

REVIEW OPEN ACCESS

Bromonitroalkanes in Organic Synthesis

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ABSTRACT

α,α' -Bromonitroalkanes (BNAs) exhibit chameleon-like reactivity, serving as carbene, radical, carbanion, and carbocation synthons. This mini-review summarizes the different reaction modes and highlights recent developments in thermal and photochemical processes. In particular, the same starting materials can yield divergent products depending on the reaction conditions, catalysts, and additives employed, making the contributions of individual research groups even more valuable when considered together. Differences and similarities to related α,α' -bromonitroalkenes are briefly discussed, noting that additions to their double bond generate the BNAs as intermediates.

1 | Introduction

α,α' -Bromonitroalkanes (BNAs) constitute a unique class of bifunctional building blocks that combine the nucleophilic reactivity of nitroalkanes with electrophilic features imparted by a vicinal halogen substituent. Although underexplored compared to their nonhalogenated counterparts, bromonitroalkanes have recently experienced a renaissance, driven by advances in both thermal and photochemical synthesis. This mini-review summarizes established and emerging strategies for preparing and applying BNAs and, in comparison, α,α' -bromonitroalkenes, highlighting similarities and differences between these two compound classes. Moreover, reactions of α,α' -bromonitroalkenes often form BNAs as intermediates, which are therefore also discussed. However, for an in-depth analysis of the chemistry of α,α' -bromonitroalkenes, we refer the reader to the excellent review by Halimehjani et al. [1] Here, we focus on the versatile reactivity of BNAs in ionic reaction pathways, as well as the rapidly expanding field of photocatalysis, where bromonitroalkanes serve as efficient precursors for radical reactions. We limit this review to reactions in which the nitro group is preserved in the product, omitting processes that transform this functionality, for example, in Nef-reactions to carbonyl compounds [2].

2 | Synthesis of BNAs

Nitro compounds have long occupied a central position in organic synthesis because of their rich, tunable reactivity and their role as key intermediates in carbon–carbon bond-forming processes. In contrast, their α -halogenated analogs have received comparatively less attention in synthesis, despite exhibiting a range of useful properties as reactive intermediates or synthetic reagents. BNAs are the preferred choice over their chlorinated or iodinated analogs for ease of synthesis, stability, and physical properties. In particular, α -bromonitromethane is convenient to handle (b.p. 146–148 °C) and is commercially available or can be readily synthesized by the direct bromination of nitromethane (Scheme 1a). Johnston et al. developed a procedure [9] that allows large-scale synthesis of simple alkyl- or aryl-substituted BNAs and, notably, describe each step in great detail, including potential pitfalls and hazards. For cyclic or structurally complex BNAs, a reliable strategy involves converting the corresponding ketone **4** into its oxime **3**, followed by reaction with potassium bromide and Oxone (Scheme 1b) [3, 4].

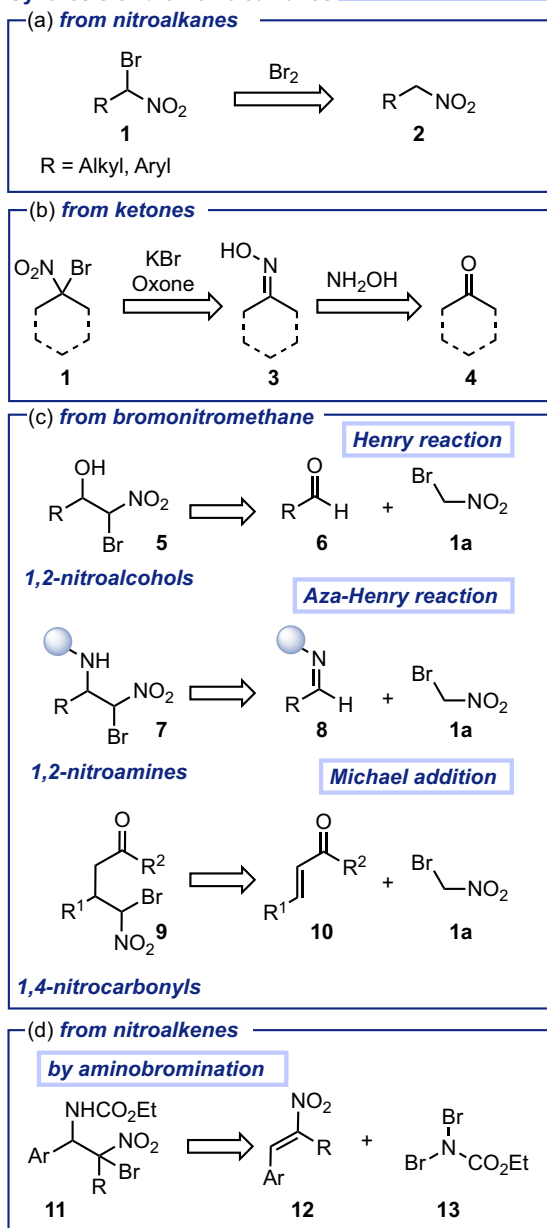
BNAs can also be obtained through carbon–carbon bond-forming reactions of nitroalkanes to C=X moieties, including

In memoriam Henning Hopf.

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Synthesis of bromonitroalkanes



SCHEME 1 | Synthesis of simple and complex BNAs: (a) by bromination of nitroalkanes [1]; (b) from ketones through oxime formation [3, 4]; from bromonitromethane through Henry [5], Aza-Henry reaction [6] or Michael addition [7]; and (d) by aminobromination from nitroalkenes [8].

Henry (nitroaldol) [5], Aza-Henry (nitro-Mannich) [6], or Michael additions of nitronates [7] (Scheme 1c). Less common approaches include the aminobromination of nitroalkenes, for example, the formation of bromonitroamines **11** starting from β -nitrostyrenes **12** and N,N -dibromourethane **13** mediated by catalytic amounts of potassium carbonate (Scheme 1d) [8].

2.1 | BNAs as Nucleophiles

BNAs exhibit chemical reactivities closely related to those of their parent nitroalkanes. The bromo substituent increases the acidity of the adjacent methylene group (Figure 1), facilitating formation of the corresponding nitronate salts, which serve as strong

pK_a values

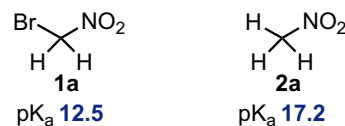


FIGURE 1 | pK_a values of bromonitromethane (**1a**) and nitromethane (**2a**) in DMSO [10].

nucleophiles. At the same time, bromide is a good leaving group; thus, BNAs can also serve as electrophiles and attractively, both reaction modes can be combined, mimicking carbene reactivity.

As with nitroalkanes, BNAs can be used to synthesize nitro compounds via Henry or Aza-Henry reactions, yielding β -nitroalcohols **5** or β -nitroamines **7** (Scheme 1c). Alternatively, BNAs enable base-free generation of nitronate salts or nitroalkyl radicals using samarium(II) iodide or indium (Scheme 2), which can act as Lewis acids and/or single-electron-transfer (SET) reagents. Switching from ionic to radical reaction modes can offer advantages, that is, overcoming steric hindrance near the newly formed carbon-carbon bond [13] by proceeding through early transition states. Furthermore, when chiral additives are employed, enantio- or diastereoselectivity is often significantly enhanced compared to the corresponding nitroalkane reactions [13–15].

Instructive studies by Soengas and Silva corroborate these rationales: both SmI_2 and indium promote nitroaldol reactions (Scheme 2) [11, 12]. Employing SmI_2 , it was postulated that traces of iodide trigger the dehalogenative formation of nitronate that adds by an ionic pathway to aldehydes being activated by the Lewis acidity of $Sm(II)$ or $Sm(III)$. Because of a tight transition state, SmI_2 typically gives poor yields with sterically demanding BNAs such as **1b** or **1c**. In contrast, stoichiometric indium enables the efficient use of highly substituted substrates [11]. It was argued that the mechanism changes, that is, indium promotes single-electron reduction of bromonitromethane, and the resulting organoindium species adds to the aldehyde via a looser transition state, making it less sensitive to steric factors. Adding elemental zinc reduces the required indium amount to catalytic quantities (Scheme 2) by reductively regenerating the active indium species [12].

Beyond the formation of 1,2-nitroalcohols, samarium iodide can also be used to generate the corresponding nitroalkenes **12** through debromination/dehydration of the Henry product (Scheme 3) [16].

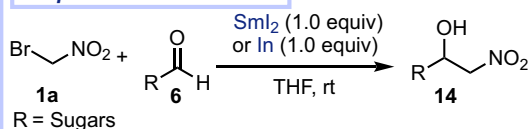
2.2 | BNAs as Bifunctional Nucleophile/Electrophiles (Carbene Equivalents)

Another prototypical transformation involves the Michael addition of BNAs to electron-deficient olefins under basic conditions. Unlike unsubstituted nitroalkanes, the bromine atom can subsequently act as a leaving group, enabling further bond-forming and cyclization reactions (Scheme 4). This reactivity has been demonstrated particularly for the synthesis of nitrocyclopropanes [17–19].

Henry reaction with bromonitroalkanes

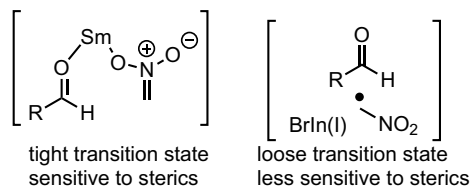
Soengas, 2012

simple bromonitroalkanes

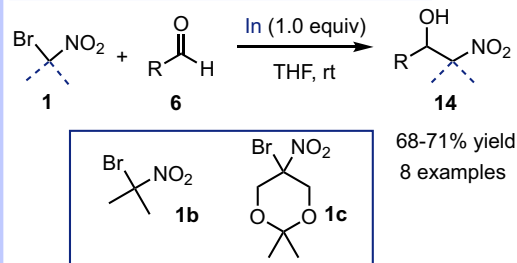


SmI₂: 75-91% yield, *anti*/*syn* 76:24 - 100:0
7 examples

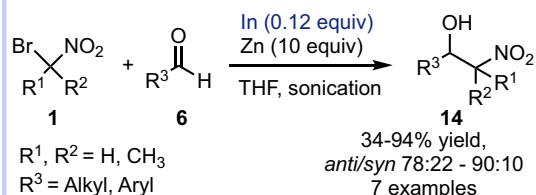
In: 71-88% yield, *anti*/*syn* 78:22 - 90:10
7 examples



sterically demanding bromonitroalkanes



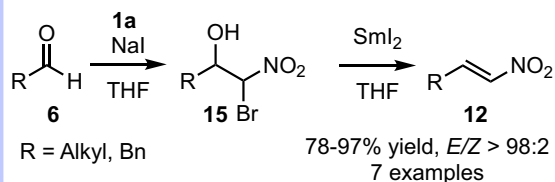
Silva, 2012



SCHEME 2 | Application of SmI₂ or indium for the synthesis of 1, 2-nitroalcohols [11, 12].

Synthesis of Nitroalkene

Concellon, 2007

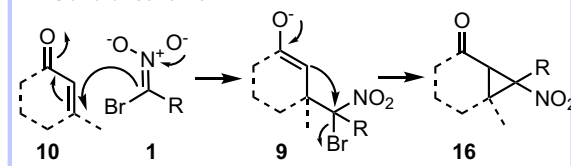


SCHEME 3 | Synthesis of nitroalkenes by Henry reaction with bromonitromethane (1a) followed by a debromination/dehydration sequence with samarium iodide [16].

For instance, Norris et al. [17] reported the cyclopropanation of *N*-benzylmaleimide (17) with bromonitromethane (1a) to afford the 6-nitro-3-azabicyclo [3.1.0]hexane core 18, a direct precursor to the antibiotic trovafloxacin (19), with almost exclusive formation of the *exo*-diastereomer (Scheme 5).

Addition on Michael acceptors

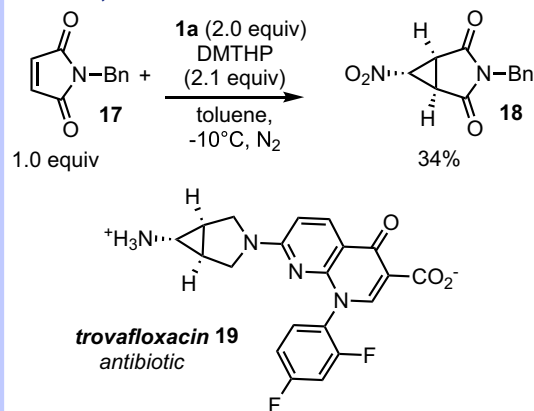
General scheme



SCHEME 4 | General reaction mechanism for the nucleophilic attack of bromonitroalkanes on a Michael acceptor followed by cyclopropanation.

Cyclopropanations

Norris, 2000



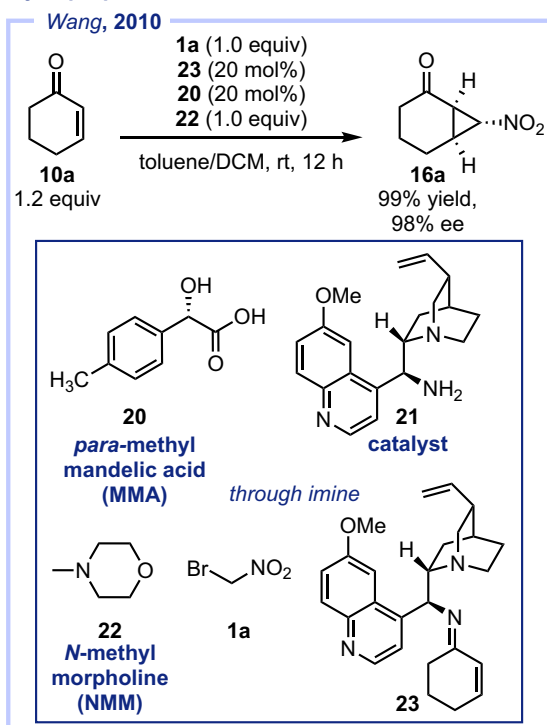
SCHEME 5 | Cyclopropanation of *N*-benzylmaleimide (17) with bromonitromethane (1a) for the synthesis of trovafloxacin precursor 18 [17].

Enantioselective variants have been developed employing chiral bases or bifunctional catalysts. Wang and coworkers [18] achieved the cyclopropanation of cyclohexanone (10a) in quantitative yield and with up to 98% ee using the chiral quinine catalyst 21. In this system, imine formation between the catalyst and the Michael acceptor 23 enables a precise orientation of the reaction partners with the quinine framework, creating a chiral environment that ensures effective preorganization prior to the nucleophilic attack (Scheme 6).

Similarly, Lin et al. [19] developed an efficient protocol for synthesizing spironitrocyclopropanes with excellent diastereo- and enantioselectivities (Scheme 7), employing the quinidine-derived bifunctional amine-thiourea catalyst 26. Thioureas form strong hydrogen bonds with nitro groups, particularly in nonpolar solvents such as toluene [20]. The sterically demanding quinidine framework further enhances chiral recognition. The reaction outcome was highly sensitive to water concentration. In the absence of water, only minimal conversion was observed, whereas excess of water inhibited product formation as well. Adding one equivalent of water afforded optimal reactivity, likely by assisting hydrogen-bond organization without interfering with catalyst coordination.

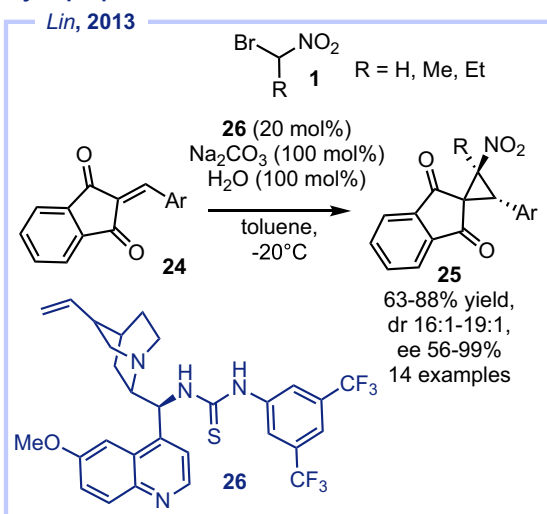
While many reports describe the use of bromonitroalkanes for the synthesis of cyclopropanated products, significantly fewer examples exist for the analogous aziridine formation via an Aza-Henry reaction.

Cyclopropanations



SCHEME 6 | Enantioselective cyclopropanation of cyclohexanone (**10a**) and bromonitromethane (**1a**) using quinine **21** as catalyst [18].

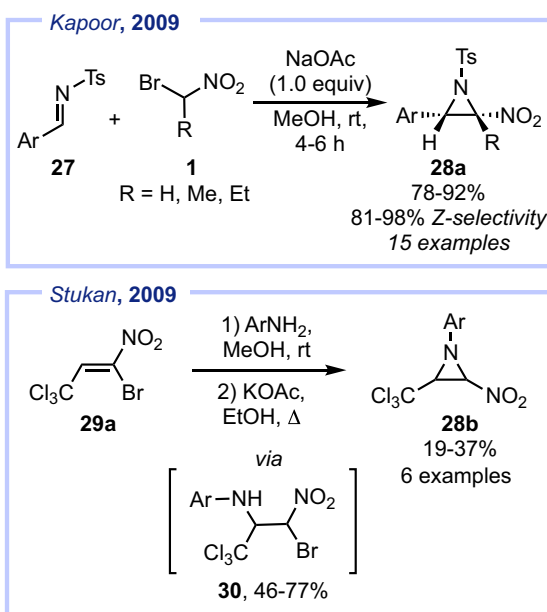
Cyclopropanations



SCHEME 7 | Enantio- and diastereoselective cyclopropanation between 2-arylidene-1,3-indandiones **24** and bromonitroalkanes **1** towards spironitrocyclopropanes **25** [19].

Kapoor and coworkers [21] reported a rare example in which the initially formed Aza–Henry product undergoes in situ cyclization through intramolecular nucleophilic attack of the amine on the brominated carbon atom, affording nitro aziridines **28a** in good yields and with high selectivity. Similarly, Stukan and coworkers [22] demonstrated the formation of nitro aziridines via nucleophilic attack of anilides on bromonitroalkene **29a**, yielding initially isolable bromonitromethanes **30**. These were subsequently cyclized to the desired aziridines **28b** (Scheme 8).

Aziridinations



SCHEME 8 | Example for aziridine formation through Aza–Henry reaction by Kapoor [21] and Stukan [22].

3 | Bromonitroalkenes

In addition to BNAs **1**, the corresponding α,α -bromonitroalkenes **33** also play a significant role in organic synthesis [23]. In contrast to bromonitroalkanes **1**, which typically act as nucleophiles upon deprotonation, bromonitroalkenes **33** display pronounced electrophilicity and readily participate in diverse carbon–carbon bond-forming reactions [1, 24]. These compounds can be prepared by brominating nitroalkenes with elemental bromine [21]; however, this route is not always optimal for accessing structurally complex bromonitroalkenes. A more practical and economical alternative involves condensing bromonitromethane (**1a**) with carbonyls **6**, followed by dehydration (Scheme 9) [23, 26].

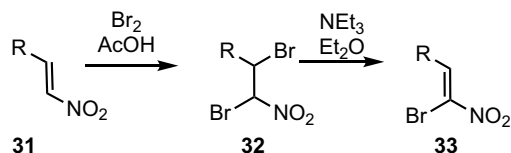
In contrast to bromonitroalkanes, which often act as Michael donors, the corresponding bromonitroalkenes can function as Michael acceptors [1]. A representative example was reported by Struchkova and coworkers [27], who reacted β -bromonitrostyrene **33c** with phenylmagnesium bromide to obtain the BNA **34a** in high yield (Scheme 10).

The presence of the bromine substituent enables subsequent bond-forming reactions via nucleophilic substitution at the brominated carbon center. Representative cyclization reactions were demonstrated by Cannon and coworkers [28], who achieved the formation of cyclopropane **16b** using dimethyl malonate as nucleophile, as well as by Parra and coworkers [28], who reported the cyclization of a predesigned enanone substrate **10b** for the annellation of a pyrrole moiety to **36** (Scheme 11).

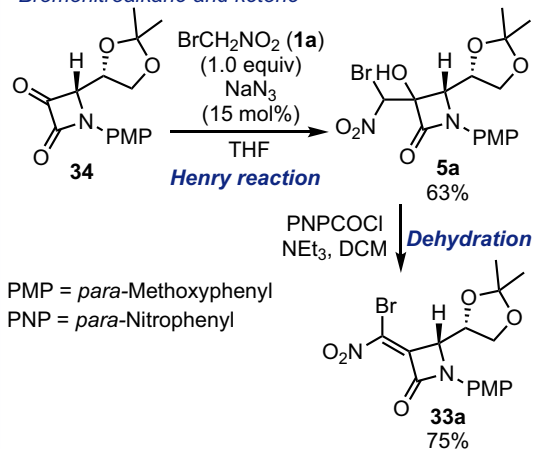
One type of reactivity characteristic of bromonitroalkenes but not accessible with the corresponding nitroalkanes is palladium-catalyzed cross-couplings. Namboothiri et al. [30] demonstrated the Suzuki (Scheme 12) and related Sonogashira couplings of

Synthesis of bromonitroalkenes

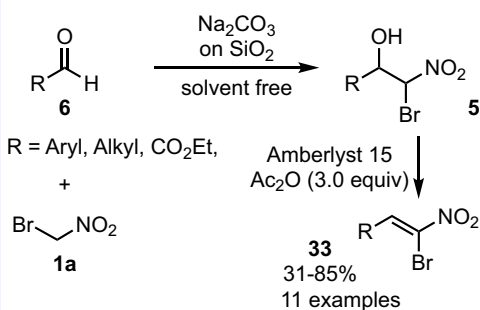
Bromine



Bromonitroalkane and ketone



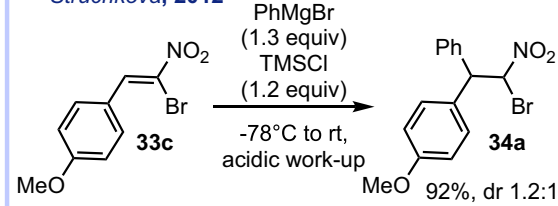
Bromonitroalkane and aldehyde



SCHEME 9 | Synthesis of α,α -bromonitroalkenes [23,25,26].

Michael Acceptor

Struchkova, 2012



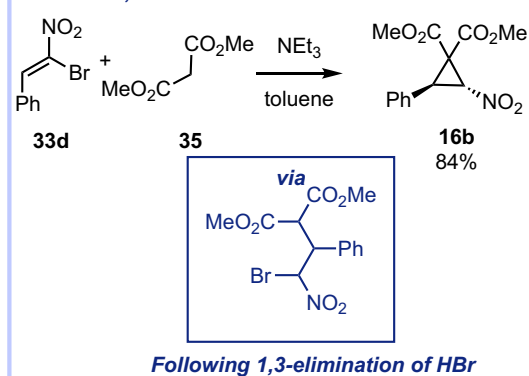
SCHEME 10 | BNAs as Michael acceptors [27].

bromonitroalkene **30c** with arylboronic acids to afford valuable coupling products **12** in high yield.

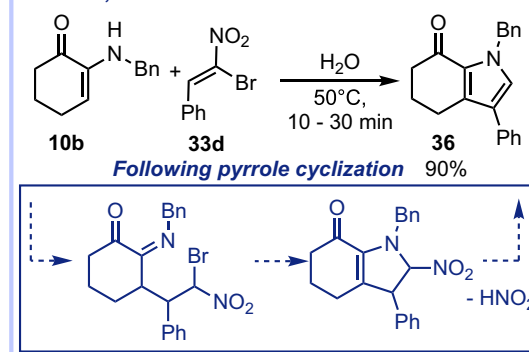
In addition, bromonitroalkenes have been shown to be competent substrates in cycloaddition reactions. Xu et al. [31] reported the 1,3 dipolar cycloaddition with ethyl diazoacetate (**37**) to yield nitropyrazoles **38**, albeit in moderate yield and with extended reaction times (Scheme 13). After initial cycloaddition, HBr elimination from the BNA adduct is facile, driven by aromatization to form **38**.

Michael Acceptor and Cyclization sequence

Connon, 2006



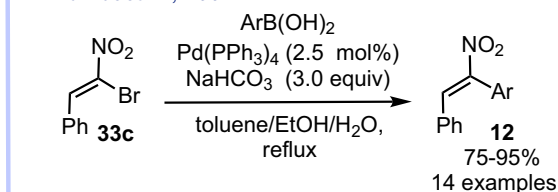
Parra, 2010



SCHEME 11 | Nucleophilic attack on **33d** with subsequent cyclization reactions [28, 29].

Palladium catalyzed coupling reactions

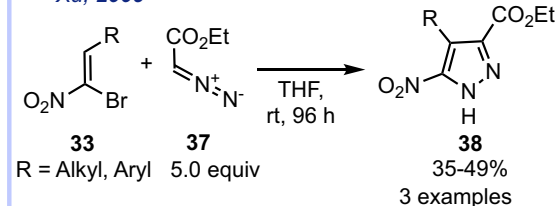
Namboothiri, 2007



SCHEME 12 | Example for palladium-catalyzed Suzuki coupling employing bromonitroalkenes [30].

1,3-Dipolar Cycloaddition

Xu, 2009



SCHEME 13 | 1,3-Dipolar cycloaddition employing bromonitroalkenes and diazoacetate [31].

Furthermore, Lesiv and coworkers [32] described a [4 + 2]cycloaddition of bromonitrostyrenes **33** with terminal alkenes to form 1,2-oxazine-*N*-oxides **40** in high yield and short reaction times,

although stoichiometric amounts of tin(IV) chloride were required (Scheme 14).

4 | BNAs as α -Nitroradicals

Nitroalkyl radicals, generated from bromonitroalkanes either thermally or photochemically, have recently been shown to be versatile intermediates in atom transfer radical additions (ATRA), which was recently reviewed in depth by Tunge and coworkers [33]. Given the transient nature of these radicals and the complex transformations described below, the proposed

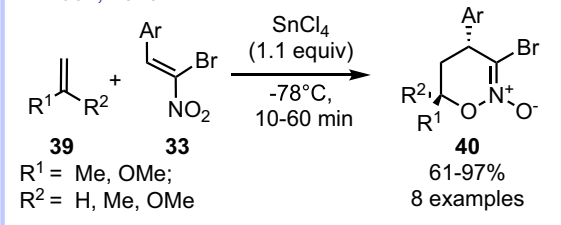
mechanisms for the underlying reactions are not always supported by firm experimental evidence. However, combining EPR and CV spectroscopy with trapping experiments and DFT calculations to map reaction pathways has produced a credible understanding of reactions involving such radicals. Especially, the formation of the parent nitromethyl radical by SET with one-electron reductants such as Cu(I) or Ir(III) to bromonitromethane (**1a**) followed by bromide extrusion could be established by EPR-spectroscopy. In turn, the oxidation of nitronates to nitroalkyl radicals by Cu(II) could also be proven by EPR.

These radicals are electrophilic and can couple with electron-rich alkenes following polarity-matching principles. Nishikata and coworkers described in 2013 [34] the addition of BNA **1d** to electron-rich styrenes **39a** to yield nitroalkenes **41a**, which was proposed to proceed via the ATRA intermediate (Scheme 15), followed by elimination of HBr. In a subsequent report [35], this group also showed addition onto α -substituted styrene **39b**, yielding the elimination product **42a** with high regioselectivity. Extending these studies, they also demonstrated a three-component reaction of highly electron-rich styrenes with ethanol as an external nucleophile to yield **44a** (Scheme 15) [36].

In all these examples, a copper-based catalytic system with nitrogen ligands and a base was employed. Initial ATRA is proposed,

[4+2] Cycloadditions

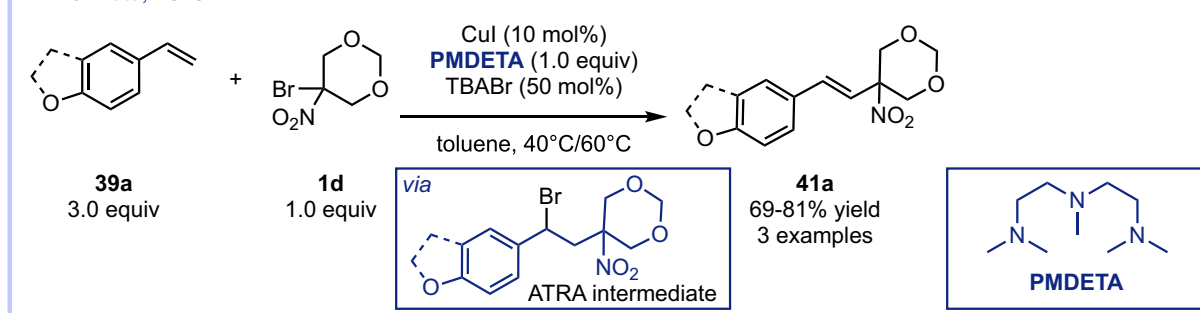
Lesiv, 2010



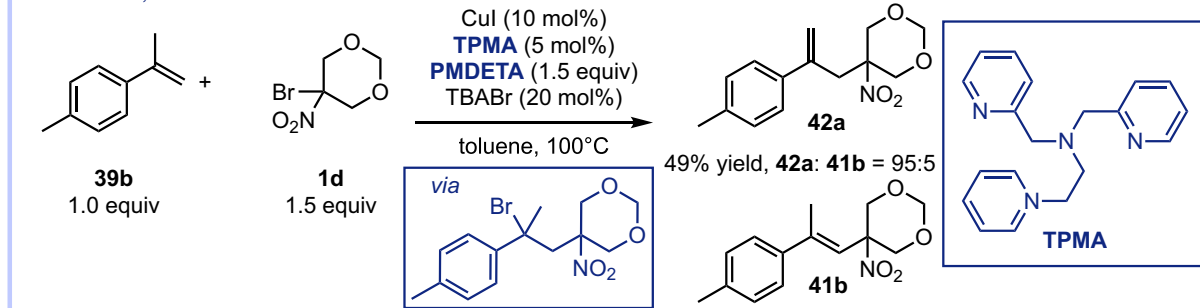
SCHEME 14 | [4 + 2] cycloadditions of bromonitroalkenes and olefins to yield 2-oxazin-N-oxides [32].

Thermal ATRA formation

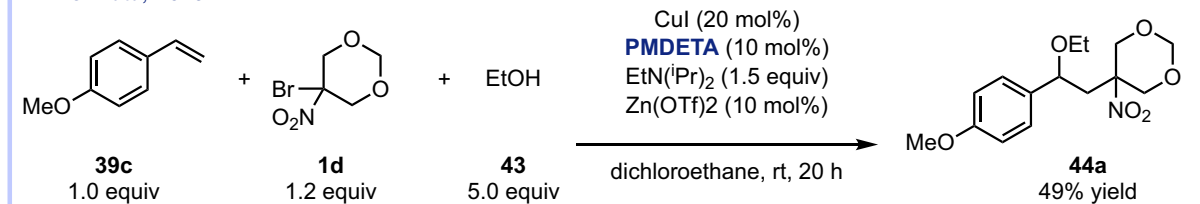
Nishikata, 2013



Nishikata, 2014

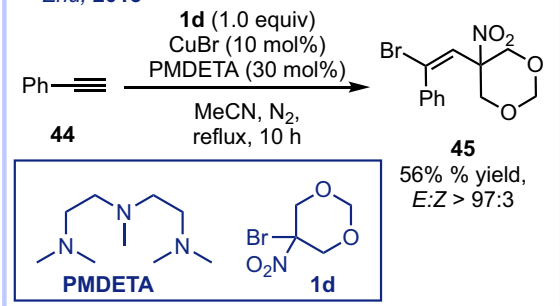


Nishikata, 2019



SCHEME 15 | Copper-catalyzed, thermal ATRA reactions of tertiary BNAs with electron-rich styrenes, followed by elimination or nucleophilic substitution [33–35].

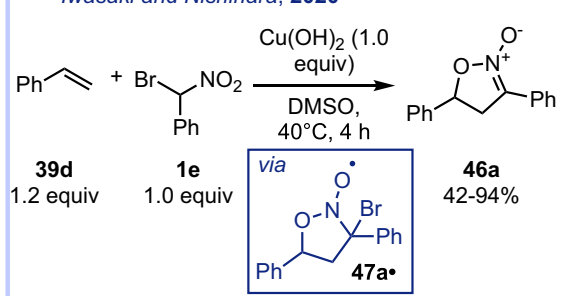
Zhu, 2015



SCHEME 16 | ATRA employing phenylacetylene as substrate [37].

Thermally generated radicals with copper(II)

Iwasaki and Nishihara, 2020

SCHEME 17 | Cu^{II} mediated synthesis of isoxazolinone **46a** from styrene (**39d**) and phenylbromo-nitromethane (**1e**) under thermal conditions [38].

followed by elimination or nucleophilic substitution, but in no case could the initial ATRA intermediates be isolated. Thus, the reaction could also proceed via oxidation of the intermediate radical species to a carbocation, especially with electron-rich alkenes.

In contrast, a similar catalytic system containing copper bromide and PMDETA as the ligand successfully isolated ATRA product **45** when alkynes were used as substrates (Scheme 16) [37].

In 2020, Iwasaki and coworkers [38] reported the Cu^I-mediated formation of isoxazolinone **46a** starting from phenylbromonitromethane (**1e**) and styrene (**39d**) under thermal conditions (Scheme 17). The reaction was proposed to follow a radical pathway initiated by single-electron oxidation of the corresponding nitronate intermediate via a stoichiometrically employed CuII salt. This way, the corresponding α -carbon-centered radical (**1e•**) is generated, which adds to the styrene double bond and subsequently undergoes cyclization to form isoxazoline radical **47a•**. A subsequent single-electron reduction with concurrent regeneration of Cu(II) and elimination of bromide then furnishes **46a** (Figure 2, pathway A). It should be noted that based on this mechanistic proposal, catalytic amounts of Cu(II) should have sufficed.

In the same year, Ooi and coworkers [39] reported an intriguing photocatalytic variant in which stoichiometric Cu(OH)₂ was replaced by catalytic amounts of an iridium-based photocatalyst. In Ooi's system, BNA **1f** undergoes single-electron reduction by Ir(III) rather than oxidation of the corresponding nitronate (Figure 2, pathway B), forming the corresponding α -nitroalkyl radical **1f•**. This radical adds to the styrene double bond, followed

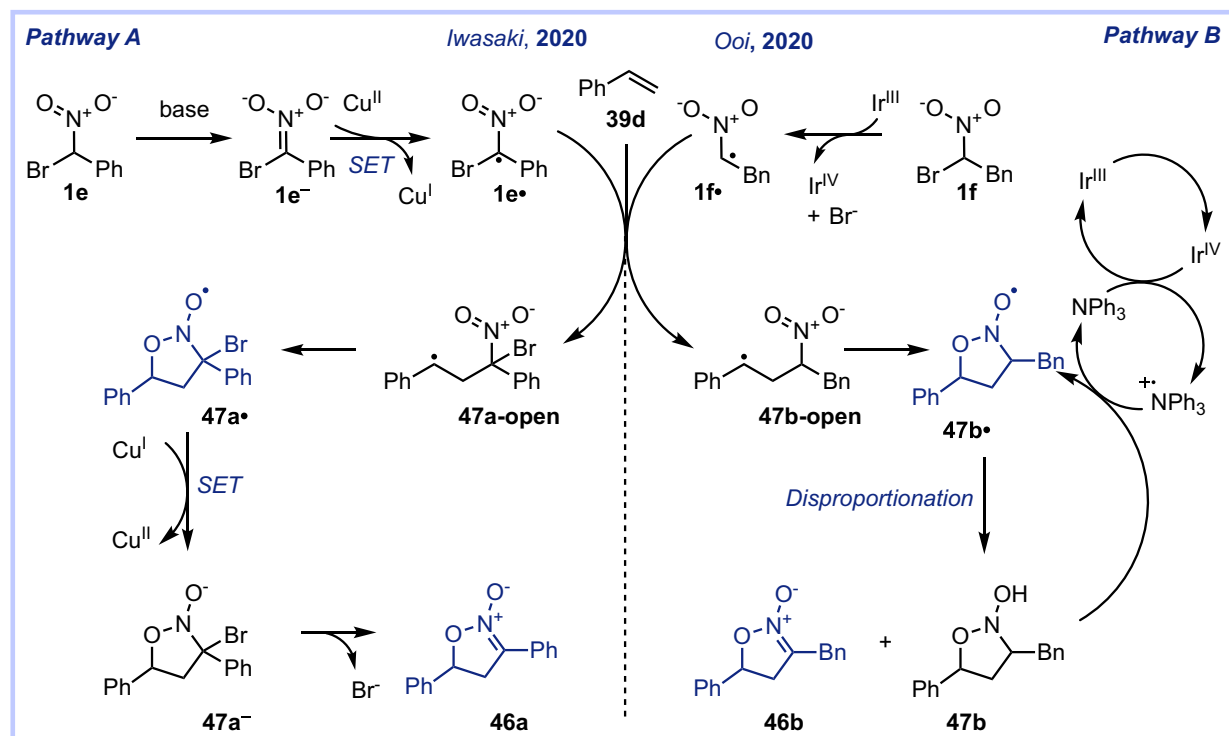


FIGURE 2 | Comparison of the mechanistic pathways for isoxazolinone formation: oxidative radical generation, pathway A [38] and reductive radical generation, pathway B [39].

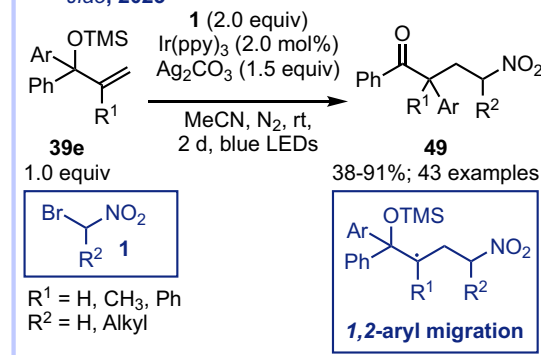
by rapid cyclization to the isoxazoline intermediate **47b[•]**, which is favored due to its persistent nature reminiscent of TEMPO despite the formally forbidden 5-*endo*-trig closure. Demonstrating today's sophistication of computational chemistry, **47b[•]** was proposed solely based on DFT calculations, while only in a subsequent study by Rehbein, Reiser, and coworkers could this intermediate also be characterized by EPR spectroscopy [40]. In the presence of NPh_3 , the strongly oxidizing Ir(IV) is rapidly reduced back to Ir(III), forcing a disproportionation of **47b[•]** to yield isoxazolinone **46b** and *N*-hydroxyisoxazoline **47b**. The latter is oxidized back to isoxazoline **47b[•]** (Figure 2, pathway B), ultimately leading to **46b** as the sole product.

In the absence of NPh_3 , **47b[•]** is oxidized by Ir(IV) to **47b⁺**, which exclusively leads to **48** upon nucleophilic ring opening by bromide (Scheme 18, top). Replacing the iridium photocatalyst with $\text{Cu}(\text{dap})_2\text{Cl}$ not only improved the yield of ATRA product **48** but also expanded the substrate scope to include simple unactivated olefins and, despite the apparent polarity mismatch, Michael acceptors (Scheme 18, bottom) [40]. The reaction was proposed to follow a different pathway based on the persistent radical nature of copper(II) complexes that allow effective interaction of transient radicals such as **47b-open**. This way, cyclization to **47b[•]** is prevented, which is indeed not observed by EPR under Cu(II)-catalysis in contrast to Ir(III)-catalysis (*vide supra*). **48** is then formed from **47b-open** either by abstraction of a bromide ligand from a $\text{Cu}^{\text{II}}\text{Br}$ species (radical ligand transfer (RLT)) or by its attack onto Cu^{II} (metal rebound), forming a Cu^{III} intermediate that undergoes reductive elimination. ATRA reactions with isocyanates show that both pathways can operate in parallel [41]. Taken together (Schemes 17 and 18), these examples impressively demonstrate the role of photocatalysts beyond initial electron transfer in determining reaction outcomes of the same starting materials.

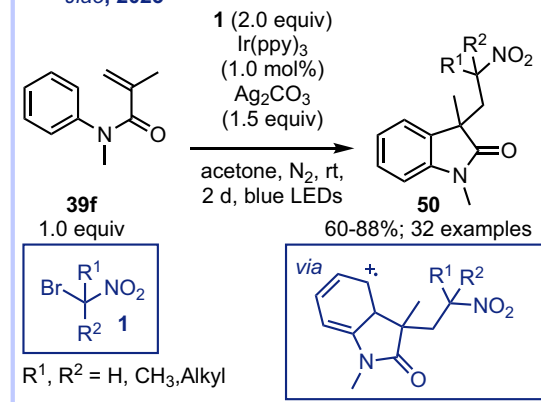
Jiao and coworkers [42] reported another variant with the oxonitroalkylation of allylsilyl ethers **39e** to **49** (Scheme 19, top) and

Ag⁺ as scavenger for bromide

Jiao, 2023



Jiao, 2023

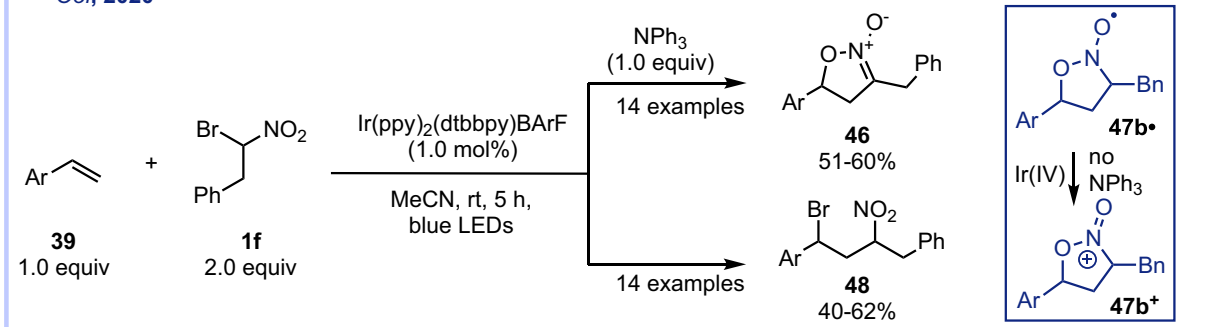


SCHEME 19 | Photocatalytic oxonitroalkylation of allylsilyl ethers with bromonitroalkanes [42] and radical cyclization of acrylanilidines for the synthesis of 2-oxindoles **50** [43].

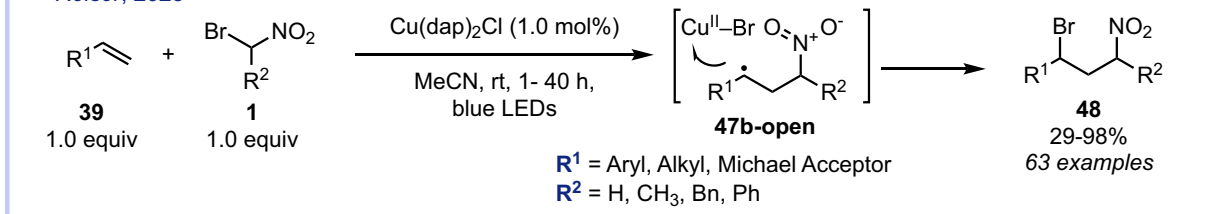
the radical cyclization of acrylanilidines **39e** to 2-oxindoles **50** (Scheme 19, bottom). Stoichiometric silver(I) salts scavenged bromide and prevented direct ATRA reactions. Thus, nitroalkyl radical addition to **39e** triggered a 1,2-aryl migration, giving **49** after

Bromonitroalkylations

Ooi, 2020



Reiser, 2023

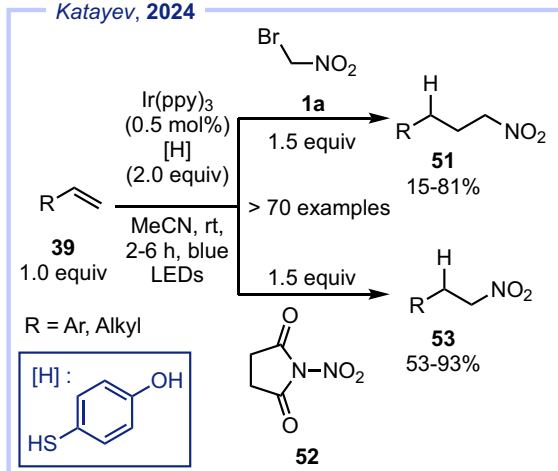


SCHEME 18 | Iridium(III) [39] versus Cu(I)-catalyzed [40] ATRA reactions of bromonitroalkanes.

subsequent oxidation and loss of TMS^+ . Applying the same reaction conditions to acrylanilidines **39f**, the silver additive again suppressed the direct ATRA process, allowing cyclization into the pendent aryl ring to give rise to 2-oxoindoles **50**.

4-hydroxythiol as additive

Katayev, 2024



SCHEME 20 | Protocol for hydronitration of styrenes employing bromonitromethane (**1a**) and *N*-nitrosuccinimide (**52**) by Katayev and coworkers [44].

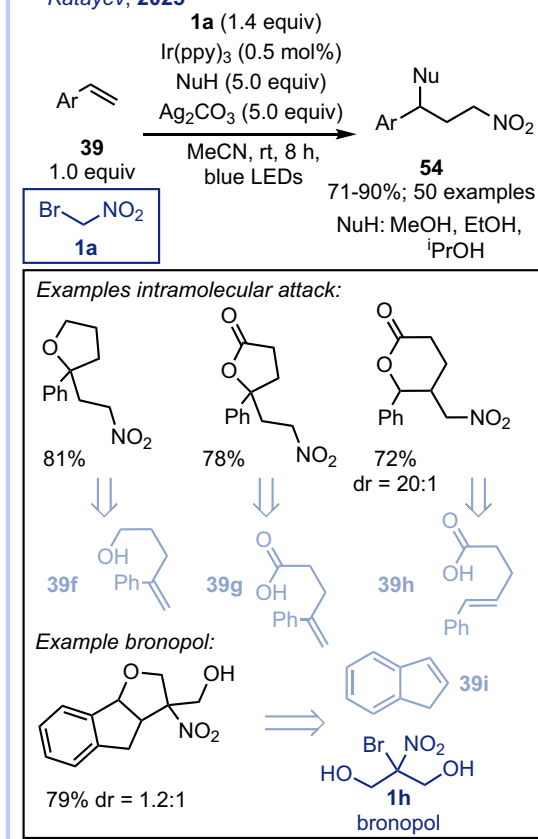
Katayev and coworkers [43] showed that a hydrogen donor, combined with Ir(III)-photocatalysis, can also outperform bromide delivery. They developed a hydronitroalkylation protocol to synthesize **51** from activated or unactivated olefins, bromonitromethane (**1a**), and 4-hydroxythiophenol, obviating the need for silver(I) additives (Scheme 20). This additive was also successful when *N*-nitrosuccinimide (**52**) was employed to access a broad range of related hydronitration products **53** [45].

In subsequent studies, Katayev further demonstrated nitroalkylations combined with chloride delivery (cat. $\text{CoCl}_2/\text{LiCl}$) [44] or inter- or intramolecular trapping by oxygen nucleophiles to yield **54** [46]. Notably, the inexpensive, commercially available disinfectant bronopol (**1h**) can serve as an ATRA reagent analogous to simple BNAs (Scheme 21).

Tunge and coworkers introduced a new concept for utilizing BNAs in metal-free, decarboxylative couplings with *N*-Boc glycine (**54**) [47]. In this protocol, a variety of previously unexplored, structurally complex BNAs derived from biologically inspired scaffolds such as norcamphor (product **55a**) or norbornene (product **55c**) were employed (Scheme 22). Trapping experiments of this intriguing process suggest oxidative decarboxylation of **54** mediated by the organophotocatalyst 2-BNP, followed by XAT and reductive radical crossover, resulting in

Nucleophilic attack

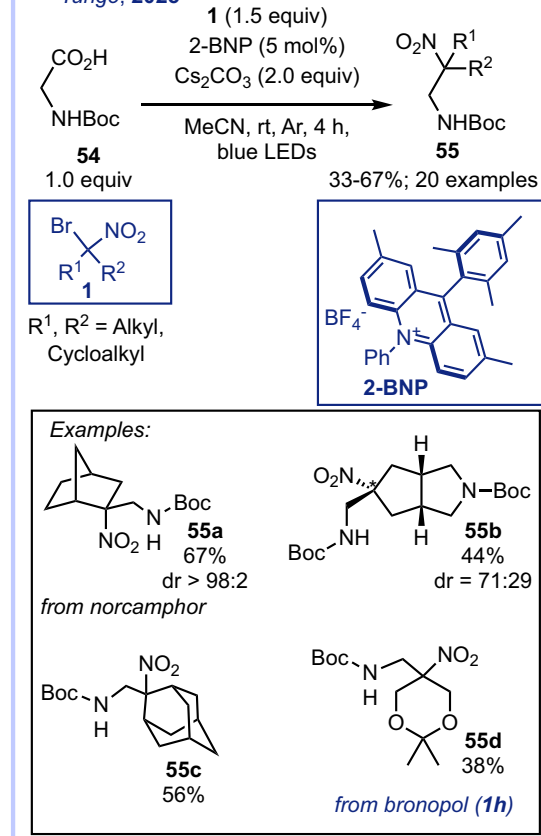
Katayev, 2025



SCHEME 21 | ATRA addition of bromonitromethane (**1a**) or bronopol (**1h**) terminated by oxygen nucleophiles [46].

Decarboxylative Coupling

Tunge, 2025



SCHEME 22 | Protocol by Tunge and coworkers [47] for photocatalyzed coupling of *N*-Boc glycine (**54**) with various complex bromonitroalkanes.

coupling of an iminium cation derived from **54** with the nitronate obtained from **55**.

A series of publications demonstrated the possibility of replacing alkenes with bicycloalkanes in the ATRA reaction with BNAs (Scheme 23) [48–50]. All reactions were initiated by addition of

an alkylnitroradical to the central, highly strained σ -bond of **56**, which then gave rise to various **57a–c** by direct ATRA or radical polar crossover pathways.

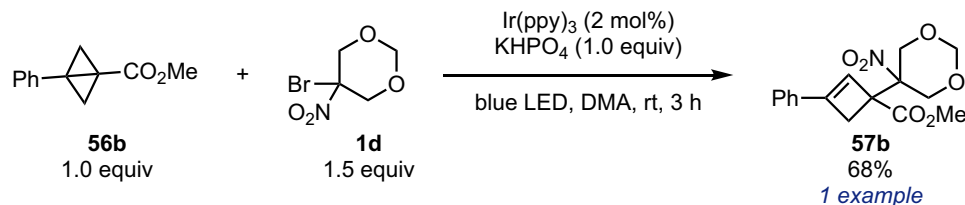
Li and coworkers could further expand the utility of BCPs in a three-component way [51] with pyridinium-*N*-oxides such as **58**

BCBs and BCPs as acceptors

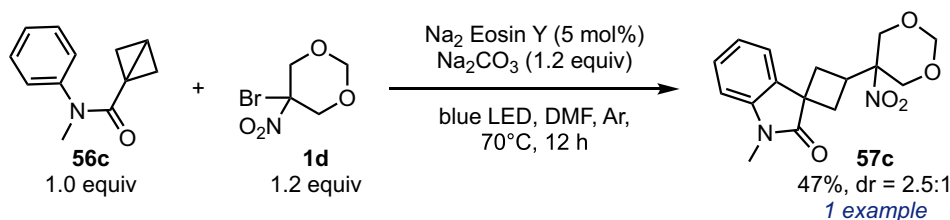
Anderson, 2019



Feng, 2023



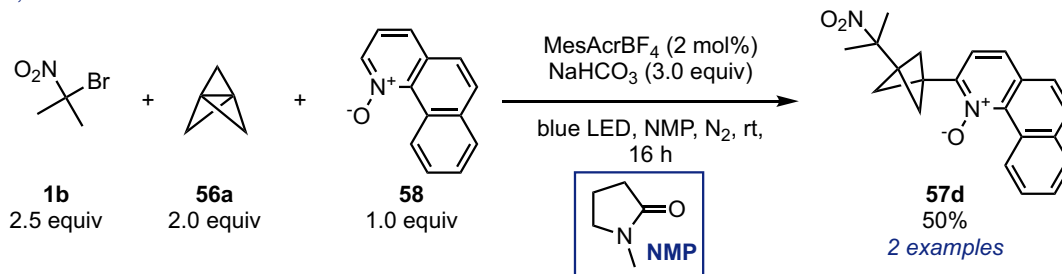
Liu, Tang, Liu, 2024



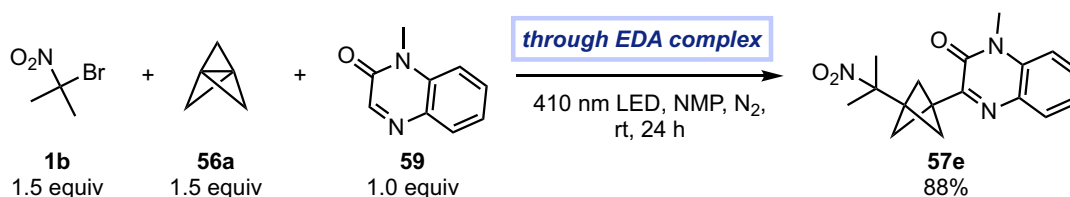
SCHEME 23 | Bicyclobutanes (BCBs) and Bicyclopentanes (BCPs) as acceptors for bromonitroalkane addition reported by the groups of Anderson [48], Feng [49], and Li [50].

BCPs for three-component reactions

Li, 2024



Li, 2025



SCHEME 24 | Examples employing BCPs in three-component reactions by the Li group [51, 52].

in the presence of an acridinium photocatalyst [52] or through the formation of an electron donor-acceptor complex (EDA) with quinoxalinone **59** (Scheme 24).

5 | Conclusion and Outlook

BNAs have become versatile synthons used as nitro-substituted carbene (cf. Schemes 4–8), α -nitroalkylradical (cf. Schemes 15–22), and anion equivalents (cf. Schemes 2 and 3) in coupling reactions with various sp^2 - and sp^3 -partners. The related α,α -bromonitroalkenes show an independent reaction profile, most notably as electrophiles, dienophiles, or dipolarophiles (Schemes 9–14). Addition to the double bond in bromo-nitroalkenes forms, in turn, a BNA intermediate, which typically undergoes further HBr elimination, but other reaction modes outlined in this review for BNAs, or reactions involving both the bromo and nitro groups [2], could be envisioned.

The 1,3-relationship between the halide and alkyl nitro fragment introduced in ATRA reactions suppresses elimination, that is frequently observed in related 1,2-addition products such as in the chlorosulfonylation or iodoform addition to alkenes [53, 54]. Thus, ATRA products **48** allow nucleophilic substitutions and cross-coupling reactions to synthesize diverse, functionalized nitroalkanes [40]. The copper-catalyzed variants introduced for such transformations have broadened the scope of the intrinsic electrophilic nitroalkyl radicals beyond polarity-matched partners to unactivated alkenes and even to Michael acceptors. To render such transformations asymmetric in the radical regime has not been successful so far, although the ability of Cu(II) to interact with transient radicals either by RLT or a rebound mechanism involving Cu(III) suggests that chiral copper complexes might be promising. Related ATRA reactions of alkenes have been shown to be feasible with impressive asymmetric inductions through chiral copper photocatalysts or additives [55].

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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