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Organoselenium small molecules as catalysts for the oxidative functionalization of organic molecules

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Organoselenium chemistry has become an exciting topic in synthetic chemistry and pharmaceuticals in the last few decades. Organoselenium molecules as reagents have been developed only recently for the epoxidation or halogenation of olefins by using peroxides and dihalogens or halogenating reagents, respectively. In the past few years, some reports were available but these did not include a clear vision for the catalytic use of organoselenium molecules and despite important breakthroughs, they signify just the very preliminary stages of a nascent field. This perspective highlights the critical analysis of the challenges, in the past decade, which led to the development of organoselenium compounds and their use as versatile catalysts in organic synthesis towards the oxidation of olefins and C–H bonds. Furthermore, the emphasis here differs from the previous reviews of the field by classifying the various types of catalyses and the diverse strategies employed not only for the oxidation of olefins but also carbon–hydrogen bond for carbon–carbon and carbon–heteroatom bond formation in the synthesis of various heterocyclic molecules by asymmetric induction.

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1. Introduction

The advances in the area of synthesis and reactivity of organoselenium compounds, as well as the discovery of the toxic properties of selenium compounds in the 1930s and the subsequent discovery that selenium is an essential trace element in the diet, has prompted intense studies of the biological properties of both organic and inorganic selenium compounds.[1] The biological and medicinal properties of organoselenium compounds are also increasingly appreciated, mainly due to their

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Sangit Kumar

Sangit Kumar graduated from Saharanpur, India. After completing his Master's in Chemistry from the University of Roorkee (now IIT Roorkee) in 1999, he joined the group of Professor Harkesh B. Singh, IIT Bombay for a PhD program. In 2005, he joined the group of Professor Lars Engman for a post-doctoral position; subsequently, he move to State University at Buffalo (SUNY) and continued working on organochalcogen chemistry under the supervision of Professor Michael R. Detty till 2008. He took an independent position as assistant professor in the Department of Chemistry at IISER, Bhopal, in 2009 and became full professor in 2018. His main research focuses are organochalcogen chemistry and transition metal free carbon–carbon and carbon–heteroatom coupling reactions.

antioxidant,[2] anti-inflammatory,[3] antimicrobial,[4] anticancer,[5] neuroprotective[6] and antiviral[7] properties.

Organoselenium compounds have been widely utilized by organic chemists in recent years[8–12] because of their effects on an extraordinary number of different reactions, including carbon–carbon bond formations, under relatively mild reaction conditions. Furthermore, organoselenium compounds can also be used in the presence of a wide variety of functional groups, thus avoiding protecting group chemistry.[13] Selenium can be introduced in an organic substrate *via* both electrophilic and nucleophilic reagents. Organoselenium anions are powerful nucleophiles, and usually, they are prepared *in situ* because of their sensitivity to air oxidation.[14] Divalent selenium forms stable bonds with carbon and are structurally analogous to the corresponding organosulfur compounds, namely, selenides (R_2Se, analogues of thioethers), diselenides (R_2Se_2, analogues of disulfides), and selenols (RSeH, analogues of thiols). Representatives of selenides, diselenides, and selenols include selenomethionine, diphenyl diselenide, and benzeneselenol, respectively. Good functional group tolerance, perfect selectivities and mild reaction conditions make this a distinctive research topic.[15] Furthermore, organoselenium catalyzed reactions are often transition-metal-free, hence, it avoids harmful toxic waste in the products, making this method economical and environment-friendly. Particularly in organochalcogen compounds, selenium exhibits variable oxidation states, and therefore, has been utilized as catalysts in several oxidation reactions.[16] Notably, selenium element appears in the 4th period after the filling of the 3d-orbitals, which makes it unique from the lighter sulfur and heavier tellurium congeners; for example, selenium in its highest oxidation state of +6 is a stronger oxidizing agent than the lighter sulfur and heavier tellurium elements. Organoselenium catalysts can even be designed in such a manner that they catalyze asymmetric transformations.[17] Several reviews have been presented on organoselenium chemistry; these either focus on their biological applications, structural features or their use as a catalyst in organic transformations.[1b,2c,8] This perspective mainly focuses on organoselenium compounds as catalysts for the oxidation of organic molecules. In addition, the roles of the selenium atom and bonded ligand in organoselenium catalysts are discussed with respect to their catalytic properties for the oxidation of organic substrates.

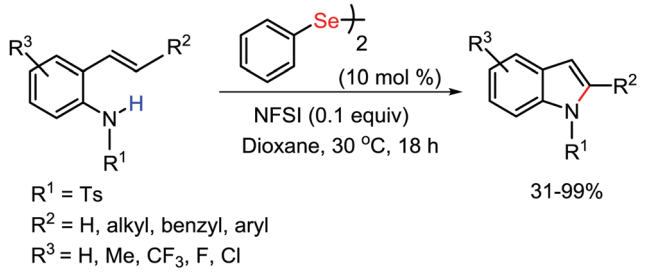
2. Selenium catalyzed indole formation

Zhao and co-workers have reported a new organoselenium-catalyzed method for the formation of indoles *via* intramolecular C–H amination, where *N*-fluorobenzenesulfonimide (NFSI) was used as an oxidant in dioxane solvent at 30 °C (Scheme 1).[18]

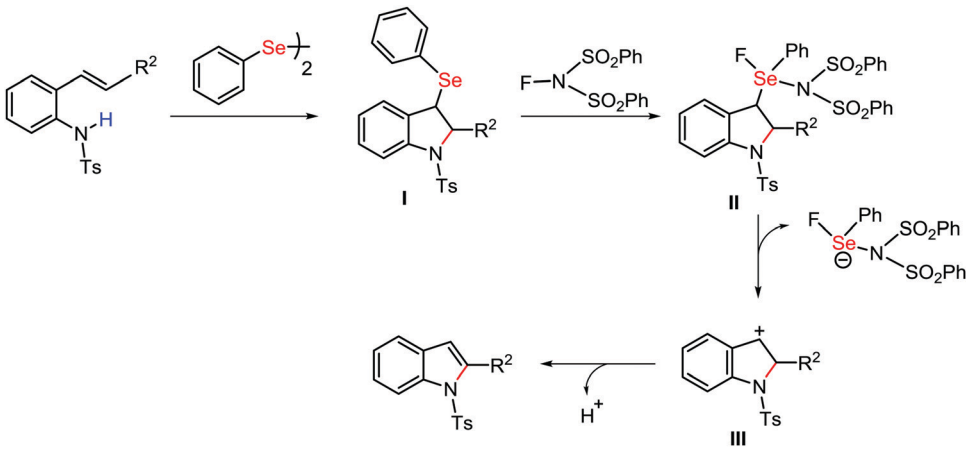
A plausible mechanism is depicted in Scheme 2. The addition of the catalyst diphenyl diselenide to the double bond resulted in intermediate **I**. Then, the removal of the PhSe group from **I** in the presence of NFSI *via* intermediate **II** would provide **III**, followed by the aromatization of **III** *via* the elimination of H^+ to afford the desired indole product.

3. Lewis base selenium catalyzed bromoaminocyclization

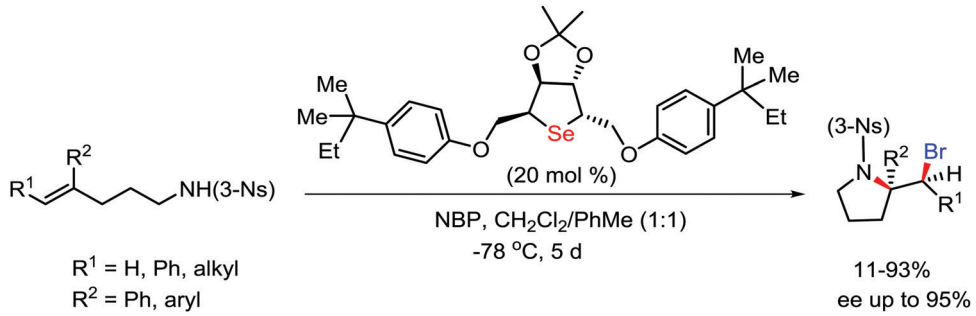
Yeung and co-workers have developed a chiral selenium catalyzed synthesis of an asymmetric pyrrolidine having two stereogenic centres, where *N*-bromophthalimide was used as the bromine source (Scheme 3).[19] Specifically, the reactions showed excellent diastereoselectivity with dr > 99% and exclusive enantiospecificity of up to 95%.



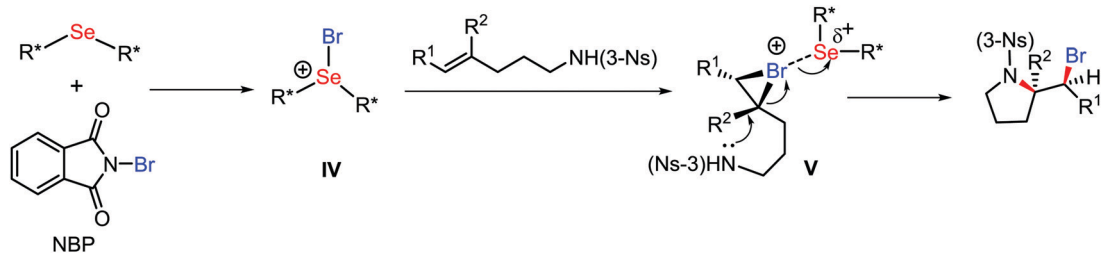
Scheme 1 Synthesis of indoles *via* intramolecular C–H amination.



Scheme 2 Mechanism for the synthesis of indoles.



Scheme 3 Lewis base catalyzed synthesis of pyrrolidine.



Scheme 4 Possible mechanism for the synthesis of bromoaminocyclization.

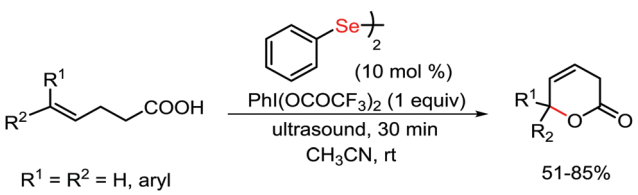
The haloaminocyclization of olefinic amides proceeds *via* the formation of activated selenium brominating species **IV**, which would interact with the olefin amide substrate resulting in the formation of selenium coordinated bromonium intermediate **V** (Scheme 4). Nucleophilic attack (S_N2) on the lone pair of the amide nitrogen and intramolecular cyclization would facilitate the formation of the desired bromo cyclic pyrrolidine product with good diastereoselectivity and enantiospecificity. The catalyst was regenerated in the reaction mixture.

4. Selenium catalyzed synthesis of six-membered lactones

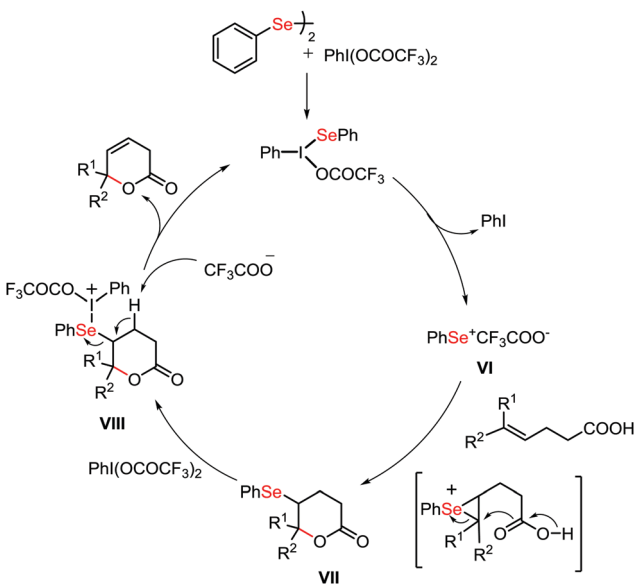
In 2011, Wirth and co-workers accomplished a new method catalyzed by selenium for the cyclization of γ,δ-unsaturated pentenoic acids at room temperature in the presence of a hypervalent iodine reagent as the oxidant. By using this method, 6-membered lactones could be synthesized under metal-free conditions (Scheme 5).[20]

The mechanism of the reaction proceeds *via* the formation of phenylselenenyl trifluoroacetate **VI**. The reaction of the γ,δ-unsaturated pentenoic acid with phenylselenenyl trifluoroacetate **VI** would provide selenolactone **VII**. The formation of selenolactone **VII** was confirmed by the isolation of **VII** as an intermediate from the reaction. Intermediate **VII** would be activated by PIFA. The resulting intermediate **VIII** would undergo elimination, leading to the formation of the desired 6-membered lactones (Scheme 6).

Furthermore, Breder and co-workers devised the aerobic dehydrogenative esterification of alkenoic acids, which facilitates the formation of five- and six-membered lactones with good yields.[21] The reaction proceeds *via* the interaction of a selenium-π-acid catalyst and photocatalyst. 2,4,6-Tris(4-methoxyphenyl)pyrylium



Scheme 5 Cyclization of γ,δ-unsaturated pentenoic acids.



Scheme 6 Mechanism of the synthesis of cyclic lactones.

tetrafluoroborate was used as the photocatalyst under air atmosphere for the oxidative lactonization of alkenes.[21]

5. Selenium catalyzed oxytrifluoromethylthiolation of alkenes

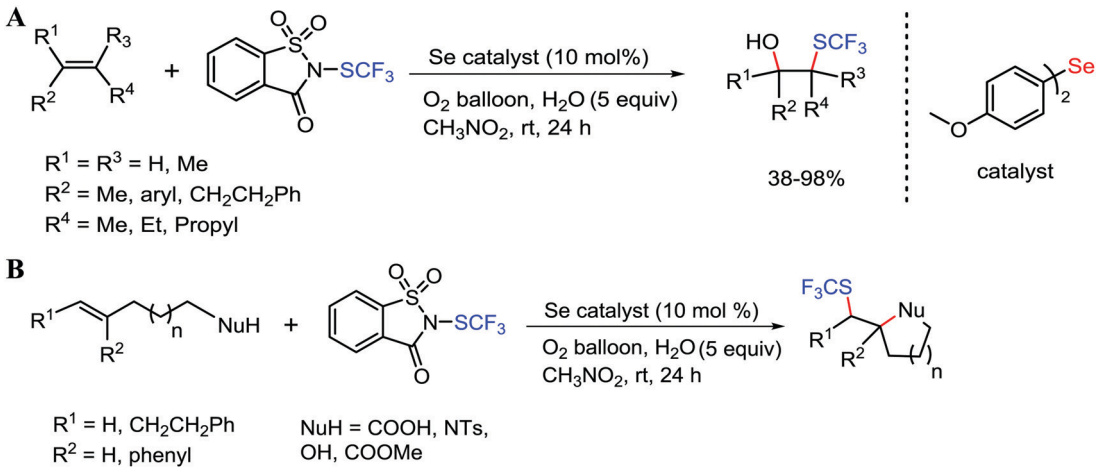
In 2017, Zhao and co-workers reported diaryl selenide catalyzed vicinal CF_3S hydroxylation of alkenes by using *N*-CF_3S-saccharin as a trifluoromethylthiolating agent and nitromethane as the solvent under oxygen atmosphere at room temperature (Scheme 7A).[22] Alkenes having carboxylic acid, hydroxy, sulfamide, or ester groups tethered to them could also successfully cyclize intramolecularly by using this protocol (Scheme 7B). The mechanism of this reaction suggests that the redox cycle between Se(II) and Se(IV) is pivotal for the complete conversion.

The mechanism of the reaction involves the generation of diaryl selenoxide **IX** by the oxidation of the selenium catalyst under O_2/CH_3NO_2 conditions, which is reduced to the selenium catalyst by the CF_3S-saccharin reagent (Scheme 8). The CF_3S reagent reacts with the catalyst to produce the intermediate **X**. An alkene reacts with **X**, which would generate episulfonium ion **XI**. Finally, the attack of H_2O on **XI** afforded the desired product and regenerated TfOH and the catalyst.

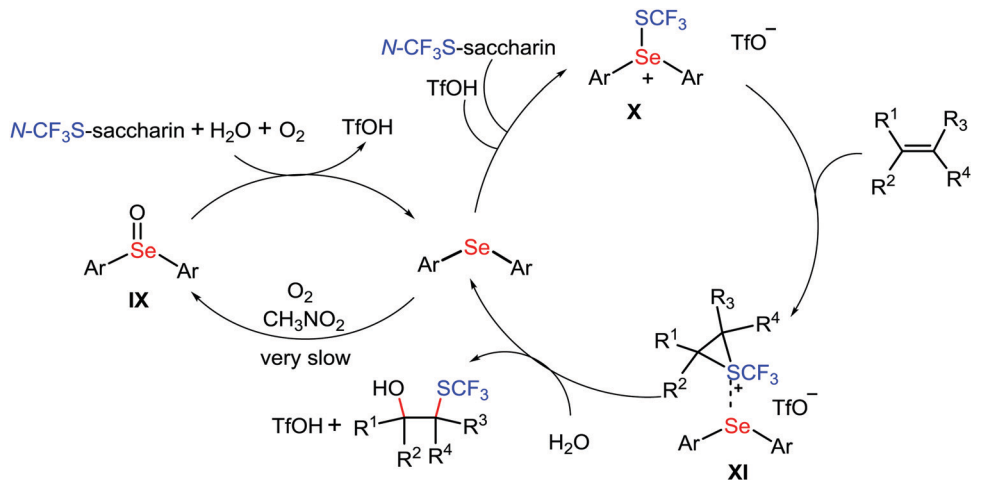
6. Organoselenium catalyzed electrophilic fluorination of olefins

In 2018, Zhao and co-workers disclosed an efficient organoselenium catalyzed method for oxidative allylic fluorination. *N*-Fluoro-2,4,6-trimethylpyridinium triflate (TMFP-OTf) was used as the fluorine source, which also acted as an oxidant in the presence of TEMPO (Scheme 9).[23] The reaction proceeds through electrophilic selenium catalysis (ESC); TEMPO as an additive affects the fluorination and provides a better substrate scope with excellent functional group tolerance.

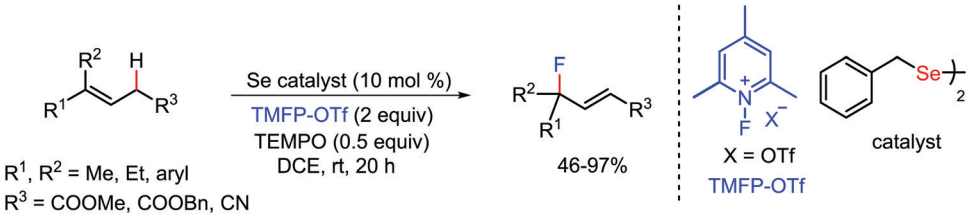
The mechanism started *via* the oxidative cleavage of the diselenide catalyst, generating benzyl selenium fluoride **XII** (Scheme 10). The reaction of the olefinic ester with benzyl selenium fluoride **XII** provided seleniranium ion **XIII**. The nucleophilic attack of the fluoride anion on the intermediate **XIII**



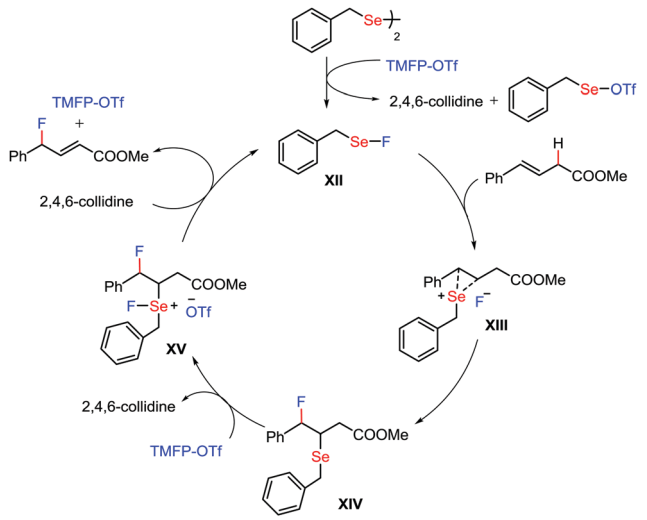
Scheme 7 (A) CF_3S hydroxylation of alkenes. (B) Oxytrifluoromethylthiolation of nucleophile tethered alkenes.



Scheme 8 Proposed mechanism for trifluoromethylthiolation.



Scheme 9 Allylic fluorination *via* olefin isomerization.



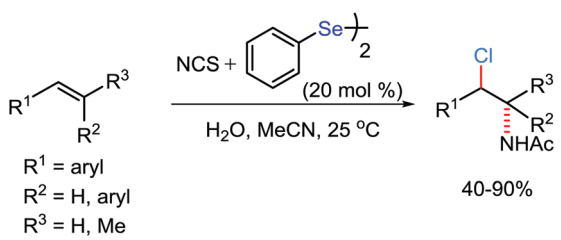
Scheme 10 Mechanism for the allylic fluorination of alkene.

would give fluoroselenenylated intermediate **XIV**. At this stage, intermediate **XIV** would undergo oxidation by TMFP-OTf, which would subsequently lead, *via* H-elimination from **XV**, to the formation of the desired allylic fluorinated product.

7. Lewis base catalyzed chloroamidation of olefins

Yeung and co-workers achieved a Lewis base catalyzed chloroamidation of olefinic substrates using diphenyl selenide as the catalyst.[24] The reaction was carried out in the presence of olefins, 20 mol% selenium catalyst, NCS and an acetonitrile–water mixture at room temperature. A wide range of substrate scope was studied, including those that were acid labile, with 40–90% yield (Scheme 11).

A plausible mechanism for the reaction is described in Scheme 12. The first step is the activation of the chlorine atom



Scheme 11 Chlorination of olefins.

by NCS *via* the Lewis basic diphenyl selenide to form intermediate **XVI**. The electrophilic Cl transfers to an olefin to form the haliranium ion intermediate **XVIII**. At this point, acetonitrile attacks the intermediate **XVIII**, which is subsequently quenched by a molecule of water to form the desired chloroamide product.

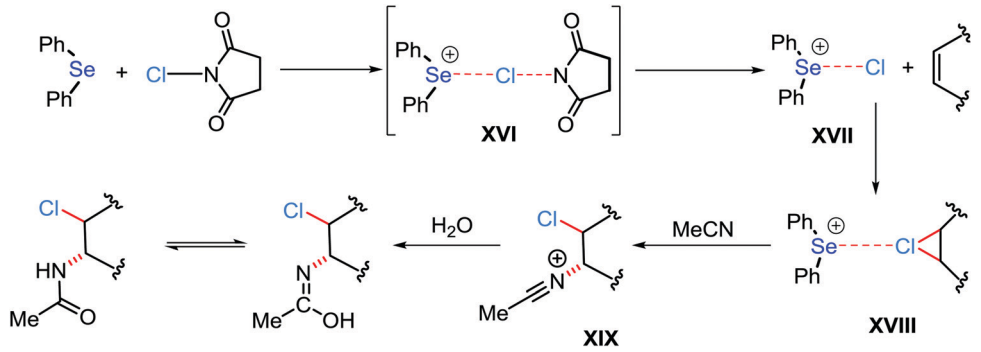
8. Selenium catalyzed bromoesterification, bromolactonization and oxidation of alcohols

Our group has developed a method for the bromolactonization of alkenoic acids with bromine or *N*-bromosuccinimide (NBS) and isoselenazolone as the catalyst in the presence of potassium carbonate. Next, the oxidation of secondary alcohols to ketones was studied using bromine as an oxidizing reagent (Scheme 13).[25]

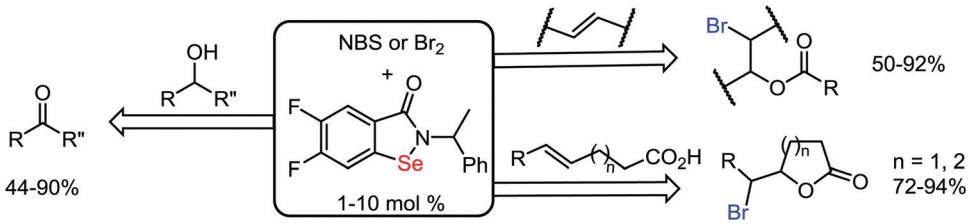
The proposed mechanism for bromolactonization is shown in Scheme 14. The reaction of bromine with isoselenazolone yielded isoselenazolone(IV) dibromide **XX**, which is in equilibrium with its ionic form **XXII**. Addition of an equimolar amount of pent-4-enoic acid to the isoselenazolone(IV) dibromide **XX** produced the isoselenazolone catalyst and the bromolactone product. Traces of a side product, presumably phenylselenolactone, were observed in the reaction mixture. Transfer of Br^+ to pent-4-enoic acid may occur by either of the two pathways: (i) reversible generation of free Br^+ in the solution from selenium(IV) dibromide and then attack of Br^+ on the carbon–carbon double bond, or (ii) formation of the associated intermediate **XXV** followed by the intramolecular transfer of Br^+ to pent-4-enoic acid.

We also compared the intermediates formed from NBS to those formed from bromine in the isoselenazolone-catalyzed bromination reaction. Addition of NBS to the isoselenazolone catalyst yielded selenium(IV) bromide succinimide **XXI**. The high reactivity of NBS in the isoselenazolone-catalyzed bromination reaction could be due to the electron-deficient selenium center in the selenium(IV) bromide succinimide **XXI**. The electron-deficient selenium atom would render a partial positive charge on the Br atom, which may facilitate faster transfer of bromine to the alkenoic acid.

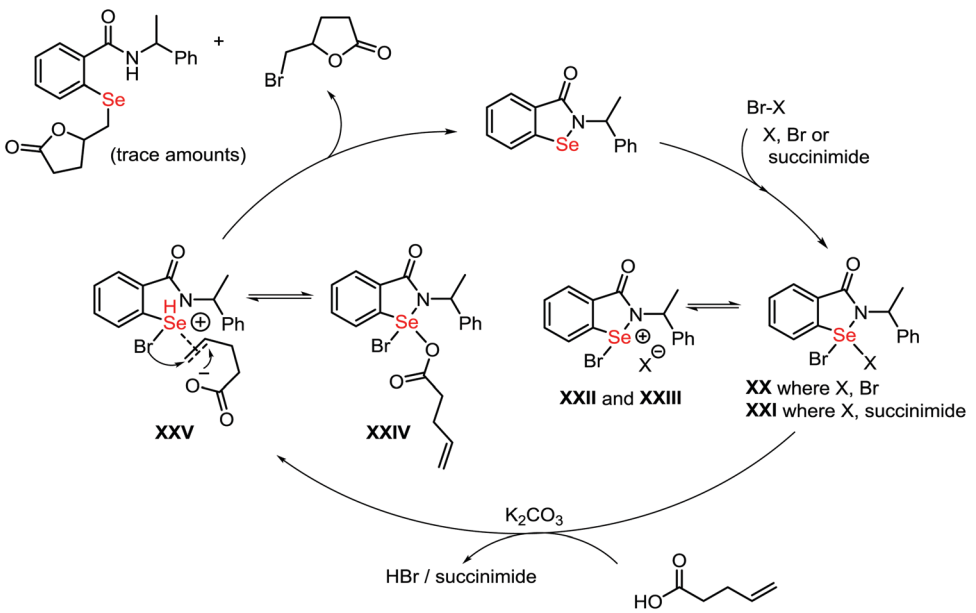
The oxidation of secondary alcohols to ketones can be rationalized by considering the proposed intermediates **XX**/**XXII** in the bromination of alkenoic acids (Scheme 15). The addition of the secondary alcohol to bromoselenonium intermediate **XXII** would give intermediate **XXVI** *via* the loss of HBr. Intermediate **XXVI** could lead to the ketone directly *via* the loss



Scheme 12 Proposed mechanism for the Lewis basic selenium catalyzed chloroamidation.



Scheme 13 Bromoesterification of alkenes and oxidation of alcohols catalyzed by isoselenazolone.



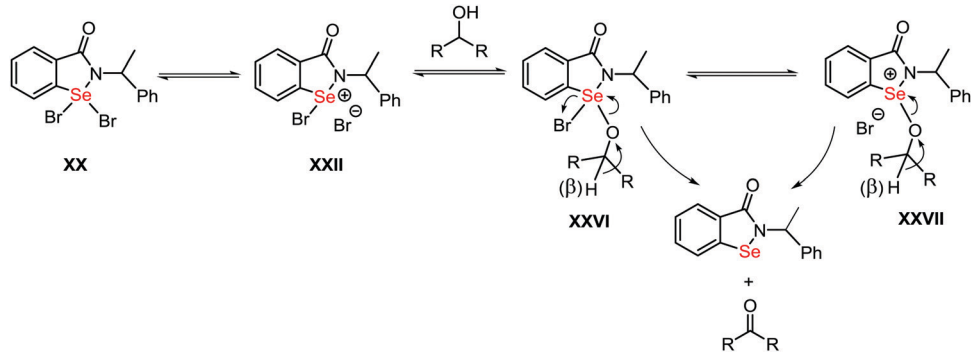
Scheme 14 Reaction mechanism for the isoselenazolone catalyzed bromination.

of a second molecule of HBr, regenerating the isoselenazolone or *via* the loss of bromide to give the Swern-like oxoselenonium intermediate **XXVII**, which then can lose a proton to give the ketone and isoselenazolone.

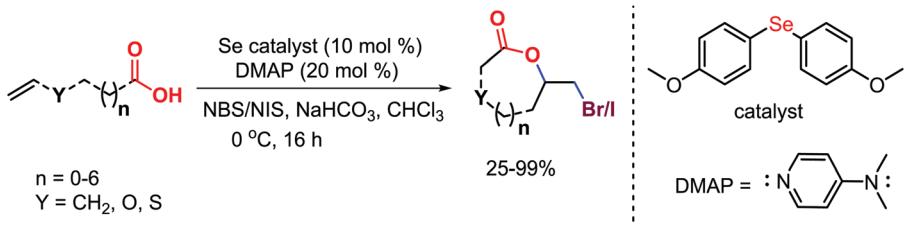
Similarly, the oxidation of benzyl alcohol into the corresponding benzoic acid was achieved by Arends and co-workers in 2009 by using *tert*-butyl hydroperoxide (TBHP) as an oxidant in the presence of a diphenyl diselenide catalyst.[26]

Further, we have reported the symmetrical bis(*p*-anisyl)selenide catalyzed bromo/iodo lactonization of linear alkenoic acids with *N*-bromo succinimide by using 4-dimethylaminopyridine (DMAP) as a co-catalyst and $NaHCO_3$ as an additive (Scheme 16). A series of medium-sized bromo/iodo lactones possessing high transannular strain were synthesized regioselectively. ^{77}Se NMR spectroscopy, HRMS, and theoretical studies revealed that the reaction proceeds *via* a selenium–DMAP active catalyst.[27]

The reaction between catalyst **A**, co-catalyst **B** and NBS provided intermediate **XXVIII** (Scheme 17). The alkene and terminal acid of alkenoic acid would bind with intermediate **XXVIII** and provide **XXIX**. The selenium–nitrogen coordination



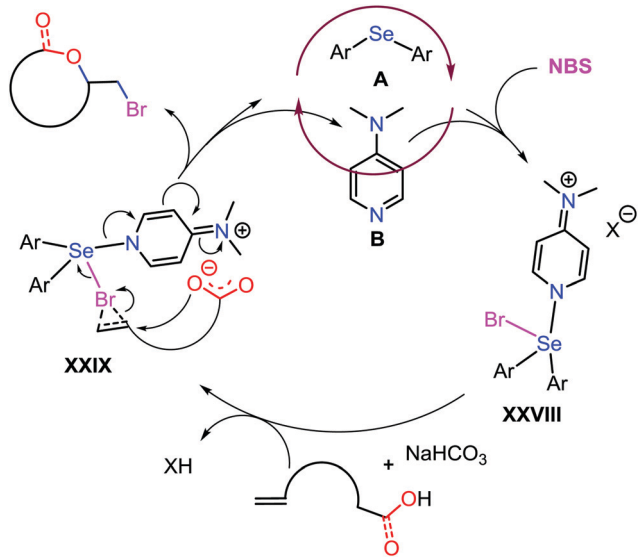
Scheme 15 Mechanism for the oxidation of secondary alcohols to ketones with bromine.



Scheme 16 Regioselective synthesis of medium-sized halolactones and bromooxepanes.

elongates the Se–Br bond and thus facilitates the generation of Br^+. The formation of the bromiranium ion and the interaction of the carboxylate ion with the ammonium ion in the same species would favour the cyclization that leads to medium-sized bromolactones and concomitant regeneration of selenium catalyst **A** and co-catalyst **B**.

Similarly, a Lewis base diphenyl selenide catalyzed method for the bromolactonization of cyclopropylmethyl diesters was demonstrated by Yeung and co-workers.[28] This protocol provided multifunctional *syn* γ-lactones.



Scheme 17 Proposed catalytic cycle for bromolactonization.

9. Lewis base selenium catalyzed carbosulfenylation of alkenylboronates

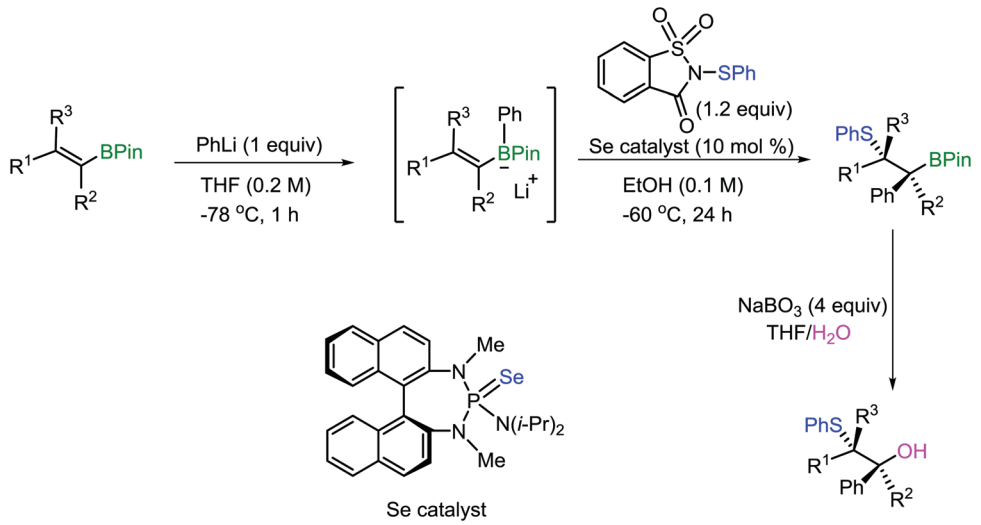
Denmark and co-workers developed a Lewis base catalyzed enantio- and diasteroselective approach for the carbosulfenylation of di- and trisubstituted alkenylboronic esters (Scheme 18).[29] The reaction was initiated *via* a 1,2-migration of a zwitterionic thiiranium–boronate that would lead to the formation of anti carbosulfenylation products containing two vicinal stereogenic centers. The reaction shows good enantioselectivity (up to 99 : 1 e.r.).

10. Oxacyclization of alkenoic acids and alkenols

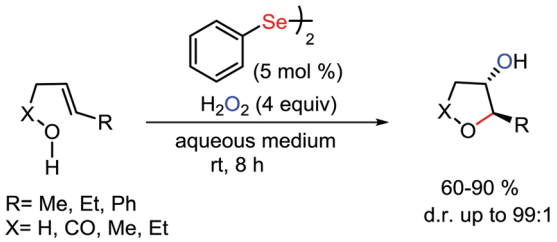
A simple organocatalytic method for the synthesis of lactones or cyclic ethers has been developed by Santi and co-workers (Scheme 19).[30] The reaction involves the cyclofunctionalization of γ,δ-unsaturated acids and alcohols by using H_2O_2 as an oxidant, providing the desired products in good yields with high stereoselectivities.

In the presence of the H_2O_2 oxidant, the diphenyl diselenide catalyst forms benzeneselenonic acid **XXX** (Scheme 20). The unsaturated acids or alcohols in the presence of **XXX** furnish epoxide intermediates **XXXI**. The epoxide intermediates afforded the stereospecific *trans*-disubstituted lactones *via* the formation of carbocations **XXXII**.

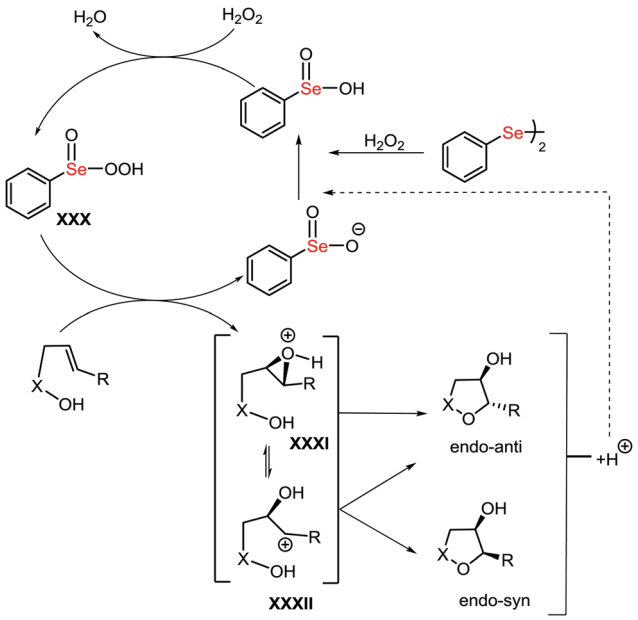
With the double bond having a substituent capable of stabilizing the nearby carbocation **XXXII**, the formation of the *anti*-isomer seemed like the major product rather than the *syn* isomer.



Scheme 18 Carbosulfenylation of alkenylboronates.



Scheme 19 Selenium catalyzed oxidative cyclization of alkenoic acids and alkenols.



Scheme 20 Proposed mechanism for oxacyclization.

11. Lewis acid selenium catalyzed bromination of arenes

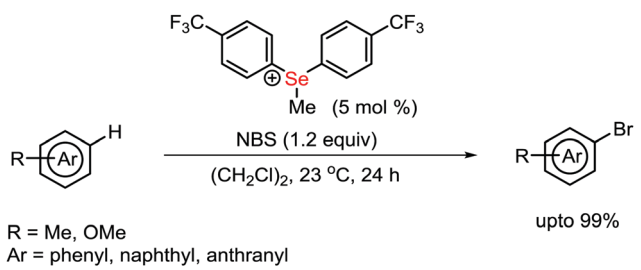
Yeung and co-workers developed a mild method for the electrophilic halogenation of arenes using selenonium salts as Lewis acids and *N*-bromo succinimide as the halogenating source (Scheme 21).[31]

12. Selenium catalyzed dichlorination of olefins

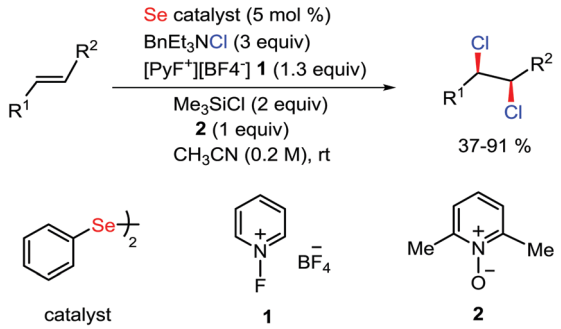
Denmark and co-workers have achieved a diphenyl diselenide catalyzed *syn* dichlorination of alkene substrates with good stereospecificity.[32] The reaction was carried out in the presence of benzyltriethylammonium chloride ($BnEt_3NCl$) as the chlorine source, *N*-fluoropyridinium salt **1** as the oxidant and 2,6-lutidine *N*-oxide **2** as an additive. A wide range of acyclic alkenes was studied with primary allylic alcohols (Scheme 22).

This approach was further utilized in the synthesis of chlorosulfolipid polychlorinated natural products.

The proposed mechanism was initiated *via* the generation of an active form of catalyst $PhSeCl_3$ (Scheme 23). Addition of an olefin to **XXXIII** provided the seleniranium ion intermediate **XXXIV**.



Scheme 21 Chalcogenium salt catalyzed electrophilic bromination of arenes.

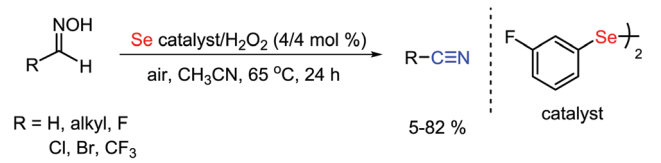


Scheme 22 Selenium-catalysed *syn*-dichlorination of alkenes.

The nucleophilic ring opening of **XXXIV** occured by the chloride ion and the resulting intermediate **XXXV** underwent the anti-elimination of selenium with Cl^- *via* intermediate **XXXVI** to provide the *syn* dichlorinated product.

13. Selenium catalyzed carbon-nitrile bond formation

A novel organoselenium catalyzed method has been accomplished by Lautens and co-workers for the synthesis of organonitriles from



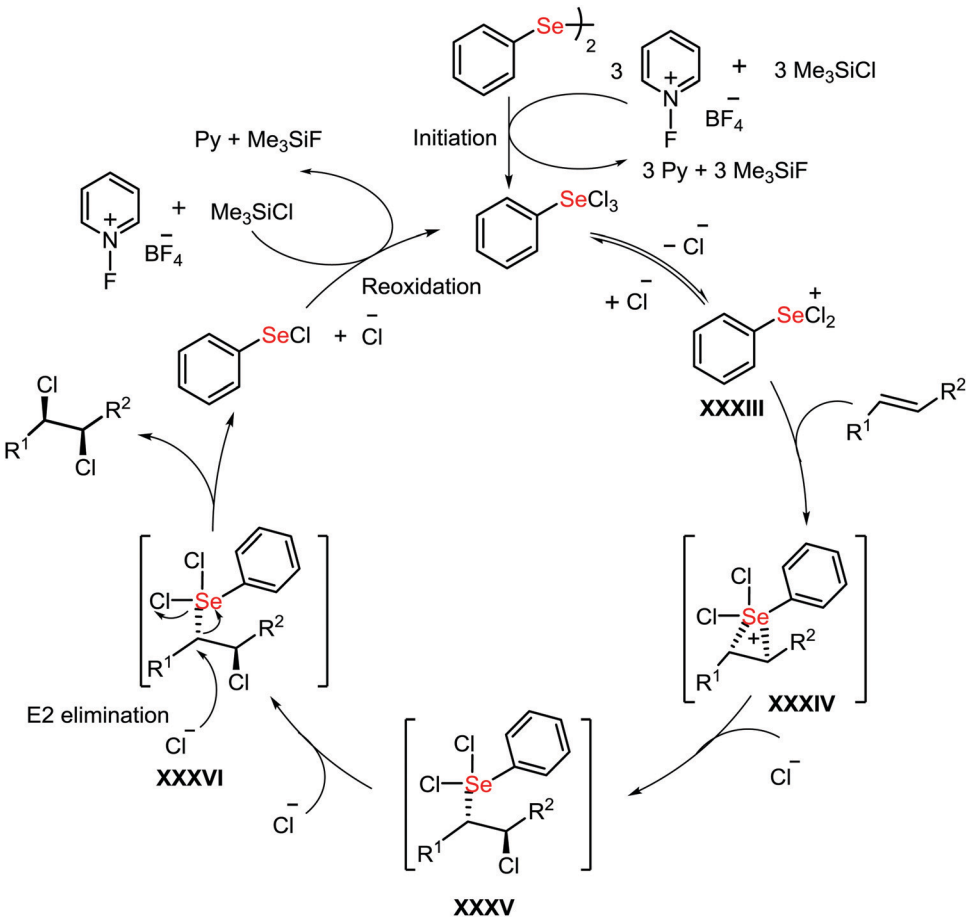
Scheme 24 Organoselenium catalyzed dehydration of aldoximes.

aldoximes in the presence of H_2O_2 as the oxidant under air atmosphere (Scheme 24).[33]

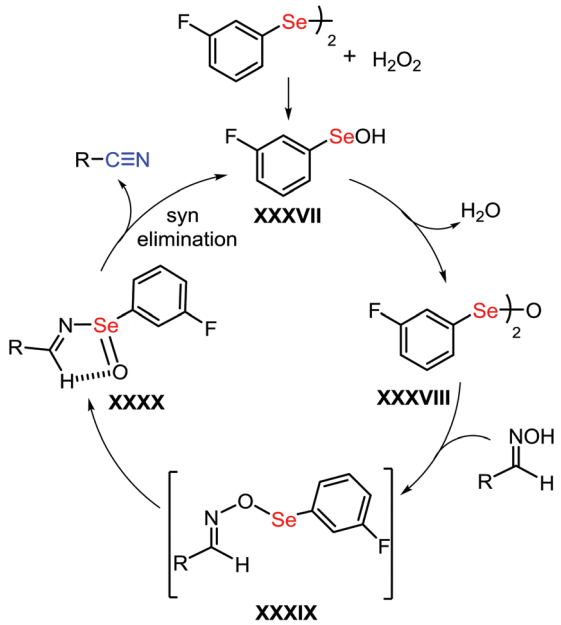
The mechanism was initiated by the oxidation of the selenium catalyst with H_2O_2 to give ArSeOH **XXXVII** that was the active form of the catalyst (Scheme 25). Aryl selenenic acid **XXXVII**, after the removal of water, provided anhydride **XXXVIII**. The reaction of the aldoxime with **XXXVIII** formed the intermediate **XXXIX**. Relocation of **XXXIX** produced the selenoxide intermediate **XXXX**, which underwent elimination and lead to the formation of the desired nitrile products. Aryl selenenic acid was regenerated in the reaction.

14. Selenium catalyzed oxidation of benzylpyridine

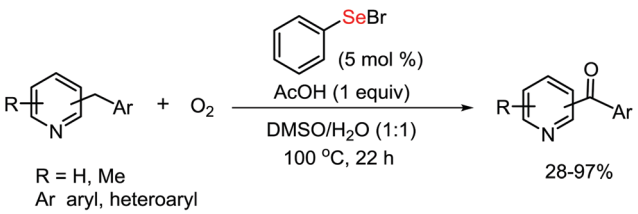
Law and co-workers have demonstrated the chemoselective oxidation of the sp^3 C–H bond of benzylpyridines by using O_2



Scheme 23 Proposed catalytic cycle for the dichlorination of alkenes.



Scheme 25 Possible catalytic cycle for the synthesis of organonitriles from aldoximes.



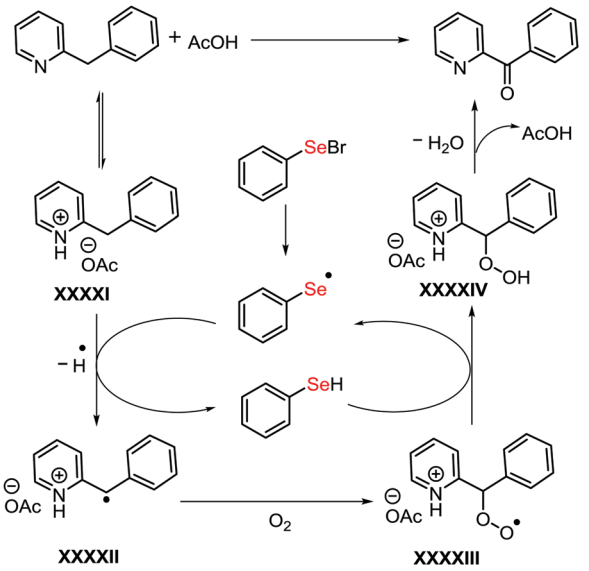
Scheme 26 Oxidation of benzylpyridines with molecular oxygen to benzoylpyridines.

as the oxidant and phenyl selenyl bromide as the catalyst to afford benzoylpyridines (Scheme 26).[34] A wide range of ketones was obtained with good yields in aqueous DMSO medium, where acetic acid acted as a promoter to initiate the reaction.

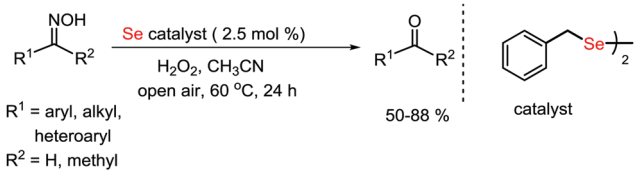
A mechanism was proposed for the oxidation of benzyl pyridine (Scheme 27). The reaction proceeds by the interaction of benzylpyridine with acetic acid to produce salt **XXXXI**. The phenyl selenyl bromide catalyst undergoes homolytic cleavage to form a phenyl selenyl radical, which interacts with **XXXXI** and generates intermediate **XXXXII**. Then, oxidation of **XXXXII** by molecular oxygen would afford peroxy radical intermediate **XXXXIII**, which upon protonation would generate hydroperoxidate intermediate **XXXXIV**. In the end, the removal of AcOH and water molecules provides the desired ketone product.

In 2017, Yu and co-workers developed an organoselenium-catalyzed green method for the deoximation of aldoximes to furnish ketones and aldehydes by using H_2O_2/air as a green oxidant (Scheme 28).[35]

Similarly, very recently in 2019, Se/Fe co-catalyzed aerobic oxidative deoximation of an aldoxime to the corresponding ketone was achieved by Xu and co-workers using peroxide as the oxidant.[36]



Scheme 27 Proposed mechanism for the oxidation of benzoylpyridines.

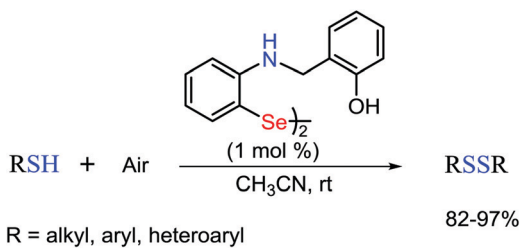


Scheme 28 Deoximation of aldoximes with H_2O_2 to aldehydes or ketones.

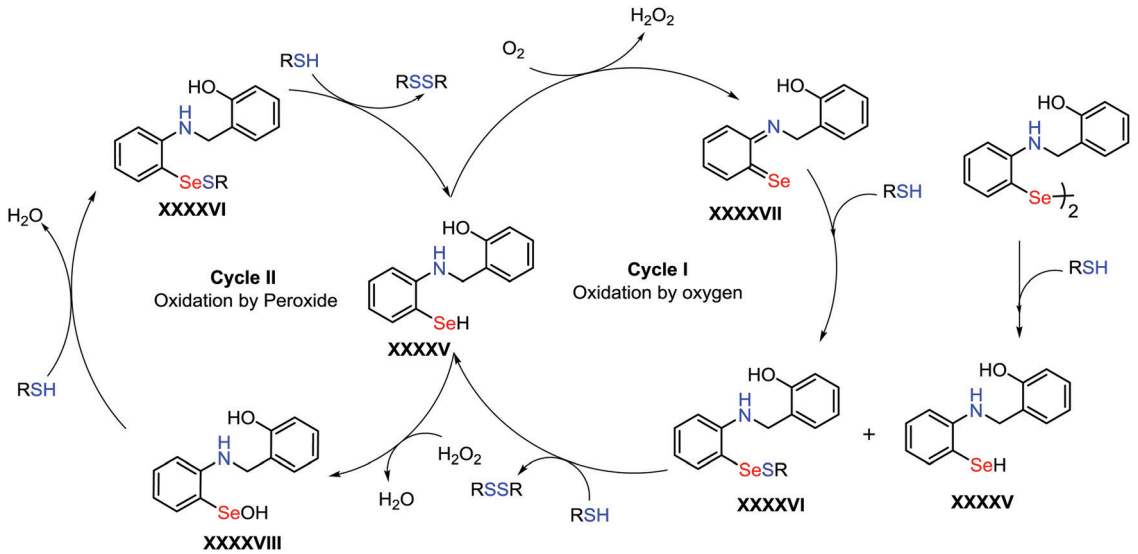
Next, Yu and co-workers demonstrated an organoselenium-catalyzed mild oxidative sp^2 C–C bond cleavage of alkenes.[37] The reaction was carried out in the presence of ethanol with hydrogen peroxide as the oxidant, which resulted in carbonyl compounds.

15. Catalytic oxidation of organothiols to organo disulfides

In 2018, we developed the aerial oxidation of organothiols to the respective disulfides in the presence of the bis(2,1-phenylene)-bis(azanediyl)bis(methylene)diphenol diselenide catalyst, which mimics sulfhydryl oxidase and glutathione peroxidase (GPx) enzymes for the oxidation of thiols by oxygen and hydrogen peroxide, respectively, into disulfides (Scheme 29).[38] The aerial oxidation of organothiols has been achieved in the presence of



Scheme 29 Aerial oxidation of organothiols to organo disulfides.



Scheme 30 Mechanism for the selenium catalyzed oxidation of thiols by air and hydrogen peroxide.

one mol% of a synthesized diselenide sulfhydryl oxidase mimic without using any external oxidant, metal, base, or photosensitized-dye at room temperature. The use of the organoselenium catalyst, which has a two electron redox property, is crucial for the transformation.

A tentative mechanism is illustrated in Scheme 30. The diselenide reacts with the thiol to produce selenol **XXXXV** and selenenyl sulfide **XXXXVI**. Selenenyl sulfide **XXXXVI** may further react with an additional molecule of thiol to produce selenol **XXXXV**, expectedly. The oxidation of **XXXXV** by O_2 would afford selone **XXXXVII** and hydrogen peroxide by an electron transfer followed by a proton transfer from N–H and Se–H bonds unprecedentedly (cycle I). Selenenyl sulfide **XXXXVI** could also react with oxygen leading to selone, $HO_2^{\bullet}$ and $PhS^{\bullet}$ radicals and the latter would dimerize to RSSR. The nucleophilic addition of sulfur from RSH to the selenium of selone **XXXXVII** followed by a proton transfer would provide selenenyl sulfide **XXXXVI** and thus complete the catalytic cycle. Selenol **XXXXV** and selenenyl sulfide **XXXXVI** also catalyze the oxidation of the thiol by the hydrogen peroxide oxidant by following the GPx-enzymatic triads **XXXXV**, **XXXXVI** and **XXXXVIII** (cycle II). The selenol reacts with peroxide to form selenenic acid **XXXXVIII**, which is reduced by another molecule of RSH to afford water and selenenyl sulfide.

16. Conclusion

In recent times, organoselenium catalysis has become a hot topic in synthetic chemistry and attracted much attention of chemists because of its virtues in organic synthesis. Organoselenium catalyzed reactions are cost-effective as compared to metal, and show good functional group tolerance under simple and mild reaction conditions. In this review, innumerable features of organoselenium compounds are summarised and major achievements from the last decade are emphasized. Mainly, diorgano diselenides were used as catalysts in various kinds of oxidation reactions. Also, it seems that organoselenium catalyzed reactions largely involved strong oxidizing agents such as peroxides or halogenating reagents. Furthermore, the oxidation of olefins has been mainly accomplished by organoselenium catalysis. The oxidation of difficult organic substrates and the utilization of environment-friendly oxidants such as aerial oxygen and water in organoselenium catalysis are yet to be explored and could be a promising research area for organoselenium catalysis in the future.

Conflicts of interest

There are no conflicts to declare.

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