studies based on a wide range of spectroscopic and control experiments suggest the vital role of the electron as determinative in the activation of ferric nitrate, delivering nitryl radicals to the reaction mixture at ambient temperature. Consequently, this protocol demonstrated exceptional chemo- and regioselectivity as well as great functional group tolerance and can be applied for a series of nitrative functionalization reactions.

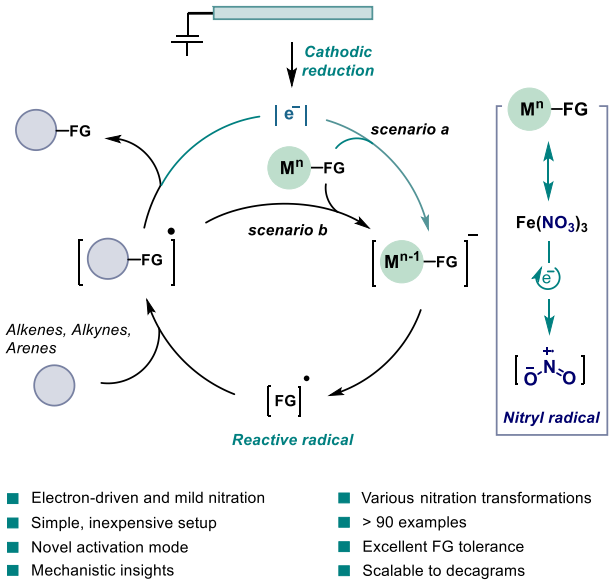
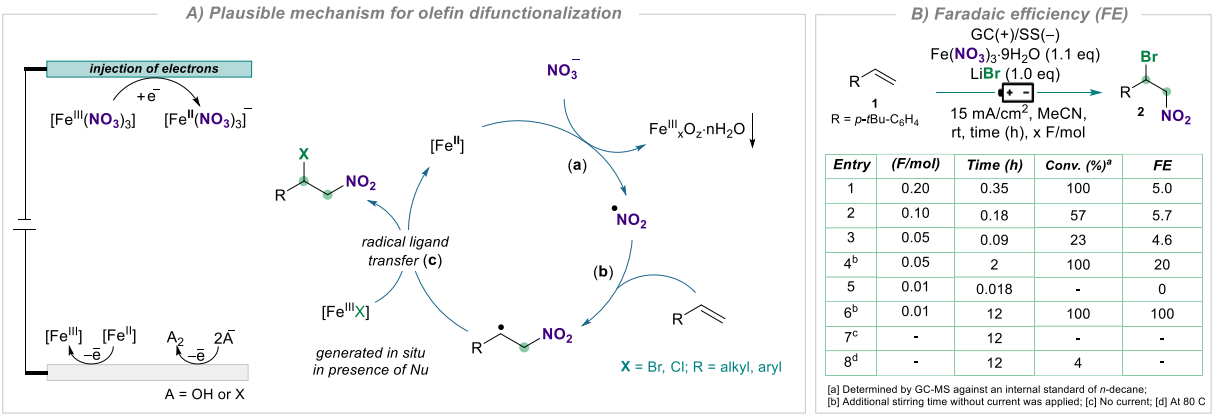


Figure 2. This work: reaction design towards electrochemically driven nitration using ferric nitrate. Scenario a – mechanistic picture viewing the electron as a catalyst, scenario b – classical representation.

3. Results and discussion

3.1. Mechanistic insights and reaction optimization

To establish the proof of concept, we carried out electrolysis experiments to design direct bromonitration methodology of olefins using 4-(tert-butyl)styrene (**1**) as model substrate, oxidatively robust graphite as the anode (working electrode) and stainless-steel as the cathode (counter electrode) in an undivided cell (Tables S1–S8). Our mechanistic hypothesis is outlined in Figure 3A. As for the nitro source, various metal nitrate and nitrite salts were investigated (Table S2) as their activation to liberate nitryl radicals has been previously reported, although under thermal conditions or in combination with additives.[28] Our efforts in this regard revealed an unprecedented formation of nitryl radicals via a single electron activation of ferric nitrate nonahydrate that occurs under mild conditions at room temperature (step a). Upon addition of nitryl radical to olefin (step b) the corresponding nitroalkyl radical species is formed. The latter intermediate is highly reactive and often leads to the formation of by-products through pathways that are inherent to radical species, such as dimerization, polymerization, and possible interactions with electrode surface. Herein, we assumed that a high level of selectivity in the formation of carbon–halogen bond can be achieved via bromo-transfer step with an iron bromide [Fe-Br] intermediate generated in situ with the nucleophile.[29] After thorough optimization of bromide sources, LiBr was identified as both an optimal reagent and as a suitable electrolyte (Table S3). Notably, this radical group transfer manifold (step c) produces Fe^{II} species that are needed to further maintain the presence of nitryl radicals in the reaction media. The choice of the solvent can be ascribed as a crucial parameter considering the solubility factor of inorganic salts and conductivity. Optimal results were obtained in acetonitrile, performing the reaction with 1.1 equivalents of $Fe(NO_3)_3{\times}9H_2O$ and 1.0 equivalent of LiBr at room temperature, providing the targeted 1-bromo-2-nitroalkane **2** in 77% yield when 1.1 F of electricity with respect to 4-(tert-butyl)styrene (**1**) was applied (Tables S1-S8). Next, we turned our attention to the Faradaic efficiency of this transformation, and preliminary optimizations displayed that applied electricity can significantly be lowered with respect to olefin, while maintaining the bromonitration reaction at high conversion (Figure 3B, Table S7). Performing the reaction under established conditions and interrupting electrolysis upon passage of 0.2 F/mol resulted in complete consumption of **1** (Figure 3B, entry 1), while reducing it further led to a significant drop in the product yield (entries 2-3). Full conversion was found when the reaction was stirred for an additional 2 h after electron injection, suggesting that a longer time is required with fewer electrons. It was also shown that the electrolysis under a constant current of 15 mA for 0.01 F/mol electricity followed by an addition stirring of 12 h results in the complete conversion of **1** (entries 4-6). No product formation or traces were detected when the reaction is carried out without electricity or at elevated temperature (entries 7-8).



Entry	(F/mol)	Time (h)	Conv. (%)[a]	FE
1	0.20	0.35	100	5.0
2	0.10	0.18	57	5.7
3	0.05	0.09	23	4.6
4[b]	0.05	2	100	20
5	0.01	0.018	-	0
6[b]	0.01	12	100	100
7[c]	-	12	-	-
8[d]	-	12	4	-

[a] Determined by GC-MS against an internal standard of *n*-decane;
[b] Additional stirring time without current was applied; [c] No current; [d] At 80 C

Figure 3. A. Plausible mechanism. B. faradic efficiency calculation.

To support the fact that the electron can be regarded as an efficient driving force, we conducted a series of on-off experiments on bromonitration reaction of **1** and their graphical representation is summarized in Figure 4A. We were pleased to find that conversion of the starting material at room temperature gradually increased not only during electrolysis but also when electricity is off. Notably, the turnover number (TON) of the reaction was much greater when on-off time intervals were increased from 2 minutes to 6 minutes, as it can be seen in the comparison of steps with 0.01 F/mol vs 0.03 F/mol (Figure 4A). Encouraged by these results, we next examined the reaction mechanism. Our attention was first dragged to the role of electrons in reactivity of ferric nitrate, as the formation of nitryl radicals from it at ambient temperature via single electron activation strategy has not been previously investigated. To acquire an initial understanding, we started with pulse radiolysis, which is a powerful method to examine the nature of short-living and highly reducing / oxidizing intermediates and radicals.[30] Our first attempts to observe fragmentation products following single electron reduction of iron nitrate were not successful, since Fe^{III} blocks the window of observation needed for UV/Vis absorption spectroscopy of products of one-electron reduced nitrate. To mimic our reaction conditions, various nitrate salts and non-protic solvents were explored. Acetonitrile as a solvent was not ideal for these measurements due to its unsaturated nature, while irradiation of an argon-saturated solution of cesium nitrate in THF (1 mM) with a 29 Gy dose showcased a build-up of a transient species with an absorbance maximum at 350 nm (Figure 4B, left), which in the sequel decayed by a second-order process. These data indicate the likelihood of a single electron reduction of NO_3^- to $NO_3^{\bullet 2-}$, which upon reaction with H^+ affords $\bullet NO_2$.[31]

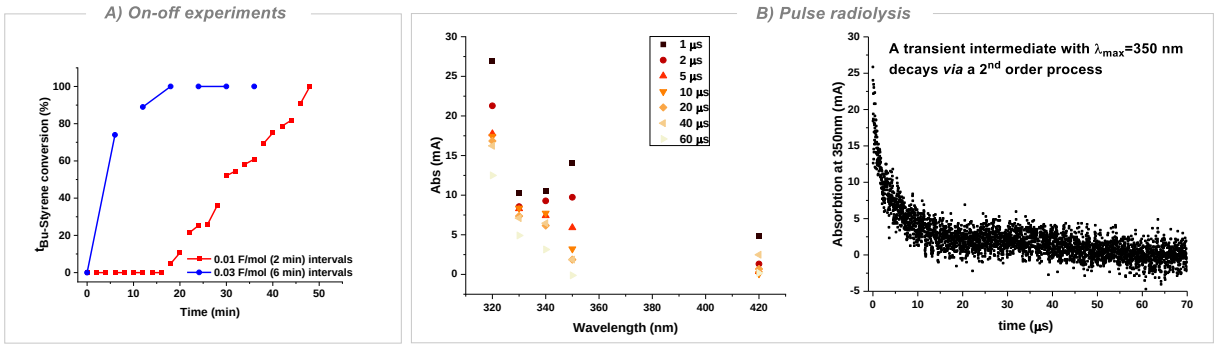


Figure 4. A. On-off experiments. B. Pulse radiolysis.

The cyclic voltammetry (CV) studies of the reaction mixture indicated an irreversible reduction of Fe^{III} to Fe^{II} (Epc at 0.74 V vs. SCE) along with the appearance of a new anodic event at 1.59 V vs SCE, which was absent during the measurement of the individual components. The latter peak was attributed to the oxidation of an in situ generated bromide-bound Fe^{II} species to the corresponding Br–Fe^{III} intermediate, which then enters in ligand transfer step c.[29d-f] To further demonstrate the formation of $•NO_2$ from $Fe(NO_3)_3$ under electrolysis, we performed a series of nitrite test experiments (Figure 5A). As presented on the chart, upon passage of the electricity through the saturated solution of ferric nitrate (test D), detection of nitrite ions NO_2^- indicates the formation of nitryl radicals during the course of reaction. The role of Fe^{II} in the regeneration of $•NO_2$ has been further elucidated by mixing $Fe(NO_3)_3×9H_2O$ or $LiNO_3$ with Fe^{II} source (tests F and I). Although the results of pulse radiolysis suggest an NO_3^-/ $NO_3^{•2-}$ conversion via SET, the possibility of reduction of NO_3^- through direct oxygen atom transfer to Fe^{II} cannot be neglected. The precipitate formed upon completion of the bromonitration reaction, conceivably during step a of the mechanism, has been additionally analyzed by X-ray photoelectron spectroscopy (XPS), which revealed the presence of Fe^{II} and Fe^{III} oxide/hydroxide by-products (Figure 5B). The radical nature of the step b, addition of $•NO_2$ to olefin, was indicated by Hammett studies showing a slightly negative reaction parameter (ρ = –0.2) (Figure 5C).

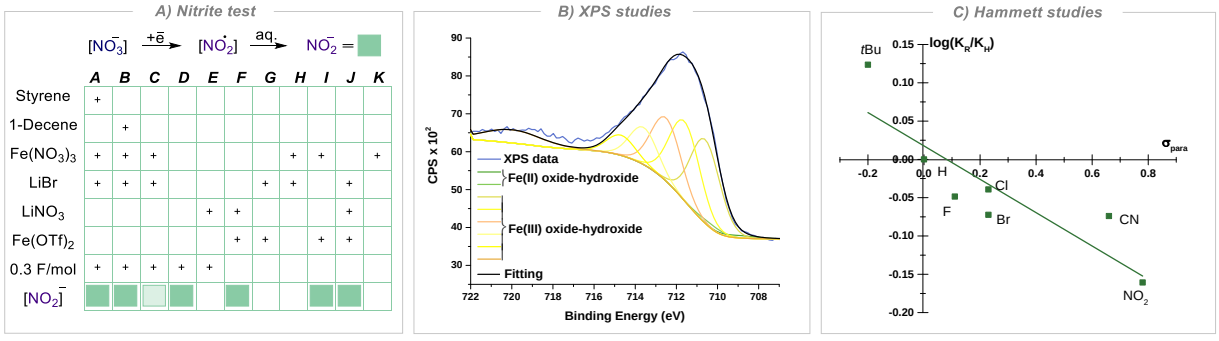


Figure 5. A. Nitrite test. B. XPS studies. C. Hammett studies.

In addition, adducts generated in radical clock experiments with olefins **3** and **5** further supported the feasibility of step b, while electrochemically initiated bromonitration of (Z)- and (E)-stilbene yielded

the corresponding products **7** with similar d.r. values (Figure 6). Notably, formation of product 4 further revealed, that bromination reaction of nitro-alkyl radical intermediate via ligand transfer (step c) is faster compared to either hydrogen radical elimination or radical cyclization.[32] It is worth mentioning, that since electrolysis experiment at 0.77 V constant voltage did not affect the formation of **2**, direct cathodic reduction of styrene **1** (ca. –1.2 V) in the reaction is unlikely under standard conditions. This is also in agreement with our hypothesis that nitryl radical formation is initiated by a single electron reduction of $Fe(NO_3)_3 \times 9H_2O$ ($E_0(Fe^{III}/Fe^{II})$ = 0.74 V vs. SCE). Finally, the radical ligand transfer step c closes the catalytic cycle and regenerates the electrochemically injected electron in the form of Fe^{II} intermediate. Nevertheless, stabilization of alkyl radical via coordination to iron followed by inner sphere ligand transfer cannot be excluded. Preservation of an active electron in the reaction mixture can presumably be explained by several anodic events occurring outside the main cycle (Figure 6). To rule out the potential oxidation of nitroalkyl radical to the corresponding carbocation, we attempted nitrative difunctionalization of **1** with various nucleophiles (AcO^-, F^-, N_3^-), which are less prone to radical ligand transfer event from iron.[33] Indeed, only traces or no product formation were detected. On the other hand, halonitration reactions of **1** in the presence of radical trapping agents such as CBr_4 and CCl_4 resulted in the products **2** and **17** formation in 11% and 5% yield, respectively. With these experimental observations, our bromonitration protocol can also be considered as electron-catalyzed since a substoichiometric number of electrons originate the transformation consisting of a series of SET events, and electrons do not exit the cycle in form of product or by-product, meeting the requirements of electron catalysis.[12]

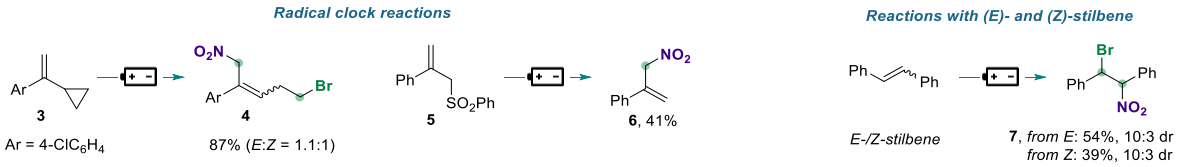


Figure 6. Control experiments

3.2. Investigation of substrate scope

Having examined the nature of the electron-mediated activation of ferric nitrate, we next set out to explore this concept in the context of halonitration of olefines. Although chloronitration reactions of alkenes have already been attempted,[34] however with poor chemo- and regioselectivity along with the formation of various by-products, bromonitration presents a formidable challenge using available methods. The optimized reaction conditions were further evaluated with respect to a wide array of readily available olefin building blocks as well as to the tolerance with common functionalities (Figure 7). A broad range of terminal styrene derivatives carrying electron-donating and electron-withdrawing aryl substituents at the ortho-, meta-, and para-positions (**2**, **8-19**, **26-27**, **31**) underwent bromonitration and chloronitration, delivering the corresponding products in good to excellent yields. Of note, halogen atoms, located at different parts of aryl olefins (**12-13**, **20-21**, **28-29**) as well as potentially sensitive functionalities, such as ether (**22**, **25**), azide (**23**), free alcohol (**22**), amide (**24**), aldehyde (**30**), ester (**36**) remained untouched, confirming the exceptional robustness and mildness of this methodology and enabling follow-up derivatization. Linear chain adorned with alkyne group of styrene derivative led to exclusive reaction on the olefin fragment, allowing to isolate the corresponding product **25** in good yield. Adducts with α-substituents (**32-36**), reacted decently, regardless of their steric and electronic nature. Various 1,2-disubstitued styrenes bearing a wide variety of acid-sensitive functionalities performed well under electrochemical conditions (**37-39**), while the presence of a carbonyl group at olefin β-center makes the reaction sluggish (**41-43**). Structure of compound **40** was unambiguously demonstrated by single-crystal X-ray crystallography.[35] We next investigated unactivated alkenes, and, despite their chemical inertness, we were pleased to find their valuable reactivity. Terminal alkenes with long alkyl linear chains or 6-, 7-, and 8-membered cyclic systems all provided the corresponding 1,2-disubstituted products (**45**, **46**, **54-57**). Bromonitration of 1-decene was challenging and led to the formation of **43** with only 15% isolated yield. The product formation could be enhanced to 70% in the presence of 1.0 equivalent of CBr_4. The efficiency of the reaction does not diminish even in the presence of carboxylic acid (**46**). Using 2 equivalents of reagents also allowed to successfully perform the simultaneous substitution of two olefin fragments of 1,7-octadien, delivering the corresponding product (**47**) with high chemical efficiency. Great synthetic flexibility was showcased with aliphatic mono- and disubstituted alkenes holding ester, carbonyl, amide, and sulfonyl functionalities, and formed the corresponding adducts in decent isolated yields (**48-54**). Encouraged by the unusually broad functional group tolerance, we also illustrated the application of this protocol in the late-stage functionalization. Our methodology was equally successful in the formation of 1-bromo-2-nitro substituted adducts for the derivatives of natural amino-acids (**58**, **59**) and D-fructopyranose (**61**), while alkene with L-camphanic acid moiety resulted in the formation of nitrohydrine product **60**. This latter example clearly demonstrates that the electronic nature of the benzyl radical plays an important role in the ligand transfer step and may significantly alter the chemoselectivity of the transformation.[36]

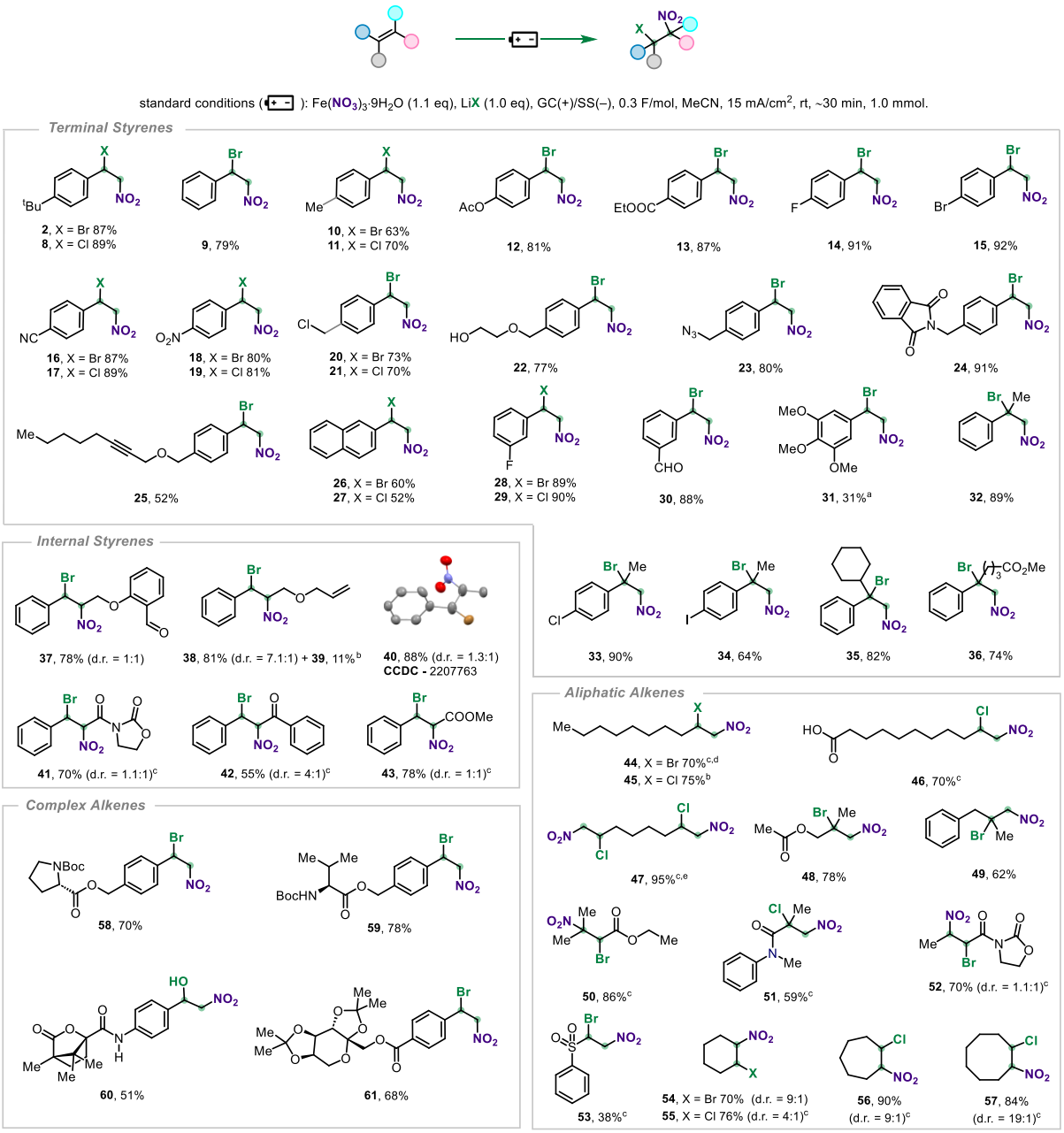


Figure 7. Scope of halonitration of alkenes. Isolated yields are reported. [a] Unstable compound. [b] Intramolecular radical cyclization adduct **39**. [c] Additional 12 h stirring without electricity was applied. [d] CBr_4 (1.0 mmol) was used instead of LiBr. [e] 2 equiv of reagents were added.

4. Applications

4.1. Scale-up synthesis

To further demonstrate the operational simplicity and scalability of the protocol, the process was applied to decagram-scale (20 grams of alkene) in batch to three representative examples, and under standard electrolysis the corresponding products **2**, **17**, and **45** were obtained (Figure 8). To be noted, when the reaction was carried out under air using commercially available inexpensive electrodes and automated overhead stirrer, no significant drop in product yields was observed, indicating the robustness of the method and the possibility of accessing a wide variety of useful chemicals on a large scale both in the laboratory and in the industry.

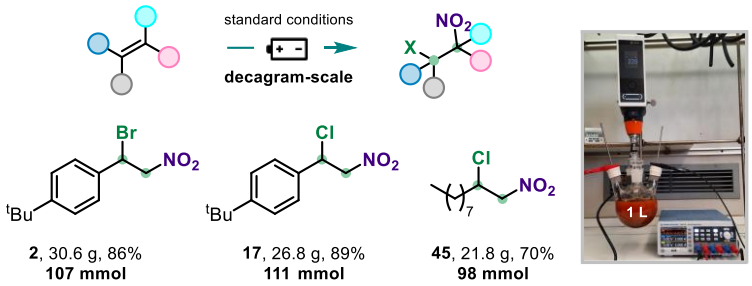


Figure 8. Scale-up synthesis.

4.2. Product derivaization

The resulting crude adduct **2** can be further manipulated in an expedient mode. In a single operation utilizing judicious choices of nucleophiles, it provides added-value building blocks by installing two functional handles (Figure 9). The newly formed C-Br bond can sequentially be substituted, resulting in the formation of dimethylmalonate **62** or nitrate **63** derivatives, while in the presence of a reducing reagent, it can be transformed into nitroalkane **66**. Compound **2** was also converted to 2-nitro-1-hydroxylamine derivative **64**, which is a masked precursor for accessing of vital 1,2-diamines. The synthetic value of the nitro group was further exposed through a set of derivatization reactions including the preparation of amine (**67**), dialkylphosphite (**68**), and triazole (**65**) derivatives. Applying common reducing agents to compound **2**, the original olefin **1** can be obtained in 95%, demonstrating the synthetic modularity of halo-nitro alkanes.

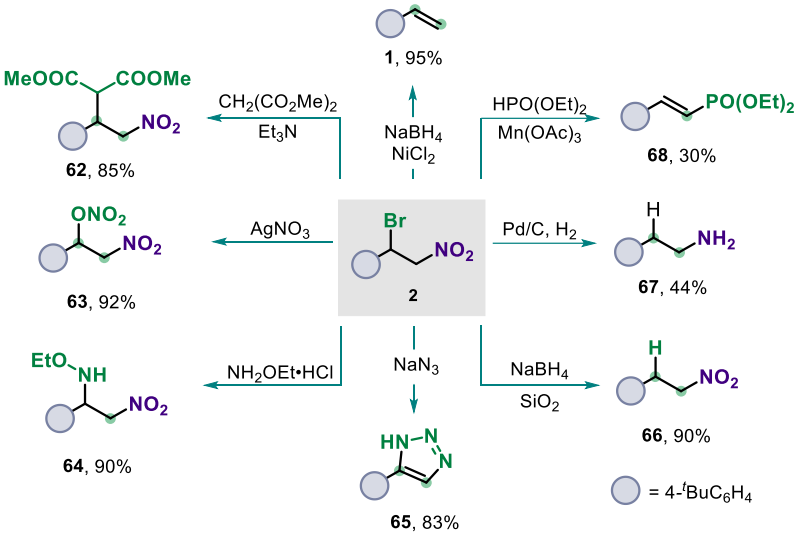


Figure 9. Product derivatization.

4.3. Miscellaneous synthetic applications

Nitration processes have tremendous importance on academic and industrial levels and traditionally rely on the use of a so-called ´mixed acid approach´.[26a, 37] These conditions are prone to unselective over-nitration, providing minimum chemoselectivity and functional group tolerance. To address this, a number of elegant methodologies and reagents have been developed in the past few decades.[26a, 38] However, it is still rare to find nitration concept that is mild and demonstrates consistent performance across different classes of organic molecules. Thus, we were interested in the application of our electron-mediated protocol for a broader range of organic reactions that would result in the formation of nitro-derived molecules. Subjecting several activated and non-activated alkenes to standard electrolysis and performing it in slightly basic media, in less than 6 hours the corresponding nitro-alkenes were formed in both a chemoselective and regioselective fashion and in typically 51-83% isolated yields (**69**-**80**) (Figure 10A).[39] Besides various substitution patterns, the reaction outcome was not altered by the presence of heterocycles such as pyridine (**74**) or thiazole (**75**). γ-Butyrolactones are presented in many bioactive molecules,[40] and are important building blocks in organic synthesis.[41] When 4-phenylpent-4-enoic acid or 2-(1-phenylvinyl)benzoic acid were exposed to electrochemical conditions, nitrative lactonization takes place, affording γ-lactones **81** and **82**, respectively (Figure 10B).[42] Next, we investigated the possibility of introducing a nitro group via ipso-nitration reactions. Aromatic α,β-unsaturated carboxylic acids were smoothly converted to nitro-alkenes (**69**, **83**-**85**) in up to 64% yield (Figure 10C).[43] Similarly, vinylboronates were likewise compatible (**69**, **72**) (Figure 10D).[44] Pleasantly, aromatic nitro compounds **86** and **87** can also be formed in excellent yields via ipso-nitration of the respective aryl boronic acids (Figure 10E).[26c, 44] Owing to the fundamental importance of aromatic nitro compounds, we approached our electron-driven strategy to the direct nitration of arenes. Nitration of anisole resulted in a slight excess of the para-regioisomeric product (**86**) with an overall 98% yield, which is in good agreement with results from nitration under mixed acid conditions or using nitronium salts.[28c, 45] Without further optimizations, the protocol proved amenable for the nitration of diverse sets of electron-rich arenes, affording the corresponding products (**86**-**95**) in up to 98% yield and good regioselectivity (Figure 10F).[46] Lastly, aromatic and aliphatic alkynes, mainly phenylacetylene, 2-methylphenylacetylene, and 1-decyne, were engaged in electrochemically catalyzed conditions (**96**-**98**).[47] Conveniently, 1-bromo-2-nitrovinyl products were obtained with satisfactory results and in exclusive (E)-configuration, however, CBr_4 was used as brominating reagent.

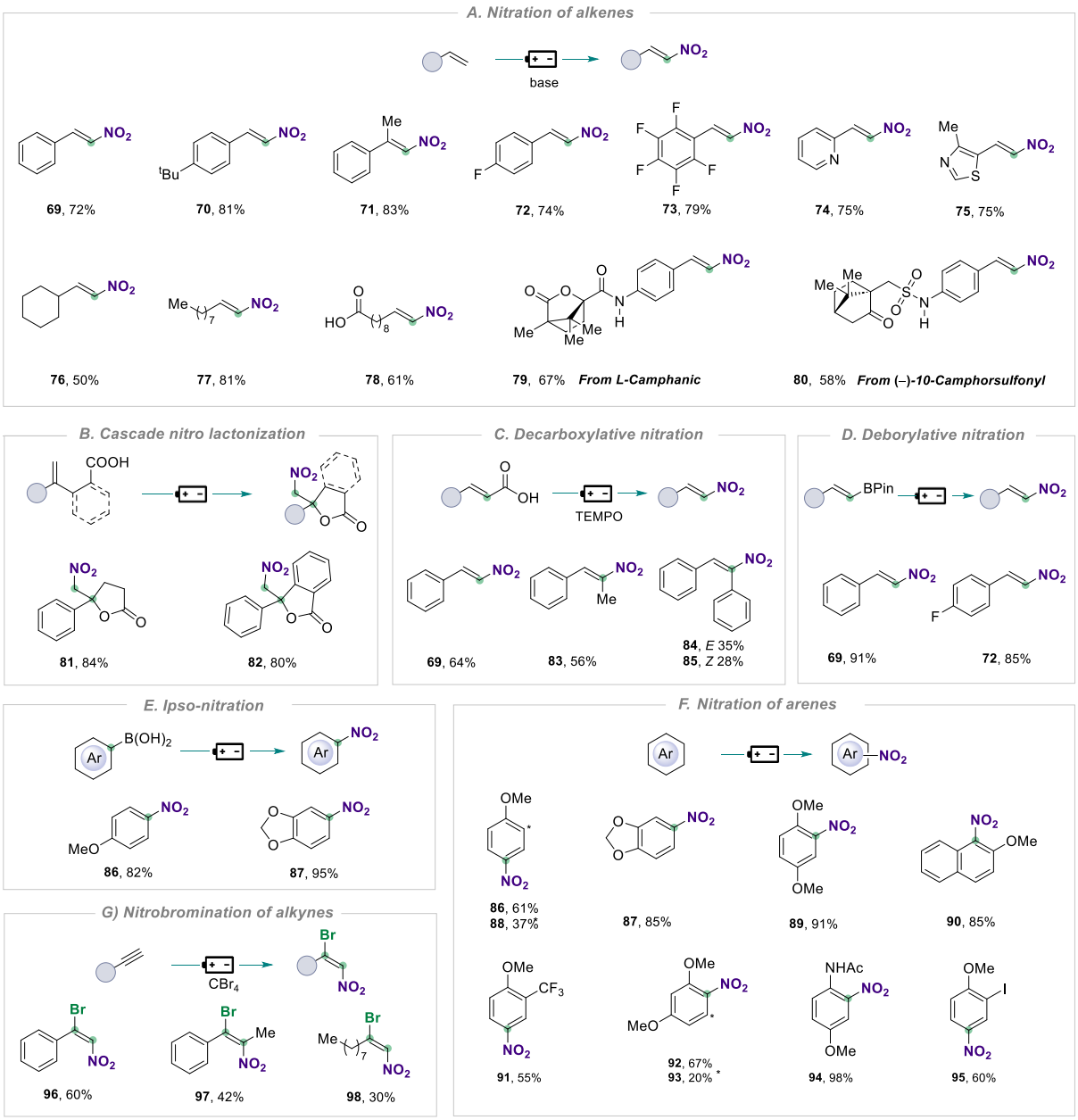


Figure 10. Miscellaneous synthetic applications

5. Conclusion

In conclusion, we introduced an electrochemically assisted concept to access a broad array of nitro compounds by activating ferric nitrate under mild and room temperature conditions. Designed process can be applied on an unprecedentedly broad number of functionalization reactions, covering most of the known nitro-group installation reactions involving nitryl radical intermediate. Generality and scalability of this paradigm have been demonstrated via the nitration of unsaturated hydrocarbons including alkenes, alkynes, and arenes, with high levels of chemo- and regioselectivity and with exceptional functional group tolerance. The performed experimental and spectroscopic mechanistic studies strongly suggest that an electrochemically injected substoichiometric amount of electrons is the driving force capable to liberate the nitryl radicals from ferric nitrate and to promote nitration. We envision that these robust and operationally simple protocols will enhance the accessibility of diverse ranges of nitro compounds that are difficult to reach using classical chemical methods.

6. Experimental section

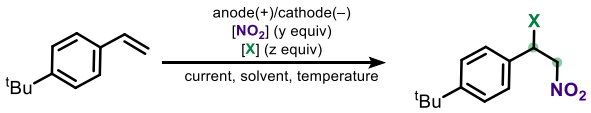
1. General Information

Unless otherwise noted, all the reactions were carried out under air. Iron (III) nitrate nonahydrate ($Fe(NO_3)_3 \cdot 9H_2O$) was purchased from Alfa Aesar and used as it is. Lithium Chloride (LiCl) and lithium bromide (LiBr) were purchased from VWR and Sigma Aldrich, respectively. Pentane, hexane, dichloromethane (DCM), toluene (PhMe), ethyl acetate (EtOAc) and diethyl ether were purchased from Fisher Chemicals and used without further purification. Acetonitrile (MeCN) was distilled over CaH_2 prior use. Commercially available olefins were purchased from Thermo Scientific Chemicals, Acros Organics, Sigma Aldrich, Apollo Scientific, Fluorochem, and TCI.

Purification of reaction products was carried out with flash chromatography using Brunschwig silica 32–63, 60 Å under 0.3–0.5 bar overpressure. Medium pressure liquid chromatography (MPLC) was performed on a CombiFlash Rf200 System from Teledyne ISCO with built-in UV-detector and fraction collector or manually using silica gel SilicaFlash P60, 40–63 μm. Teledyne ISCO RediSep Rf flash columns used for the purification have a 0.035 0.070 mm particle size and 230–400 mesh. HR–MS (ESI+) mass spectra were measured on a Bruker FTMS 4.7T BioAPEX II and Thermo Scientific LTQ Orbitrap XL equipped with a static nanospray ion source and mass spectrometry service operated on VG-TRIBRID for electron impact ionization (EI), or Varian IonSpec Spectrometer for electrospray ionization (ESI) and are reported as (m/z). Electron impact ionization mass spectra (EI–MS) were run on a gas chromatography–mass spectrometry (GC-MS) instrument of Agilent 8890 series GC system and Aglient 5977B GC/MSD.

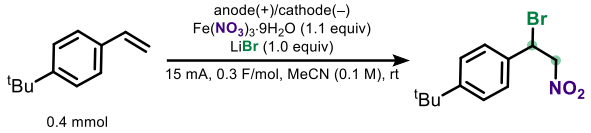
^{1}H- and ^{13}C-NMR spectra were recorded on Bruker DPX-300 (operating at 300.1 MHz and 75.5 MHz, respectively) and Bruker DPX-400 (operating at 400.1 MHz and 100.6 MHz, respectively), and ^{19}F-NMR spectra on Bruker Bruker DPX-300 (at 282 MHz) and Bruker DPX-400 (at 376 MHz). The chemical shifts are reported in parts per million (ppm) and coupling constants (*J*) are given in Hertz (Hz). ^{1}H-NMR spectra are reported with the solvent resonance as the reference unless noted otherwise ($CDCl_3$ at 7.26 ppm). ^{13}C-NMR spectra were recorded with ^{1}H-decoupling and are reported with the solvent resonance as the reference unless noted otherwise ($CDCl_3$ at 77.16 ppm). Peaks are reported as (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet or unresolved, coupling constant(s) in Hz, integration). Infrared (IR) data was obtained on a JASCO FT-IR-4100 spectrometer with only major peaks being reported. The peaks are reported as absorption maxima (cm^{-1}). Cyclic voltammetry (CV) was measured using the Osilla potentiostat, an Ag^{+}(0.01M $AgNO_3$)/Ag or AgCl/KCl(3M)/Ag reference electrode, a platinum disc working electrode, and a platinum counter electrode. All measurements were carried out in acetonitrile (MeCN) (0.1 M NBu_4PF_6) at room temperature if not stated otherwise.

2. Development of the Reaction Conditions



Without any precautions to exclude air or moisture an ElectraSyn vial (5 mL) with a stir bar was charged with a nitrating reagent, a halide source, followed by distilled MeCN and alkene substrate. The vial cap equipped with anode and cathode were inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current. The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated in vacuum. An aliquot was analyzed by GC-MS to obtain the calibrated yields and characterization for the desired product.

2.1 Survey of Electrodes

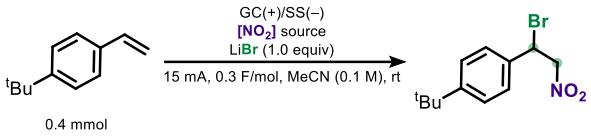


0.4 mmol

Entry	Electrode		Yield of 2 (%)[a]
	anode	cathode	
1	GC	GC	38
2	SS	SS	9
3	SS	GC	49
4	GC	Zn	63
5	GC	Pt	66
6	GC	Ni	41
7	GC	Mg	50
8	**GC**	**SS**	**77**

Table S1: Reaction conditions: 4-*tert*-butylstyrene **1** (0.4 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (0.44 mmol, 1.1 equiv), LiBr (0.4 mmol, 1.0 equiv), MeCN (0.1 M), 15 mA current for 0.3 F/mol at room temperature. [a]Yields were determined by GC-MS against an internal standard *n*-decane. Electrodes: GC = graphite carbon, SS = stainless steel, Zn = zinc, Pt = platinum, Ni = nickel, Mg = magnesium.

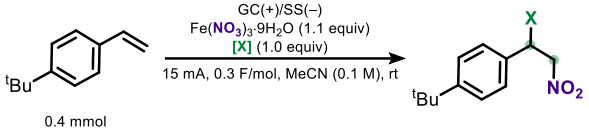
2.2 Evaluation of Nitrating Reagents



Entry	$[NO_2]$ (1.1 equiv)	Yield of 2 (%)[a]
1	**$Fe(NO_3)_3 \cdot 9H_2O$**	**73**
2	$Cr(NO_3)_3 \cdot 9H_2O$	28
3	$Zn(NO_3)_3 \cdot 6H_2O$	n.d.
4	$Co(NO_3)_3 \cdot 6H_2O$	n.d.
5	$Mn(NO_3)_2 \cdot 4H_2O$	n.d.
6	$LiNO_3$	n.d.
7	$NaNO_3$	n.d.
8	KNO_3	n.d.
9	NH_4NO_3	n.d.
10	$AgNO_3$	n.d.
11	$Ba(NO_3)_2$	n.d.
12	$Mg(NO_3)_2 \cdot 6H_2O$	n.d.
13	$Al(NO_3)_3 \cdot 9H_2O$	1
14	$Bi(NO_3)_3 \cdot 5H_2O$	n.d.
15	$Ni(NO_3)_2 \cdot 6H_2O$	n.d.

Table S2: Reaction conditions: 4-*tert*-butylstyrene **1** (0.4 mmol, 1.0 equiv), $[NO_2]$ reagent (0.44 mmol, 1.1 equiv), LiBr (0.4 mmol, 1.0 equiv), MeCN (0.1 M), 15 mA current for 0.3 F/mol at room temperature, GC as anode and SS as cathode. [a]Yields were determined by GC-MS against an internal standard *n*-decane.

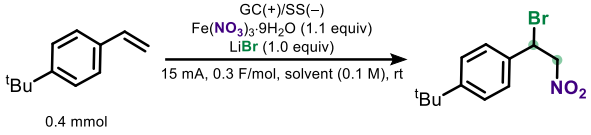
2.3 Survey of Halogen Sources



Entry	Halide Source (equiv)	Yield of 2 (%)[a]
1	NaCl (2.0)	44
2	KCl (2.0)	n.d
3	$FeCl_2·4H_2O$ (2.0)	n.d
4	$FeCl_3$ (2.0)	14
5	$MgCl_2·6H_2O$ (2.0)	n.d
6	NH_4Cl (2.0)	n.d
7	$BiCl_3$ (2.0)	61
8	*n*-Bu_4NCl (2.0)	42
9	LiCl (2.0)	66
10	LiCl (3.0)	16
11	LiCl (4.0)	1
12	LiCl (10.0)	1
13	LiCl (2.0)	66
14	**LiCl (1.0)**	**69**
15	LiBr (1.7)	76
16	**LiBr (1.0)**	**77**
17	LiBr (3.0)	31
18	LiBr (5.0)	n.d.
19	KBr (1.0)	<1
20	NaBr (1.0)	55
21	$MnBr_2$ (1.0)	67
22	$FeBr_3$ (1.0)	9

Table S3: Reaction conditions: 4-*tert*-butylstyrene **1** (0.4 mmol, 1.0 equiv), $Fe(NO_3)_3·9H_2O$ (0.44 mmol, 1.1 equiv), halide source (0.4 mmol, 1.0 equiv), MeCN (0.1 M), 15 mA current for 0.3 F/mol at room temperature, GC as anode and SS as cathode. [a]Yields were determined by GC-MS against am internal standard *n*-decane.

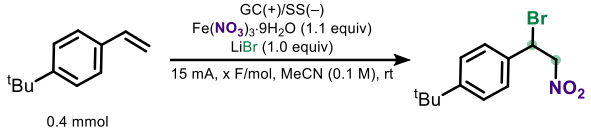
2.4 Evaluation of Solvents



Entry	Solvent	Yield of 2 (%)[a]
1	MeOH	0
2	THF	56
3	THF/MeCN 1:1	29
4	THF/MeCN 3:1	25
5	DMF	0
6	DMA	2
7	1,4-Dioxane/MeCN 4:1	73
8	1,4-Dioxane/MeCN 1:1	39
9	1,4-Dioxane/MeCN 1:3	38
10	EtOAc	8
11	MeCN/AcOH 3.9:0.1	43
12	MeCN/AcOH 3:1	36
13	MeCN/MeOH 3.5:0.5	0
14	Acetone	25
15	Et_2O	0
16	EtOAc:MeCN 4:1	73
17	**MeCN**	**77**

Table S4: Reaction conditions: 4-*tert*-butylstyrene **1** (0.4 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (0.44 mmol, 1.1 equiv), LiBr (0.4 mmol, 1.0 equiv), solvent (0.1 M), 15 mA current for 0.3 F/mol at room temperature, GC as anode and SS as cathode. [a]Yields were determined by GC-MS against an internal standard *n*-decane.

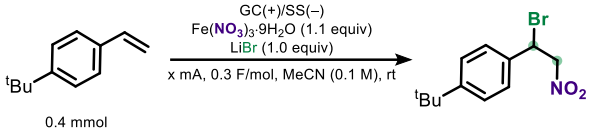
2.5 Survey of Applied Charge



Entry	F/mol	Yield of 2 (%)[a]
1	1.1 F/mol	77
2	**0.3 F/mol**	**79**
3	0.2 F/mol	76
4	0.1 F/mol	n.d.

Table S5: Reaction conditions: 4-*tert*-butylstyrene **1** (0.4 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (0.44 mmol, 1.1 equiv), LiBr (0.4 mmol, 1.0 equiv), MeCN (0.1 M), 15 mA current at room temperature, GC as anode and SS as cathode. [a]Yields were determined by GC-MS against an internal standard *n*-decane.

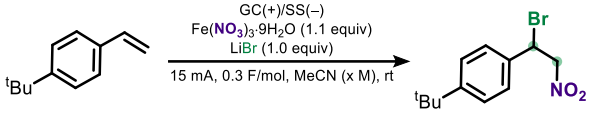
2.6 Evaluation of Current Density



Entry	X mA	Yield of 2 (%)[a]
1	5 mA	71
2	10 mA	73
3	12.5 mA	76
4	**15 mA**	**79**
5	17.5 mA	75
6	20 mA	78
7	25 mA	68

Table S6: Reaction conditions: 4-*tert*-butylstyrene **1** (0.4 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (0.44 mmol, 1.1 equiv), LiBr (0.4 mmol, 1.0 equiv), MeCN (0.1 M), 0.3 F/mol at room temperature, GC as anode and SS as cathode. [a]Yields were determined by GC-MS against an internal standard *n*-decane.

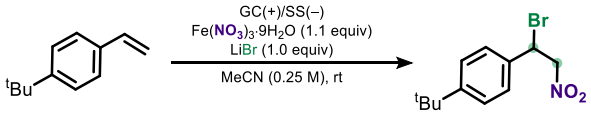
2.7 Concentration Effect



Entry	Concentration (M)	Yield of 2 (%)[a]
1	0.025	n.d.
2	0.05	14
2	0.1	77
3	0.2	83
4	**0.25**	**94**
5	0.3	64

Table S7: Reaction conditions: 4-*tert*-butylstyrene **1** (1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 equiv), LiBr (1.0 equiv), MeCN (4 mL), 15 mA current for 0.3 F/mol at room temperature, GC as anode and SS as cathode. [a]Yields were determined by GC-MS against an internal standard *n*-decane.

2.8 Control Experiments



Entry	Deviation from standard conditions	Yield[a] (%)
1	no current, rt	0
2	no current, 40 °C	0
3	no current, 80 °C	4
4	no electrodes, 80 °C	0

Table S8: Reaction conditions: 4-*tert*-butylstyrene (1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 equiv), LiBr (1.0 equiv), MeCN (4 mL), GC as anode and SS as cathode. [a]Yields were determined by GC-MS against an internal standard *n*-decane.

3. Mechanistic Investigations

3.1 Electricity On-Off Experiments

Electricity on-off experiments were performed on a 2.0 mmol scale. A mixture of 4-*tert*-butylstyrene **1** (2.0 mmol, 1.0 eq), $Fe(NO_3)_3 \cdot 9H_2O$ (2.0 mmol, 1.0 eq) and LiBr (2.0 mmol, 1.0 eq) in acetonitrile (8 mL) was placed in 10 mL IKA reaction vessel equipped with a teflon-coated stirring bar. *n*-Decane (100 µl, 0.51 mmol) was added as an internal standard for GC-MS in the beginning of the reaction. The reaction mixture was then subjected to the following sequence: reaction mixture was charged with X F/mol for Y min and then stirred at room temperature without current for additional Y min. At the end of each time interval, a 25 µl aliquot of the reaction mixture was filtrated through a short pot of silica gel (with 2 mL acetonitrile to ensure full eluation) and subjected to GC-MS analysis afterward. Changes in the amount of the reagents were assumed as small and neglected for the calculation of F/mol. Results of the experiments are presented on Figure S1 (with X = 0.03 F/mol, Y = 6 min and X = 0.01 F/mol, Y = 2 min), connected dots represent the time when the voltage was applied, and dots that are not connected represent the time when the voltage was not applied. Preparation of the first 4 samples for the experiment with 0.01 F/mol (each 2 min.) can lead to the quenching of reactive species (e.g., oxidation of radicals and Fe(II)) that are present in very low concentration in the reaction mixture. This may result in the observed long induction period.

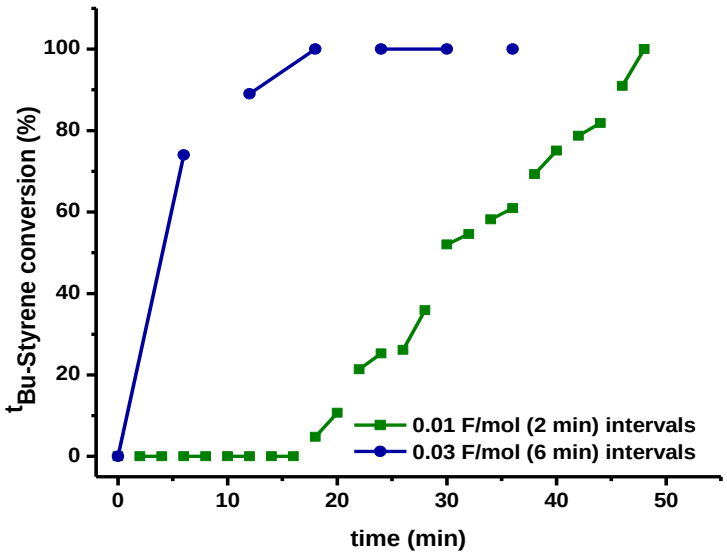
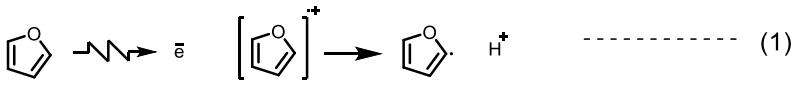


Figure S1. Graphical representation of electricity on-off experiments.

3.2 Pulse Radiolysis

Pulse radiolysis experiments were conducted at the Rapid Kinetics Facility at ETH Zürich (Febetron 705/2 MeV accelerator; 6 cm optical quartz cell). All experiments were performed under inert atmosphere (4 vacuum-argon cycles), THF was distilled twice over sodium under argon, immediately before performing experiments.

Pulse radiolysis is method utilizing extremely short pulses of strong γ irradiation with following analysis of absorption spectra on distinct wavelength in ns to μs diapason. Under the γ irradiation solvent is being ionized generating solvated electrons, which acts as reductant. Upon the initial trials we found out that acetonitrile is not suitable for the measurements, since the lifetime of forming electrons is extremely short and, presumably, they are being trapped by molecules of acetonitrile itself. While THF demonstrated suitability for the bromonitration reaction during optimization studies, we choose this solvent for the analysis of nitrate reduction. For THF the initial electron generation can be described by the following equation (1):



(1)

Aiming to study reduction of nitrate, we firstly checked iron(III) nitrate. However, absorption of iron was too high, making precise measurements of short-living species impossible. Thus, as a counter ion cesium was chosen, since it intensifies solubility in organic solvents and is not active in Ox-Red reactions. Upon pulse radiolysis of cesium nitrate solution, we observed short-living species, which absorb at 320–400 nm (Figure S2 & S3). Absorption spectra agrees with the previously reported data for NO_3^{2-} in water.[1]

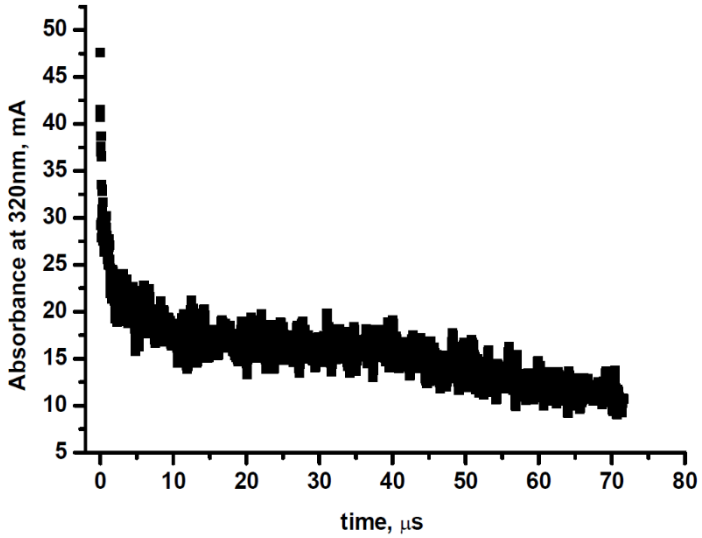


Figure S2. Absorption decay over time at 320 nm.

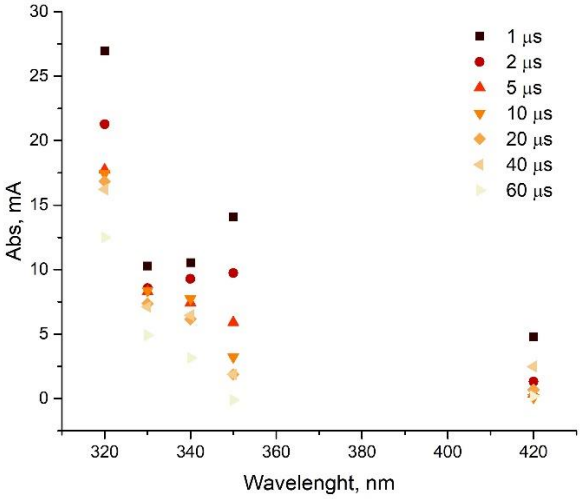


Figure S3. Absorbance spectrum of cesium nitrate after irradiation.

3.3 Cyclic Voltammetry (CV) Analysis

A series of cyclic voltammetry measurements were carried out using Ossila cyclic voltammetry setup. A platinum disc working electrode (2 mm diameter), a Pt-counter electrode and Ag^+ (0.01 M $AgNO_3$)/Ag was used as reference electrode. n-Tetrabutyl ammonium hexafluorophophate (0.1 M) was used as supporting electrolyte. The solution was degassed by sparging with argon for 30 min. Then the analyte was added and cyclic voltammetric measurements were carried out. Generally, a scan rate of 100 mVs^{-1} was used to measure the reaction components. 4-*tert*-Butylstyrene **1** (^{t}BuSty), LiBr and $Fe(NO_3)_3 \cdot 9H_2O$ were measured as 0.01 M solution in MeCN.

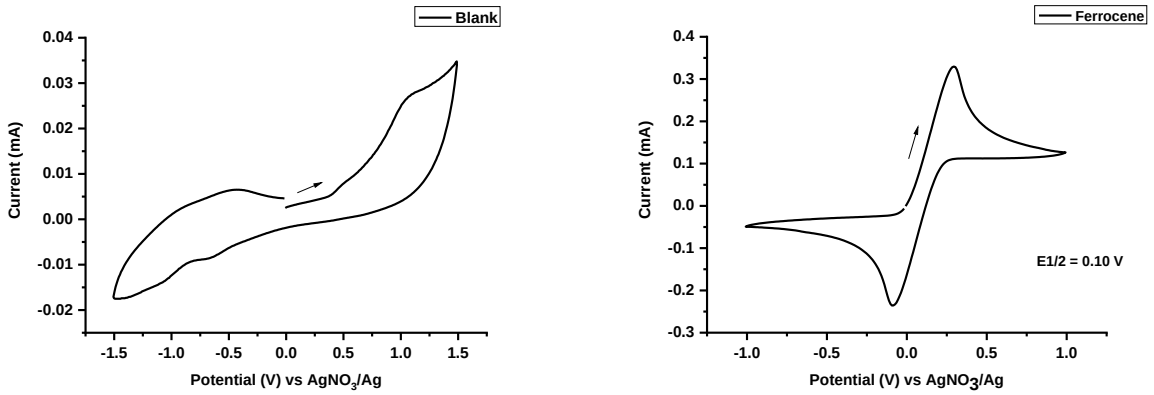


Figure S4. Left: Cyclic voltammetry measurements of blank solvent MeCN (0.1 M NBu_4PF_6). Scan rates - 100 mVs^{-1}. Right: Cyclic voltammetry measurements of ferrocene (0.01 M) in MeCN (0.1 M NBu_4PF_6). Scan rates - 100 mVs^{-1}.

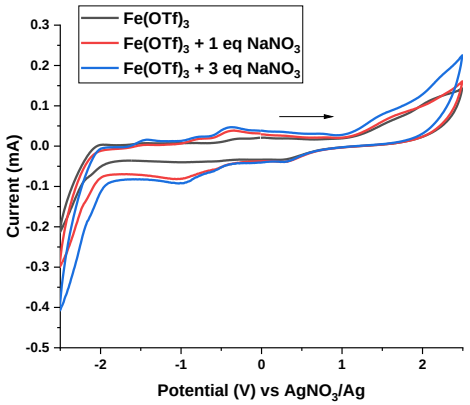


Figure S5. Cyclic voltammetry measurements of $Fe(OTf)_3$ and with $NaNO_3$.

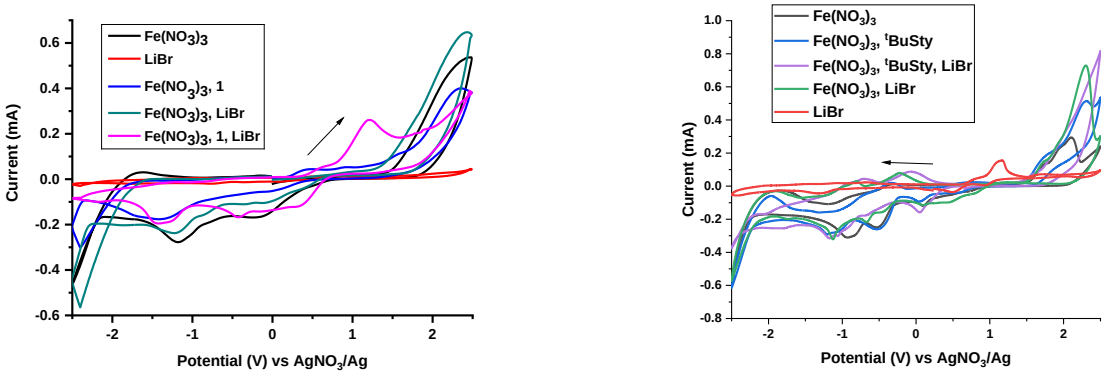


Figure S6. Cyclic voltammetry measurements of $Fe(NO_3)_3 \cdot 9H_2O$, LiBr, mixture of $Fe(NO_3)_3 \cdot 9H_2O$ and **1**, mixture of $Fe(NO_3)_3 \cdot 9H_2O$ and LiBr and reaction mixture in MeCN (0.1 M NBu_4PF_6). Scan rates - 100 mVs^{-1}. Left – positive direction, right – negative direction. Due to the rapid formation of the [Fe-Br] complex in solution and hence the low concentration of LiBr, the latter anodic peaks are suppressed. The appearance of anodic event is attributed to the possible ligand transfer step, and it is observed only in the presence of all components.

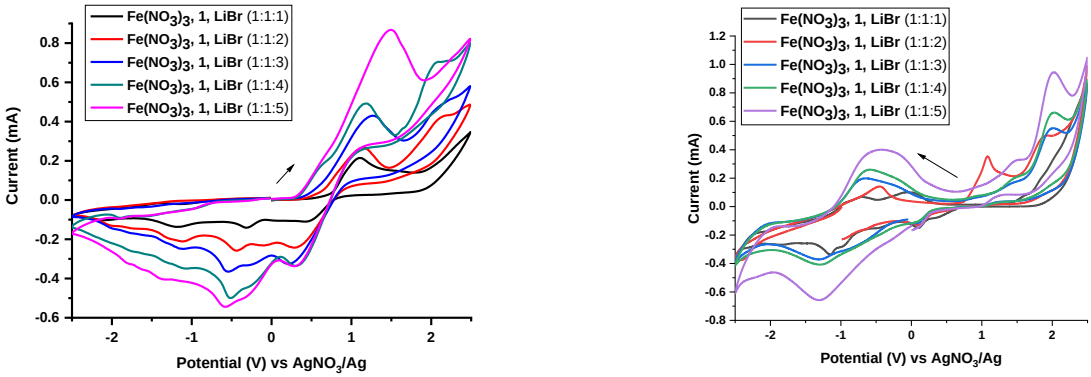


Figure S7. Cyclic voltammetry measurements of mixture of $Fe(NO_3)_3 \cdot 9H_2O$, 4-*tert*-butylstyrene **1**, and LiBr at different concentration of LiBr in MeCN (0.1 M NBu_4PF_6). Scan rates - 100 mVs^{-1}. Left – positive direction, right – negative direction.

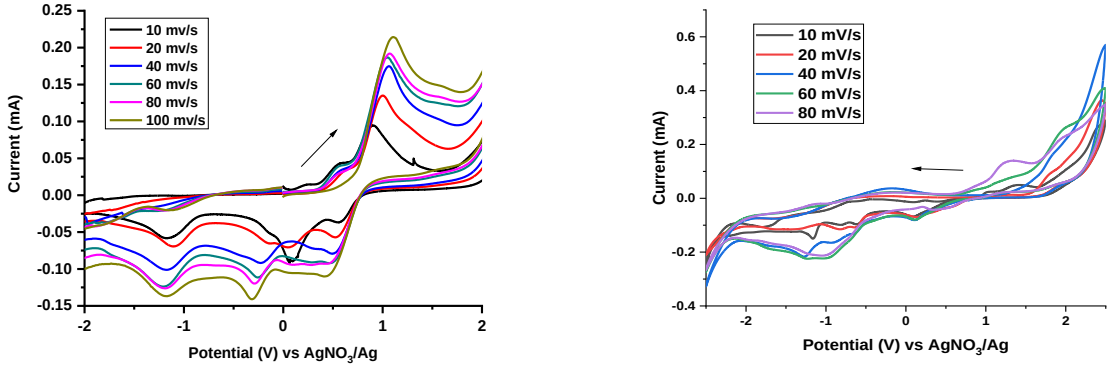


Figure S8. Cyclic voltammetry measurements of reaction mixture in MeCN (0.1 M NBu_4PF_6) at different scan rate from 10 mVs^{-1} to 100 mVs^{-1}. Left – positive direction, right – negative direction.

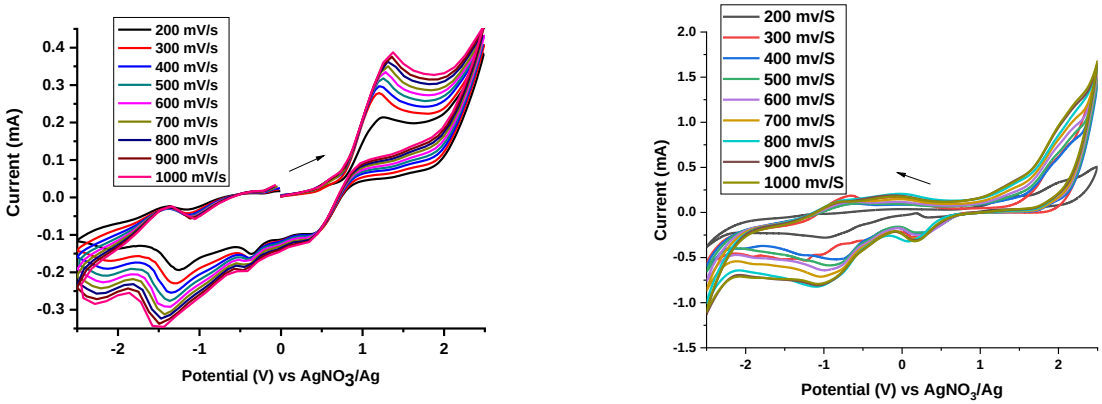
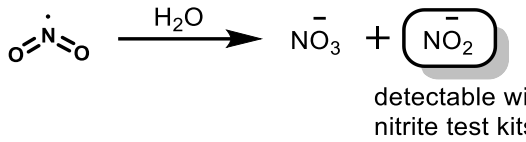


Figure S9. Cyclic voltammetry measurements of reaction mixture in MeCN (0.1 M NBu_4PF_6) at different scan rate from 200 mVs^{-1} to 1000 mVs^{-1}. Left – positive direction, right – negative direction.

3.4 Nitrite Tests

Presence of nitrite in the reaction mixture after aqueous hydrolysis indicates the existence of nitryl radical (eq. 2). Meanwhile, nitrite test kits are commercially available and do not interfere with many common anions, such as carboxylic acids or halogens (instructions should be checked for every test kit separately). Thus, we used this setup it as a conventional way to determine whether nitrous oxide is generated in the reaction media.



---------- (2)

While the outcome of **test C** (suppression of $\bullet NO_2$) may appear unexpected, we think that the Br_2 produced during the oxidation of Br^- may oxidize the nitryl radical in the acidic medium. To validate this, **test I** was repeated and Br_2 (1.0 equiv) was added subsequently after 5 min. As expected, a negative result was found, supporting the outcome of **test C**.

The nitrite test was performed with commercially available colorimetric test strips available from Merck (MQuant). According to the procedure provided by Merck, an aliquot (100 μL) of analyzing acetonitrile solution was diluted with 1 mL of water. Neutral pH was achieved upon the addition of NaOAc (approx. 20 mg/mL) and tested with universal pH test paper strips. After 5 min a few drops of the resulting aqueous solution were placed on the nitrite test strips, and the results were analyzed. Setup of the experiment is represented on the Figure S10. The analyzing solution was prepared as follows:

For electrochemical reactions:

Without any precautions to exclude air or moisture a 5 mL ElectraSyn vial with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv.), LiCl (1.0 mmol, 1.0 equiv.), alkene (1.0 mmol, 1.0 equiv.), and distilled MeCN (4.0 mL). The vial cap equipped with anode (graphite) and cathode (stainless steel) were inserted into the mixture. After stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol.

For reactions without electricity:

Each reactant (1.0 mmol), summarized in Table S9, was dissolved in 4 mL of MeCN and stirred at room temperature for 30 min before analysis.

Figure S10. Results of nitrite tests of reaction medias with colorimetric test strips (colorimetric, 2-80 mg/L (NO_2^-), MQuant, SKU: 1100070002). The results of nitrite tests are represented below in Table S9.

	A	B	C	D	E	F	G	H	I	J	K
Styrene	+										
1-Decene		+									
$Fe(NO_3)_3$	+	+	+	+				+	+		+
LiBr	+	+	+				+	+		+	
$LiNO_3$					+	+				+	
$Fe(OTf)_2$						+	+		+	+	
0.3 F/mol	+	+	+	+	+						
$[NO_2^-]$											

Table S9: Results of the nitrite tests.

3.5 X-ray Photoelectron Spectroscopy (XPS)

XPS measurements were carried out on an Axis Supra (Kratos Analytical) using the monochromated K X-ray line of an Aluminium anode. The pass energy was set to 40eV with a step size of 0.15 eV. The samples were electrically insulated from the sample holder and charge neutralization was used to limit charging effects. Data were fitted using CasaXPS following M. Biesinger et al[2] after having referenced the binding energy scale at 407.2 eV using residual nitrates observed on the N 1s orbital.

Samples for XPS were prepared according to General Procedure **GP4** in Glove Box under argon atmosphere. After completion of the reaction, reaction mixture was filtrated, solids were washed with dry acetonitrile and dried in vacuum. Resulting samples were closed under argon and transferred for measurements. Despite of the preciousness taken to exclude oxidation by oxygen from air, partial oxidation of the samples is possible during transfer to the measuring unit.

Three samples (**XPS.1**, **XPS.2**, **XPS.3**) were prepared as follows:

XPS.1: Inside glovebox, using an IKA ElectraSyn 2.0 with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol), LiBr (1.0 mmol), and MeCN (4 mL). The reaction was run for 0.3 F at a constant current of 15 mA using GC anode and SS cathode. The reaction mixture was filtered using a fritted glass. The residue was dried under high vacuum and then XPS was measured.

XPS.2: Inside glovebox, using an IKA ElectraSyn 2.0 with 4-*tert*-butylstyrene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4 mL). The reaction was run for 0.3 F at a constant current of 15 mA using GC anode and SS cathode. The reaction mixture was filtered using a fritted glass. The residue was dried under high vacuum and then XPS was measured.

XPS.3: Inside glovebox, using an IKA ElectraSyn 2.0 with 1-decene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol), LiBr (1.0 mmol), and MeCN (4 mL). The reaction was run for 0.3 F at a constant current of 15 mA using GC anode and SS cathode. The reaction mixture was filtered using a fritted glass. The residue was dried under high vacuum and then XPS was measured.

Composition of iron species for all 3 samples have similar pattern. Namely, a complex mixture of iron compounds was revealed. It includes iron hydrated oxides, and iron in oxidation state II, as well as a mixture of Fe(0), presumably from the stainless steel electrode. (Figure S11–S13). Composition of the components for samples presented in Table S10.

	Sample	**XPS.1**		**XPS.2**		**XPS.3**	
	Substrate	–		4-^{t}Bustyrene		1-decene	
Component	Position	Area	Part, %	Area	Part, %	Area	Part, %
Fe2p3 Fe(0)	707	2.88	0.02	0	0	62.43	0.3
Fe2p3 FeO	709	141.58	0.9	140.49	1.1	55.56	0.28

Fe2p3 FeO	710.3	175.55	1.1	174.21	1.4	68.89	0.35
Fe2p3 FeO	711.5	84.8	0.5	84.15	0.6	33.28	0.17
Fe2p3 FeO	712.7	149.65	1.0	148.5	1.1	58.72	0.3
Fe2p3 FeO	716	32.7	0.210465	32.45	0.25	12.83	0.06
Fe2p3 Fe2O3	710.2	34.3	0.2	493.44	3.8	140.9	0.7
Fe2p3 Fe2O3	711.2	31.55	0.2	453.97	3.5	129.63	0.7
Fe2p3 Fe2O3	712	24.01	0.15	345.41	2.7	98.63	0.5
Fe2p3 Fe2O3	713.1	12.9	0.08	185.53	1.4	52.98	0.27
Fe2p3 Fe2O3	714.1	12.86	0.08	185.04	1.4	52.84	0.27
Fe2p3 Fe2O3	719.4	12	0.08	172.71	1.3	49.31	0.25
Fe2p3 FeOOH	710.7	4011.4	25.8	3072.2	23.9	5101	25.9
Fe2p3 FeOOH	711.7	3931.1	25.3	3010.8	23.5	4999	25.4
Fe2p3 FeOOH	712.6	3048.6	19.6	2334.9	18.2	3876.8	19.7
Fe2p3 FeOOH	713.7	1676.7	10.8	1284.2	10.01326	2132.2	10.8
Fe2p3 FeOOH	714.8	922.61	5.9	706.62	5.5	1173.2	6.0
Fe2p3 FeOOH	720.1	1231.5	7.9	--	0	1566	8.0
Total area		15536.7		12824.66		19664.35	

Table S10: Composition of components in samples **XPS.1**, **XPS 2**, and **XPS.3** measured by XPS.

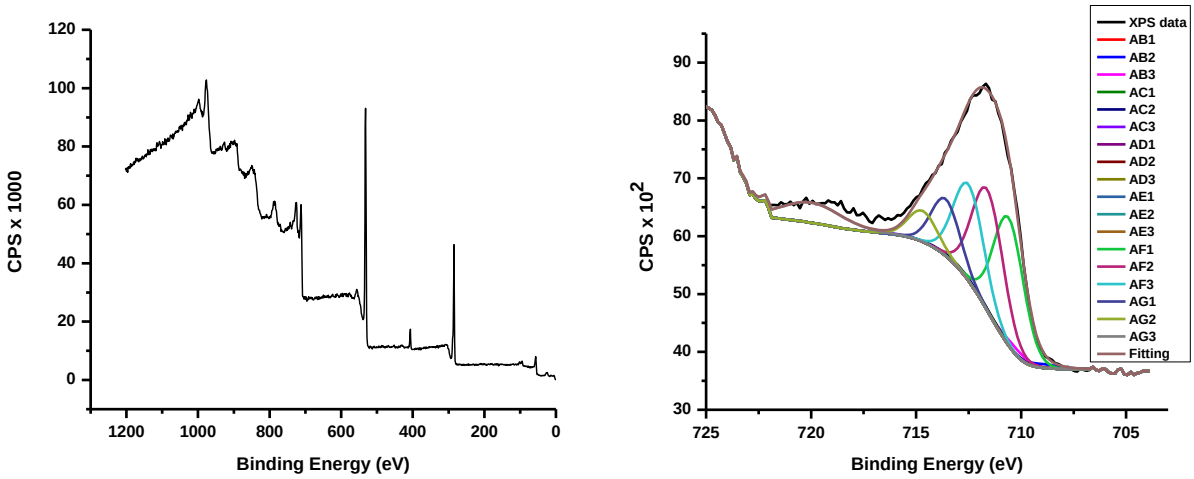


Figure S11. XPS spectra of sample **XPS.1**. Full range (left) and iron-components (right).

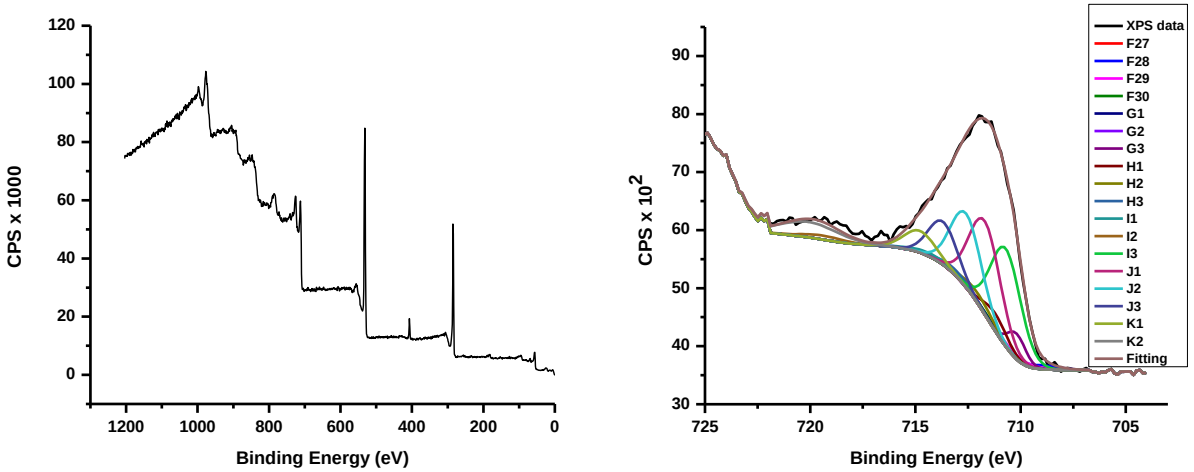


Figure S12. XPS spectra of sample **XPS.2**. Full range (left) and iron-components (right).

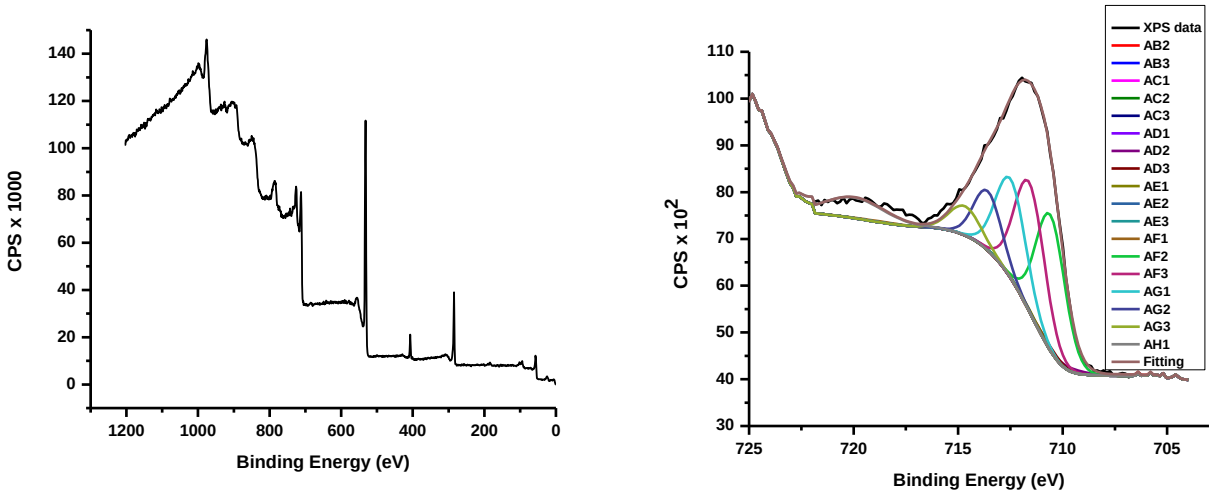
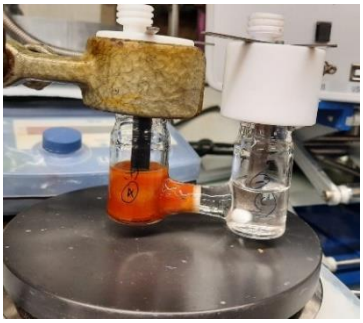
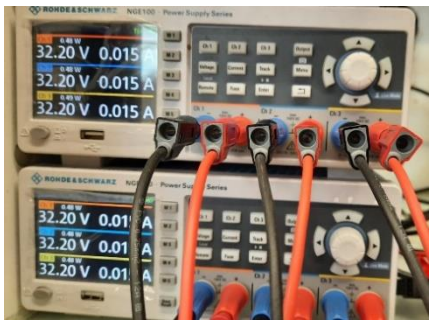


Figure S13. XPS spectra of sample **XPS.3**. Full range (left) and iron-components (right).

3.6 Reaction Studies in Divided Cell

Without any precautions to exclude air or moisture, one compartment of a divided cell (P4 frit was used) bearing a teflon coated magnetic stir bar was charged with **1** (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (8.0 mL) and another compartment was charged with electrolyte NBu_4PF_6 (1.0 mmol, 1.0 equiv). The vial cap equipped with anode and cathode was inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current for 1 hour at room temperature using graphite carbon as an anode and stainless steel as a cathode. The resulting reaction mixture was analyzed by GC-MS. The results on table S11 suggest the cathodic event as an essential process and the reaction is initiated by the reduction of ferric nitrate.





Entry	Cathode (SS)	Anode (GC)	Results	
			2 (cathodic chamber)	**2** (anodic chamber)
1	NBu_4PF_6	**1,** $Fe(NO_3)_3 \cdot 9H_2O$, LiBr	-	~5%
2	**1,** $Fe(NO_3)_3 \cdot 9H_2O$, LiBr	NBu_4PF_6	~80%	-

Table S11: Control experiments have been performed in the divided cell.

3.7 Hammett Studies

Hammett studies were performed for the bromonitration reaction. The measured k_R/k_H value was obtained based on the conversion of substituted styrene derivatives. A mixture of 5 *para*-substituted styrenes (1.0 mmol) was introduced under the standard reaction conditions (1.0 mmol of reagents), together with n-decane as internal standard Before the beginning and after completion of the reaction, an aliquot (0.1 mL) was taken, filtered through silica gel (with 2 mL of MeCN as eluent) and subjected to GC-MS analysis. The conversion was determined by the change in relative area of starting materials peaks.[3,4] The Hammett studies reviled correlation between the speed of the reaction with σ_{para} constants[5] with $\rho = -0.2$ (Figure S14). For accuracy, measurements were carried out twice, and the average data of two experiments are presented in the table below.

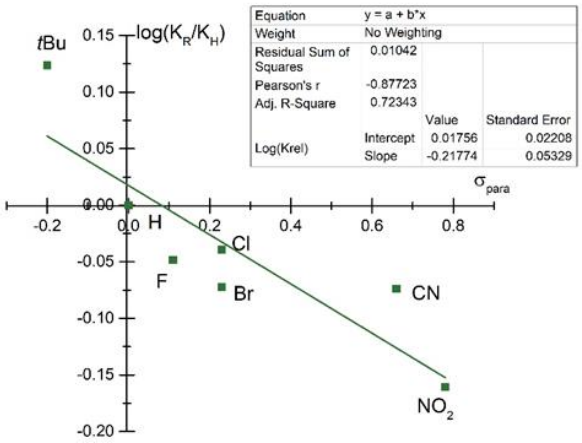


Figure S14. Hammett plot for the reaction of various *p*-substituted styrenes.

R, substituent in *para* position	**σ_{para}**	$\frac{S/S_{n-decane}}{S^0/S^0_{n-decane}}$	**ln(conversion)**	$K_{rel} = \frac{ln(conversion)_R}{ln(conversion)_H}$	**$\log_{10}(K_{rel})$**
***t*Bu**	-0.17	0.66	-0.41	1.3	0.12
H	0	0.73	-0.31	1	0
F	0.11	0.76	-0.28	0.89	-0.048
Br	0.23	0.77	-0.26	0.85	-0.072
Cl	0.23	0.75	-0.28	0.91	-0.039
CN	0.66	0.77	-0.26	0.84	-0.074
NO_2	0.78	0.81	-0.21	0.69	-0.16

Table S12: Raw data for the determination of influence of electronic properties of *para* substituents in styrenes on reaction rate.

3.8 Control Experiments

3.8.1 Radical clock experiment with 1-chloro-4-(1-cyclopropylvinyl)benzene 3

Without any precautions to exclude air or moisture an ElectraSyn vial (5 mL) bearing a teflon coated magnetic stir bar was charged with 1-chloro-4-(1-cyclopropylvinyl)benzene **3** (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). The vial cap equipped with anode and cathode was inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current. The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated in vacuum. An aliquot was analyzed by ^{1}H-NMR.

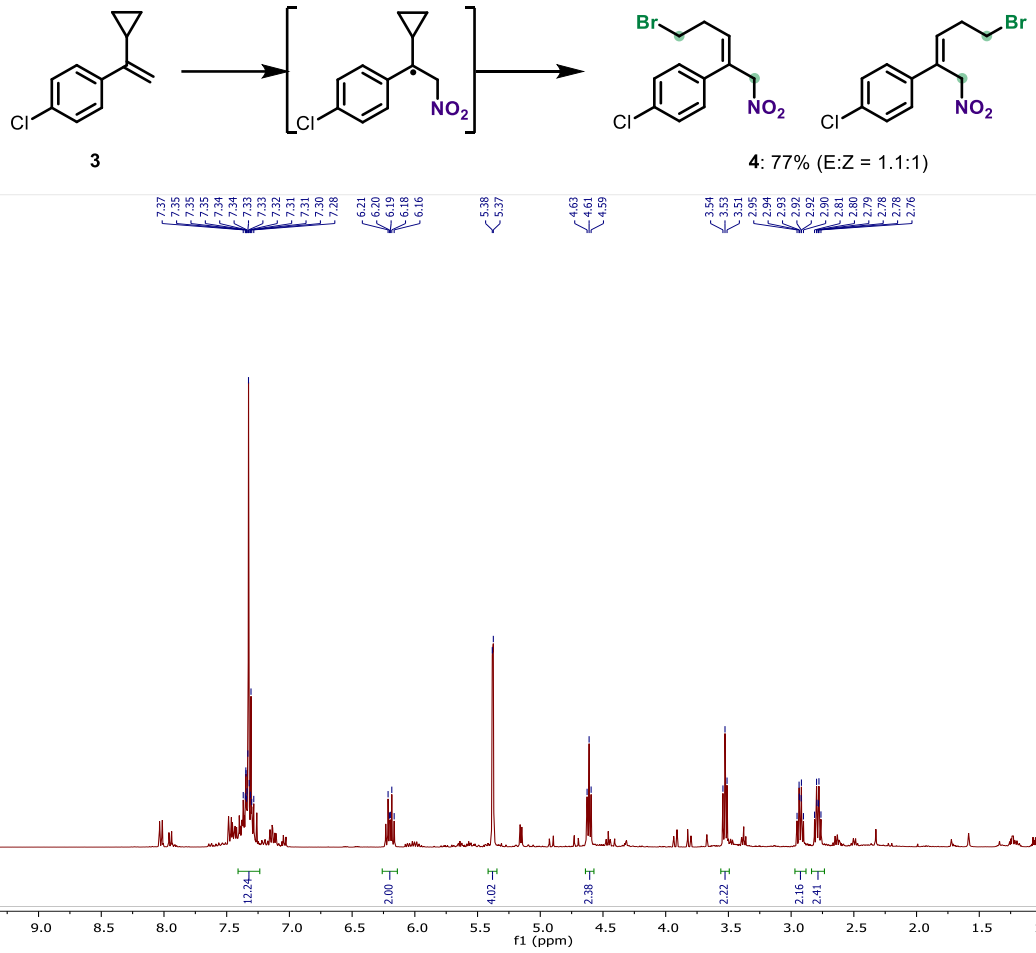
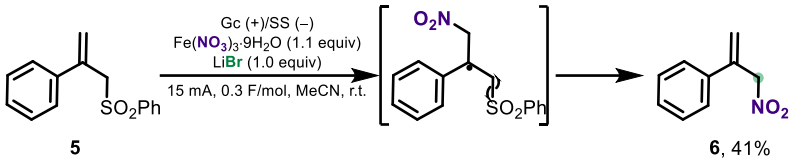


Figure S15. ^{1}H-NMR of reaction mixture of **4**.

3.8.2 Radical clock experiment with ((2-phenylallyl)sulfonyl)benzene 5

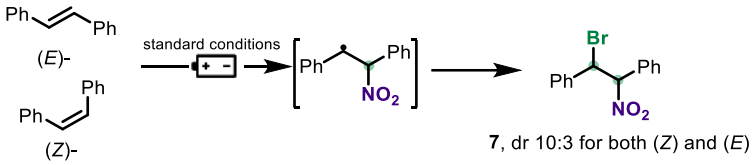
Without any precautions to exclude air or moisture an ElectraSyn vial (5 mL) with a stir bar was charged with ((2-phenylallyl)sulfonyl)benzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). The vial cap equipped with anode and cathode was inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed

at a constant current. The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated under reduced pressure. The product was purified *via* column chromatography.



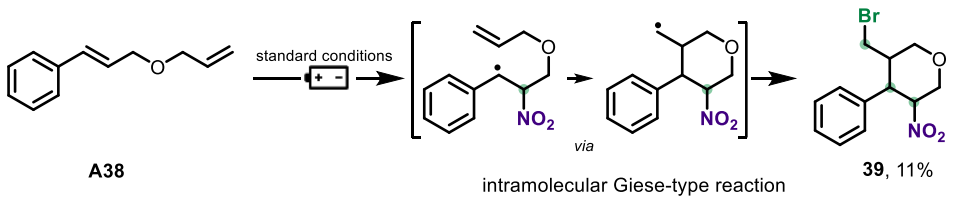
3.8.3 Reaction with (E)- and (Z)-stilbene

Without any precautions to exclude air or moisture a ElectraSyn vial (5 mL) with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), stilbene (1.0 mmol, 1.0 equiv), and distilled MeCN (4 mL). The vial cap equipped with graphite carbon anode and stainless-steel cathode was inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol. The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated under reduced pressure and analyzed by ^{1}H NMR. The crude mixture was purified by flash column chromatography on silica gel using EtOAc/hexane eluent to afford the desired product.



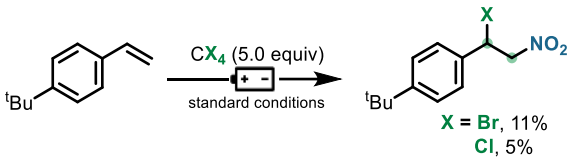
3.8.4 Reaction with (E)-(3-(allyloxy)prop-1-en-1-yl)benzene A38

Without any precautions to exclude air or moisture a ElectraSyn vial (5 mL) with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), (*E*)-(3-(allyloxy)prop-1-en-1-yl)benzene (1.0 mmol, 1.0 equiv), and distilled MeCN (4 mL). The vial cap equipped with graphite carbon anode and stainless-steel cathode was inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol. The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated under reduced pressure. The crude mixture was purified by flash column chromatography on silica gel using EtOAc/hexane eluent to afford the desired product.



3.8.5 Radical trapping experiments

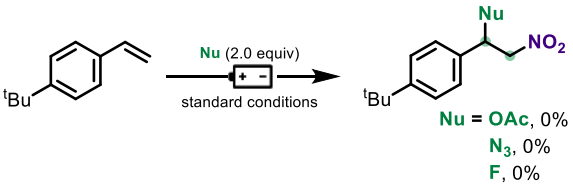
Without any precautions to exclude air or moisture a ElectraSyn vial (5 mL) with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), CX_4 (5.0 mmol, 5.0 equiv), 1-(*tert*-butyl)-4-vinylbenzene **1** (1.0 mmol, 1.0 equiv), and distilled MeCN (4 mL). The vial cap equipped with graphite carbon anode and stainless-steel cathode were inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol. The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated in vacuum. Reaction mixture was analyzed by GC-MS using n-decane as internal standard.



3.8.6 Reaction with nucleophiles

Without any precautions to exclude air or moisture a ElectraSyn vial (5 mL) with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), NaOAc (2.0 mmol, 2.0 equiv), 1-(*tert*-butyl)-4-vinylbenzene **1** (1.0 mmol, 1.0 equiv), and distilled MeCN (4 mL). The vial cap equipped with graphite carbon anode and stainless-steel cathode were inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol. The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). GC-MS of the reaction mixture was checked, and acetated incorporated product was not observed.

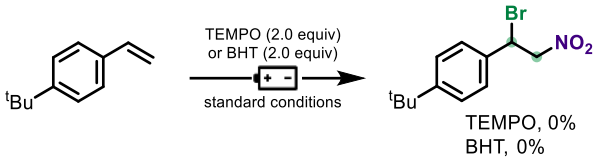
The above procedure was repeated using KF (2.0 mmol, 2.0 equiv) and NaN_3 (2.0 mmol, 2.0 equiv) instead of sodium acetate. However, fluoride or azide incorporated products were not observed by GC-MS.



3.8.7 Reaction with radical inhibitors

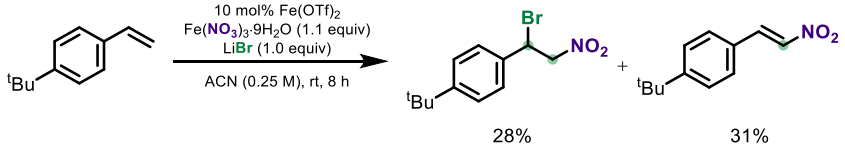
Without any precautions to exclude air or moisture a ElectraSyn vial (5 mL) with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), TEMPO (2.0 mmol, 2.0 equiv), 1-(*tert*-butyl)-4-vinylbenzene (1.0 mmol, 1.0 equiv), and distilled MeCN (4 mL). The vial cap equipped with graphite carbon anode and stainless-steel cathode were inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol.

The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). GC-MS of the reaction mixture was checked, and the desired product **2** was not observed. Similar result was found when butylated hydroxytoluene (BHT) was used as radical inhibitor in the reaction mixture instead of TEMPO.



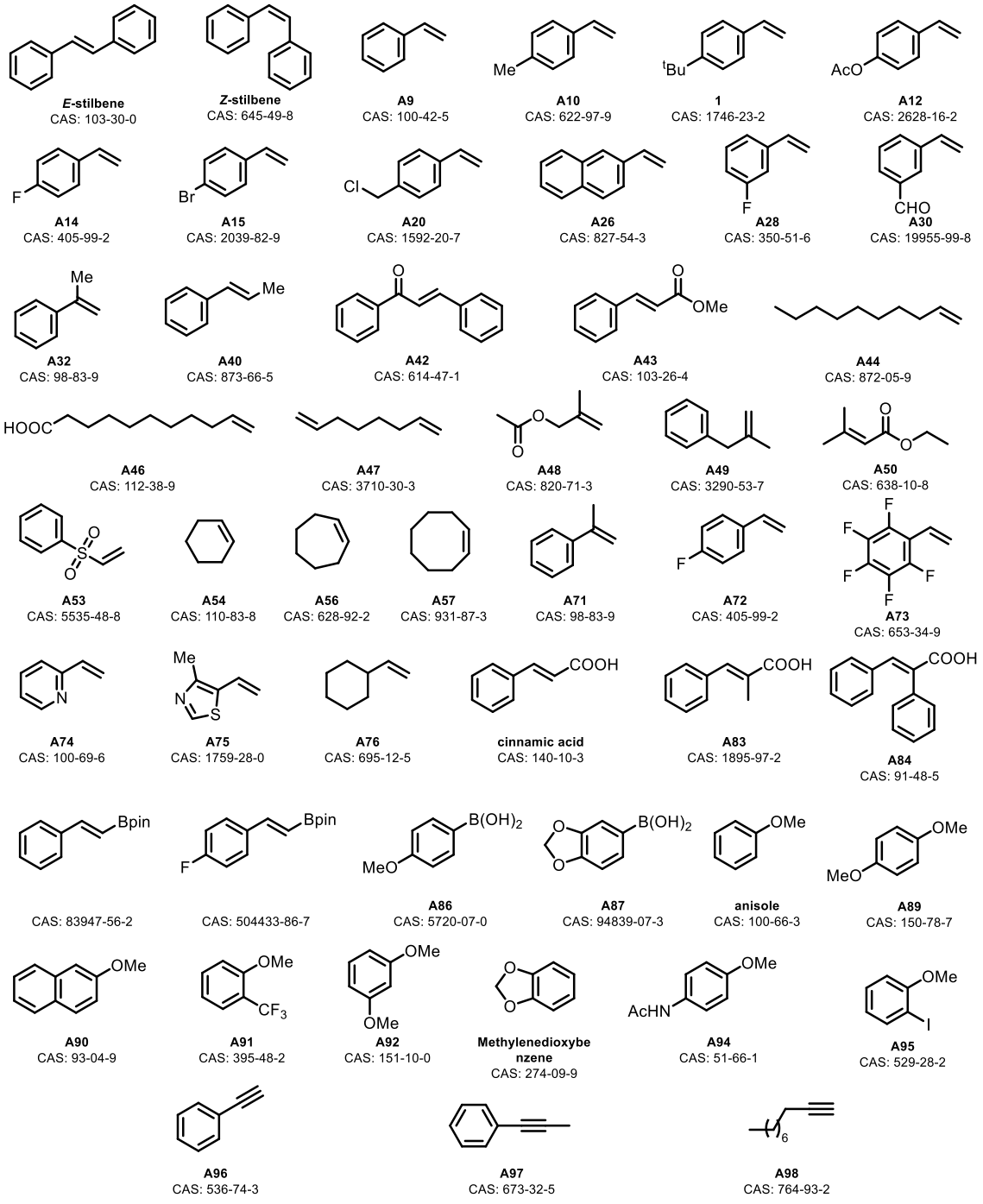
3.8.8 Reaction with iron (II) triflate

Without any precautions to exclude air or moisture a vial with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), $Fe(OTf)_2$ (0.1 mmol, 0.1 equiv), 1-(*tert*-butyl)-4-vinylbenzene **1** (1.0 mmol, 1.0 equiv), and distilled MeCN (4 mL). The vial was capped and stirred at room temperature for 8 h. An aliquot was analyzed by GC-MS.



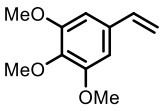
4. Synthesis of Substrates

4.1 Commercially Available Starting Materials

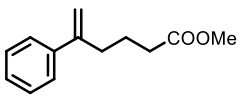


4.2 Prepared Complex Alkenes

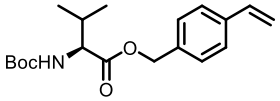
The following starting materials were prepared according to reported literature procedures.



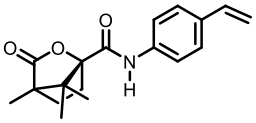
A31



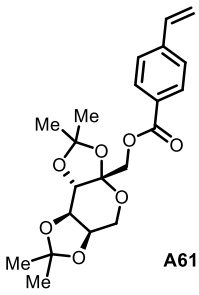
A36



A59

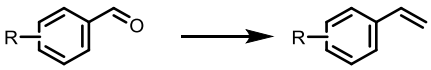


A60



A61

4.3 General Procedures for Synthesis of A14-15, A24, A33, A34-35:

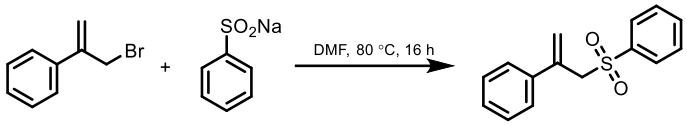


GP1: A mixture of methyltriphenylphosphonium bromide (11.0 mmol, 1.1 equiv) and potassium carbonate (16.0 mmol, 1.6 equiv) was stirred in 150 mL of 1,4-dioxane under a nitrogen atmosphere at room temperature for 4 h in a 250 mL 2-necked round bottom flask. Corresponding benzaldehyde (10 mmol, 1.0 equiv) was added dropwise to the reaction mixture and then stirred at 100 °C. After reaction completion (checked by TLC), the flask was cooled to room temperature. The reaction mixture was filtered, and solvents were removed under reduced pressure. The products were purified by silica gel chromatography.

GP2: A mixture of methyltriphenylphosphonium bromide (15.0 mmol, 1.5 equiv.) in dry THF (700 mL) was cooled to 0 °C under Ar atmosphere. Then, *n*-BuLi (1.6 M solution in hexane,15.0 mmol, 1.5 equiv) was added slowly under stirring. The orange mixture was stirred under Ar atmosphere at 0 °C for 4 h. Corresponding benzaldehyde (10 mmol, 1.0 equiv) was added dropwise to the reaction mixture and then stirred at room temperature. After reaction completion (checked by TLC), the reaction mixture was filtered, and solvents were removed under reduced pressure. The products were purified by silica gel chromatography.

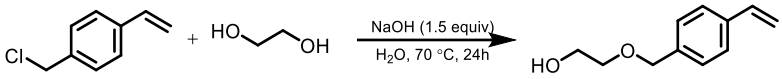
4.4 Synthesis of Alkenes 5, A22-25, A37-38, A58:

((2-Phenylallyl)sulfonyl)benzene [CAS 74866-37-8] **(5):**



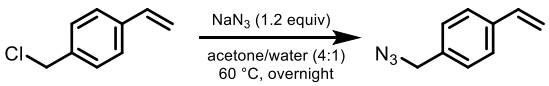
In a 50 mL round bottom flask, *p*-toluenesulfinate (1.26 g, 7.69 mmol, 1.5 equiv) was added to the solution of 3-bromo-2-phenyl-1-propene (1.0 g, 5.13 mmol, 1.0 equiv) in dry DMF (15 mL). The reaction mixture was stirred 16 h at 80 °C. The solution was cooled to room temperature, quenched with water (15 mL) and extracted with EtOAc (20 mL × 3). The combined organic phase was washed with brine, dried over anhydrous $MgSO_4$ and concentrated under reduced pressure. The titled compound was purified by flash column chromatography on silica gel (hexane/EtOAc = 4/1). Compound **5** was isolated as white solid (83% yield, 5% hexane in ethyl acetate as eluent).

2-((4-Vinylbenzyl)oxy)ethan-1-ol (A22):



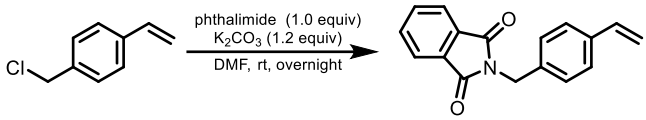
To a solution of 4-vinylbenzyl chloride (20.0 mmol, 1.0 equiv) sodium hydroxide (20 mmol, 1.0 equiv) and water (20.0 mmol, 1.0 equiv) ethylene glycol (530 mmol, 27.0 equiv) was added at room temperature and the reaction mixture was stirred at 70 °C for 24 h. The reaction was cooled to room temperature and water (100 mL) was added. Next, the solution was extracted with Et_2O (100 mL × 3). The combined organic phase was washed with brine, dried over $MgSO_4$, and concentrated under vacuum. The crude product was purified by flash column chromatography on silica (hexane/EA = 7:3) to afford the titled compound as yellow oil (65% yield, 8% hexane in ethyl acetate as eluent).

1-(Azidomethyl)-4-vinylbenzene (A23):



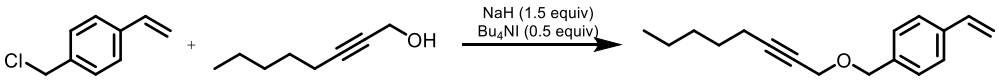
4-Vinylbenzyl chloride (12.0 mmol, 1.0 equiv) was added to a solution of sodium azide (14.4 mmol, 1.2 equiv) in 50 mL mixture of acetone and water (4:1). The mixture was stirred at 60 °C for overnight. Next, the product was extracted with Et_2O (50 mL × 3). The combined organic layer was washed with brine and dried over $MgSO_4$. The crude was concentrated under reduced pressure and purified by flash column chromatography on silica gel. The titled compound was isolated as yellow liquid (93% yield, 5% hexane in ethyl acetate as eluent).

2-(4-Vinylbenzyl)isoindoline-1,3-dione (A24):



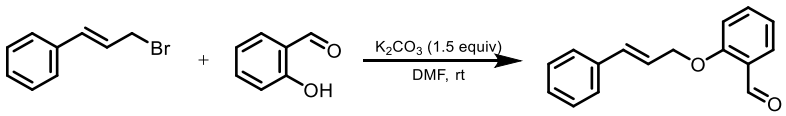
4-Vinylbenzyl chloride (10.0 mmol, 1.0 equiv) was added to a solution of phthalimide (10 mmol, 1.0 equiv) in DMF (0.2 M). The mixture was stirred at room temperature for overnight. Next, the product was extracted with Et_2O (50 mL × 3). The combined organic layer was washed with saturated $NaHCO_3$, brine and dried over $MgSO_4$. Upon filtration and organic solvents were removed under reduced pressure and the crude was purified by flash column chromatography on silica gel. The titled compound was isolated as a white solid (84% yield, 10% hexane in ethyl acetate as eluent).

1-((oct-2-yn-1-yloxy)methyl)-4-vinylbenzene (A25):



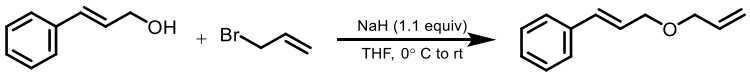
To a solution of 2-octyn-1-ol (7.21 mmol, 1.1 equiv) in distilled THF (10 mL) was added sodium hydride (9.83 mmol, 1.5 equiv, 60% dispersion) at 0 °C and the reaction mixture was stirred at room temperature for 1 h. Then 4-vinylbenzyl chloride (6.55 mmol, 1.0 equiv) and Bu_4NI (3.28 mmol, 0.5 equiv) was dissolved in THF (10 mL) and slowly added to the reaction mixture. The resulting mixture was stirred under reflux for 16 h. The solvent was removed under reduced pressure. Next, DCM (50 mL) and water (25 mL) were added and extracted with DCM (50 mL× 3). The combined organic phase was washed with brine, dried over $MgSO_4$ and concentrated under vacuum. The crude product was purified by flash column chromatography on silica (hexane/EA = 6:1) to afford the titled compound as a colorless liquid (78% yield, 5% hexane in ethyl acetate as eluent).

2-[(*E*)-(3-Phenyl-2-propenyl)oxy]benzaldehyde (A37):



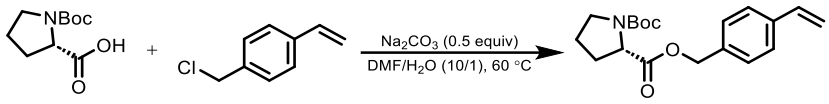
To a solution of salicylaldehyde (10.0 mmol, 1.0 eq.) and K_2CO_3 (12.0 mmol, 1.2 equiv) in DMF (15 mL) was added cinnamyl bromide (12.0 mmol, 1.2 equiv) at room temperature under constant stirring during 10 minutes. The mixture was then additionally stirred for 24 h. The organic layer was extracted with EtOAc (30 mL × 3). The combined organic layer was washed with brine, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The titled compound was purified by flash column chromatography on silica gel and isolated as a white solid (90% yield, 10% hexane in ethyl acetate as eluent).

(*E*)-(3-(Allyloxy)prop-1-en-1-yl)benzene (A38):



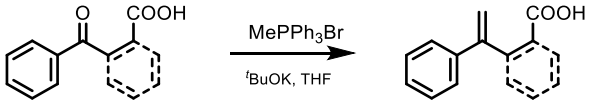
A solution of (*E*)-3-phenylprop-2-en-1-ol (10.0 mmol, 1.0 equiv) in dry THF (10 mL) was added slowly to a suspension of NaH (60%, dispersion in paraffin oil, 11.0 mmol, 1.1 equiv) in THF (20 mL) at 0 °C under constant stirring and under argon atmosphere. The mixture was warmed to room temperature and then stirred for additional 2 h. Next, the reaction mixture was cooled to 0 °C and a solution of allyl bromide (11.0 mmol, 1.1 equiv) in THF (10 mL) was added via syringe. The resulting mixture was stirred at room temperature for 16 h. Upon colling to 0 °C and the solution was quenched with water. The organic layer was extracted with diethyl ether (30 mL × 3). The combined organic layer was washed with brine, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude was purified by flash column chromatography on silica gel. The titled compound was isolated as colorless oil (74% yield, 5% hexane in ethyl acetate as eluent).

1-(*tert*-Butyl)-2-(4-vinylbenzyl)-(S)-pyrrolidine-1,2-dicarboxylate (A58):



To a solution of (*tert*-butoxycarbonyl)-L-proline (10.0 mmol, 1.0 equiv) and Na_2CO_3 (5.0 mmol, 0.5 equiv) in 40 mL DMF:H_2O (10:1), 1-(chloromethyl)-4-vinylbenzene (10.0 mmol, 1.0 equiv) was added dropwise. The suspension was stirred overnight at 60 °C. The reaction mixture was cooled to room temperature and aq. solution of HCl (1.0 M) (20 mL) was added. The mixture was extracted with EtOAc (50 mL × 3). The combined organic phases were dried over $MgSO_4$ and concentrated under vacuum. The crude was purified by chromatography on silica gel (hexane/EtOAc = 7:3). The titled compound was isolated as a colorless viscous oil (80%).

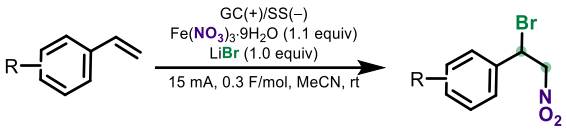
4.4 General Procedure for Synthesis of A81-82



GP3: To a suspension of methyltriphenylphosphonium bromide (40.0 mmol, 2.0 equiv.) in THF (200 mL) was added potassium *tert*-butoxide (60.0 mmol, 3.0 equiv.) at 0 °C under nitrogen atmosphere. The mixture was stirred at room temperature for 2 h. Corresponding carbonyl compound (20 mmol, 1.0 equiv.) was added slowly to the reaction mixture and then stirred at room temperature overnight. After reaction completion (checked by TLC), the flask was cooled to room temperature and solvent was removed under vacuum. Then residue was diluted with dichloromethane (100 mL) and treated with aqueous NaOH (1 M, 100 mL). The aqueous layer was separated, washed with dichloromethane (100 mL), and acidified with conc. HCl to pH 1. Combined organic solvent was evaporated and the corresponding product was purified by silica gel chromatography.

5. General Procedures for Electrocatalytic Nitration

5.1 Bromonitration of Alkenes



GP4: Without any precautions to exclude air or moisture a 5 mL ElectraSyn vial with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv.), LiBr (1.0 mmol, 1.0 equiv), alkene (1.0 mmol, 1.0 equiv.), and distilled MeCN (4.0 mL). The vial cap equipped with anode (graphite) and cathode (stainless steel) were inserted into the mixture. After pre-stirring for 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol (approx. time 40 mins). The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated under reduced pressure. The crude material was purified by flash column chromatography on silica gel using EtOAc/hexane to give the desired product. Both the anode and cathode were cleaned and reused without impact on the reaction yield. The following setup in Electrasyn 2.0 was employed:

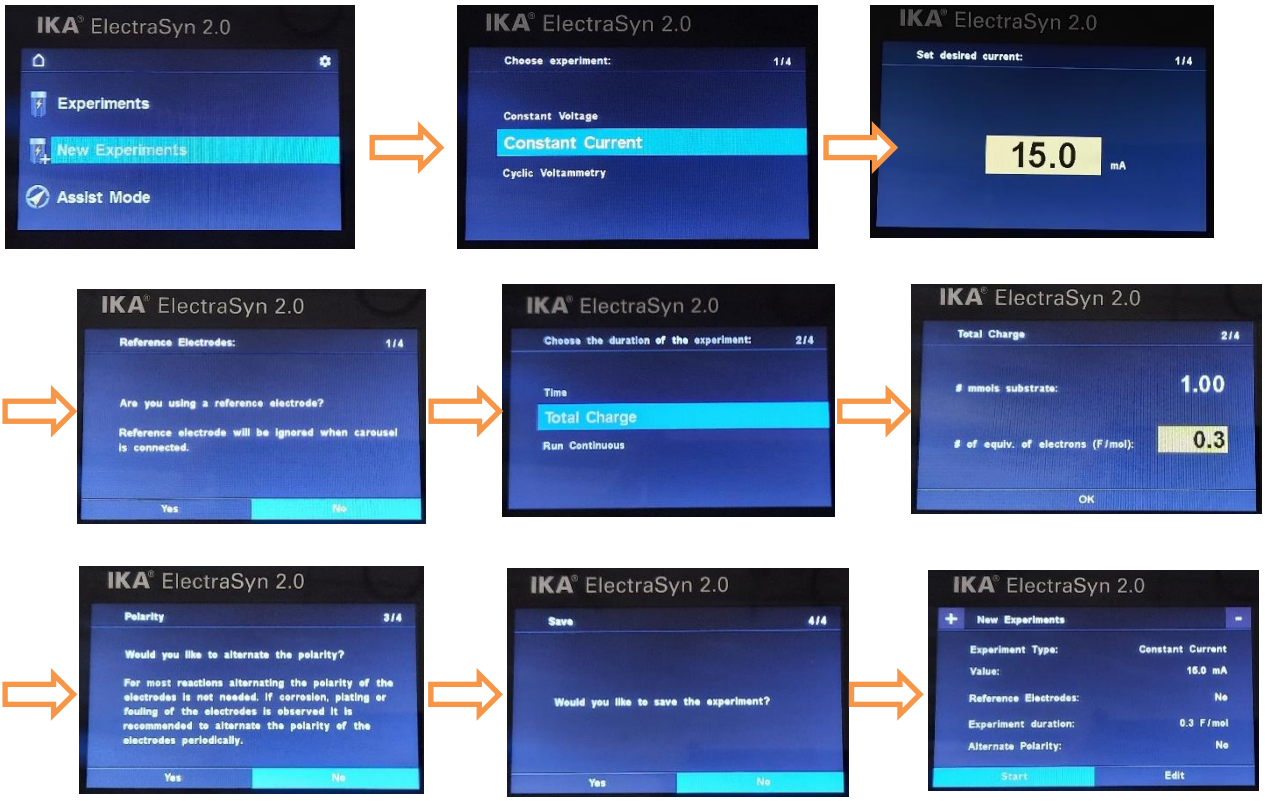
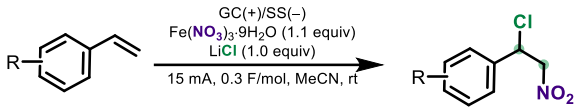


Figure S16. Graphical representation of the reaction setup for bromonitration reactions using ElectraSyn.

5.2 Chloronitration of Alkenes



GP5: Without any precautions to exclude air or moisture a 5 mL ElectraSyn vial with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv.), LiCl (1.0 mmol, 1.0 equiv), alkene (1.0 mmol, 1.0 equiv), and distilled MeCN (4.0 mL). The vial cap equipped with anode (graphite) and cathode (stainless steel) were inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol (see individual compounds) (approx. time 40 mins). The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated under reduced pressure. The crude material was purified by flash column chromatography on silica gel using EtOAc/hexane to give the desired product. The following setup in ElectraSyn 2.0 was employed:

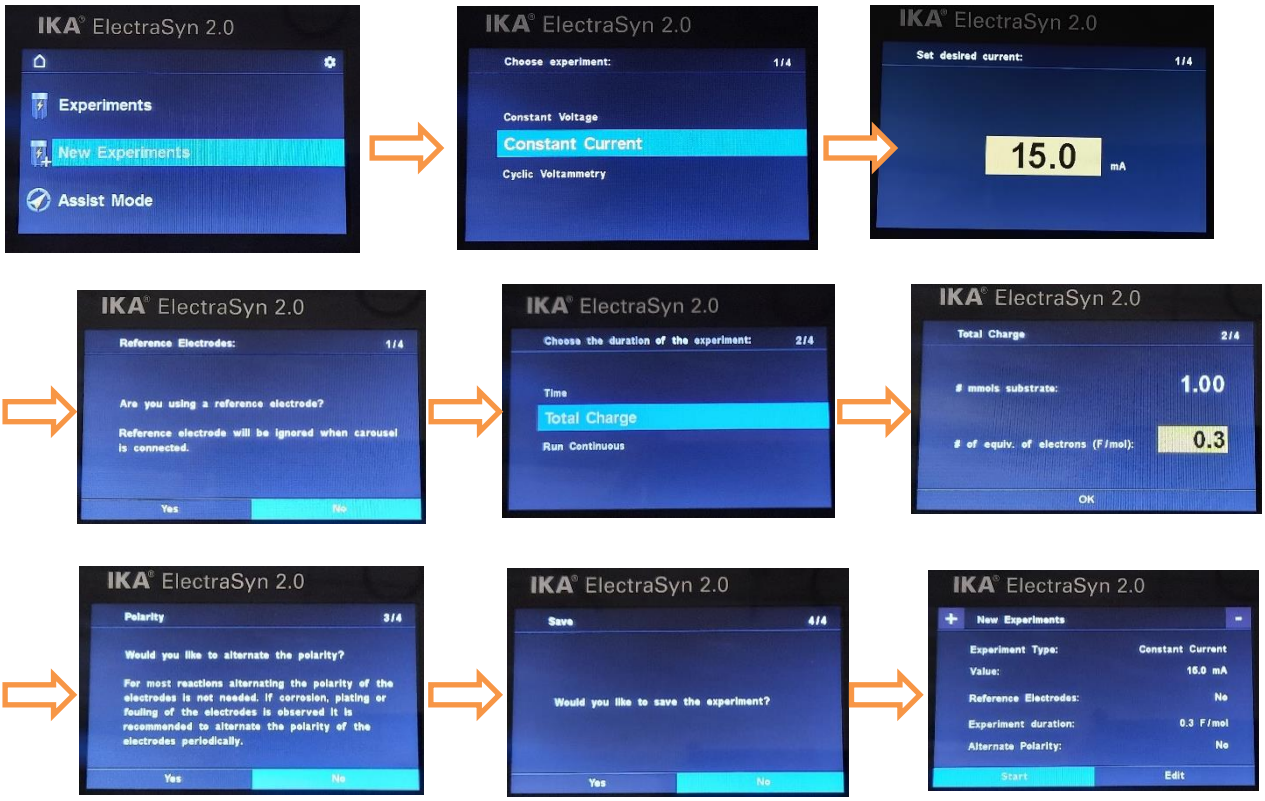
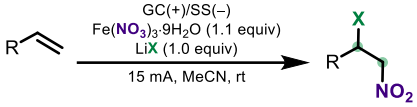


Figure S17. Reaction set-up, optimization on ElectaSyn 2.0.

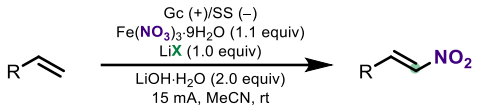
5.3 Large-scale Synthesis



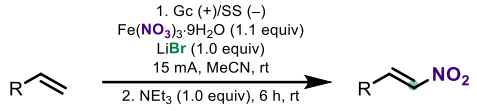
GP6: Without any precautions to exclude air or moisture a 1 L reactor was charged with alkene (20.0 g, 1.0 equiv.), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 equiv.), LiBr (1.0 equiv.) or LiCl (1.0 equiv), and distilled MeCN (2.5 M). The reactor was further equipped with graphite anode (10.0 cm × 2.0 cm × 0.2 cm) and stainless steel cathode (10.0 cm × 2.0 cm × 0.2 cm). After pre-stirring for about 10 minutes using a mechanical stirrer, the reaction mixture was electrolyzed at a constant current of 15 mA. The reaction was monitored by thin layer chromatography (TLC). After completion of the reaction electrodes were rinsed with MeCN (5 mL). The resulting reaction mixture was filtered and concentrated under reduced pressure. The crude material was purified by flash column chromatography on silica gel using EtOAc/hexane to give the desired product. The following setup was employed:

Figure S18. Reaction setup for decagram-scale.

5.4 Direct Nitration of Alkenes

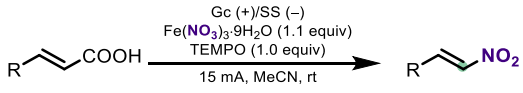


GP7: Without any precautions to exclude air or moisture a 5 mL ElectraSyn vial with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv.) or LiCl (1.0 mmol, 1.0 equiv), alkene (1.0 mmol, 1.0 equiv), $LiOH \cdot H_2O$ (2.0 mmol, 2.0 equiv), and distilled MeCN (4.0 mL). The vial cap equipped with anode (graphite) and cathode (stainless steel) were inserted into the reaction mixture. After pre-stirring for 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA until complete consumption of starting material (monitored by TLC). The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated in vacuum. The crude material was purified by flash column chromatography on silica to give the desired product.



GP8: Without any precautions to exclude air or moisture a 5 mL ElectraSyn vial with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), alkene (1.0 mmol, 1.0 equiv), and distilled MeCN (4.0 mL). The vial cap equipped with anode (graphite) and cathode (stainless steel) were inserted into the mixture. After pre-stirring for 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol. The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). To the reaction mixture triethylamine (1.0 mmol, 1.0 equiv) was added and stirred at room temperature for 6 h. Then distilled water (5 mL) was added and extracted with ethyl acetate (10 mL × 3). The resulting reaction mixture was dried over $MgSO_4$ and concentrated in vacuum. The crude material was purified by flash column chromatography on silica gel to give the desired product.

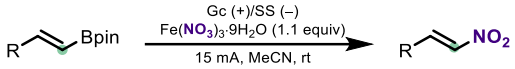
5.5 Decarboxylative Nitration



GP9: Without any precautions to exclude air or moisture a 5 mL ElectraSyn vial with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv) or LiCl (1.0 mmol, 1.0 equiv.), alkene (1.0 mmol, 1.0 equiv), $LiOH \cdot H_2O$ (2.0 mmol, 2.0 equiv), and distilled MeCN (4.0 mL). The vial cap equipped with anode (graphite) and cathode (stainless steel) were inserted into the mixture. After pre-stirring for 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA until complete consumption of starting material (monitored by TLC). The ElectraSyn vial cap was

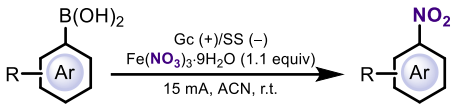
removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated in vacuum. The crude material was purified by flash column chromatography on silica gel to afford the desired product.

5.6 Deborylative Nitration



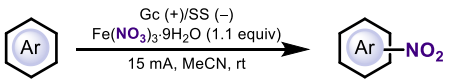
GP10: Without any precautions to exclude air or moisture a 5 mL ElectraSyn vial with a stir bar was charged with $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv.), dioxaborolanealkene (1.0 mmol, 1.0 equiv.), and distilled MECN (4.0 mL). The vial cap equipped with anode (graphite) and cathode (Stainless steel) were inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol. The ElectraSyn vial cap was removed, and electrodes were rinsed with MECN (3 mL). The resulting reaction mixture was concentrated in vacuum. The crude material was purified by flash column chromatography on silica to give the desired product.

5.7 *ipso*-Nitration of Arylboronic Acids



GP11: Without any precautions to exclude air or moisture a 5 mL ElectraSyn vial with a stir bar was charged with $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), aryl boronic acids (1.0 mmol, 1.0 equiv), and distilled MeCN (4.0 mL). The vial cap equipped with anode (graphite) and cathode (stainless steel) were inserted into the mixture. After pre-stirring for 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol and stirred additionally (if required) at room temperature until full consumption of the starting material. The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated in vacuum. The crude material was purified by flash column chromatography on silica gel to give the desired product.

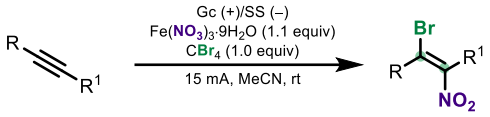
5.8 Direct Nitration of Arenes



GP12: Without any precautions to exclude air or moisture a 5 mL ElectraSyn vial with a stir bar was charged with $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), electron-rich aryls(1.0 mmol, 1.0 equiv), and distilled MeCN (4.0 mL). The vial cap equipped with anode (graphite) and cathode (Stainless steel) were inserted into the mixture. After pre-stirring for 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol and stirred additionally (if required) at room temperature until full consumption of the starting material. The ElectraSyn vial cap was removed, and electrodes

were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated in vacuum. The crude material was purified by flash column chromatography on silica gel to give the desired product.

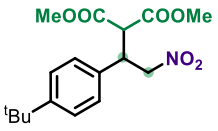
5.9 Halonitration of Alkynes



GP13: Without any precautions to exclude air or moisture a 5 mL ElectraSyn vial with a stir bar was charged with $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), CBr_4 (1.0 mmol, 1.0 equiv), alkyne (1.0 mmol, 1.0 equiv), and distilled MeCN (4.0 mL). The vial cap equipped with anode (graphite) and cathode (stainless steel) were inserted into the mixture. After pre-stirring for about 10 minutes, the reaction mixture was electrolyzed at a constant current of 15 mA for 0.3 F/mol and then stirred additionally (if required) at room temperature until complete consumption of starting material (monitored by TLC). The ElectraSyn vial cap was removed, and electrodes were rinsed with MeCN (3 mL). The resulting reaction mixture was concentrated in vacuum. The crude material was purified by flash column chromatography on silica gel to give the desired product.

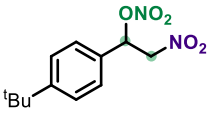
6. Post-synthetic Modifications

Dimethyl 2-(1-(4-(*tert*-butyl)phenyl)-2-nitroethyl)malonate (62):



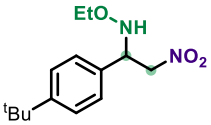
1-(1-Bromo-2-nitroethyl)-4-(*tert*-butyl)benzene **2** (1.0 mmol, 1.0 equiv), dimethyl malonate (1.1 mmol, 1.1 equiv), and NEt_3 (1.0 mmol, 1.0 equiv) were stirred at room temperature for 6 h. Then volatiles were removed under vacuum, and extracted with dichloromethane, the organic layer was washed with water, brine, dried over anhydrous magnesium sulfate, filtered and concentrated under vacuum. After column chromatography on silica the titled compound was isolated as light-yellow solid (85% yield, 5% hexane in ethyl acetate as eluent).

1-(4-(*tert*-Butyl)phenyl)-2-nitroethyl nitrate (63):



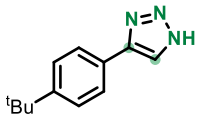
To a solution of 1-(1-bromo-2-nitroethyl)-4-(*tert*-butyl)benzene **2** (1.0 mmol, 1.0 equiv) in MeCN (4 mL) was added $AgNO_3$ (1.5 mmol, 1.5 equiv) and the reaction mixture was stirred at room temperature under dark for 3 h. Then the volatiles were removed under vacuum. Column chromatography on silica afforded the titled compound as yellow oil (92% yield, 5% hexane in ethyl acetate as eluent).

N-(1-(4-(*tert*-Butyl)phenyl)-2-nitroethyl)-*O*-ethylhydroxylamine (64):



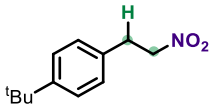
To an oven-dried 10 mL vial charged with 1-(1-bromo-2-nitroethyl)-4-(*tert*-butyl)benzene **2** (1.0 mmol, 1.0 equiv), ethoxyamine hydrochloride (1.2 mmol, 1.2 equiv), potassium tert-butoxite (1.0 mmol, 1.0 equiv), triethylamine (1.0 mmol, 1.0 equiv) were added 5 mL of DMF at 0 °C. The reaction mixture was then stirred for 15 min at 0 °C and then 20 min at room temperature. The reaction mixture was extracted with ethyl acetate (3 × 10 mL). The combined organic layer was washed with brine (10mL) and dried over $MgSO_4$, then concentrated under vacuum and purified by column chromatography on silica gel. The titled compound was isolated as a yellow solid (90% yield, 8% hexane in ethyl acetate as eluent).

5-(4-(*tert*-Butyl)phenyl)-1H-imidazole (65):



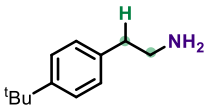
To a solution of 1-(1-bromo-2-nitroethyl)-4-(*tert*-butyl)benzene **2** (1.0 mmol, 1.0 equiv) in DMSO (4mL) was added NaN_3 (4.0 mmol, 4.0 equiv) and stirred at room temperature for overnight. After completion, reaction mixture was diluted by saturated $NaHCO_3$ (15 mL), extracted with Et_2O (3 × 10 mL). Combined organic layers were dried over with $MgSO_4$, concentrated under vacuum, and then purified by column chromatography on silica gel. The titled compound was isolated as solid (83% yield, 20% hexane in ethyl acetate as eluent).

1-(*tert*-Butyl)-4-(2-nitroethyl)benzene (66):



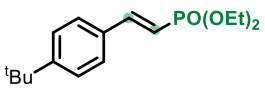
To a solution of 1-(1-bromo-2-nitroethyl)-4-(*tert*-butyl)benzene **2** (1.0 mmol, 1.0 equiv) in a mixture of DCM:MeOH (5 mL, 2:1) was added $NaBH_4$ (3.0 mmol, 3.0 equiv), and silica gel (2 g). The reaction mixture was stirred at room temperature for 3 h. Then the volatiles were removed under vacuum. Column chromatography on silica afforded the titled compound as yellow oil (90% yield, 1% hexane in ethyl acetate as eluent).

2-(4-(*tert*-Butyl)phenyl)ethan-1-amine (67):



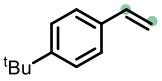
To a solution of 1-(1-bromo-2-nitroethyl)-4-(*tert*-butyl)benzene **2** (5.0 mmol, 1.0 equiv) and 10 mol% of Pd/C was dissolved in MeOH (20 mL). The reaction mixture was stirred at 50 °C for 48 h with 50 bar pressure of hydrogen. The reaction mixture was filtered, and the volatiles were removed under vacuum. Column chromatography on silica afforded the titled compound as yellow oil (44 % yield, 2 % MeOH in DCM as eluent).

Diethyl (*E*)-(4-(*tert*-butyl)styryl)phosphonate (68):



To a solution of 1-(1-bromo-2-nitroethyl)-4-(tert-butyl)benzene **2** (0.5 mmol, 0.5 equiv), diethyl phosphite (1.5 mmol, 3.0 equiv) and HOAc (3 mL) was added $Mn(OAc)_3$ (1.25 mmol, 2.5 equiv) at 80 °C. The reaction was monitored by TLC and stirred until completion. Then water (15 mL) was added to the reaction mixture and extracted with ethyl acetate (15 mL × 5). The combined organic fractions were dried over anhydrous $MgSO_4$ and concentrated under vacuum. The crude product was purified by column chromatography on silica gel. The titled compound was isolated as brown oil (30 % yield, 10% hexane in ethyl acetate as eluent).

1-(*tert*-Butyl)-4-vinylbenzene (1):



To a solution of 1-(1-bromo-2-nitroethyl)-4-(*tert*-butyl)benzene **2** (1.0 mmol, 1.0 equiv) in MeOH (4mL) was added $NiCl_2{\cdot}6H_2O$ (2.0 mmol, 2.0 equiv), and $NaBH_4$ (4.5 mmol, 4.5 equiv). The reaction mixture was stirred at room temperature for 2 h. Then the volatiles were removed under vacuum. Column chromatography on silica afforded the titled compound as colorless oil (95% yield, 1 % hexane in ethyl acetate as eluent).

7. Plausible Mechanisms

7.1 Electrolytic Nitration of Alkenes and Cascade Nitrolactonization

A plausible mechanism for the alkene nitration and cascade nitrolactonization based on the experimental observations and literature reports is illustrated below:

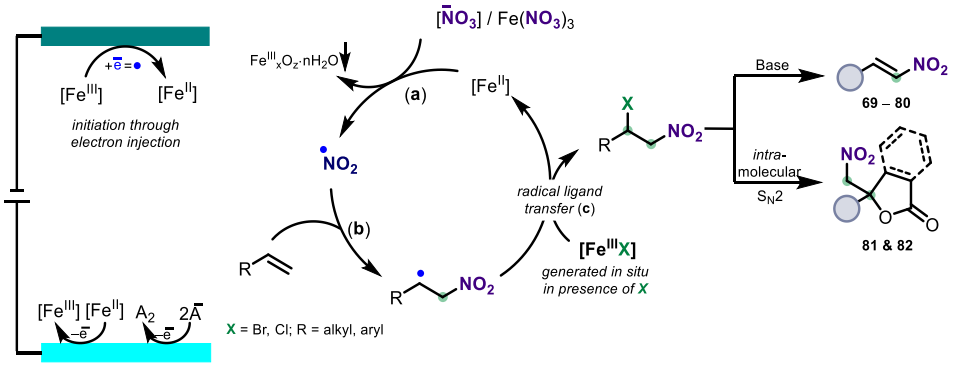


Figure S19. Plausible mechanism for electrolytic nitration of alkenes and cascade nitrolactonization.

7.2 Electrolytic Decarboxylative Nitration

A plausible mechanism for the decarboxylative nitration of vinylic acids based on the experimental observations and literature reports is illustrated below:[6,7,8]

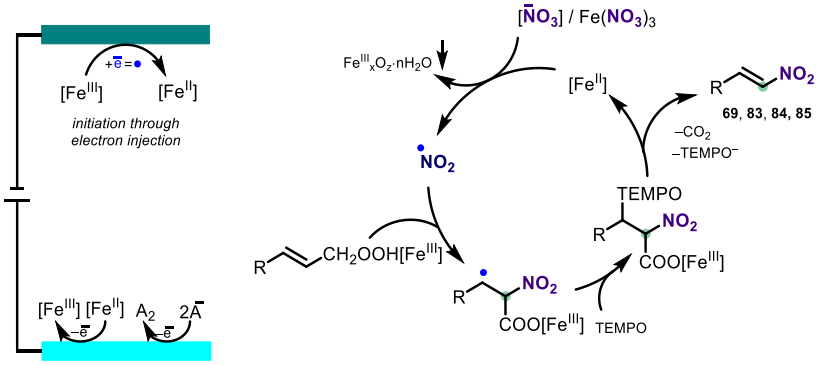


Figure S20. Plausible mechanism for electrolytic decarboxylative nitration.

7.3 Electrolytic Deborylative Nitration

A plausible mechanism for the decarboxylative nitration based on the experimental observations and literature reports is illustrated below:

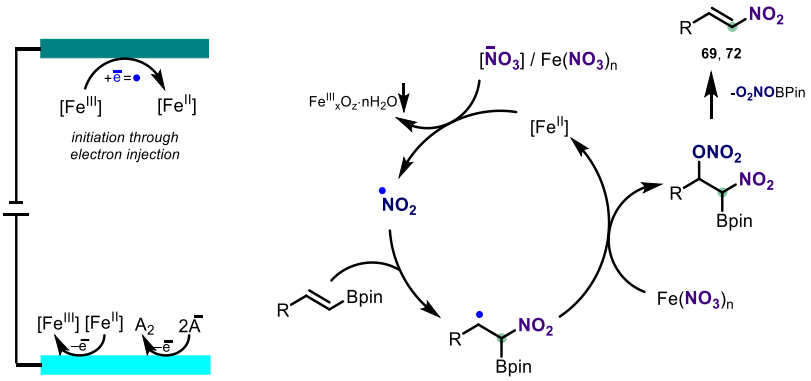


Figure S21. Plausible mechanism for electrocatalytic deborylative nitration.

7.4 Electrolytic *ipso*-Nitration of Aryl Boronic Acids and Aromatic Nitration

A plausible mechanism for the *ipso*-nitration of aryl boronic acids and nitration of arenes based on the experimental observations and literature reports is illustrated below:[9]

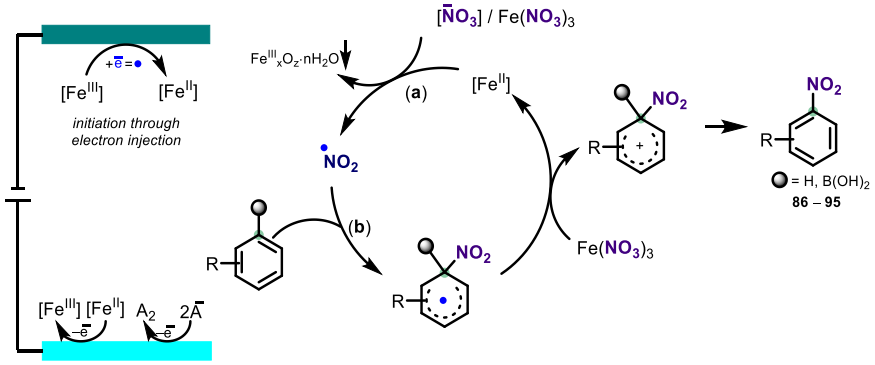
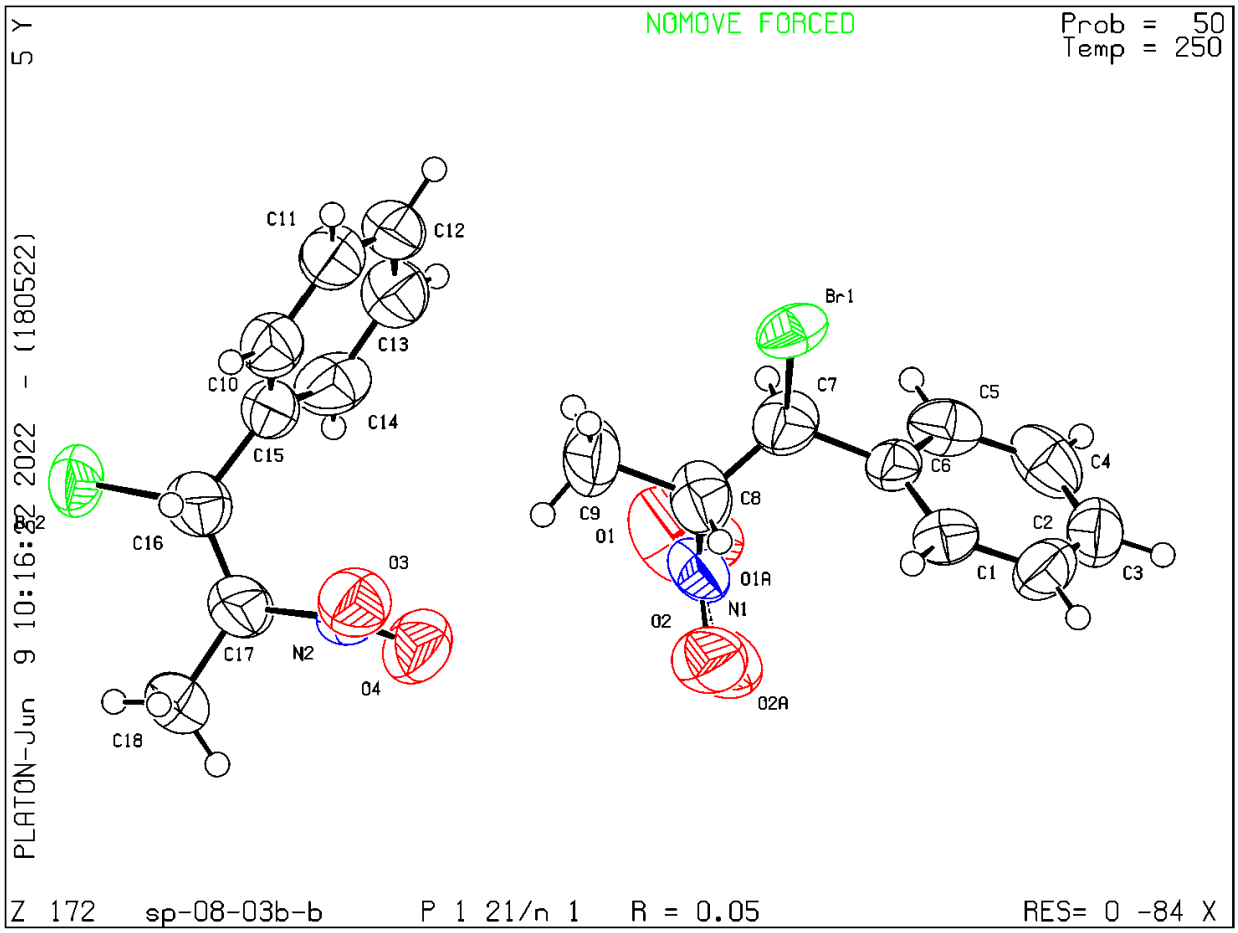


Figure S22. Plausible mechanism for electrolytic *ipso*-nitration of boronic acids and nitration of arenes.

8. X-Ray Diffraction Data

Data for compound (1-bromo-2-nitropropyl)benzene (40)



Identification code	SP-08-03b-b	**b/Å**	5.5916(2)
CCDC	2207763	**c/Å**	23.7488(9)
Empirical formula	$C_9H_{10}BrNO_2$	**α/°**	90
Formula weight	244.09	**β/°**	105.221(3)
Temperature/K	250	**γ/°**	90
Crystal system	monoclinic	**Volume/Å^3**	2037.07(13)
Space group	$P2_1/n$	**Z**	8
a/Å	15.8978(6)	**ρ_{calc}g/cm^3**	1.592

μ/mm^{-1}	5.261	**Independent reflections**	3674 [R_{int} = 0.0529, R_{sigma} = 0.0225]
F(000)	976.0	**Data/restraints/ parameters**	3674/2/256
Crystal size/mm^3	0.66 × 0.26 × 0.04	**Goodness-of-fit on F^2**	1.038
Radiation	Cu Kα (λ = 1.54186)	**Final R indexes [I>=2σ (I)]**	R_1 = 0.0542, wR_2 = 0.1434
2Θ range for data collection/°	15.498 to 136.468	**Final R indexes [all data]**	R_1 = 0.0593, wR_2 = 0.1500
Index ranges	-18 ≤ h ≤ 18, -4 ≤ k ≤ 6, -26 ≤ l ≤ 28	**Largest diff. peak/hole / e Å^{-3}**	1.28/-0.58
Reflections collected	29747		

Table S13. Crystal data and structure refinement for compound **40**.

Atom	***x***	***y***	***z***	**U(eq)**
Br1	4626.0(4)	7768.6(9)	9530.1(2)	66.6(2)
O1	5100(40)	1400(30)	8319(13)	123(8)
O2	4778(19)	4180(50)	7677(6)	91(5)
N1	4934(3)	3370(9)	8160(2)	67.3(10)
C1	3070(3)	6700(9)	8241.0(19)	61.1(11)
C2	2205(3)	6486(11)	7980(2)	72.8(13)
C3	1748(3)	4617(11)	8095(3)	76.1(15)
C4	2155(4)	2879(10)	8479(3)	80.6(16)
C5	3042(4)	3056(9)	8751(2)	69.2(13)
C6	3508(3)	5005(8)	8633.5(17)	53.8(10)
C7	4455(4)	5100(10)	8954(2)	72.1(13)
C8	5085(4)	5371(12)	8612(3)	80.0(16)
C9	6042(4)	5458(15)	8925(3)	98(2)
Br2	10053.3(3)	326.7(11)	9057.2(3)	74.6(2)
O3	7877(3)	6279(8)	8327.5(17)	85.6(11)
O4	7171(3)	3202(9)	7953(2)	93.5(12)
N2	7828(3)	4223(9)	8186.2(17)	69.0(11)
C10	8765(4)	4362(10)	9762(2)	72.0(13)
C11	8366(4)	4357(10)	10203(2)	72.0(13)
C12	7811(4)	2569(10)	10258(2)	70.6(13)
C13	7650(4)	754(10)	9859(3)	76.5(14)
C14	8060(4)	749(11)	9406(2)	80.6(16)
C15	8624(3)	2569(10)	9362(2)	68.6(13)
C16	9122(4)	2771(13)	8898(3)	90.1(19)
C17	8650(4)	2677(13)	8296(3)	90.4(19)
C18	9094(4)	3238(12)	7827(2)	79.7(15)
O1A	4820(30)	1370(30)	8266(10)	74(10)
O2A	4680(40)	3800(130)	7652(9)	116(16)

Table S14. Fractional Atomic Coordinates ($\times 10^4$) and Equivalent Isotropic Displacement Parameters ($Å^2 \times 10^3$) for **40**. U_{eq} is defined as 1/3 of the trace of the orthogonalised U_{IJ} tensor.

Atom	**U_{11}**	**U_{22}**	**U_{33}**	**U_{23}**	**U_{13}**	**U_{12}**
Br1	83.5(4)	61.6(3)	45.3(3)	-8.55(19)	0.3(2)	7.6(2)
O1	150(20)	73(7)	177(17)	2(7)	89(12)	-1(7)
O2	90(8)	103(9)	78(9)	16(9)	21(6)	-29(7)
N1	67(2)	72(3)	73(3)	-12(2)	35(2)	-15(2)
C1	72(3)	57(3)	53(2)	3(2)	13(2)	-3(2)
C2	67(3)	82(3)	60(3)	2(3)	2(2)	14(3)
C3	53(3)	97(4)	76(3)	-21(3)	14(2)	0(3)
C4	91(4)	69(3)	97(4)	-20(3)	53(3)	-25(3)
C5	100(4)	52(2)	60(3)	7(2)	28(3)	13(2)
C6	54(2)	63(3)	42(2)	-9.1(18)	8.8(17)	7.1(19)
C7	72(3)	75(3)	64(3)	-22(2)	8(2)	3(2)
C8	63(3)	90(4)	88(4)	-33(3)	21(3)	-13(3)
C9	52(3)	140(6)	97(4)	-30(4)	12(3)	-3(3)
Br2	53.6(3)	81.7(4)	87.3(4)	-1.4(3)	16.1(3)	14.1(2)
O3	92(3)	87(3)	78(2)	-10(2)	22(2)	5(2)
O4	78(3)	108(3)	85(3)	-20(2)	4(2)	2(2)
N2	68(3)	93(3)	45.1(19)	2(2)	14.4(18)	17(2)
C10	67(3)	75(3)	74(3)	9(3)	18(2)	5(2)
C11	73(3)	72(3)	69(3)	-10(2)	16(2)	7(3)
C12	72(3)	82(3)	62(3)	2(2)	25(2)	9(3)
C13	76(3)	72(3)	81(3)	1(3)	21(3)	-7(3)
C14	99(4)	76(3)	61(3)	-16(3)	9(3)	18(3)
C15	63(3)	83(4)	62(3)	16(2)	20(2)	25(2)
C16	87(4)	112(5)	75(4)	11(3)	30(3)	39(3)
C17	84(4)	123(5)	71(3)	17(3)	33(3)	38(4)
C18	74(3)	106(4)	66(3)	-6(3)	31(3)	2(3)
O1A	95(17)	59(10)	68(17)	-7(6)	23(12)	-11(7)
O2A	120(20)	150(30)	89(19)	-50(20)	43(14)	-54(19)

Table S15. Anisotropic Displacement Parameters ($Å^2×10^3$) for **40**. The Anisotropic displacement factor exponent takes the form: $-2\pi^2[h^2a^{*2}U_{11}+2hka^*b^*U_{12}+\ldots]$.

Atom	**Atom**	**Length/Å**	**Atom**	**Atom**	**Length/Å**
Br1	C7	1.995(5)	C8	C9	1.510(8)
O1	N1	1.173(13)	Br2	C16	1.977(6)
O2	N1	1.198(10)	O3	N2	1.194(6)
N1	C8	1.525(7)	O4	N2	1.192(6)

N1	O1A	1.172(15)	N2	C17	1.531(7)
N1	O2A	1.193(16)	C10	C11	1.359(8)
C1	C2	1.357(7)	C10	C15	1.360(8)
C1	C6	1.382(6)	C11	C12	1.362(8)
C2	C3	1.341(8)	C12	C13	1.367(8)
C3	C4	1.372(9)	C13	C14	1.397(8)
C4	C5	1.393(8)	C14	C15	1.378(8)
C5	C6	1.387(7)	C15	C16	1.520(8)
C6	C7	1.498(7)	C16	C17	1.429(9)
C7	C8	1.453(8)	C17	C18	1.501(8)

Table S16. Bond Lengths for **40**.

Atom	**Atom**	**Atom**	**Angle/°**	**Atom**	**Atom**	**Atom**	**Angle/°**
O1	N1	O2	130(2)	C9	C8	N1	108.7(5)
O1	N1	C8	118.9(18)	O3	N2	C17	120.4(5)
O2	N1	C8	110.5(16)	O4	N2	O3	125.2(5)
O1A	N1	C8	123.7(13)	O4	N2	C17	114.4(5)
O1A	N1	O2A	112(4)	C11	C10	C15	120.9(5)
O2A	N1	C8	121(3)	C10	C11	C12	121.4(5)
C2	C1	C6	121.2(5)	C11	C12	C13	119.1(5)
C3	C2	C1	120.9(5)	C12	C13	C14	119.8(5)
C2	C3	C4	120.1(5)	C15	C14	C13	120.1(5)
C3	C4	C5	120.0(5)	C10	C15	C14	118.8(5)
C6	C5	C4	119.5(5)	C10	C15	C16	115.5(6)
C1	C6	C5	118.3(4)	C14	C15	C16	125.6(6)
C1	C6	C7	125.3(5)	C15	C16	Br2	108.4(4)
C5	C6	C7	116.4(4)	C17	C16	Br2	109.7(4)
C6	C7	Br1	108.2(3)	C17	C16	C15	119.0(6)
C8	C7	Br1	108.4(4)	C16	C17	N2	110.5(5)
C8	C7	C6	117.9(5)	C16	C17	C18	120.5(6)
C7	C8	N1	108.2(4)	C18	C17	N2	107.6(5)
C7	C8	C9	118.9(6)				

Table S17. Bond Angles for **40**.

A	**B**	**C**	**D**	**Angle/°**	**A**	**B**	**C**	**D**	**Angle/°**
Br1	C7	C8	N1	-178.4(4)	O3	N2	C17	C16	54.2(8)
Br1	C7	C8	C9	57.0(7)	O3	N2	C17	C18	-79.2(6)

O1	N1	C8	C7	-69(3)	O4	N2	C17	C16	-126.2(6)
O1	N1	C8	C9	61(3)	O4	N2	C17	C18	100.4(6)
O2	N1	C8	C7	121.5(16)	C10	C11	C12	C13	-0.4(8)
O2	N1	C8	C9	-108.1(16)	C10	C15	C16	Br2	107.8(5)
C1	C2	C3	C4	-0.3(8)	C10	C15	C16	C17	-126.0(7)
C1	C6	C7	Br1	69.0(5)	C11	C10	C15	C14	0.7(8)
C1	C6	C7	C8	-54.3(7)	C11	C10	C15	C16	-179.0(5)
C2	C1	C6	C5	0.6(7)	C11	C12	C13	C14	0.5(8)
C2	C1	C6	C7	-178.6(5)	C12	C13	C14	C15	0.0(9)
C2	C3	C4	C5	0.2(8)	C13	C14	C15	C10	-0.6(8)
C3	C4	C5	C6	0.3(8)	C13	C14	C15	C16	179.2(5)
C4	C5	C6	C1	-0.7(7)	C14	C15	C16	Br2	-71.9(6)

Table S18. Torsion Angles for **40**.

Atom	***x***	***y***	***z***	**U(eq)**
H1	3373.97	8010.17	8154.07	73
H2	1925.13	7651.41	7718.19	87
H3	1155.27	4499.17	7914.98	91
H4	1836.93	1581.24	8557.28	97
H5	3320.01	1876.95	9010.31	83
H7	4593.64	3608.27	9175.07	87
H8	4946.16	6875.74	8395.56	96
H9A	6190.6	4099.51	9178.66	146
H9B	6165.79	6900.45	9150.32	146
H9C	6380.13	5427.54	8643.65	146
H10	9138.76	5608.3	9734.15	86
H11	8473.5	5600.71	10472.46	86
H12	7545.35	2582.66	10563.62	85
H13	7269.46	-473.19	9888.67	92
H14	7952.66	-484.07	9133.28	97
H16	9415.61	4327.25	8956.57	108
H17	8443.34	1024.5	8225.41	108
H18A	8684.24	3081.75	7451.86	120
H18B	9568.82	2146	7853.75	120
H18C	9313.23	4845.59	7875.78	120

Table S19. Hydrogen Atom Coordinates ($Å \times 10^4$) and Isotropic Displacement Parameters ($Å^2 \times 10^3$) for **40.**

Atom	***Occupancy***	**Atom**	***Occupancy***	**Atom**	***Occupancy***
O1	0.66(12)	O2	0.66(12)	O1A	0.34(12)
O2A	0.34(12)				

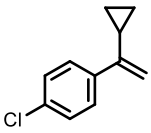
Table S20. Atomic Occupancy for 40.

Experimental Procedure

Single crystals of $C_9H_{10}BrNO_2$ [SP-08-03b (**40**)] were crystalized by slow evaporation from a hexane:ether (1:1) mixture. A suitable crystal was selected and mounted on loop with oil on a STOE STADIVARI diffractometer. The crystal was kept at 250 K during data collection. Using Olex2, the structure was solved with the SHELXT structure solution program using Intrinsic Phasing and refined with the SHELXL refinement package using Least Squares minimization.

9. Analytical Data

1-Chloro-4-(1-cyclopropylvinyl)benzene [CAS 1009-33-2] **(3):**

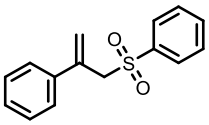


Following **GP2**, the titled compound was isolated as colorless liquid (82% yield, 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.52 (d, *J* = 8.6 Hz, 2H), 7.30 (d, *J* = 8.6 Hz, 2H), 5.29–5.24 (m, 1H), 4.95 (t, *J* = 1.1 Hz, 1H), 1.60 (ttd, *J* = 8.2, 5.3, 1.2 Hz, 1H), 0.88–0.81 (m, 2H), 0.61–0.55 (m, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 148.4, 140.2, 133.4, 128.4, 127.6, 109.8, 15.7, 6.8.

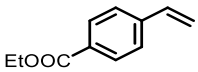
((2-Phenylallyl)sulfonyl)benzene [CAS 74866-37-8] **(5):**



The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.77 (dd, *J* = 8.4, 1.4 Hz, 2H), 7.56–7.49 (m, 1H), 7.45–7.38 (m, 2H), 7.28–7.19 (m, 5H), 5.57 (d, *J* = 0.6 Hz, 1H), 5.21 (d, *J* = 0.8 Hz, 1H), 4.25 (d, *J* = 0.8 Hz, 2H).

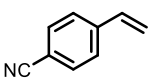
Ethyl 4-vinylbenzoate [CAS 2715-43-7] **(A13):**



The titled compound was prepared from 4-vinylbenzoic acid according to a known procedure as yellow oil (81% yield, 5% hexane in ethyl acetate as eluent). The characterization data match the literature.[15]

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.00 (d, *J* = 8.2 Hz, 2H), 7.46 (d, *J* = 8.2 Hz, 2H), 6.75 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.86 (dd, *J* = 17.6, 0.8 Hz, 1H), 5.41–5.26 (m, 1H), 4.37 (q, *J* = 7.1 Hz, 2H), 1.39 (t, *J* = 7.1 Hz, 3H).

4-Vinylbenzonitrile [CAS 3435-51-6] **(A16):**

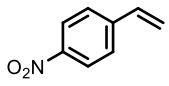


Following **GP1**, the titled compound was isolated as light-yellow oil (84% yield, 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.60 (d, *J* = 8.2 Hz, 2H), 7.47 (d, *J* = 8.2 Hz, 2H), 6.72 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.87 (dd, *J* = 17.6, 0.6 Hz, 1H), 5.44 (dd, *J* = 10.9, 0.6 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 142.0, 135.5, 132.5, 126.8, 119.0, 117.8, 111.2.

1-Nitro-4-vinylbenzene [CAS 100-13-0] **(A18):**

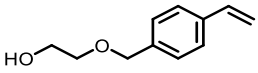


Following **GP1**, the titled compound was isolated as light-yellow oil (89% yield, 2% hexane in ethyl acetate as eluent). The characterization data match the literature.[13]

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.20–8.17 (m, 2H), 7.55–7.52 (m, 2H), 6.78 (dd, *J* = 17.6, 10.8 Hz, 1H), 5.93 (d, *J* = 17.6 Hz, 1H), 5.50 (d, *J* = 10.8 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 147.3, 144.0, 135.1, 126.9, 124.1, 118.7.

2-((4-Vinylbenzyl)oxy)ethan-1-ol (A22):

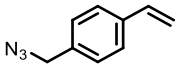


The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.40 (d, *J* = 8.2 Hz, 2H), 7.30 (d, *J* = 8.2 Hz, 2H), 6.72 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.75 (dd, *J* = 17.6, 0.9 Hz, 1H), 5.25 (dd, *J* = 10.9, 0.9 Hz, 1H), 4.55 (s, 2H), 3.79–3.72 (m, 2H), 3.62–3.56 (m, 2H), 2.17 (s, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 137.7, 137.3, 136.6, 128.1, 126.4, 114.1, 73.1, 71.5, 71.5, 62.0, 62.0.

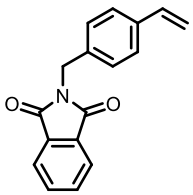
1-(Azidomethyl)-4-vinylbenzene (A23):



The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44 (d, *J* = 8.2 Hz, 2H), 7.29 (d, *J* = 8.2 Hz, 2H), 6.73 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.78 (dd, *J* = 17.6, 0.8 Hz, 1H), 5.29 (dd, *J* = 10.9, 0.8 Hz, 1H), 4.33 (s, 2H).

2-(4-Vinylbenzyl)isoindoline-1,3-dione [CAS: 63413-74-1] **(A24):**

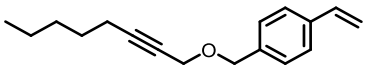


The titled compound was isolated as white solid (84% yield, 5-10% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.84 (dd, *J* = 5.4, 3.0 Hz, 2H), 7.70 (dd, *J* = 5.4, 3.0 Hz, 2H), 7.45–7.29 (m, 4H), 6.67 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.71 (dd, *J* = 17.6, 1.0 Hz, 1H), 5.22 (dd, *J* = 10.9, 1.0 Hz, 1H), 4.83 (s, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 168.2, 137.4, 136.5, 136.0, 134.1, 132.3, 129.0, 126.6, 123.5, 114.3, 41.5.

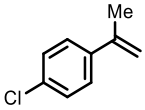
1-((Oct-2-yn-1-yloxy)methyl)-4-vinylbenzene (A25):



^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.40 (d, *J* = 8.1 Hz, 2H), 7.32 (d, *J* = 8.3 Hz, 2H), 6.72 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.75 (dd, *J* = 17.6, 1.0 Hz, 1H), 5.32–5.21 (m, 1H), 4.58 (s, 2H), 4.16 (t, *J* = 2.2 Hz, 2H), 2.24 (tt, *J* = 7.1, 2.2 Hz, 2H), 1.60–1.48 (m, 2H), 1.46–1.29 (m, 4H), 0.91 (t, *J* = 7.1 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 137.5, 137.3, 136.7, 128.4, 126.4, 114.0, 87.5, 75.9, 71.2, 57.8, 31.2, 28.5, 22.3, 18.9, 14.1.

1-Chloro-4-(prop-1-en-2-yl)benzene [CAS: 1712-70-5] **(A33):**

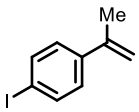


Following **GP2**, the titled compound was isolated as colorless oil (83% yield, 1% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.45–7.36 (m, 2H), 7.34–7.26 (m, 2H), 5.36 (dt, *J* = 1.5, 0.8 Hz, 1H), 5.13–5.07 (m, 1H), 2.14 (dd, *J* = 1.5, 0.8 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 142.3, 139.8, 133.3, 128.5, 127.0, 113.1, 21.9.

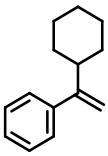
1-Iodo-4-(prop-1-en-2-yl)benzene [CAS: 561023-21-0] **(A34):**



Following **GP2**, the titled compound was isolated as colorless solid (79% yield, 1% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.65 (d, *J* = 8.6 Hz, 2H), 7.20 (d, *J* = 8.6 Hz, 2H), 5.36 (dd, *J* = 1.4, 0.8 Hz, 1H), 5.09 (t, *J* = 1.5 Hz, 1H), 2.12 (dd, *J* = 1.4, 0.8 Hz, 3H).

(1-Cyclohexylvinyl)benzene [CAS 5700-44-7] **(A35):**

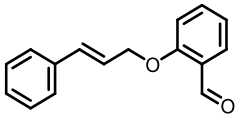


Following **GP1**, the titled compound was isolated as light-yellow oil (87% yield, 1% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.41–7.26 (m, 5H), 5.18 (d, *J* = 1.5 Hz, 1H), 5.05 (t, *J* = 1.4 Hz, 1H), 2.54–2.40 (m, 1H), 1.95–1.70 (m, 5H), 1.45–1.15 (m, 5H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 155.2, 143.1, 128.3, 127.1, 126.8, 110.5, 42.8, 32.9, 27.0, 26.6.

2-[(*E*)-(3-Phenyl-2-propenyl)oxy]benzaldehyde (A37):

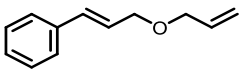


^{1}H-NMR (400 MHz, $CDCl_3$): δ 10.58 (s, 1H), 7.87 (dd, *J* = 7.9, 1.9 Hz, 1H), 7.55 (ddd, *J* = 8.4, 7.3, 1.9 Hz, 1H), 7.46–7.40 (m, 2H), 7.39–7.31 (m, 2H), 7.31–7.27 (m, 1H), 7.08–7.01 (m, 2H), 6.77 (d, *J* = 16.1 Hz, 1H), 6.43 (dt, *J* = 16.0, 5.7 Hz, 1H), 4.84 (dd, *J* = 5.7, 1.5 Hz, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 189.9, 161.2, 136.3, 136.0, 133.7, 128.8, 128.7, 128.3, 126.8, 125.3, 123.58, 121.1, 113.1, 69.3.

The characterization data match the literature.

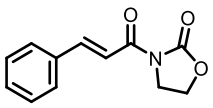
(*E*)-(3-(Allyloxy)prop-1-en-1-yl)benzene (A38):



^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.34–7.29 (m, 2H), 7.26–7.21 (m, 2H), 7.19–7.14 (m, 1H), 6.54 (dt, *J* = 16.0, 1.6 Hz, 1H), 6.23 (dt, *J* = 15.9, 6.0 Hz, 1H), 5.88 (ddt, *J* = 17.2, 10.4, 5.6 Hz, 1H), 5.24 (dq, *J* = 17.2, 1.7 Hz, 1H), 5.16–5.11 (m, 1H), 4.09 (dd, *J* = 6.1, 1.5 Hz, 2H), 3.97 (dt, *J* = 5.6, 1.4 Hz, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 136.9, 134.9, 132.6, 128.7, 127.8, 126.6, 126.2, 117.3, 71.3, 70.8. The characterization data match the literature.

3-Cinnamoyloxazolidin-2-one (A41):

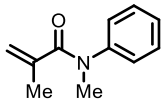


The titled product was obtained as white crystals (77% yield, 5% hexane in ethyl acetate as eluent) according to a literature method.The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.95–7.83 (m, 2H), 7.62 (ddt, *J* = 5.0, 3.6, 1.4 Hz, 2H), 7.44–7.36 (m, 3H), 4.50–4.41 (m, 2H), 4.18–4.10 (m, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 165.5, 153.8, 146.5, 134.7, 130.8, 129.0, 128.8, 116.8, 62.2, 43.0.

_N_-Methyl-_N_-phenylmethacrylamide (A51):

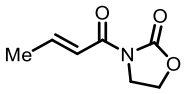


The titled product was obtained as white solid (75% yield, 5% hexane in ethyl acetate as eluent) according to a literature method. The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.32–7.22 (m, 2H), 7.22–7.12 (m, 1H), 7.10–7.01 (m, 2H), 4.96 (dd, *J* = 1.7, 1.2 Hz, 1H), 4.91 (t, *J* = 1.1 Hz, 1H), 3.28 (s, 3H), 1.69 (dd, *J* = 1.7, 1.1 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 172.1, 144.8, 140.8, 129.3, 127.0, 126.6, 119.5, 37.8, 20.4.

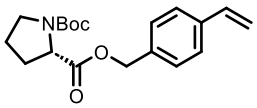
(_E_)-3-(But-2-enoyl)oxazolidin-2-one (A52):



The titled product was obtained as white crystals (85% yield, 5% hexane in ethyl acetate as eluent) according to a literature method. The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.32–6.98 (m, 2H), 4.35 (dd, *J* = 8.6, 7.5 Hz, 2H), 3.99 (dd, *J* = 8.6, 7.5 Hz, 2H), 1.89 (dd, *J* = 6.5, 1.2 Hz, 3H). **^{13}C-NMR** (101 MHz, $CDCl_3$): □ 165.3, 153.6, 146.9, 121.6, 62.1, 42.8, 18.6.

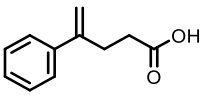
1-(_tert_-Butyl)-2-(4-vinylbenzyl)-(S)-pyrrolidine-1,2-dicarboxylate (A58):



^{1}H-NMR (400 MHz, $CDCl_3$): δ 6.70 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.75 (dt, *J* = 17.7, 1.2 Hz, 1H), 5.30–5.01 (m, 3H), 4.32 (ddd, *J* = 49.1, 8.6, 3.6 Hz, 1H), 3.61–3.32 (m, 2H), 2.29–2.09 (m, 1H), 2.01–1.78 (m, 3H), 1.46 (s, 3H), 1.34 (s, 6H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 173.2, 172.9, 154.5, 153.9, 137.87, 137.6, 136.5, 136.4, 135.5, 135.3, 128.7, 128.4, 126.5, 126.4, 114.5, 114.3, 80.0, 79.9, 66.5, 66.5, 59.3, 59.3, 46.7, 46.5, 31.0, 30.0, 28.6, 28.4, 24.4, 23.7.

4-Phenylpent-4-enoic acid [CAS 5747-06-8] **(A81):**

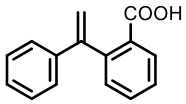


Following **GP5**, the titled compound was isolated as white solid (95% yield, 10% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 11.07 (br, 1H), 7.45–7.23 (m, 5H), 5.33 (d, J = 1.0 Hz, 1H), 5.12 (t, J = 1.3 Hz, 1H), 2.86 (ddd, J = 8.0, 6.8, 1.4 Hz, 2H), 2.61–2.50 (m, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 179.3, 146.7, 140.6, 128.6, 127.8, 126.2, 113.1, 33.1, 33.1, 30.30.

2-(1-Phenylvinyl)benzoic acid [CAS 17582-84-2] **(A82):**

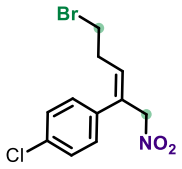


Following **GP5**, the titled compound was isolated as off-white solid (85% yield, 10% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 10.76 (br, 1H), 7.92 (dd, J = 7.7, 1.4 Hz, 1H), 7.56 (td, J = 7.6, 1.4 Hz, 1H), 7.43 (td, J = 7.6, 1.3 Hz, 1H), 7.37 (dd, J = 7.6, 1.3 Hz, 1H), 7.27–7.16 (m, 5H), 5.67 (d, J = 1.0 Hz, 1H), 5.22 (d, J = 1.0 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 172.0, 149.7, 143.7, 141.0, 132.5, 131.7, 130.8, 129.6, 128.2, 127.8, 127.6, 126.9, 114.5.

(*E*)-1-(5-Bromo-1-nitropent-2-en-2-yl)-4-chlorobenzene (4):



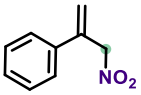
According to general procedure **GP4**, using 1-chloro-4-(1-cyclopropylvinyl)benzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as pale-yellow liquid (79% yield, 2% hexane in ethyl acetate as eluent).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.36–7.32 (m, 4H), 6.22 (t, J = 7.4 Hz, 1H), 5.38 (s, 2H), 3.53 (t, J = 6.5 Hz, 2H), 2.94 (dt, J = 7.4, 6.5 Hz, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 137.7, 135.7, 134.5, 131.5, 129.2, 127.6, 74.6, 32.3, 31. **IR** (ATR, neat): 2972, 1552, 1491, 1385.

HRMS (EI): *m/z* calcd for $C_{11}H_{11}{}^{79}Br^{35}ClNO_2$: 302.9656; found 302.9656.

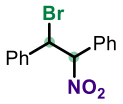
(3-Nitroprop-1-en-2-yl)benzene [CAS 58502-68-4] **(6):**



According to general procedure **GP4**, using ((2-phenylallyl)sulfonyl)benzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow oil (41% yield, 1% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.46–7.36 (m, 5H), 5.83 (s, 1H), 5.54 (s, 1H), 5.37 (s, 2H).

(1-Bromo-2-nitroethane-1,2-diyl)dibenzene (7):



According to general procedure **GP4**, using stilbene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as pale-yellow liquid (34% yield, 2% hexane in ethyl acetate as eluent).

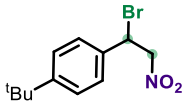
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.54–7.50 (m, 1H), 7.44–7.30 (m, 9H), 6.30 (d, J = 7.9 Hz, 1H), 5.15 (d, J = 7.9 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 129.8, 129.4, 129.2, 128.9, 128.8, 128.7, 128.7, 128.1, 127.8, 86.6, 56.2.

IR (ATR, neat): 2930, 2368, 1630, 1457, 1271, 917, 859, 735, 699.

HRMS (ESI): *m/z* calcd for [$C_{14}H_{12}{}^{79}Br\text{-}NO_2$]: 259.0118; found 259.0117.

1-(1-Bromo-2-nitroethyl)-4-(tert-butyl)benzene (2):



According to general procedure **GP4**, using 11-(*tert*-butyl)-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (87% yield, 2% hexane in ethyl acetate as eluent).

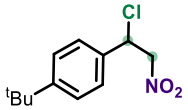
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.40 (d, J = 8.6 Hz, 2H), 7.35 (d, J = 8.5 Hz, 2H), 5.57 (dd, J = 8.2, 7.1 Hz, 1H), 5.03 (dd, J = 13.6, 8.2 Hz, 1H), 4.95 (dd, J = 13.7, 7.1 Hz, 1H), 1.31 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 153.2, 133.5, 127.3, 126.4, 80.8, 45.5, 34.9, 31.3.

IR (ATR, neat): 2968, 1557, 1525, 1378, 1273.

HRMS (ESI): *m/z* calcd for $C_{12}H_{16}{}^{79}BrNO_2{+}Na^+$: 308.0257; found 308.0252.

1-(*tert*-Butyl)-4-(1-chloro-2-nitroethyl)benzene (8):

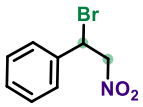


According to general procedure **GP5**, using 1-(*tert*-butyl)-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiCl (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow oil (89% yield, 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.43 (d, J = 8.4, 2H), 7.36 (d, J = 8.4, 2H), 5.55 (dd, J = 9.2, 5.6, 1H), 4.91 (dd, J = 13.6, 9.2, 1H), 4.78 (dd, J = 13.6, 5.6, 1H), 1.33 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 153.2, 132.9, 127.0, 126.3, 81.0, 56.9, 34.9, 31.3.

(1-Bromo-2-nitroethyl)benzene (9):



According to general procedure **GP4**, using styrene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as pale-yellow liquid (79% yield, 2% hexane in ethyl acetate as eluent).

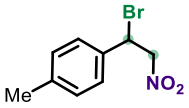
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.46–7.33 (m, 5H), 5.57 (dd, J = 8.2, 7.1 Hz, 1H), 5.04 (dd, J = 13.7, 8.2 Hz, 1H), 4.95 (dd, J = 13.7, 7.1 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 136.6, 129.9, 129.4, 127.6, 80.6, 45.5.

IR (ATR, neat): 3001, 2975, 1556, 1378, 1250.

HRMS (ESI): *m/z* calcd for $C_8H_8{}^{79}BrNO_2$: 228.9738; found 228.9740.

1-(1-Bromo-2-nitroethyl)-4-methylbenzene (10):



According to general procedure **GP4**, using 1-methyl-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as pale-yellow liquid (63% yield, using 2% hexane in ethyl acetate as eluent).

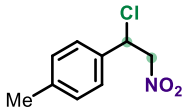
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.32 (d, J = 8.2 Hz, 2H), 7.20 (d, J = 8.0 Hz, 2H), 5.55 (t, J = 7.7 Hz, 1H), 5.03 (dd, J = 13.6, 8.1 Hz, 1H), 4.94 (dd, J = 13.6, 7.3 Hz, 1H), 2.36 (s, 3H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 140.1, 133.6, 130.1, 127.5, 80.7, 45.7, 21.4.

IR (ATR, neat): 2982, 1554, 1395, 1270.

HRMS (EI): *m/z* calcd for $C_9H_{10}{}^{79}BrNO_2$: 242.9889; found 242.9890.

1-(1-Chloro-2-nitroethyl)-4-methylbenzene (11):

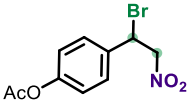


According to general procedure **GP5**, using 1-(*tert*-butyl)-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiCl (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow oil (89% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.31 (d, J = 8.2 Hz, 2H), 7.22 (d, J = 8.2 Hz, 2H), 5.54 (dd, J = 9.1, 5.6 Hz, 1H), 4.90 (dd, J = 13.4, 9.1 Hz, 1H), 4.77 (dd, J = 13.4, 5.6 Hz, 1H), 2.37 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 140.0, 133.0, 130.0, 127.2, 81.0, 57.0, 21.3.

4-(1-Bromo-2-nitroethyl)phenyl acetate (12):



According to general procedure **GP4**, using 4-vinylphenyl acetate (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (81% yield, using 5% hexane in ethyl acetate as eluent).

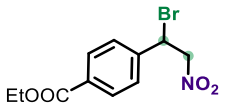
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 (d, J = 8.6 Hz, 2H), 7.13 (d, J = 8.6 Hz, 2H), 5.56 (dd, J = 8.2, 7.2 Hz, 1H), 5.02 (dd, J = 13.7, 8.2 Hz, 1H), 4.93 (dd, J = 13.7, 7.2 Hz, 1H), 2.30 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 169.2, 151.6, 134.0, 128.9, 122.6, 80.7, 44.6, 21.3.

IR (ATR, neat): 3003, 1658, 1596, 1225, 1483, 1334, 1197.

HRMS (ESI): *m/z* calcd for $C_{10}H_{10}O_4N^{79}Br$+Na: 309.9685; found 309.9690.

Ethyl 4-(1-bromo-2-nitroethyl)benzoate (13):



According to general procedure **GP4**, using ethyl 4-vinylbenzoate (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (87% yield, using 5% hexane in ethyl acetate as eluent).

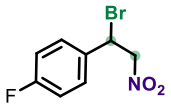
^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.05 (d, J = 8.4 Hz, 2H), 7.50 (d, J = 8.4 Hz, 2H), 5.57 (t, J = 7.7 Hz, 1H), 5.04 (dd, J = 13.8, 7.9 Hz, 1H), 4.97 (dd, J = 13.8, 7.5 Hz, 1H), 4.38 (q, J = 7.1 Hz, 2H), 1.39 (t, J = 7.1 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 165.7, 141.1, 131.9, 130.6, 127.7, 80.2, 61.4, 44.2, 14.4.

IR (ATR, neat): 3109, 1698, 1635, 1498, 13461257, 1128.

HRMS (ESI): *m/z* calcd for $C_{11}H_{13}O_4N^{79}Br$: 302.0033; found 302.0032.

1-(1-Bromo-2-nitroethyl)-4-fluorobenzene (14):



According to general procedure **GP4**, using 1-fluoro-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (91% yield, using 2% hexane in ethyl acetate as eluent).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.45−7.40 (m, 2H), 7.11−7.05 (m, 2H), 5.55 (t, J = 8.0, 1H), 5.02 (dd, J = 12.0, 8.0, 1H), 4.92 (dd, J = 12.0, 8.0, 1H).

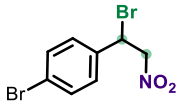
^{13}C-NMR (101 MHz, $CDCl_3$): δ 162.3 (d, J = 449 Hz), 132.6 (d, J = 4 Hz), 129.6 (d, J = 6.0 Hz), 116.5 (d, J = 22.0 Hz), 80.7, 44.4.

^{19}F-NMR (376 MHz, $CDCl_3$): δ −110.5.

IR (ATR, neat): 3003, 2989, 1564, 1387, 1268, 1155.

HRMS (ESI): *m/z* calcd for $C_8H_7{}^{79}BrFNO_2$: 248.0514; found 248.0512.

1-Bromo-4-(1-bromo-2-nitroethyl)benzene (15):



According to general procedure **GP4**, using 1-bromo-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as white solid (92% yield, using 2% hexane in ethyl acetate as eluent).

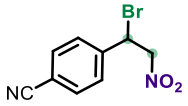
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.53 (d, J = 8.5 Hz, 2H), 7.31 (d, J = 8.5 Hz, 2H), 5.51 (t, J = 7.7 Hz, 1H), 5.01 (dd, J = 13.7, 7.7 Hz, 1H), 4.93 (dd, J = 13.7, 7.7 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 135.7, 132.7, 129.3, 124.1, 80.3, 44.2.

IR (ATR, neat): 2980, 1562, 1334, 1166.

HRMS (EI): *m/z* calcd for $C_8H_7{}^{79}Br_2NO_2$: 306.8838; found 306.8836.

4-(1-Bromo-2-nitroethyl)benzonitrile (16):



According to general procedure **GP4**, using 4-vinylbenzonitrile (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (87% yield, using 2% hexane in ethyl acetate as eluent).

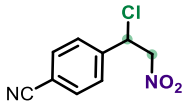
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.69 (d, J = 8.6 Hz, 2H), 7.56 (d, J = 8.4 Hz, 2H), 5.54 (t, J = 7.7 Hz, 1H), 5.04 (dd, J = 13.9, 7.7 Hz, 1H), 4.97 (dd, J = 13.9, 7.7 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 141.6, 133.1, 128.5, 117.9, 113.7, 79.8, 43.3.

IR (ATR, neat): 2952, 2230, 1557, 1417, 1378, 1240, 1171.

HRMS (ESI): *m/z* calcd for $[C_9H_7O_2N_2{}^{79}Br-H]^-$: 252.9618; found 252.9619.

4-(1-Chloro-2-nitroethyl)benzonitrile (17):

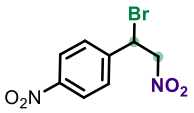


According to general procedure **GP5**, using 4-vinylbenzonitrile (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiCl (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow oil (89% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.[27]

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.73 (d, J = 8.2 Hz, 2H), 7.57 (d, J = 8.2 Hz, 2H), 5.58 (dd, J = 8.4, 6.3 Hz, 1H), 4.91 (dd, J = 13.6, 8.4 Hz, 1H), 4.79 (dd, J = 13.6, 6.3 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 140.9, 133.2, 128.3, 117.9, 114.00, 80.2, 55.6.

1-(1-Bromo-2-nitroethyl)-4-nitrobenzene (18):



According to general procedure **GP4**, using 1-nitro-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (80% yield, using 2% hexane in ethyl acetate as eluent).

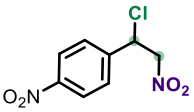
^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.24 (d, J = 8.8 Hz, 2H), 7.63 (d, J = 8.8 Hz, 2H), 5.60 (t, J = 7.8 Hz, 1H), 5.07 (dd, J = 14.0, 7.8 Hz, 1H), 5.01 (dd, J = 14.0, 7.8 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 148.5, 143.4, 128.9, 124.6, 79.8, 42. 8.

IR (ATR, neat): 3008, 1556, 1520, 1375, 1347.

HRMS (EI): *m/z* calcd for $C_8H_7O_4N_2{}^{79}Br$: 273.9584; found 273.9577.

1-(1-Chloro-2-nitroethyl)-4-nitrobenzene (19):

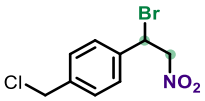


According to general procedure **GP5**, using 1-nitro-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiCl (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow oil (81% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.23 (d, J = 8.8 Hz, 2H), 7.65 (d, J = 8.8 Hz, 2H), 5.65 (dd, J = 8.6, 6.0 Hz, 1H), 4.96 (dd, J = 13.8, 8.6 Hz, 1H), 4.86 (dd, J = 13.8, 6.0 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 148.5, 142.6, 128.6, 124.4, 80.0, 55.3.

1-(1-Bromo-2-nitroethyl)-4-(chloromethyl)benzene (20):



According to general procedure **GP4**, using 4-vinylbenzyl chloride (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow liquid (73% yield, using 2% hexane in ethyl acetate as eluent).

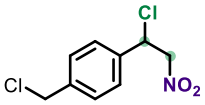
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45–7.39 (m, 4H), 5.55 (t, J = 7.7 Hz, 1H), 5.08–4.90 (m, 2H), 4.57 (s, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.2, 136.7, 129.5, 128.1, 80.5, 45.4, 44.7.

IR (ATR, neat): 3033, 2958, 1718, 1634, 1555, 1517, 1418, 1374, 1338.

HRMS (EI): *m/z* calcd for $C_9H_9O_2N^{81}BrCl$: 278.9479; found 278.9478.

1-(1-Chloro-2-nitroethyl)-4-(chloromethyl)benzene (21):



According to general procedure **GP5**, using 4-vinylbenzyl chloride (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiCl (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow liquid (70% yield, using 2% hexane in ethyl acetate as eluent).

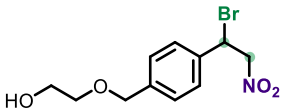
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.43 (s, 4H), 5.55 (t, J = 7.7 Hz, 1H), 5.11–4.88 (m, 2H), 4.58 (s, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.3, 136.7, 129.6, 128.1, 80.5, 45.4, 44.7.

IR (ATR, neat): 3028, 2925, 1644, 1556, 1522, 1420, 1376, 1266.

HRMS (EI): *m/z* calcd for $C_9H_9O_2N^{35}Cl_2$: 233.0005; found: 233.0001.

2-((4-(1-Bromo-2-nitroethyl)benzyl)oxy)ethan-1-ol (22):



According to general procedure **GP4**, using 2-((4-vinylbenzyl)oxy)ethan-1-ol (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow liquid (77% yield, using 5% hexane in ethyl acetate as eluent).

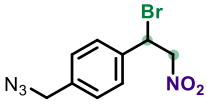
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.43−7.42 (m, 1H), 7.38−7.3 (m, 1H), 5.55 (t, J = 9.6, 2.4, 1H), 7.07 (tdd, J = 8.4, 2.8, 1.2, 1H), 5.53 (t, J = 7.6, 1H), 5.01 (dd, J = 13.6, 7.6, 1H), 4.95 (dd, J = 13.6, 7.6, 1H), 4.56 (s, 3H), 3.78−3.76 (m, 2H), 3.62−3.60 (m, 2H), 1.98 (s, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 140.1, 136.0, 128.5, 127.8, 80.6, 72.7, 71.8 62.0, 45.1.

IR (ATR, neat): 3330, 3115, 3051, 2959, 2864, 1558, 1338, 1265.

HRMS (ESI): *m/z* calcd for $C_{11}H_{14}O_2{}^{79}Br\text{-}NO_2$: 257.0172; found 257.0173.

1-(Azidomethyl)-4-(1-bromo-2-nitroethyl)benzene (23):



According to general procedure **GP4**, using 1-(azidomethyl)-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow liquid (80% yield, using 2% hexane in ethyl acetate as eluent).

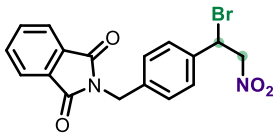
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 (d, J = 8.2 Hz, 2H), 7.35 (d, J = 8.2 Hz, 2H), 5.56 (t, J = 7.7 Hz, 1H), 5.04 (dd, J = 13.7, 7.9 Hz, 1H), 4.95 (dd, J = 13.7, 7.5 Hz, 1H), 4.37 (s, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 137.4, 136.6, 129.0, 128.2, 80.5, 54.3, 44.7.

IR (ATR, neat): 2934, 2101, 1685, 1610, 1553, 1418, 1277.

HRMS (EI): *m/z* calcd for $C_9H_9O_2N_4{}^{79}Br$: 283.9903; found: 283.9900.

2-(4-(1-Bromo-2-nitroethyl)benzyl)isoindoline-1,3-dione (24):



According to general procedure **GP4**, using 2-(4-vinylbenzyl)isoindoline-1,3-dione (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as white solid (91% yield, using 10% hexane in ethyl acetate as eluent).

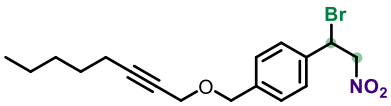
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.84 (dd, J = 5.4, 3.1 Hz, 2H), 7.71 (dd, J = 5.4, 3.1 Hz, 2H), 7.48–7.41 (m, 2H), 7.40–7.34 (m, 2H), 5.52 (dd, J = 8.2, 7.2 Hz, 1H), 4.99 (dd, J = 13.8, 8.2 Hz, 1H), 4.91 (dd, J = 13.8, 7.2 Hz, 1H), 4.83 (s, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 168.0, 138.2, 136.2, 134.3, 132.1, 129.7, 128.0, 123.6, 80.5, 44.9, 41.2.

IR (ATR, neat): 3033, 2976, 1765, 1706, 1556, 1424, 1395, 1333, 1267.

HRMS (ESI): *m/z* calcd for $C_{17}H_{13}O_4N_2{}^{79}BrNa$: 410.9951; found 410.9951.

1-(1-Bromo-2-nitroethyl)-4-((oct-2-yn-1-yloxy)methyl)benzene (25):



According to general procedure **GP4**, using 1-((oct-2-yn-1-yloxy)methyl)-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow liquid (52% yield, using 2% hexane in ethyl acetate as eluent).

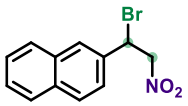
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.46–7.33 (m, 4H), 5.56 (t, J = 7.8 Hz, 1H), 5.03 (dd, J = 13.6, 8.1 Hz, 1H), 4.94 (dd, J = 13.6, 7.4 Hz, 1H), 4.58 (s, 2H), 4.17 (t, J = 2.2 Hz, 2H), 2.23 (tt, J = 7.0, 2.2 Hz, 2H), 1.53 (ddd, J = 14.2, 7.0, 4.8 Hz, 2H), 1.43–1.25 (m, 4H), 0.90 (t, J = 7.0 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.9, 135.9, 128.8, 127.7, 87.9, 80.6, 70.7, 58.3, 45.1, 31.2, 28.4, 22.3, 18.9, 14.1.

IR (ATR, neat): 3020, 2931, 2643, 1612, 1562, 1442, 1359.

HRMS (EI): *m/z* calcd for $C_{17}H_{22}O^{79}Br\text{-}NO_2$: 321.0849; found: 321.0842.

2-(1-Bromo-2-nitroethyl)naphthalene (26):



According to general procedure **GP4**, using 2-vinylnaphthalene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as white solid (60% yield, using 2% hexane in ethyl acetate as eluent).

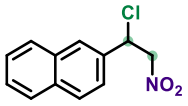
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.92–7.81 (m, 4H), 7.58–7.49 (m, 3H), 5.75 (t, J = 7.7 Hz, 1H), 5.18–5.01 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 133.8, 133.7, 133.1, 129.7, 128.3, 127.9, 127.5, 127.2, 127.2, 124.5, 80.6, 45.9.

IR (ATR, neat): 2986, 1559, 1373, 1264.

HRMS (ESI): *m/z* calcd for $C_{12}H_{10}O_2N^{79}Br$: 278.9889; found 278.9891.

2-(1-Chloro-2-nitroethyl)naphthalene [CAS 2460631-43-8] **(27):**

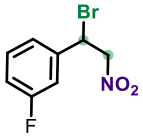


According to general procedure **GP5**, using 2-vinylnaphthalene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiCl (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as white solid (52% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.[27]

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.94–7.83 (m, 4H), 7.58–7.49 (m, 3H), 5.74 (dd, J = 9.0, 5.7 Hz, 1H), 5.01 (dd, J = 13.4, 9.0 Hz, 1H), 4.89 (dd, J = 13.4, 5.7 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 133.8, 133.1, 129.6, 128.3, 128.0, 127.4, 127.2, 127.1, 124.0, 80.9, 57.3.

1-(1-Bromo-2-nitroethyl)-3-fluorobenzene (28):



According to general procedure **GP4**, using 1-fluoro-3-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (90% yield, using 2% hexane in ethyl acetate as eluent).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.40−7.320 (m, 1H), 7.23−7.20 (m, 1H), 7.16 (dt, J = 9.6, 2.4, 1H), 7.07 (tdd, J = 8.4, 2.8, 1.2, 1H), 5.53 (t, J = 7.6, 1H), 5.01 (dd, J = 13.6, 7.6, 1H), 4.94 (dd, J = 13.6, 7.6, 1H).

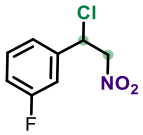
^{13}C-NMR (101 MHz, $CDCl_3$): δ 163.0 (d, J = 247 Hz), 138.9 (d, J = 7.4 Hz), 131.1 (d, J = 8.3 Hz), 123.3 (d, J = 3.0 Hz), 116.5 (d, J = 21.0 Hz), 117.0 (d, J = 22 Hz), 114.9 (d, J = 22.8 Hz), 80.4, 44.1 (d, J = 1.9 Hz).

^{19}F-NMR (376 MHz, $CDCl_3$): δ −110.8.

IR (ATR, neat): 3029, 2928, 1558, 1387, 1166.

HRMS (ESI): *m/z* calcd for $C_8H_7{}^{79}BrFNO_2$: 246.9638; found 246.9642.

1-(1-Chloro-2-nitroethyl)-3-fluorobenzene (29):



According to general procedure **GP5**, using 1-fluoro-3-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiCl (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (91% yield, using 2% hexane in ethyl acetate as eluent).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.39 (td, J = 8.0, 5.7 Hz, 1H), 7.24–7.05 (m, 3H), 5.54 (dd, J = 8.8, 5.9 Hz, 1H), 4.89 (dd, J = 13.5, 8.8 Hz, 1H), 4.78 (dd, J = 13.5, 5.9 Hz, 1H).

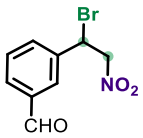
^{13}C-NMR (75 MHz, $CDCl_3$): δ 164.65, 161.35, 138.29, 138.20, 131.09 (d, J = 8.3 Hz), 123.04 (d, J = 3.1 Hz), 116.99 (d, J = 21.1 Hz), 114.58 (d, J = 23.0 Hz), 80.66, 56.03 (d, J = 2.2 Hz).

^{19}F-NMR (377 MHz, $CDCl_3$): δ −110.8.

IR (ATR, neat): 3031, 2925, 1649, 1557, 1377, 1266.

HRMS (EI): *m/z* calcd for $[C_8H_7{}^{35}ClFNO_2\text{-}HNO_2]$: 156.0138; found 156.0137.

3-(1-Bromo-2-nitroethyl)benzaldehyde (30):



According to general procedure **GP4**, using 3-vinylbenzaldehyde (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (88% yield, using 5% hexane in ethyl acetate as eluent).

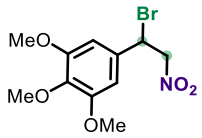
^{1}H-NMR (300 MHz, $CDCl_3$): δ 10.03 (s, 1H), 7.96 (t, J = 1.8 Hz, 1H), 7.88 (dt, J = 7.5, 1.4 Hz, 1H), 7.71 (dt, J = 7.8, 1.4 Hz, 1H), 7.59 (t, J = 7.6 Hz, 1H), 5.61 (t, J = 7.7 Hz, 1H), 5.12–4.96 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 191.2, 138.0, 137.3, 133.5, 131.3, 130.3, 128.3, 80.2, 43.9.

IR (ATR, neat): 3020, 2846, 2736, 1695, 1553, 1374, 1146.

HRMS (ESI): *m/z* calcd for $[C_9H_8{}^{79}BrNO_3+H]^+$: 257.9760; found 257.9762.

5-(1-Bromo-2-nitroethyl)-1,2,3-trimethoxybenzene (31):



According to general procedure **GP4**, using 1,2,3-trimethoxy-5-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound, which is very unstable and decomposes on column was isolated as yellow solid (31% yield, using 5% hexane in ethyl acetate as eluent). Note: unstable compound and **31a** forms during separation.

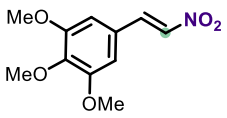
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.26 (s, 1H), 7.05 (s, 1H), 5.79 (d, J = 9.8 Hz, 1H), 4.69 (dd, J = 13.6, 2.3 Hz, 1H), 4.40 (dd, J = 13.6, 9.8 Hz, 1H), 3.91–3.88 (m, 9H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 152.7, 142.4, 131.6, 105.4, 78.5, 69.2, 60.3, 55.4.

IR (ATR, neat): 2929, 1558, 1483, 1395, 1328, 1102, 1008.

HRMS (ESI): *m/z* calcd for $[C_{11}H_{13}BrNO_6+O^{-}\text{-}H]^{-}]^{+}$: 333.9924; found 333.9934.

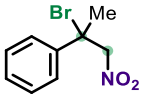
(E)-1,2,3-trimethoxy-5-(2-nitrovinyl)benzene (31a):



^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.94 (d, J = 13.5 Hz, 1H), 7.53 (d, J = 13.6 Hz, 1H), 6.76 (s, 2H), 3.92 (s, 3H), 3.91 (m, 6H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 153.9, 142.0, 139.4, 136.5, 125.5, 106.6, 61.2, 56.5.

(2-Bromo-1-nitropropan-2-yl)benzene (32):



According to general procedure **GP4**, using prop-1-en-2-ylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow liquid (89% yield, using 2% hexane in ethyl acetate as eluent).

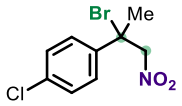
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.67–7.54 (m, 2H), 7.46–7.30 (m, 3H), 5.24 (d, J = 12.4 Hz, 1H), 5.06 (d, J = 12.4 Hz, 1H), 2.46 (s, 3H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 140.6, 129.2, 128.9, 126.7, 86.2, 59.3, 30.0.

IR (ATR, neat): 2955, 1552, 1420, 1375, 1112.

HRMS (EI): *m/z* calcd for $C_9H_{10}{}^{79}Br$: 194.9804; found 194.9809.

1-(2-Bromo-1-nitropropan-2-yl)-4-chlorobenzene (33):



According to general procedure **GP4**, using 1-chloro-4-(prop-1-en-2-yl)benzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (90% yield, using 2% hexane in ethyl acetate as eluent).

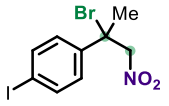
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.52 (d, J = 8.8 Hz, 2H), 7.36 (d, J = 8.8 Hz, 2H), 5.22 (d, J = 12.6 Hz, 1H), 5.04 (d, J = 12.6 Hz, 1H), 2.43 (s, 3H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 139.2, 135.2, 129.1, 128.1, 86.0, 58.2, 30.0.

IR (ATR, neat): 3005, 2921, 1554, 1481, 1377, 1331, 1065.

HRMS (ESI): *m/z* calcd for $C_9H_9NO_2{}^{79}Br^{35}Cl$: 274.9343; found 274.9342.

1-(2-Bromo-1-nitropropan-2-yl)-4-iodobenzene (34):



According to general procedure **GP4**, using 1-iodo-4-(prop-1-en-2-yl)benzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as red liquid (64% yield, using 2% hexane in ethyl acetate as eluent).

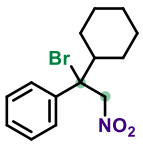
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.74–7.68 (m, 2H), 7.35–7.28 (m, 2H), 5.21 (d, J = 12.6 Hz, 1H), 5.02 (d, J = 12.6 Hz, 1H), 2.40 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 140.5, 138.0, 128.5, 95.3, 85.8, 58.3, 29.8.

IR (ATR, neat): 3028, 1550, 1485, 1371, 1337, 1004.

HRMS (ESI): *m/z* calcd for $C_9H_8O_2N^{79}BrI$: 367.8778; found 367.8780.

(1-Bromo-1-cyclohexyl-2-nitroethyl)benzene (35):



According to general procedure **GP4**, using (1-cyclohexylvinyl)benzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (90% yield, using 2% hexane in ethyl acetate as eluent).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.55 (dd, J = 7.5, 1.9 Hz, 2H), 7.40–7.29 (m, 3H), 5.25 (d, J = 12.7 Hz, 1H), 5.09 (d, J = 12.7 Hz, 1H), 2.14 (ddd, J = 10.8, 7.8, 2.9 Hz, 1H), 2.01 (dq, J = 9.5, 2.9 Hz, 1H), 1.88

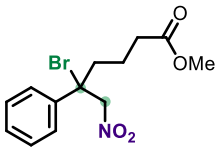
(dtd, *J* = 7.5, 5.7, 2.9 Hz, 1H), 1.79–1.61 (m, 3H), 1.47–1.33 (m, 2H), 1.27 (qd, *J* = 12.0, 11.2, 2.9 Hz, 2H), 1.17 (ddt, *J* = 16.4, 10.4, 3.4 Hz, 1H).

^{13}C-NMR (126 MHz, $CDCl_3$): *δ* 138.8, 128.6, 128.5, 128.2, 84.1, 74.9, 47.0, 29.5, 29.1, 26.2, 26.1.

IR (ATR, neat): 3009, 2927, 2858, 1586, 1472, 1392.

HRMS (EI): *m/z* calcd for $C_{14}H_{18}O_2N^{79}Br$: 311.0515; found 311.0514.

Methyl 5-bromo-6-nitro-5-phenylhexanoate (36):



According to general procedure **GP4**, using methyl 5-phenylhex-5-enoate (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (74% yield, using 2% hexane in ethyl acetate as eluent).

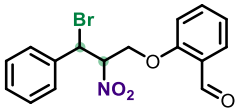
^{1}H-NMR (500 MHz, $CDCl_3$): *δ* 7.59–7.54 (m, 2H), 7.42–7.32 (m, 3H), 5.13 (d, *J* = 12.5 Hz, 1H), 5.07 (d, *J* = 12.5 Hz, 1H), 3.69 (s, 3H), 2.63 (ddd, *J* = 14.6, 11.0, 5.0 Hz, 1H), 2.54–2.47 (m, 1H), 2.43 (td, J = 7.3, 2.4 Hz, 2H), 1.98–1.80 (m, 2H).

^{13}C-NMR (126 MHz, $CDCl_3$): *δ* 138.8, 128.6, 128.5, 128.2, 84.1, 74.9, 47.0, 29.5, 29.1, 26.2, 26.1.

IR (ATR, neat): 1706, 1552, 1376, 1265.

HRMS (ESI): *m/z* calcd for $[C_{13}H_{16}{}^{79}BrNO_4–NO_2]$: 283.0334; found 283.0332.

2-(3-Bromo-2-nitro-3-phenylpropoxy)benzaldehyde (37):



According to general procedure **GP4**, using 2-[(*E*)-(3-phenyl-2-propenyl)oxy]benzaldehyde (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as brown oil (d.r. = 1:1; 78% yield, using 5-10% hexane in ethyl acetate as eluent).

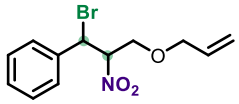
^{1}H-NMR (400 MHz, $CDCl_3$): *δ* 10.39 (s, 1H), 7.87 (dd, *J* = 7.7, 1.8 Hz, 1H), 7.59 (ddd, *J* = 8.4, 7.4, 1.8 Hz, 1H), 7.50–7.44 (m, 2H), 7.39 (dddd, *J* = 6.8, 5.6, 4.2, 2.3 Hz, 3H), 7.13 (tt, *J* = 7.4, 1.0 Hz, 1H), 7.02 (dd, *J* = 8.5, 1.0 Hz, 1H), 5.54 (ddd, *J* = 10.5, 7.8, 2.8 Hz, 1H), 5.43 (d, *J* = 10.5 Hz, 1H), 4.96 (dd, *J* = 10.5, 2.8 Hz, 1H), 4.86 (dd, *J* = 10.5, 7.8 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): *δ* 188.9, 159.5, 136.0, 135.9, 130.2, 129.4, 129.0, 128.0, 125.5, 122.5, 112.6, 90.5, 68.5, 47.0.

IR (ATR, neat): 3012, 2858, 1735, 1686, 1600, 1557, 1485, 1454, 1236, 1051.

HRMS (ESI): *m/z* calcd for $[C_{16}H_{14}{}^{79}BrNO_4+H]^+$: 364.0192; found 364.0187.

(3-(Allyloxy)-1-bromo-2-nitropropyl)benzene (38):



According to general procedure **GP4**, using (*E*)-(3-(allyloxy)prop-1-en-1-yl)benzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colorless oil (d.r. = 7.1:1; 81% yield, using 2% hexane in ethyl acetate as eluent).

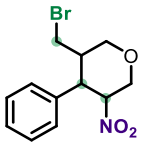
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44–7.29 (m, 5H), 5.87 (ddt, J = 17.3, 10.3, 5.7 Hz, 1H), 5.38–5.18 (m, 4H), 4.30–4.24 (m, 1H), 4.18 (ddd, J = 10.8, 5.1, 2.5 Hz, 1H), 4.07 (ddt, J = 5.5, 2.6, 1.4 Hz, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 136.7, 133.6, 129.8, 129.2, 128.0, 118.4, 91.4, 72.7, 69.9, 47.2.

IR (ATR, neat): 3034, 2915, 2852, 1556, 1351, 1094.

HRMS (ESI): *m/z* calcd for $[C_{12}H_{14}{}^{79}BrNO_3+H]$: 300.0235; found 300.0625.

3-(Bromomethyl)-5-nitro-4-phenyltetrahydro-2H-pyran (39):



According to general procedure **GP4**, using (*E*)-(3-(allyloxy)prop-1-en-1-yl)benzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). The titled compound was isolated as colorless oil (11% yield, using 2% hexane in ethyl acetate as eluent).

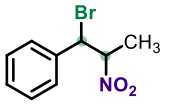
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.47–7.29 (m, 5H), 5.35–5.18 (m, 3H), 4.42–4.22 (m, 2H), 3.96–3.79 (m, 2H), 3.62–3.46 (m, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 136.3, 130.0, 129.3, 128.0, 91.0, 91.0, 79.9, 71.6, 69.4, 69.4, 46.9, 27.3, 27.2.

IR (ATR, neat): 30022, 2977, 1553, 1265.

HRMS (ESI): *m/z* calcd for $[C_{12}H_{14}{}^{79}BrNO_3+H]$: 300.0235; found 300.0625.

(1-Bromo-2-nitropropyl)benzene (40):



According to general procedure **GP4**, using methyl cinnamate (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless sticky oil (d.r. = 1.3:1; 88% yield, using 2% hexane in ethyl acetate as eluent).

Major isomer (39a): Isolated as white solid.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44–7.39 (m, 2H), 7.38–7.28 (m, 3H), 5.29 (d, J = 9.2 Hz, 1H), 5.08 (dq, J = 9.2, 6.6 Hz, 1H), 1.87 (d, J = 6.6 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 137.1, 129.6, 129.1, 128.0, 87.9, 53.03, 18.6.

Minor isomer (39b): Isolated as colorless liquid.

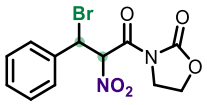
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44–7.32 (m, 5H), 5.26 (d, J = 10.3 Hz, 1H), 5.16 (dq, J = 10.3, 6.6 Hz, 1H), 1.37 (d, J = 6.6 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 136.3, 129.8, 129.5, 128.2, 89.2, 52.0, 18.6.

IR (ATR, neat): 3033, 2942, 1551, 1452, 1387, 1356, 1289.

HRMS (EI): *m/z* calcd for $[C_9H_{10}{}^{79}BrNO_2]$: 242.9889; found 242.9884.

3-(3-Bromo-2-nitro-3-phenylpropanoyl)oxazolidin-2-one (41):



According to general procedure **GP4**, using 3-cinnamoyloxazolidin-2-one (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as yellow liquid (d.r. = 1.1:1; 70% yield, using 2% hexane in ethyl acetate as eluent).

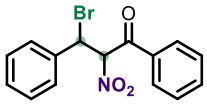
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.50–7.35 (m, 10H), 6.53 (d, J = 11.6 Hz, 1H), 6.41 (d, J = 10.6 Hz, 1H), 5.93 (d, J = 10.6 Hz, 1H), 5.51 (d, J = 11.6 Hz, 1H), 4.55–4.49 (m, 4H), 4.24–4.06 (m, 4H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 167.6, 167.0, 152.8, 152.6, 137.6, 133.6, 130.3, 129.6, 129.1, 129.0, 128. 6, 128.5, 83.3, 62.5, 62.4, 50.5, 43.4, 43.0, 42.9, 40.1.

IR (ATR, neat): 3056, 3035, 2928, 2911, 1780, 1689, 1648, 1395, 1266, 1218.

HRMS (ESI): *m/z* calcd for $[C_{12}H_{11}{}^{79}BrN_2O_5–NO_2]$: 295.9922; found 295.9919.

3-Bromo-2-nitro-1,3-diphenylpropan-1-one (42):



According to general procedure **GP4**, using (*E*)-chalcone (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as solid (d.r. = 4:1; 55% yield, using 5% hexane in ethyl acetate as eluent).

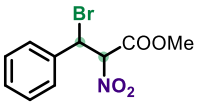
^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.10–8.03 (m, 2H), 7.70–7.63 (m, 1H), 7.58–7.51 (m, 4H), 7.48–7.39 (m, 3H), 6.58 (d, *J* = 10.4 Hz, 1H), 5.30 (d, *J* = 10.4 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 190.6, 134.6, 134.4, 134.0, 130.2, 129.2, 129.1, 129.0, 128.4, 82.7, 43.5.

IR (ATR, neat): 3031, 2935, 1679, 1626, 1594, 1448, 1372, 1272, 1220.

HRMS (ESI): *m/z* calcd for $[C_{15}H_{12}{}^{79}BrNO_3–HNO_2]$: 285.9988; found 285.9979.

Methyl 3-bromo-2-nitro-3-phenylpropanoate (43):



According to general procedure **GP4**, using methyl cinnamate (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as red liquid (d.r. = 1:1; 78% yield, using 5% hexane in ethyl acetate as eluent).

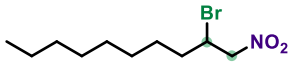
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.45–7.35 (m, 10H), 6.24 (d, *J* = 10.4 Hz, 1H), 5.34 (d, *J* = 11.8 Hz, 1H), 4.85 (d, *J* = 11.8 Hz, 1H), 4.43 (d, *J* = 10.4 Hz, 1H), 3.90 (s, 3H), 3.87 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 168.5, 167.9, 137.7, 133.7, 130.3, 129.6, 129.1, 129.0, 129.0 128.2, 128.2, 83.6, 53.8, 53.6, 50.8, 46.9, 42.9.

IR (ATR, neat): 3010, 2952, 1736, 1648, 1434, 1274, 1145.

HRMS (ESI): *m/z* calcd for $[C_{10}H_{10}{}^{79}BrNO_4–NO_2]$: 240.9864; found 240.9859.

2-Bromo-1-nitrodecane (44):



According to general procedure **GP4**, using dec-1-ene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), CBr_4 (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (75% yield, using 1% hexane in ethyl acetate as eluent).

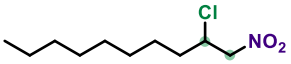
^{1}H-NMR (400 MHz, $CDCl_3$): δ 4.75–4.62 (m, 2H), 4.56–4.46 (m, 1H), 1.91–1.79 (m, 2H), 1.56 (dp, *J* = 8.8, 3.5, 3.0 Hz, 1H), 1.52–1.41 (m, 1H), 1.38–1.21 (m, 10H), 0.93–0.84 (m, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 81.0, 46. 9, 35.7, 31.9, 29.4, 29.3, 28.8, 27.1, 22.8, 14.2.

IR (ATR, neat): 2926, 2856, 1557, 1377.

HRMS (EI): *m/z* calcd for $C_{10}H_{19}ON^{79}Br$: 248.0645; found 248.0645.

2-Chloro-1-nitrodecane [CAS 1257309-97-9] **(45):**

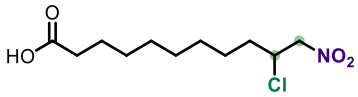


According to general procedure **GP5**, using dec-1-ene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), LiCl (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (75% yield, using 1% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.60–4.54 (m, 2H), 4.53–4.48(m, 1H), 1.83–1.74 (m, 2H), 1.58–1.49 (m, 2H), 1.32–1.26 (m, 10H), 0.91–0.86 (m, 3H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 80.7, 56.4, 35.2, 31.9, 29.4, 29.3, 29.0, 26.0, 22.8, 14.2.

10-Chloro-11-nitroundecanoic acid (46):



According to general procedure **GP5**, using octa-1,7-diene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), LiCl (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (70% yield, using 5-20% hexane in ethyl acetate as eluent).

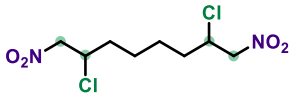
^{1}H-NMR (300 MHz, $CDCl_3$): δ 11.18 (s, 1H), 4.62–4.56 (m, 2H), 4.55–4.45 (m, 1H), 2.35 (t, J = 7.5 Hz, 2H), 1.88–1.70 (m, 2H), 1.68–1.27 (m, 12H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 180.2, 80.7, 56.3, 35.1, 34.1, 29.2, 29.1, 29.0, 28.8, 25.9, 24.7.

IR (ATR, neat): 3306, 3034, 2915, 2852, 1556, 1456, 1351.

HRMS (ESI): *m/z* calcd for $[C_{11}H_{20}O_4N^{35}Cl{-}H]^-$: 264.1008; found 264.1009.

2,7-Dichloro-1,8-dinitrooctane (47):



According to general procedure **GP5**, using octa-1,7-diene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (2.2 mmol, 2.2 equiv), LiCl (2.0 mmol, 2.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (95% yield, using 2% hexane in ethyl acetate as eluent).

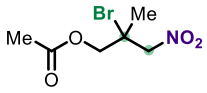
^{1}H-NMR (400 MHz, $CDCl_3$): δ 4.62−4.56 (m, 4H), 4.55−4.46 (m, 2H), 1.88−1.71 (m, 4H), 1.68−1.46 (m, 4H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 80.5, 80.5, 56.1, 34.6, 34.6, 25.2, 25.2.

IR (ATR, neat): 2946, 2867, 1552, 1421, 1379, 1278.

HRMS (ESI): *m/z* calcd for $[C_8H_{14}O_4N_2{}^{35}Cl_2-H]^-$: 271.0258; found 271.0262.

2-Bromo-2-methyl-3-nitropropyl acetate (48):



According to general procedure **GP4**, using 2-methylallyl acetate (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (78% yield, using 5% hexane in ethyl acetate as eluent).

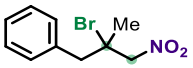
^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.92–4.68 (m, 2H), 4.50 (d, J = 12.1 Hz, 1H), 4.36 (d, J = 12.1 Hz, 1H), 2.14 (s, 3H), 1.93 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 169.9, 82.2, 69.1, 55.9, 26.9, 20.8.

IR (ATR, neat): 2964, 1717, 1559, 1264.

HRMS (ESI): *m/z* calcd for $[C_6H_{10}{}^{79}BrNO_4+Na]^+$: 263.0428; found 263.0412.

(2-Bromo-2-methyl-3-nitropropyl)benzene (49):



According to general procedure **GP4**, using (2-methylallyl)benzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (62% yield, using 2% hexane in ethyl acetate as eluent).

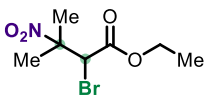
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.34 (s, 5H), 4.77–4.64 (m, 2H), 3.39 (s, 2H), 1.93 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.1, 131.1, 128.5, 127.8, 84.1, 60.7, 48.3, 30.0.

IR (ATR, neat): 3064, 3031, 2927, 1664, 1553, 1453, 1372.

HRMS (ESI): *m/z* calcd for $[C_{10}H_{12}{}^{79}BrNO_2+H]^+$: 259.1230; 259.1785.

Ethyl 2-bromo-3-methyl-3-nitrobutanoate (50):



According to general procedure **GP4**, using ethyl 3-methylbut-2-enoate (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (86% yield, using 5% hexane in ethyl acetate as eluent).

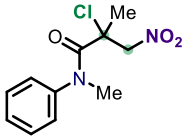
^{1}H-NMR (400 MHz, $CDCl_3$): δ 5.02 (s, 1H), 4.31–4.17 (m, 2H), 1.77 (s, 3H), 1.73 (s, 3H), 1.29 (t, J = 7.1 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 166.9, 89.9, 62.8, 49.1, 23.5, 22.3, 14.0.

IR (ATR, neat): 2968, 1720, 1580, 1265.

HRMS (ESI): *m/z* calcd for $[C_7H_{12}{}^{79}BrNO_4+K]^+$: 293.1783; found 293.1750.

2-Chloro-N,2-dimethyl-3-nitro-N-phenylpropanamide (51):



According to general procedure **GP5**, using *N*-methyl-*N*-phenylmethacrylamide (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiCl (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (59% yield, using 8% hexane in ethyl acetate as eluent).

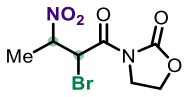
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.47–7.29 (m, 5H), 4.93 (d, *J* = 14.4 Hz, 1H), 4.72 (d, *J* = 14.4 Hz, 1H), 3.35 (s, 3H), 1.63 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 167.2, 143.5, 129.7, 128.8, 128.5, 83.1, 63.2, 41.9, 27.8.

IR (ATR, neat): 2983, 1646, 1595, 1559, 1495, 1373, 1266.

HRMS (EI): *m/z* calcd for $C_{11}H_{13}{}^{35}ClN_2O_3$: 256.0609; found 256.0607.

3-(2-Bromo-3-nitrobutanoyl)oxazolidin-2-one (52):



According to general procedure **GP4**, using (E)-3-(but-2-enoyl)oxazolidin-2-one (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colourless liquid (d.r. = 1.1:1; 78% yield, using 6% hexane in ethyl acetate as eluent).

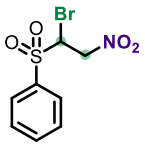
^{1}H-NMR (300 MHz, $CDCl_3$): δ 5.95 (d, *J* = 10.3 Hz, 1H), 5.68 (dq, *J* = 9.4, 6.0 Hz, 1H), 5.60 (d, *J* = 9.4 Hz, 1H), 5.16 (dq, *J* = 10.3, 7.0 Hz, 1H), 4.55–4.45 (m, 4H), 4.15–4.00 (m, 4H), 1.89 (d, *J* = 7.0 Hz, 3H), 1.66 (d, *J* = 6.0 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 167.4, 166.9, 152.5, 146.9, 82.3, 78.4, 62.5, 62. 5, 42.8, 42.7, 41.3, 40.2, 18.3, 16.8.

IR (ATR, neat): 1974, 1779, 1699, 1639, 1557, 1388, 1278.

HRMS (ESI): *m/z* calcd for $[C_7H_9{}^{79}BrN_2O_5+Na]^+$: 302.9587; found 302.9588.

((1-Bromo-2-nitroethyl)sulfonyl)benzene (53):



According to general procedure **GP4**, using (vinylsulfonyl)benzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (38% yield, using 2% hexane in ethyl acetate as eluent).

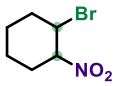
^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.02–7.97 (m, 2H), 7.80–7.74 (m, 1H), 7.69–7.61 (m, 2H), 5.15 (dd, *J* = 13.0, 5.2 Hz, 1H), 5.03 (dd, *J* = 7.3, 5.2 Hz, 1H), 4.85 (dd, *J* = 13.0, 7.3 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 135.5, 135.1, 130.1, 129.6, 69.7, 58.7.

IR (ATR, neat): 2963, 1645, 1448, 1328, 1277, 1152, 1083.

HRMS (ESI): *m/z* calcd for $C_8H_8{}^{79}BrNO_4S$: 292.9192; found 292.9185.

1-Bromo-2-nitrocyclohexane (54):



According to general procedure **GP4**, using cyclohexene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (78% yield, using 2% hexane in ethyl acetate as eluent).

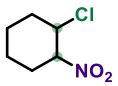
^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.61 (td, *J* = 10.8, 4.3 Hz, 1H), 4.36 (td, *J* = 11.0, 4.6 Hz, 1H), 2.52–2.33 (m, 2H), 2.01–1.65 (m, 5H), 1.49–1.33 (m, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 91.8, 48.1, 35.7, 32.7, 25.9, 23.6.

IR (ATR, neat): 2924, 2856, 1557, 1377.

HRMS (EI): *m/z* calcd for $C_6H_8{}^{79}Br$: 158.9804; found 158.9804.

1-Chloro-2-nitrocyclohexane [CAS 42606-47-3] **(55):**



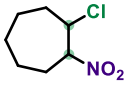
According to general procedure **GP5**, using cyclohexene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiCl (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as

colourless liquid (88% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.[28]

^{1}H-NMR (400 MHz, $CDCl_3$): δ 4.60 (ddd, J = 11.2, 10.2, 4.4 Hz, 1H), 4.36 (ddd, J = 11.8, 10.2, 4.6 Hz, 1H), 2.50–2.34 (m, 2H), 1.98–1.72 (m, 5H), 1.50–1.35 (m, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 91.6, 57.8, 34.9, 32.1, 24.9, 23.6.

1-Chloro-2-nitrocycloheptane [CAS 1346273-79-7] **(56):**

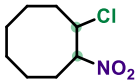


According to general procedure **GP5**, using cycloheptene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), LiCl (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (90% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 4.68 (td, J = 9.0, 3.8 Hz, 1H), 4.57 (td, J = 9.0, 3.8 Hz, 1H), 2.26 (m, 1H), 2.21–1.92 (m, 3H), 1.91–1.71 (m, 2H), 1.69–1.57 (m, 4H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 95.4, 61.0, 35.0, 31.7, 27.3, 23.8, 23.7.

1-Chloro-2-nitrocyclooctane [CAS 1346273-92-4] **(57):**

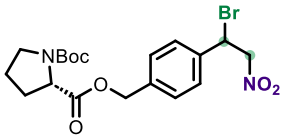


According to general procedure **GP5**, using cyclohoctene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), LiCl (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (84% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.85 (ddd, J = 10.2, 7.3, 2.7 Hz, 1H), 4.71 (ddd, J = 10.4, 6.5, 2.7 Hz, 1H), 2.36–2.22 (m, 1H), 2.16–2.02 (m, 3H), 1.96–1.57 (m, 7H), 1.51–1.35 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 94.2, 61.0, 31.5, 31.4, 26.8, 25.7, 24.8, 23.6.

4-(1-Bromo-2-nitroethyl)benzyl (pivaloyloxy)-L-prolinate (58):



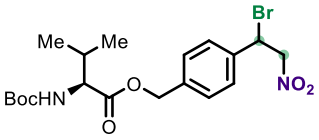
According to general procedure **GP4**, using 4-vinylbenzyl (pivaloyloxy)-L-prolinate (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (70% yield, using 10-20% hexane in ethyl acetate as eluent).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.41 (q, J = 6.5 Hz, 4H), 5.54 (t, J = 7.7 Hz, 1H), 5.26–4.86 (m, 5H), 4.32 (ddd, J = 35.7, 8.5, 3.6 Hz, 1H), 3.59–3.31 (m, 2H), 2.31–2.10 (m, 1H), 2.02–1.80 (m, 3H), 1.45 (s, 3H), 1.31 (s, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 173.1, 172.9, 154.5, 153.9, 137.9, 137.6, 136.7, 136.3, 80.6, 80.4, 80.1, 80.0, 65.9, 59.2, 59.0, 46.7, 46.5, 45.0, 44.7, 31.0, 30.0, 28.6, 28.4, 24.5, 23.8.

IR (ATR, neat): 2978, 1792, 1716, 1652, 1578, 1533, 1489, 1353, 1266.

4-(1-Bromo-2-nitroethyl)benzyl (pivaloyloxy)-L-valinate (59):



According to general procedure **GP4**, using 4-vinylbenzyl (pivaloyloxy)-L-valinate (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (78% yield, using 10-20% hexane in ethyl acetate as eluent).

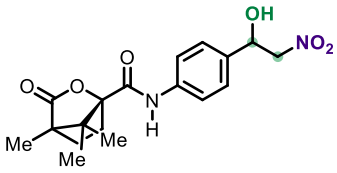
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.44−7.42 (m, 2H), 7.39−7.37 (m, 2H), 5.56 (t, J = 12.0 Hz, 1H), 5.20−5.12 (m, 2H), 5.05−4.92 (m, 3H), 4.28−4.25 (m, 1H), 2.17−2.12 (m, 1H), 1.44 (s, 9H), 0.95 (d, J = 4.0 Hz, 3H), 0.86 (d, J = 4.0 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 172.0, 156.8, 137.4, 136.7, 129.1, 127.9, 80.5, 80.0, 66.1, 58.8, 44.8, 31.4, 28.5, 19.2, 17.7.

IR (ATR, neat): 2978, 1792, 1716, 1652, 1578, 1533, 1489, 1353, 1266.

HRMS (ESI): *m/z* calcd for $[C_{19}H_{27}{}^{79}BrN_2O_6{+}Na]^+$: 481.0945; found 481.0946.

(1S,4S)-*N*-(4-(1-Hydroxy-2-nitroethyl)phenyl)-4,7,7-trimethyl-3-oxo-2-oxabicyclo[2.2.1]-heptane-1-carboxamide (60):



According to general procedure **GP4**, using (1R)-4,7,7-trimethyl-3-oxo-*N*-(4-vinylphenyl)-2-oxabicyclo[2.2.1]heptane-1-carboxamide (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (51% yield, using 15% hexane in ethyl acetate as eluent). The generated benzylic nitroalkyl radical is highly stabilizex due to the presence of amide at para position, and can lead to the follow up abstraction of OH from FeL_2–OH complex.

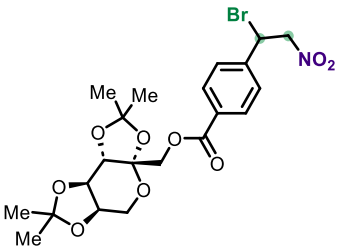
^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.21 (s, 1H), 7.60 (d, J = 8.6 Hz, 2H), 7.38 (d, J = 8.6 Hz, 2H), 5.44 (dt, J = 9.5, 2.6 Hz, 1H), 4.58 (dd, J = 13.2, 9.5 Hz, 1H), 4.49 (dd, J = 13.2, 3.2 Hz, 1H), 3.20 (s, 1H), 2.65–2.51 (m, 1H), 2.04–1.94 (m, 2H), 1.73 (ddd, J = 11.4, 7.5, 4.2 Hz, 1H), 1.15 (s, 3H), 1.14 (s, 3H), 0.97 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 178.1, 165.7, 137.3, 135.1, 126.9, 120.7, 92.5, 81.3, 70.6, 55.6, 54.6, 30.6, 29.2, 16.9, 16.7, 9.8.

IR (ATR, neat): 3463, 3301, 2968, 2931, 2876, 1781, 1675, 1598, 1535, 1417, 1378, 1166.

HRMS (EI): *m/z* calcd for $[C_8H_{21}O_6N_2\text{-}H]^-$: 361.1405; found: 361.1406.

((3aS,5aR,8aR,8bS)-2,2,7,7-Tetramethyltetrahydro-3aH-bis([1,3]dioxolo)[4,5-b:4',5'-d]pyran -3a-yl)methyl 4-(1-bromo-2-nitroethyl)benzoate (61):



According to general procedure **GP4**, using ((3aS,5aR,8aR,8bS)-2,2,7,7-tetramethyltetrahydro-3aH-bis([1,3]dioxolo)[4,5-b:4',5'-d]pyran-3a-yl)methyl 4-vinylbenzoate (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as light-yellow solid (68% yield, using 8% hexane in ethyl acetate as eluent).

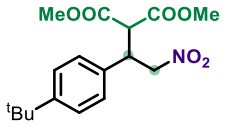
^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.10 (d, J = 8.4 Hz, 2H), 7.51 (d, J = 8.4 Hz, 2H), 5.57 (t, J = 7.7 Hz, 1H), 5.04 (dd, J = 13.8, 7.8 Hz, 1H), 4.97 (ddd, J = 13.8, 7.6, 0.6 Hz, 1H), 4.70–4.62 (m, 2H), 4.43 (d, J = 2.7 Hz, 1H), 4.35 (d, J = 11.7 Hz, 1H), 4.26 (ddd, J = 7.9, 2.0, 0.8 Hz, 1H), 3.95 (dd, J = 13.0, 2.0 Hz, 1H), 3.80 (dd, J = 13.0, 0.8 Hz, 1H), 1.55 (s, 4H), 1.45 (s, 3H), 1.37 (s, 3H), 1.35 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 165.1, 141.5, 131.3, 130.8, 127.8, 109.4, 109.0, 101.7, 80.2, 70.9, 70.8, 70.2, 66.0, 61.5, 44.0, 26.7, 26.0, 25.7, 24.2.

IR (ATR, neat): 3010, 2920, 2667, 2543, 2357, 1693, 1636, 1610, 1557, 1415, 1374, 1274.

HRMS (ESI): *m/z* calcd for $[C_{21}H_{26}{}^{79}BrNO_9\text{+Na}]^+$: 538.0683; found: 538.0675.

Dimethyl 2-(1-(4-(*tert*-butyl)phenyl)-2-nitroethyl)malonate [CAS 1448300-55-7] **(62):**

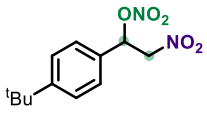


The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.31 (d, J = 8.4 Hz, 2H), 7.14 (d, J = 8.4 Hz, 2H), 4.96–4.81 (m, 2H), 4.22 (td, J = 8.6, 5.5 Hz, 1H), 3.85 (d, J = 8.7 Hz, 1H), 3.75 (s, 3H), 3.56 (s, 3H), 1.27 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 168.1, 167.5, 151.4, 133.2, 127.6, 126.0, 77.5, 55.0, 53.1, 52.9, 42.6, 34.6, 31.3.

1-(4-(*tert*-Butyl)phenyl)-2-nitroethyl nitrate (63):

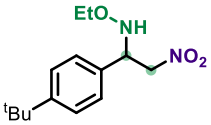


^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.46 (d, J = 8.4 Hz, 2H), 7.34 (d, J = 8.4 Hz, 2H), 6.56 (dd, J = 10.2, 3.5 Hz, 1H), 4.84 (dd, J = 14.6, 10.2 Hz, 1H), 4.60 (dd, J = 14.6, 3.5 Hz, 1H), 1.32 (s, 9H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 154.0, 129.4, 126.7, 126.6, 79.8, 75.6, 35.0, 31.3.

IR (ATR, neat): 2964, 1632, 1605, 1507, 1335, 1268, 1186.

***N*-(1-(4-(*tert*-Butyl)phenyl)-2-nitroethyl)-O-ethylhydroxylamine (64):**



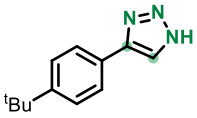
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.42 (d, J = 8.5 Hz, 2H), 7.30 (d, J = 8.5 Hz, 2H), 5.76 (s, 1H), 4.92 (dd, J = 12.4, 7.8 Hz, 1H), 4.81 (dd, J = 7.8, 5.2 Hz, 1H), 4.62 (dd, J = 12.4, 5.2 Hz, 1H), 3.75 (q, J = 7.0 Hz, 2H), 1.35 (s, 9H), 1.17 (t, J = 7.0 Hz, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 152.0, 132.8, 127.4, 125.9, 78.1, 70.2, 62.8, 34.6, 31.3, 13.9.

IR (ATR, neat): 2964, 1523, 1378, 1275, 1040.

HRMS (EI): *m/z* calcd for $C_{14}H_{22}N_2O_3$: 266.1625; found 266.1624.

5-(4-(*tert*-Butyl)phenyl)-1H-imidazole [CAS 35222-80-1] **(65):**

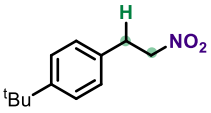


The characterization data match the literature.

^{1}H-NMR (300 MHz, DMSO-d_6): δ 14.90 (br, 1H), 8.19 (s, 1H), 7.78 (d, J = 8.0 Hz, 2H), 7.46 (d, J = 8.1 Hz, 2H), 3.36 (s, 1H), 1.29 (s, 9H).

^{13}C-NMR (75 MHz, DMSO-d_6): δ 150.7, 146.3, 130.6, 127.7, 125.6, 125.4, 34.4, 31.04.

1-(*tert*-Butyl)-4-(2-nitroethyl)benzene [CAS 1267108-03-1] **(66):**

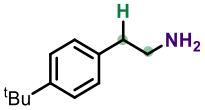


The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.36 (dd, *J* = 8.3, 1.8 Hz, 2H), 7.15 (dd, *J* = 8.3, 1.8 Hz, 2H), 4.60 (t, *J* = 7.5 Hz, 2H), 3.30 (t, *J* = 7.5 Hz, 2H), 1.32 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 150.5, 132.7, 132.7, 128.4, 126.0, 76.4, 34.6, 33.1, 31.4.

2-(4-(*tert*-Butyl)phenyl)ethan-1-amine [CAS 91552-82-8] **(67):**

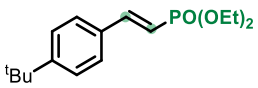


The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.24 (d, *J* = 8.4 Hz, 2H), 7.13 (d, *J* = 8.4 Hz, 2H), 3.28 (dd, *J* = 10.4, 6.1 Hz, 2H), 3.11 (dd, *J* = 10.4, 6.1 Hz, 2H), 1.24 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 150.1, 133.3, 128.6, 126.0, 125.9, 125.8, 41.8, 34.5, 33.1, 31.4.

Diethyl (*E*)-(4-(*tert*-butyl)styryl)phosphonate [CAS 2097490-21-4] **(68):**



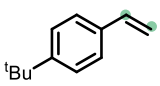
The characterization data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45–7.37 (m, 4H), 6.19 (t, *J* = 17.7 Hz, 1H), 4.14–4.07 (m, 4H), 1.33 (t, *J* = 7.1 Hz, 6H), 1.30 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 153.9, 153.92, 148.8 (d, J = 6.6 Hz), 132.3 (d, J = 23.3 Hz), 126.8 (d, J = 130.2 Hz), 113.0 (d, J = 191.6 Hz), 61.9 (d, J = 5.3 Hz), 31.30, 16.54 (d, J = 6.4 Hz).

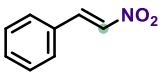
^{31}P-NMR (121 MHz, $CDCl_3$): δ 20.0.

1-(*tert*-Butyl)-4-vinylbenzene [CAS 1746-23-2] **(1):**



^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.39 (m, 4H), 6.80–6.68 (m, 1H), 5.74 (ddd, *J* = 17.6, 3.0, 1.5 Hz, 1H), 5.23 (ddd, *J* = 10.9, 3.0, 1.5 Hz, 1H), 1.36 (s, 9H).

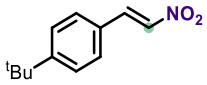
(*E*)-(2-Nitrovinyl)benzene [CAS 5153-67-3] **(69):**



According to general procedure **GP7**, using styrene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), $LiOH \cdot H_2O$ (2.0 mmol, 2.0 equiv), MeCN (4.0 mL). Titled compound was isolated as yellow oil (72% yield, using 2% hexane in ethyl acetate as eluent).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.01 (d, J = 13.7 Hz, 1H), 7.59 (d, J = 13.7 Hz, 1H), 7.57–7.54 (m, 2H), 7.53–7.42 (m, 3H).

(*E*)-1-(*tert*-Butyl)-4-(2-nitrovinyl)benzene [CAS 1056474-04-4] **(70):**

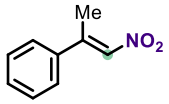


According to general procedure **GP7**, using 1-(tert-butyl)-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), $LiOH \cdot H_2O$ (2.0 mmol, 2.0 equiv), MeCN (4.0 mL). Titled compound was isolated as yellow oil (81% yield, using 2% hexane in ethyl acetate as eluent).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.00 (d, J = 13.6 Hz, 1H), 7.58 (d, J = 13.6 Hz, 1H), 7.53–7.43 (m, 4H), 1.34 (s, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 156.3, 139.2, 136.5, 129.2, 127.4, 126.5, 35.3, 31.1.

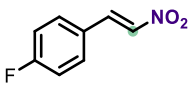
(*E*)-(1-Nitroprop-1-en-2-yl)benzene [CAS 15241-24-4] **(71):**



According to general procedure **GP7**, using prop-1-en-2-ylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), $LiOH \cdot H_2O$ (2.0 mmol, 2.0 equiv), MeCN (4.0 mL). Titled compound was isolated as yellow oil (93% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.49–7.41 (m, 5H), 7.31 (q, J = 1.4 Hz, 1H), 2.65 (d, J = 1.4 Hz, 3H).

(*E*)-1-Fluoro-4-(2-nitrovinyl)benzene [CAS 5153-69-5] **(72):**



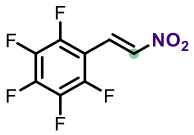
According to general procedure **GP7**, using 1-fluoro-4-vinylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), $LiOH \cdot H_2O$ (2.0 mmol, 2.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as light-yellow solid (74% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.98 (d, J = 13.7 Hz, 1H), 7.60–7.50 (m, 3H), 7.15 (t, J = 8.6 Hz, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 165.1 (d, J = 254.9 Hz), 138.0, 137.0, 131.4 (d, J = 8.9 Hz), 126.5 (d, J = 3.5 Hz), 117.0 (d, J = 22.1 Hz).

^{19}F-NMR (376 MHz, $CDCl_3$): δ −105.8.

(*E*)-1,2,3,4,5-Pentafluoro-6-(2-nitrovinyl)benzene (73):

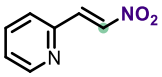


According to general procedure **GP7**, using 2,3,4,5,6-pentafluorostyrene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), $LiOH{\cdot}H_2O$ (2.0 mmol, 2.0 equiv), and MeCN (4.0 mL). Titled compound was isolated as colorless oil (79% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.03 (d, J = 14.0 Hz, 1H), 7.81 (d, J = 14.0 Hz, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 147.36 (ddd, J = 11.7, 7.4, 3.8 Hz), 145.0–144.4 (m), 142.7–142.3 (m), 142.2–141.8 (m), 139.7–139.3 (m), 137.2–136.7 (m), 123.2 (dt, J = 3.0, 1.7 Hz), 106.3 (td, J = 13.9, 4.2 Hz).

(*E*)-2-(2-Nitrovinyl)pyridine [CAS 100446-36-4] **(74):**

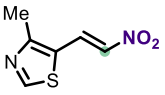


According to general procedure **GP7**, using 2-vinylpyridine (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), $LiOH{\cdot}H_2O$ (2.0 mmol, 2.0 equiv), MeCN (4.0 mL). Titled compound was isolated as brown-yellow solid (73% yield, using 6% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.68 (dd, J = 5.0, 1.8 Hz, 1H), 8.02 (d, J = 13.1 Hz, 1H), 7.92 (d, J = 13.1 Hz, 1H), 7.78 (td, J = 7.8, 1.8 Hz, 1H), 7.47 (d, J = 7.8 Hz, 1H), 7.38 (ddd, J = 7.7, 4.8, 1.2 Hz, 1H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 150.8, 149.6, 140.9, 137.3, 137.3, 126.4, 125.8.

(*E*)-4-Methyl-5-(2-nitrovinyl)thiazole (75):



According to general procedure **GP7**, using 4-methyl-5-vinylthiazole (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), $LiOH{\cdot}H_2O$ (2.0 mmol, 2.0 equiv), MeCN (4.0 mL). Titled compound was isolated as orange solid (75% yield, using 2% hexane in ethyl acetate as eluent).

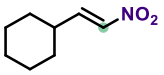
^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.87–8.81 (m, 1H), 8.20 (dd, J = 13.3, 1.0 Hz, 1H), 7.39 (d, J = 13.3 Hz, 1H), 2.64 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 160.3, 155.0, 137.2, 129.0, 123.1, 16.1.

IR (ATR, neat): 3105, 3080, 2990, 1616, 1580, 1390.

HRMS (EI): *m/z* calcd for $C_6H_6O_2N_2S$: 170.0145; found: 170.0145.

(*E*)-(2-Nitrovinyl)cyclohexane [CAS 132839-80-6] **(76):**

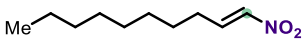


According to general procedure **GP7**, using vinylcyclohexane (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), LiBr (1.0 mmol, 1.0 equiv), $LiOH{\cdot}H_2O$ (2.0 mmol, 2.0 equiv), MeCN (4.0 mL). Titled compound was isolated as light-yellow liquid (51% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.24–7.17 (m, 1H), 6.93 (dd, J = 13.5, 1.4 Hz, 1H), 2.33–2.17 (m, 1H), 1.86–1.68 (m, 5H), 1.36–1.18 (m, 5H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 147.4, 138.4, 37.7, 31.6, 25.8, 25.6.

(*E*)-1-Nitrodec-1-ene [CAS 115134-98-0] **(77):**

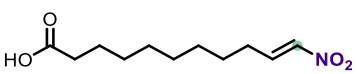


According to general procedure **GP7**, using dec-1-ene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), LiCl (1.0 mmol, 1.0 equiv), $LiOH{\cdot}H_2O$ (2.0 mmol, 2.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colorless liquid (81% yield, using 1% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.34–7.23 (m, 1H), 6.98 (dt, J = 13.4, 1.6 Hz, 1H), 2.27 (qd, J = 7.4, 1.6 Hz, 2H), 1.56–1.46 (m, 2H), 1.40–1.21 (m, 12H), 0.92–0.86 (m, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 143.0, 139.7, 31.9, 29.4, 29.2, 29.2, 28.6, 27.9, 22.8, 14.2.

(*E*)-11-Nitroundec-10-enoic acid (78):



According to general procedure **GP8**, using octa-1,7-diene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.1 equiv), LiCl (1.0 mmol, 1.0 equiv), NEt_3 (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as white solid (61% yield, using 5% hexane in ethyl acetate as eluent).

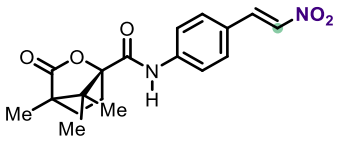
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.27 (dt, J = 13.2, 7.6, 1H), 6.98 (dt, J = 13.2, 1.6, 1H), 2.35 (t, J = 7.6 Hz, 2H), 2.26 (qd, J = 7.6, 1.6 Hz, 2H), 1.69–1.57 (m, 2H), 1.56–1.45 (m, 2H), 1.38–1.28 (m, 9H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 179.0, 142.8, 139.8, 33.9, 29.2, 29.1, 29.1, 28.6, 27.8, 24.7.

IR (ATR, neat): 3545, 1767, 1723, 1317, 1191,1118, 1074, 759.

HRMS (ESI): *m/z* calcd for $[C_{11}H_{19}NO_4–H]^-$: 228.1236; found 228.1244.

(1R)-4,7,7-Trimethyl-N-(4-((E)-2-nitrovinyl)phenyl)-3-oxo-2-oxabicyclo[2.2.1]heptane-1-carboxamide (79):



According to general procedure **GP8**, using (1R)-4,7,7-trimethyl-3-oxo-N-(4-vinylphenyl)-2-oxabicyclo[2.2.1]heptane-1-carboxamide (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3·9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), NEt_3 (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (67% yield, using 15% hexane in ethyl acetate as eluent).

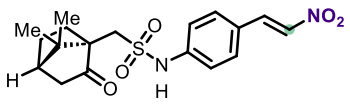
^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.32 (s, 1H), 7.97 (d, J = 13.6 Hz, 1H), 7.76–7.68 (m, 2H), 7.61–7.51 (m, 3H), 2.68–2.53 (m, 1H), 2.09–1.94 (m, 2H), 1.84–1.70 (m, 1H), 1.17 (s, 3H), 1.15 (s, 3H), 0.99 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 177.8, 165.8, 140.3, 138.4, 136.6, 130.5, 126.5, 120.4, 92.4, 55.7, 54.7, 30.7, 29.2, 16.9, 16.7, 9.9.

IR (ATR, neat): 3314, 2967, 2931, 1787, 1677, 1632, 1589, 1520, 1415.

HRMS (ESI): *m/z* calcd for $C_{18}H_{19}O_5N_2$-H: 343.1299; found: 343.1302.

1-((1S,4S)-7,7-Dimethyl-2-oxobicyclo[2.2.1]heptan-1-yl)-N-(4-((E)-2-nitrovinyl)phenyl) methanesulfonamide (80):



According to general procedure **GP8**, using 1-((1S,4S)-7,7-dimethyl-2-oxobicyclo[2.2.1]heptan-1-yl)-N-(4-vinylphenyl)methanesulfonamide (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3·9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), NEt_3 (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (67% yield, using 2% hexane in ethyl acetate as eluent).

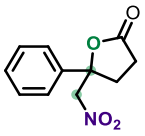
^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.11 (s, 1H), 7.97 (d, *J* = 13.6 Hz, 1H), 7.59–7.49 (m, 3H), 7.38 (d, *J* = 8.7 Hz, 2H), 3.36 (d, *J* = 15.3 Hz, 1H), 2.96 (d, *J* = 15.3 Hz, 1H), 2.46 (ddd, *J* = 18.8, 4.9, 2.4 Hz, 1H), 2.20–2.06 (m, 3H), 2.00 (d, *J* = 18.8 Hz, 1H), 1.56–1.43 (m, 1H), 0.97 (s, 3H), 0.85 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 218.0, 141.4, 138.4, 136.6, 130.7, 126.7, 121.5, 59.9, 50.4, 49.5, 43.3, 42.9, 27.8, 27.2, 20.1, 19.4.

IR (ATR, neat): 3355, 3012, 2929, 1790, 1716, 1580, 1612, 1390, 1194, 1272, 1187, 735.

HRMS (ESI): *m/z* calcd for $C_{18}H_{21}O_5N_2S$-H: 377.1177; found: 377.1176.

5-(Nitromethyl)-5-phenyldihydrofuran-2(3*H*)-one (81):

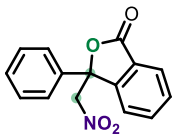


According to general procedure **GP4**, using 4-phenylpent-4-enoic acid (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (84% yield, using 5% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.48–7.33 (m, 5H), 4.82 (d, *J* = 12.8 Hz, 1H), 4.76 (d, *J* = 12.8 Hz, 1H), 3.00–2.86 (m, 1H), 2.77–2.62 (m, 2H), 2.61–2.44 (m, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 174.8, 138.9, 129.3, 129.3, 124.8, 84.8, 82.1, 31.9, 28.0.

3-(Nitromethyl)-3-phenylisobenzofuran-1(3*H*)-one (82):

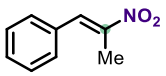


According to general procedure **GP4**, using 2-(1-phenylvinyl)benzoic acid (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), LiBr (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as off-white solid (80% yield, using 5% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.91 (dt, *J* = 7.7, 1.0 Hz, 1H), 7.78–7.72 (m, 2H), 7.64–7.55 (m, 1H), 7.59–7.52 (m, 2H), 7.46–7.35 (m, 3H), 5.28 (d, *J* = 13.2 Hz, 1H), 5.20 (d, *J* = 13.2 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 168.5, 147.7, 134.9, 130.6, 129.7, 129.4, 126.5, 125.1, 123.1, 85.7, 80.2.

(*E*)-(2-nitroprop-1-en-1-yl)benzene [CAS 58321-79-2] **(83):**

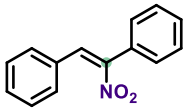


According to general procedure **GP9**, using (*E*)-2-methyl-3-phenylacrylic acid (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), TEMPO (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as yellow oil (56% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.09 (s, 1H), 7.47–7.39 (m, 5H), 2.46 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 147.9, 133.7, 132.6, 130.1, 130.1, 129.1, 14.2.

(*E*)-(1-Nitroethene-1,2-diyl)dibenzene [CAS 1215-07-2] **(84):**

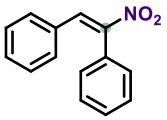


According to general procedure **GP9**, using (*E*)-2,3-diphenylacrylic acid (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), TEMPO (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as light-yellow solid (35% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.23 (s, 1H), 7.52–7.49 (m, 3H), 7.35–7.29 (m, 3H), 7.23 (t, J = 7.6 Hz, 2H), 7.12–7.08 (m, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 149.8, 134.9, 131.3, 130.9, 130.7, 130.2, 129.4, 128.9, 128.3.

(*Z*)-(1-Nitroethene-1,2-diyl)dibenzene [CAS 1215-07-2] **(85):**

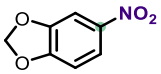


According to general procedure **GP9**, using (*Z*)-2,3-diphenylacrylic acid (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.1 equiv), TEMPO (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as light-yellow solid (28% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.49–7.43 (m, 5H), 7.38–7.38 (m, 5H), 6.85 (s, 1H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 150.7, 131.7, 131.5, 131.4, 130.2, 129.8, 129.3, 129.2, 125.8, 121.8.

5-Nitrobenzo[d][1,3]dioxole [CAS 2620-44-2] **(87):**

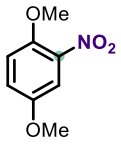


According to general procedure **GP11**, using benzo[d][1,3]dioxole (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (1.1 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as yellow solid (95% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.88 (dd, J = 8.4, 2.4 Hz, 1H), 7.65 (d, J = 2.4 Hz, 1H), 6.86 (d, J = 8.4 Hz, 1H), 6.14 (s, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 153.3, 148.4, 143.0, 120.0, 107.7, 104.6, 103.2.

1,4-Dimethoxy-2-nitrobenzene [CAS 89-39-4] **(89):**

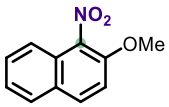


According to general procedure **GP12**, using 1,4-dimethoxybezene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as yellow solid (91% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.39 (d, J = 4.0 Hz, 1H), 7.11 (dd, J = 8.0, 4.0 Hz, 1H), 7.03 (d, J = 8.0 Hz, 1H), 3.92 (s, 3H), 3.82 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 153.1, 147.6, 121.1, 115.3, 110.1, 57.3, 56.2.

2-Methoxy-1-nitronaphthalene [CAS 4900-66-7] **(90):**

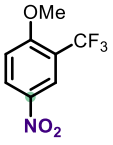


According to general procedure **GP12**, using 2-methoxynaphthalene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as yellow solid (92% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.95 (dd, J = 9.2, 0.9 Hz, 1H), 7.83 (dt, J = 8.2, 0.9 Hz, 1H), 7.67 (dq, J = 8.4, 0.9 Hz, 1H), 7.59 (ddd, J = 8.4, 6.8, 1.2 Hz, 1H), 7.45 (ddd, J = 8.2, 6.8, 1.2 Hz, 1H), 7.33 (d, J = 9.2 Hz, 1H), 4.02 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 148.8, 132.3, 129.3, 128.3, 128.2, 125.8, 125.3, 120.5, 113.2, 57.2.

1-Methoxy-4-nitro-2-(trifluoromethyl)benzene [CAS 654-76-2] **(91):**

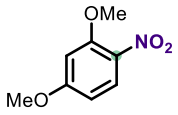


According to general procedure **GP12**, using 2-(trifluoromethyl)anisole (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as orange solid (55% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.50 (d, J = 2.8 Hz, 1H), 8.43 (dd, J = 9.2, 2.8 Hz, 1H), 7.11 (d, J = 9.2 Hz, 1H), 4.04 (s, 3H).

^{19}F-NMR (376 MHz, $CDCl_3$): δ −63.3.

2,4-Dimethoxy-1-nitrobenzene [CAS 4920-84-7] **(92):**

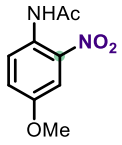


According to general procedure **GP12**, using 1,3-dimethoxybenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as yellow solid (67% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.01 (dd, J = 8.8, 4.0 Hz, 1H), 6.54−6.50 (m, 2H), 3.59 (s, 3H), 3.89 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 164.9, 155.9, 128.8, 104.9, 99.9, 56.6, 56.1.

***N*-(4-Methoxy-2-nitrophenyl)acetamide** [CAS 119-81-3] **(94):**

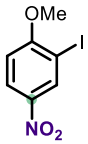


According to general procedure **GP12**, using *N*-(4-methoxyphenyl)acetamide (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as yellow solid (98% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 10.05 (br s, 1H), 8.62 (d, J = 9.2 Hz, 1H), 7.66 (d, J = 3.2 Hz, 1H), 7.23 (ddd, J = 9.2, 3.2, 0.8 Hz, 1H), 3.85 (s, 3H), 2.27 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 169.0, 155.2, 137.3, 128.6, 124.0, 123.5, 108.7, 56.0, 25.5.

2-Iodo-1-methoxy-4-nitrobenzene [CAS 5399-03-1] **(95):**

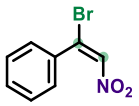


According to general procedure **GP12**, using 1-iodo-2-methoxybenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as light-yellow solid (61% yield, using 2% hexane in ethyl acetate as eluent). The characterization data match the literature.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.67 (d, J = 2.7 Hz, 1H), 8.26 (dd, J = 9.1, 2.7 Hz, 1H), 6.87 (d, J = 9.1 Hz, 1H), 4.00 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 163.2, 135.3, 125.9, 109.7, 85.3, 57.3.

(*E*)-(1-Bromo-2-nitrovinyl)benzene (96):



According to general procedure **GP13**, using phenylacetylene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), CBr_4 (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as white solid (60% yield, using 2% hexane in ethyl acetate as eluent).

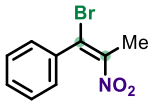
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.61 (s, 1H), 7.46–7.41 (m, 3H), 7.41–7.37 (m, 2H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 138.0, 138.0, 135.2, 131.1, 128.71, 128.2.

IR (ATR, neat): 3110,1625, 1520, 1442, 1334, 1304.

HRMS (ESI): *m/z* calcd for $C_8H_6O_2N^{79}Br$: 226.9576; found 226.9572.

(*E*)-(1-Bromo-2-nitroprop-1-en-1-yl)benzene (97):



According to general procedure **GP13**, using prop-1-yn-1-ylbenzene (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), CBr_4 (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (42% yield, using 2% hexane in ethyl acetate as eluent).

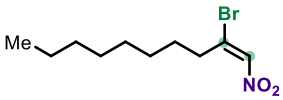
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.40–7.28 (m, 5H), 2.54 (s, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 148.1, 136.8, 130.1, 128.8, 128.0, 127.9, 20.5.

IR (ATR, neat): 1697, 1562, 1526, 1334.

HRMS (EI): *m/z* calcd for $C_9H_8O_2N^{79}Br$: 240.9733; found 240.9728.

(*E*)-2-Bromo-1-nitrodec-1-ene (98):



According to general procedure **GP13**, using 1-decyne (1.0 mmol, 1.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (1.1 mmol, 1.0 equiv), CBr_4 (1.0 mmol, 1.0 equiv), MeCN (4.0 mL). Titled compound was isolated as colourless liquid (30% yield, using 2% hexane in ethyl acetate as eluent).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 (s, 1H), 3.18–3.08 (m, 2H), 1.69 (p, J = 7.4 Hz, 2H), 1.41–1.24 (m, 10H), 0.92–0.84 (m, 3H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 147.0, 139.1, 37.2, 31.9, 29.3, 29.2, 28.9, 28.2, 22.8, 14.2.

IR (ATR, neat): 2923, 2855, 1525, 1337.

HRMS (EI): *m/z* calcd for $C_{10}H_{17}ON^{79}Br$: 246.0488; found 246.0489.

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Chapter 7:

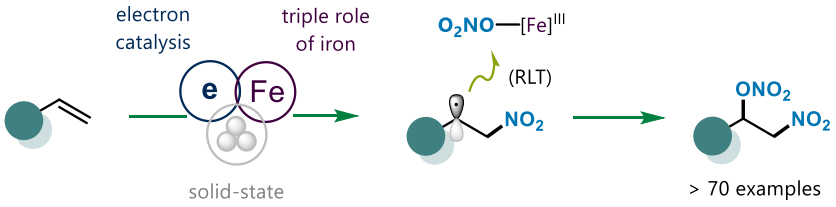
Mechanochemistry Drives Alkene Difunctionalization via Radical Ligand Transfer and Electron Catalysis

This Chapter is adapted from the following publication in peer reviewed journal:

S. Patra, B. N. Nandasana, V. Valsamidou, D. Katayev, "Mechanochemistry Drives Alkene Difunctionalization via Radical Ligand Transfer and Electron Catalysis", *Adv. Sci*. **2024**, *11*, 2402970. DOI:org/10.1002/advs.202402970.

1. Abstract

We report a general and modular protocol for olefin difunctionalization through mechanochemistry, facilitated by cooperative radical ligand transfer (RLT) and electron catalysis. Utilizing mechanochemical force and catalytic amounts of TEMPO, ferric nitrate can leverage nitryl radicals, transfer nitrooxy-functional group via RLT, and mediate an electron catalysis cycle under room temperature. A diverse range of activated and unactivated alkenes exhibited chemo- and regioselective 1,2-nitronitrooxylation under solvent-free or solvent-less conditions, showcasing excellent functional group tolerance. Mechanistic studies indicated a significant impact of mechanochemistry and highlighted the radical nature of this nitrative difunctionalization process.



2. Introduction

The increasing interest in the selective difunctionalization of alkenes emphasizes the potential of this strategy to generate molecular complexity from readily available organic feedstock and in high atom- and step-economy fashion.[1] The interplay between intermolecular two- or three-component radical difunctionalization processes offers a fresh avenue for this purpose.[2] Single electron transfer (SET), homolytic scission (HS), hydrogen (HAT) and halogen atom transfer (XAT), are few catalytic concepts that facilitate the access to radical intermediates, while atom transfer radical addition (ATRA) and radical polar crossover (RPC) stand as fundamental methods to drive selectivity in radical-based olefin difunctionalization.[2,3] Despite significant advances of these radical toolboxes, incorporation of two distinct functionalities from orthogonal reagents, especially across unactivated olefin molecules, remains challenging in the field of synthetic radical chemistry. The mechanistic feature of the sequential events of hydrogen atom abstraction and radical rebound, identified in metalloenzyme catalyzed $C(sp^3)$−H hydroxylation, has been recently conceptualized into a general synthetic paradigm – radical ligand transfer (RLT) (Figure 1A).[4] A noteworthy advantage of this innovative manifold is its ability to be integrated with various radical-based elementary steps, functionalizing alkyl radicals in catalytic and selective manner. For example, when coupled with electrochemical or photochemical approaches, RLT has demonstrated substantial potential in the seamless attachment of two different functional groups across an unsaturated bond of both activated and unactivated alkenes.[5] Mechanistically, it entails the outer-sphere shuttle of a ligand from a redox-active metal center to a transient alkyl radical intermediate, forming a new carbon–ligand bond, while the metal undergoes reduction through SET. Sequential reoxidation of the metal center occurs in the presence of a stoichiometric anionic ligand, regenerating the active species for the RLT step and enabling catalysis. However, the use of harmful organic solvents, complex reaction conditions, elevated temperatures, and extended reaction times need to be addressed if RLT process is intended for use in sustainable and fine-chemical synthesis.

In this context, solvent-less or solvent-free mechanochemical transformations using ball milling have emerged as notable alternatives for researchers across various disciplines (Figure 1B).[6] This straightforward and environmentally friendly approach has been widely adopted in material science,[7] polymer chemistry,[8] and (in)organic synthesis,[9] providing cleaner and more sustainable methodologies. In addition to their environmental benefits, mechanochemistry offers the potential to explore new chemical space with unique reactivities and selectivity, contrasting with conventional liquid-phase reactions.[10] Despite rapid progress in mechanochemical two-electron transformations, catalytic radical reactions that proceed effectively under solid-state conditions remain relatively scarce in the literature (Figure 1B). Significant advances in this field have been demonstrated with the exploration of mechanochemical redox chemistry using piezoelectric materials such as tetragonal $BaTiO_3$, which effectively mimic the well-established oxidative quenching cycle of a photoredox catalysis.[11] Notably, mechanochemistry has recently been enhanced with other energy sources, offering new opportunities

for conducting SET transformations with minimal or even in the absence of solvents.[12] In the realm of successfully developed mechanochemical radical transformations, the predominant focus has been on establishing single chemical bonds, whereas the installation of two distinct functionalities across the π-bond of an olefin molecule via two- or three-component catalytic mechanochemical processes has almost no documentation in the literature (Figure 1C).

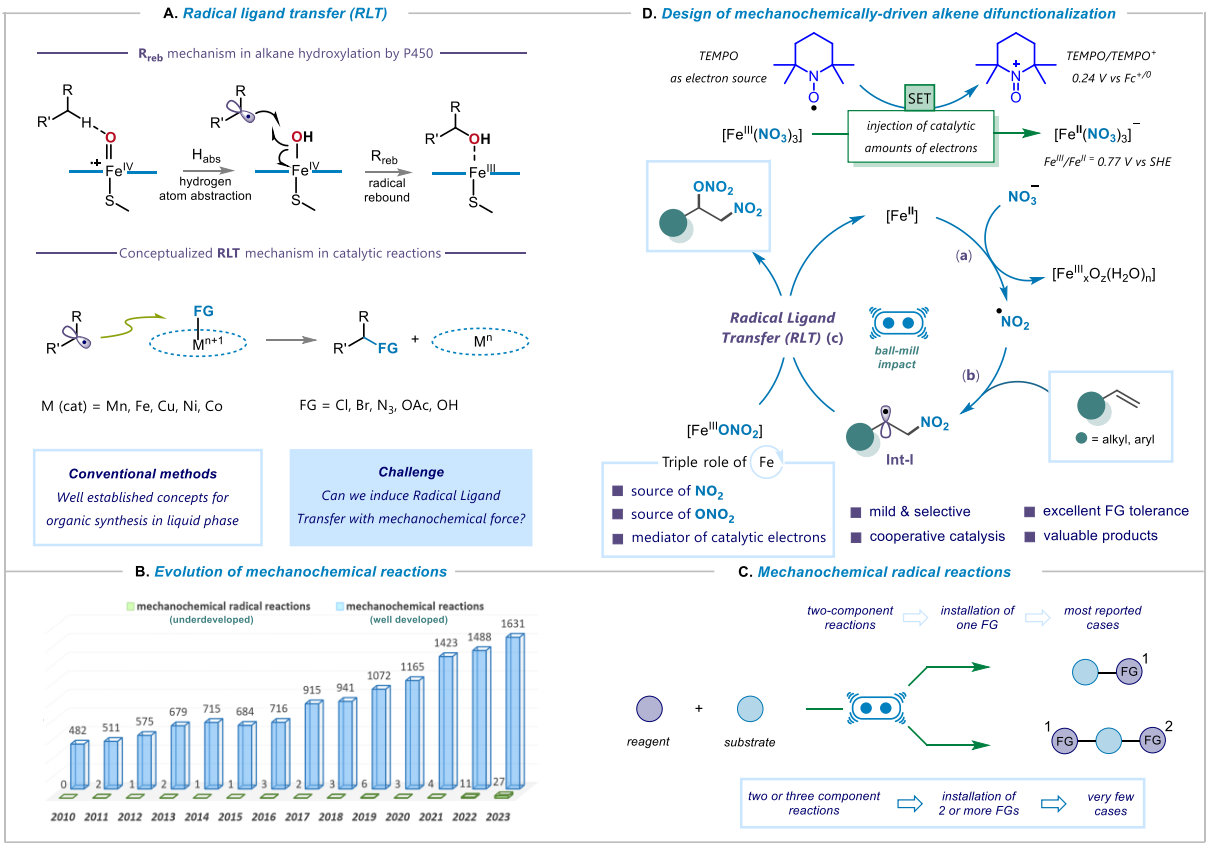


Figure 1. (A) Radical ligand transfer concept. (B) Evaluation of mechanochemical transformations since 2010 (blue), progress in mechanochemical radical reactions (green). (C) Two and three component mechanochemical radical reactions. (D) This work: design of mechanochemically-driven alkene difunctionalization.

3. Results and discussion

3.1. Reaction optimization

Given our focus on difunctionalization reactions using RPC and RLT liquid-phase catalysis,[13] with an emphasis on nitro compounds synthesis, we set out to develop a modular catalytic platform for the radical difunctionalization of alkenes that operates under mechanochemical conditions. We propose the general design plan for mechanoredox alkene difunctionalization, as detailed in Figure 1D. In light of our recent development in the electron-driven nitration of unsaturated hydrocarbons using ferric nitrate,[14] we hypothesized that injecting catalytic amounts of electrons (from TEMPO) could reduce $Fe(NO_3)_3{\times}9H_2O$ under mechanochemical force, sustaining the continuous presence of $\bullet NO_2$ in the reaction medium. The generation of nitryl radicals from ferric nitrate via SET process was previously studied using pulse radiolysis.[14] Pulse radiolysis is a robust technique for investigating short-living and highly reactive intermediates and radicals. The study suggested the possibility of a single-electron reduction of NO_3^- to $NO_3^{\bullet 2-}$, which, upon reaction with H^+, delivers $\bullet NO_2$. A Giese-type addition[15] of N-centered radicals to an olefin molecule will occur, leading to the formation of transient nitroalkyl intermediate **Int-I**. The oxidation of these species with an external oxidant to perform RPC may pose a challenge to the redox balance of the system. Therefore, we anticipated, that the radical ligand transfer with ferric nitrate, if operational under mechanochemical force, could facilitate the selective transfer of a second functional group (ONO_2), delivering a difunctionalized product and restoring an electron to complete the catalytic cycle. Herein, we report that mechanochemical approach using ball milling allows for a highly selective, robust, and modular method for radical difunctionalization of unsaturated hydrocarbons. Carrying out the reaction in the presence of ferric nitrate and catalytic amounts of TEMPO, rapid nitronitrooxylation[16] of alkenes takes place, delivering unique adducts with high levels of chemo- and regioselectivity. Importantly, the success of this protocol relies on the cooperative processes of radical ligand transfer (RLT) and electron (e) catalysis,[17] which can be effectively mediated under mechanochemical force. A significant deviation of the reaction outcome can be observed between liquid and solid-state phases. The modularity of this mechanochemically driven catalytic platform is further demonstrated by its ability to selectively introduce other functional groups. With our group's keen interest in developing novel tools to access nitro-derived molecules,[18] we initiated an examination of the proposed mechanistic scenario in Figure 1D using 4-tert-butylstyrene as the model substrate, ferric nitrate as the source of nitro- and nitrooxy-functional groups and TEMPO as the electron-donating agent. Mechanochemical optimization was carried out using a Retch MM400 mixer mill in a 5 mL stainless-steel milling jar with 5 mm-diameter stainless-steel balls. The best outcome was found during the ball milling of **1a** in the presence of 2 eq. $Fe(NO_3)_3{\times}9H_2O$ and 10 mol% of TEMPO at 30 Hz frequency for 60 minutes, using 3 stainless-steel balls, leading to a quantitative formation of disubstituted product **1** with an isolated yield of 95% (Figure 2A, entry 1). Reducing the loading of TEMPO or iron nitrate had

a notable impact on the product formation, as shown in entries 2-5. Other electron donors including phthalimide-N-oxyl (PINO) and 9-azabicyclo[3.3.1]nonane N-oxyl (ABNO) can also be used in this transformation, yielding a comparable amount of product 1. Additionally, we compared reactivity using a PTFE jar under the optimized conditions. The results closely aligned with the initial estimates, yielding 46% of the desired product **1**. The yield is lower than the yield obtained with stainless steel jar, possibly due to the difference in hardness of material (Figure 2A, entry 6).

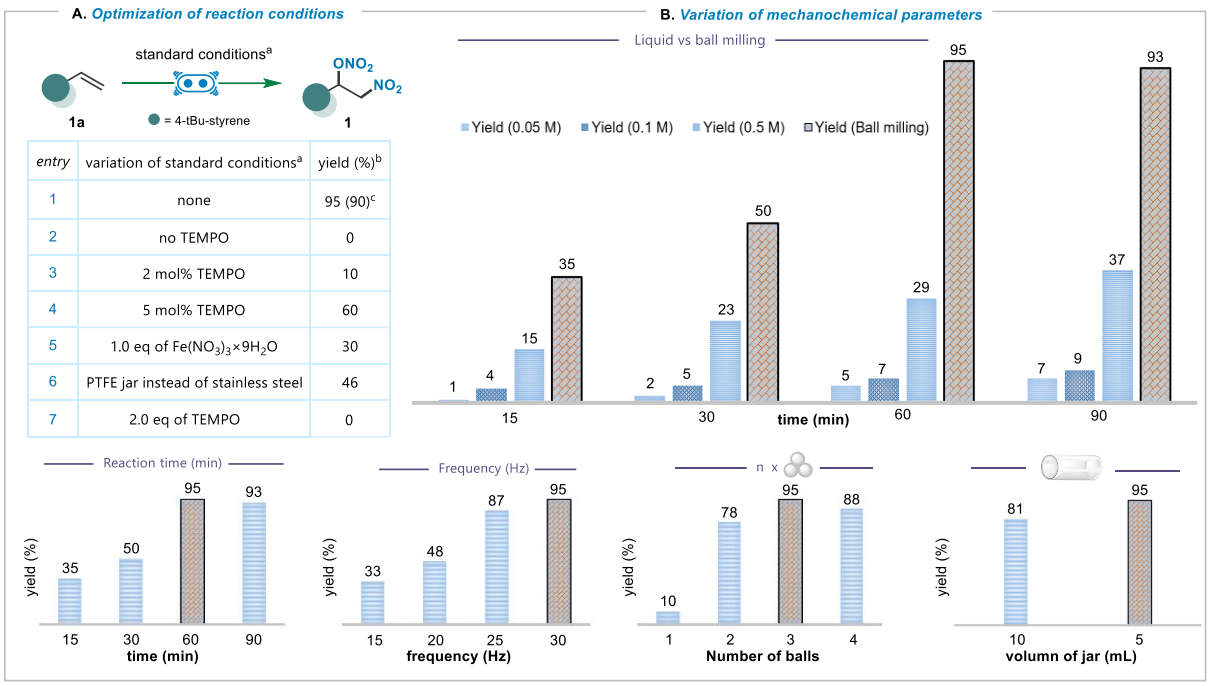


Figure 2. Reaction development. (A) Optimization of reaction conditions. (B) Variation of mechanochemical parameters. (C) Mechanistic insights

It's noteworthy that catalytic TEMPO is essential for this transformation (Figure 2A, entry 2). However, increasing the TEMPO loading to 2 equivalents led to the complete cessation of the reaction, as anticipated for a radical process (Figure 2A, entry 7). The effects of grinding time and ball milling frequency were also tested, and 60 minutes and 30 Hz were found optimal in terms of 1a conversion and product formation (Figure 2B). To maximize ball milling yield, balls must move freely within the jar during vibration to ensure proper mechanical impact. Our study found that using 3 balls in a 5 mL jar delivers optimal impact/contact on the reaction mixture, yielding the highest results, while more balls or larger jar volumes decreased yield (Figure 2B). Having optimized the reaction under solvent-free conditions, we were curious about the performance of this transformation in the liquid-phase. As illustrated in Figure 2B, in a liquid-phase reaction with a concentration of 0.05 M (dimethyl carbonate), only a small amount of product **1** could be obtained. By elevating the concentration to 0.5 M and extending the reaction time to 90 minutes, a modest improvement in yield up to 37% was attained. The presented results emphasize the significant influence of mechanochemical force on both the rate and efficiency of this catalytic transformation.[20]

3.2. Mechanistic insights

Next, we directed our efforts towards investigating the mechanistic aspects of the reaction through an experimental approach, specifically focusing on its radical nature and the involvement of a radical ligand transfer paradigm. When ball milling the nitro-styrene **2a** using standard reaction conditions, product **2** was not detected, indicating that the reaction does not proceed through Michael-type addition (Figure 3, A). Similarly, the potential involvement of nitronium Next, we directed our efforts towards investigating the mechanistic aspects of the reaction through an experimental approach, specifically focusing on its radical nature and the involvement of a radical ligand transfer paradigm. When ball milling the nitro-styrene **2a** using standard reaction conditions, product **2** was not detected, indicating that the reaction does not proceed through Michael-type addition (Figure 3, A). Similarly, the potential involvement of nitronium ions in the reaction mixture was ruled out through the attempted nitration under standard conditions of the alcohol moiety (Figure 3, B). Remarkably, the evidence for the formation of $TEMPO^+$ was confirmed through iron(III) nitrate/TEMPO-catalyzed alcohol oxidation under ball milling conditions with substrate **3a** (Figure 3, C).[20] The generation of nitroalkyl radical species was also supported by the difunctionalization reaction of (Z)- and (E)-β-methylstyrene, yielding the corresponding product **4** in 52% and 79% yield respectively with similar d.r. values. Radical probe experiments with substrate **5a** and radical clock reaction with **6a** were also successfully conducted under ball milling conditions, thereby reducing the likelihood of the potential oxidation of an in situ generated nitroalkyl radical intermediate. In addition, alkene **7a** also underwent nitronitrooxylation to produce **7** in 65%, providing further support for the exclusion of the RPC pathway and preference of RLT.

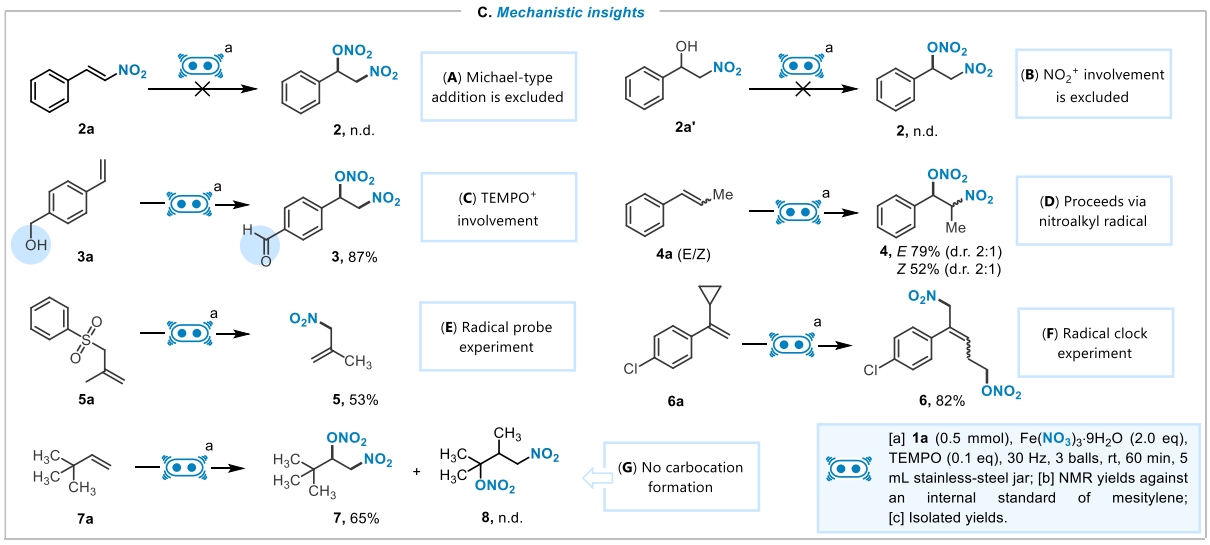


Figure 3. Mechanistic insights.

3.3. Investigation of substrate scope

With the optimized conditions in hand, we proceeded to investigate the substrate scope (Figure 4). Initially, aryl substituted olefins containing both electron donating and withdrawing common functionalities at ortho-, meta- and para-positions was examined, revealing a high level of chemo- and regioselectivity, with product yields ranging from 74% to 95%. It is noteworthy that halogen substituents (**14-17**, **20**, **21**, **32**), aldehydes (**3**, **18**), esters, and nitrate esters (**22**, **23**, **27**) remained completely untouched under ball milling conditions. Alkene building blocks including di- and tri-substituted aryl substrates (**12, 21**) and polycyclic aromatics (**28-30**) all gave the desired products in excellent yields. Substitution patterns on the alkene fragment (**24**, **31**[21], **32-35**) were also well tolerated. Despite the chemical inertness of unactivated alkenes, they demonstrated valuable reactivity under mechanochemically- driven catalytic conditions. Terminal alkenes with alkyl linear chains (**36**, **37**, **39**) or cyclic systems (**38**) with amide functional group (**40**) all yielded the corresponding 1,2-disubstituted adducts. Encouraged by the excellent reactivity of alkenes and functional group tolerance, we next showcased the successful application of this protocol in the late-stage functionalization of ibuprofen and AHTN derivatives (**41**, **42**). Encouragingly, our protocol successfully cyclized carboxylic acids and sulfamide functional groups, yielding the cyclized products (**43**, **44**, **47**) in good yield. We hypothesize that the presence of free acid and sulfamide facilitated the intramolecular cyclization of the corresponding nitronitrooxylation, leading to the formation of 5-membered cyclic nitrative derivatives. However, (E)-6-phenylhex-5-enoic acid yielded product **46**, which was unstable during the purification and converted to **45**. To extend the scope of the protocol to alkynes, phenylacetylene, and 1-octyne were examined under standard reaction conditions. However, after several attempts, only a complex reaction mixture was observed. ions in the reaction mixture were observed.

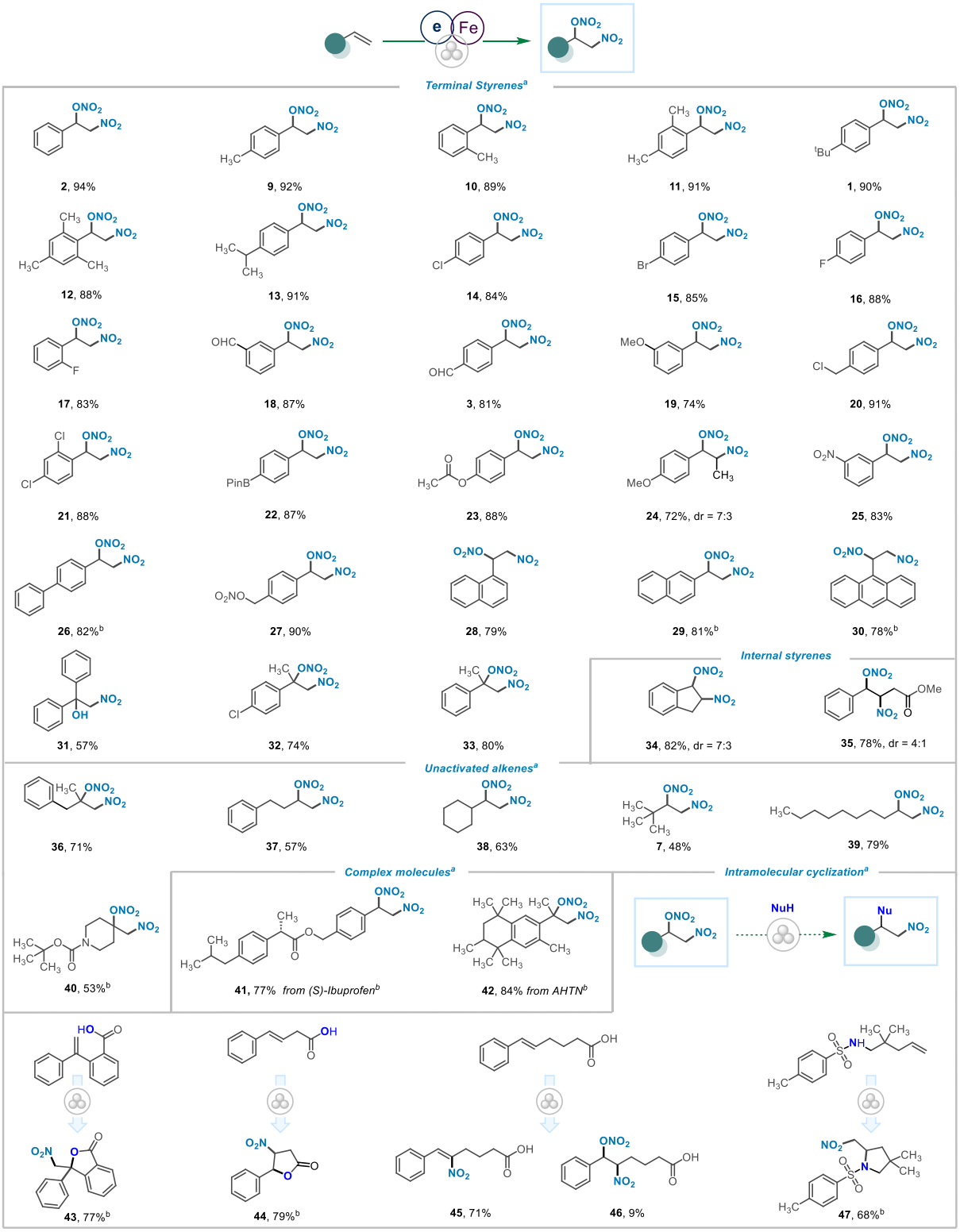


Figure 4. Substrate scope. [a] Standard conditions: alkene (0.5 mmol), $Fe(NO_3)_3{\times}9H_2O$ (2.0 eq), TEMPO (0.1 eq), 30 Hz, 3 stainless-steel balls, rt, 60 min, 5 mL stainless-steel jar. [b] 'Green' solvent Me_2CO_3 (0.1 μL/mg) was added for solid alkenes.

3.4. Synthesis of nitro-alkenes and concept extension

The ball milling strategy proved highly effective for the in-situ conversion of 1,2-nitronitrooxy adducts to the corresponding nitro alkenes under solvent-free reaction conditions, facilitated by the addition of triethylamine. As demonstrated in Figure 5, activated (**48-53**, **55-59**), unactivated (**54**, **62**), and complex nitro alkenes (**60-61**) can effectively be generated in good to excellent chemical yields. Interestingly, 3,3-dimethylpent-4-enoic acid under standard conditions yielded nitroalkene **62** in good yield.

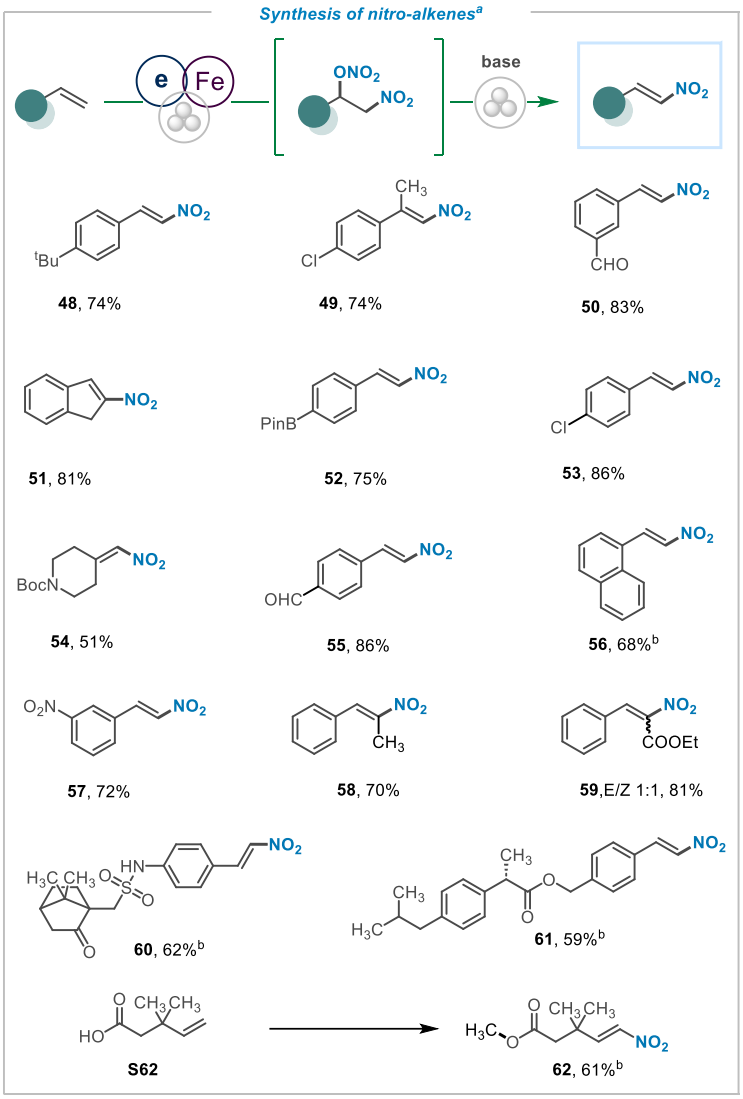


Figure 5. Synthesis of nitro-alkenes. [a] Standard conditions after that NEt_3 (1.5 eq) was added and ball milling for an additional 60 min.

Expanding on our mechanistic insights, we speculated that radical ligand transfer, under mechanochemical force, could shuttle other functional groups FG[1], as rapid ligand exchange with nucleophiles may occur at the metal center. Indeed, adding stoichiometric amounts of LiCl or NH_4Br led to the selective alkene halonitration, delivering the corresponding 1-chloro- (**63-65**) and 1-bromo-2-nitroalkanes (**66-68**) in up to 63% isolated yield (Figure 6A). These results indicate the potential for a

ligand exchange step in a solid-state or solvent-less environments under mechanochemical conditions. The FG^2 can also be altered in the presence of competitive radical sources. For example, addition of $TMSN_3$ allowed to generate azidyl radicals (via TEMPO-mediated azide oxidation)[22] and the corresponding 1,2-azidonitrooxy derivative **69** was isolated in 29% (Figure 6A).

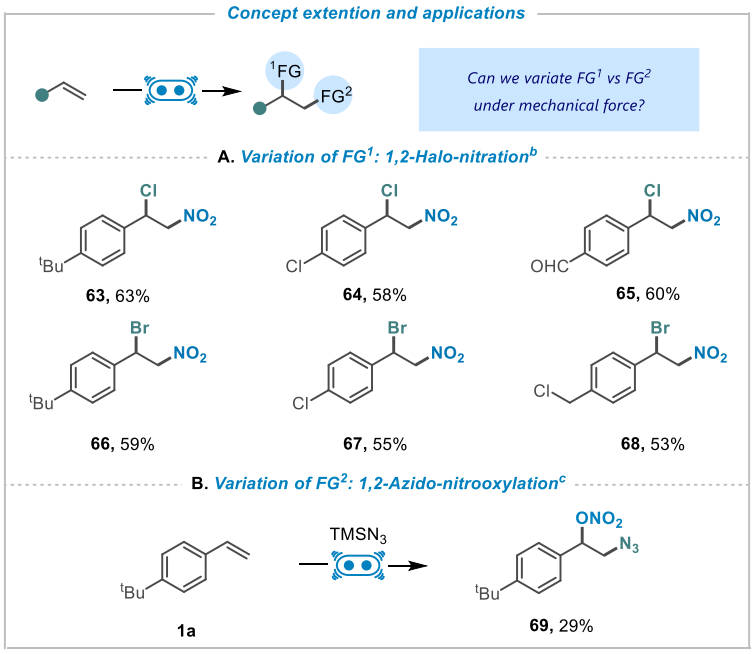


Figure 6. Concept extension and applications. (A & B) Variation of functional groups. [b] Standard conditions with addition of 2.0 eq of LiCl (or of NH_4Br) and Me_2CO_3 (0.1 μL/mg). [c] Standard conditions with addition of Me_2CO_3 (0.1 μL/mg) and $TMSN_3$ (1.0 eq).

3.5. Applications

To further highlight the operational simplicity and scalability of this protocol, the process was applied to 10 mmol scale in a 10 mL stainless-steel ball-milling jar using 10 mm-diameter balls (Figure 7A). The corresponding 1,2-nitronitrooxy-derivatives (**9**, **23**, **38**) were obtained with yields almost unaffected by the scale-up. The 1,2-nitronitrooxy-alkanes serve as compelling synthetic building blocks and can undergo various modifications. Conducting hydrogenation in the presence of Pd/C allows for the facile synthesis of an important class of 1,2-aminoalcohols (**70-72**), while performing nucleophilic substitution with NaN_3 in DMF led to the preparation of diverse triazole derivatives (**73-75**) (Figure 7B).

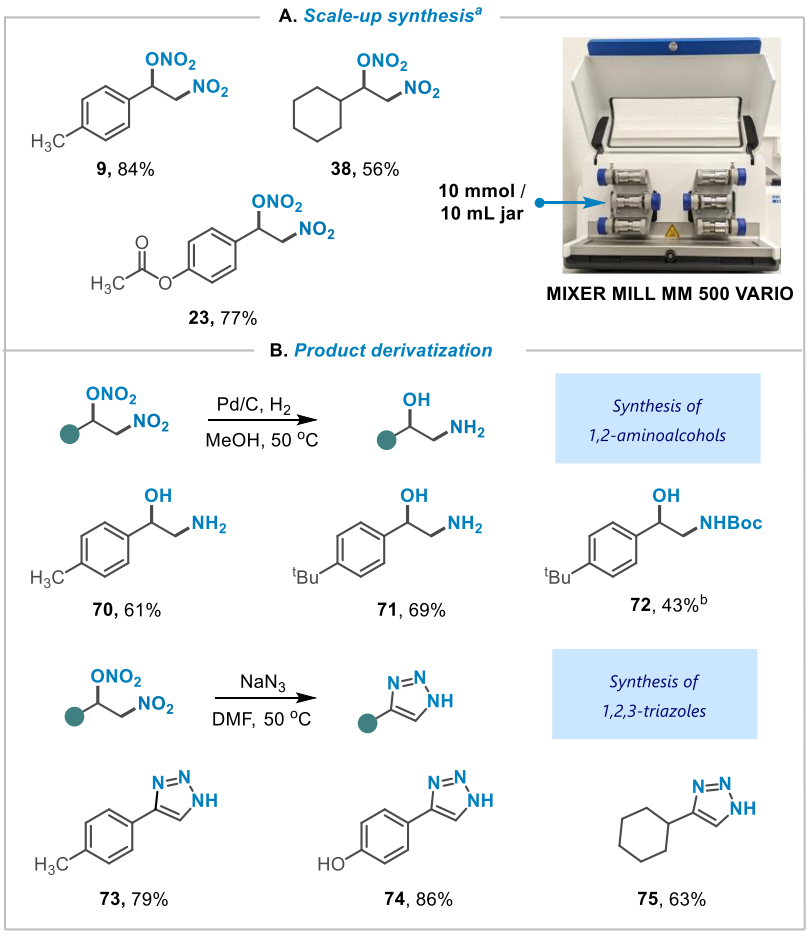


Figure 7. (A) Scale-up synthesis. (B) Product derivatization. [a] Standard solvent-free conditions using 10 mL jar. [b] Di-tert-butyl decarbonate was added without isolation of **71**.

4. Conclusion

In conclusion, we developed a mechanochemical process for the difunctionalization of alkenes that proceeds via synergistic radical ligand transfer (RLT) and electron catalysis. In this system, ferric nitrate can be effectively activated in solid-state at room temperature in the presence of catalytic amounts of TEMPO, acting as a donor of nitro- and nitrooxy-functional groups as well as an electron mediator to promote the catalytic cycle. A broad array of unique 1,2-nitronitrooxyalkanes can be synthesized from activated and unactivated olefines using this catalytic platform in a chemo- and regioselective fashion, while tolerating a great number of functionalities. The performed mechanistic studies strongly suggested that the process is accelerated by mechanochemistry and proceeds via a radical pathway. We anticipate that this robust and straightforward protocol will serve as a driving force for developing solid-state alkene difunctionalization processes.

5. Experimental section

1. General Information

1.1. Material and methods

• Starting materials were commercially available from Thermoscientific – Acros, Sigma Aldrich, Apollo Scientific, Fluorochem, and TCI, unless otherwise specified.

• All ball milling reactions were performed using a Mixer Mill (MM 400 Retsch Gmbh, Hann, Germany) equipped with 5 mL stainless steel grinding vessels and stainless steel balls, unless otherwise specified. Scale up synthesis was performed using Mixer Mill MM 500 Vario equipped with 10 mL stainless steel grinding vessels.

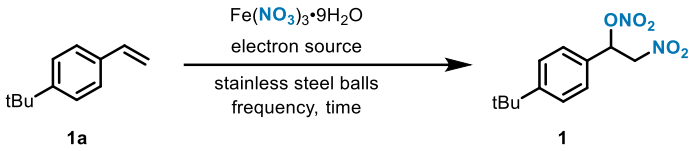
• Reaction progress was monitored by analytical Thin Layer Chromatography (TLC) on Merck silica gel 60 F254 TLC glass plates and visualized with 254 nm light or potassium permanganate staining solutions followed by heating for detection.

• Reaction product purification was performed by flash chromatography using Brunschwig silica 32-63, 60Å under 0.3-0.5 bar overpressure. Medium pressure liquid chromatography (MPLC) was carried out on a CombiFlash Rf 200 System from Teledyne ISCO with a built-in UV-detector and fraction collector, or manually using silica gel SilicaFlash P60, 40-63 µm. Teledyne ISCO RediSep Rf flash columns had particle sizes of 0.035–0.070 mm and 230–400 mesh. Normal phase preparatory HPLC purification was conducted on a Teledyne Isco CombiFlash EZ Prep system using a Macherey-Nagel VP 250/21 Nucleosil 50-5 column.

• ^{1}H- and ^{13}C-NMR spectra were recorded on a Bruker Ultrashield 300 (operating at 300.0 MHz and 75.0 MHz, respectively). Chemical shifts are reported in parts per million (ppm) and coupling constants (J) in Hertz (Hz). ^{1}H-NMR spectra are referenced to the solvent resonance unless noted otherwise ($CDCl_3$ at 7.26 ppm). Peaks are designated as (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet or unresolved) with coupling constant(s) in Hz and integration. ^{13}C-NMR spectra were recorded with ^{1}H-decoupling and referenced to the solvent resonance unless noted otherwise ($CDCl_3$ at 77.16 ppm). ^{19}F-NMR spectra were recorded with ^{1}H-decoupling unless noted otherwise. Infrared spectra were recorded on a Bruker Tensor III spectrometer equipped with a golden gate.

• Melting points were measured using the OptiMelt Automated Melting Point System Type K/°C. HR-MS (ESI+) mass spectra were measured on a Bruker FTMS 4.7T BioAPEX II and Thermo Scientific LTQ Orbitrap XL equipped with a static nanospray ion source. Mass spectrometry service was operated on VG-TRIBRID for electron impact ionization (EI) or Varian IonSpec Spectrometer for electrospray ionization (ESI), and mass spectra are reported as (m/z). Electron impact ionization mass spectra (EI-MS) were obtained using an Agilent 8890 series GC system and Aglient 5977B GC/MSD.

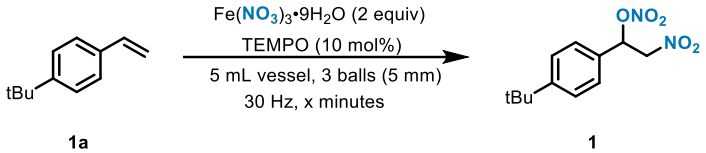
2. Development of the Reaction Conditions



1a 1

Without any precautions to exclude air or moisture, a Retsch stainless steel vessel (5 mL) equipped with steel balls was charged with a nitrating reagent, reductant, followed by alkene substrate. The reaction vessel cap was locked and placed in the mixer mill. After completion of the reaction, the crude product was dissolved in a solvent, a reference (mesitylene as a standard) was added, and the sample was analyzed by ^{1}H-NMR to determine the corresponding yield.

2.1. Optimisation of reaction time

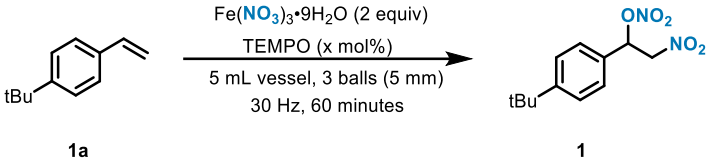


1a 1

Entry[a]	*Time (mins)*	*Yield (%)*[b]
1	30	50
2	60	95
3	90	93

Table 2.1. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), $Fe(NO_3)_3 \times 9H_2O$ (2.0 equiv), TEMPO (0.1 equiv), 30 Hz, 3 stainless steel balls (5 mm), 30-90 minutes. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

2.2. Catalyst loading

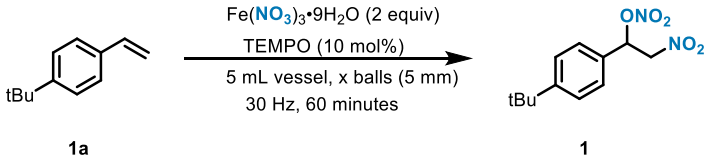


1a 1

Entry[a]	*TEMPO (equiv)*	*Yield (%)*[b]
1	0.02	10
2	0.05	60
3	0.10	95
4	0.20	88

Table 2.2. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), $Fe(NO_3)_3 \times 9H_2O$ (2.0 equiv), TEMPO (0.02-0.20 equiv), 30 Hz, 3 stainless steel balls (5 mm), 60 mins. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

2.3. Impact of the number of stainless-steel balls

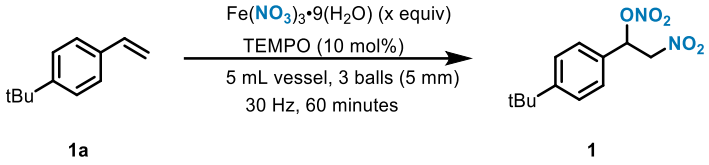


1a 1

Entry[a]	Number of balls	Yield (%)[b]
1	1	10
2	2	78
3	3	95
4	4	88

Table 2.3. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), $Fe(NO_3)_3 \times 9H_2O$ (2.0 equiv), TEMPO (0.1 equiv), 30 Hz, (1-4) stainless steel balls (5 mm), 60 mins. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

2.4. Effect of ferric nitrate loading

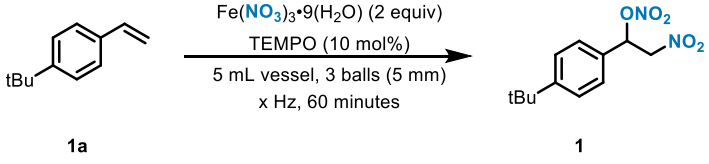


1a 1

Entry[a]	Fe(NO3)3•9H2O (equiv)	Yield (%)[b]
1	1	30
2	1.5	67
3	2	95

Table 2.4. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), $Fe(NO_3)_3 \times 9H_2O$ (1-2 equiv), TEMPO (0.1 equiv), 30 Hz, 3 stainless steel balls (5 mm), 60 mins. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

2.5. Effect of frequency



1a 1

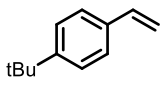
Entry[a]	Frequency [Hz]	Yield (%)[b]
1	15	33
2	20	48
3	25	87
4	30	95

Table 2.5. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), $Fe(NO_3)_3 \times 9H_2O$ (2.0 equiv), TEMPO (0.1 equiv), (15-30) Hz, 3 stainless steel balls (5 mm), 60 mins. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

3. Availability of Starting Materials

3.1. Commercially available starting materials

Commercially available starting materials were purchased from Thermoscientific – Acros, Sigma Aldrich, Apollo Scientific, Fluorochem and TCI companies.



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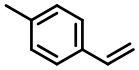

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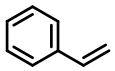

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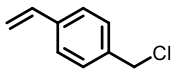

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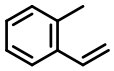

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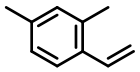

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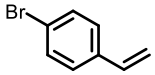

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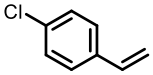

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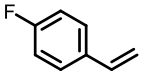

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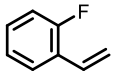

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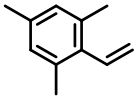

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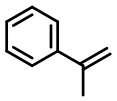

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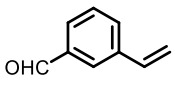

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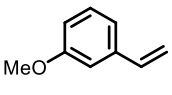

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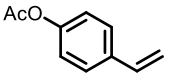

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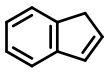

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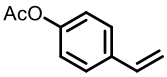

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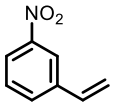

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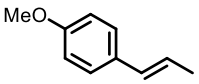

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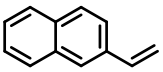
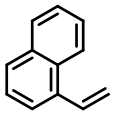


CAS 827-54-3



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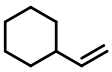
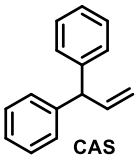
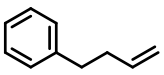


CAS 695-12-5

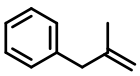
CAS 558-37-2



CAS 558-37-2



CAS 768-56-9



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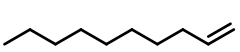
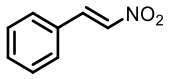


CAS 872-05-9

3.2. Synthesis of starting materials

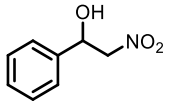
(E)-(2-nitrovinyl)benzene (S-1)



The titled compound was prepared according to our previous reported procedure.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.01 (d, *J* = 13.7 Hz, 1H), 7.62 – 7.54 (m, 3H), 7.53 – 7.43 (m, 3H).

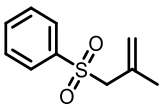
2-nitro-1-phenylethan-1-ol (S-2)



The titled compound was prepared according to our previous reported procedure.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.44 – 7.33 (m, 5H), 5.46 (dd, *J* = 9.4, 3.2 Hz, 1H), 4.67 – 4.46 (m, 2H), 2.84 (s, 1H).

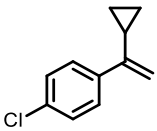
(2-methylallyl)sulfonyl)benzene (S-3)



The titled compound was prepared according to reported procedure.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.91 – 7.84 (m, 2H), 7.68 – 7.60 (m, 1H), 7.58 – 7.50 (m, 2H), 5.05 – 4.99 (m, 1H), 4.71 – 4.66 (m, 1H), 3.76 (d, *J* = 0.9 Hz, 2H), 1.86 (dd, *J* = 1.6, 1.0 Hz, 3H).

1-chloro-4-(1-cyclopropylvinyl)benzene (S-4)

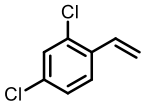


The titled compound was prepared according to reported procedure.[1] A 250 mL three-necked round-bottom flask was flame-dried and then cooled to room temperature under a nitrogen atmosphere. Methyltriphenylphosphonium bromide (1.2 equiv.) and NaH (1.3 equiv., 60% dispersion in mineral oil) were added to the flask along with THF (0.5 M). The mixture was refluxed for 1 hour and then cooled to 0°C. A solution of the corresponding ketone in THF (20 mL) was added dropwise, and the reflux was continued for 12 hours. The reaction was quenched with saturated NH_4Cl (10 mL) until the starting material disappeared, monitored by TLC. The reaction mixture was concentrated under vacuum and filtered on silica gel. The combined filtrates were concentrated under vacuum and further purified by flash chromatography.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.53 (d, *J* = 8.6 Hz, 2H), 7.30 (d, *J* = 8.6 Hz, 2H), 5.30 – 5.23 (m, 1H), 4.96 (t, *J* = 1.1 Hz, 1H), 1.61 (ttd, *J* = 8.3, 5.2, 1.2 Hz, 1H), 0.89 – 0.81 (m, 2H), 0.63 – 0.53 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 148.4, 140.2, 133.4, 128.4, 128.4, 127.5, 109.7, 15.7, 6.8.

2,4-dichloro-1-vinylbenzene (S-5)

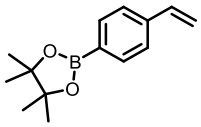


A mixture of methyltriphenylphosphonium bromide (11.0 mmol, 1.1 equiv) and K_2CO_3 (16.0 mmol, 1.6 equiv) was stirred in 150 mL of 1,4-dioxane under a nitrogen atmosphere at room temperature for 4 h in a 250 mL 2-necked round bottom flask. Corresponding benzaldehyde (10 mmol, 1.0 equiv) was added dropwise to the reaction mixture and refluxed for 12 h. Then flask was cooled to room temperature, reaction mixture was filtered, and solvents were removed under vacuum. The products were purified by silica gel chromatography using n-hexane : EtOAc (10:1) as the eluent. The title compound was obtained as a colorless oil in 83% isolated yield.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.49 (d, *J* = 8.4 Hz, 1H), 7.37 (d, *J* = 2.1 Hz, 1H), 7.21 (ddd, *J* = 8.4, 2.1, 0.6 Hz, 1H), 7.04 (dd, *J* = 17.5, 11.0 Hz, 1H), 5.73 (dd, *J* = 17.5, 1.0 Hz, 1H), 5.41 (dd, *J* = 11.0, 0.9 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 134.5, 134.0, 133.8, 132.3, 129.5, 127.5, 127.4, 117.2.

4,4,5,5-tetramethyl-2-(4-vinylphenyl)-1,3,2-dioxaborolane (S-6)

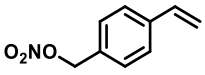


Pinacol (5.5 mmol, 1.1 equiv) was added in one portion to a solution of 4-vinylphenylboronic acid (5.0 mmol, 1.0 equiv) and $MgSO_4$ (10 mol%) in THF (15.0 mL). After stirring the resulting mixture for 2 hours at room temperature, it was filtered and concentrated under vacuum. The crude product was then purified by column chromatography on silica gel using Hexanes: EtOAc 95 : 5 (v/v). The title compound **S-6** was obtained as a colorless oil in 95%.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.79 (d, *J* = 8.1 Hz, 2H), 7.42 (d, *J* = 8.0 Hz, 2H), 6.74 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.82 (dd, *J* = 17.6, 1.0 Hz, 1H), 5.30 (dd, *J* = 10.8, 0.9 Hz, 1H), 1.36 (s, 12H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 140.3, 137.0, 135.2, 125.6, 115.0, 83.9, 25.0.

4-vinylbenzyl nitrate (S-7)



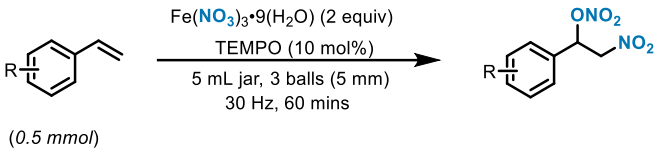
A suspension of $AgNO_3$ (10.0 mmol, 5.0 equiv) in CH_3CN (2 mL) was combined with a solution of 1a (2.0 mmol, 1.0 equiv) in CH_3CN (15 mL), and the resulting mixture was stirred at 60°C for 4 hours under light-shielding. Afterward, the mixture was filtered through Celite to remove insoluble materials, and the filtrate was concentrated. The titled compound was purified on a silica gel column using EtOAc: n-hexane (9:1) as the eluent, yielding **S-7** in 90% as colorless oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 77.44 (d, *J* = 8.3 Hz, 2H), 7.36 (d, *J* = 8.3 Hz, 2H), 6.72 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.79 (dd, *J* = 17.6, 0.8 Hz, 1H), 5.41 (s, 2H), 5.32 (dd, *J* = 10.9, 0.8 Hz, 1H).

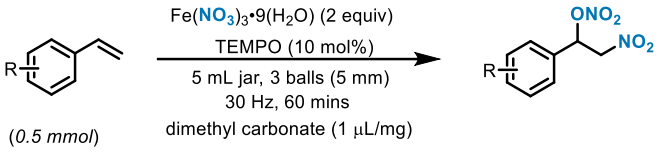
^{13}C-NMR (101 MHz, $CDCl_3$): δ 138.9, 136.2, 129.5, 129.0, 126.8, 115.3, 74.7.

4. General procedures

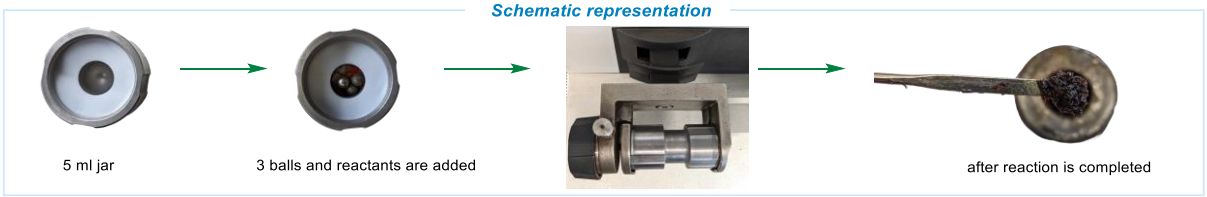
4.1. General procedures for 1,2-nitronitroxylation



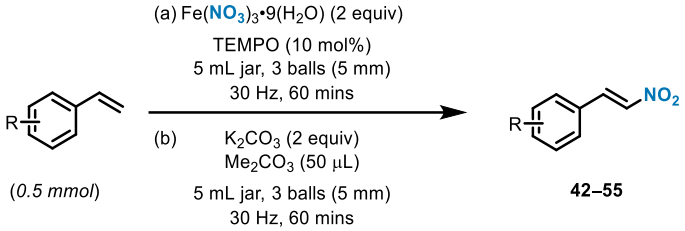
GP1: An alkene (0.50 mmol, 1.0 equiv), $Fe(NO_3)_3{\times}9H_2O$ (1.0 mmol, 2.0 equiv) and TEMPO (10 mol%) were placed in a stainless-steel vessel (5 mL) equipped with 3 stainless-steel balls (5 mm) udder air. Next, the ball milling vessel was closed and placed in the mixer mill (Retch MM400) for 60 mins at a frequency of 30 Hz. After the reaction was completed, the contents were removed from the vessel and either purified directly by column chromatography on silica gel using EtOAc/n-hexane (1/10) as the eluent or collected without further purification to obtain the desired product.



GP2: An alkene (0.50 mmol, 1.0 equiv), $Fe(NO_3)_3{\times}9H_2O$ (1.0 mmol, 2.0 equiv), dimethyl carbonate (1 μL/mg of alkene) and TEMPO (10 mol%) were placed in a stainless-steel vessel (5 mL) with 3 stainless-steel balls (5 mm). Next, the ball milling vessel was sealed and placed in the mixer mill (Retch MM400) for 60 minutes at a frequency of 30 Hz. After the reaction was finished, the contents were scraped off the vessel and purified directly by column chromatography on silica gel using EtOAc/n-hexane(1/10) as the eluent or collected without further purification to obtain the desired product.

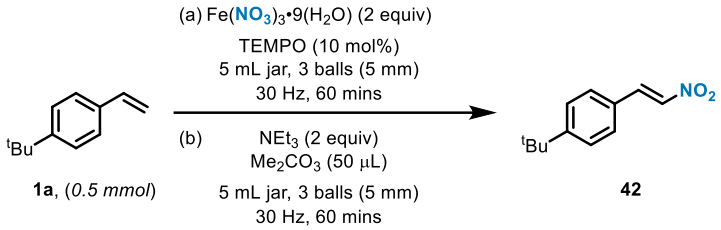


4.2. General procedure for nitro-alkene synthesis



GP3: An alkene (0.50 mmol, 1.0 equiv), $Fe(NO_3)_3 \times 9H_2O$ (1.0 mmol, 2.0 equiv) and TEMPO (10 mol%) were placed in a stainless-steel vessel (5 mL) equipped with 3 stainless-steel balls (5 mm). Next, the ball milling vessel was closed and placed in the mixer mill (Retch MM400) for 60 mins at a frequency of 30 Hz. After the reaction was completed, K_2CO_3 (2.0 equiv), and dimethyl carbonate (50 μL) were added to the reaction vessel. After that the reaction mixture was placed again in the mixer mill (Retch MM400) for additional 60 mins at a frequency of 30 Hz. The contents were scraped off the vessel and subsequently purified by column chromatography on silica gel using a mixture of EtOAc/n-hexane (1/10) as the eluent.

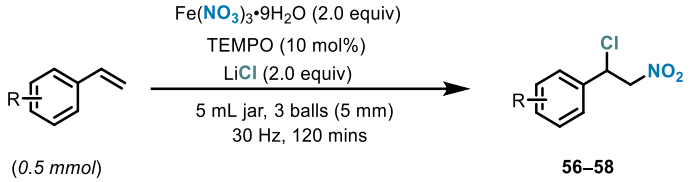
4.2. Screening of bases



Entry	*Base (2 equiv)*	*Yield (%)[a]*
1	$NaHCO_3$	16
2	$LiOH.H_2O$	59
3	Na_2CO_3	24
4	K_2CO_3	68
5	NEt_3	88

Table 4.2. a. Yield of **42** determined by ^{1}H-NMR against mesitylene.

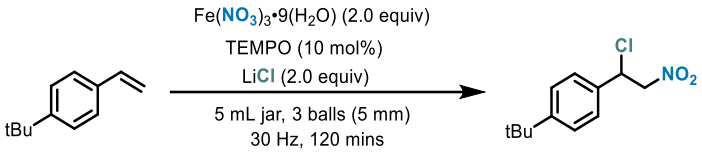
4.3. General procedure for 1,2-chloro-nitration



(*0.5 mmol*) **56–58**

GP4: An alkene (0.50 mmol, 1.0 equiv), $Fe(NO_3)_3 \times 9H_2O$ (1.0 mmol, 2.0 equiv), TEMPO (10 mol%), LiCl (1.0 mmol, 2.0 equiv) and dimethyl carbonate (1 μL/mg) were placed in a stainless-steel vessel (5 mL) equipped with 3 stainless-steel balls (5 mm). Next, the ball milling vessel was closed and placed in the mixer mill (Retch MM400) for 120 mins at a frequency of 30 Hz. After the reaction was finished, the contents were scraped off the vessel and purified directly on silica gel using EtOAc/n-hexane (1/10) as the eluent.

4.3. Screening of chloride salts

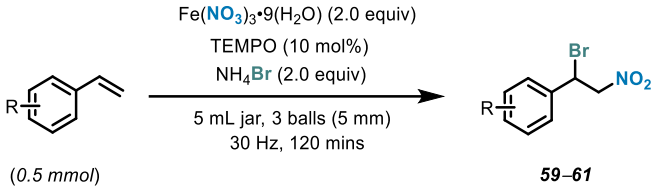


1a, *0.5 mmol* **56**

Entry	*Additive (2 equiv)*	*Yield (%)[a]*
1	KCl	12
2	NH_4Cl	46
3	NaCl	31
4	LiCl	65

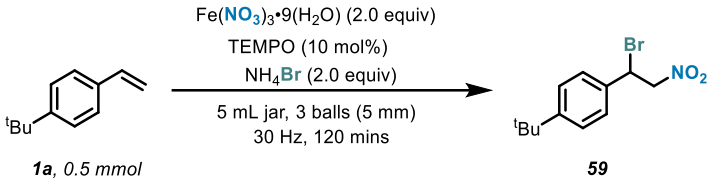
Table 4.3. a. Yield of **56** determined by ^{1}H-NMR against mesitylene.

4.4. General procedure for 1,2-bromo-nitration



GP5: An alkene (0.50 mmol, 1.0 equiv), $Fe(NO_3)_3 \times 9H_2O$ (1.0 mmol, 2.0 equiv), TEMPO (10 mol%), NH_4Br (1.0 mmol, 2.0 equiv) and dimethyl carbonate (1 μL/mg) were placed in a stainless-steel vessel (5 mL) with 3 stainless-steel balls (5 mm). Next, the ball milling vessel was closed and placed in the mixer mill (Retch MM400) for 120 mins at a frequency of 30 Hz. After the reaction was finished, the content was scraped off the vessel and purified directly on silica gel using EtOAc/n-hexane (1/10) as the eluent.

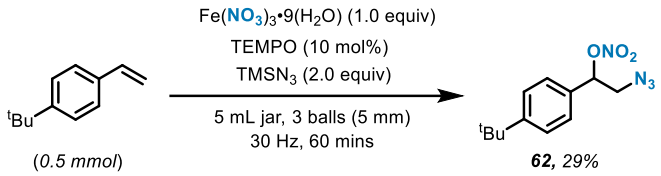
4.4. Screening of bromide salts



Entry	*Additive (X eq)*	*Yield (%)[a]*
1	KBr	5
2	NH_4Br	64
3	NaBr	3
4	LiBr	29

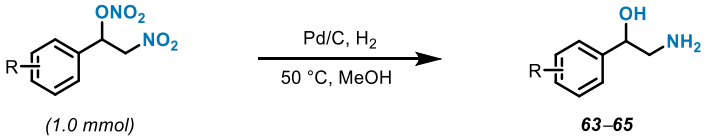
Table 4.4. a. Yield of **59** determined by ^{1}H-NMR against mesitylene.

4.5. General procedure for 1,2-azido-nitroxilation



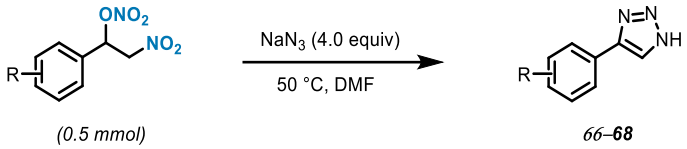
GP6: 4-Tertbutyl styrene (0.50 mmol, 1.0 equiv), $Fe(NO_3)_3 \times 9H_2O$ (0.5 mmol, 1.0 equiv), TEMPO (10 mol%), and $TMSN_3$ (1.0 mmol, 2.0 equiv) were placed in a stainless-steel vessel (5 mL) additionally equipped with 3 stainless-steel balls (5 mm). Next, the ball milling vessel was closed and placed in the mixer mill (Retch MM400) for 60 mins at frequency of 30 Hz. After the reaction was finished, the contents were scratched off the vessel and purified directly by column chromatography on silica gel using EtOAc/n-hexane (1/10) as the eluent.

4.6. General procedure for 1,2-aminoalcohol synthesis



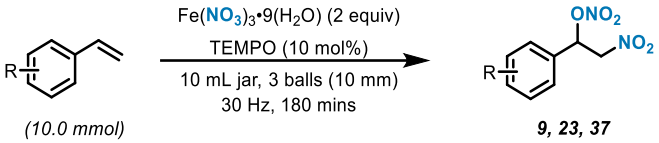
GP7: Nitronitrooxylated compound (1.0 mmol) was placed in a crimp vial and dissolved in MeOH (2 mL). Pd/C (5 wt%, 0.40 equiv) was added and the vial was closed with a crimp cap. The ballon of H_2 was placed over the vial. The reaction mixture was stirred for 12 h at 50°C. After completion, the crude mixture was purified by column chromatography on silica gel (DCM/MeOH/TEA). Note: The amino alcohol (e.g., **64**) can also be protected prior to purification by adding anhydrous $NaHCO_3$ (2.0 equiv) and Boc_2O (1.2 equiv) to the crude mixture and stirring for 12 h at rt. The protected compound was then purified by column chromatography on silica gel using EtOAc/n-hexane (4/6) as the eluent.

4.7. General procedure for triazole synthesis



GP8: Nitronitrooxylated compound (0.5 mmol) was dissolved in DMF (2 mL) and sodium azide (2.0 mmol, 4 equiv) was added. The mixture was stirred for 12 h at 50°C and was then washed with a saturated Na_2CO_3 solution (2 mL) and extracted with diethyl ether (3 x 5 mL). The organic layer was washed with water (5 x 10 mL) and brine and then dried over magnesium sulfate, filtered, and concentrated under vacuum. The crude mixture was purified with column chromatography on silica gel using EtOAc/n-hexane (3/7) as the eluent.

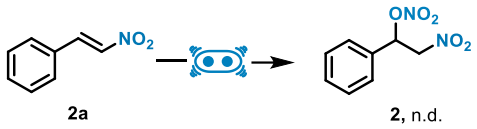
4.8. Scale-Up Synthesis



A 10 mL ball milling vessel equipped with 3 balls (10 mm) was charged with alkene (10.0 mmol, 1.0 equiv), $Fe(NO_3)_3 \times 9H_2O$ (2.0 equiv), and TEMPO (10 mol%). The jar was then closed and placed into the ball milling machine and reaction was carried out at 30 Hz frequency for 180 minutes. The crude product was purified by flash column chromatography on silica gel using EtOAc/n-hexane (1/10) as the eluent to get the desired product.

5. Mechanistic insights

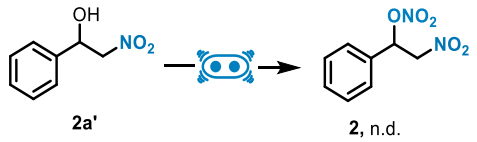
5.1. Experiment 1:



2a **2**, n.d.

A 5 mL ball milling vessel equipped with 3 balls (5 mm) was charged under air with (E)-(2-nitrovinyl)benzene (0.5 mmol, 1.0 equiv), $Fe(NO_3)_3 \times 9H_2O$ (2.0 eq), and TEMPO (10 mol%). The jar was then closed and placed into the ball milling machine and the reaction was carried out at 30 Hz frequency for 60 minutes. The crude product was shortly purified via silica gel and analyzed by ^{1}H-NMR.

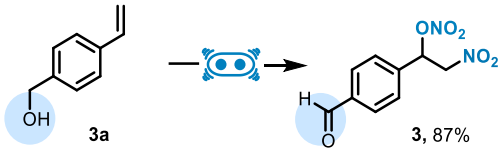
5.2. Experiment 2:



2a' **2**, n.d.

2-Nitro-1-phenylethane-1-ol (0.5 mmol, 1.0 equiv) was added to a 5 mL ball milling vessel equipped with 3 balls (5 mm). After that $Fe(NO_3)_3 \times 9H_2O$ (2.0 eq), and TEMPO (10 mol%) were introduced sequentially under air. The jar was then closed and placed into the ball milling machine, and the reaction was carried out at 30 Hz frequency for 60 minutes. The crude product was shortly purified via silica gel and analyzed by ^{1}H-NMR.

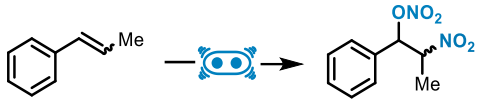
5.3. Experiment 3:



3a **3**, 87%

A 5 mL ball milling vessel equipped with 3 balls (5 mm) was charged with (4-vinylphenyl)methanol (0.5 mmol, 1.0 equiv) was added into the jar. After that $Fe(NO_3)_3 \times 9H_2O$ (2.0 eq), and TEMPO (10 mol%) were introduced sequentially. The jar was then closed and placed into the ball milling machine and the reaction was carried out at 30 Hz frequency for 60 minutes. The crude product was shortly purified via silica gel and analyzed by ^{1}H-NMR.

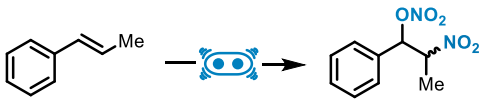
5.4. Experiment 4:



4a (E/Z)

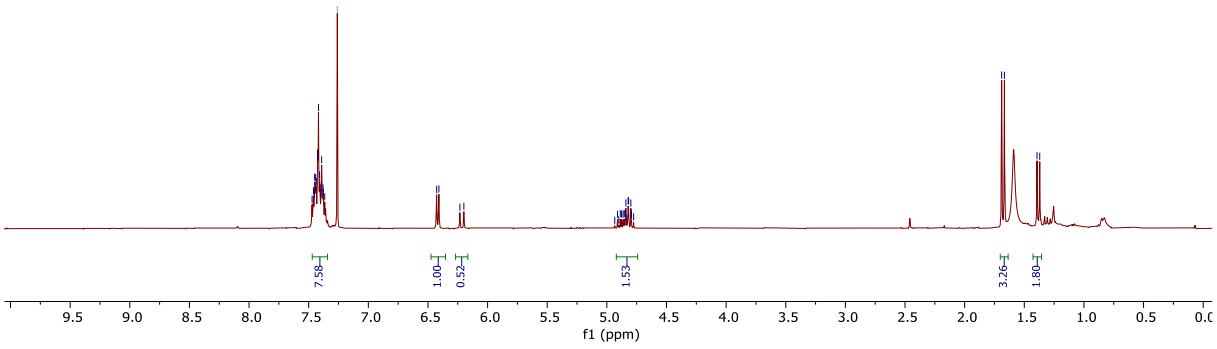
4, *from E* 79% (d.r. 2:1)
from Z 52% (d.r. 2:1)

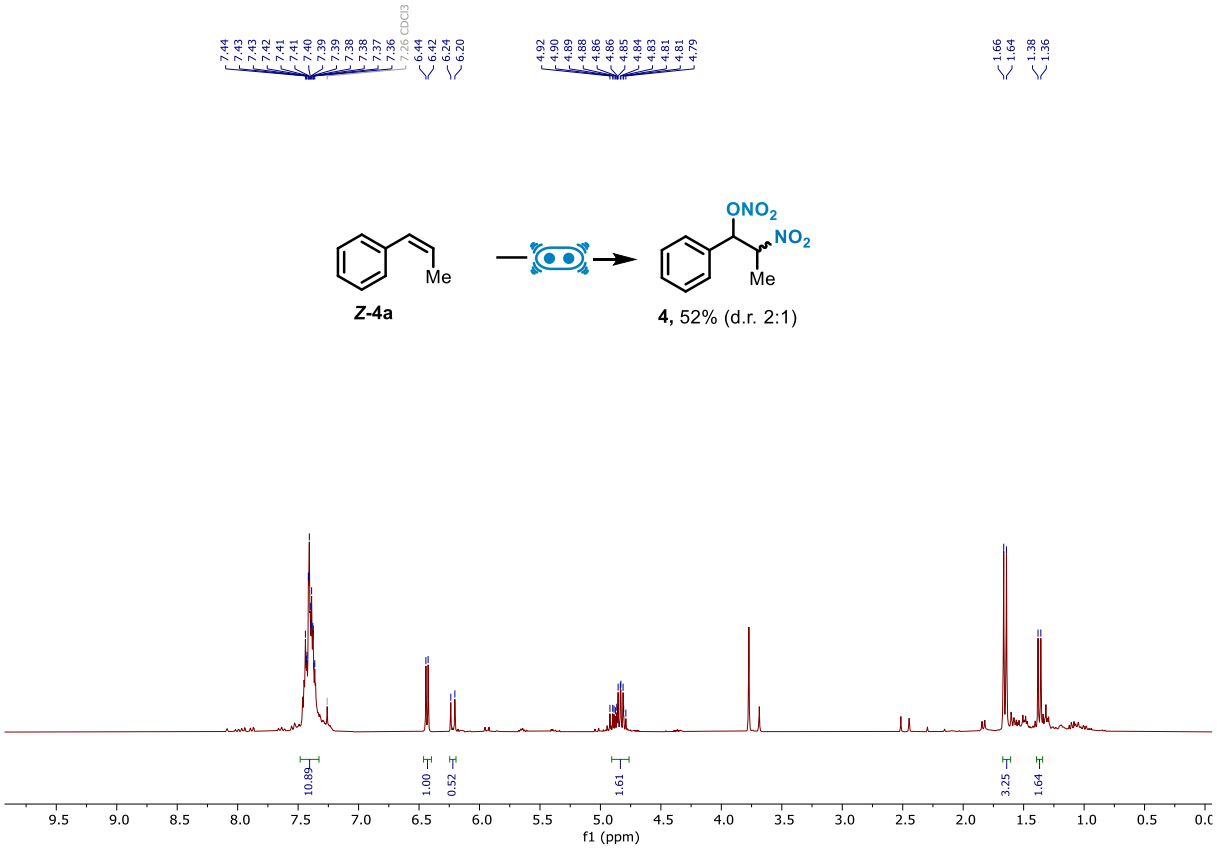
A 10 mL ball milling jar equipped with 3 balls (10 mm) was taken and then either (*E*)-prop-1-en-1-ylbenxene or (*Z*)-prop-1-en-1-ylbenxene (0.5 mmol, 1.0 eq) was added into the jar. After that $Fe(NO_3)_3 \times 9H_2O$ (2.0 eq), and TEMPO (10 mol%) were added. The jar was then placed into the ball milling machine and reaction was carried out at 30 Hz frequency for 60 minutes. The crude product was shortly purified via silica gel and analyzed by ^{1}H-NMR.



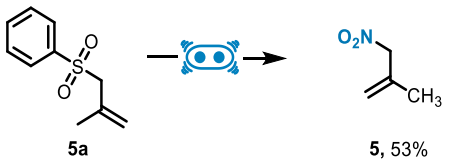
***E*-4a**

4, 79% (d.r. 2:1)



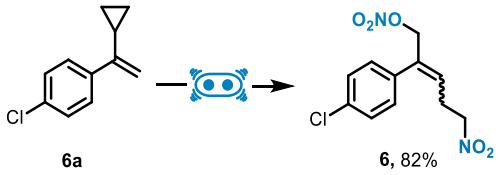


5.5. Experiment 5:



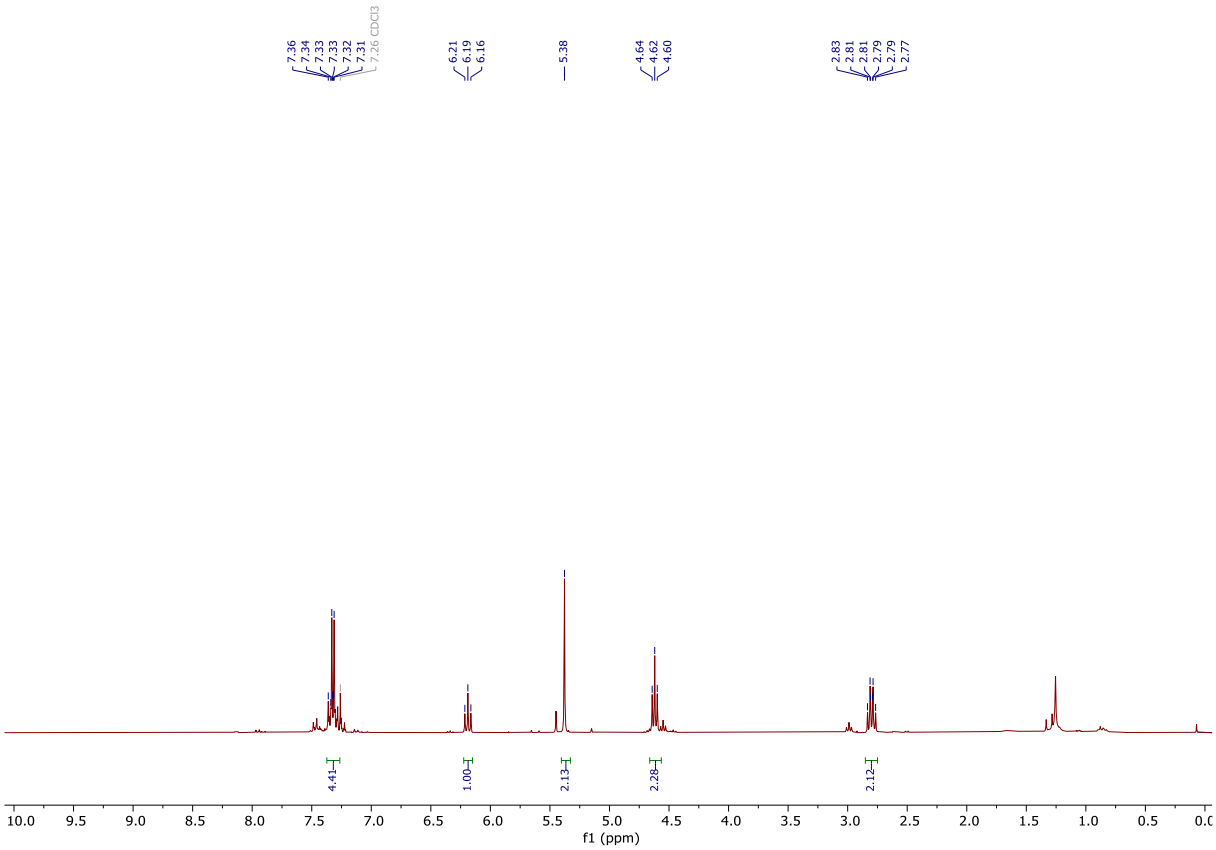
A 5 mL ball milling vessel equipped with 3 balls (5 mm) was charged with (2-methylallyl)sulfonyl)benzene (0.5 mmol, 1.0 equiv). After that $Fe(NO_3)_3 \times 9H_2O$ (2.0 eq), and TEMPO (10 mol%) were introduced sequentially. The jar was then closed and placed into the ball milling machine and reaction was carried out at 30 Hz frequency for 60 minutes. The crude product was shortly purified via silica gel and analyzed by ^{1}H-NMR. For analytical data see page S18.

5.6. Experiment 6:



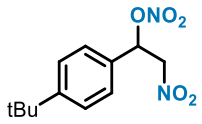
A 5 mL ball milling vessel equipped with 3 balls (5 mm) was charged with 1-chloro-4-(1-cyclopropylvinyl)benzene (0.5 mmol, 1.0 equiv). After that $Fe(NO_3)_3 \times 9H_2O$ (2.0 eq), and TEMPO (10 mol%) were introduced sequentially. The jar was then closed and placed into the ball milling machine

and reaction was carried out at 30 Hz frequency for 60 minutes. The crude product was shortly purified via silica gel and analyzed by ^{1}H-NMR.



6. NMR Data

1-(4-(tert-butyl)phenyl)-2-nitroethyl nitrate (1)[1]

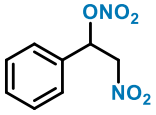


Compound **1** was obtained according to general procedure **GP1** from 1-(tert-butyl)-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (90% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.48 (d, *J* = 8.5 Hz, 2H), 7.36 (d, *J* = 8.4 Hz, 2H), 6.58 (dd, *J* = 10.2, 3.5 Hz, 1H), 4.86 (dd, *J* = 14.6, 10.2 Hz, 1H), 4.62 (dd, *J* = 14.6, 3.5 Hz, 1H), 1.33 (s, 9H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 154.0, 129.4, 126.7, 126.6, 79.8, 75.6, 35.0, 31.3.

2-nitro-1-phenylethyl nitrate (2)



Compound **2** was obtained according to general procedure **GP1** from styrene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (94% yield).

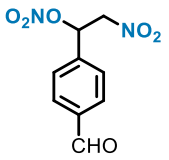
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.49 – 7.39 (m, 5H), 6.58 (dd, *J* = 10.1, 3.5 Hz, 1H), 4.84 (dd, *J* = 14.6, 10.1 Hz, 1H), 4.62 (dd, *J* = 14.6, 3.5 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 132.6, 130.7, 130.6, 129.8, 129.7, 129.4, 129.2, 126.9, 79.8, 75.6.

IR (ATR, neat): 3060, 2971, 1662, 1371, 1280, 1214, 1163.

HRMS (ESI) *m/z*, calcd for $C_8H_8N_2O_5$–HNO_3: 149.0477; found 149.0475.

1-(4-formylphenyl)-2-nitroethyl nitrate (3)



Compound **3** was obtained according to general procedure **GP1** from 4-vinylbenzaldehyde (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (81% yield).

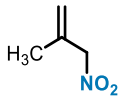
^{1}H-NMR (300 MHz, $CDCl_3$): δ 10.05 (s, 1H), 7.98 (d, *J* = 7.8 Hz, 2H), 7.62 (d, *J* = 7.8 Hz, 2H), 6.64 (dd, *J* = 9.8, 3.6 Hz, 1H), 4.86 (dd, *J* = 14.6, 9.8 Hz, 1H), 4.65 (dd, *J* = 14.6, 3.6 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 191.2, 138.7, 137.8, 130.8, 127.5, 78.9, 75.3.

IR (ATR, neat): 3012, 2853, 1738, 1647, 1616, 1547, 1464, 1233, 1056.

HRMS (ESI) *m/z*, calcd for $C_9H_8N_2O_6$–HNO_3: 177.0426; found 177.0424.

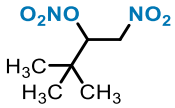
2-methyl-3-nitroprop-1-ene (5)



Compound **5** was obtained according to general procedure **GP1** from ((2-methylallyl)sulfonyl)benzene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (53% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 5.27 – 5.15 (m, 2H), 4.89 (d, *J* = 1.1 Hz, 2H), 1.90 – 1.87 (m, 3H).

3,3-dimethyl-1-nitrobutan-2-yl nitrate (7)



Compound **7** was obtained according to general procedure **GP1** from 3,3-dimethylbut-1-ene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (65% yield).

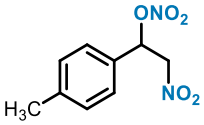
^{1}H-NMR (300 MHz, $CDCl_3$): δ 5.23 (dd, *J* = 15.7, 10.7 Hz, 1H), 5.00 (dd, *J* = 10.7, 2.0 Hz, 1H), 4.68 (dd, *J* = 15.7, 2.0 Hz, 1H), 1.11 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 91.7, 72.9, 34.6, 26.8.

IR (ATR, neat): 2843, 1637, 1536, 1326, 1216, 1186.

HRMS (ESI) *m/z*, calcd for $C_6H_{12}N_2O_5$–HNO_3: 129.0790; found 129.0788.

2-nitro-1-(p-tolyl)ethyl nitrate (9)



Compound **9** was obtained according to general procedure **GP1** from 1-methyl-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as yellow solid (92% yield).

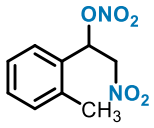
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.28 (q, *J* = 8.1 Hz, 4H), 6.53 (dd, *J* = 10.1, 3.6 Hz, 1H), 4.83 (dd, *J* = 14.5, 10.1 Hz, 1H), 4.58 (dd, *J* = 14.5, 3.7 Hz, 1H), 2.37 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 140.9, 130.3, 129.6, 126.9, 79.8, 77.2, 75.7, 21.4.

IR (ATR, neat): 3014, 2983, 1626, 1566, 1347, 1237, 1147.

HRMS (ESI) *m/z*, calcd for $C_9H_{10}N_2O_5$–HNO_3: 163.0633; found 163.0631.

2-nitro-1-(o-tolyl)ethyl nitrate (10)



Compound **10** was obtained according to general procedure **GP1** from 1-methyl-2-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (89% yield).

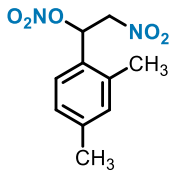
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.32 – 7.15 (m, 4H), 6.74 (dd, *J* = 10.2, 3.2 Hz, 1H), 4.70 (dd, *J* = 14.7, 10.2 Hz, 1H), 4.45 (dd, *J* = 14.7, 3.2 Hz, 1H), 2.43 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.7, 131.5, 131.0, 130.2, 127.3, 125.8, 77.0, 75.0, 19.0.

IR (ATR, neat): 3003, 2973, 2868, 1626, 1552, 1237, 1136.

HRMS (ESI) *m/z*, calcd for $C_9H_{10}N_2O_5$–HNO_3: 163.0633; found 163.0631.

1-(2,4-dimethylphenyl)-2-nitroethyl nitrate (11)



Compound **11** was obtained according to general procedure **GP1** from 2,4-dimethyl-1-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (91% yield).

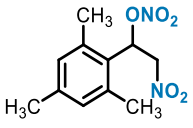
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.25 (d, *J* = 7.8 Hz, 1H), 7.09 (d, *J* = 8.6 Hz, 2H), 6.78 (dd, *J* = 10.1, 3.3 Hz, 1H), 4.78 (dd, *J* = 14.6, 10.2 Hz, 1H), 4.51 (dd, *J* = 14.6, 3.3 Hz, 1H), 2.47 (s, 3H), 2.33 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 140.4, 135.6, 132.2, 128.0, 125.9, 77.2, 77.1, 75.2, 21.2, 18.9.

IR (ATR, neat): 3012, 2822, 1636, 1466, 1383, 1282, 1153, 741.

HRMS (ESI) *m/z*, calcd for $C_{10}H_{12}N_2O_5$–HNO_3: 177.0790; found 177.0788.

1-mesityl-2-nitroethyl nitrate (12)



Compound **12** was obtained according to general procedure **GP1** from 1,3,5-trimethyl-2-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (88% yield).

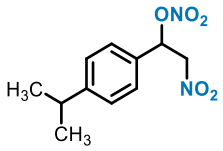
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.07 (dd, *J* = 10.4, 3.3 Hz, 1H), 6.90 (s, 2H), 5.08 (dd, *J* = 14.7, 10.4 Hz, 1H), 4.54 (dd, *J* = 14.7, 3.3 Hz, 1H), 2.47 (s, 6H), 2.28 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 140.1, 137.1, 130.9, 125.8, 77.5, 74.3, 21.0, 20.4.

IR (ATR, neat): 3030, 2937, 1634, 1465, 1353, 1147,1047.

HRMS (ESI) *m/z*, calcd for $C_{11}H_{14}N_2O_5$–HNO_3: 191.0941; found 191.0943.

1-(4-isopropylphenyl)-2-nitroethyl nitrate (13)



Compound **13** was obtained according to general procedure **GP1** from 1-isopropyl-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (91% yield).

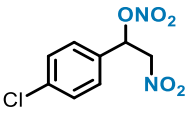
^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.34 (d, *J* = 8.6 Hz, 2H), 7.30 (d, *J* = 8.6 Hz, 2H), 6.56 (dd, *J* = 10.2, 3.5 Hz, 1H), 4.84 (dd, *J* = 14.6, 10.2 Hz, 1H), 4.60 (dd, *J* = 14.6, 3.5 Hz, 1H), 2.93 (p, *J* = 6.9 Hz, 1H), 1.25 (d, *J* = 6.9 Hz, 6H).

^{13}C-NMR (101 MHz, $CDCl_3$): δ 151.7, 129.9, 127.7, 127.0, 79.8, 75.7, 34.1, 23.9.

IR (ATR, neat): 3016, 2968, 1638, 1538, 1384, 1243, 1127.

HRMS (ESI) *m/z*, calcd for $C_{11}H_{14}N_2O_5$–HNO_3: 191.0946; found 191.0943.

1-(4-chlorophenyl)-2-nitroethyl nitrate (14)



Compound **14** was obtained according to general procedure **GP1** from 1-chloro-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (84% yield).

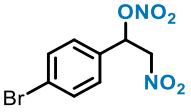
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.46 – 7.35 (m, 4H), 6.54 (dd, *J* = 9.9, 3.7 Hz, 1H), 4.82 (dd, *J* = 14.6, 9.9 Hz, 1H), 4.60 (dd, *J* = 14.6, 3.7 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.8, 131.1, 130.4, 130.0, 129.9, 128.3, 79.0, 75.4.

IR (ATR, neat): 3016, 2993, 1583, 1437, 1343, 1258, 1148.

HRMS (ESI) *m/z*, calcd for $C_8H_7ClN_2O_5$–HNO_3: 183.0087; found 183.0085.

1-(4-bromophenyl)-2-nitroethyl nitrate (15)



Compound **15** was obtained according to general procedure **GP1** from 1-bromo-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a yellow solid (85% yield).

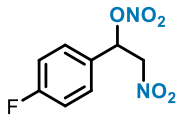
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.60 (d, *J* = 8.5 Hz, 2H), 7.31 (d, *J* = 8.4 Hz, 2H), 6.53 (dd, *J* = 9.9, 3.7 Hz, 1H), 4.82 (dd, *J* = 14.6, 9.9 Hz, 1H), 4.60 (dd, *J* = 14.6, 3.8 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 132.9, 131.6, 130.5, 128.5, 125.0, 79.0, 75.3.

IR (ATR, neat): 3024, 2974, 1548, 1494, 1359, 1348, 1258 1083.

HRMS (ESI) *m/z*, calcd for $C_8H_7BrN_2O_5$–HNO_3: 226.9582; found 226.9580.

1-(4-fluorophenyl)-2-nitroethyl nitrate (16)



Compound **16** was obtained according to general procedure **GP1** from 1-fluoro-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (88% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.43 (dd, *J* = 8.7, 5.0 Hz, 2H), 7.15 (t, *J* = 8.6 Hz, 2H), 6.56 (dd, *J* = 9.9, 3.8 Hz, 1H), 4.84 (dd, *J* = 14.5, 9.9 Hz, 1H), 4.60 (dd, *J* = 14.5, 3.8 Hz, 1H).

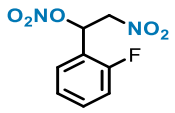
^{13}C-NMR (75 MHz, $CDCl_3$): δ 163.9 (d, *J* = 251.0 Hz), 129.1 (d, *J* = 8.7 Hz), 128.5, 116.9 (d, *J* = 22.1 Hz), 79.0, 75.5.

^{19}F-NMR (282 MHz, $CDCl_3$): δ -109.4.

IR (ATR, neat): 3031, 2921, 1635, 1557, 1377, 1266, 1085.

HRMS (ESI) *m/z*, calcd for $C_8H_7FN_2O_5$–HNO_3: 167.0383; found 167.0382.

1-(2-fluorophenyl)-2-nitroethyl nitrate (17)



Compound **17** was obtained according to general procedure **GP1** from 1-fluoro-2-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (83% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.59 – 7.48 (m, 2H), 7.38 – 7.23 (m, 2H), 6.95 (dd, *J* = 9.9, 3.4 Hz, 1H), 4.99 (dd, *J* = 14.8, 9.9 Hz, 1H), 4.79 (dd, *J* = 14.8, 3.4 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 161.6, 158.3, 132.3 (d, *J* = 8.5 Hz), 128.1 (d, *J* = 2.8 Hz), 125.2 (d, *J* = 3.7 Hz), 119.9 (d, *J* = 13.1 Hz), 116.5 (d, *J* = 20.8 Hz), 78.1 – 76.01 (m), 74.3 (dd, *J* = 10.7, 2.7 Hz).

^{19}F-NMR (282 MHz, $CDCl_3$): δ -116.6.

IR (ATR, neat): 3026, 2983, 1637, 1538, 1373, 1265, 1167.

HRMS (ESI) *m/z*, calcd for $C_8H_7FN_2O_5$–HNO_3: 167.0383; found 167.0381.

1-(3-formylphenyl)-2-nitroethyl nitrate (18)

Compound **18** was obtained according to general procedure **GP1** from 3-vinylbenzaldehyde (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (87% yield).

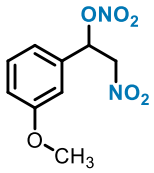
^{1}H-NMR (300 MHz, $CDCl_3$): δ 10.06 (s, 1H), 8.01 – 7.93 (m, 2H), 7.76 – 7.61 (m, 2H), 6.66 (dd, *J* = 9.8, 3.8 Hz, 1H), 4.88 (dd, *J* = 14.6, 9.8 Hz, 1H), 4.66 (dd, *J* = 14.6, 3.8 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 191.0, 137.5, 134.1, 132.5, 132.0, 130.6, 127.4, 78.9, 75.4.

IR (ATR, neat): 3027, 2883, 2737, 1692, 1547, 1373, 1164.

HRMS (ESI) *m/z*, calcd for $C_9H_8N_2O_6$–HNO_3: 177.0426; found 177.0424.

1-(3-methoxyphenyl)-2-nitroethyl nitrate (19)



Compound **19** was obtained according to general procedure **GP1** from 1-methoxy-3-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (74% yield).

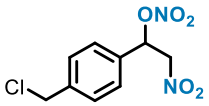
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.36 (t, *J* = 7.9 Hz, 1H), 7.04 – 6.89 (m, 3H), 6.54 (dd, *J* = 10.1, 3.5 Hz, 1H), 4.82 (dd, *J* = 14.6, 10.1 Hz, 1H), 4.60 (dd, *J* = 14.6, 3.5 Hz, 1H), 3.83 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 160.5, 134.1, 130.9, 118.8, 115.8, 112.5, 79.7, 75.7, 55.6.

IR (ATR, neat): 3012, 2947, 1616, 1548, 1384, 1238, 1037.

HRMS (ESI) *m/z*, calcd for $C_9H_{10}N_2O_6$–HNO_3: 179.0582; found 179.0580.

1-(4-(chloromethyl)phenyl)-2-nitroethyl nitrate (20)



Compound **20** was obtained according to general procedure **GP1** from 1-(chloromethyl)-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (91% yield).

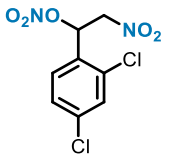
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.51 – 7.41 (m, 4H), 6.58 (dd, *J* = 10.0, 3.6 Hz, 1H), 4.83 (dd, *J* = 14.6, 10.0 Hz, 1H), 4.61 (d, *J* = 13.4 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 140.1, 132.7, 129.8, 127.3, 79.3, 75.5, 45.3.

IR (ATR, neat): 3035, 2973, 1536, 1516, 1374, 1274, 1137.

HRMS (ESI) *m/z*, calcd for $C_9H_9ClN_2O_5$–HNO_3: 197.0244; found 197.0243.

1-(2,4-dichlorophenyl)-2-nitroethyl nitrate (21)



Compound **21** was obtained according to general procedure **GP1** from 2,4-dichloro-1-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (88% yield).

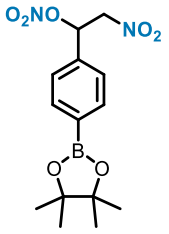
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.50 (dd, *J* = 1.9, 0.4 Hz, 1H), 7.45 – 7.34 (m, 2H), 6.95 (dd, *J* = 7.0, 5.9 Hz, 1H), 4.72 – 4.66 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.9, 133.1, 130.4, 129.2, 128.5, 127.9, 77.1, 75.9, 73.8.

IR (ATR, neat): 2986, 1658, 1536, 1384, 122, 1136.

HRMS (ESI) *m/z*, calcd for $C_8H_6Cl_2N_2O_5$–HNO_3: 216.9697; found 216.9695.

2-nitro-1-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)ethyl nitrate (22)



Compound **22** was obtained according to general procedure **GP1** from 4,4,5,5-tetramethyl-2-(4-vinylphenyl)-1,3,2-dioxaborolane (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (87% yield).

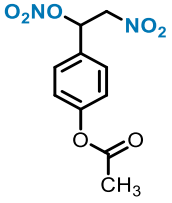
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.89 (d, *J* = 8.2 Hz, 2H), 7.46 – 7.38 (m, 2H), 6.57 (dd, *J* = 10.1, 3.5 Hz, 1H), 4.82 (dd, *J* = 14.6, 10.1 Hz, 1H), 4.59 (dd, *J* = 14.6, 3.5 Hz, 1H), 1.34 (s, 12H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.0, 135.2, 126.0, 84.4, 79.8, 75.5, 25.0.

IR (ATR, neat): 2980, 2933, 1612, 1542, 1352, 1126, 1064, 739.

HRMS (ESI) *m/z*, calcd for $C_{14}H_{19}BN_2O_7$–HNO_3: 275.1329; found 275.1327.

4-(2-nitro-1-(nitrooxy)ethyl)phenyl acetate (23)



Compound **23** was obtained according to general procedure **GP1** from 4-vinylphenyl acetate (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (88% yield).

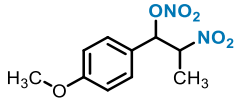
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.50 (d, *J* = 8.6 Hz, 2H), 7.25 (d, *J* = 8.7 Hz, 2H), 6.63 (dd, *J* = 10.1, 3.5 Hz, 1H), 4.88 (dd, *J* = 14.7, 10.1 Hz, 1H), 4.66 (dd, *J* = 14.7, 3.5 Hz, 1H), 2.37 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 169.2, 152.3, 130.0, 128.2, 123.0, 79.1, 75.5, 21.2.

IR (ATR, neat): 3003, 1659, 1578, 1573, 1483, 1374, 1125.

HRMS (ESI) *m/z*, calcd for $C_{10}H_{10}N_2O_7$–HNO_3: 207.0532; found 207.0530.

1-(4-methoxyphenyl)-2-nitropropyl nitrate (24)



Compound **24** was obtained according to general procedure **GP1** from (Z)-1-methoxy-4-(prop-1-en-1-yl)benzene (0.5 mmol, 1.0 equiv). Isolated as a colorless liquid (72% yield).

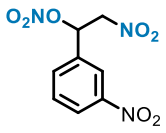
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.33 (d, *J* = 8.7 Hz, 2H), 6.96 (d, *J* = 8.7 Hz, 2H), 6.17 (d, *J* = 10.2 Hz, 1H), 4.87 (dq, *J* = 10.2, 6.9 Hz, 1H), 3.83 (s, 3H), 1.37 (d, *J* = 6.9 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 160.7, 129.5, 126.0, 114.6, 87.2, 79.3, 55.5, 16.5.

IR (ATR, neat): 2963, 1636, 1564, 1473, 1395, 1328, 1107, 1008.

HRMS (ESI) *m/z*, calcd for $C_{12}H_{10}N_2O_5$–HNO_3: 193.0739; found 193.0737.

2-nitro-1-(3-nitrophenyl)ethyl nitrate (25)



Compound **25** was obtained according to general procedure **GP1** from 1-nitro-3-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (83% yield).

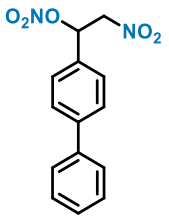
^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.38 – 8.30 (m, 2H), 7.84 – 7.77 (m, 1H), 7.70 (t, *J* = 8.2 Hz, 1H), 6.68 (dd, *J* = 9.7, 3.9 Hz, 1H), 4.89 (dd, *J* = 14.6, 9.7 Hz, 1H), 4.68 (dd, *J* = 14.7, 3.9 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 142.6, 134.9, 132.8, 131.0, 125.5, 122.0, 78.2, 75.1.

IR (ATR, neat): 2993, 1645, 1632, 1435, 1385, 1271, 1045.

HRMS (ESI) *m/z*, calcd for $C_8H_7N_3O_7$–HNO_3: 194.0328; found 194.0324.

1-([1,1'-biphenyl]-4-yl)-2-nitroethyl nitrate (26)



Compound **26** was obtained according to general procedure **GP2** from 4-vinyl-1,1'-biphenyl (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (82% yield).

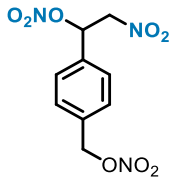
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.70 – 7.64 (m, 2H), 7.61 – 7.55 (m, 2H), 7.53 – 7.39 (m, 5H), 6.63 (dd, *J* = 10.0, 3.6 Hz, 1H), 4.89 (dd, *J* = 14.6, 10.1 Hz, 1H), 4.65 (dd, *J* = 14.6, 3.6 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 143.6, 139.9, 131.3, 129.1, 128.3, 128.2, 127.4, 127.3, 79.7, 75.6, 48.6, 24.9, 11.9.

IR (ATR, neat): 3016, 2984, 1626, 1573, 1368, 1233, 1068.

HRMS (ESI) *m/z*, calcd for $C_{14}H_{12}N_2O_5$–HNO_3: 225.0790; found 225.0788.

2-nitro-1-(4-((nitrooxy)methyl)phenyl)ethyl nitrate (27)



Compound **27** was obtained according to general procedure **GP1** from 4-vinylbenzyl nitrate (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (90% yield).

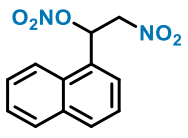
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.49 (t, *J* = 2.3 Hz, 4H), 6.59 (dd, *J* = 10.0, 3.6 Hz, 1H), 5.44 (s, 2H), 4.83 (dd, *J* = 14.6, 10.0 Hz, 1H), 4.66 – 4.58 (m, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.0, 133.8, 130.03, 127.4, 79.2, 75.4, 73.7.

IR (ATR, neat): 3030, 2974, 1651, 1493, 1381, 1226, 1174.

HRMS (ESI) *m/z*, calcd for $C_9H_9N_3O_8$–HNO_3: 224.0433; found 224.0431.

1-(naphthalen-1-yl)-2-nitroethyl nitrate (28)



Compound **28** was obtained according to general procedure **GP2** from 1-vinylnaphthalene (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (81% yield).

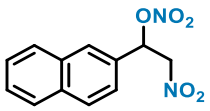
^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.12 (dq, *J* = 8.6, 1.0 Hz, 1H), 8.01 – 7.89 (m, 2H), 7.72 – 7.49 (m, 4H), 7.40 (dd, *J* = 10.1, 3.0 Hz, 1H), 4.91 (dd, *J* = 14.8, 10.1 Hz, 1H), 4.74 (dd, *J* = 14.8, 3.0 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 134.0, 130.9, 129.7, 129.6, 128.4, 128.0, 126.8, 125.5, 124.5, 121.6, 77.3, 75.2.

IR (ATR, neat): 3018, 3001, 2987, 1627, 1568, 1237, 1182.

HRMS (ESI) *m/z*, calcd for $C_{12}H_{10}N_2O_5$–HNO_3: 199.0633; found 199.0630.

1-(naphthalen-2-yl)-2-nitroethyl nitrate (29)



Compound **29** was obtained according to general procedure **GP2** from 1-vinylnaphthalene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (81% yield).

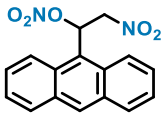
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.98 – 7.84 (m, 4H), 7.62 – 7.54 (m, 2H), 7.46 (dd, *J* = 8.6, 1.8 Hz, 1H), 6.75 (dd, *J* = 10.1, 3.6 Hz, 1H), 4.94 (dd, *J* = 14.6, 10.1 Hz, 1H), 4.69 (dd, *J* = 14.6, 3.6 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 134.1, 133.1, 129.9, 129.7, 128.3, 128.0, 127.7, 127.4, 127.1, 123.1, 80.0, 75.6.

IR (ATR, neat): 3036, 3005, 2994, 1626, 1573, 1227, 1147.

HRMS (ESI) *m/z*, calcd for $C_{12}H_{10}N_2O_5$–HNO_3: 199.0633; found 199.0630.

1-(anthracen-9-yl)-2-nitroethyl nitrate (30)



Compound **30** was obtained according to general procedure **GP2** from 9-vinylanthracene (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (78% yield).

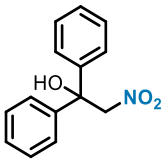
^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.63 (s, 1H), 8.16 – 8.00 (m, 4H), 7.65 (ddd, *J* = 8.8, 6.6, 1.5 Hz, 2H), 7.55 (ddd, *J* = 7.8, 6.6, 1.0 Hz, 2H), 7.06 (dd, *J* = 8.2, 3.2 Hz, 1H), 6.22 (dd, *J* = 13.2, 8.2 Hz, 1H), 5.00 (dd, *J* = 13.2, 3.2 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 134.3, 131.8, 131.6, 130.2, 128.7, 127.4, 125.6, 122.1, 81.5, 71.2.

IR (ATR, neat): 3073, 3001, 2974, 1636, 1563, 1279.

HRMS (ESI) *m/z*, calcd for $C_{16}H_{12}N_2O_5$–HNO_3: 249.0790; found 249.0787.

2-nitro-1,1-diphenylethan-1-ol (31)

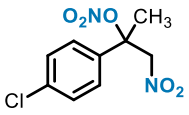


Compound **31** was obtained according to general procedure **GP1** from ethene-1,1-diyldibenzene (0.5 mmol, 1.0 equiv). Isolated as a white solid (57% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.48 – 7.42 (m, 4H), 7.41 – 7.28 (m, 6H), 5.09 (s, 2H), 4.61 (s, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 142.0, 128.8, 128.34, 125.9, 82.7, 77.3.

2-nitro-1-(4-((nitrooxy)methyl)phenyl)ethyl nitrate (32)



Compound **32** was obtained according to general procedure **GP1** from 1-chloro-4-(prop-1-en-2-yl)benzene (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (74% yield).

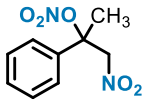
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.43 (d, *J* = 8.7 Hz, 2H), 7.33 (d, *J* = 8.8 Hz, 2H), 5.18 – 5.05 (m, 1H), 4.85 (d, *J* = 11.8 Hz, 1H), 2.04 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.6, 135.8, 129.8, 125.9, 86.2, 81.0, 23.4.

IR (ATR, neat): 2973, 1628, 1489, 1431, 1347, 1225, 1009.

HRMS (ESI) *m/z*, calcd for $C_9H_9ClN_2O_5$–HNO_3: 197.0244; found 197.0242.

1-nitro-2-phenylpropan-2-yl nitrate (33)



Compound **33** was obtained according to general procedure **GP1** from prop-1-en-2-ylbenzene (0.5 mmol, 1.0 equiv). Isolated as a light-yellow liquid (80% yield).

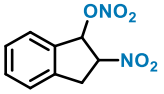
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.49 – 7.35 (m, 5H), 5.18 (d, *J* = 11.7 Hz, 1H), 4.87 (d, *J* = 11.7 Hz, 1H), 2.05 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.2, 129.6, 124.3, 86.7, 81.1, 23.5.

IR (ATR, neat): 3006, 2984, 2894, 1547, 1471, 1363, 1285.

HRMS (ESI) *m/z*, calcd for $C_9H_{10}N_2O_5$–HNO_3: 163.0633; found 163.0631.

2-nitro-2,3-dihydro-1H-inden-1-yl nitrate (34)



Compound **34** was obtained according to general procedure **GP1** from 1*H*-indene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (82% yield).

Isomer 34a: **^{1}H-NMR** (300 MHz, $CDCl_3$): δ 7.50 – 7.43 (m, 2H), 7.41 – 7.29 (m, 2H), 6.91 (d, *J* = 3.4 Hz, 1H), 5.34 (ddd, *J* = 8.6, 5.0, 3.5 Hz, 1H), 3.80 (dd, *J* = 17.2, 8.6 Hz, 1H), 3.59 (dd, *J* = 17.2, 5.0 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.8, 133.3, 131.5, 128.7, 126.1, 125.2, 88.3, 88.2, 36.8.

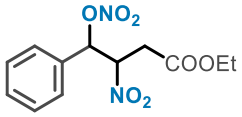
Isomer 34b: **^{1}H-NMR** (300 MHz, $CDCl_3$): δ 7.51 – 7.41 (m, 2H), 7.40 – 7.33 (m, 2H), 6.66 (d, *J* = 6.2 Hz, 1H), 5.50 (dt, *J* = 7.3, 6.3 Hz, 1H), 3.93 – 3.77 (m, 1H), 3.41 (dd, *J* = 16.6, 7.3 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.7, 133.3, 131.7, 128.5, 126.3, 125.5, 84.3, 82.9, 34.0.

IR (ATR, neat): 3012, 2924, 2886, 1535, 1473, 1384.

HRMS (ESI) *m/z*, calcd for $C_9H_8N_2O_5$–HNO_3: 161.0477; found 161.0475.

ethyl 3-nitro-4-(nitrooxy)-4-phenylbutanoate (35)



Compound **35** was obtained according to general procedure **GP1** from methyl (*E*)-4-phenylbut-3-enoate (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (78% yield).

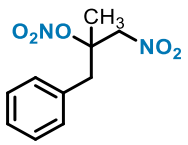
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.44 – 7.30 (m, 5H), 5.57 (t, *J* = 3.7 Hz, 1H), 5.07 (dt, *J* = 10.4, 3.2 Hz, 1H), 3.64 (s, 3H), 3.31 (dd, *J* = 17.8, 10.4 Hz, 1H), 2.66 – 2.54 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 170.6, 138.2, 129.1, 129.0, 125.8, 88.0, 74.0, 52.5, 30.7.

IR (ATR, neat): 3004, 2996, 1702, 1648, 1552, 1387, 1295.

HRMS (ESI) *m/z*, calcd for $C_{11}H_{12}N_2O_7$–HNO_3: 221.0688; found 221.0685.

2-methyl-1-nitro-3-phenylpropan-2-yl nitrate (36)



Compound **35** was obtained according to general procedure **GP1** from (2-methylallyl)benzene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (71% yield).

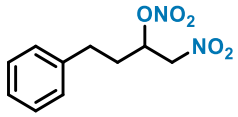
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.37 (d, *J* = 7.6 Hz, 3H), 7.25 (dd, *J* = 7.4, 2.1 Hz, 2H), 4.98 (d, *J* = 12.0 Hz, 1H), 4.86 (d, *J* = 12.0 Hz, 1H), 3.31 (d, *J* = 14.2 Hz, 1H), 3.19 (d, *J* = 14.2 Hz, 1H), 1.59 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 133.00, 130.75, 128.99, 128.07, 87.51, 78.42, 41.79, 21.00.

IR (ATR, neat): 3065, 2930, 1656, 1634, 1497, 1456, 1435, 1385, 1263, 1180.

HRMS (ESI) *m/z*, calcd for $C_{10}H_{12}N_2O_5$–HNO_3: 177.0790; found 177.0787.

1-nitro-4-phenylbutan-2-yl nitrate (37)



Compound **36** was obtained according to general procedure **GP1** from but-3-en-1-ylbenzene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (57% yield).

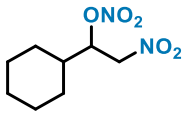
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.39 – 7.26 (m, 3H), 7.23 – 7.16 (m, 2H), 5.72 – 5.58 (m, 1H), 4.64 – 4.53 (m, 2H), 2.82 (dt, *J* = 8.6, 6.7 Hz, 2H), 2.21 – 2.08 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.2, 129.0, 128.3, 127.0, 77.8, 75.6, 32.1, 31.0.

IR (ATR, neat): 3009, 2996, 1653, 1569, 1536, 1291.

HRMS (ESI) *m/z*, $[M+H]^+$ calcd for $C_{10}H_{12}N_2O_5$–HNO_3: 177.0790; found 177.0788.

1-cyclohexyl-2-nitroethyl nitrate (38)



Compound **37** was obtained according to general procedure **GP1** from but-3-en-1-ylbenzene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (57% yield).

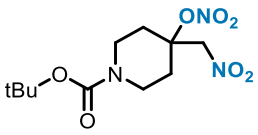
^{1}H-NMR (300 MHz, $CDCl_3$): δ 5.32 – 5.12 (m, 1H), 5.06 (ddd, *J* = 10.5, 5.8, 2.0 Hz, 1H), 4.61 (dd, *J* = 15.5, 2.0 Hz, 1H), 2.03 (ddt, *J* = 11.8, 5.8, 2.9 Hz, 1H), 1.89 – 1.77 (m, 2H), 1.77 – 1.65 (m, 3H), 1.33 – 1.04 (m, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 87.6, 72.8, 40.2, 29.3, 28.9, 25.8, 25.8, 25.6.

IR (ATR, neat): 2934, 1634, 1464, 1376, 1273, 1183, 1152, 1036.

HRMS (ESI) *m/z*, $[M+H]^+$ calcd for $C_8H_{14}N_2O_5$–HNO_3: 155.0946; found 155.0943.

tert-butyl 4-(nitromethyl)-4-(nitrooxy)piperidine-1-carboxylate (39)



Compound **38** was obtained according to general procedure **GP2** from *tert*-butyl 4-methylenepiperidine-1-carboxylate (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (53% yield).

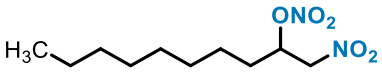
^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.93 (br s, 2H), 3.95 (d, *J* = 11.7 Hz, 2H), 3.16 (t, *J* = 12.8 Hz, 2H), 2.27 (d, *J* = 14.5 Hz, 2H), 1.82 (ddd, *J* = 14.6, 11.5, 4.7 Hz, 2H), 1.46 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 154.4, 84.7, 80.7, 78.7, 31.6, 29.8, 28.5.

IR (ATR, neat): 2896, 1706, 1643, 1552, 1376, 1265.

HRMS (ESI) *m/z*, $[M+H]^+$ calcd for $C_{11}H_{19}N_3O_7$–HNO_3: 242.1267; found 242.1266.

1-nitrodecan-2-yl nitrate (40)



Compound **39** was obtained according to general procedure **GP1** from dec-1-ene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (79% yield).

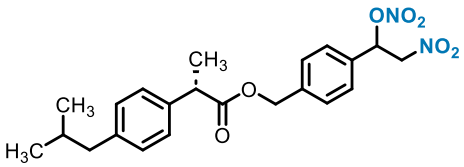
^{1}H-NMR (300 MHz, $CDCl_3$): δ 5.31 – 5.07 (m, 2H), 4.64 – 4.51 (m, 1H), 2.09 – 1.80 (m, 2H), 1.42 – 1.20 (m, 12H), 0.92 – 0.83 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 82.7, 74.1, 31.8, 31.3, 29.2, 29.1, 28.9, 25.4, 22.7, 14.2.

IR (ATR, neat): 2842, 2874, 1548, 1456, 1378, 1237.

HRMS (ESI) *m/z*, $[M+H]^+$ calcd for $C_{10}H_{20}N_2O_5$–HNO_3: 185.1416; found 185.1414.

4-(2-nitro-1-(nitrooxy)ethyl)benzyl (2S)-2-(4-isobutylphenyl)propanoate (41)



Compound **40** was obtained according to general procedure **GP2** from (*S*)-Ibuprofen (0.5 mmol, 1.0 equiv). Isolated as a yellow solid (77% yield).

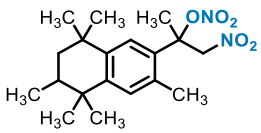
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.37 (d, *J* = 8.3 Hz, 2H), 7.30 (d, *J* = 8.3 Hz, 2H), 7.23 (d, *J* = 8.2 Hz, 2H), 7.13 (d, *J* = 8.1 Hz, 2H), 6.58 (dd, *J* = 10.0, 3.6 Hz, 1H), 5.18 – 5.10 (m, 2H), 4.83 (dd, *J* = 14.6, 10.1 Hz, 1H), 4.60 (dd, *J* = 14.6, 3.6 Hz, 1H), 3.80 (q, *J* = 7.1 Hz, 1H), 2.50 (d, *J* = 7.2 Hz, 2H), 1.89 (dt, *J* = 13.5, 6.7 Hz, 1H), 1.55 (d, *J* = 7.2 Hz, 3H), 0.94 (d, *J* = 6.6 Hz, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 174.5, 140.9, 138.9, 137.5, 132.2, 129.5, 128.6, 127.3, 127.0, 79.4, 75.5, 65.40, 45.2, 45.1, 30.3, 22.5, 18.4.

IR (ATR, neat): 3011, 2996, 2964, 1714, 1555, 1254.

HRMS (ESI) *m/z*, calcd for $C_{22}H_{26}N_2O_7$–HNO_3: 367.1784; found 367.1782.

2-(3,5,5,6,8,8-hexamethyl-5,6,7,8-tetrahydronaphthalen-2-yl)-1-nitropropan-2-yl nitrate (42)



Compound **41** was obtained according to general procedure **GP2** from 1,1,2,4,4,7-hexamethyl-6-(prop-1-en-2-yl)-1,2,3,4-tetrahydronaphthalene (0.5 mmol, 1.0 equiv). Isolated as a colorless liquid (84% yield).

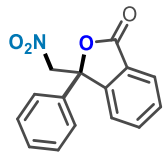
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.33 (d, *J* = 3.0 Hz, 1H), 7.12 (s, 1H), 5.00 (dd, *J* = 12.6, 1.5 Hz, 1H), 4.66 (dd, *J* = 12.6, 1.2 Hz, 1H), 2.52 (s, 3H), 1.85 (dqd, *J* = 13.3, 6.7, 2.5 Hz, 1H), 1.72 (s, 3H), 1.62 (t, *J* = 13.2 Hz, 1H), 1.40 – 1.33 (m, 2H), 1.31 (d, *J* = 0.9 Hz, 3H), 1.27 (d, *J* = 5.4 Hz, 3H), 1.23 (d, *J* = 4.4 Hz, 3H), 1.05 (s, 3H), 0.98 (d, *J* = 6.8 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 146.1, 146.0, 142.7, 142.7, 136.9, 136.9, 132.1, 131.8, 131.8, 123.8, 123.8, 83.9, 83.9, 74.8, 74.7, 43.8, 37.4, 34.6, 34.3, 32.5, 32.4, 32.1, 32.0, 28.5, 28.5, 26.7, 26.7, 25.0, 22.1, 16.9.

IR (ATR, neat): 3002, 2985, 1636, 1526, 1375, 1267, 1036.

HRMS (ESI) *m/z*, $[M+H]^+$ calcd for $C_{19}H_{28}N_2O_5$–HNO_3: 301.2042; found 301.2040.

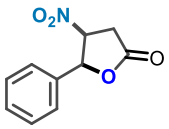
3-(nitromethyl)-3-phenylisobenzofuran-1(3*H*)-one (43)



Compound **43** was obtained according to general procedure **GP2** from 2-(1-phenylvinyl)benzoic acid (0.5 mmol, 1.0 equiv). Isolated as a white solid (77% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.03 – 7.88 (m, 1H), 7.80 – 7.73 (m, 2H), 7.67 – 7.53 (m, 3H), 7.49 – 7.38 (m, 3H), 5.26 (d, *J* = 13.1 Hz, 1H), 5.17 (d, *J* = 13.1 Hz, 1H).

3-(nitromethyl)-3-phenylisobenzofuran-1(3*H*)-one (trans) (44)

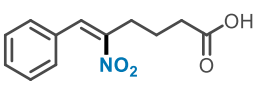


Compound **44** was obtained according to general procedure **GP2** from (*E*)-4-phenylbut-3-enoic acid (0.5 mmol, 1.0 equiv). Isolated as a yellow solid (79% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 (td, *J* = 6.2, 3.3 Hz, 3H), 7.39 – 7.31 (m, 2H), 5.97 (s, 1H), 5.16 (dt, *J* = 8.2, 2.9 Hz, 1H), 3.42 – 3.27 (m, 1H), 3.07 (dd, *J* = 18.8, 8.2 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 171.6, 135.7, 129.8, 129.6, 124.9, 86.6, 82.7, 31.9.

(*Z*)-5-nitro-6-phenylhex-5-enoic acid (45)



Compound **45** was obtained according to general procedure **GP2** from (*E*)-6-phenylhex-5-enoic acid (0.5 mmol, 1.0 equiv). Isolated as a colorless liquid (71% yield).

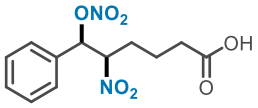
^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.10 (s, 1H), 7.55 – 7.36 (m, 5H), 2.97 – 2.87 (m, 2H), 2.51 (t, *J* = 7.0 Hz, 2H), 2.07 – 1.94 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 179.2, 151.0, 134.7, 132.1, 130.4, 129.9, 129.2, 33.3, 26.7, 22.8.

IR (ATR, neat): 3306, 3005, 2996, 2953, 1674, 1575, 1336, 1274, 1063.

HRMS (ESI) *m/z*, calcd for $C_{12}H_{12}O_4N$: 234.0772; found 234.0770.

5-nitro-6-(nitrooxy)-6-phenylhexanoic acid (46)



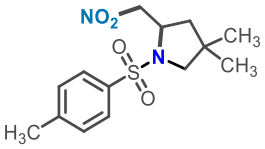
Compound **46** was obtained according to general procedure **GP2** from (*E*)-6-phenylhex-5-enoic acid (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (9% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.50 – 7.36 (m, 6H), 6.19 (d, *J* = 10.2 Hz, 1H), 4.82 (td, *J* = 10.4, 3.3 Hz, 1H), 2.27 (td, *J* = 7.1, 4.3 Hz, 2H), 1.95 – 1.83 (m, 1H), 1.58 (dq, *J* = 9.4, 6.7 Hz, 2H), 1.48 – 1.39 (m, 1H).

IR (ATR, neat): 3302, 3014, 2983, 1663, 1574, 1347, 1297.

HRMS (ESI) *m/z*, calcd for $C_{12}H_{13}O_7N2$: 297.0728; found 297.0730.

4,4-dimethyl-2-(nitromethyl)-1-tosylpyrrolidine (47)



Compound **45** was obtained according to general procedure **GP2** from *N*-(2,2-dimethylpent-4-en-1-yl)-4-methylbenzenesulfonamide (0.5 mmol, 1.0 equiv). Isolated as a colorless liquid (68% yield).

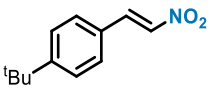
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.75 (d, *J* = 8.3 Hz, 2H), 7.41 – 7.30 (m, 2H), 5.18 (dd, *J* = 12.8, 4.2 Hz, 1H), 4.48 (dd, *J* = 12.8, 8.9 Hz, 1H), 4.15 (dtd, *J* = 8.9, 7.7, 4.2 Hz, 1H), 3.21 (d, *J* = 10.5 Hz, 1H), 3.05 (dd, *J* = 10.5, 1.3 Hz, 1H), 2.44 (s, 3H), 1.85 (ddd, *J* = 12.9, 7.5, 1.2 Hz, 1H), 1.70 – 1.62 (m, 1H), 1.06 (s, 3H), 0.51 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 144.4, 133.5, 130.1, 127.9, 79.8, 61.6, 56.8, 44.7, 37.7, 26.3, 25.6, 21.7.

IR (ATR, neat): 3002, 2994, 2875, 1624, 1567, 1297, 1092.

HRMS (ESI) *m/z*, calcd for $C_{14}H_{20}N_2O_4S$: 312.1144; found 312.1142.

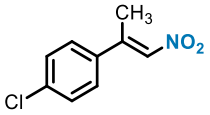
(*E*)-1-(tert-butyl)-4-(2-nitrovinyl)benzene (48)



Compound **42** was obtained according to general procedure **GP3** from 1-chloro-4-(prop-1-en-2-yl)benzene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (85% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.00 (d, *J* = 13.7 Hz, 1H), 7.58 (d, *J* = 13.7 Hz, 1H), 7.48 (d, *J* = 1.5 Hz, 4H), 1.34 (s, 9H).

(*E*)-1-chloro-4-(1-nitroprop-1-en-2-yl)benzene (49)

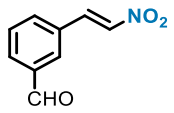


Compound **43** was obtained according to general procedure **GP3** from 1-chloro-4-(prop-1-en-2-yl)benzene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (74% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.44 – 7.36 (m, 4H), 7.28 (d, *J* = 1.5 Hz, 1H), 2.62 (d, *J* = 1.5 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 148.6, 136.8, 136.8, 136.6, 129.5, 128.3, 18.6.

(*E*)-3-(2-nitrovinyl)benzaldehyde (50)

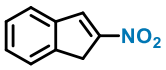


Compound **44** was obtained according to general procedure **GP3** from 3-vinylbenzaldehyde (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (83% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 10.07 (s, 1H), 8.11 – 7.96 (m, 3H), 7.85 – 7.77 (m, 1H), 7.72 – 7.61 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 191.1, 138.6, 137.5, 137.4, 134.5, 133.0, 131.3, 130.4, 129.7.

2-nitro-1*H*-indene (51)

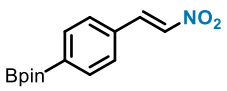


Compound **45** was obtained according to general procedure **GP3** from 1*H*-indene (0.5 mmol, 1.0 equiv). Isolated as a colorless liquid (81% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.92 (td, *J* = 2.0, 0.7 Hz, 1H), 7.65 – 7.59 (m, 1H), 7.55 – 7.38 (m, 4H), 3.99 (d, *J* = 1.9 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 153.5, 141.9, 139.5, 136.4, 130.1, 128.0, 125.4, 124.8, 36.7.

(*E*)-4,4,5,5-tetramethyl-2-(4-(2-nitrovinyl)phenyl)-1,3,2-dioxaborolane (52)

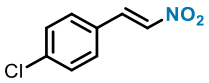


Compound **46** was obtained according to general procedure **GP3** from 4,4,5,5-tetramethyl-2-(4-vinylphenyl)-1,3,2-dioxaborolane (0.5 mmol, 1.0 equiv). Isolated as a colorless liquid (75% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.00 (d, *J* = 13.7 Hz, 1H), 7.87 (d, *J* = 8.2 Hz, 2H), 7.61 (d, *J* = 13.7 Hz, 1H), 7.56 – 7.49 (m, 2H), 1.36 (s, 12H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.0, 137.8, 135.7, 132.6, 128.4, 84.4, 25.0.

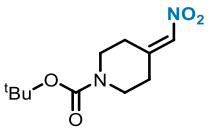
(*E*)-1-chloro-4-(2-nitrovinyl)benzene (53)



Compound **47** was obtained according to general procedure **GP3** from 1-chloro-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (86% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.97 (d, *J* = 13.7 Hz, 1H), 7.56 (d, *J* = 13.7 Hz, 1H), 7.49 (d, *J* = 8.6 Hz, 2H), 7.44 (d, *J* = 8.7 Hz, 2H).

tert-butyl 4-(nitromethylene)piperidine-1-carboxylate (54)



Compound **48** was obtained according to general procedure **GP3** from *tert*-butyl 4-methylenepiperidine-1-carboxylate (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (51% yield).

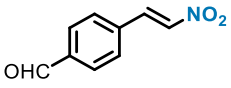
^{1}H-NMR (300 MHz, $CDCl_3$): δ 6.99 (t, *J* = 1.3 Hz, 1H), 3.56 (q, *J* = 5.9 Hz, 4H), 2.99 (t, *J* = 6.2 Hz, 2H), 2.36 – 2.29 (m, 2H), 1.48 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 150.8, 134.1, 80.6, 78.8, 33.0, 29.9, 29.0, 28.5, 28.2.

IR (ATR, neat): 3012, 2973, 1796, 1717, 1655, 1573, 1538, 1353, 1266.

HRMS (ESI) *m/z*, calcd for $C_{11}H_{18}N_2O_4$: 242.1267; found 242.1265.

(*E*)-4-(2-nitrovinyl)benzaldehyde (55)

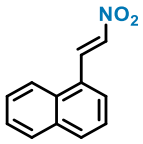


Compound **49** was obtained according to general procedure **GP3** from 4-vinylbenzaldehyde (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (86% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 10.07 (s, 1H), 8.03 (d, *J* = 13.7 Hz, 1H), 7.97 (d, *J* = 8.3 Hz, 2H), 7.72 (d, *J* = 8.3 Hz, 2H), 7.65 (d, *J* = 13.7 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 191.2, 139.3, 138.5, 137.4, 135.7, 130.5, 129.7.

(*E*)-1-(2-nitrovinyl)naphthalene (56)

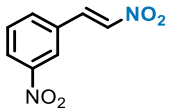


Compound **50** was obtained according to general procedure **GP3** from 1-vinylnaphthalene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (68% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.85 (d, *J* = 13.4 Hz, 1H), 8.18 – 8.12 (m, 1H), 8.01 (d, *J* = 8.2 Hz, 1H), 7.96 – 7.90 (m, 1H), 7.79 – 7.74 (m, 1H), 7.69 – 7.56 (m, 3H), 7.56 – 7.49 (m, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.7, 136.3, 133.9, 132.7, 131.7, 129.2, 127.9, 127.2, 127.0, 126.5, 125.6, 123.1.

(*E*)-1-nitro-3-(2-nitrovinyl)benzene (57)

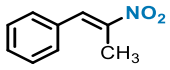


Compound **51** was obtained according to general procedure **GP3** from 1-nitro-3-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (72% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.42 (t, *J* = 2.0 Hz, 1H), 8.38 – 8.32 (m, 1H), 8.06 (d, *J* = 13.7 Hz, 1H), 7.91 – 7.85 (m, 1H), 7.72 – 7.64 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.4, 136.4, 134.6, 131.9, 130.7, 126.3, 123.6.

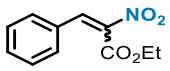
(*E*)-(2-nitroprop-1-en-1-yl)benzene (58)



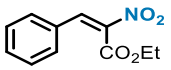
Compound **52** was obtained according to general procedure **GP3** from 1-nitro-3-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (70% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.10 (d, *J* = 1.2 Hz, 1H), 7.47 – 7.41 (m, 5H), 2.46 (d, *J* = 1.1 Hz, 3H).

ethyl-2-nitro-3-phenylacrylate (59)

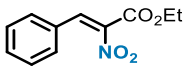


Compound **52** was obtained according to general procedure **GP3** from ethyl cinnamate (0.5 mmol, 1.0 equiv). Isolated as a yellow oil (81% yield).



***E*-59: ^{1}H-NMR** (300 MHz, $CDCl_3$): δ 8.08 (s, 1H), 7.54 – 7.41 (m, 5H), 4.44 (q, *J* = 7.2 Hz, 2H), 1.35 (t, *J* = 7.2 Hz, 3H).

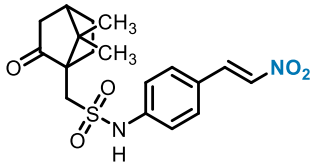
***E*-59: ^{13}C-NMR** (75 MHz, $CDCl_3$): δ 161.3, 136.7, 132.5, 130.6, 129.9, 129.4, 129.1, 63.3, 13.9.



***Z*-59: ^{1}H-NMR** (300 MHz, $CDCl_3$): δ 7.54 (s, 1H), 7.49 – 7.40 (m, 5H), 4.38 (q, *J* = 7.1 Hz, 2H), 1.35 (d, *J* = 7.1 Hz, 3H).

***Z*-59: ^{13}C-NMR** (75 MHz, $CDCl_3$): δ 159.3, 136.7, 133.0, 132.3, 129.9, 129.5, 129.1, 63.2, 14.2.

(*E*)-1-(7,7-dimethyl-2-oxobicyclo[2.2.1]heptan-1-yl)-N-(4-(2-nitrovinyl)phenyl)methanesulfonamide (60)

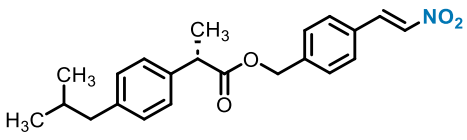


Compound **53** was obtained according to general procedure **GP3** from 1-(7,7-dimethyl-2-oxobicyclo[2.2.1]heptan-1-yl)-*N*-(4-vinylphenyl)methanesulfonamide (0.5 mmol, 1.0 equiv). Isolated as a solid (62% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 10.13 (s, 1H), 8.45 (d, *J* = 2.2 Hz, 1H), 8.20 (d, *J* = 8.8 Hz, 1H), 7.97 (d, *J* = 13.7 Hz, 1H), 7.85 (dd, *J* = 8.9, 2.2 Hz, 1H), 7.61 (d, *J* = 13.7 Hz, 1H), 3.68 (d, *J* = 14.9 Hz, 1H), 3.16 (d, *J* = 14.9 Hz, 1H), 2.47 – 2.26 (m, 2H), 2.18 – 2.04 (m, 2H), 1.93 (d, *J* = 18.6 Hz, 1H), 1.89 – 1.79 (m, 1H), 1.50 (ddd, *J* = 13.1, 9.2, 3.9 Hz, 1H), 1.07 (s, 3H), 0.84 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 215.2, 138.2, 137.6, 136.2, 136.0, 135.5, 127.5, 124.9, 119.9, 60.5, 58.8, 51.2, 48.8, 42.9, 42.6, 27.1, 25.5, 21.2, 19.9, 19.6, 14.3.

(*E*)-4-(2-nitrovinyl)benzyl (S)-2-(4-isobutylphenyl)propanoate (61)



Compound **54** was obtained according to general procedure **GP3** from (*S*)-Ibuprofen (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (59% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.97 (d, *J* = 13.7 Hz, 1H), 7.55 (d, *J* = 13.7 Hz, 1H), 7.46 (d, *J* = 8.2 Hz, 2H), 7.26 (d, *J* = 8.4 Hz, 3H), 7.20 (d, *J* = 8.1 Hz, 2H), 7.10 (d, *J* = 8.2 Hz, 2H), 5.14 (d, *J* = 4.8 Hz,

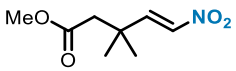
2H), 3.77 (q, *J* = 7.2 Hz, 1H), 2.46 (d, *J* = 7.2 Hz, 2H), 1.85 (dt, *J* = 13.5, 6.6 Hz, 1H), 1.52 (d, *J* = 7.2 Hz, 3H), 0.91 (d, *J* = 6.6 Hz, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 174.5, 140.9, 140.7, 138.6, 137.5, 137.4, 129.8, 129.5, 129.3, 128.4, 127.4, 65.5, 45.3, 45.2, 30.4, 22.5, 18.4.

IR (ATR, neat): 3014, 2927, 1693, 1636, 1557, 1374, 1274.

HRMS (ESI) *m/z*, calcd for $C_{22}H_{25}NO_4$: 367.1784; found 367.1782.

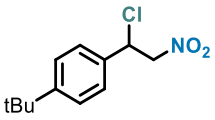
methyl (*E*)-3,3-dimethyl-5-nitropent-4-enoate (62)



Compound **55** was obtained according to general procedure **GP4** from 3,3-dimethylpent-4-enoic acid (0.5 mmol, 1.0 equiv). Isolated as a colorless liquid (61% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.37 (d, *J* = 13.6 Hz, 1H), 6.93 (d, *J* = 13.6 Hz, 1H), 3.66 (s, 3H), 2.45 (s, 2H), 1.25 (s, 7H).

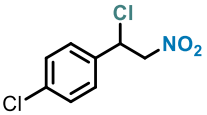
1-(tert-butyl)-4-(1-chloro-2-nitroethyl)benzene (63)



Compound **55** was obtained according to general procedure **GP4** from 1-(tert-butyl)-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a colorless liquid (63% yield).

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.43 (d, *J* = 8.5 Hz, 2H), 7.36 (d, *J* = 8.5 Hz, 2H), 5.56 (dd, *J* = 9.2, 5.4 Hz, 1H), 4.91 (dd, *J* = 13.4, 9.2 Hz, 1H), 4.78 (dd, *J* = 13.4, 5.5 Hz, 1H), 1.33 (s, 9H).

1-chloro-4-(1-chloro-2-nitroethyl)benzene (64)

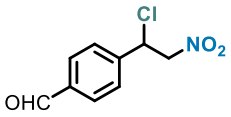


Compound **56** was obtained according to general procedure **GP4** from 1-chloro-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a colorless liquid (58% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.38 (s, 4H), 5.60 – 5.47 (m, 1H), 4.89 (ddd, *J* = 13.5, 8.7, 1.2 Hz, 1H), 4.76 (ddd, *J* = 13.5, 6.1, 1.2 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.0, 134.5, 129.7, 128.7, 80.7, 56.1.

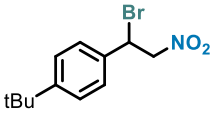
4-(1-chloro-2-nitroethyl)benzaldehyde (65)



Compound **57** was obtained according to general procedure **GP4** from 4-vinylbenzaldehyde (0.5 mmol, 1.0 equiv). Isolated as a colourless liquid (60% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 10.03 (s, 1H), 7.93 (d, *J* = 8.3 Hz, 2H), 7.62 (d, *J* = 8.2 Hz, 2H), 5.61 (dd, *J* = 8.7, 6.0 Hz, 1H), 4.93 (dd, *J* = 13.6, 8.7 Hz, 1H), 4.82 (dd, *J* = 13.6, 6.0 Hz, 1H).

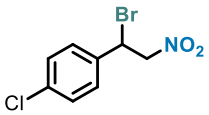
1-(1-bromo-2-nitroethyl)-4-(tert-butyl)benzene (66)



Compound **58** was obtained according to general procedure **GP5** from 1-(tert-butyl)-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (59% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.43 – 7.31 (m, 4H), 5.57 (dd, *J* = 8.2, 7.1 Hz, 1H), 4.99 (qd, *J* = 13.6, 7.7 Hz, 2H), 1.31 (s, 9H).

1-(1-bromo-2-nitroethyl)-4-chlorobenzene (67)

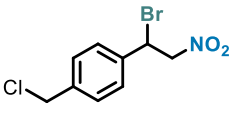


Compound **59** was obtained according to general procedure **GP5** from 1-chloro-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a white solid (55% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.37 (s, 4H), 5.52 (t, *J* = 7.7 Hz, 1H), 5.08 – 4.87 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.9, 135.2, 129.7, 129.0, 80.4, 44.2.

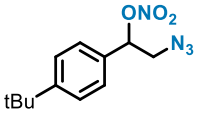
1-(1-bromo-2-nitroethyl)-4-(chloromethyl)benzene (68)



Compound **60** was obtained according to general procedure **GP5** from 1-(chloromethyl)-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (53% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.43 (s, 4H), 5.55 (t, *J* = 7.7 Hz, 1H), 5.10 – 4.88 (m, 2H), 4.57 (s, 2H).

2-azido-1-(4-(tert-butyl)phenyl)ethyl nitrate (69)

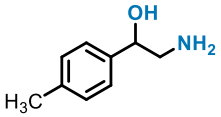


Compound **61** was obtained according to general procedure **GP6** from 1-(tert-butyl)-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a yellow liquid (29% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.35 (d, *J* = 8.4 Hz, 2H), 7.23 (d, *J* = 8.4 Hz, 2H), 5.85 (dd, *J* = 8.7, 4.1 Hz, 1H), 3.66 (dd, *J* = 13.6, 8.7 Hz, 1H), 3.44 (dd, *J* = 13.6, 4.1 Hz, 1H), 1.24 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 153.1, 131.6, 126.5, 126.2, 83.5, 53.5, 31.3.

2-amino-1-(p-tolyl)ethan-1-ol (70)

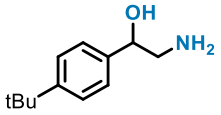


Compound **62** was obtained according to general procedure **GP7** from 1-methyl-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a off-white solid (61% yield).

^{1}H-NMR (300 MHz, MeOH-*d*$_4$): δ 7.30 (d, *J* = 8.1 Hz, 2H), 7.19 (d, *J* = 7.9 Hz, 2H), 5.34 (dd, *J* = 9.6, 3.7 Hz, 1H), 4.72 – 4.51 (m, 2H), 2.33 (s, 3H).

^{13}C-NMR (75 MHz, MeOH-*d*$_4$): δ 139.3, 138.3, 130.3, 127.1, 82.8, 72.0, 21.1.

2-amino-1-(4-(tert-butyl)phenyl)ethan-1-ol (71)



Compound **63** was obtained according to general procedure **GP7** from 1-(tert-butyl)-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a white solid (69% yield).

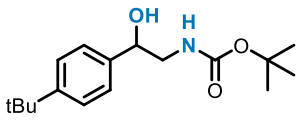
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.37 (d, *J* = 8.4 Hz, 2H), 7.30 (s, 2H), 4.62 (dd, *J* = 7.8, 4.0 Hz, 1H), 3.00 (dd, *J* = 12.8, 4.0 Hz, 1H), 2.83 (dd, *J* = 12.8, 7.8 Hz, 1H), 2.17 (s, 3H), 1.31 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 150.7, 139.6, 125.8, 125.5, 74.3, 49.3, 34.7, 31.5.

IR (ATR, neat): 3363, 3032, 2935, 2873, 1572, 1451, 1204, 1062, 745.

HRMS (ESI) *m/z*, calcd for $C_{12}H_{19}NO$+H: 194.1539; found 194.1536.

tert-butyl (2-(4-(tert-butyl)phenyl)-2-hydroxyethyl)carbamate (72)

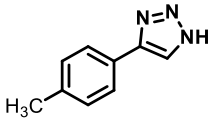


Compound **64** was obtained according to general procedure **GP7** from 1-(tert-butyl)-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a white solid after two steps (43% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.38 (d, *J* = 8.6 Hz, 2H), 7.29 (d, *J* = 8.3 Hz, 2H), 4.97 (s, 1H), 4.79 (dd, *J* = 8.1, 3.6 Hz, 1H), 3.46 (d, *J* = 7.2 Hz, 1H), 3.26 (ddd, *J* = 13.8, 7.9, 4.9 Hz, 1H), 1.44 (s, 9H), 1.31 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 150.9, 138.9, 125.8, 125.6, 79.9, 73.9, 48.3, 34.7, 31.5, 28.5.

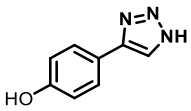
4-(p-tolyl)-1*H*-1,2,3-triazole (73)



Compound **65** was obtained according to general procedure **GP8** from 1-methyl-4-vinylbenzene (0.5 mmol, 1.0 equiv). Isolated as a white solid (79% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.96 (s, 1H), 7.71 (d, *J* = 8.1 Hz, 2H), 7.27 (d, *J* = 7.9 Hz, 3H), 2.40 (s, 3H).

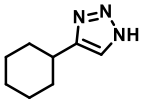
4-(1H-1,2,3-triazol-4-yl)phenol (74)



Compound **66** was obtained according to general procedure **GP8** from 4-vinylphenol (0.5 mmol, 1.0 equiv). Isolated as a yellow solid (86% yield).

^{1}H-NMR (300 MHz, DMSO-d_6): δ 9.61 (s, 1H), 8.13 (s, 1H), 7.65 (d, J = 8.6 Hz, 2H), 6.83 (d, J = 8.6 Hz, 2H).

4-cyclohexyl-1H-1,2,3-triazole (75)



Compound **67** was obtained according to general procedure **GP8** from vinylcyclohexane (0.5 mmol, 1.0 equiv). Isolated as a colorless liquid (63% yield).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.10 (s, 1H), 4.27 (dd, *J* = 5.7, 2.2 Hz, 1H), 1.73 (p, *J* = 6.0 Hz, 1H), 1.51 – 1.24 (m, 6H), 0.99 – 0.87 (m, 3H)

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Chapter 8:

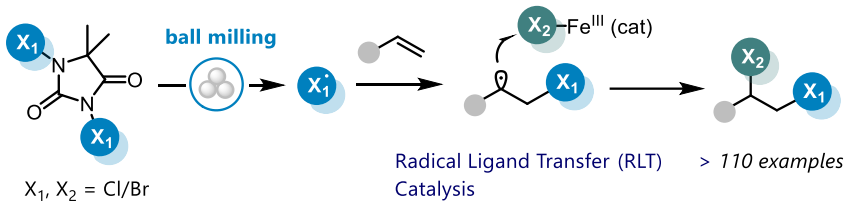
Merging Iron-Mediated Radical Ligand Transfer (RLT) Catalysis and Mechanochemistry for Facile Dihalogenation of Alkenes

This Chapter is adapted from the following publication in peer reviewed journal:

S. Patra, V. Valsamidou, B. N. Nandasana, D. Katayev, "Merging Iron-Mediated Radical Ligand Transfer (RLT) Catalysis and Mechanochemistry for Facile Dihalogenation of Alkenes", *ACS Catal*. **2024**, *14*, 13747–13758. DOI:org/10.1021/acscatal.4c03660.

1. Abstract

With the growing emphasis on cost- and atom-economic chemical synthesis, mechanochemistry has attracted considerable attention for providing environmentally friendly alternatives to traditional solvent-based organic transformations. Herein, we demonstrate the use of mechanochemistry to facilitate alkene dihalogenation via iron-mediated radical ligand transfer (RLT) catalysis, producing diverse vicinal dichloro, dibromo, and bromochloro molecules. The method is characterized by its simplicity, rapid reaction time, high chemo- and regioselectivity, and broad functional group tolerance, accommodating both activated and unactivated alkenes and alkynes. Mechanistic insights suggest the radical nature of these processes, underscoring the effectiveness of mechanochemically-driven RLT catalysis for the modular functionalization of unsaturated hydrocarbons.



2. Introduction

Vicinal dihalides are common structural motifs in many bioactive natural products, pharmaceuticals, and agrochemicals (Figure 1).[1] Due to the notorious effects of halogens, modulation of various properties such as metab-olitic stability, biological activity, lipophilicity, acidity, and other physicochemical features of a molecule can be achieved, often leading to substantial improvements in pharmacokinetics and pharmacodynamics.[2] Halogens also find relevance in the agrochemical industry to increase molecular potency and environmental stability.[3] Organo-halides are also essential intermediates in molecular architecture, serving as building-block materials for a variety of chemical transformations.[4] Additionally, organohalides are essential in materials sciences, contributing to the development of advanced materials such as polymers and electronic components.[5]

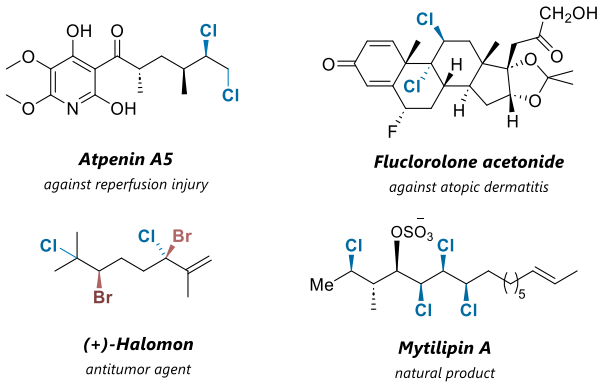


Figure 1. Representative examples of drugs and natural products bearing vicinal dihalide moieties.

Dihalogenation of unsaturated hydrocarbons, particularly alkenes, is a widely used method for incorporating halogen atoms into organic framework. Historically, this process requires the use of hazardous elemental halogens (Cl_2 or Br_2) or halide salts in combination with strong oxidizing agents, often resulting in low atom economy, undesirable side reactions, and limitations in functional group compatibility.[6] Over the past decades, various electrophilic halogenating reagents have been developed to overcome harmful conditions to construct C–X bonds, including $[Py_2I]^+BF_4^-$, $Et_2SX{\bullet}SbCl_5X$ (X = Br or Cl), Palau'chlor, among others.[7] The organic reagents based on heterocyclic structures, e.g. N-halosuccinimides (NXS) and 1,3-dihalo-5,5-dimethylhydantoin (DXDMH), are bench-stable and cost-effective molecules, but they generally exhibit low levels of reactivity and selectivity (Figure 2).[8] To facilitate the release of halogenating reactive species, several strategies have been developed, mostly utilizing N-, P-, S-, and Se-centered Lewis base catalysts or employing Brønsted base catalysis.[9-12] This advancement has led not only to the expansion of the scope of halogenating molecules, but also to asymmetric approaches.[9]

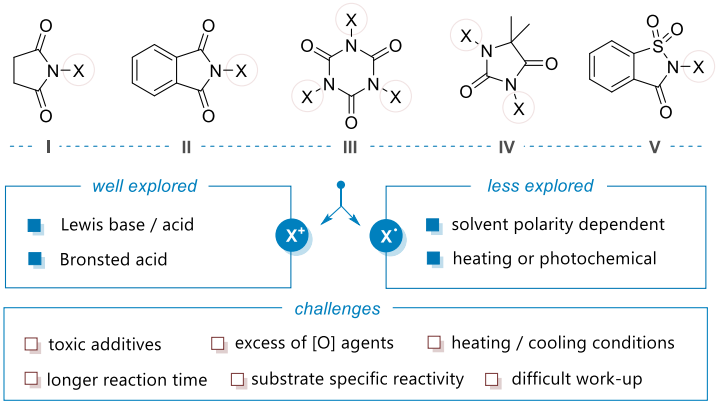


Figure 2. Readily available organic-based halogenating reagents for radical and electrophilic halogenation reactions.

Developing radical-based strategies for vicinal dihalogenation, especially dichlorination, has posed considerable difficulties due to the high oxidation potential of chloride ion to chlorine radical ($E^{ox}_{1/2}$ = 2.03 V vs. SCE), which is also often incompatible with most organic solvents and functional groups (FGs).[13] In recent years, several reports on transition-metal- mediated radical dihalogenation reactions using photochemical and electrochemical strategies, as efficient and sustainable alternatives to conventional chemical approaches for redox transformations, have emerged (Figure 3). For example, Wan and co-workers detailed a photoredox vicinal dichlorination of alkenes, employing visible light-induced ligand-to-metal charge transfer (LMCT) activation approach of $CuCl_2$.[14] This work builds upon Kochi's pioneering studies on the direct photolysis of $CuCl_2$ to access chlorine radicals.[15] Nonetheless, this transformation necessitates the employment of a corrosive and volatile HCl solution as the chloride source, limiting its application to terminal unactivated alkenes. Feng[16] and König[17] groups also employed iron LMCT strategy to accomplish vicinal dichlorination of unactivated alkenes. Shortly after, West et al. combined the LMCT process with a subsequent radical ligand transfer (RLT) approach, utilizing 20 mol% $Fe(NO_3)_3$•$9H_2O$ as a catalyst and NaCl as a reagent for alkene dichlorination.[18] This method achieved reactivity for both activated and unactivated alkenes. However, a universal photocatalytic strategy that accommodates various unsaturated hydrocarbons is scarce. Met-al catalysis in cooperation with electrochemistry was also attempted to demonstrate this reactivity.[19] Elegant studies conducted by the Lin group utilized electricity as the terminal oxidant, allowing nucleophilic reactants to serve as radical precursors.[20]

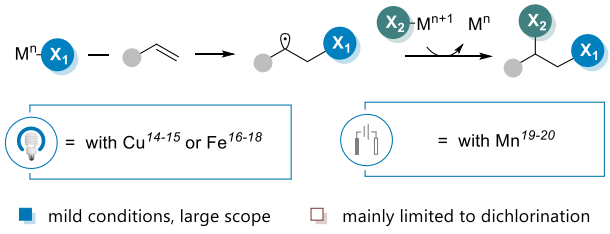


Figure 3. Examples of metal-catalyzed radical dihalogenation of alkenes.

While these advancements are promising, the high cost of electrochemical apparatus and the need for multivariate optimization of factors such as electrode composition, morphology, and mass transport present significant obstacles to establishing this strategy as a general approach for the modular dihalogenation of alkenes. Moreover, the solvent must be separated and collected for disposal as hazardous organic waste, a process that should be minimized, especially in industrial settings. Amidst the growing interest in green chemistry, mechanochemistry has gained increased attention over the past 15 years, even being recognized as one of the top ten emerging sustainable technologies by IUPAC in 2019.[21]

This form of chemistry, driven by impact and friction, eliminates the need for solvents, reduces reaction times, and enhances reagent reactivity through efficient mixing.[22] Mechanochemical processes typically yield a lower environmental footprint compared to solution-based methods, aligning with green chemistry principles.[23] An intriguing observation in mechanochemical reactions is their potential to achieve divergent reactivity compared to liquid-phase reactions, suggesting altered kinetics and thermodynamics unique to milling.[24] This hints at the possibility of accessing unique molecules exclusively through this method. Furthermore, compelling benefits over solution chemistry, including faster reaction time and improved selectivity, have already been demonstrated in several radical transformations.[25]

Careful analysis of halogenation reactions with imide-type reagents revealed a significant impact of solvent system on their efficiency. As such, reagents NXS (X = Cl, Br)[26] and DXDMH (X = Cl, Br)[27] are known for liberating electrophilic bromine under various conditions influenced by solvents and additives, while the formation of X• via homolytic cleavage of N–X bond can be observed mainly under photochemical, heating or in non-polar solvent conditions such as diethyl ether (Figure 1B).[28] On the other hand, mechanochemistry can significantly alter the equilibrium of reactions, often leading to different outcomes.[29] Leveraging the influence of mechanical energy on thermodynamics and kinetics, we sought to exploit these possibilities to alter reaction pathways of imide-type reagents. This approach, involving reactions under neat or non-polar liquid-assisted grinding (LAG) conditions, may uncover a spectrum of reactivity contrasting with those in solution-based or polar LAG environments. Our prior success in ole-fin difunctionalization[30a-e] via mechanochemistry, employing cooperative iron-based radical ligand transfer (RLT) and electron catalysis, showcased the interception of transient alkyl radical intermediates under ball-milling conditions.[30f-g]

We speculated that these imide-type reagents could also be activated under solvent-free, mechanochemical conditions to liberate the corresponding halogen radicals (Cl• or Br•)[31] These species could then undergo radical addition to various alkenes, forming new alkyl radical intermediates. The transient alkyl radicals thus formed could be further captured by a high-valent Fe–Nu species to yield either homodifunctionalization or heterodifunctionalization adducts (Figure 4). Herein, we present the

successful realization of this concept using mechanochemistry that drives alkene dihalogenation via iron-mediated radical ligand transfer catalysis to access various vicinal dichlorinated, dibrominated, and bromochlorinated compounds of diverse complexity. Key advantages of this approach include its simplicity, robustness, fast reaction time, excellent level of chemo- and regioselectivity, unprecedented functional group tolerance, and broad substrate scope of activated and unactivated alkenes and alkynes including complex molecules (>110 examples). Mechanistic studies support the radical nature of this approach, revealing the mechanochemically-driven RLT catalysis as a powerful reaction manifold for catalytic and modular difunctionalization of unsaturated hydrocarbons.

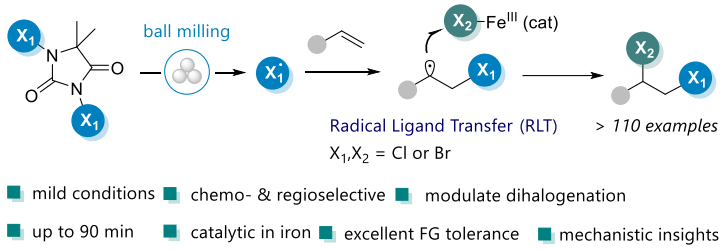


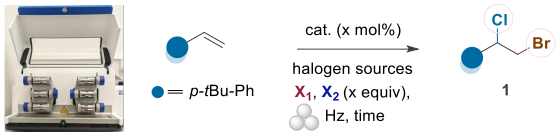
Figure 4. This work: modular dihalogenation of unsaturated hydrocarbons via merger of iron-mediated radical ligand transfer (RLT) catalysis and mechano-chemistry.

3. Results and discussion

3.1. Reaction design and reaction optimization

We first aimed to investigate the potential for challenging vicinal bromochlorination process using styrene derivative as a model substrate under solvent-free mechanochemical conditions. We selected N-bromosuccinimide (NBS) as a prospective source of bromine radicals (Br•), which can be generated under mechanical force using a Retsch MM500 Vario ball milling apparatus furnished with a 5 mL stain-less-steel milling jar and stainless-steel balls (ø = 5 mm). According to our mechanistic hypothesis involving RLT catalysis, various commercially available chloride sources, in conjunction with iron catalysts, were screened to establish the desired reactivity. During the initial optimization experiments for difunction-alization of 4-tert-butylstyrene, we were pleased to observe the formation of the desired product **1** in amounts up to 73% when using NBS (1.0 equiv) as the bromine radical source and LiCl (2.0 equiv) with $FeCl_3 \cdot 6H_2O$ (20 mol%) catalyst as the system for delivering chlorine atom (Table 1, entries 1-3). Notably, at this stage we already observed a great level of regioselectivity with almost no formation of dichloro- and dibromo by-products. Several other readily accessible salts including NaCl, KCl, $CuCl_2$, $BiCl_3$, and organic ammonium chlorides (n-Bu_4NCl, NH_4Cl) were also thoroughly investigated as alternative chloride sources, however LiCl was identified as an optimal reagent in the presence of iron catalyst. The use of inexpensive $FeCl_3 \cdot 6H_2O$ as the chloride ion source was also examined, however, only 65% of 1 was detected (entry 6). When iron catalyst was replaced with other metal halides such as $BiCl_3$, $CoCl_2$ and $MnCl_2$, the product yields significantly dropped to a range of 16-35% (entries 7-9). Next, we carried out detailed screening of imide-type reagents including N-bromophthalimide ([Br]-**II**), dibromoisocyanuric acid ([Br]-**III**) and 1,3-dibromo-5,5-dimethylhydantoin DBDMH ([Br]-**IV**). To our great delight, when 4-tert-butylstyrene was treated with 1.0 equivalent of [Br]-**III**, bromochlorination was obtained in 85% yield. This yield was further improved to excellent 96% when 0.60 equivalents of [Br]-**IV** were employed (entries 10-11). With the newly chosen reagent/catalyst system, we were able to further reduce the loading of LiCl from 2.0 to 1.2 equivalent, which did not affect the product yield. Likewise, the catalyst loading was reduced to 10 mol%, which continued to give unaffected 98% of **1**. Lastly, several ball milling parameters were carefully optimized. The reduction of the milling time to 45 minutes at 25 or 30 Hz lowered the product yield to 73% and 87%, respectively (entries 12-13). A reaction time of 30 min at 25 or 30 Hz and even 15 min at 25 Hz, delivered product **1** in approximately 63% yield. This indicates that the rapid dihalogenation process takes place within the initial minutes of this mechanochemical protocol. To maximize yield during ball milling, the balls must move freely within the jar during vibration to ensure proper mechanical impact. For this reason, the reaction was carried out in the presence of 1, 2, and 4 stainless-steel balls (entries 14-15). Unfortunately, any variations of this parameter diminished the product yield, resulting in 80%, 82%, and 93% of **1**, respectively. This effect occurs likely due to a

suboptimal impact to contact ratio between the reactants and the balls and walls of the steel jar. Reaction was found to proceed smoothly in a PTFE coated jar with PTFE coated balls, suggesting that stainless-steel material is not involved into catalytic transformation (entry 16).



Entry	Variation from standard conditions[a]	1 (%)[b]
1	none	98 (94)[c]
2	[Br]-**I**, NaCl	46
3	[Br]-**I**, KCl	34
4	[Br]-**I**, LiCl	73
5	[Br]-**I**, n-Bu_4NCl	69
6	[Br]-**I**, $FeCl_3 \cdot 6H_2O$ (2.0 equiv)	65
7	[Br]-**I**, $BiCl_3$ instead of $FeCl_3 \cdot 6H_2O$	16
8	[Br]-**I**, $MnCl_2$ instead of $FeCl_3 \cdot 6H_2O$	35
9	[Br]-**I**, $CoCl_2$ instead of $FeCl_3 \cdot 6H_2O$	28
10	[Br]-**II** instead of [Br]-**IV**	81
11	[Br]-**III** instead of [Br]-**IV**	85
12	25 Hz, 45 min	73
13	30 Hz, 45 min	87
14	1 or 2 s.s. balls	80/82
15	4 s.s. balls	93
16	PTFE coated jar and balls	80

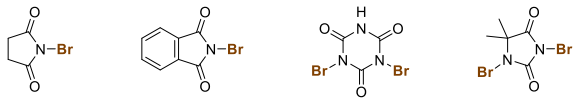


Table 1. [a]Optimal reaction conditions: (entry 1) 4-tert-butylstyrene (0.5 mmol, 1.0 equiv), DBDMH ([Br]-**IV**) (0.60 equiv), LiCl (1.2 equiv), 25 Hz, 3 stainless-steel balls (ø = 5 mm), 5 mL stainless-steel milling jar, 10 mol% of $FeCl_3 \cdot 6H_2O$, 60 min. [b]Yields of **1** are determined by ^{1}H-NMR against mesitylene. [c]Isolated yield is reported after purification on silica gel. s.s. = stainless-steel.

3.2. Investigation of substrate scope

Scope of Bromochlorination

With the optimized reaction conditions in hand, we first performed dihalogenation of a broad range of terminal styrene derivatives (Figure 5). For the bromochlorination reaction, styrene derivatives carrying both electron-donating and electron-withdrawing aryl substituents in o-, m- and p-positions (**1**, **3-11**) were efficiently difunctionalized with good to excellent yields (up to 98%). Potentially labile functionalities, such as halogen atoms (**6-9**, **11**) and easily oxidized aldehyde (**5**) were well tolerated, displaying the robustness and compatibility of this mechanochemical protocol. The 1,2-substitution patterns on the alkene moiety of styrene derivatives **12** and **13** did not impede the reaction despite their electron-withdrawing nature. However, such structural changes significantly influenced the syn/anti ratios of the installed halogen at-oms, with d.r. greater than 19:1 for **12** and d.r. of 3:2 for **13**, with preference for anti-selectivity. Likewise, cyclic *1*H-indene afforded the corresponding adduct **14** with an excellent 91% yield and >19:1 of diastereomeric ratio. Furthermore, we sought to evaluate the reactivity of electron-poor terminal alkenes and were pleased to observe effortless bromochlorination for ester-containing substrates **15** and **16**. Electron-rich terminal alkenes such as vinyl benzoates (**17-18**), alkyl benzoates (**19-21**), and N-vinylphthalimide (**22**) also showcased tolerance under the reaction conditions with good to excellent yields. Notably, an en-yne molecule such as but-3-en-1-yn-1-ylbenzene, when treated with 2 equivalents of reagents, delivered disubstituted product **23** in a two-fold manner with an overall yield of 84%.

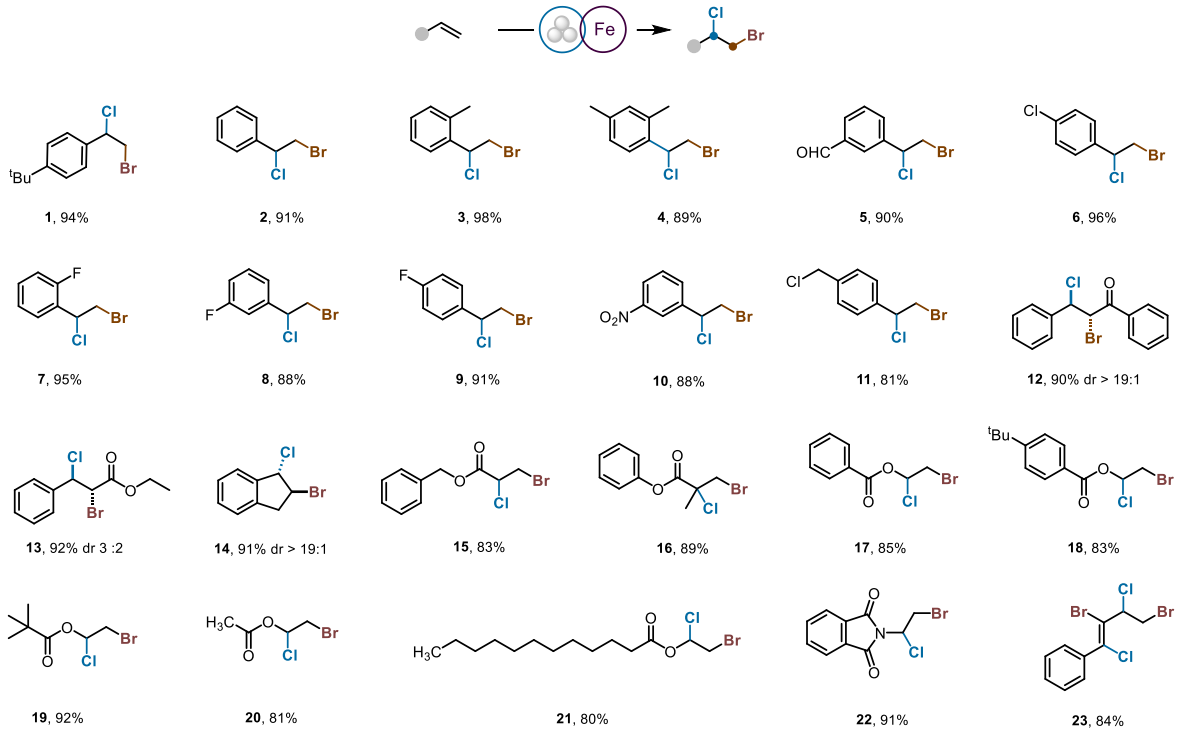


Figure 5. Substrate scope of bromochlorination. Reaction conditions: alkene (0.5 mmol, 1.0 equiv), DBDMH (0.6 equiv), LiCl (1.2 equiv), 25 Hz, 3 stainless-steel balls (5 mm), 10 mol% of $FeCl_3 \cdot 6H_2O$, 60 mins, isolated yields.

Scope of Dichlorination

Similar to the protocol development for the mechano-chemical bromochlorination reaction, we initially conducted extensive optimization, mainly focused on determining the suitable N-heterocyclic reagent and an anionic chloride source. The optimized conditions for dichlorination reaction, based on the use of DCDMH (0.6 equiv), n-Bu_4NCl (1.1 equiv), and 15 mol% of $FeCl_3 \cdot 6H_2O$ for 90 min at 30 Hz, were evaluated across a wide range of olefins with diverse functionalities (Figure 6). Styrene derivatives with activating and deactivating aryl substituents (**24-26**) and 2-vinylnaphthalene (**27**) reacted smoothly, delivering the corresponding 1,2-dichloro adducts in up to 94% isolated yields. Similarly, alkene with α-benzoyl group yielded the desired product **28** in great yield, but with a low diastereomeric ratio of 2:1. In the next step, we explored a broad spectrum of unactivated alkenes. The presence of the β-methyl group with the ester did not hinder the formation of the tertiary carbon center, yielding **29** in 79%. We were pleased to see that alkenes with electron-rich aromatic rings were also converted to the corresponding vicinal disubstituted products in excellent yields (**30** and **31**) without observing any aryl chlorination. Great synthetic flexibility was showcased with aliphatic mono-substituted alkenes holding aryl, ester, chloride, and bromide moieties, enabling synthesis of the corresponding adducts **32-38** in reasonable isolated yields. Various vinyl esters derived from alkyl or aromatic carboxylic acids underwent 1,2-dichlorination with a high level of chemical efficiency (**39-42**). Unprotected amide-tethered alkene was also tested under established reaction conditions, leading to exclusive dichlorinated product **43**. Cyclohexyl-containing internal alkenes produced the corresponding adducts **44-45** with a notable yield of 94% and high diastereomeric ratio. The sulfoxide **46** and protected imide **47** were likewise well tolerated. Lastly, an internal alkyne was successfully di-functionalized, resulting in compound **48** with an excellent yield of 95%, a Z/E ratio greater than 20:1, and without undergoing polychlorination.

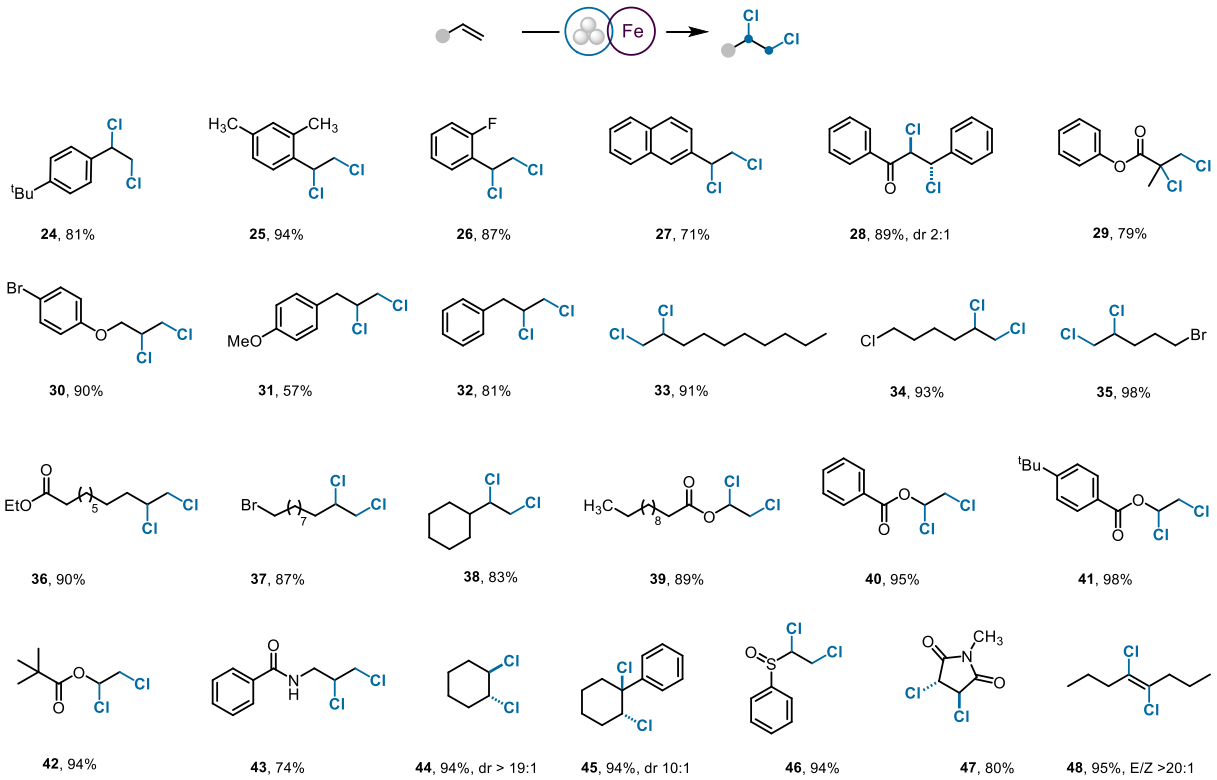


Figure 6. Olefin dichlorination scope. Reaction conditions: alkene (0.5 mmol, 1.0 equiv), DCDMH (0.6 equiv), n-Bu_4NCl (1.1 equiv), 30 Hz, 3 stainless-steel balls (5 mm), 15 mol% of $FeCl_3 \cdot 6H_2O$, 90 mins, isolated yields.

Scope of Dibromination

Motivated by the fascinating results of the first two scope explorations, particularly the unprecedented functional group tolerance, we next proceeded to optimize the reaction conditions for establishing a mechanochemical 1,2-dibromination process. The optimal result was achieved using DBDMH and LiBr as two distinct bromide sources, with the reaction conduct-ed in the presence of 5 mol% of $Fe(NO_3)_3 \cdot 9H_2O$ catalyst for 90 min at 30 Hz using 4 stainless-steel balls. Reminiscent of the high efficiency of both previous protocols, aryl-substituted styrenes containing both electron-donating or electron-withdrawing functionalities, such as alkyl-, halogen-, nitro-, nitrile and ester-groups at *o*-, *m*- or *p*-positions were functionalized with very good to excellent yields (**49-61**) (Figure 7). 1,2-Disubstituted styrenes with electron-withdrawing or heteroaryl substituents participated smoothly in the difunctionalization reaction, yielding products **61-63** in up to 92% and excellent diastereomeric ratio. Michael acceptors with methyl ketone, ester group and substituted amides all readily underwent dichlorination (**64-70**). It is noteworthy that electron-rich alkenes with ester, amide, or benzyloxy functional groups (**71-73**) were also well tolerated. We then turned our attention to unactivated alkenes. Allylbenzenes underwent efficient dichlorination (**74** and **75**), just as terminal alkenes with longer alkyl linear chains (**76**–**79**). Using 2.0 equivalents of reagents enabled the concurrent substitution of two olefin fragments of 1,5-hexadiene, yielding **77** with high chemical efficiency. Disubstituted internal (E)-1,4-dibromobut-2-ene and various trisubstituted terminal alkenes produced vicinal dibromination adducts with good output, regardless of their steric and electronic nature, resulting in tertiary bromide hydrocarbons (**80-83**). Gratifyingly, both terminal and internal alkyne derivatives were well tolerated (**84-89**). We were delighted to find the successful dibromination of an allene moiety of phenylallene to access synthetically challenging molecule **90**. Internal alkenes enclosed in 5-, 6-, and 7-membered rings provided the corresponding adducts **91-93** with excellent yields and diastereomeric ratios. Silane and sulfonyl groups were also compatible under the ball-milling protocol. Allyltriisopropylsilane delivered 94% in 91% isolated yield, while (vinylsulfonyl)benzene generated ((1,2-dibromoethyl)sulfonyl)benzene (**95**) in 78%. However, due to the electron-withdrawing properties of the sulfonyl group, difunctionalized product decomposed to ((1-bromovinyl)sulfonyl)benzene slowly during the purification on silica gel.

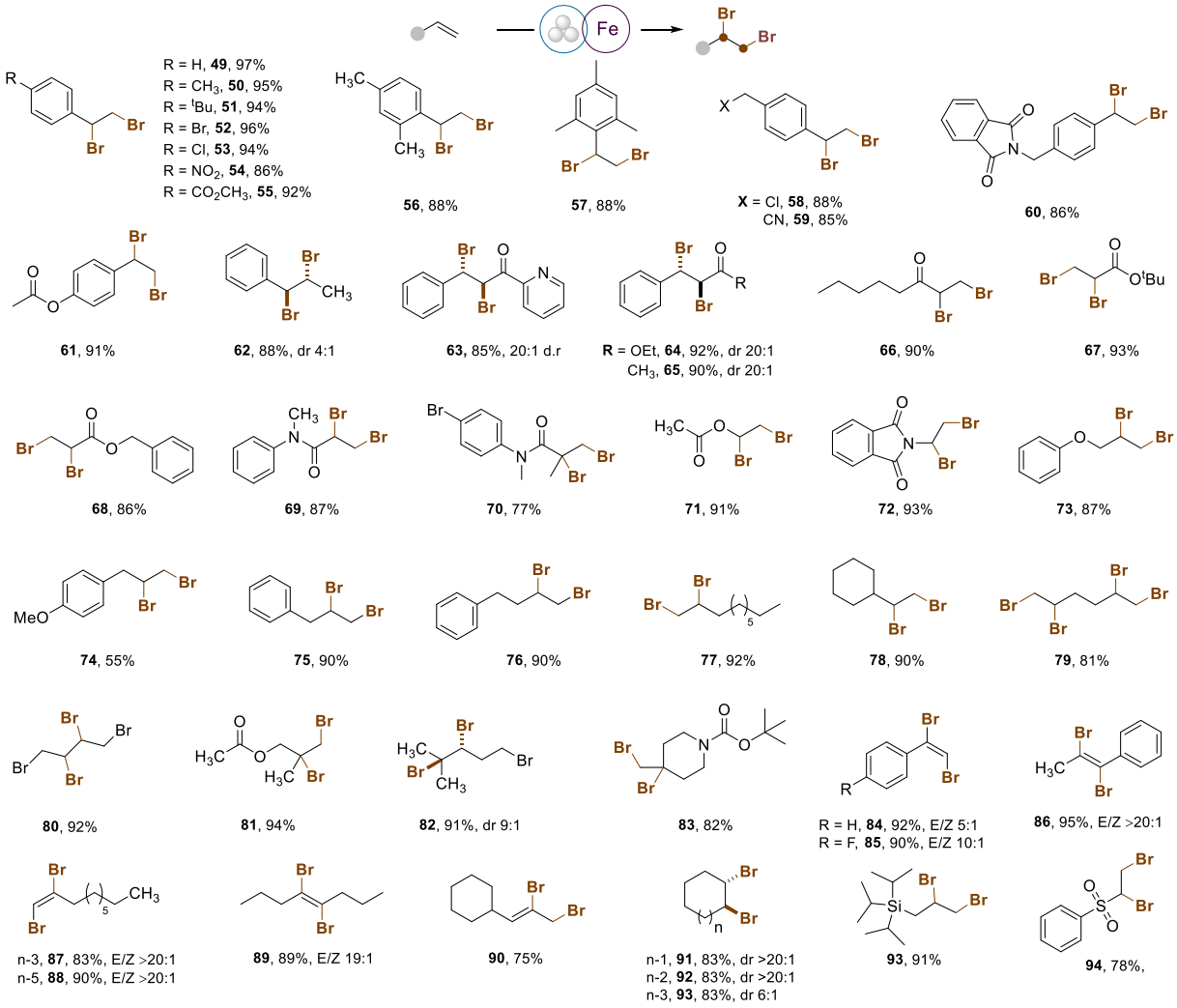


Figure 7. Substrate scope of dibromination. Reaction conditions: alkene (0.5 mmol, 1.0 equiv), DBDMH (0.6 equiv), LiBr (1.2 equiv), 30 Hz, 4 stainless-steel balls (5 mm), 5 mL jar, 5 mol% of $Fe(NO_3)_3 \cdot 9H_2O$, 90 mins, isolated yields.

Scope of Mechanochemical Dihalogenation of Complex Molecules

With valuable results in hand and considering the im-portance of halogenated pharmaceutical molecules and the vast amount of over 4700 halogenated natural products - approximately half of them containing C(sp^3)-halogen bonds[32] - we were interested in the exploration of synthetically challenging targets via late-stage dihalogenation of complex molecules bearing unsaturated patterns. Consequently, we applied our difunctionalization protocols on several natural products and pharmaceutical com-pounds and were delighted to see an efficient and highly chemoselective 1,2-dihalogenation (Figure 8). Despite their deactivated nature, D-Carvone, Geranyl acetate and Limonene derivatives could be selectively dibrominated in a one-fold or two-fold-fashion, by adjusting the reaction conditions to either one or two equivalents of reagent (**96-100**). In all cases the terminal alkene was preferentially functionalized. This methodology was equally successful for the derivatives of Lithocholic acid (**101**), 10-Camphorsulfonyl (**102**) Oleic ester (**103**), and Gemfibrozil (**104**).

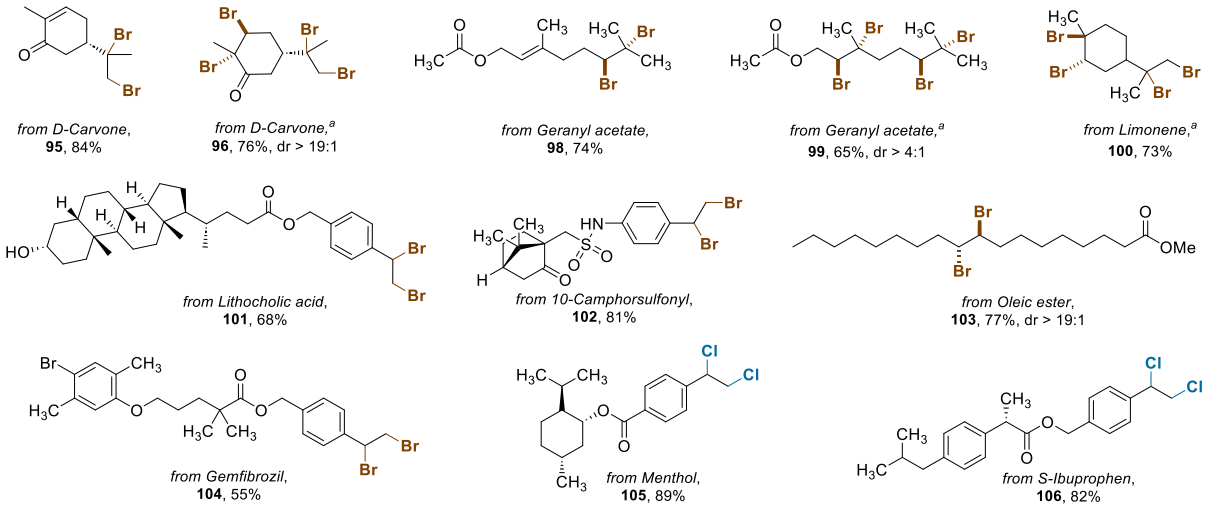


Figure 8. Functionalization of complex molecules. [a]2 equiv of reagents were used.

3.3. Mechanistic insights

Our mechanistic hypothesis is illustrated in Figure 9 and is supported by a series of conducted control experiments. The reaction is initiated by the activation of an imide-type reagent under solvent-free conditions through mechano-chemical impact, which liberates the corresponding halo-gen radicals (X_1 = Cl• or Br•) via homolytic cleavage of N–X_1 bond. Upon addition of X_1• to an olefin, the corresponding transient alkyl radical intermediate is formed. The latter intermediate is highly reactive and often leads to the formation of by-products through pathways that are inherent to radical species, such as dimerization, polymerization. Herein, we hypothesize that a high level of selectivity in the formation of a second carbon-halogen bond can be achieved via a radical ligand transfer (RLT) event with an [Fe^{III}–X_2] intermediate generated in situ in the presence of stoichiometric amounts of halogen nucleophile. Subsequent oxidation of Fe^{II} to Fe^{III} by the aerobic oxygen would regenerate the catalyst and close the catalytic cycle.

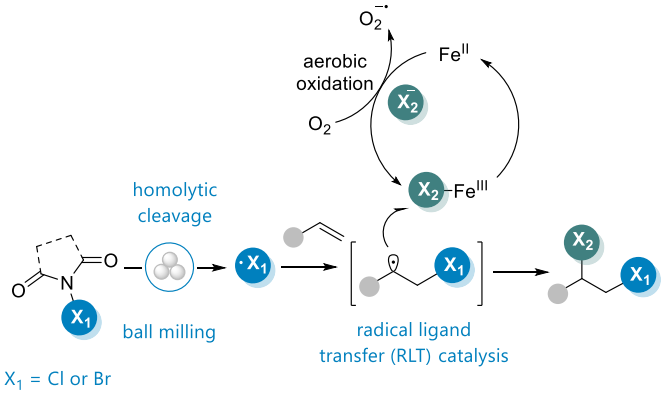


Figure 9. Plausible reaction mechanism for radical dihalogenation.

To confirm the involvement of radical intermediates in this highly efficient difunctionalization system, we conducted control experiments to differentiate between radical and ionic pathways. When adding the radical scavenger 2,2,6,6-tetramethyl-1-piperidinyloxy (TEMPO, 2 equivalents) into the reaction mixture, no formation of the dihalogenated product was found, suggesting the presence of radical intermediates during the course of reaction. Com-petition experiment of radical addition between 4-tert-butylstyrene and more activated 1,1-diphenylethylene resulted in exclusive bromination of the latter alkene (**107**, 85%), while only traces of compound **1** could be found (Figure 10).

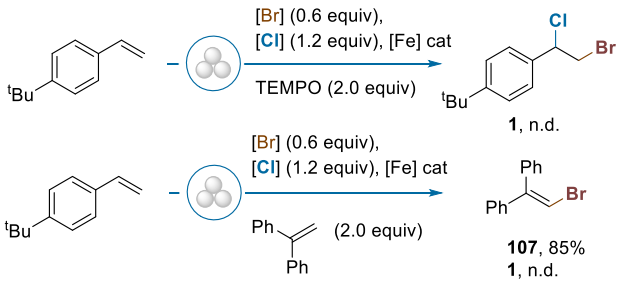


Figure 10. Radical scavenger experiment.

The involvement of a Cl• in the reaction with alkenes and the subsequent formation of carbon-centered radicals under mechanochemical conditions was demonstrated through the chlorination of ((2-phenylallyl)sulfonyl)benzene **108** with DCMDH reagent, yielding product **109** in 17% (Figure 11A). In radical clock experiments, cyclopropyl-substituted alkenes, upon addition of a bromine radical under solvent-free conditions, underwent efficient a ring-opening step, producing products **110** and **111** in 85% and 91% yields, respectively, with high E/Z selectivity (9:1). Similar results were observed with p-substituted aromatics, yielding products **112** and **113**. Using 2 equivalents of reagents, synthetically useful polybrominated products **114-116** were easily generated (Figure 11B). We next sought to compare our mechanochemical conditions with previously reported liquid-phase dihalogenation processes to gain additional knowledge regarding the radical nature of this transformation. When performing the reaction in acetonitrile and dichloromethane, we detected compound **117** in up to 15% along with the expected product **111** (Figure 11B). Notably, the ball-milling protocol prevented the formation of **117**, suggesting a potential shift in the mechanism towards an ionic pathway in the liquid phase.

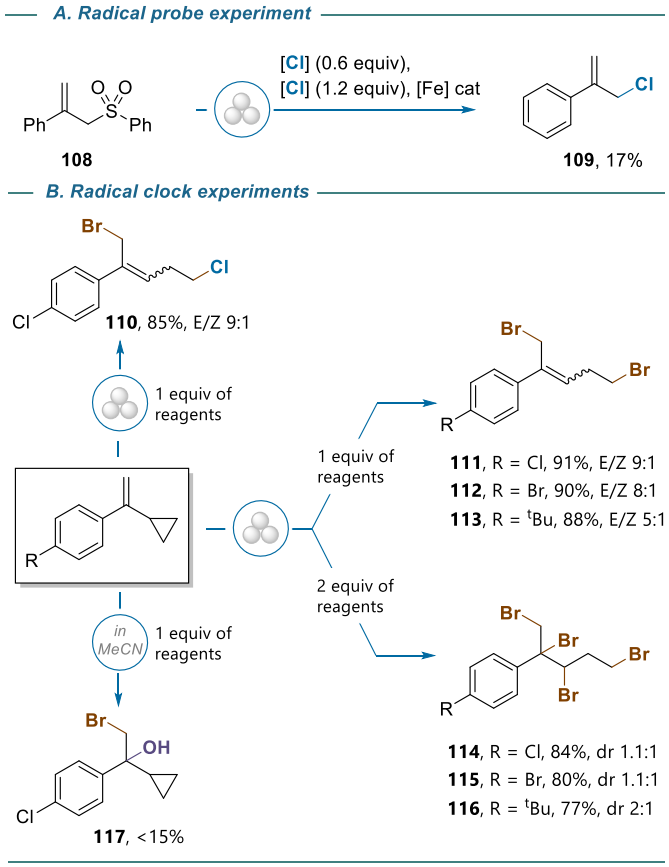
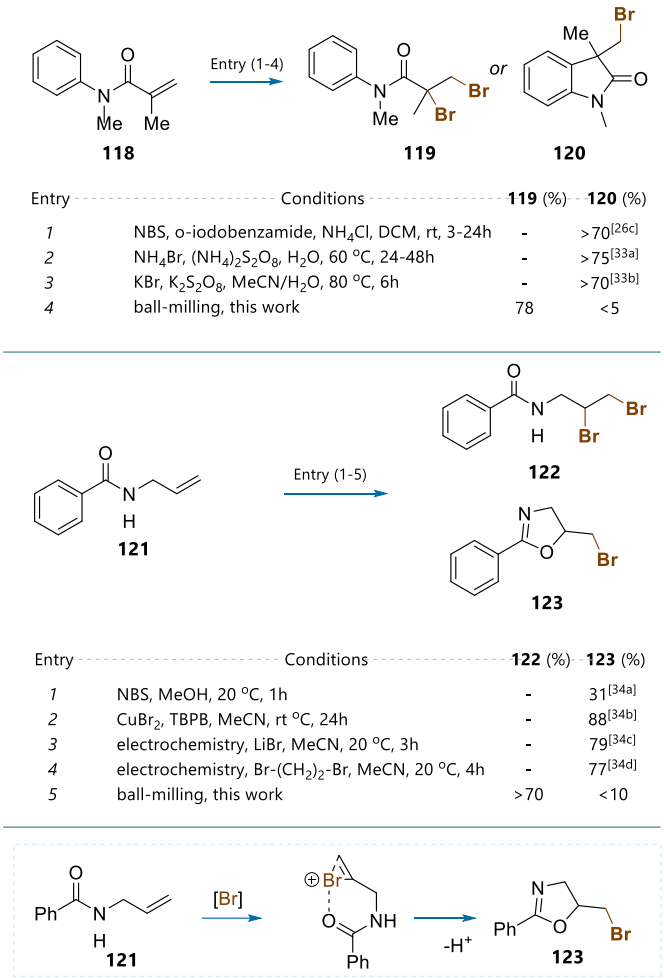


Figure 11. (A) Radical probe experiment. (B) Radical clock experiments under mechanochemical conditions and liquid-phase conditions. Standard reaction conditions for dibromination, dichlorination and bromochlorination reactions were used for all test experiments.

Comparison of previously reported liquid-phase conditions with our ball-milling reaction conditions.

Following our results on the generation and addition of halogen radical species to alkenes, we investigated whether the second halide could be delivered via a radical-polar crossover (RPC) process or through radical ligand transfer (RLT) catalysis mediated by iron. Further investigations using acrylamide **118** revealed that under ball-milling conditions, the dibromination product **119** was isolated in 78% yield, with only traces of **120**. This result suggests a significant radical nature of the process under solvent-free conditions (Figure 12). Literature analysis of the reactivity of this substrate (entries 1-3) under electrophilic halogenation suggests that in contrast **120** is predominantly formed through in situ generation of X_2, leading to the formation of a halonium ion, followed by intramolecular carbocyclization.[26c,33] We also performed dibromination on unprotected amide-tethered alkene **121**. The reaction could yield the cyclized by-product **123** if the alkyl carbon radical is oxidized to a carbocation or via intramolecular nucleophilic cyclization of a bromonium ion intermediate, as shown in Figure 12 (entries 1-4).[34] Notably, under ball milling conditions, 1,2-dibromination product **122** was obtained in over 70% yield, further indicating the involvement of a radical path-way.

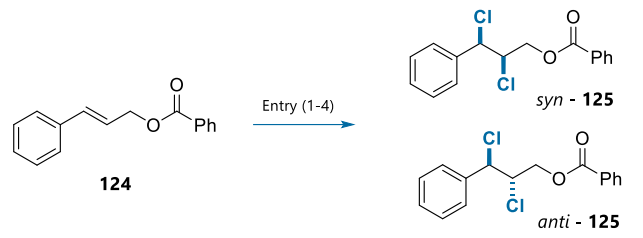


Entry	Conditions	**119** (%)	**120** (%)
1	NBS, o-iodobenzamide, NH_4Cl, DCM, rt, 3-24h	-	>70[26c]
2	NH_4Br, $(NH_4)_2S_2O_8$, H_2O, 60 °C, 24-48h	-	>75[33a]
3	KBr, $K_2S_2O_8$, MeCN/H_2O, 80 °C, 6h	-	>70[33b]
4	ball-milling, this work	78	<5

Entry	Conditions	**122** (%)	**123** (%)
1	NBS, MeOH, 20 °C, 1h	-	31[34a]
2	$CuBr_2$, TBPB, MeCN, rt °C, 24h	-	88[34b]
3	electrochemistry, LiBr, MeCN, 20 °C, 3h	-	79[34c]
4	electrochemistry, Br-$(CH_2)_2$-Br, MeCN, 20 °C, 4h	-	77[34d]
5	ball-milling, this work	>70	<10

Figure 12. Haloheterocyclization vs dihalogenation of alkenes under mechanochemical conditions.. Standard reaction conditions for dibromination, reactions were used for all test experiments.

Testing diastereoselectivity outcome with cinnamyl benzoate (**124**), our mechanochemical protocol produced 1,2-dichloro adduct **125** in the anti-configuration (d.r. = 3:1). This aligns with radical dihalogenation pathways under electrochemical or photochemical conditions and contrasts with Cl_2-mediated reactions, suggesting iron-mediated RLT catalysis (Figure 13).



Entry	Conditions	**125** % (*anti*:*syn*)
1	Cl_2, $CHCl_3$	70 (1:5)[20]
2	electrochemistry, $MnCl_2$, $MgCl_2$, HOAc/MeCN, 40 °C, 2.5h	87 (12:1)[20]
3	photochemistry, $Fe(NO_3)_3$ $9H_2O$, NaCl, Selectfluor, rt, 24h	53 (20:1)[18]
4	ball-milling, this work	85 (3:1)

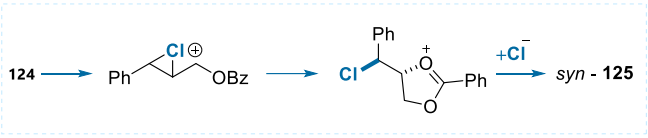


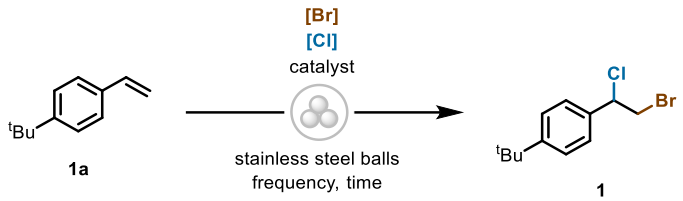
Figure 13. Diastereoselectivity test. TBPB – tert-butyl peroxybenzoate. Standard reaction conditions for dichlorination reactions were used for all test experiments.

4. Conclusion

In summary, we have developed a simple, tunable, sol-vent-free, mechanochemical dihalogenation concept that enables the targeted transformation of a wide variety of alkenes into their corresponding vicinal dibromo, dichloro, or bromochloro products. The system is based on the use of a low-cost, bench-stable and safe halogen sources and readily available iron catalyst. The protocol's mildness and robustness allow it to tolerate a wide range of functional groups, enabling the selective functionalization of unsaturated moieties in complex molecules without compromising their overall structure. A thorough investigation of the mechanism, through various control experiments and mechanistic studies, revealed the radical nature of the process, which is unique to the solvent-free mechanochemical application. Key to these transformations is iron-mediated radical ligand transfer (RLT) catalysis driven by mechanical forces, which enables the flexible introduction of two different halogen atoms across the unsaturated bond. The use of a common, transient alkyl radical inter-mediate in cooperation with RLT catalysis in mechano-chemistry opens up a wealth of opportunities for generating a diverse library of molecules from orthogonal, inexpensive, and safe nucleophiles, all facilitated by one general catalytic platform, which is the current focus of our laboratory research.

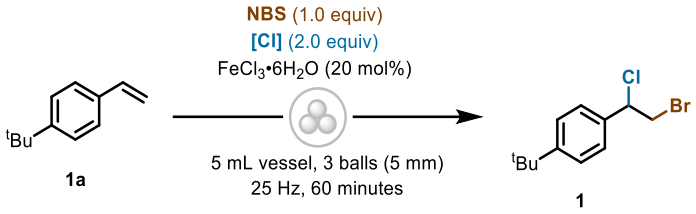
5. Experimental section

5.1. Development of the Reaction Conditions for Bromochlorination



Without any precautions to exclude air or moisture, a Retsch stainless steel vessel (5 mL) equipped with steel balls was charged with a [Br]-source, catalyst, and [Cl]-source followed by 4-*tert*-butylstyrene **1a**. The reaction vessel cap was locked and placed in the mixer mill. After completion of the reaction, the crude product was dissolved in a solvent, a reference (mesitylene as a standard) was added, and the sample was analyzed by ^{1}H-NMR to determine the corresponding yield.

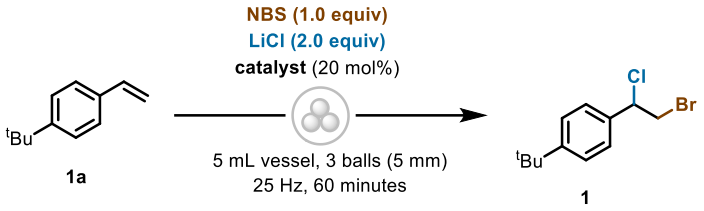
2.1. Optimization of [Cl]-source



Entry[a]	*[Cl]-source (2.0 equiv)*	*Yield (%)*[b]
1	NaCl	46
2	KCl	34
3	**LiCl**	**73**
4	NH_4Cl	30
5	$CuCl_2$	71
6	$BiCl_3$	64
7	$MgCl_2·6H_2O$	47
8	Et_4NCl	61
9	$^{n}Bu_4NCl$	69
10	$FeCl_3·6H_2O$	65

Table 2.1. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), *N*-bromosuccinimide (NBS) (1.0 equiv), *[Cl]-source* (2.0 equiv), 25 Hz, 3 stainless steel balls (5 mm), 20 mol% of $FeCl_3·6H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

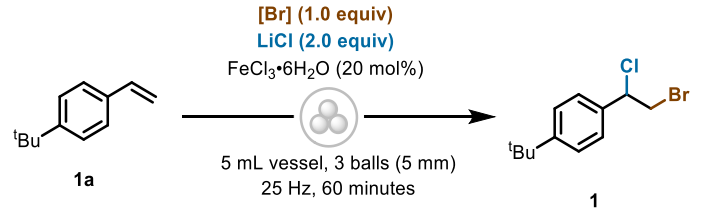
2.2. Optimization of catalyst



Entry[a]	*catalyst (20 mol%)*	*Yield (%)*[b]
1	$BiCl_3$	16
2	$CoCl_2$	28
3	**$FeCl_3 \cdot 6H_2O$**	**73**
4	$MnCl_2$	35

Table 2.2. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), *N*-bromosuccinimide (NBS) (1.0 equiv), LiCl (2.0 equiv), 25 Hz, 3 stainless steel balls (5 mm), 20 mol% of *catalyst*. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

2.3. Optimization of *[Br]*-source



Entry[a]	*[Br]-source (equiv)*	*Yield (%)*[b]
1	*[Br]*-1 (1.0 equiv)	73
2	*[Br]*-2 (1.0 equiv)	63
3	*[Br]*-3 (1.0 equiv)	81
4	***[Br]*-4 (1.0 equiv)**	**85**

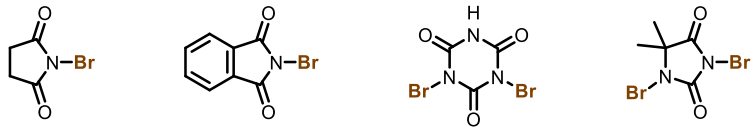
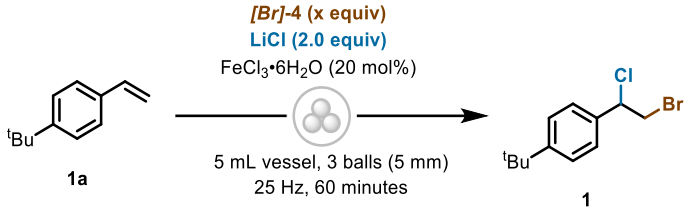


Table 2.3. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), *[Br]-source* (1.0 equiv), LiCl (2.0 equiv), 25 Hz, 3 stainless steel balls (5 mm), 20 mol% of $FeCl_3 \cdot 6H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

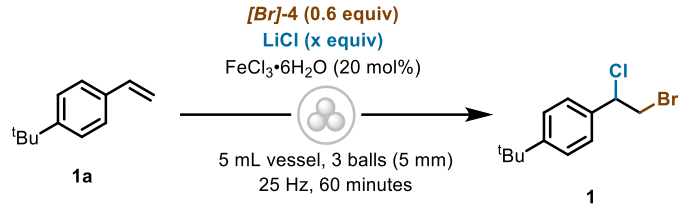
2.4. Optimization of *[Br]*-4 loading



Entry[a]	*[Br]-4 (x equiv)*	*Yield (%)*[b]
1	1.0	85
2	0.5	93
3	**0.6**	**96**
4	0.8	94

Table 2.4. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), *[Br]*-4 (x equiv), LiCl (2.0 equiv), 25 Hz, 3 stainless steel balls (5 mm), 20 mol% of $FeCl_3 \cdot 6H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

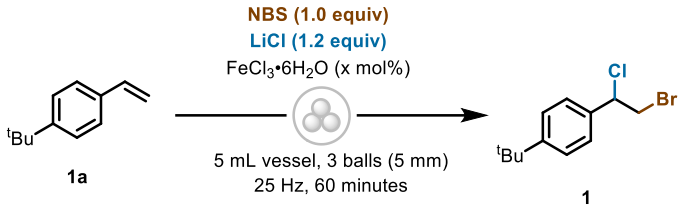
2.5. Optimization of *LiCl* loading



Entry[a]	*LiCl (x equiv)*	*Yield (%)*[b]
1	1	93
2	1.5	95
3	**1.2**	**97**
4	3	94
5	5	93

Table 2.5. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), *[Br]*-4 (0.6 equiv), LiCl (x equiv), 25 Hz, 3 stainless steel balls (5 mm), 20 mol% of $FeCl_3 \cdot 6H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

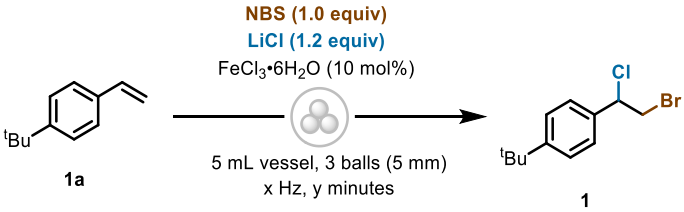
2.6. Optimization of *catalyst* loading



Entry[a]	*$FeCl_3$·6H_2O [x mol%]*	*Yield (%)*[b]
1	**10**	**98**
2	5	97
3	3	96
4	2	97
5	1	96

Table 2.6. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), *[Br]*-4 (0.6 equiv), LiCl (1.2 equiv), 25 Hz, 3 stainless steel balls (5 mm), x mol% of $FeCl_3$·6H_2O as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

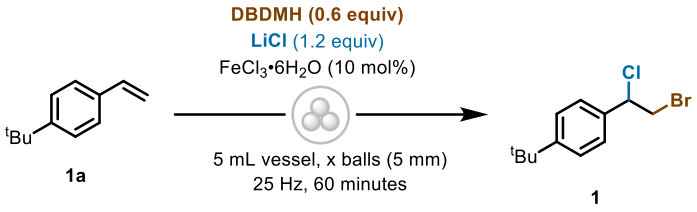
2.7. Optimization of reaction time and frequency



Entry[a]	*Time (mins)*	*Frequency (Hz)*	*Yield (%)*[b]
1	45	25	73
2	30	25	68
3	15	25	63
4	30	30	71
5	45	30	87
6	**60**	**25**	**98**

Table 2.7. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), *[Br]*-4 (0.6 equiv), LiCl (1.2 equiv), x Hz, 3 stainless steel balls (5 mm), 10 mol% of $FeCl_3$·6H_2O as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

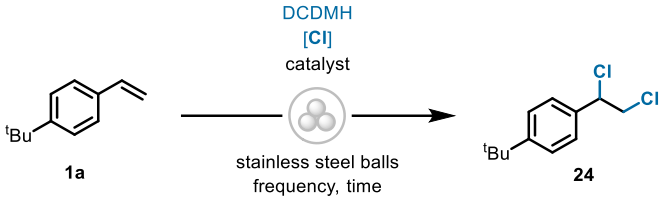
2.8. Impact of the number of stainless-steel balls



Entry[a]	*Ball amount (mm)*	*Yield (%)*[b]
1	1 (5 mm)	80
2	2 (5 mm)	82
3	**3 (5 mm)**	**98 (94)**[c]
4	4 (5 mm)	93

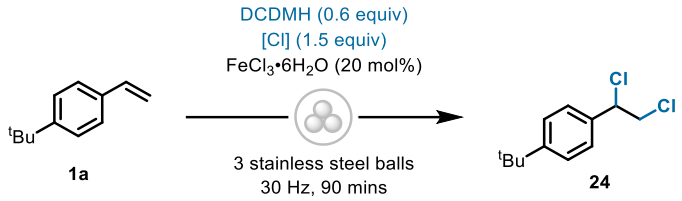
Table 2.8. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), *[Br]*-4 (0.6 equiv), LiCl (1.2 equiv), 25 Hz, x stainless steel balls (5 mm), 10 mol% of $FeCl_3 \cdot 6H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene. **c.** Isolated yield.

3. Development of the Reaction Conditions for Dichlorination



Without any precautions to exclude air or moisture, a Retsch stainless steel vessel (5 mL) equipped with steel balls was charged with a DCDMH, catalyst, and chloride salts followed by an alkene substrate. The reaction vessel cap was locked and placed in the mixer mill. After completion of the reaction, the crude product was dissolved in a solvent, a reference (mesitylene as a standard) was added, and the sample was analyzed by ^{1}H-NMR to determine the corresponding yield.

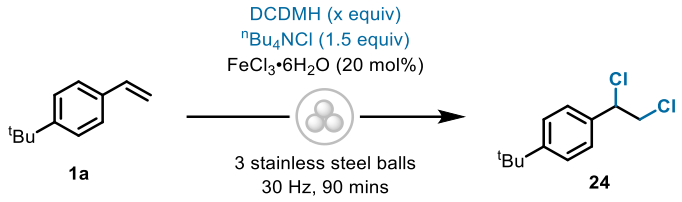
3.1. Optimization of chloride source



Entry[a]	*[Cl] (1.5 equiv)*	*Yield (%)*[b]
1	LiCl	55
2	NH_4Cl	52
3	KCl	54
4	NaCl	43
5	**$^{n}Bu_4NCl$**	**74**

Table 3.1. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dichloro-5,5-dimethylimidazolidine-2,4-dione (DCDMH) (0.6 equiv), [Cl] (1.5 equiv), 25 Hz, 3 stainless steel balls (5 mm), 20 mol% of $FeCl_3 \times 6H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

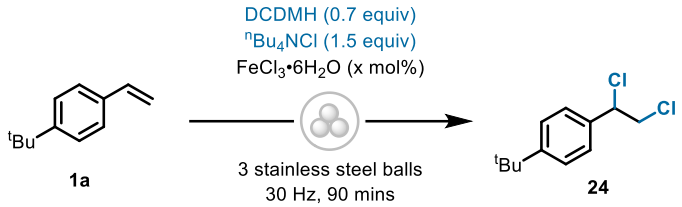
3.2. Optimization of DCDMH loading



Entry[a]	*DCDMH (equiv)*	*Yield (%)*[b]
1	0.6	74
2	**0.7**	**78**
3	0.8	77
4	0.9	75
5	1.0	74

Table 3.2. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dichloro-5,5-dimethylimidazolidine-2,4-dione (DCDMH) (x equiv), $^{n}Bu_4NCl$ (1.5 equiv), 25 Hz, 3 stainless steel balls (5 mm), 20 mol% of $FeCl_3 \times 6H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

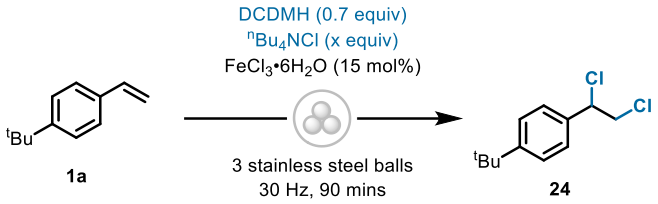
3.3. Optimization of catalyst loading



Entry[a]	*$FeCl_3 \cdot 6H_2O$ (x equiv)*	*Yield (%)*[b]
1	0.05	66
2	0.10	71
3	**0.15**	**79**
4	0.20	78
5	0.30	76

Table 3.3. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dichloro-5,5-dimethylimidazolidine-2,4-dione (DCDMH) (0.7 equiv), $^{n}Bu_4NCl$ (1.5 equiv), 25 Hz, 3 stainless steel balls (5 mm), x mol% of $FeCl_3 \times 6H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

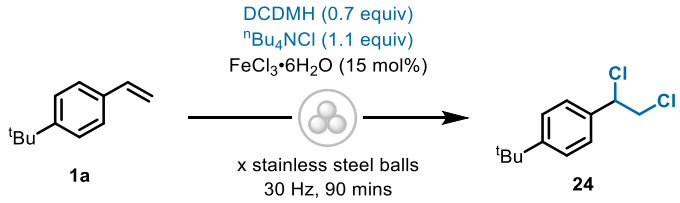
3.4. Optimization of $^{n}Bu_4NCl$ loading



Entry[a]	*$^{n}Bu_4NCl$ (equiv)*	*Yield (%)*[b]
1	0.6	55
2	**1.10**	**81**
3	1.30	79
4	1.80	73
5	2.50	70

Table 3.4. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dichloro-5,5-dimethylimidazolidine-2,4-dione (DCDMH) (0.7 equiv), $^{n}Bu_4NCl$ (x equiv), 30 Hz, 3 stainless steel balls (5 mm), 15 mol% of $FeCl_3 \times 6H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

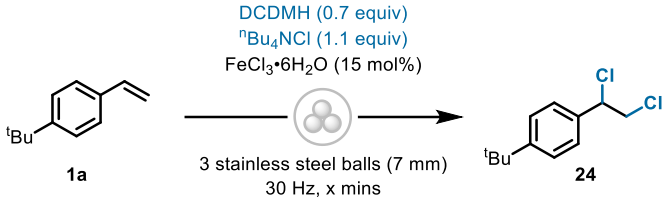
3.5. Impact of the number and size of stainless-steel balls



Entry[a]	*Number of balls (mm)*	*Yield (%)*[b]
1	1 (7 mm)	71
2	2 (7 mm)	78
3	**3** (7 mm)	**85**
4	3 (3 mm)	78
5	3 (5 mm)	71
6	3 (10 mm)	83
7	4 (7 mm)	83

Table 3.5. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dichloro-5,5-dimethylimidazolidine-2,4-dione (DCDMH) (0.7 equiv), $^{n}Bu_4NCl$ (1.1 equiv), 30 Hz, x stainless steel balls (x mm), 15 mol% of $FeCl_3 \times 6H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

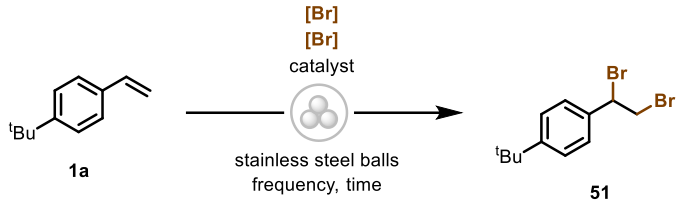
3.6. Optimization of reaction time



Entry[a]	*Time [mins]*	*Yield (%)*[b]
1	30	68
2	40	73
3	50	78
4	60	81
5	**90**	**85 (81)**[c]

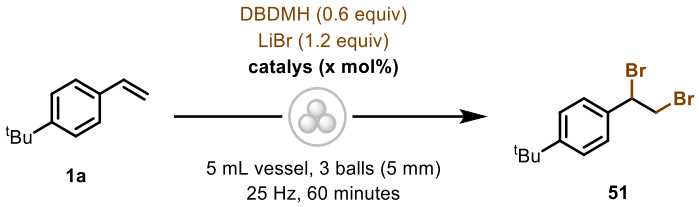
Table 3.6. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dichloro-5,5-dimethylimidazolidine-2,4-dione (DCDMH) (0.7 equiv), $^{n}Bu_4NCl$ (1.1 equiv), 30 Hz, 3 stainless steel balls (7 mm), 15 mol% of $FeCl_3 \times 6H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene. **c.** Isolated yield.

4. Development of the Reaction Conditions for Dibromination



Without any precautions to exclude air or moisture, a Retsch stainless steel vessel (5 mL) equipped with steel balls was charged with a [Br]-source, catalyst, followed by 4-*tert*-butylstyrene **1a**. The reaction vessel cap was locked and placed in the mixer mill. After completion of the reaction, the crude product was dissolved in a solvent, a reference (mesitylene as a standard) was added, and the sample was analyzed by ^{1}H-NMR to determine the corresponding yield.

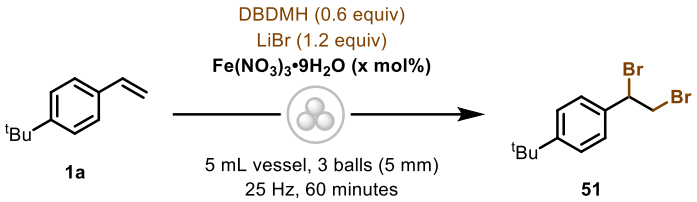
4.1. Optimization of catalyst



Entry[a]	***Catalyst (5 mol%)***	***Yield (%)***[b]
1	$FeCl_3(H_2O)_6$	68
2	$FeBr_3$	72
3	**$Fe(NO_3)_3(H_2O)_9$**	**87**
4	$Fe(OAc)_2$	13
5	$Fe(acac)_3$	37
6	$Fe(OTf)_3$	61
7	$Fe(OTf)_2$	77
8	FeF_3	64

Table 4.1. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dibromo-5,5-dimethylimidazolidine-2,4-dione (DBDMH) (0.6 equiv), LiBr (1.2 equiv), 25 Hz, 3 stainless steel balls (5 mm), catalyst (5 mol%). **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

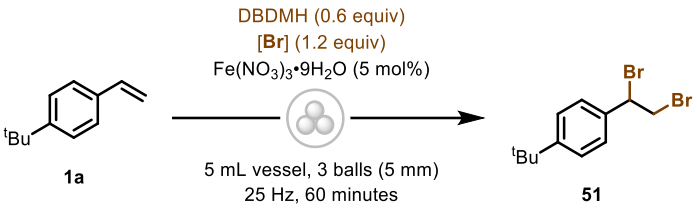
4.2. Optimization of catalyst loading



Entry[a]	*$Fe(NO_3)_3$•$9H_2O$ (x mol%)*	*Yield (%)*[b]
1	-	27
2	2	57
3	**5**	**87**

Table 4.2. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dibromo-5,5-dimethylimidazolidine-2,4-dione (DBDMH) (0.6 equiv), LiBr (1.2 equiv), 25 Hz, 3 stainless steel balls (5 mm), x mol% of $Fe(NO_3)_3 \times 9H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

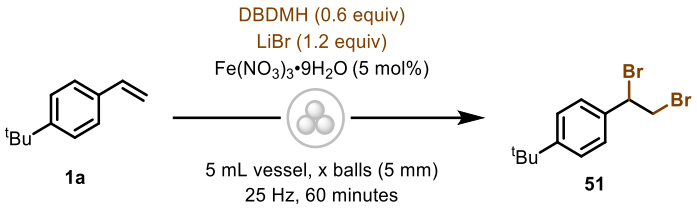
4.3. Optimization of bromide source



Entry[a]	*[Br] (1.2 equiv)*	*Yield (%)*[b]
1	$CaBr_2$	64
2	NaBr	77
3	**LiBr**	**87**
4	KBr	62
5	NH_4Br	80

Table 4.3. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dibromo-5,5-dimethylimidazolidine-2,4-dione (DBDMH) (0.6 equiv), MBr (1.2 equiv), 25 Hz, 3 stainless steel balls (5 mm), 5 mol% of $Fe(NO_3)_3 \times 9H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

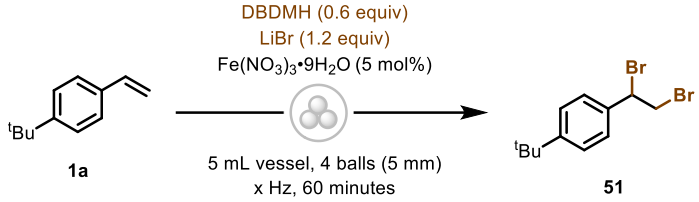
4.4. Impact of the number of stainless-steel balls



Entry[a]	*Number of balls*	*Yield (%)*[b]
1	1	72
2	2	76
3	3	87
4	**4**	**89**

Table 4.4. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dibromo-5,5-dimethylimidazolidine-2,4-dione (DBDMH) (0.6 equiv), LiBr (1.2 equiv), 25 Hz, x stainless steel balls (5 mm), 5 mol% of $Fe(NO_3)_3{\times}9H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

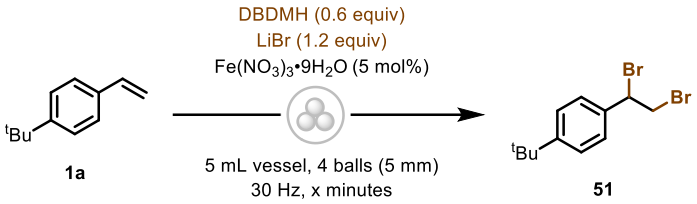
4.5. Optimization of frequency



Entry[a]	*Frequency [Hz]*	*Yield (%)*[b]
1	20	81
2	25	89
3	**30**	**96**
4	35	93

Table 4.5. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dibromo-5,5-dimethylimidazolidine-2,4-dione (DBDMH) (0.6 equiv), LiBr (1.2 equiv), x Hz, 4 stainless steel balls (5 mm), 5 mol% of $Fe(NO_3)_3{\times}9H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene.

4.6. Optimization of reaction time



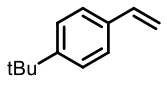
Entry[a]	*Time (mins)*	*Yield (%)*[b]
1	30	90
2	45	91
3	60	94
4	**90**	**98 (94)**[c]

Table 4.6. a. Reaction conditions: 4-*tert*-butylstyrene **1a** (0.5 mmol, 1.0 equiv), 1,3-dibromo-5,5-dimethylimidazolidine-2,4-dione (DBDMH) (0.6 equiv), LiBr (1.2 equiv), 30 Hz, 4 stainless steel balls (5 mm), 5 mol% of $Fe(NO_3)_3 \times 9H_2O$ as catalyst. **b.** Yield of **1** determined by ^{1}H-NMR against mesitylene. **c.** Isolated yield.

5. Availability of Starting Materials

5.1. Commercially available starting materials

Commercially available starting materials were purchased from Thermoscientific – Acros, Sigma Aldrich, Apollo Scientific, Fluorochem and TCI companies.



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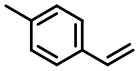
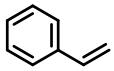


CAS 622-97-9



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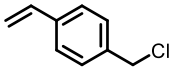

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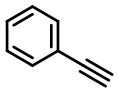

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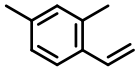

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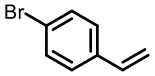

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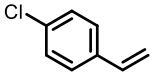

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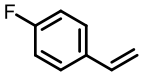
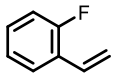
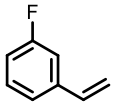


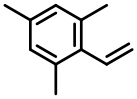
CAS 405-99-2



CAS 394-46-7



CAS 350-51-6



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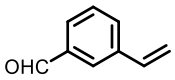

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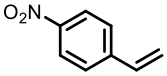

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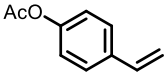

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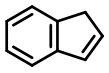
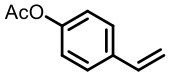


CAS 95-13-6



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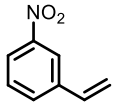

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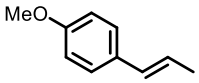

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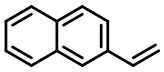

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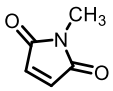

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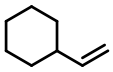
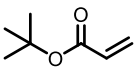


CAS 695-12-5



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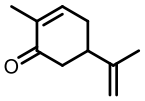

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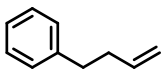

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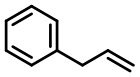

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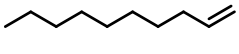

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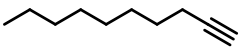

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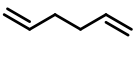


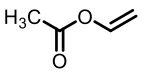
CAS 592-42-7

CAS 110-83-8

CAS 628-92-2

CAS 931-87-3

CAS 111-78-4



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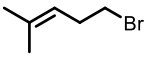

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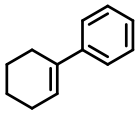

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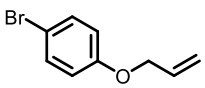

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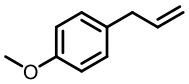

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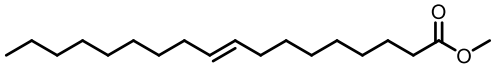

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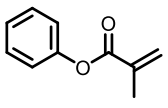

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CAS 692-86-4

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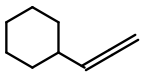

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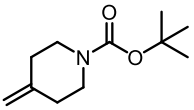

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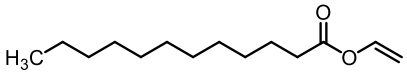

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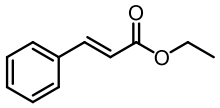

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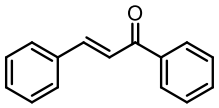

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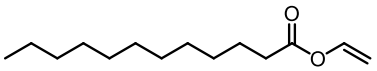

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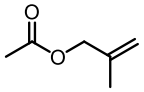

CAS
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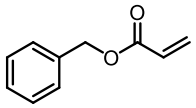

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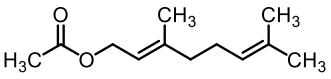

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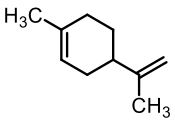

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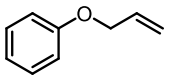

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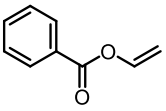

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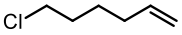
769-78-8



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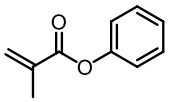

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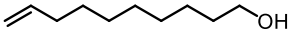

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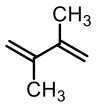

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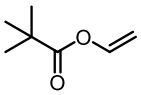
513-81-5



CAS
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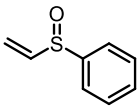

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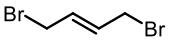

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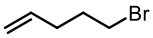
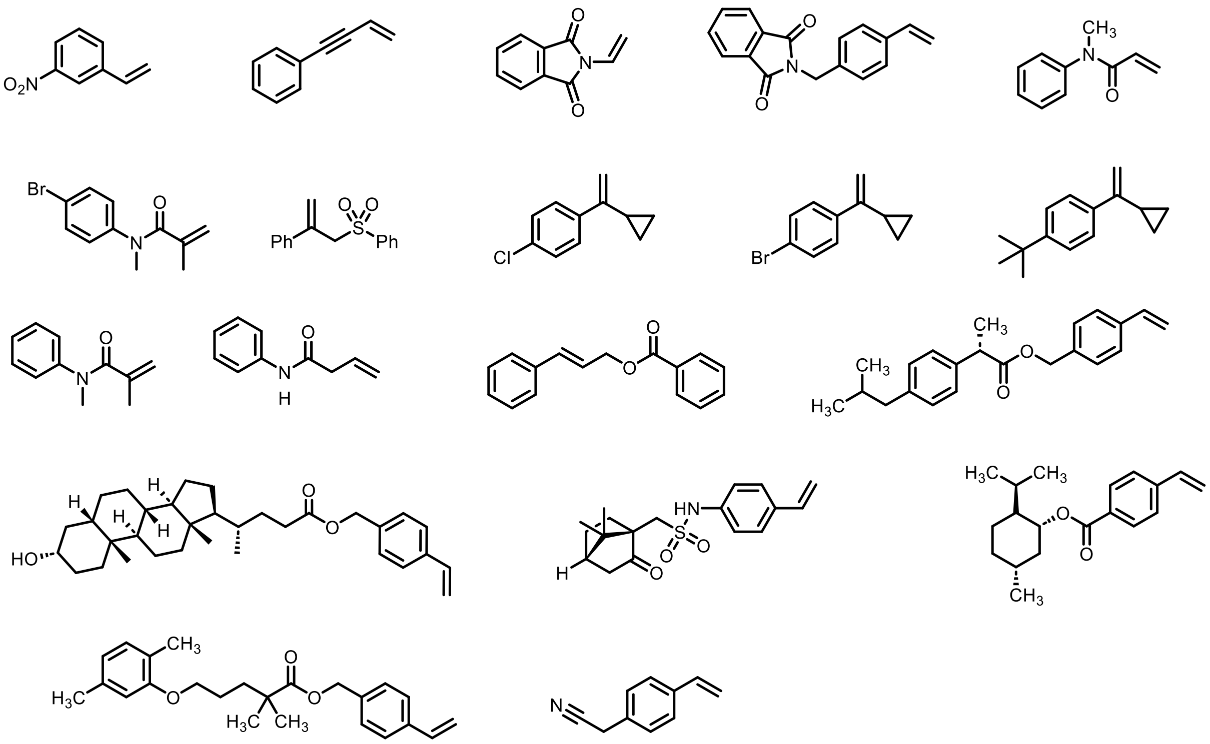


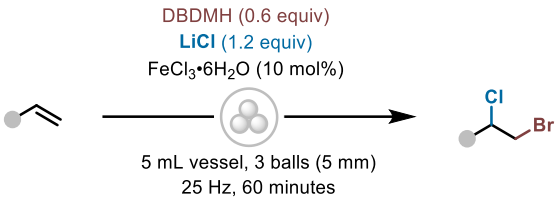
CAS
1119-51-3

5.2. The following compounds were prepared following the reported procedures.



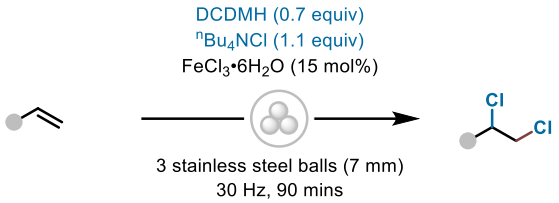
6. General procedures

6.1. General procedure for bromochlorination



GP1: Without any precautions to exclude air or moisture, a Retsch stainless steel vessel (5 mL) equipped with stainless-steel balls (5 mm) was charged with alkene (0.50 mmol, 1.0 equiv) [For solid starting materials DCM (0.1 μL/mg of solid alkenes) was used], DBDMH (0.6 equiv), LiCl (1.2 equiv), and $FeCl_3 \cdot 6H_2O$ (10 mol%). Next, the ball milling vessel was sealed and placed in the mixer mill (Retch MM400) for 60 minutes at a frequency of 25 Hz. After the reaction was finished, the contents were scraped off the vessel and purified directly by column chromatography on silica gel using EtOAc/n-hexane as the eluent or collected without further purification to obtain the desired product.

6.2. General procedure for dichlorination



GP2: Without any precautions to exclude air or moisture, a Retsch stainless steel vessel (5 mL) equipped with 3 stainless-steel balls (7 mm) was charged with alkene (0.50 mmol, 1.0 equiv) [For solid starting materials DCM (0.1 μL/mg of solid alkenes) was used], DCDMH (0.7 equiv), $^{n}Bu_4NCl$ (1.1 equiv), and $FeCl_3 \cdot 6H_2O$ (15 mol%). Next, the ball milling vessel was sealed and placed in the mixer mill (Retch MM400) for 90 minutes at a frequency of 90 Hz. After the reaction was finished, the contents were scraped off the vessel and purified directly by column chromatography on silica gel using EtOAc/n-hexane as the eluent or collected without further purification to obtain the desired product.

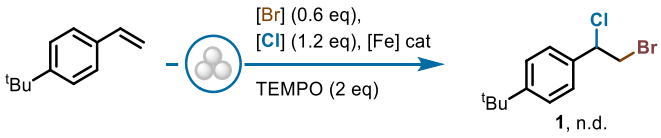
6.3. General procedure for dibromination

GP3: : Without any precautions to exclude air or moisture, a Retsch stainless steel vessel (5 mL) equipped with stainless-steel balls (5 mm) was charged with alkene (0.50 mmol, 1.0 equiv) [For solid starting materials DCM (0.1 μL/mg of solid alkenes) was used], DBDMH (0.6 equiv), LiBr (1.2 equiv),

and $Fe(NO_3)_3 \cdot 9H_2O$ (5 mol%). Next, the ball milling vessel was sealed and placed in the mixer mill (Retch MM400) for 90 minutes at a frequency of 30 Hz. After the reaction was finished, the contents were scraped off the vessel and purified directly by column chromatography on silica gel using EtOAc/n-hexane as the eluent or collected without further purification to obtain the desired product.

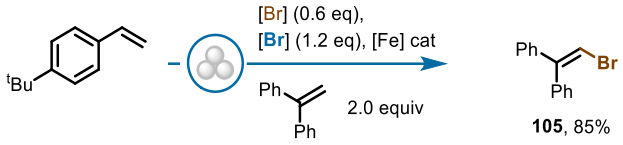
7. Mechanistic Investigations

7.1. Experiment 1:



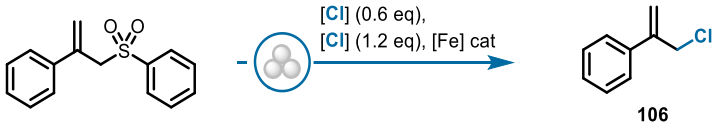
A 5 mL ball milling vessel equipped with 3 balls (5 mm) was charged under air with **1** (0.5 mmol, 1.0 equiv), DBDMH (0.6 equiv), LiCl (1.2 equiv), $FeCl_3 \times 6H_2O$ (10 mol%), and TEMPO (2 equiv). The jar was then closed and placed into the ball milling machine and the reaction was carried out at 25 Hz frequency for 60 minutes. The crude product was shortly purified via silica gel and analyzed by ^{1}H-NMR and GCMS.

7.2. Experiment 2:



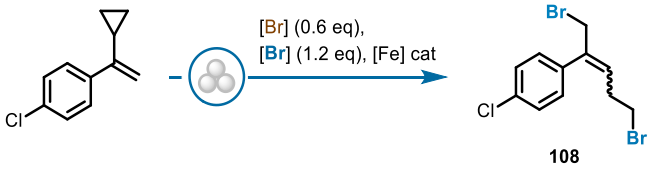
A 5 mL ball milling vessel equipped with 4 balls (5 mm) was charged under air with **1** (0.5 mmol, 1.0 equiv), DBDMH (0.6 equiv), LiBr (1.2 equiv), $Fe(NO_3)_3 \times 9H_2O$ (5 mol%), and 1,1-diphenyethylene (2 equiv). The jar was then closed and placed into the ball milling machine and the reaction was carried out at 30 Hz frequency for 60 minutes. The crude product was shortly purified via silica gel and analyzed by ^{1}H-NMR and GCMS.

7.3. Experiment 3:



A 5 mL ball milling vessel was charged with ((2-phenylallyl)sulfonyl)benzene (0.5 mmol, 1.0 equiv) DCDMH (0.7 equiv), ^{n}Bu$_4$NCl (1.1 equiv), and $FeCl_3 \times 6H_2O$ (15 mol%) were placed in a stainless-steel vessel (5 mL) with 3 stainless-steel balls (7 mm). Next, the ball milling vessel was sealed and placed in the mixer mill (Retch MM400) for 90 minutes at a frequency of 90 Hz. The crude product was shortly purified via silica gel and analyzed by GCMS.

7.4. Experiment 4:



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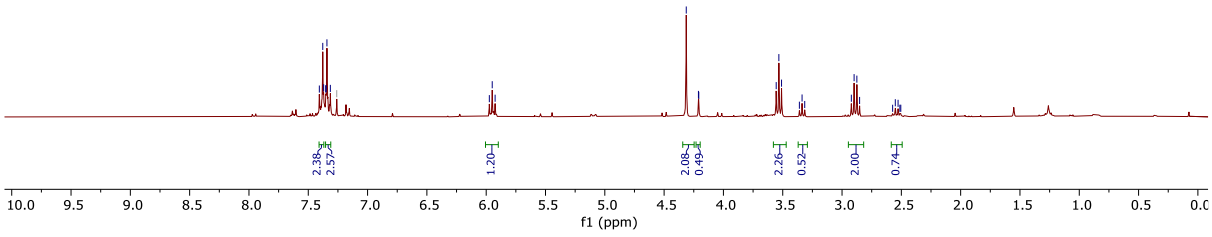
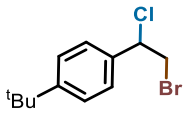
A 5 mL ball milling vessel equipped with 3 balls (5 mm) was charged with 1-chloro-4-(1-cyclopropylvinyl)benzene (0.5 mmol, 1.0 equiv), DBDMH (0.6 equiv), LiBr (1.2 equiv), and $Fe(NO_3)_3 \cdot 9H_2O$ (10 mol%) were placed in a stainless-steel vessel (5 mL) with 3 stainless-steel balls (5 mm). Next, the ball milling vessel was sealed and placed in the mixer mill (Retch MM400) for 90 minutes at a frequency of 30 Hz. The crude product was shortly purified via silica gel and analyzed by ^{1}H-NMR.



8. NMR Data

1-(2-bromo-1-chloroethyl)-4-(tert-butyl)benzene (1)



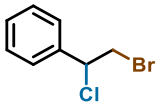
Compound **1** was obtained according to general procedure **GP1** as a colourless oil (94% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): ™ 7.41 (d, *J* = 8.4 Hz, 2H), 7.33 (d, *J* = 8.4 Hz, 2H), 5.06 (dd, *J* = 8.4, 6.5 Hz, 1H), 3.96 – 3.72 (m, 2H), 1.33 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): ™ 152.4, 135.5, 127.1, 125.9, 61.6, 36.2, 34.8, 31.4.

HRMS (EI) calcd for $C_{12}H_{16}{}^{79}Br^{35}Cl$: 274.0123; found 274.0122.

(2-bromo-1-chloroethyl)benzene (2)

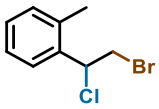


Compound **2** was obtained according to general procedure **GP1** as a colourless oil (91% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.43 – 7.37 (m, 5H), 5.06 (dd, *J* = 8.7, 6.2 Hz, 1H), 3.94 – 3.79 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.5, 129.3, 128.9, 127.5, 61.5, 36.1.

1-(2-bromo-1-chloroethyl)-2-methylbenzene (3)



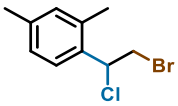
Compound **3** was obtained according to general procedure **GP1** as a colorless oil (98% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.48 – 7.43 (m, 1H), 7.31 – 7.17 (m, 3H), 5.37 (dd, *J* = 8.5, 6.8 Hz, 1H), 3.99 – 3.88 (m, 2H), 2.44 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.6, 136.3, 130.9, 129.1, 126.9, 126.3, 57.3, 35.2, 19.4.

HRMS (EI) calcd for $C_9H_{10}{}^{79}Br^{35}Cl$: 231.9654; found 231.9651.

1-(2-bromo-1-chloroethyl)-2,4-dimethylbenzene (4)



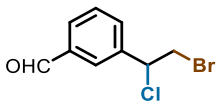
Compound **4** was obtained according to general procedure **GP1** as a colorless oil (89% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.34 (d, *J* = 8.0 Hz, 1H), 7.10 (dd, *J* = 7.9, 1.9 Hz, 1H), 7.03 (d, *J* = 1.9 Hz, 1H), 5.35 (dd, *J* = 8.6, 6.7 Hz, 1H), 3.99 – 3.87 (m, 2H), 2.41 (s, 3H), 2.34 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.0, 136.2, 133.6, 131.7, 127.6, 126.2, 57.3, 35.2, 21.2, 19.3.

HRMS (EI) calcd for $C_{10}H_{12}{}^{79}Br^{35}Cl$: 245.9811; found 245.9809.

3-(2-bromo-1-chloroethyl)benzaldehyde (5)



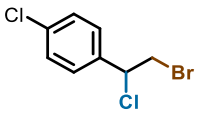
Compound **5** was obtained according to general procedure **GP1** as a colorless oil (90% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 10.05 (s, 1H), 7.94 – 7.83 (m, 2H), 7.70 – 7.65 (m, 1H), 7.59 (t, *J* = 7.6 Hz, 1H), 5.12 (dd, *J* = 9.3, 5.6 Hz, 1H), 3.94 (dd, *J* = 10.4, 5.7 Hz, 1H), 3.88 – 3.75 (m, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 191.7, 139.8, 137.0, 133.5, 130.8, 129.7, 128.5, 60.2, 35.5.

HRMS (EI) calcd for $C_9H_8{}^{79}Br^{35}ClO$: 245.9447; found 245.9445.

1-(2-bromo-1-chloroethyl)-4-chlorobenzene (6)[1]

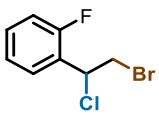


Compound **6** was obtained according to general procedure **GP1** as a colorless oil (96% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.39 – 7.32 (m, 4H), 5.02 (dd, *J* = 9.2, 5.8 Hz, 1H), 3.89 (dd, *J* = 10.4, 5.8 Hz, 1H), 3.77 (dd, *J* = 10.4, 9.2 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 137.0, 135.2, 129.2, 128.9, 60.4, 35.7.

1-(2-bromo-1-chloroethyl)-2-fluorobenzene (7)



Compound **7** was obtained according to general procedure **GP1** as a colorless oil (95% yield). No further purification was required.

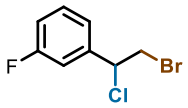
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.47 (td, *J* = 7.5, 1.8 Hz, 1H), 7.36 (tdd, *J* = 7.3, 5.1, 1.8 Hz, 1H), 7.24 – 7.17 (m, 1H), 7.10 (ddd, *J* = 9.7, 8.3, 1.1 Hz, 1H), 5.40 (t, *J* = 7.5 Hz, 1H), 3.94 – 3.87 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 160.24 (d, *J* = 249.6 Hz), 130.97 (d, *J* = 8.5 Hz), 128.82 (d, *J* = 2.9 Hz), 125.86, 124.75 (d, *J* = 3.7 Hz), 116.04 (d, J = 21.8 Hz), 54.33 (d, J = 3.3 Hz), 34.78 (d, J = 2.0 Hz).

^{19}F-NMR (282 MHz, $CDCl_3$): δ -117.15.

HRMS (EI) calcd for $C_8H_7{}^{79}Br^{35}ClF$: 235.9404; found 235.9401.

1-(2-bromo-1-chloroethyl)-3-fluorobenzene (8)



Compound **8** was obtained according to general procedure **GP1** as a colorless oil (88% yield). No further purification was required.

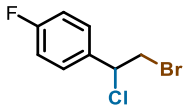
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.36 (td, *J* = 8.0, 5.8 Hz, 1H), 7.21 – 7.02 (m, 4H), 5.03 (dd, *J* = 9.0, 6.0 Hz, 1H), 3.89 (dd, *J* = 10.5, 6.0 Hz, 1H), 3.78 (dd, *J* = 10.5, 9.0 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 162.90 (d, *J* = 247.4 Hz), 130.48 (d, *J* = 8.3 Hz), 123.31 (d, *J* = 3.0 Hz), 116.34 (d, *J* = 21.2 Hz), 114.59 (d, *J* = 22.6 Hz), 60.37 (d, *J* = 2.0 Hz), 35.63.

^{19}F-NMR (282 MHz, $CDCl_3$): δ -111.81.

HRMS (EI) calcd for $C_8H_7{}^{79}Br^{35}ClF$: 235.9404; found 235.9400.

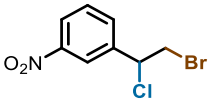
1-(2-bromo-1-chloroethyl)-4-fluorobenzene (9)



Compound **9** was obtained according to general procedure **GP1** as a colorless oil (91% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.42 – 7.35 (m, 2H), 7.13 – 7.05 (m, 2H), 5.05 (dd, *J* = 9.2, 5.9 Hz, 1H), 3.90 (dd, *J* = 10.4, 5.9 Hz, 1H), 3.78 (dd, *J* = 10.4, 9.1 Hz, 1H).

1-(2-bromo-1-chloroethyl)-3-nitrobenzene (10)

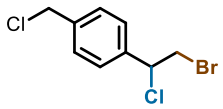


Compound **10** was obtained according to general procedure **GP1** as a colorless oil (88% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.28 (q, *J* = 1.7 Hz, 1H), 8.23 (ddd, *J* = 8.1, 2.3, 1.1 Hz, 1H), 7.75 (dt, *J* = 7.7, 1.5 Hz, 1H), 7.62 – 7.55 (m, 1H), 5.14 (dd, *J* = 9.5, 5.5 Hz, 1H), 3.94 (dd, *J* = 10.5, 5.4 Hz, 1H), 3.81 (dd, *J* = 10.5, 9.5 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 148.5, 140.5, 133.7, 130.0, 124.2, 122.7, 59.3, 35.2.

1-(2-bromo-1-chloroethyl)-4-(chloromethyl)benzene (11)



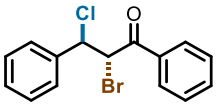
Compound **11** was obtained according to general procedure **GP1** as a colorless oil (81% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.41 (d, *J* = 1.6 Hz, 4H), 5.06 (dd, *J* = 8.9, 6.1 Hz, 1H), 4.59 (s, 2H), 3.90 (dd, *J* = 10.4, 6.1 Hz, 1H), 3.81 (dd, *J* = 10.4, 8.9 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.6, 138.5, 129.1, 127.9, 60.8, 45.7, 35.8.

HRMS (EI) calcd for $C_9H_9{}^{79}Br^{35}Cl_2$: 265.9265; found 265.9263.

2-bromo-3-chloro-1,3-diphenylpropan-1-one (12)

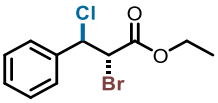


Compound **12**was obtained according to general procedure **GP1** as a colorless oil (90% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.14 – 8.05 (m, 2H), 7.71 – 7.62 (m, 1H), 7.59 – 7.50 (m, 4H), 7.48 – 7.38 (m, 3H), 5.59 (s, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 191.3, 137.9, 134.7, 134.3, 129.5, 129.1, 129.1, 128.9, 128.3, 59.9, 47.6.

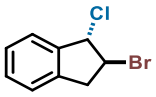
ethyl 2-bromo-3-chloro-3-phenylpropanoate (13)



Compound **13** was obtained according to general procedure **GP1** as a colorless oil (92% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 – 7.34 (m, 5H), 5.27 (d, *J* = 11.3 Hz, 1H), 4.62 (d, *J* = 11.3 Hz, 1H), 4.36 (qd, *J* = 7.1, 2.2 Hz, 2H), 1.41 – 1.34 (m, 4H).

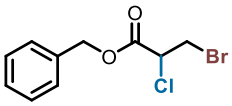
2-bromo-1-chloro-2,3-dihydro-1*H*-indene (14)



Compound **14** was obtained according to general procedure **GP1** as a colorless oil (91% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.50 – 7.43 (m, 1H), 7.38 – 7.28 (m, 3H), 5.48 (d, *J* = 2.5 Hz, 1H), 4.69 (dt, *J* = 5.7, 2.7 Hz, 1H), 3.81 (ddt, *J* = 17.3, 6.0, 0.9 Hz, 1H), 3.30 (dd, *J* = 17.2, 2.9 Hz, 1H).

Benzyl 3-bromo-2-chloropropanoate (15)



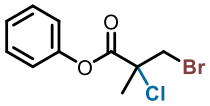
Compound **15** was obtained according to general procedure **GP1** as a light-yellow oil (81% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.41 – 7.35 (m, 5H), 5.26 (d, *J* = 1.0 Hz, 2H), 4.41 (dd, *J* = 10.4, 4.8 Hz, 1H), 4.12 – 4.02 (m, 1H), 3.82 (dd, *J* = 10.9, 4.8 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 167.5, 134.9, 128.8, 128.8, 128.4, 68.3, 43.3, 41.9.

HRMS (EI) *m/z*, calcd for $C_{10}H_{10}{}^{79}Br^{35}ClO_2$: 275.9547; found 275.9548.

phenyl 3-bromo-2-chloro-2-methylpropanoate (16)



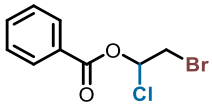
Compound **16** was obtained according to general procedure **GP1** as a colorless oil (89% yield) after purification by column chromatography (SiO_2, hexane/EA=10:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.47 – 7.37 (m, 3H), 7.33 – 7.27 (m, 1H), 7.20 – 7.11 (m, 3H), 4.47 (dd, *J* = 10.8, 0.7 Hz, 1H), 3.92 (d, *J* = 10.8 Hz, 1H), 2.13 (d, *J* = 0.7 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 167.6, 150.6, 129.7, 126.6, 121.2, 55.9, 50.2, 25.5.

HRMS (EI) calcd for $C_{10}H_{10}{}^{79}Br^{35}ClO_2$: 275.9553; found 275.9550.

2-bromo-1-chloroethyl benzoate (17)



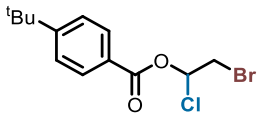
Compound **17** was obtained according to general procedure **GP1** as a colorless oil (85% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.16 – 8.06 (m, 2H), 7.67 – 7.60 (m, 1H), 7.53 – 7.45 (m, 2H), 6.80 (dd, *J* = 8.4, 3.5 Hz, 1H), 3.98 – 3.79 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 164.1, 134.3, 130.4, 128.8, 128.4, 80.8, 33.1.

HRMS (EI) calcd for $C_9H_8{}^{79}Br^{35}ClO_2$: 261.9396; found 261.9394.

2-bromo-1-chloroethyl 4-(tert-butyl)benzoate (18)



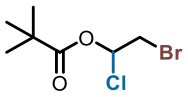
Compound **18** was obtained according to general procedure **GP1** as a colorless oil (83% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.06 – 8.00 (m, 2H), 7.55 – 7.49 (m, 2H), 6.79 (dd, J = 8.4, 3.4 Hz, 1H), 3.99 – 3.78 (m, 2H), 1.35 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 164.0, 158.3, 130.3, 125.8, 125.5, 80.8, 35.4, 33.2, 31.2.

HRMS (EIMS) *m/z*, calcd for $C_{13}H_{16}{}^{79}Br^{35}ClO_2$: 318.0022; found 318.0018.

2-bromo-1-chloroethyl pivalate (19)



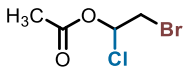
Compound **19** was obtained according to general procedure **GP1** as a colorless oil (92% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 6.53 (dd, *J* = 8.5, 3.8 Hz, 1H), 3.80 – 3.68 (m, 2H), 1.26 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 175.8, 80.2, 39.1, 32.9, 26.8.

HRMS (EI) calcd for $C_7H_{12}{}^{79}Br^{35}ClO_2$: 241.9709; found 241.9706.

2-bromo-1-chloroethyl acetate (20)



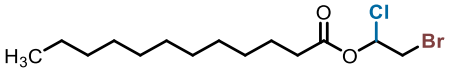
Compound **20** was obtained according to general procedure **GP1** as a colorless oil (81% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 6.53 (dd, *J* = 7.6, 4.5 Hz, 1H), 3.78 – 3.66 (m, 2H), 2.17 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 168.4, 80.2, 32.9, 20.8.

HRMS (HRGCMS) *m/z*, calcd for $C_4H_6O_2{}^{79}Br^{35}Cl$: 199.9234; found 199.9236.

2-bromo-1-chloroethyl dodecanoate (21)



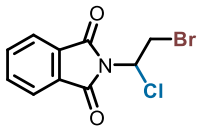
Compound **21** was obtained according to general procedure **GP1** as a colorless oil (80% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 6.55 (dd, *J* = 7.8, 4.3 Hz, 1H), 3.76 – 3.68 (m, 2H), 2.41 (t, *J* = 7.5 Hz, 2H), 1.66 (q, *J* = 7.3 Hz, 2H), 1.27 (d, *J* = 6.2 Hz, 16H), 0.92 – 0.82 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 171.3, 80.1, 34.1, 32.9, 32.1, 29.7, 29.7, 29.5, 29.5, 29.3, 29.1, 24.7, 22.8, 14.3.

HRMS (EI) calcd for $C_{14}H_{26}{}^{79}Br^{35}ClO_2$: 340.0805; found 340.0803.

2-(2-bromo-1-chloroethyl)isoindoline-1,3-dione (22)



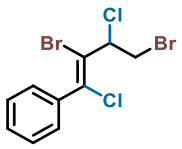
Compound **22** was obtained according to general procedure **GP1** as a colorless oil (91% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.94 (dd, *J* = 5.5, 3.1 Hz, 2H), 7.81 (dd, *J* = 5.5, 3.0 Hz, 2H), 6.23 (dd, *J* = 11.1, 4.8 Hz, 1H), 4.73 (t, *J* = 10.8 Hz, 1H), 3.92 (dd, *J* = 10.5, 4.8 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 166.1, 135.1, 131.5, 124.3, 61.2, 30.7.

HRMS (EI) calcd for $C_{10}H_7{}^{79}Br^{35}ClNO_2$: 286.9349; found 286.9346.

(E)-(2,4-dibromo-1,3-dichlorobut-1-en-1-yl)benzene (23)



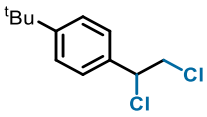
Compound **23** was obtained according to general procedure **GP1** as a white solid (84% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.39 (d, *J* = 0.9 Hz, 6H), 5.59 (dd, *J* = 9.9, 5.4 Hz, 1H), 3.98 (dd, *J* = 11.0, 9.9 Hz, 1H), 3.84 (dd, *J* = 11.0, 5.3 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 139.9, 129.5, 128.9, 128.6, 123.9, 120.6, 61.1, 45.9.

HRMS (EI) *m/z*, calcd for $C_{10}H_8{}^{79}Br_2{}^{35}Cl_2$: 355.8364; found 355.8364.

1-(tert-butyl)-4-(1,2-dichloroethyl)benzene (24)[4]

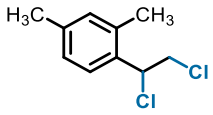


Compound **24** was obtained according to general procedure **GP1** as a white solid (91% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.43 (d, *J* = 8.7 Hz, 2H), 7.35 (d, *J* = 8.3 Hz, 2H), 5.01 (t, *J* = 7.2 Hz, 1H), 4.05 – 3.89 (m, 2H), 1.34 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 152.4, 135.1, 127.2, 125.9, 62.0, 48.6, 34.8, 31.4.

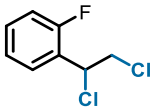
1-(1,2-dichloroethyl)-2,4-dimethylbenzene (25)



Compound **25** was obtained according to general procedure **GP2** as a colorless oil (94% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.40 (d, *J* = 7.9 Hz, 1H), 7.06 (d, *J* = 7.9 Hz, 1H), 6.99 (s, 1H), 5.08 (dt, *J* = 9.1, 3.0 Hz, 1H), 3.74 – 3.53 (m, 2H), 2.32 (d, *J* = 3.0 Hz, 6H).

1-(1,2-dichloroethyl)-2-fluorobenzene (26)



Compound **26** was obtained according to general procedure **GP2** as a colorless oil (87% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

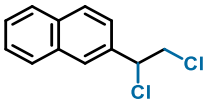
^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.47 (td, *J* = 7.5, 1.8 Hz, 1H), 7.36 (tdd, *J* = 7.3, 5.1, 1.8 Hz, 1H), 7.24 – 7.17 (m, 1H), 7.10 (ddd, *J* = 9.7, 8.3, 1.1 Hz, 1H), 5.40 (t, *J* = 7.5 Hz, 1H), 3.98 – 3.84 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 160.2 (d, *J* = 249.3 Hz), 131.0 (d, *J* = 8.6 Hz), 128.8 (d, *J* = 3.0 Hz), 125.8 (d, *J* = 12.6 Hz), 124.8 (d, *J* = 3.8 Hz), 116.0 (d, *J* = 21.8 Hz), 54.3 (d, *J* = 3.3 Hz), 34.8 (d, *J* = 2.0 Hz).

^{19}F-NMR (282 MHz, $CDCl_3$): δ -117.15.

HRMS (EI) calcd for $C_8H_7{}^{35}Cl_2F$: 191.9909; found 191.9907.

2-(1,2-dichloroethyl)naphthalene (27)

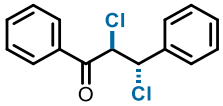


Compound **27** was obtained according to general procedure **GP2** as a white solid (71% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.95 – 7.81 (m, 4H), 7.57 – 7.47 (m, 3H), 5.18 (dd, *J* = 8.1, 6.5 Hz, 1H), 4.15 – 3.97 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.3, 133.7, 133.1, 129.1, 128.3, 127.9, 127.4, 127.0, 126.8, 124.3, 62.2, 48.3.

2,3-dichloro-1,3-diphenylpropan-1-one (28)

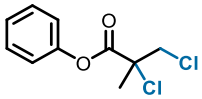


Compound **28** was obtained according to general procedure **GP2** as a white solid (89% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.13 – 8.06 (m, 2H), 7.71 – 7.62 (m, 1H), 7.60 – 7.49 (m, 4H), 7.47 – 7.39 (m, 3H), 5.50 (d, *J* = 1.7 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 191.5, 137.2, 134.9, 134.4, 129.5, 129.2, 128.9, 128.5, 60.2, 57.2.

phenyl 2,3-dichloro-2-methylpropanoate (29)

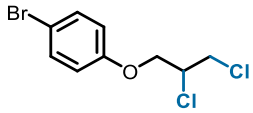


Compound **29** was obtained according to general procedure **GP2** as a white solid (79% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 – 7.38 (m, 2H), 7.31 – 7.27 (m, 1H), 7.18 – 7.11 (m, 2H), 4.26 (dd, *J* = 10.9, 0.7 Hz, 1H), 3.86 (d, *J* = 10.9 Hz, 1H), 1.98 (d, *J* = 0.6 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 167.4, 150.6, 129.7, 126.6, 121.3, 65.5, 50.1, 24.9.

1-bromo-4-(2,3-dichloropropoxy)benzene (30)



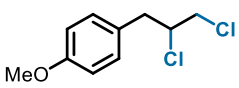
Compound **30** was obtained according to general procedure **GP2** as a light-yellow oil (90% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.40 (d, *J* = 8.9 Hz, 2H), 6.82 (d, *J* = 9.0 Hz, 2H), 4.40 – 4.30 (m, 1H), 4.25 (d, *J* = 5.0 Hz, 2H), 3.96 – 3.87 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 157.3, 132.6, 116.7, 114.1, 68.6, 57.2, 44.9.

HRMS (ESI) *m/z*, calcd for $C_9H_9O^{79}Br^{35}Cl_2$: 281.9208; found 281.9209.

1-(2,3-dichloropropyl)-4-methoxybenzene (31)



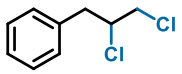
Compound **31** was obtained according to general procedure **GP2** as a colorless oil (57% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.19 (d, *J* = 8.6 Hz, 2H), 6.87 (d, *J* = 8.7 Hz, 2H), 4.22 (tdd, *J* = 7.0, 5.8, 4.8 Hz, 1H), 3.81 (s, 3H), 3.68 (qd, *J* = 11.4, 5.8 Hz, 2H), 3.24 (dd, *J* = 14.3, 5.8 Hz, 1H), 3.03 (dd, *J* = 14.3, 7.1 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 158.9, 130.7, 128.4, 114.1, 61.4, 55.4, 47.5, 40.2.

HRMS (EI) calcd for $C_{10}H_{12}{}^{35}Cl_2O$: 218.0265; found 218.0263.

(2,3-dichloropropyl)benzene (32)

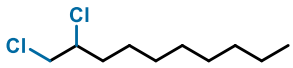


Compound **32** was obtained according to general procedure **GP2** as a colorless oil (81% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.40 – 7.27 (m, 5H), 4.34 – 4.21 (m, 1H), 3.70 (qd, *J* = 11.5, 5.8 Hz, 2H), 3.32 (dd, *J* = 14.1, 5.7 Hz, 1H), 3.07 (dd, *J* = 14.2, 7.3 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.4, 129.7, 128.7, 127.3, 61.1, 47.6, 41.2.

1,2-dichlorodecane (33)

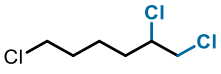


Compound **33** was obtained according to general procedure **GP2** as a colorless oil (91% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.03 (dddd, *J* = 8.9, 7.4, 5.2, 3.8 Hz, 1H), 3.76 (dd, *J* = 11.3, 5.2 Hz, 1H), 3.65 (dd, *J* = 11.3, 7.4 Hz, 1H), 2.05 – 1.88 (m, 1H), 1.77 – 1.60 (m, 1H), 1.29 (dq, *J* = 7.3, 3.2 Hz, 11H), 0.93 – 0.84 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 61.4, 48.4, 35.2, 32.0, 29.5, 29.3, 29.1, 26.0, 22.8, 14.2.

1,2,6-trichlorohexane (34)



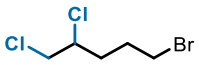
Compound **34** was obtained according to general procedure **GP2** as a colorless oil (93% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.06 (dddd, *J* = 8.6, 7.6, 5.0, 3.6 Hz, 1H), 3.81 (dd, *J* = 11.3, 5.0 Hz, 1H), 3.67 (dd, *J* = 11.3, 7.7 Hz, 1H), 3.59 (t, *J* = 6.4 Hz, 2H), 2.13 – 1.97 (m, 1H), 1.90 – 1.68 (m, 4H), 1.68 – 1.59 (m, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 60.8, 48.2, 44.7, 34.4, 32.0, 23.4.

HRMS (EI) calcd for $C_6H_{11}{}^{35}Cl_3$: 187.9926; found 187.9923.

5-bromo-1,2-dichloropentane (35)



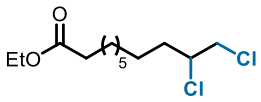
Compound **35** was obtained according to general procedure **GP2** as a colorless oil (98% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.13 – 3.99 (m, 1H), 3.79 (dd, J = 11.3, 5.0 Hz, 1H), 3.65 (dd, *J* = 11.3, 7.7 Hz, 1H), 3.46 (t, *J* = 6.2 Hz, 2H), 2.27 – 2.06 (m, 2H), 2.05 – 1.77 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 60.2, 48.1, 33.8, 32.7, 29.1.

HRMS (EI) calcd for $C_5H_9{}^{79}Br{}^{35}Cl_2$: 217.9265; found 217.9263.

ethyl 10,11-dichloroundecanoate (36)



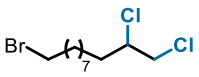
Compound **36** was obtained according to general procedure **GP2** as a colorless oil (90% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.12 (qd, *J* = 7.1, 1.1 Hz, 2H), 4.02 (tdd, *J* = 8.8, 4.3, 2.5 Hz, 1H), 3.81 – 3.70 (m, 1H), 3.70 – 3.58 (m, 1H), 2.28 (t, *J* = 7.5 Hz, 2H), 2.04 – 1.90 (m, 1H), 1.76 – 1.50 (m, 6H), 1.44 – 1.22 (m, 12H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 174.0, 61.4, 60.3, 48.4, 35.2, 34.5, 29.3, 29.3, 29.2, 29.0, 25.9, 25.1, 14.4.

HRMS (EI) calcd for $C_{10}H_{20}{}^{35}Cl_2O_2$: 242.0840; found 242.0838.

11-bromo-1,2-dichloroundecane (37)

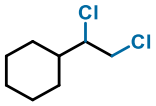


Compound **37** was obtained according to general procedure **GP2** as a colorless oil (87% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.03 (dddd, *J* = 8.9, 7.4, 5.2, 3.8 Hz, 1H), 3.76 (dd, *J* = 11.3, 5.2 Hz, 1H), 3.65 (dd, *J* = 11.3, 7.4 Hz, 1H), 3.41 (t, *J* = 6.9 Hz, 2H), 2.05 – 1.91 (m, 1H), 1.89 – 1.79 (m, 2H), 1.76 – 1.63 (m, 1H), 1.50 – 1.25 (m, 12H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 61.2, 48.3, 35.0, 34.0, 32.8, 29.3, 29.3, 28.9, 28.7, 28.1, 25.8.

(1,2-dichloroethyl)cyclohexane (38)



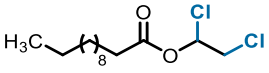
Compound **38** was obtained according to general procedure **GP2** as a colorless oil (83% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.02 – 3.93 (m, 1H), 3.77 (s, 1H), 3.75 (s, 1H), 1.91 (dt, *J* = 6.8, 3.5 Hz, 1H), 1.83 – 1.75 (m, 3H), 1.72 – 1.65 (m, 2H), 1.34 – 1.15 (m, 5H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 67.0, 46.4, 40.4, 30.5, 26.8, 26.2, 26.2, 25.9.

HRMS (EI) calcd for $C_8H_{14}{}^{35}Cl_2$: 180.0473; found 180.0470.

1,2-dichloroethyl dodecanoate (39)



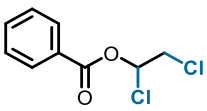
Compound **39** was obtained according to general procedure **GP2** as a colorless oil (89% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 6.51 (dd, *J* = 7.2, 4.7 Hz, 1H), 3.89 – 3.82 (m, 2H), 2.41 (t, *J* = 7.5 Hz, 2H), 1.72 – 1.62 (m, 2H), 1.27 (d, *J* = 6.5 Hz, 16H), 0.93 – 0.84 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 171.4, 80.7, 46.0, 34.1, 32.1, 29.7, 29.7, 29.5, 29.5, 29.3, 29.1, 24.7, 22.8, 14.3.

HRMS (ESI) *m/z*, calcd for $C_{14}H_{26}{}^{35}Cl_2O_2$: 296.1310; found 296.1307.

1,2-dichloroethyl benzoate (40)



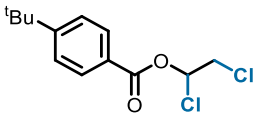
Compound **40** was obtained according to general procedure **GP2** as a colorless oil (95% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.14 – 8.07 (m, 2H), 7.67 – 7.60 (m, 1H), 7.54 – 7.45 (m, 2H), 6.76 (dd, *J* = 7.9, 3.8 Hz, 1H), 4.09 – 3.93 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 164.1, 134.3, 130.3, 128.8, 81.4, 46.1.

HRMS (EI) calcd for $C_9H_8{}^{35}Cl_2O_2$: 217.9901; found 217.9899.

1,2-dichloroethyl 4-(tert-butyl)benzoate (41)



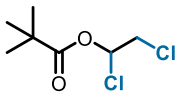
Compound **41** was obtained according to general procedure **GP2** as a colorless oil (98% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.06 – 7.99 (m, 2H), 7.50 (d, *J* = 8.6 Hz, 2H), 6.76 (dd, *J* = 7.9, 3.7 Hz, 1H), 4.10 – 3.93 (m, 2H), 1.35 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 164.1, 158.3, 130.3, 125.8, 81.4, 46.2, 35.4, 31.2.

HRMS (ESI) *m/z*, calcd for $C_{13}H_{16}{}^{35}Cl_2O_2$: 274.0522; found 274.0525.

1,2-dichloroethyl pivalate (42)



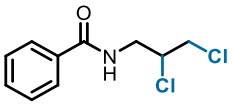
Compound **42** was obtained according to general procedure **GP2** as a colorless oil (94% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 6.49 (dd, *J* = 7.7, 4.2 Hz, 1H), 3.90 – 3.82 (m, 2H), 1.25 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 175.9, 80.8, 46.0, 39.1, 26.8.

HRMS (ESI) *m/z*, calcd for $C_7H_{12}{}^{35}Cl_2O_2$–^{35}Cl: 163.0526; found 163.0447.

N-(2,3-dichloropropyl)benzamide (43)



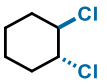
Compound **43** was obtained according to general procedure **GP2** as a colorless oil (74% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.83 – 7.75 (m, 2H), 7.57 – 7.40 (m, 3H), 6.64 (s, 1H), 4.38 (dddd, *J* = 7.4, 6.4, 5.2, 4.3 Hz, 1H), 4.06 (ddd, *J* = 14.3, 6.4, 4.3 Hz, 1H), 3.85 – 3.65 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 167.9, 133.9, 132.1, 128.8, 127.1, 59.9, 46.3, 43.8.

HRMS (EI) calcd for $C_{10}H_{11}{}^{35}Cl_2NO$: 231.0218; found 231.0215.

1,2-dichlorocyclohexane (44)

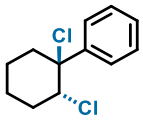


Compound **44** was obtained according to general procedure **GP2** as a colorless oil (94% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 4.09 – 3.93 (m, 2H), 2.40 – 2.24 (m, 2H), 1.82 – 1.66 (m, 4H), 1.50 – 1.34 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 63.3, 33.6, 23.2.

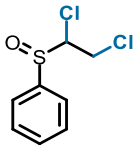
(1,2-dichlorocyclohexyl)benzene (45)



Compound **45** was obtained according to general procedure **GP2** as a colorless oil (94% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.26 (dd, *J* = 7.1, 2.1 Hz, 1H), 7.20 – 7.10 (m, 2H), 7.04 (dd, *J* = 7.2, 1.8 Hz, 1H), 5.14 (dd, *J* = 3.3, 1.3 Hz, 1H), 4.56 (dt, *J* = 5.3, 2.8 Hz, 1H), 3.07 (td, *J* = 11.3, 5.6 Hz, 1H), 2.76 (ddd, *J* = 17.4, 6.0, 2.8 Hz, 1H), 2.63 – 2.49 (m, 1H), 2.10 – 1.98 (m, 1H).

((1,2-dichloroethyl)sulfinyl)benzene (46)



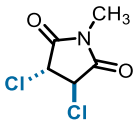
Compound **46** was obtained according to general procedure **GP2** as a colorless oil (94% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.70 – 7.62 (m, 2H), 7.57 (dd, *J* = 5.2, 1.9 Hz, 3H), 4.67 (t, *J* = 6.9 Hz, 1H), 4.18 (dd, *J* = 12.0, 6.9 Hz, 1H), 3.61 (dd, *J* = 12.0, 6.9 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.7, 132.3, 129.3, 125.4, 76.0, 42.7.

HRMS (ESI) *m/z*, calcd for $C_8H_8{}^{35}Cl_2SO$–HCl: 185.9901; found 185.9903.

3,4-dichloro-1-methylpyrrolidine-2,5-dione (47)



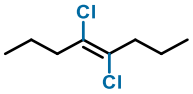
Compound **47** was obtained according to general procedure **GP2** as a white solid (80% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.67 (s, 2H), 3.14 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 169.3, 57.4, 26.4.

HRMS (EI) calcd for $C_5H_5{}^{35}Cl_2NO_2$: 180.9697; found 180.9694.

(E)-4,5-dichlorooct-4-ene (48)



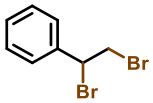
Compound **48** was obtained according to general procedure **GP2** as a colorless oil (95% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 2.56 (t, *J* = 7.3 Hz, 2H), 2.18 – 2.11 (m, 2H), 1.66 – 1.57 (m, 2H), 1.53 (q, *J* = 7.2 Hz, 2H), 1.02 – 0.93 (m, 6H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 129.9, 80.2, 37.6, 22.6, 20.8, 20.2, 13.5, 13.1.

HRMS (HRGCMS) *m/z*, calcd for $C_8H_{14}{}^{35}Cl_2$: 180.0467; found 180.0469.

(1,2-dibromoethyl)benzene (49)[CAS: 93-52-7]

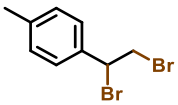


Compound **49** was obtained according to general procedure **GP3** as a white solid (97% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.47 – 7.31 (m, 5H), 5.15 (dd, *J* = 10.4, 5.7 Hz, 1H), 4.13 – 3.96 (m, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 138.6, 129.2, 128.9, 127.7, 50.9, 35.1.

1-(1,2-dibromoethyl)-4-methylbenzene (50)

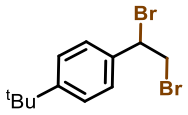


Compound **50** was obtained according to general procedure **GP3** as a colorless oil (95% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.30 (d, *J* = 8.2 Hz, 2H), 7.19 (d, *J* = 8.0 Hz, 2H), 5.14 (dd, *J* = 10.4, 5.7 Hz, 1H), 4.13 – 3.96 (m, 2H), 2.36 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 139.4, 135.8, 129.7, 127.7, 51.2, 35.2, 21.4.

1-(tert-butyl)-4-(1,2-dibromoethyl)benzene (51)

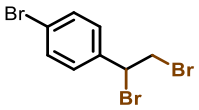


Compound **51** was obtained according to general procedure **GP3** as a colorless oil (98% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.39 (d, *J* = 8.5 Hz, 2H), 7.33 (d, *J* = 8.5 Hz, 2H), 5.16 (dd, *J* = 10.0, 5.9 Hz, 1H), 4.10 – 3.99 (m, 2H), 1.32 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 152.5, 135.7, 127.4, 126.0, 51.4, 35.3, 34.9, 31.4.

1-bromo-4-(1,2-dibromoethyl)benzene (52)

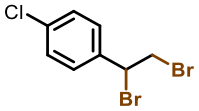


Compound **52** was obtained according to general procedure **GP3** as a white solid (96% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.52 (d, *J* = 8.5 Hz, 2H), 7.28 (d, *J* = 8.5 Hz, 2H), 5.09 (dd, *J* = 11.0, 5.2 Hz, 1H), 4.12 – 3.86 (m, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 137.8, 132.2, 129.5, 123.3, 49.7, 34.7.

1-chloro-4-(1,2-dibromoethyl)benzene (53)

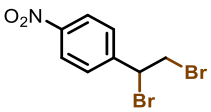


Compound **53** was obtained according to general procedure **GP3** as a white solid (94% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.35 (s, 4H), 5.11 (dd, *J* = 11.0, 5.2 Hz, 1H), 4.10 – 3.92 (m, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 137.3, 135.1, 129.5, 129.3, 129.2, 128.3, 49.7, 34.8.

1-(1,2-dibromoethyl)-4-nitrobenzene (54)



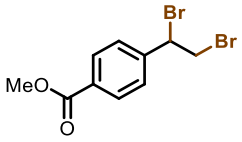
Compound **54** was obtained according to general procedure **GP3** as a colorless oil (86% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.29 – 8.22 (m, 2H), 7.62 – 7.54 (m, 2H), 5.17 (dd, *J* = 11.2, 5.0 Hz, 1H), 4.10 (dd, *J* = 10.4, 5.0 Hz, 1H), 3.98 (dd, *J* = 11.3, 10.4 Hz, 1H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 163.8, 145.6, 129.0, 124.3, 47.9, 34.0.

HRMS (ESI) *m/z*, calcd for $C_8H_7{}^{79}BrNO_2$–Br: 227.9655; found 227.9658.

methyl 4-(1,2-dibromoethyl)benzoate (55)

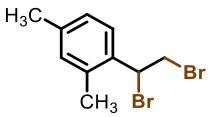


Compound **55** was obtained according to general procedure **GP3** as a white solid (92% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.06 (d, *J* = 8.5 Hz, 2H), 7.48 (d, *J* = 8.4 Hz, 2H), 5.15 (dd, *J* = 10.8, 5.3 Hz, 1H), 4.11 – 3.96 (m, 2H), 3.93 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 166.5, 143.5, 131.0, 130.3, 127.9, 52.4, 49.5, 34.5.

1-(1,2-dibromoethyl)-2,4-dimethylbenzene (56)



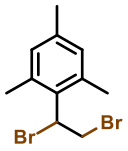
Compound **56** was obtained according to general procedure **GP3** as a colorless oil (86% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.33 (d, *J* = 8.0 Hz, 1H), 7.13 – 7.06 (m, 1H), 7.00 (d, *J* = 1.9 Hz, 1H), 5.43 (dd, *J* = 9.3, 7.1 Hz, 1H), 4.21 – 4.08 (m, 2H), 2.38 (s, 3H), 2.32 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 139.2, 136.5, 133.7, 131.8, 127.8, 126.3, 47.3, 34.3, 21.3, 19.3.

HRMS (ESI) *m/z*, calcd for $C_{10}H_{12}{}^{79}Br$ –Br: 211.0117; found 211.0119.

2-(1,2-dibromoethyl)-1,3,5-trimethylbenzene (57)



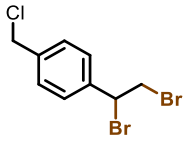
Compound **57** was obtained according to general procedure **GP3** as a colorless oil (88% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 6.86 (d, *J* = 3.8 Hz, 2H), 5.72 (dd, *J* = 11.1, 6.3 Hz, 1H), 4.32 (dd, *J* = 11.1, 10.2 Hz, 1H), 4.08 (dd, *J* = 10.2, 6.3 Hz, 1H), 2.53 (s, 3H), 2.38 (s, 3H), 2.26 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 138.9, 137.8, 131.9, 129.6, 47.7, 34.1, 20.9.

HRMS (ESI) *m/z*, calcd for $C_{11}H_{14}{}^{79}Br$–Br: 225.0273; found 225.0276.

1-(chloromethyl)-4-(1,2-dibromoethyl)benzene (58)

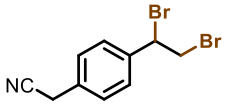


Compound **58** was obtained according to general procedure **GP3** as a colorless oil (89% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.41 (s, 4H), 5.14 (dd, *J* = 10.6, 5.4 Hz, 1H), 4.59 (s, 2H), 4.11 – 3.96 (m, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 138.9, 138.5, 129.2, 128.2, 50.2, 45.7, 34.9.

2-(4-(1,2-dibromoethyl)phenyl)acetonitrile (59)



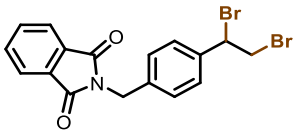
Compound **59** was obtained according to general procedure **GP3** as a off-white solid (85% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.50 – 7.31 (m, 4H), 5.13 (dd, *J* = 10.9, 5.2 Hz, 1H), 4.14 – 3.94 (m, 2H), 3.77 (s, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 138.9, 131.0, 128.6, 128.6, 117.5, 49.8, 34.8, 23.6.

HRMS (EI) calcd for $C_{10}H_9{}^{79}Br_2N$: 300.9102; found 300.9100.

2-(4-(1,2-dibromoethyl)benzyl)isoindoline-1,3-dione (60)



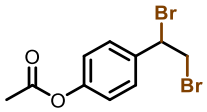
Compound **59** was obtained according to general procedure **GP3** as a white solid (86% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.85 (dd, *J* = 5.5, 3.1 Hz, 2H), 7.70 (dd, *J* = 5.5, 3.1 Hz, 2H), 7.45 (d, *J* = 8.3 Hz, 2H), 7.35 (d, *J* = 8.3 Hz, 2H), 5.11 (dd, *J* = 10.5, 5.5 Hz, 1H), 4.84 (s, 2H), 4.08 – 3.91 (m, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 168.1, 138.3, 137.5, 134.2, 132.2, 129.3, 128.1, 123.5, 50.5, 41.3, 34.9.

HRMS (EI) calcd for $C_{17}H_{13}{}^{79}BrNO_2$–Br: 342.0130; found 342.0127.

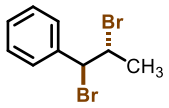
4-(1,2-dibromoethyl)phenyl acetate (61)



Compound **60** was obtained according to general procedure **GP3** as a white solid (68% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.42 (d, *J* = 8.6 Hz, 2H), 7.12 (d, *J* = 8.7 Hz, 2H), 5.14 (dd, *J* = 10.6, 5.4 Hz, 1H), 4.10 – 3.93 (m, 2H), 2.31 (s, 3H).

(1,2-dibromopropyl)benzene (62)

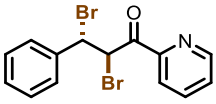


Compound **61** was obtained according to general procedure **GP3** as a colorless oil (88% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.44 (dd, *J* = 7.6, 2.2 Hz, 2H), 7.35 (dd, *J* = 5.0, 2.0 Hz, 3H), 5.23 (d, *J* = 5.7 Hz, 1H), 4.66 – 4.56 (m, 1H), 1.71 (d, J = 6.8 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 137.4, 129.2, 129.0, 128.4, 59.1, 52.9, 22.6.

anti-2,3-dibromo-3-phenyl-1-(pyridin-2-yl)propan-1-one (63)

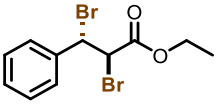


Compound **62** was obtained according to general procedure **GP3** as a white solid (85% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.79 (d, *J* = 4.4 Hz, 1H), 8.25 (d, *J* = 7.9 Hz, 1H), 7.94 (td, *J* = 7.7, 1.7 Hz, 1H), 7.59 (dd, *J* = 7.7, 1.5 Hz, 3H), 7.47 – 7.34 (m, 3H), 6.79 (d, *J* = 11.9 Hz, 1H), 5.67 (d, *J* = 11.9 Hz, 1H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 149.2, 138.4, 137.5, 129.3, 128.9, 128.4, 128.1, 123.8, 49.6, 45.3.

ethyl 2,3-dibromo-3-phenylpropanoate (64)

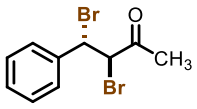


Compound **63** was obtained according to general procedure **GP3** as a colorless oil (92% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 – 7.35 (m, 5H), 5.35 (d, *J* = 11.8 Hz, 1H), 4.83 (dd, *J* = 11.7, 0.6 Hz, 1H), 4.36 (q, *J* = 7.1 Hz, 2H), 1.38 (t, *J* = 7.1 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 168.0, 137.8, 129.5, 129.1, 128.2, 62.8, 50.9, 47.2, 14.1.

3,4-dibromo-4-phenylbutan-2-one (65)

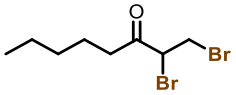


Compound **63** was obtained according to general procedure **GP3** as a white solid (90% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.45 – 7.34 (m, 5H), 5.32 (d, *J* = 11.6 Hz, 1H), 4.94 (d, *J* = 11.7 Hz, 1H), 2.48 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 198.5, 137.9, 129.5, 129.0, 128.3, 52.9, 49.6, 27.1.

1,2-dibromooctan-3-one (66)



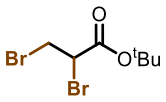
Compound **64** was obtained according to general procedure **GP3** as a colorless oil (90% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.52 (dd, *J* = 11.0, 4.2 Hz, 1H), 3.95 (dd, *J* = 11.0, 9.9 Hz, 1H), 3.63 (dd, *J* = 9.8, 4.2 Hz, 1H), 2.76 (dt, *J* = 17.3, 7.4 Hz, 1H), 2.58 (dt, *J* = 17.3, 7.1 Hz, 1H), 1.72 – 1.60 (m, 2H), 1.32 (dd, *J* = 7.2, 3.7 Hz, 4H), 0.93 – 0.85 (m, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 201.2, 46.6, 40.3, 31.2, 28.6, 23.4, 22.5, 14.0.

HRMS (ESI) *m/z*, calcd for $C_6H_9O^{79}Br_2$: 254.9015; found 254.9017.

tert-butyl 2,3-dibromopropanoate (67)

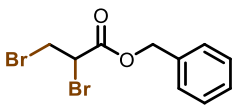


Compound **65** was obtained according to general procedure **GP3** as a colorless oil (93% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.32 (dd, *J* = 11.4, 4.4 Hz, 1H), 3.89 – 3.85 (m, 1H), 3.64 (dd, *J* = 9.8, 4.4 Hz, 1H), 1.51 (s, 9H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 166.5, 83.6, 42.9, 30.2, 27.8.

benzyl 2,3-dibromopropanoate (68)



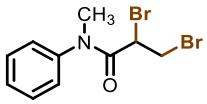
Compound **66** was obtained according to general procedure **GP3** as a light-yellow oil (86% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.39 (d, *J* = 3.3 Hz, 5H), 5.27 (s, 2H), 4.49 (dd, *J* = 11.3, 4.4 Hz, 1H), 3.95 (dd, *J* = 11.3, 9.9 Hz, 1H), 3.69 (dd, *J* = 9.9, 4.4 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 167.5, 134.9, 128.8, 128.8, 128.5, 68.3, 41.1, 29.7.

HRMS (EI) *m/z*, calcd for $C_{10}H_{10}{}^{79}Br_2O_2$: 321.9027; found 321.9019.

2,3-dibromo-N-methyl-N-phenylpropanamide (69)

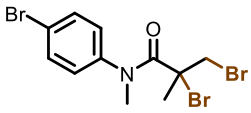


Compound **67** was obtained according to general procedure **GP3** as a white solid (87% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.52 – 7.38 (m, 3H), 7.38 – 7.28 (m, 2H), 4.34 (dd, *J* = 11.6, 3.8 Hz, 1H), 4.16 – 4.04 (m, 1H), 3.52 (ddd, *J* = 9.3, 4.0, 0.9 Hz, 1H), 3.34 (d, *J* = 0.6 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 166.7, 142.5, 130.2, 128.9, 127.7, 39.3, 38.3, 30.7.

2,3-dibromo-N-(4-bromophenyl)-N,2-dimethylpropanamide (70)



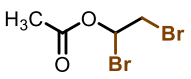
Compound **68** was obtained according to general procedure **GP1** as a white solid (77% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.59 – 7.50 (m, 2H), 7.36 (d, *J* = 8.7 Hz, 2H), 3.93 (dd, *J* = 9.9, 1.1 Hz, 1H), 3.55 (d, *J* = 9.9 Hz, 1H), 3.30 (s, 3H), 1.77 (d, *J* = 1.0 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 166.8, 142.6, 132.7, 130.2, 122.6, 57.3, 42.0, 40.8, 30.0.

HRMS (EI) *m/z*, calcd for $[C_{11}H_{12}{}^{79}Br_3NO+H]^+$: 411.8542; found 411.8538.

1,2-dibromoethyl acetate (71)



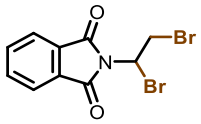
Compound **69** was obtained according to general procedure **GP3** as a colorless oil (68% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 6.71 (dd, *J* = 9.4, 3.4 Hz, 1H), 3.96 – 3.82 (m, 2H), 2.17 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 168.2, 70.7, 33.2, 20.8.

HRMS (EI) calcd for $C_4H_6{}^{79}Br_2O_2$: 243.8735; found 243.8732.

2-(1,2-dibromoethyl)isoindoline-1,3-dione (72)



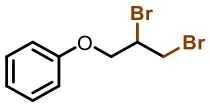
Compound **70** was obtained according to general procedure **GP3** as a white solid (93% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.94 (dd, *J* = 5.5, 3.1 Hz, 2H), 7.81 (dd, *J* = 5.5, 3.1 Hz, 2H), 6.35 (dd, *J* = 11.8, 4.5 Hz, 1H), 4.90 (dd, *J* = 11.8, 10.5 Hz, 1H), 3.99 (dd, *J* = 10.5, 4.5 Hz, 1H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 165.9, 135.1, 131.6, 124.3, 49.5, 31.1.

HRMS (EI) calcd for $C_{10}H_7{}^{79}BrNO_2$–Br: 251.9660; found 251.9658.

(2,3-dibromopropoxy)benzene (73)

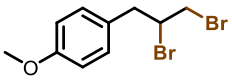


Compound **71** was obtained according to general procedure **GP3** as a colorless oil (87% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.40 – 7.29 (m, 2H), 7.08 – 6.92 (m, 3H), 4.49 – 4.43 (m, 1H), 4.42 – 4.33 (m, 2H), 4.00 – 3.87 (m, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 158.1, 129.7, 121.8, 115.0, 69.2, 47.9, 32.9.

1-(2,3-dibromopropyl)-4-methoxybenzene (74)

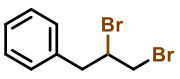


Compound **47** was obtained according to general procedure **GP3** as a colorless oil (55% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.22 (d, *J* = 8.6 Hz, 2H), 6.88 (d, *J* = 8.6 Hz, 2H), 4.39 – 4.26 (m, 1H), 3.85 – 3.76 (m, 4H), 3.62 (dd, *J* = 10.4, 8.9 Hz, 1H), 3.42 (dd, *J* = 14.6, 4.9 Hz, 1H), 3.11 (dd, *J* = 14.6, 7.5 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 158.9, 130.7, 128.9, 114.0, 55.4, 53.0, 41.2, 36.1.

(2,3-dibromopropyl)benzene (75)[CAS: 1586-98-7]

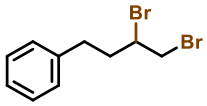


Compound **73** was obtained according to general procedure **GP3** as a colorless oil (90% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.40 – 7.27 (m, 5H), 4.45 – 4.28 (m, 1H), 3.84 (dd, *J* = 10.5, 4.2 Hz, 1H), 3.64 (dd, *J* = 10.5, 8.9 Hz, 1H), 3.52 (dd, *J* = 14.5, 4.8 Hz, 1H), 3.15 (dd, *J* = 14.5, 7.8 Hz, 1H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 137.0, 129.6, 128.6, 127.3, 52.6, 42.1, 36.2.

(3,4-dibromobutyl)benzene (76)

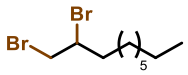


Compound **74** was obtained according to general procedure **GP3** as a colorless oil (90% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.30 (d, *J* = 6.0 Hz, 2H), 7.24 (d, *J* = 7.0 Hz, 3H), 4.12 (tdd, *J* = 9.6, 4.4, 2.9 Hz, 1H), 3.87 (dd, *J* = 10.3, 4.4 Hz, 1H), 3.72 – 3.61 (m, 1H), 2.95 (ddd, *J* = 13.9, 9.3, 4.8 Hz, 1H), 2.76 (ddd, *J* = 13.7, 9.1, 7.2 Hz, 1H), 2.49 (dddd, *J* = 14.6, 9.3, 7.2, 2.9 Hz, 1H), 2.17 – 2.02 (m, 1H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 140.4, 128.7, 128.7, 126.4, 52.2, 37.9, 36.4, 33.1.

1,2-dibromodecane (77)

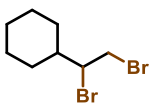


Compound **75** was obtained according to general procedure **GP3** as a colorless oil (92% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.24 – 4.10 (m, 1H), 3.85 (dd, *J* = 10.2, 4.4 Hz, 1H), 3.63 (t, *J* = 10.0 Hz, 1H), 2.13 (dddd, *J* = 14.6, 10.1, 5.5, 3.3 Hz, 1H), 1.86 – 1.69 (m, 1H), 1.63 – 1.50 (m, 1H), 1.29 (dt, *J* = 10.2, 3.3 Hz, 11H), 0.93 – 0.85 (m, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 53.3, 36.5, 36.2, 32.0, 29.5, 29.3, 29.0, 26.9, 22.8, 14.3.

(1,2-dibromoethyl)cyclohexane (78)

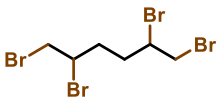


Compound **76** was obtained according to general procedure **GP3** as a colorless oil (90% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.16 (ddd, *J* = 9.0, 5.3, 3.4 Hz, 1H), 3.88 – 3.68 (m, 2H), 1.84 – 1.59 (m, 6H), 1.39 – 1.12 (m, 5H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 60.5, 40.1, 3.3, 31.9, 26.7, 26.2, 26.1, 25.7.

1,2,5,6-tetrabromohexane (79)

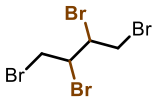


Compound **77** was obtained according to general procedure **GP3** as a colorless oil (81% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.25 – 4.12 (m, 2H), 3.88 (ddd, *J* = 10.4, 4.4, 2.7 Hz, 2H), 3.64 (td, *J* = 10.1, 2.1 Hz, 2H), 2.52 (d, *J* = 8.3 Hz, 1H), 2.43 – 2.28 (m, 1H), 2.17 – 2.03 (m, 1H), 1.91 (ddd, *J* = 10.6, 8.0, 4.5 Hz, 1H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 51.6, 51.2, 35.9, 35.8, 33.8, 33.6.

1,2,3,4-tetrabromobutane (80)



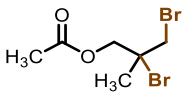
Compound **78** was obtained according to general procedure **GP3** as a colorless oil (92% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.59 (t, *J* = 1.5 Hz, 2H), 4.15 (ddd, *J* = 11.6, 2.5, 1.4 Hz, 2H), 3.95 (ddd, *J* = 11.7, 2.4, 1.3 Hz, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 52.8, 38.0.

HRMS (EI) calcd for $C_4H_6{}^{79}Br_4$: 369.7203; found 369.7200.

2,3-dibromo-2-methylpropyl acetate (81)



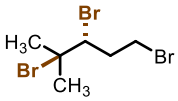
Compound **79** was obtained according to general procedure **GP3** as a colorless oil (94% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.41 (d, *J* = 12.1 Hz, 1H), 4.28 (d, *J* = 12.3 Hz, 1H), 3.98 (d, *J* = 10.4 Hz, 1H), 3.77 (d, *J* = 10.2 Hz, 1H), 2.14 (s, 3H), 1.86 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 170.2, 69.2, 61.4, 39.3, 27.1, 20.9.

HRMS (ESI) *m/z*, calcd for $C_6H_{10}O_2{}^{79}Br$ –Br: 192.9859; found 192.9858.

1,3,4-tribromo-4-methylpentane (82)



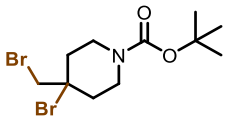
Compound **80** was obtained according to general procedure **GP3** as a colorless oil (91% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.42 (dd, *J* = 11.0, 1.7 Hz, 1H), 3.70 (ddd, *J* = 10.0, 6.3, 3.7 Hz, 1H), 3.60 (td, *J* = 10.0, 5.2 Hz, 1H), 2.88 (dddd, *J* = 15.2, 9.9, 6.3, 1.7 Hz, 1H), 2.43 – 2.23 (m, 1H), 1.99 (s, 3H), 1.83 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 67.0, 63.9, 38.6, 35.0, 31.5, 29.2.

HRMS (ESI) *m/z*, calcd for $C_6H_{11}{}^{79}Br_3$: 319.8411; found 319.84108.

tert-butyl 4-bromo-4-(bromomethyl)piperidine-1-carboxylate (83)



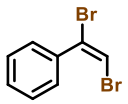
Compound **81** was obtained according to general procedure **GP3** as a light-yellow oil (82% yield) after purification by column chromatography (SiO_2, hexane/EA=9:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.15 (s, 2H), 3.89 (s, 2H), 3.12 (s, 2H), 2.00 (td, *J* = 13.4, 4.8 Hz, 2H), 1.84 (d, *J* = 11.9 Hz, 2H), 1.46 (s, 9H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 154.7, 80.1, 69.2, 43.7, 37.3, 28.6.

HRMS (ESI) *m/z*, calcd for $C_{11}H_{19}O_2N^{79}Br_2$: 354.9777; found 354.9779.

(Z)-(1,2-dibromovinyl)benzene (84)

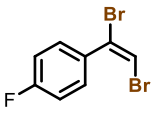


Compound **82** was obtained according to general procedure **GP3** as a colorless oil (92% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): (Mixture of E and Z isomer) δ 7.54 – 7.48 (m, 3H), 7.44 – 7.33 (m, 4H), 6.81 (s, 1H).

^{13}C NMR (75 MHz, $CDCl_3$): (Mixture of E and Z isomer) δ 137.19, 129.55, 129.30, 128.72, 128.42, 127.86, 121.48, 108.96, 103.17.

(E)-1-(1,2-dibromovinyl)-4-fluorobenzene (85)



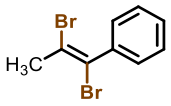
Compound **83** was obtained according to general procedure **GP3** as a colorless oil (90% yield). No further purification was required.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.51 (dd, *J* = 8.9, 5.2 Hz, 2H), 7.08 (dd, *J* = 8.9, 8.5 Hz, 2H), 6.81 (s, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 163.00 (d, *J* = 250.4 Hz), 133.17 (d, *J* = 3.6 Hz), 131.42 (d, *J* = 8.6 Hz), 120.37, 115.54 (d, *J* = 22.0 Hz), 103.55.

^{19}F-NMR (282 MHz, $CDCl_3$): δ 1 -110.44.

(E)-(1,2-dibromoprop-1-en-1-yl)benzene (86)

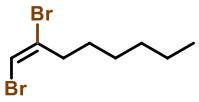


Compound **84** was obtained according to general procedure **GP3** as a colorless oil (95% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.40 – 7.33 (m, 5H), 2.62 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 140.9, 129.2, 128.7, 128.4, 117.4, 117.0, 29.5

(Z)-1,2-dibromooct-1-ene (87)

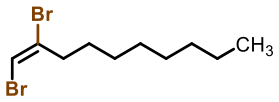


Compound **85** was obtained according to general procedure **GP3** as a colorless oil (83% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 6.40 (s, 1H), 2.68 – 2.53 (m, 2H), 1.62 – 1.52 (m, 2H), 1.36 – 1.28 (m, 7H), 0.92 – 0.86 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 127.2, 102.2, 37.0, 31.7, 28.2, 27.1, 22.7, 14.2.

(Z)-1,2-dibromodec-1-ene (88)

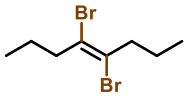


Compound **86**was obtained according to general procedure **GP3** as a colorless oil (90% yield). No further purification was required.

^{1}H NMR (300 MHz, $CDCl_3$): δ 6.40 (s, 1H), 2.59 (t, *J* = 7.1 Hz, 2H), 1.29 (d, *J* = 7.6 Hz, 12H), 0.90 (d, J = 6.4 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 127.2, 102.2, 37.0, 32.0, 29.5, 29.3, 28.5, 27.2, 22.8, 14.3.

(Z)-4,5-dibromooct-4-ene (89)

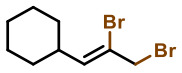


Compound **87** was obtained according to general procedure **GP3** as a colorless oil (89% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 2.75 – 2.57 (m, 4H), 1.69 – 1.52 (m, 4H), 0.94 (t, *J* = 7.4 Hz, 6H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 121.8, 42.7, 21.0, 13.1.

(Z)-(2,3-dibromoprop-1-en-1-yl)cyclohexane (90)

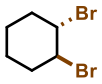


Compound **88** was obtained according to general procedure **GP3** as a colorless oil (75% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 5.92 (dd, *J* = 9.4, 5.3 Hz, 1H), 4.22 (d, *J* = 0.7 Hz, 2H), 2.48 – 2.26 (m, 1H), 1.78 – 1.56 (m, 5H), 1.38 – 1.00 (m, 5H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 139.9, 120.5, 40.8, 39.3, 31.4, 26.0, 25.6.

1,2-dibromocyclohexane (91)

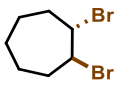


Compound **89** was obtained according to general procedure **GP3** as a colorless oil (83% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.45 (dd, *J* = 5.1, 2.5 Hz, 2H), 2.53 – 2.36 (m, 2H), 1.96 – 1.75 (m, 4H), 1.54 – 1.47 (m, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 55.4, 32.1, 22.5.

1,2-dibromocycloheptane (92)

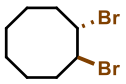


Compound **90** was obtained according to general procedure **GP3** as a colorless oil (87% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.70 – 4.63 (m, 2H), 2.41 – 2.28 (m, 2H), 2.13 – 2.00 (m, 2H), 1.92 – 1.79 (m, 2H), 1.70 – 1.59 (m, 4H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 60.3, 33.3, 26.6, 23.3.

1,2-dibromocyclooctane (93)

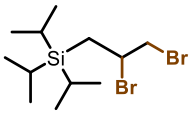


Compound **91** was obtained according to general procedure **GP3** as a colorless oil (89% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.62 – 4.54 (m, 2H), 2.49 – 2.35 (m, 2H), 2.15 – 2.05 (m, 2H), 1.83 (dd, *J* = 9.0, 4.3 Hz, 2H), 1.73 – 1.64 (m, 2H), 1.64 – 1.57 (m, 2H), 1.51 – 1.42 (m, 2H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 61.7, 33.4, 26.1, 25.6.

(2,3-dibromopropyl)triisopropylsilane (94)



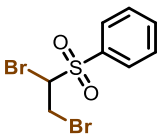
Compound **92** was obtained according to general procedure **GP3** as a colorless oil (91% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.37 (dddd, *J* = 10.1, 8.6, 4.7, 4.0 Hz, 1H), 3.89 (dd, *J* = 10.2, 4.7 Hz, 1H), 3.65 (dd, *J* = 10.2, 8.4 Hz, 1H), 1.88 (dd, *J* = 15.5, 4.0 Hz, 1H), 1.41 – 1.28 (m, 1H), 1.13 – 1.06 (m, 21H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 50.4, 41.4, 19.9, 19.0, 11.5.

HRMS (ESI) *m/z*, calcd for $C_{12}H_{26}{}^{79}Br_2Si$: 356.0171; found 356.0169.

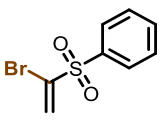
((1,2-dibromoethyl)sulfonyl)benzene (95)



Compound **93** was obtained according to general procedure **GP3** as a white solid. Due to the electron-withdrawing properties of the sulfonyl group, product **93** decomposed slowly to ((1-bromovinyl)sulfonyl)benzene **93a** during the purification on silica gel.

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.01 – 7.96 (m, 2H), 7.80 – 7.72 (m, 1H), 7.67 – 7.61 (m, 2H), 4.94 (dd, *J* = 10.3, 3.2 Hz, 1H), 4.28 (dd, *J* = 11.5, 3.2 Hz, 1H), 3.58 (dd, *J* = 11.5, 10.3 Hz, 1H).

((1-bromovinyl)sulfonyl)benzene (95a)

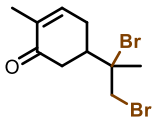


Compound **93** was obtained according to general procedure **GP3** as a white solid (65% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.99 – 7.91 (m, 2H), 7.71 – 7.62 (m, 1H), 7.58 (dd, *J* = 7.4, 1.1 Hz, 2H), 7.11 (d, *J* = 3.1 Hz, 1H), 6.28 (d, *J* = 3.1 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): 136.6, 134.5, 129.3, 129.3, 129.2.

(5R)-(1,2-dibromopropan-2-yl)-2-methylcyclohex-2-en-1-one (96)



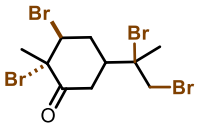
Compound **94** was obtained according to general procedure **GP3** as a colorless oil (84% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 6.74 (s, 1H), 3.95 (dd, *J* = 10.4, 5.8 Hz, 1H), 3.83 (t, *J* = 10.4 Hz, 1H), 2.64 – 2.32 (m, 5H), 1.87 (d, *J* = 5.8 Hz, 3H), 1.79 (d, *J* = 1.7 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 198.6, 198.1, 143.8, 143.5, 135.5, 135.4, 71.2, 71.1, 42.4, 42.2, 40.8, 40.7, 40.7, 40.1, 28.9, 28.5, 28.0, 15.7.

HRMS (EI) *m/z*, calcd for $C_{10}H_{14}O^{79}Br$ –Br: 229.0223; found 229.0227.

2,3-dibromo-5-(1,2-dibromopropan-2-yl)-2-methylcyclohexan-1-one (97)



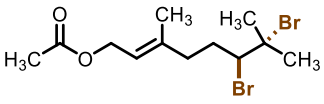
Compound **95** was obtained according to general procedure **GP3** as a colorless oil (76% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.85 – 4.77 (m, 1H), 3.91 – 3.80 (m, 2H), 3.37 (ddd, *J* = 43.1, 14.9, 12.3 Hz, 1H), 3.02 (dddd, *J* = 40.6, 14.2, 11.5, 2.7 Hz, 1H), 2.86 – 2.72 (m, 1H), 2.66 – 2.55 (m, 1H), 2.40 – 2.25 (m, 1H), 2.01 (s, 3H), 1.89 (d, *J* = 14.7 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 58.4, 58.0, 41.0, 40.9, 40.7, 38.1, 37.5, 33.9, 33.0, 29.4, 29.2, 27.9, 27.9.

HRMS (EI) *m/z*, calcd for $C_{10}H_{11}O^{79}Br$ –3HBr: 225.9988; found 225.9983.

(E)-6,7-dibromo-3,7-dimethyloct-2-en-1-yl acetate (98)

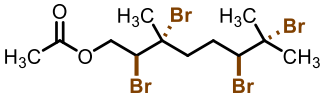


Compound **96** was obtained according to general procedure **GP3** as a colorless oil (74% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 5.44 (q, *J* = 1.3 Hz, 1H), 4.60 (d, *J* = 7.0 Hz, 2H), 4.13 (dd, *J* = 11.0, 1.5 Hz, 1H), 2.58 (dtd, *J* = 14.2, 8.1, 1.5 Hz, 1H), 2.49 – 2.35 (m, 1H), 2.26 – 2.15 (m, 1H), 2.06 (s, 3H), 1.98 (s, 3H), 1.85 (d, *J* = 2.8 Hz, 1H), 1.81 (s, 3H), 1.74 (dd, *J* = 1.4, 0.7 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 171.2, 140.3, 120.2, 68.7, 65.8, 61.3, 37.8, 35.6, 33.7, 28.2, 21.2, 16.5.

2,3,6,7-tetrabromo-3,7-dimethyloctyl acetate (99)



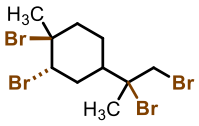
Compound **97** was obtained according to general procedure **GP3** as a light-yellow oil (65% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.85 (ddd, *J* = 12.0, 3.7, 2.6 Hz, 1H), 4.62 – 4.40 (m, 2H), 4.19 – 4.12 (m, 1H), 2.86 – 2.58 (m, 1H), 2.56 – 2.33 (m, 1H), 2.14 (s, 4H), 2.10 – 2.03 (m, 2H), 2.01 – 1.91 (m, 7H), 1.86 – 1.82 (m, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 170.6, 69.1, 68.5, 68.1, 67.2, 67.2, 66.1, 65.6, 61.2, 40.1, 40.0, 35.6, 35.4, 32.8, 32.5, 31.4, 31.2, 28.5, 28.1, 21.0.

HRMS (DIP-EI-MS) *m/z*, calcd for $C_{12}H_{19}O_2{}^{79}Br_4$: 510.8119; found 510.8118.

1,2-dibromo-4-(1,2-dibromopropan-2-yl)-1-methylcyclohexane (100)



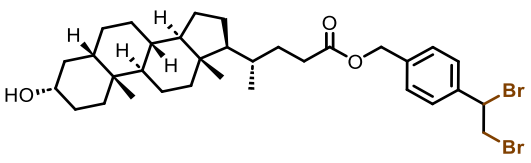
Compound **98** was obtained according to general procedure **GP3** as a colorless oil (73% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.79 – 4.70 (m, 1H), 4.15 – 3.74 (m, 2H), 2.87 – 2.52 (m, 1H), 2.32 – 1.70 (m, 12H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 71.5, 71.4, 69.4, 69.3, 60.5, 60.2, 41.6, 41.3, 38.6, 38.5, 35.8, 35.6, 35.1, 35.1, 34.8, 34.0, 29.2, 29.2, 25.0, 24.4.

HRMS (EI) *m/z*, calcd for $C_{10}H_{16}{}^{79}Br$ –3Br: 215.0430; found 215.0432.

4-(1,2-dibromoethyl)benzyl-(4R)-4-((3R,5R,8R,9S,10S,13R,14S,17R)-3-hydroxy-10,13-dimethylhexadecahydro-1H-cyclopenta[a]phenanthren-17-yl)pentanoate (101)



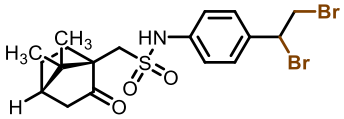
Compound **99** was obtained according to general procedure **GP3** as a colorless oil (68% yield) after purification by column chromatography (SiO_2, hexane/EA=3:2).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.44 – 7.33 (m, 4H), 5.21 – 5.05 (m, 3H), 4.20 – 3.94 (m, 2H), 3.62 (tt, *J* = 10.4, 4.5 Hz, 1H), 2.48 – 2.21 (m, 2H), 1.99 – 1.72 (m, 6H), 1.61 – 1.50 (m, 2H), 1.39 (d, *J* = 7.4 Hz, 9H), 1.32 – 1.15 (m, 5H), 1.12 (d, *J* = 9.3 Hz, 5H), 0.91 (d, *J* = 5.6 Hz, 6H), 0.62 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 174.2, 138.6, 137.4, 128.7, 128.0, 72.0, 65.6, 56.6, 56.1, 50.5, 42.9, 42.2, 40.6, 40.3, 36.6, 36.0, 35.5, 35.5, 35.0, 34.7, 31.4, 31.1, 30.7, 28.3, 27.3, 26.6, 24.4, 23.5, 21.0, 18.4, 12.2.

HRMS (ESI) *m/z*, calcd for $C_{33}H_{48}{}^{79}Br_2O_3$: 650.1970; found 650.1967.

N-(4-(1,2-dibromoethyl)phenyl)-1-((1R,4S)-7,7-dimethyl-2-oxobicyclo[2.2.1]heptan-1-yl)methanesulfonamide (102)



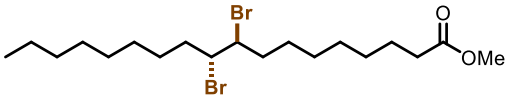
Compound **100** was obtained according to general procedure **GP3** as a colorless oil (81% yield) after purification by column chromatography (SiO_2, hexane/EA=7:3).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.90 (s, 1H), 7.40 – 7.27 (m, 4H), 5.13 (dd, *J* = 10.7, 5.4 Hz, 1H), 4.18 – 3.90 (m, 2H), 3.38 (d, *J* = 15.6 Hz, 1H), 2.91 (d, *J* = 15.3 Hz, 1H), 2.53 – 2.38 (m, 1H), 2.18 – 2.00 (m, 5H), 1.55 – 1.41 (m, 1H), 1.32 – 1.19 (m, 1H), 0.97 (s, 3H), 0.85 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 217.6, 138.4, 135.5, 128.9, 121.8, 121.8, 59.8, 50.3, 49.7, 49.2, 43.1, 42.9, 35.0, 34.9, 27.7, 27.1, 19.9, 19.3.

HRMS (ESI) *m/z*, calcd for $C_{18}H_{23}{}^{79}BrNO_3$–Br: 412.0582; found 412.0580.

methyl 9,10-dibromooctadecanoate (103)

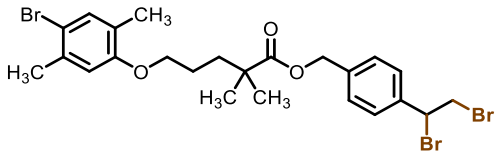


Compound **101** was obtained according to general procedure **GP3** as a colorless oil (77% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.21 (s, 1H), 4.16 (s, 1H), 3.64 (s, 3H), 2.28 (t, *J* = 7.5 Hz, 2H), 1.99 (dd, *J* = 7.7, 4.4 Hz, 2H), 1.81 (td, *J* = 9.6, 5.0 Hz, 2H), 1.28 (d, *J* = 15.4 Hz, 22H), 0.87 (d, *J* = 6.5 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 174.2, 59.8, 59.8, 51.5, 51.5, 35.0, 34.9, 34.1, 31.9, 29.5, 29.3, 29.1, 28., 28.7, 27.9, 27.8, 25.0, 22.7, 14.2.

4-(1,2-dibromoethyl)benzyl 5-(4-bromo-2,5-dimethylphenoxy)-2,2-dimethylpentanoate (104)



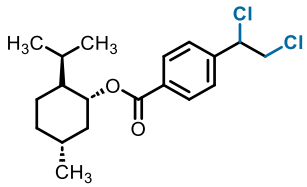
Compound **102** was obtained according to general procedure **GP3** as a colorless oil (55% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.41 – 7.32 (m, 4H), 7.25 (d, *J* = 0.9 Hz, 1H), 6.63 (s, 1H), 5.18 – 5.08 (m, 3H), 4.12 – 3.97 (m, 2H), 3.86 (t, *J* = 5.4 Hz, 2H), 2.33 (s, 3H), 2.13 (s, 3H), 1.80 – 1.66 (m, 4H), 1.26 (s, 6H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 177.6, 156.3, 138.5, 137.5, 135.7, 133.8, 128.3, 128.0, 126.4, 114.7, 113.6, 68.3, 65.6, 50.4, 42.3, 37.2, 35.0, 25.3, 25.2, 23.0, 15.6.

HRMS (DIP) *m/z*, calcd for $C_{24}H_{29}O_3{}^{79}Br_3$: 601.9661; found 601.9685.

(1R,2R,5R)-2-isopropyl-5-methylcyclohexyl 4-(1,2-dichloroethyl)benzoate (105)



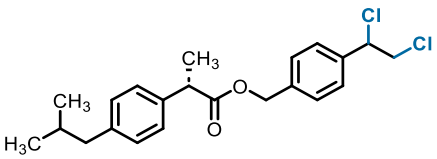
Compound **103** was obtained according to general procedure **GP3** as a colorless oil (89% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.07 (d, *J* = 8.4 Hz, 2H), 7.49 (d, *J* = 8.4 Hz, 2H), 5.03 (dd, *J* = 8.3, 6.2 Hz, 1H), 4.94 (td, *J* = 10.9, 4.4 Hz, 1H), 4.01 (dd, *J* = 11.3, 6.2 Hz, 1H), 3.92 (dd, *J* = 11.3, 8.3 Hz, 1H), 2.11 (d, *J* = 11.7 Hz, 1H), 1.95 (pd, *J* = 7.0, 2.8 Hz, 1H), 1.79 – 1.67 (m, 2H), 1.59 (d, J = 3.1 Hz, 1H), 1.52 (t, *J* = 3.1 Hz, 1H), 1.17 – 1.03 (m, 2H), 0.92 (dd, *J* = 6.8, 4.0 Hz, 7H), 0.79 (d, *J* = 7.0 Hz, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 165.5, 142.6, 131.8, 130.2, 127.7, 75.3, 60.9, 48.1, 47.4, 41.1, 34.5, 31.6, 26.7, 23.8, 22.2, 20.9, 16.7.

HRMS (HRGCMS) *m/z*, calcd for $C_{19}H_{26}O_2{}^{35}Cl$ –Cl: 321.1616; found 321.1620.

4-(1,2-dichloroethyl)benzyl (2S)-2-(4-isobutylphenyl)propanoate (106)



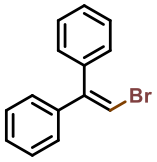
Compound **104** was obtained according to general procedure **GP3** as a colorless oil (68% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.34 (d, *J* = 8.2 Hz, 2H), 7.25 – 7.16 (m, 4H), 7.09 (d, *J* = 8.2 Hz, 2H), 5.11 (s, 2H), 4.97 (dd, *J* = 8.1, 6.4 Hz, 1H), 4.05 – 3.82 (m, 2H), 3.76 (q, *J* = 7.1 Hz, 1H), 2.46 (d, *J* = 7.1 Hz, 2H), 1.85 (dp, *J* = 13.5, 6.8 Hz, 1H), 1.53 (t, *J* = 7.5 Hz, 4H), 0.92 (s, 3H), 0.90 (s, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 174.6, 140.8, 137.8, 137.7, 137.4, 129.5, 128.2, 127.7, 127.4, 65.8, 61.4, 48.3, 45.3, 45.2, 30.3, 22.5, 18.5.

HRMS (HRGCMS) *m/z*, calcd for $C_{22}H_{26}O_2{}^{35}Cl$: 392.1310; found 392.1307.

(2-bromoethene-1,1-diyl)dibenzene (107)

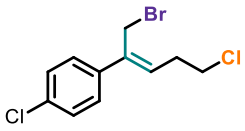


Compound **105** was obtained according to general procedure **GP3** as a colorless oil (85% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.35 – 7.05 (m, 10H), 6.68 (s, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 147.0, 140.8, 139.2, 129.8, 128.6, 128.4, 128.2, 128.1, 127.8, 105.3.

(Z)-1-(1-bromo-5-chloropent-2-en-2-yl)-4-chlorobenzene (110)



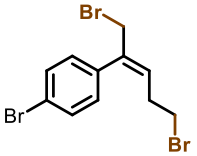
Compound **107** was obtained according to general procedure **GP1** as a colorless oil (85% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.42 – 7.29 (m, 4H), 5.98 (t, *J* = 7.4 Hz, 1H), 4.32 (s, 2H), 3.69 (t, *J* = 6.7 Hz, 2H), 2.78 (q, 138.43, 137.98, 133.83, 130.31, 128.81, 127.50, 43.22, 31.97, 28.44. = 6.8 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.4, 138.0, 133.8, 130.3, 128.8, 127.5, 43.2, 32.0, 28.4.

HRMS (EI) *m/z*, calcd for $C_{11}H_{11}{}^{79}Br^{35}Cl_2$: 291.9416; found 291.9419.

(E)-1-bromo-4-(1,5-dibromopent-2-en-2-yl)benzene (111)



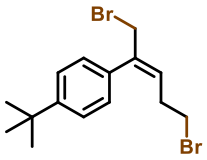
Compound **109** was obtained according to general procedure **GP3** as a colorless oil (90% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.49 (d, *J* = 8.6 Hz, 2H), 7.33 (d, *J* = 8.6 Hz, 2H), 5.95 (t, *J* = 7.3 Hz, 1H), 4.31 (s, 2H), 3.53 (t, *J* = 6.8 Hz, 2H), 2.88 (q, *J* = 6.9 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 138.9, 138.0, 131.8, 131.3, 127.9, 122.1, 32.0, 31.2, 28.3.

HRMS (EI) *m/z*, calcd for $C_{11}H_{11}{}^{79}Br_3$: 379.8411; found 379.8409.

(E)-1-(tert-butyl)-4-(1,5-dibromopent-2-en-2-yl)benzene (113)



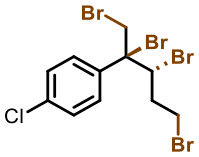
Compound **110** was obtained according to general procedure **GP3** as a colorless oil (88% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.43 – 7.36 (m, 4H), 5.96 (t, *J* = 7.3 Hz, 1H), 4.36 (s, 2H), 3.53 (t, *J* = 6.9 Hz, 2H), 2.89 (q, *J* = 7.0 Hz, 2H), 1.33 (s, 9H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 151.1, 138.6, 137.0, 130.1, 125.8, 125.7, 34.7, 32.2, 31.4, 31.4, 28.8.

HRMS (EI) *m/z*, calcd for $C_{15}H_{20}{}^{79}Br_2$: 357.9926; found 357.9935.

1-chloro-4-(1,2,3,5-tetrabromopentan-2-yl)benzene (114)



Compound **11** was obtained according to general procedure **GP3** as a colorless oil (83% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

111a: ^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.62 (d, *J* = 8.8 Hz, 2H), 7.36 (d, *J* = 8.9 Hz, 2H), 5.10 (dd, *J* = 10.6, 1.7 Hz, 1H), 4.50 (d, *J* = 10.5 Hz, 1H), 4.03 (d, *J* = 10.4 Hz, 1H), 3.79 – 3.57 (m, 2H), 2.64 – 2.47 (m, 1H), 2.31 (dddd, *J* = 16.0, 11.1, 5.1, 1.7 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.3, 135.2, 130.6, 128.7, 74.6, 58.8, 45.1, 39.0, 31.4.

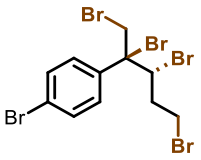
HRMS (ESI) *m/z*, calcd for $[C_{11}H_{11}{}^{79}Br_4{}^{35}Cl\text{-}HBr]$: 413.8021; found 413.8025.

111b: ^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.63 (d, *J* = 8.8 Hz, 2H), 7.35 (d, *J* = 8.8 Hz, 2H), 5.00 (dd, *J* = 11.0, 1.9 Hz, 1H), 4.33 (d, *J* = 2.4 Hz, 2H), 3.69 – 3.55 (m, 2H), 2.72 (dddd, *J* = 15.0, 9.7, 6.5, 1.9 Hz, 1H), 2.22 – 2.07 (m, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 135.7, 135.4, 130.9, 128.4, 73.6, 59.6, 42.9, 37.8, 30.9.

HRMS (ESI) *m/z*, calcd for [$C_{11}H_{11}{}^{79}Br_4{}^{35}Cl$-HBr]: 413.8021; found 413.8025.

1-bromo-4-(1,2,3,5-tetrabromopentan-2-yl)benzene (115)



Compound **112** was obtained according to general procedure **GP3** as a colorless oil (80% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

112a: **^{1}H-NMR** (300 MHz, $CDCl_3$): δ 7.63 – 7.44 (m, 4H), 5.09 (dd, *J* = 10.7, 1.7 Hz, 1H), 4.49 (d, *J* = 10.5 Hz, 1H), 4.03 (d, *J* = 10.4 Hz, 1H), 3.78 – 3.58 (m, 2H), 2.56 (ddt, *J* = 15.8, 10.6, 3.6 Hz, 1H), 2.31 (dddd, *J* = 16.0, 11.1, 5.1, 1.8 Hz, 1H).

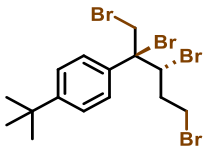
^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.9, 131.7, 130.9, 123.5, 74.7, 58.7, 45.0, 39.0, 31.4.

112b: **^{1}H-NMR** (300 MHz, $CDCl_3$): δ 7.54 (q, *J* = 8.9 Hz, 4H), 4.99 (dd, *J* = 11.1, 1.9 Hz, 1H), 4.39 – 4.26 (m, 2H), 3.68 – 3.54 (m, 2H), 2.80 – 2.63 (m, 1H), 2.14 (ddt, *J* = 15.1, 11.0, 4.3 Hz, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 136.3, 131.4, 131.1, 123.7, 73.7, 59.5, 42.8, 37.8, 30.9.

HRMS (DIP EI) *m/z*, calcd for $C_{11}H_{11}{}^{79}Br_4$: 458.7553; found 458.7556.

1-(tert-butyl)-4-(1,2,3,5-tetrabromopentan-2-yl)benzene (116)



Compound **113** was obtained according to general procedure **GP3** as a colorless oil (77% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

113a: **^{1}H NMR** (300 MHz, $CDCl_3$): δ 7.57 (d, *J* = 8.7 Hz, 2H), 7.36 (d, *J* = 8.7 Hz, 2H), 5.21 – 5.11 (m, 1H), 4.54 (d, *J* = 10.2 Hz, 1H), 4.06 (d, *J* = 10.2 Hz, 1H), 3.79 – 3.58 (m, 2H), 2.61 – 2.49 (m, 1H), 2.42 (dddd, *J* = 15.9, 10.7, 5.4, 1.9 Hz, 1H), 1.33 (s, 9H).

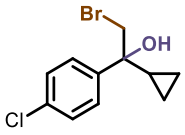
^{13}C NMR (101 MHz, $CDCl_3$): δ 152.2, 134.6, 128.9, 125.4, 75.7, 59.4, 45.7, 39.1, 34.7, 31.6, 31.3.

113b: **^{1}H NMR** (300 MHz, $CDCl_3$): δ 7.61 (d, *J* = 8.7 Hz, 2H), 7.37 (d, *J* = 8.7 Hz, 2H), 5.04 (dd, *J* = 11.1, 1.9 Hz, 1H), 4.45 (d, *J* = 11.4 Hz, 1H), 4.31 (d, *J* = 11.4 Hz, 1H), 3.68 – 3.53 (m, 2H), 2.77 (dt, *J* = 14.9, 7.6 Hz, 1H), 2.21 – 2.06 (m, 1H), 1.33 (s, 10H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 152.3, 133.9, 129.2, 125.2, 74.4, 60.2, 43.6, 37.8, 34.7, 31.3, 31.2.

HRMS (DIP EI) *m/z*, calcd for $C_{15}H_{20}{}^{79}Br_4$: 515.8299; found 515.8296.

2-bromo-1-(4-chlorophenyl)-1-cyclopropylethan-1-ol (117)



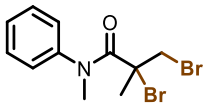
Compound **114** was obtained according to general procedure **GP3** as a colorless oil (10% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.42 – 7.29 (m, 4H), 3.93 (d, *J* = 10.6 Hz, 1H), 3.82 (d, *J* = 10.6 Hz, 1H), 2.31 (s, 1H), 1.36 – 1.15 (m, 2H), 0.61 – 0.48 (m, 2H), 0.43 – 0.31 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 142.3, 133.5, 128.5, 127.2, 73.6, 45.1, 20.3, 2.3, 1.1.

HRMS (DIP EI) *m/z*, calcd for $C_{11}H_{12}{}^{79}Br^{35}ClO$: 273.9760; found 273.9758.

2,3-dibromo-N,2-dimethyl-*N*-phenylpropanamide (119)



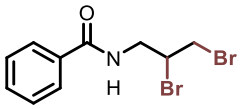
Compound **116** was obtained according to general procedure **GP3** as white solid (78% yield) after purification by column chromatography (SiO_2, hexane/EA=4:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.49 – 7.33 (m, 5H), 3.99 (dd, *J* = 9.7, 1.0 Hz, 1H), 3.52 (d, *J* = 9.7 Hz, 1H), 3.31 (s, 3H), 1.69 (d, *J* = 1.0 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 166.9, 143.5, 129.4, 128.7, 128.5, 57.5, 42.0, 41.1, 29.8.

HRMS (EI) *m/z*, calcd for $[C_{11}H_{13}{}^{79}Br_2NO+H]^+$: 346.9437; found 333.9436.

N-(2,3-dibromopropyl)benzamide (122)

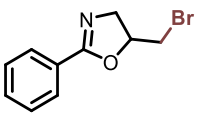


Compound **119** was obtained according to general procedure **GP3** as a white solid (73% yield) after purification by column chromatography (SiO_2, hexane/EA=3:2).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.83 – 7.76 (m, 2H), 7.58 – 7.51 (m, 1H), 7.49 – 7.41 (m, 2H), 6.58 (s, 1H), 4.53 – 4.42 (m, 1H), 4.19 (ddd, *J* = 14.6, 6.4, 4.0 Hz, 1H), 3.89 – 3.67 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 167.7, 133.9, 132.1, 128.9, 127.2, 51.6, 44.8, 33.7.

5-(bromomethyl)-2-phenyl-4,5-dihydrooxazole (123)

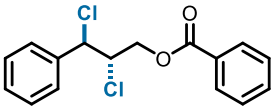


Compound **47** was obtained according to general procedure **GP3** as a white solid (8% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.00 – 7.89 (m, 2H), 7.52 – 7.36 (m, 3H), 4.93 (dtd, *J* = 9.6, 6.5, 5.0 Hz, 1H), 4.19 (dd, *J* = 15.2, 9.6 Hz, 1H), 3.92 (dd, *J* = 15.2, 6.7 Hz, 1H), 3.58 – 3.46 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ 163.8, 131.7, 128.5, 128.3, 127.5, 78.0, 59.5, 33.8.

anti-2,3-dichloro-3-phenylpropyl benzoate (125)



Compound **122-anti** was obtained according to general procedure **GP2** as a colorless oil (85% yield) after purification by column chromatography (SiO_2, hexane/EA=20:1).

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.13 – 8.04 (m, 2H), 7.65 – 7.54 (m, 1H), 7.52 – 7.36 (m, 7H), 5.16 (d, *J* = 8.4 Hz, 1H), 4.80 (dd, *J* = 4.7, 1.2 Hz, 2H), 4.65 (dt, *J* = 8.4, 4.7 Hz, 1H).

^{13}C NMR (75 MHz, $CDCl_3$): δ 166.0, 137.7, 133.5, 129.9, 129.6, 129.3, 128.8, 128.7, 128.1, 65.7, 62.3, 61.8.

6. References

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List of Common Abbreviations

aq.	Aqueous
eq.	Equivalence/ Equivalent(s)
equiv.	Equivalence/ Equivalent(s)
HAT	Hydrogen Atom Transfer
HPLC	High Performance Liquid Chromatography
HRMS	High Resolution Mass Spectrometry
GC	Gas chromatography
GC-MS	Gas chromatography-Mass spectrometry
IR	Infrared spectroscopy
UV	Ultraviolet spectroscopy
NMR	Nuclear Magnetic Resonance
rt	Room temperature (ca. 25 °C)
sat.	Saturated
SET	Single Electron Transfer
sol.	Solution
THF	Tetrahydrofuran
TLC	Thin Layer Chromatography
TEMPO	(2,2,6,6-Tetramethylpiperidin-1-yl)oxyl
PINO	Phthalimide-N-oxyl
ABNO	9-azabicyclo[3.3.1]nonane N-oxyl
e^-	Electron
conc.	Concentration
d	Doublet
δ	Chemical shift
DMF	N,N-Dimethylformamide
DCM	Dichloromethane
DMSO	Dimethyl sulfoxide
EtOAc	Ethyl acetate
MeOH	Methanol
TEA	Triethylamine
q	Quadruplet
s	Singlet
*t*Bu	Tert-Butyl
RLT	Radical Ligand Transfer

Hz	Hertz
h	Hour(s)
g	Gram(s)
mg	Milligram(s)
mL	Millilitre(s)
min.	Minute(s)
mmol	Millimole
ppm	parts per million
µL	Microliter
calcd.	Calculated
Boc	Tert-butoxy carbonyl
$AgNO_2$	Silver nitrite
$NaNO_2$	Sodium nitrite
H_2SO_4	Sulfuric Acid
HNO_3	Nitric acid
$Fe(NO_3)_3$	Iron(III) nitrate
t-BuONO	Tert-Butyl nitrite
Al_2O_3	Aluminium oxide
SiO_2	Silicon dioxide