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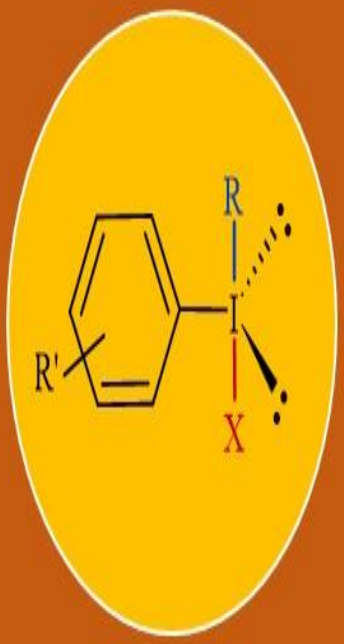
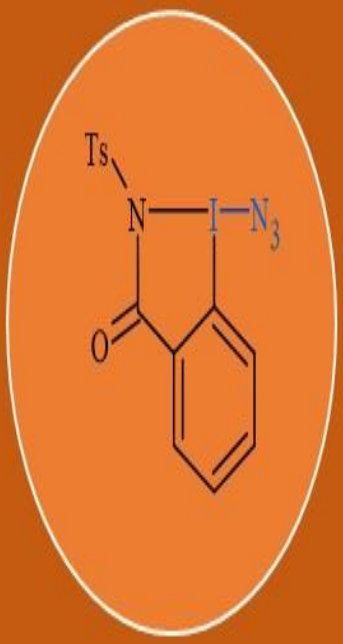
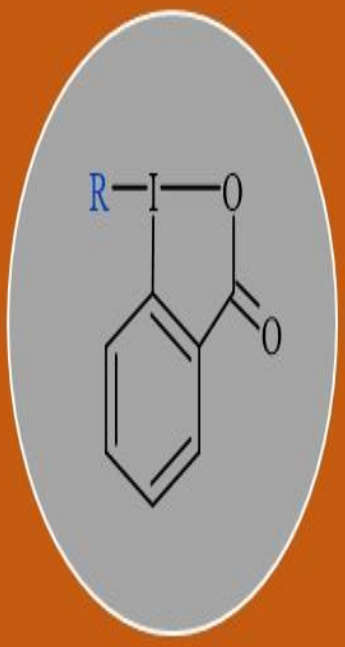
Hypervalent Iodine Reagents: *Highlight*







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Hypervalent Iodine Reagents: *Highlight*

Atef S. Iskander

Hypervalent iodine reagents have outstanding synthetic potential and the ability to undergo practical and chemoselectivity of transformations either *via* ionic or radical reactions. These features enable them to access a variety of molecules of relevant to multi-disciplines, including drug discovery, material science, and agrochemistry. This highlight briefly illustrates recent developments in this burgeoning area, focusing on the application of these reagents as precursors in a range of reactions. The illustrated paradigms would offer a potential avenue to expedite scientific endeavors toward further progress.

KEYWORDS: Hypervalent iodine, Iodonium ylides, Carbenoids, Trifluromethylation, Trifluoromethoxylation.

1. Introduction

Since the development of the first stable iodonium ylide by Neilands and co-workers in 1957,[1] many researchers have been fascinated by the suitability of hypervalent iodine-mediated chemistry. Hypervalent iodine(III) compounds have the potential to act as a significant powerful tool in organic chemistry due to their characteristic features, such as versatility, high reactivity, similarity to some heavy metals derivatives, solubility in common organic solvents, and eco-friendly nature.[2] Recent years have revealed the significant role of the use of these reagents in a wide range of reactions, such as precursors for carbenes, electrophilic functionality, electrophilic iodonium activation of carbon-carbon π-bonds, radical acceptors, and as chiral components in enantioselective synthesis.[3] Aryl iodonium ylides, subset of hypervalent iodine(III) compounds, have been used for metal-catalyzed or uncatalyzed reactions with alkenes,[4,5] ketenes,[6] alkynes,[7] nitriles,[8] isocyanates,[9] thiols,[10] and carbodiimides.[11]

The vast majority of iodonium ylides have a relatively low thermal stability, and some of these reagents have poor solubility in organic solvents. However, thermal stability and solubility of iodonium ylides can be significantly improved by introduction of a coordinating substituent in the *ortho*-position of the phenyl ring.[12] For example, iodonium ylides bearing an *ortho*-alkoxy group in the phenyl ring are stable at room temperature for acyclic iodonium ylides owing to the intramolecular coordination of iodine by the alkoxy group. Cyclic iodonium ylides, in which the iodonium atom is incorporated in a five-membered ring, have even higher thermal stability. Iodonium ylides derived from phenolic substrates represent an important class of zwitter-

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ionic iodonium compounds, in which the system is stabilized and effective by the presence of at least one electron–withdrawing substituent on the aromatic ring. The systematic evaluation of the electrostatic potential energy maps of iodonium ylides revealed that they possess two σ-holes of different electron deficiencies. The more electropositive σ-hole located opposite the dative I-C bond to the β-dicarbonyl motif, and the lesser electropositive σ-hole located opposite the iodoarene C-I bond.[13]
The electronic features of hypervalent iodine(III) molecules are described as a three-atom-four-electron bond model (hypervalent bond). The R-I-X bond in these molecules is highly polarized, significantly longer, and weaker compared to the corresponding I-R and I-X bonds in regular iodides (Figure 1).[3]

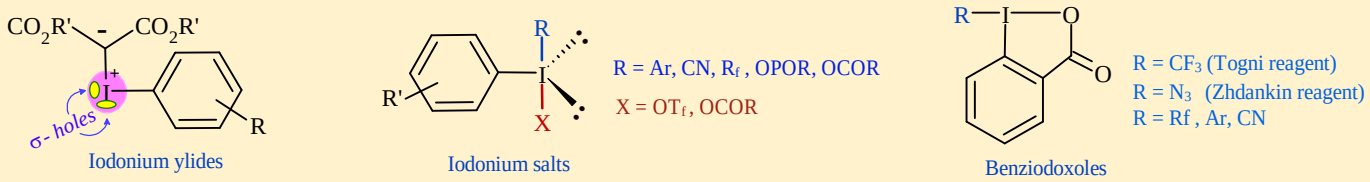

Figure l. Hypervalent iodine(III) compounds.

In terms of reactivity, hypervalent iodine(III) reagents exhibit either ionic or radical reactivity to undergo ligand substitution. Because of their high electrophilicity, the ionic reactivity of these reagents mostly expresses an associative mechanism. In some cases, a Lewis or a Brønsted acid is required to enhance the electrophilicity of iodine(III) molecules.

The radical reactivity of iodine(III) reagents can be achieved *via* homolytic or single-electron transfer (SET) pathways under appropriate conditions. Thermal or irradiation mediated homolysis of the weak hypervalent bond affords biradical species (Scheme 1).[3] In the case of the two radical species (X· and aryl-I·-R) are not covalently bonded, the homolysis of X-I bond leads to the generation of two heteroatom centered radicals. These radicals can react with a substrate (R"-H) *via* H-abstraction to yield the C-radical, which upon further reaction (mostly oxidation or trapping) forms the C-H functionalization product.[3] Both of the two radical species (X· and aryl-I·-R) can also undergo H-abstraction. As a special case, if α-fragmentation of iodanyl radicals (aryl-I·-R) would result in a high energy radical R·, iodanyl radicals can express radical chemistry at the iodine atom, because they live longer, e.g. the addition of iodanyl radicals (R = CN) to alkynes.[3]
An alternative way in the radical chemistry of iodine(III) reagents is the one-electron reduction of compounds using single electron transfer (SET) reducing reagents, such as transition metals, photocatalysts, organic reductants, and electron-rich π-systems. SET reduction of these reagents provides radical intermediate, which fragments to the radical R· and an anion. The radical R· can undergo in typical addition reactions to arenes, alkenes, or alkynes, which are then oxidized and trapped to forge the corresponding products (Scheme 1). In the present highlight, the recent progress in the applications of hypervalent iodine(III) reagents are briefly discussed to manifest their powerful utility in organic synthesis.

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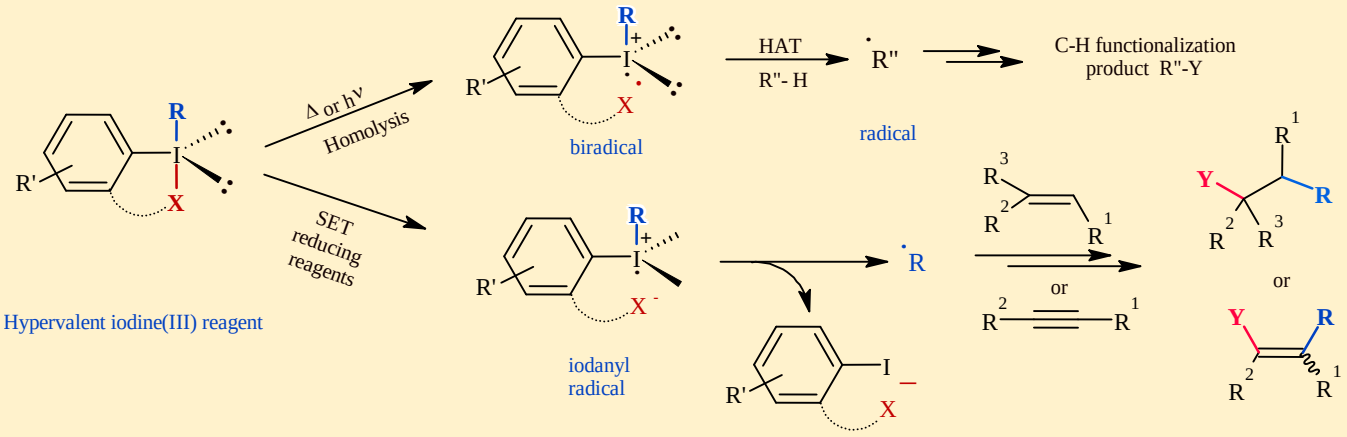

Scheme 1. Generation of radicals employing iodine (III) reagents.

2. Radical reactivity of hypervalent iodine(III) reagents

The ability of radical reactivity of hypervalent iodine reagents to undergo a wide range of transformations makes their use as a powerful tool in organic chemistry. Mostly, a variety of complex molecular architectures are accessible by harnessing the generation in radical approaches that complement a number of ionic counterparts. In general terms, the advantageous properties of radicals are inert to the host of reactive functionalities, such as amines and alcohols. Due to their early transition states and lack of stifling aggregation spheres, they are insensitive to steric crowding. Generally, these radical processes exhibit high functional group tolerance, good stereo- and regioselectivity, and the ability to be employed in cascade reactions.

2.1. Synthesis of heterocycles using hypervalent iodine (III) reagents

Azaheterocycles constitute the most valuable skeletons in biologically active structures, various natural products, and medicinally related compounds. To access azaheterocycles, alkene aminoalkynylation is considered a versatile building block to construct these molecules and install an alkyne group in a single step. Inspired by the developments of alkene functionalization of hypervalent iodine reagents, Shen and Wang reported a copper-catalyzed aminoalkynylation reaction of alkene substrates **1** and ethynylbenziodoxolone

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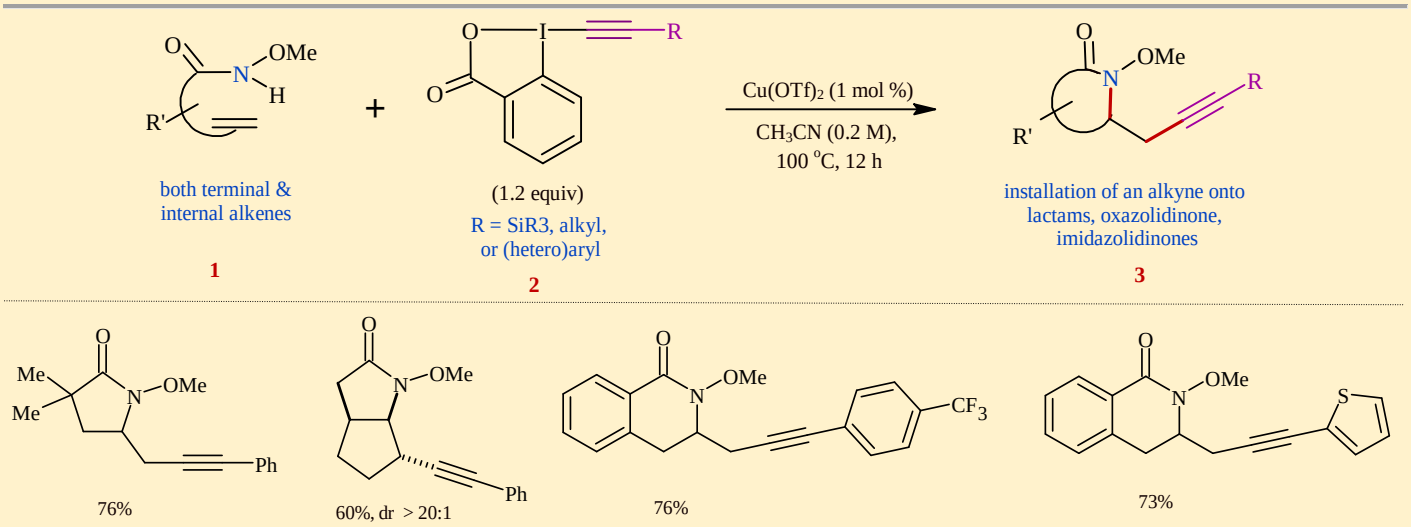
reagents **2**, which allows construction of azahetereocyclic skeletons and the installation an alkynyl group **3** in one step (Scheme 2).[14]



Scheme 2. Alkenes and alkynyl groups for the aminoalkynylation reactions.

To gain a mechanistic insight, an aminoxygenation product **5** was obtained in 99% yield when the reaction of unsaturated amide **4** with iodine(III) **2** took place in the presence of TEMPO as a radical scavenger (Scheme 3A). Moreover, the aminoalkynylation reaction of unsaturated amide substrate containing a standard radical clock cyclopropane moiety at the vinyl position **6** with iodine(III) **2** afforded a ring-opened product **7** in 45% yield, which indicates the presence of radical alkyl intermediates after the aminocyclization step (Scheme 3B). These reactions may probably be proceeded either by coordination of the copper with alkene, followed by intramolecular aminocupration, that may undergo a reversible C-Cu(II) homolysis to form a radical intermediate, and would then attack the α-position of alkynyliodonium salt **8** followed by β-elimination, or *via* other mechanism in which the copper-mediated activation of alkynyliodonium salt leads to aminocyclization, which would further undergo similar homolysis forming a radical intermediate **9** (Scheme 3).

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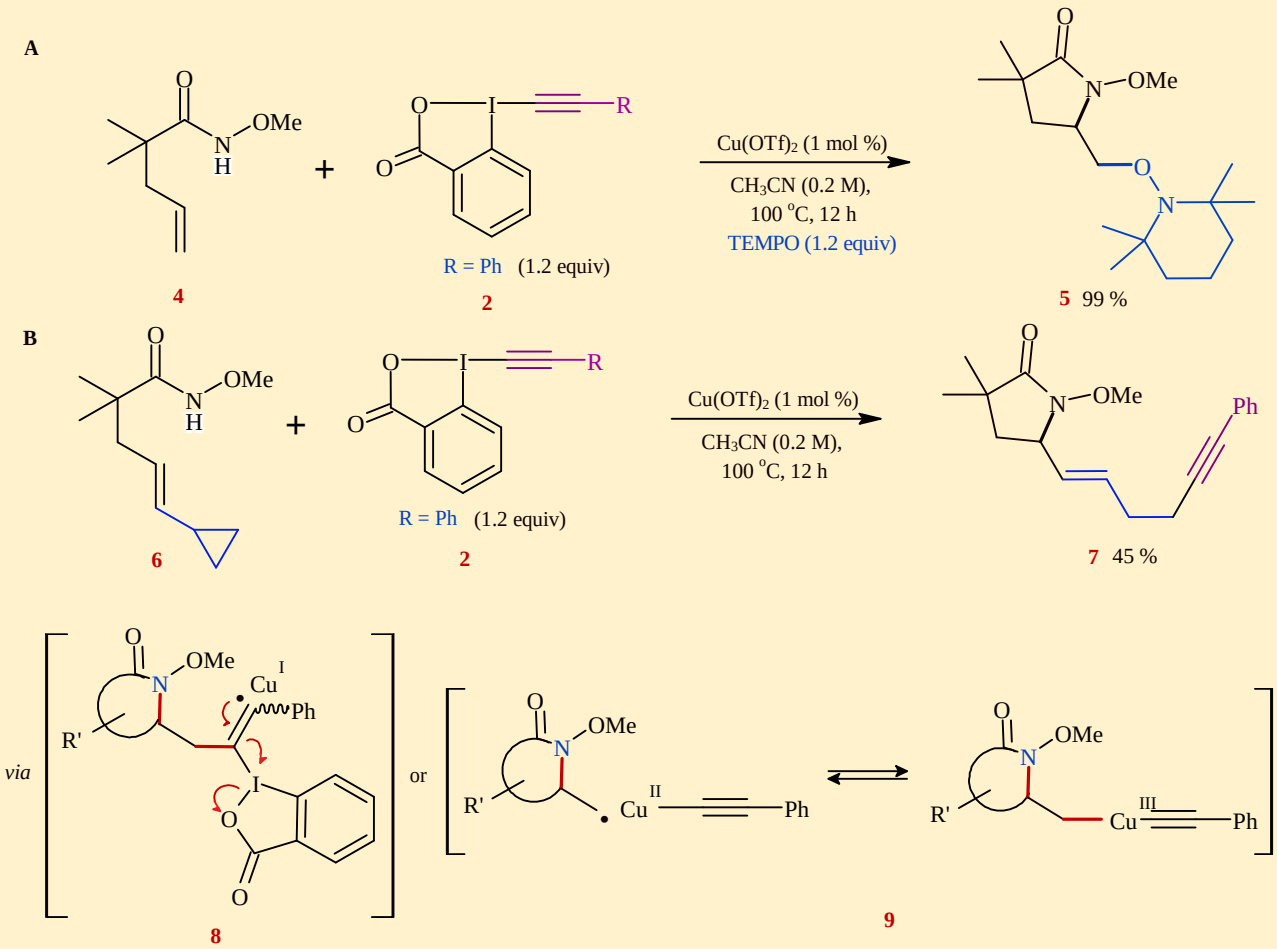
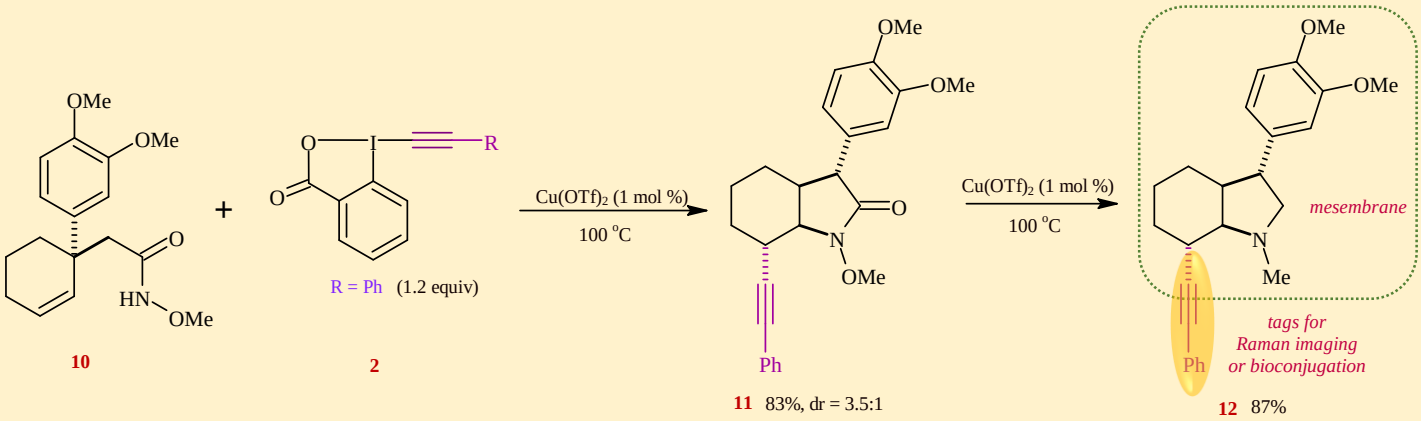


Scheme 3. Mechanistic insights.

Support for the feasibility of this synthetic pathway, they realized the synthesis of alkyn-labelled derivatives of alkaloid mesembrane **12**, which have the potential for a wide range of applications in Raman imaging, and bioconjugation (Scheme 4).



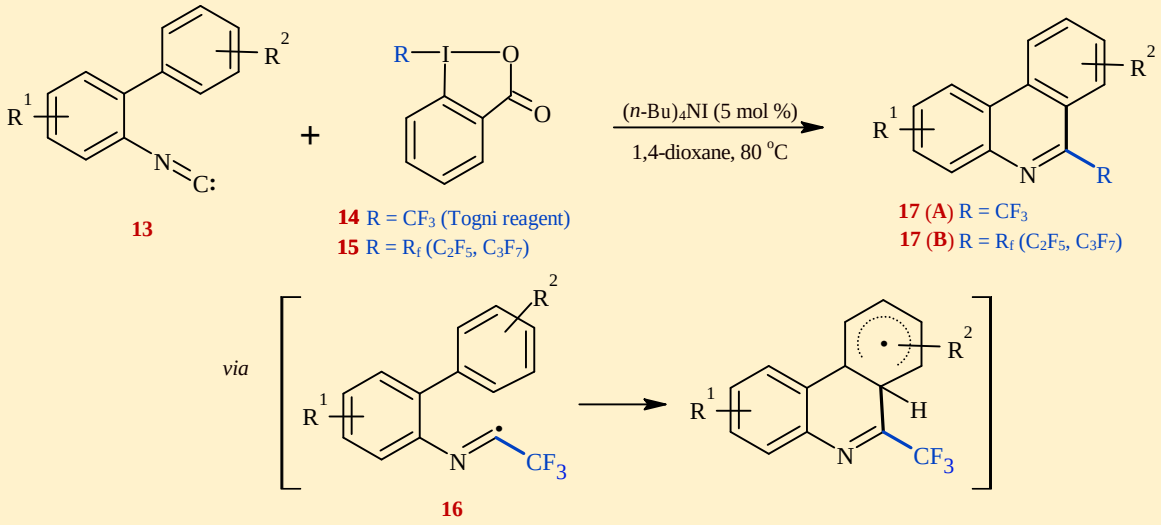
Scheme 4. Synthesis of alkyne-labelled derivatives of mesembrane.

2.2. Trifluoromethylation via SET reduction of the Togni reagent

The trifluoromethyl (CF_3) group is an excellent methyl bioisostere, due to their favorable physicochemical attributes, such as lipophilicity and metabolic stability. The synthesis of nitrogen heterocycles containing trifluoromethyl group **17 (A)** and **(B)** were achieved *via* radical cascade reactions of *ortho*-isocyanobiaryls **13** as CF_3-radical acceptors using Togni reagent **14** and reagent **15** (R_f = C_2F_5, C_3F_7) as triflurormethyl and perfluoroalkyl radical precursors, respectively, in the presence of (n-Bu)$_4$NI as a radical initiator (Scheme 5).[3] The reaction proceeds through the intermediacy of a highly reactive trifluoromethyl radical, which adds to the isonitrile to generate imidoyl radical **16** followed by intramolecular base promoted homolytic aromatic substitution.

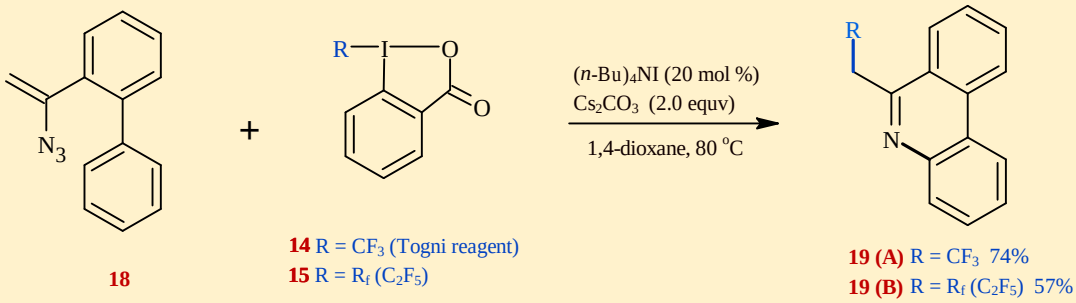
The synthesis of phenanthridines **19 (A & B)** was also accomplished by such cascades *via* the reaction of azides **18** as CF_3-radical acceptor with reagents **13** and **14** (R_f = C_2F_5) in the presence of (n-Bu)$_4$NI and Cs_2CO_3 (Scheme 6).[3]

Notably, the langlois's salt [CF_3–SO_2]Na was also affected the conversion of C-H bonds into C-CF_3 bond in the presence of a cheap industrial oxidant "*tert*-butyl hydroperoxide", *t*-BuOOH (TBHP), in which the trifluoromethyl radical intermediate engages a wide range of both electron-deficient and electron-rich heteroarens.[15] For instance, the functionalization of biomedically relevant substrate deoxyuridine **20** leads to trifluridine (Viroptic) **21** (Scheme 7). The efficiency of Langlois's salt as radical precursor is related to its



Scheme 5. Reaction of 2-isocyanobiaryls with hypervalent iodine (III) reagents.

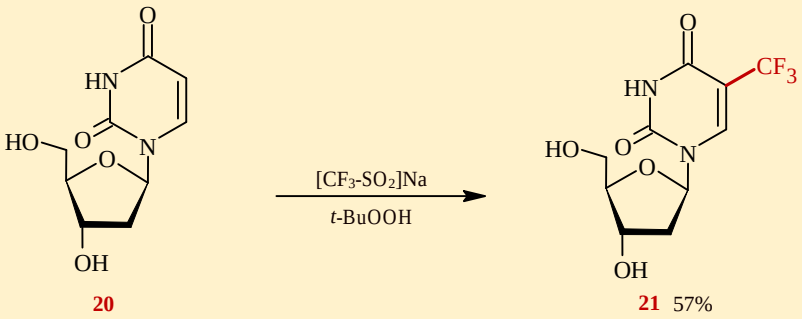
weak C-S bond, and its tendency to extrude SO_2 under oxidation conditions entropically favors radical formation. However, the sodium fluoroalkanesulfinates frequently lack stability or reactivity, the counterpart zinc salts showed superior, such as zinc difluoromethanesulfinate, or an air-stable compound $[CF_2H\text{-}SO_2]_2Zn$ (dubbed "DFMS") that allowed for the conversion of C-H to C-CF_2H.[15]



Scheme 6. Vinyl azides as CF_3-radical acceptors

In fact, the *tert*-butyl hydroperoxide was also employed as co-oxidant with hypervalent iodine (III) reagents for H-abstraction through iodanyl radicals. For example, the site-selective oxidation of *t*-Bu-cyclohexane **22**

with *t*-BuOOH and reagents **23** afforded the regioisomeric ketones **24** and **25** (Scheme 8).[16] The site-selectivity of oxidation can be optimized through the rational design of these reagents.

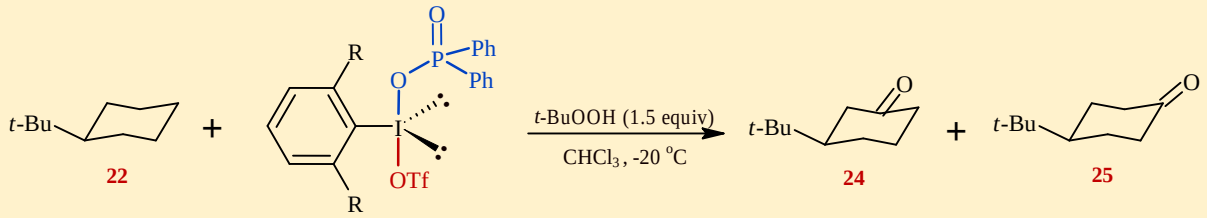


20 **21** 57%

Scheme 7. Trifluoromethylation of deoxyuridine.

2.3. *Alkene azidation via cyclic hypervalent iodine reagents*

Azides are versatile functional groups, leading to products that can be readily converted into valuable structural motives. Azide-containing hypervalent iodine(III) reagents are sources of azido radicals, which are generated by homolysis of the I-N_3 bond in these reagents. As a valuable azide source, the azidobenz-iodoxolone **26** (Zhdankin reagent) is applied for the functionalization of C-H bonds under mild thermal activation. The SET reduction of **26** by a Cu(I)-complex generates azido radicals, which react, for example, with styrene derivatives **27** to forge azidooxygenation products **28** *via* the formation of a benzylic radical followed by a Cu(II)-catalyzed the oxidation process (Scheme 9).[3,17]



Scheme 8. Site-selective oxidation of unactivated secondary C-H bonds.

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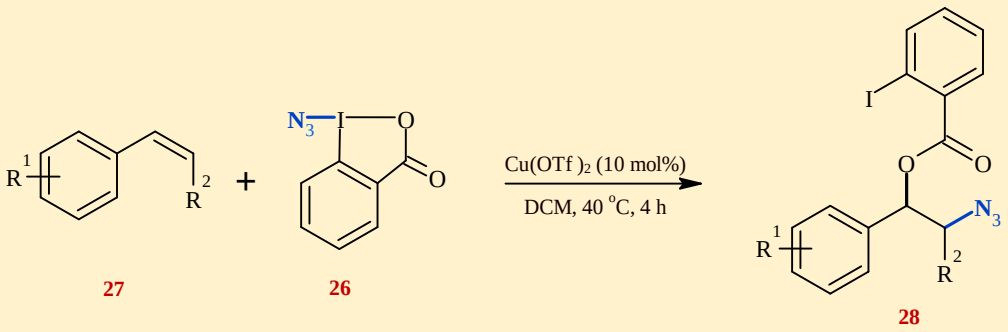
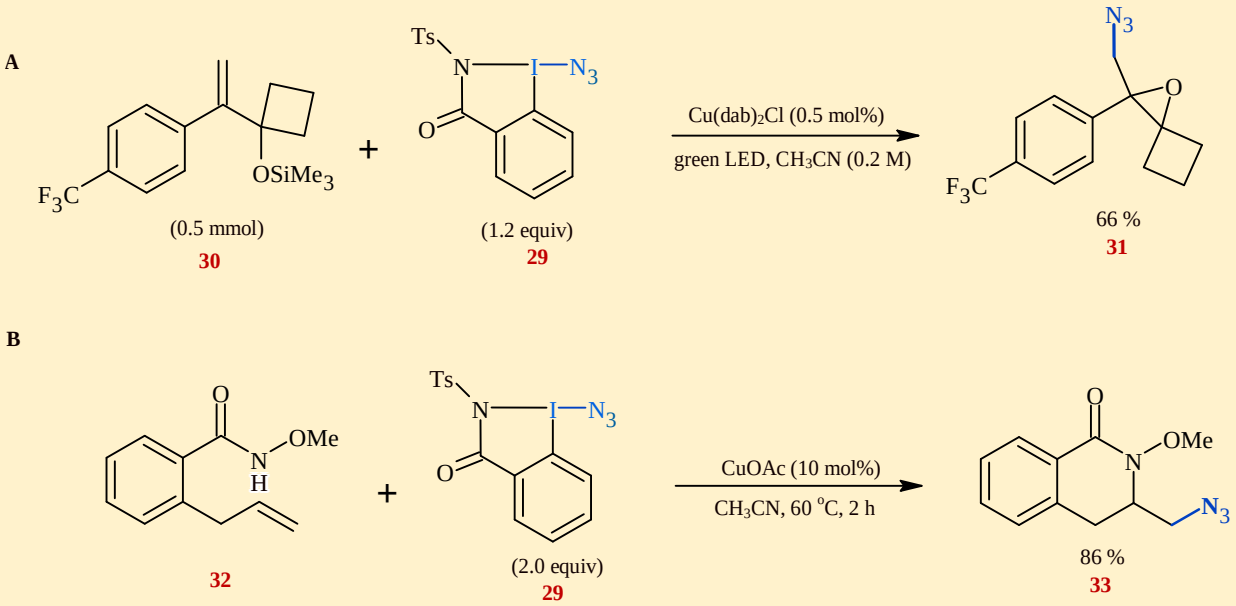


27 26 28

Scheme 9. Copper-mediated vicinal oxyazidation of styrenes.

Towards a better safety profile, Waser *et al.* reported that azidobenziodazolone (ABZ) **29** has an enhanced safety profile than the Zhdankin reagent, demonstrating its potent potential comparable to Zhdankin reagent in a photoredox-mediated ring expansion process and in established radical- or metal mediated transformation.[18] The azidated epoxide **31** was obtained as the sole product in the azidation-ring expansion reaction of the *para*-CF_3-substituted styrene **30** with ABZ *via* azido radical formation under photoredox conditions (Scheme 10 **A**).[18] Support for the potential of ABZ in metal-catalyzed transformations, the copper-catalyzed aminoazidation of alkene **32** was accomplished under thermal conditions (Scheme 10 **B**).[18]

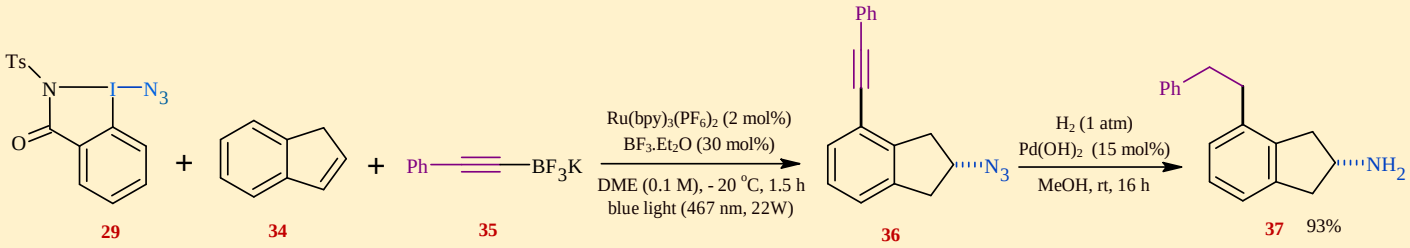


(0.5 mmol) 30 (1.2 equiv) 29 66 % 31

32 (2.0 equiv) 29 86 % 33

Scheme 10. The potential of azidobenziodazolone (ABZ) reagents.

Based on the radical-polar crossover strategy, Waser *et al.* also demonstrated the synthesis of a large variety of homopropargylic azides *via* photocatalyzed azido-alkynylation of alkenes using a combination of an azidoiodane ABZ reagents **29** as azide radical sources upon single electron reduction and potassium alkynyl-trifluoroborates as nucleophilic alkynes.[19] The 3-component reaction of ABZ reagent **29**, the less flexible cyclic indene **34**, and alkynyl **35** under photoredox conditions with $BF_3.Et_2O$ as additive and in the presence of rhodium complex afforded the homopropargylic azides **36** in 63% yield and a diastereoselectivity of 5.4:1 in favor of the *trans* isomer (Scheme 11).[19] Upon further reduction of **36,** the amino-alkylation **37** was obtained in 93% yield.



Scheme 11. The photocatalyzed azido-alkynylation of alkenes.

2.4. Transfer of two ligands from hypervalent iodine reagents

The sequential transferring of two ligands from hypervalent iodine (III) reagents to alkynes is a significantly valuable process. For instance, aryl(cyano)iodonium triflates **38** were reacted with the alkyl aryl alkynes **39** to afford a **40** with complete regiochemistry and excellent *Z*/*E*-stereoselectivity (> 72:1), using $Fe(OAc)_3$ and 1,10-phenanthroline (Scheme 12).[3] The reaction proceeds *via* SET-reduction of **38** by the Fe(II)-phen complex to generate a radical, which adds to the alkyne to provide vinyl radical **41**. SET oxidation of **41** by the Fe(III)-complex leads to cation **42** regenerating the Fe(II)-complex. Reductive elimination at the I(III) center forms the cationic acrylonitrile, which gets trapped by the triflate anion *syn* to the sterically less shielding cyano group.[3]

Aryl(perfluoroalkyl)iodonium triflates **43** were also applied for alkyne perfluoroalkyltriflation of **44** to forge **45** with excellent regio- and stereoselectivity (*Z*/*E* > 20:1) (Scheme 13).[3]

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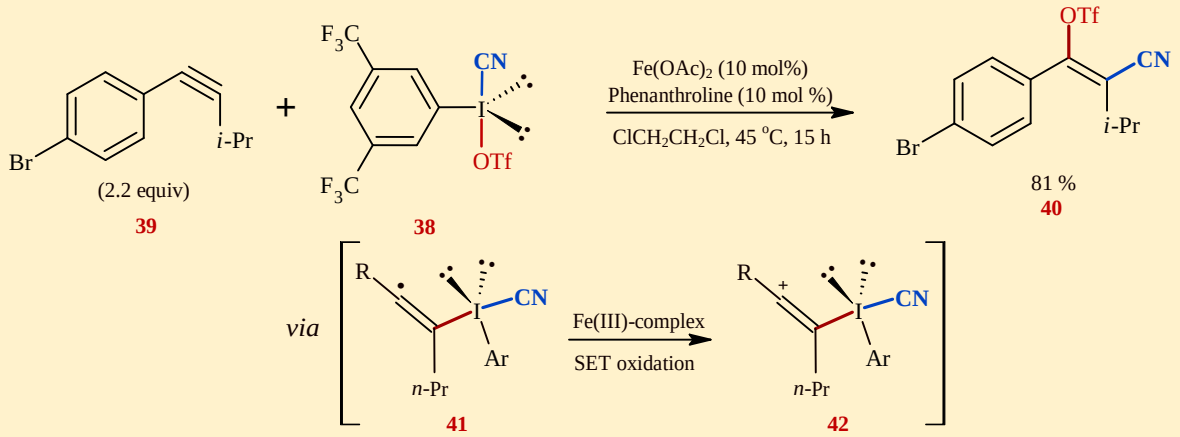
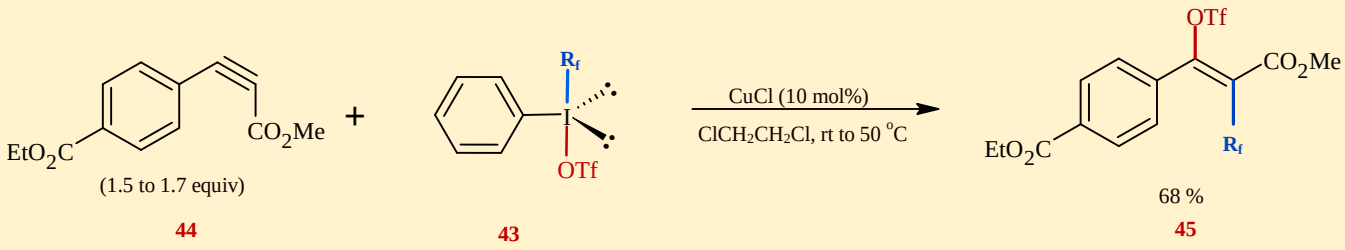
2.5. *Trifluoromethoxylation of functionalized pyridines and pyrimidines*

As valuable synthetic building blocks in biologically active molecules and functional materials, the regioselective trifluoromethoxylation of *N*-protected hydroxylamines derived from functionalized pyridines and pyrimidines was demonstrated by Ngai and co-workers, employing Togni reagents **46**.[20] For example,



Scheme 12. Fe-Catalyzed alkyne cyanotriflation.

pyridines bearing a wide array of heteroaryl substituents (**47a-d**), such as pyrazole (**a**), 2,6-dichloropurine (**b**), thiazole (**c**), ketone (estron conjugated pyridines) (**d**), could be trifluoromethoxylated in one pot under mild reaction conditions to afford the corresponding products in high yields and without observable epimerization (Scheme 14). Furthermore, pyrimidines with heteroaryl substituents (**47e-h**), such as benzimidazolyl (**e**), indolyl (**f**), phenoxy (**g**), or estronyl (**h**), provided the corresponding desired products in good yields (Scheme 14). They suggested that the addition of deprotonated *N*-hydroxyl anion to Togni reagent leads to the formation of *N*-hydroxyl radical **49** and trifluoromethyl radical as a result of SET with



Scheme 13. Perfluoroalkyltriflation of alkynes.

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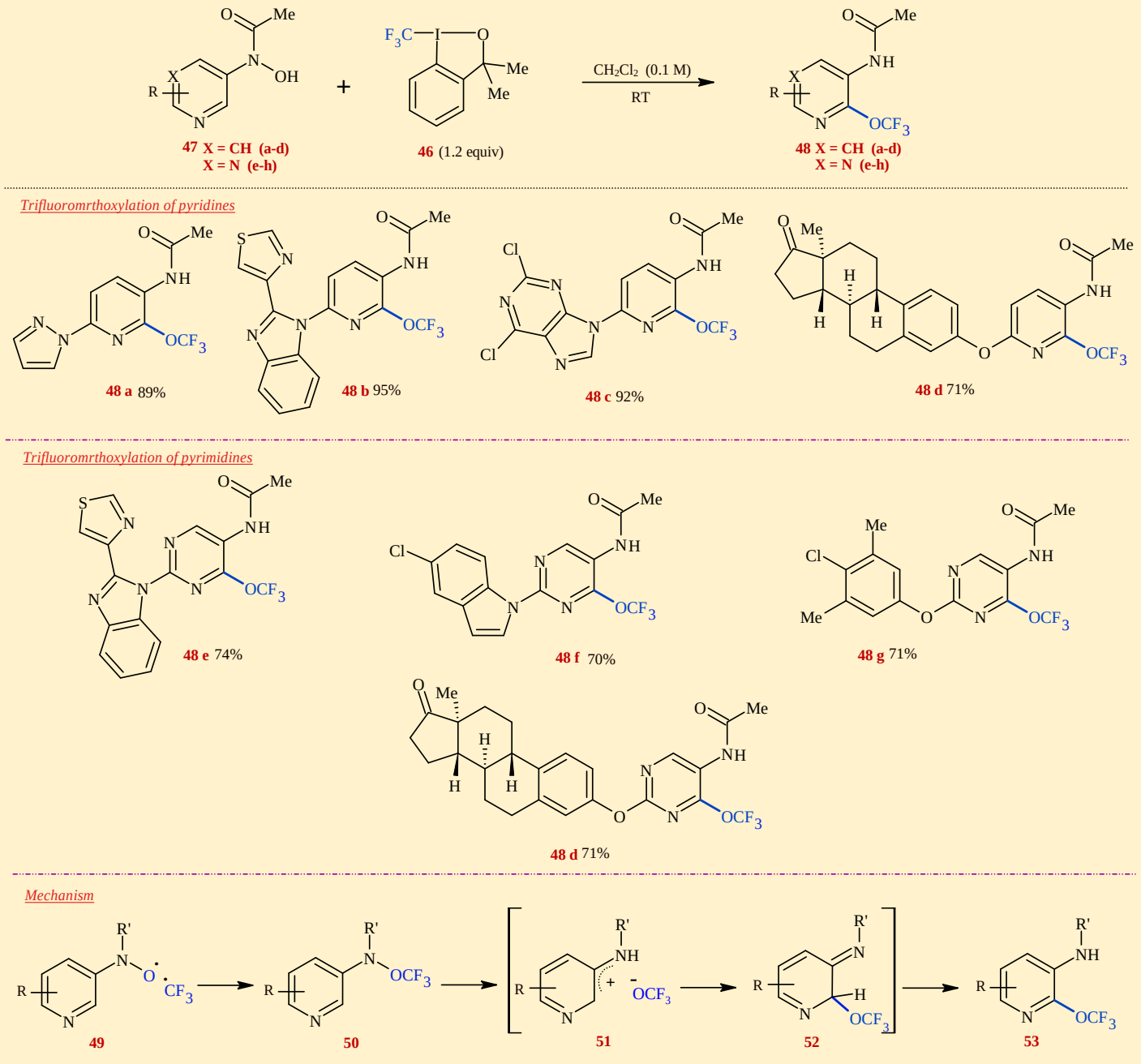
Togni reagent to forge *O*-trifluoromethylated hydroxylamine intermediate **50**. Thermal heterolytic cleavage of the N-O bond of this intermediate forms a tight ion pair of nitrenium ion **51** and trifluoromethoxide, followed by rapid recombination and migration of proton **52,** affording the desired product **53** (Scheme 14).



Scheme 14. *O*-Trifluoromethoxylation reaction of protected *N*-heteroaryl-*N*-hydroxylamines.

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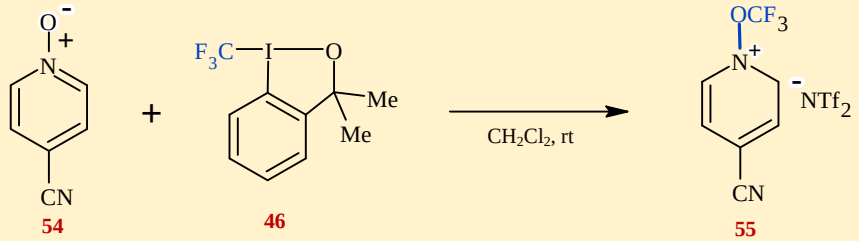
Further screening of the potential hypervalent iodine(III) reagents for radical trifluoromethoxylation of heteroarenes showed that 4-cyano-*N*-trifluoromethoxypyridinium salt **55** could be prepared *via* trifluoromethylation of 4-cyanopyridine *N*-oxide **54** using Togni reagent **46** (Scheme 15).[21] Activation of Togni reagent **46** with *N*-trimethylsilylbis(trifluoromethanesulfonyl)imide allowed obtaining the desired product in 63% yield. The thermally stable pyridinium reagent **55** is a source of the trifluoromethoxyl radical in the presence of strongly reducing photocatalyst $Ru(bby)_3(PF_6)_2$, which transfers this elusive radical to a variety of arenes, providing access to aryl trifluoromethyl ethers in a selection of biorelevant compounds in an operationally simple manner.



Scheme 15. Trifluoromethylation of 4-cyanopyridine *N*-oxide.

3. The ionic reactivity of hypervalent iodine(III) reagents

Hypervalent iodine(III) reagents exhibit outstanding ionic reactivity due to their high electrophilicity, which allows them to undergo a variety of transformations, such as cycloaddition, intramolecular bonding, or metallocarbene-based reactions, and also serve as electrophiles or nucleophiles, offering the potential to alter the physical properties (e.g., stability, solubility) of these reagents. In fact, the diverse reactivity of these reagents demonstrates emerging avenues for tuning their reactivity and improving their reaction outcomes. This section presents some paradigms that reflect the potential of these reagents towards the possibility of developing valuable transformations.

3.1. Electrophilic attack at the nucleophilic carbon center of the iodonium ylides

Mayr *et al.* investigated the reactions of a characterized group of *β*-dicarbonyl-substituted iodonium ylides **56a-d** (Figure 2) with stabilized π-conjugated carbenium and iminium ions to test the accessibility of electrophilic attack at the nucleophilic carbon center of this group.[22] In theses reactions, the initial rate-

determining C-C bond-forming step afforded iodonium ions **57a-d**, followed by rapid expulsion of iodobenzene and undergoing different subsequent reactions (Scheme 16). The rate constant calculated by the linear free energy relationship eq (1) for the cyclopropanation of the cinnamaldehyde-derived iminium ion **58** by the iodonium ylide **56a** indicates that this reaction proceeds through a stepwise mechanism in which the initial nucleophilic attack of the iodonium ylide at the iminium ion **59** is rate-determining (Scheme 17).

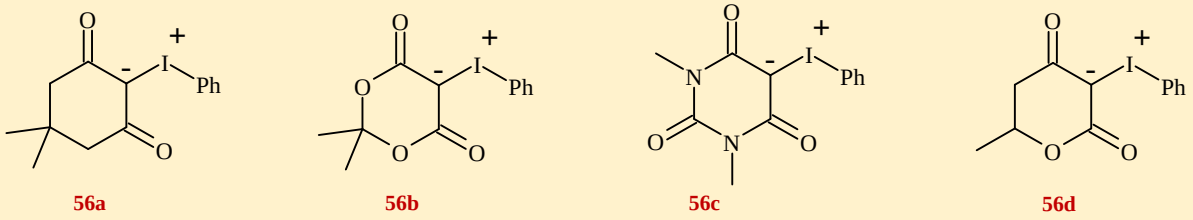
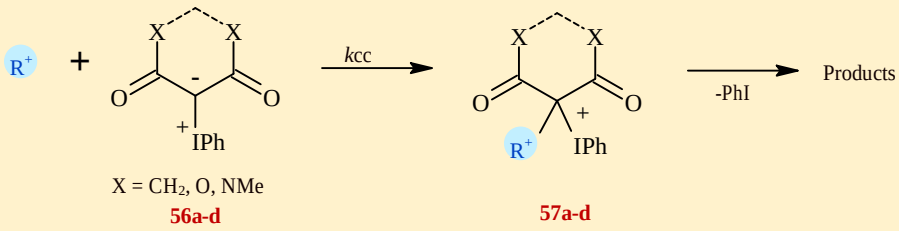


Figure 2. *β*-dicarbonyl-substituted iodonium ylides.

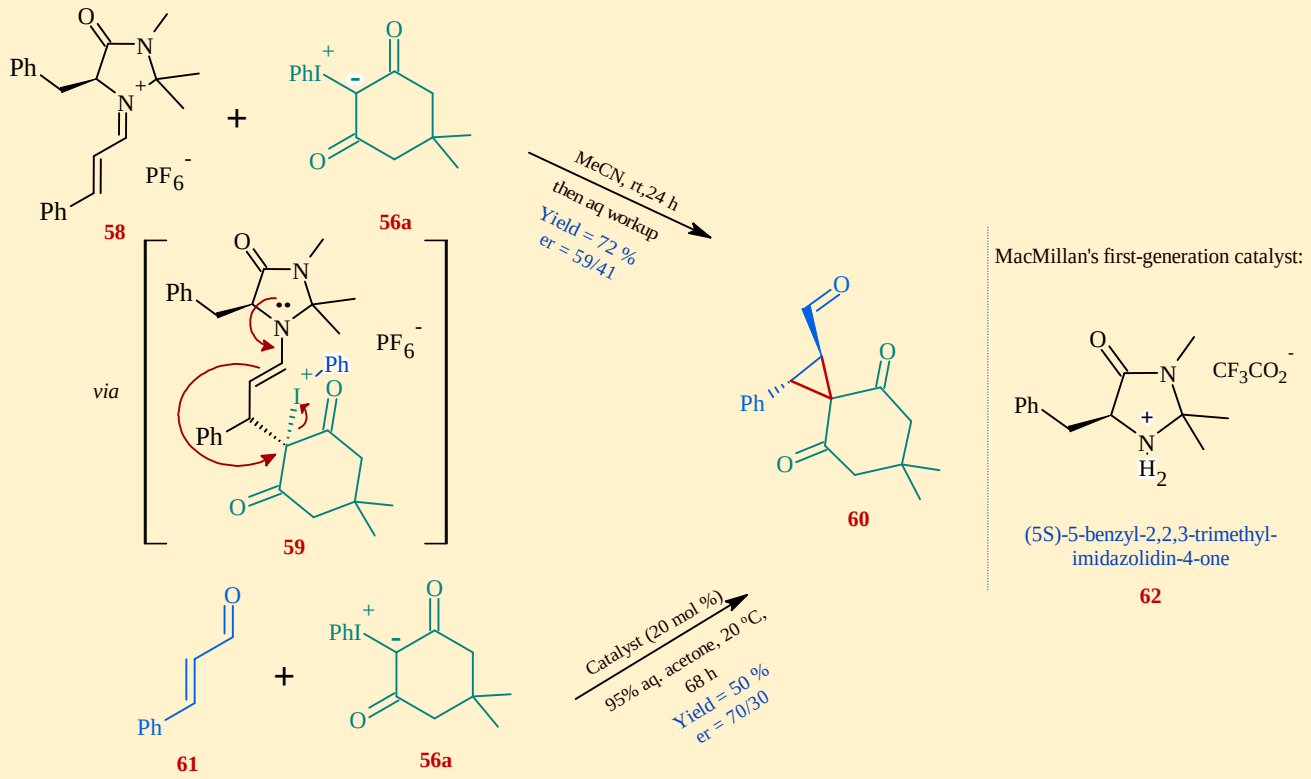
$$\log k_{20\,^{\circ}C} = s_N (N + E) \quad (1)$$

[where E is an electrophilicity parameter, N is a nucleophilicity parameter, and s_N is a nucleophile-specific susceptibility parameter.]



Scheme 16. Second-order rate constants (k_2) for the reactions of iodonium ylides with π-conjugated carbenium and iminium ions.

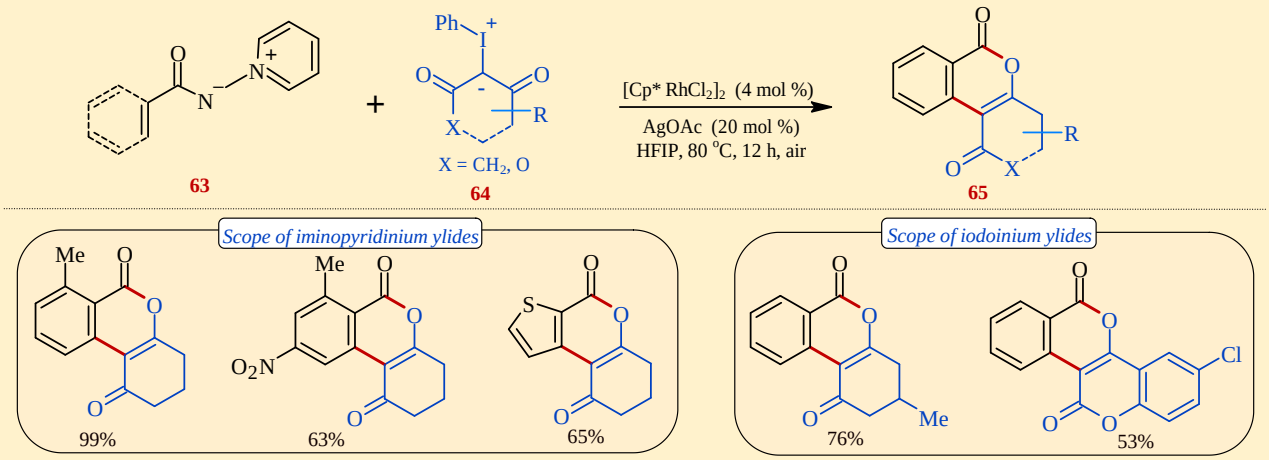
Moreover, the reaction of cinnamaldehyde **61** with iodonium ylide **56a**, catalyzed by (5*S*)-5-benzyl-2,2,3-trimethyl-imidazolidin-4-one (**62**, MacMillan's first-generation catalyst), yields the corresponding cyclopropane **60** with an enantiomeric ratio of ca. 70/30 and 50% yield, indicating the suitability of iodonium ylides to act as substrates for iminium-activated cyclopropanations. (Scheme 17).



Scheme 17. The reactions of iodonium ylide **56a** with either iminium ion **58** or a combination of cinnamaldehyde **61** and catalyst **62**.

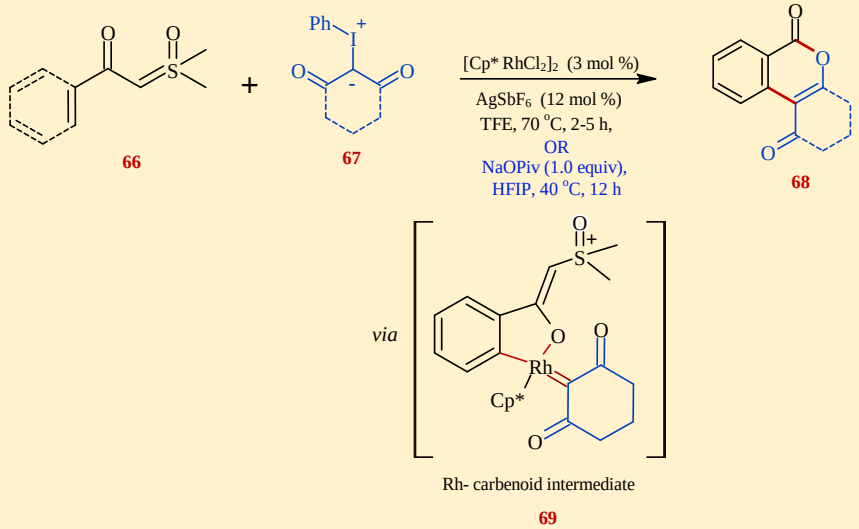
3.2. Oxygen-containing heterocycles

Oxygen-bearing heterocyclic compounds are significantly important structural motifs in synthetic chemistry and are existing in a wide range of natural products and biologically active compounds. Thus, facile procedures for preparation of these compounds remain a significant interest in the field. In this context, iodonium ylides constitute an important carbene precursor to access oxygen heterocycles *via* transition metal catalyzed C-H functionalizations, involving the catalytic activation of the arene C-H bond, followed by annulation with iodonium ylides. Recently, Liu *et al.* reported a Rh(III)-catalyzed redox-neutral annulation of iminopyridinium ylides **63** with iodonium ylides **64** to forge the biologically active isocoumarin skeletons **65**, in which iminopyridinium ylides serve as directing group, and iodine(III) as carbene coupling partners. The reaction proceeded smoothly *via* cleavage of the C-N bond in the ylide directing group (Scheme 18).[23,24]



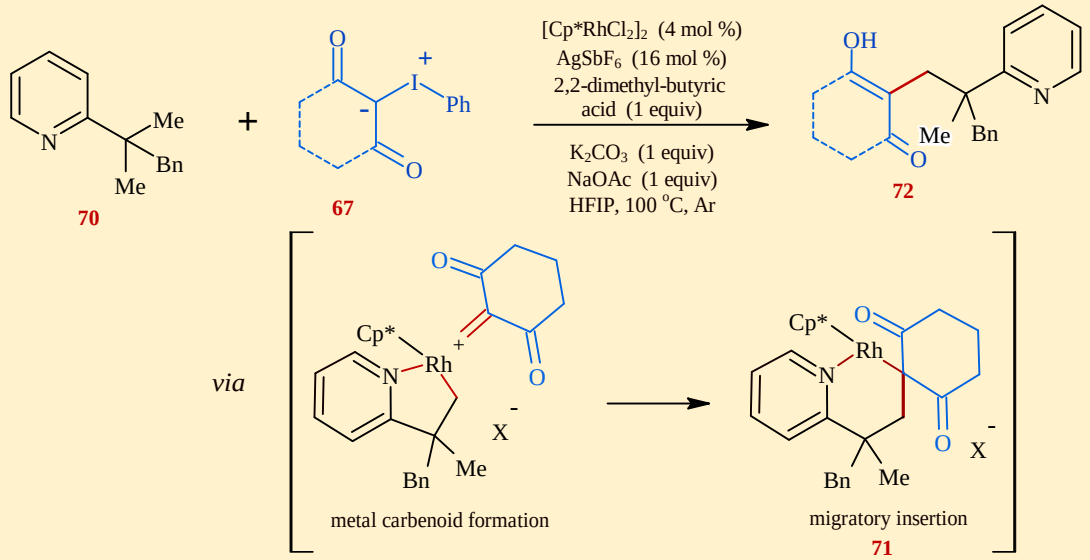
Scheme 18. Rh(III)-catalyzed C–H functionalization of iminopyridinium ylides.

Notably, this strategy was further extended to the synthesis of dihydrobenzo[*c*]chromen-6-one frameworks **68** using a Rh(III)-catalyzed cross coupling reaction between sulfoxonium ylides **66** and iodonium ylides **67** (Scheme 19).[24,25] The reaction proceeds *via* sequential C-H activation and coordination of iodonium ylides followed by extrusion of aryl iodide, leading to the formation of Rh carbenoid intermediate **69**. Subsequent migratory insertion and proto-demetallation provided an alkenylation product, which underwent intramolecular nucleophilic addition/cyclization through the subsequent loss of Corey-Chaykovsky reagent (sulfoxonium methylide) to yield the desired product **68**. Yu *et al.* demonstrated a similar reaction, in which the [3+3]-cyclization accomplished under oxidant-free conditions using NaOPiv/HFIP to provide the isocoumarin derivatives.[24,26]



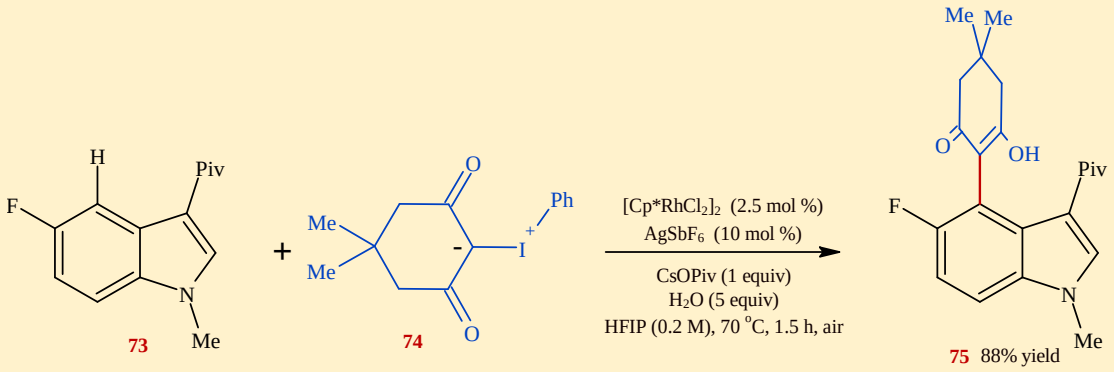
Scheme 19. Synthesis of dihydrobenzo[*c*]chromen-6-one frameworks.

To access the all-carbon quaternary center of substituted pyridine or quinoline substrates, Liu *et al.* realized direct C-H alkylations of pyridine **70** or quinoline containing a *gem*-dimethyl group with iodonium ylides **67** as C1 synthons using rhodium catalyst. The reaction proceeds *via* inert C(sp^3)-H carbene insertion reaction **71**, leading to the C-C bond formation, which affords the monoalkylation product **72** exclusively (Scheme 20).[27]



Scheme 20. Rh(III)-catalyzed C–C coupling of unactivated C(sp^3)–H bonds with iodonium ylides.

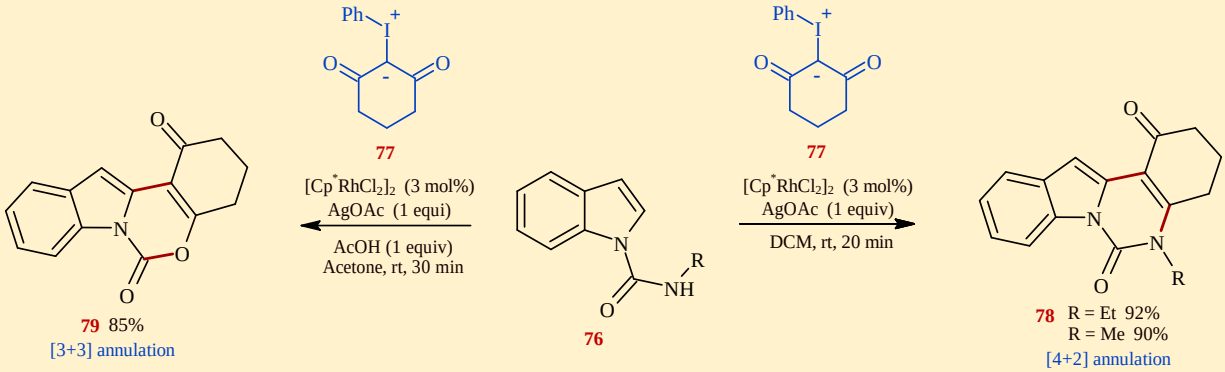
Likewise, Zhang *et al.* demonstrated the Rh(III)-catalyzed regioselective C(sp^2)-H activation of indoles at C4-position by using iodonium ylides as carbine precursors. The one-pot synthesis of C4-selective functionalization of N1-protected and 3-pivaloyl indoles **73** with iodonium ylides **74** under redox neutral reaction conditions afforded the product **75** in high yields (Scheme 21).[28] This approach exhibits good functional group tolerance with excellent yields, one-pot synthesis, and scale-up synthesis.



Scheme 21. Rhodium(III)-catalyzed regioselective C(sp^2)–H activation of indoles with iodonium ylides.

3.3. *Nitrogen-containing heterocycles*

An elegant protocol developed by Kanchupalli *et al.* for the synthesis of tricyclic and tetracyclic *N*-heterocycles *via* an acid-switchable chemodivergent of Rh(III)-catalyzed [4+2] and [3+3] annulations of *N*-carboxamide indoles **76** as directing groups with iodonium ylides **77** as carbene precursors. In this protocol, the synthesis of 3,4-dihydroindolo[1,2-*c*]quinazoline-1,6(2*H*,5*H*)-dione **78** and 1*H*-[1,3]oxazino[3,4-*a*]indol-1-one **79** derivatives were realized under mild conditions. Interestingly, in the presence of $[Cp^*RhCl_2]_2$, AgOAc and DCM as a solvent, the desired [4 + 2] annulation was achieved. In contrast, a complete switch in selectivity was observed using a catalytic system comprising $[Cp^*RhCl_2]_2$, AgOAc, AcOH, and acetone as the solvent, which delivered the [3 + 3] annulation product in excellent yields (Scheme 22).[29]



Scheme 22. Rh(III)-catalyzed [4+2]- and [3+3]-annulations of indole *N*-carboxamide indoles with iodonium ylides.

4. Conclusion

In this highlight, the aforementioned reactions reveal the remarkable chemical reactivity of hypervalent iodine compounds in diverse reactions. They have the ability to undergo a wide range of transformations including transition-metal-catalyzed C-H functionalizations via radical or ionic pathways. These capabilities reflect the ability to construct diverse carbon-carbon and carbon-heteroatom bonds. Moreover, they have the potential to tune their reactivity through rational design of these molecules as well as the coupling partners with them to achieve diverse transformations of carbo/hetero-cyclizations. The versatility and chemoselectivity of the reactions enable rapid access to molecules relevant to multi-disciplines. Thus, these reactive precursors possess an inherent potential to lead to new types of transformations and inspire chemists to further improve the synthetic chemistry landscape.

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