A survey of chiral hypervalent iodine reagents in asymmetric synthesis
Soumen Ghosh‡, Suman Pradhan‡ and Indranil Chatterjee*

Abstract
The recent years have witnessed a remarkable growth in the area of chiral hypervalent iodine chemistry. These environmentally friendly, mild and economic reagents have been used in catalytic or stoichiometric amounts as an alternative to transition metals for delivering enantioenriched molecules. Varieties of different chiral reagents and their use for demanding asymmetric transformations have been documented over the last 25 years. This review highlights the contribution of different chiral hypervalent iodine reagents in diverse asymmetric conversions.

Introduction
It is more than one century ago since the discovery of the first hypervalent iodine reagent (HIR) [1] and hypervalent iodine chemistry has started to flourish as one of the important and leading areas in organic synthesis. In recent years many excellent reviews have detailed the bonding, reactivity, synthesis, and uses of hypervalent iodine reagents [2-14]. These compounds feature a unique three-centered four-electron bond [15-20] that renders them valuable and important alternatives to transition-metal chemistry. Over the last 25 years hypervalent iodine reagents have gained growing application due to their reduced toxicity, ready availability and lower costs as replacement for transition metals leading to several “metal-free” like chemical transformations.

The ongoing demand of modern synthetic chemistry for the development of catalytic enantioselective C–C bond formation reactions turned the attention of the scientific community towards the evolution of new chiral hypervalent iodine reagents. In recent years, many complex synthetic challenges have been successfully addressed by applying these reagents [21,22]. The superior advantage of these reagents lies in their strong electrophilicity and appreciable oxidizing properties. The transformat-
ions associated with asymmetric induction mainly focused on the asymmetric oxidation and oxidative dearamatization chemistry. Asymmetric difunctionalization of alkenes, $\alpha$-functionalization of carbonyls and also some typical 1,2-aryl rearrangement reactions add further value to this chemistry.

The strategies used for the synthesis of chiral hypervalent iodine reagents include either the introduction of chirality through the attachment of chiral acids or chiral alcohols to the iodine centers by ligand exchange or are achieved by the introduction of axial chirality through the iodoarene backbone. A series of chiral iodine reagents are documented below (Scheme 1). In many cases chiral I(I) reagents get oxidized in situ to the hypervalent I(III) reagents and/or these chiral I(III)/I(V) reagents are used in a catalytic amount in the presence of an external oxidant. The use of catalytic chiral hypervalent iodine reagents in asymmetric catalysis is one of the most challenging ongoing topics and this review will focus on the development of various chiral hypervalent iodine reagents and their application in typical organic transformations.

**Review**

**Asymmetric oxidation of sulfides**

Pribam was the first to use chiral iodine reagents [23]. After a long time without further developments in this direction, Imamoto et al. introduced a new class of hypervalent iodine reagents 1 obtained by the reaction of iodosylbenzene with various derivatives of L-tartaric acid anhydrides in 1986. A promising asymmetric induction was achieved for the oxidation of sulfides 23 to sulfoxides 24. This marked the beginning of an era of asymmetric oxidation of sulfides. However, the presence of $C_2$ symmetry in the chiral unit is essential to obtain decent enantioselectivity [24]. Later, Kita et al. used chiral tartaric acid derivatives to synthesize chiral I(V) reagents 2 from PhiO$_2$. This represented the first example of the catalytic use of chiral hypervalent reagents in the oxidation of sulfides to sulfoxides with decent enantioselectivities (ees, Scheme 2a). The asymmetric oxidations were examined in 20 mol % cetyltrimethylammonium bromide (CTAB) reversed micelles [25]. Interestingly, Varvoglis et al. synthesized another new class of a chiral reagent 3 using (+)-camphor sulfonic acids as the source of chirality [26] which was used by Chen et al. for the oxidation of sulfides to sulfoxides with good yields but with poor enantioselectivity (Scheme 2b) [27]. Later, Zhdankin et al. synthesized different classes of chiral I(V) reagents 4 based on various amino acids as sources of chirality. The oxidation of the readily available 2-iodobenzenamines (synthesized from amino acid derivatives) with potassium bromate or Oxone (2KHSO$_5$/KHSO$_4$/K$_2$SO$_4$) efficiently delivered the I(V) reagents 4 (Scheme 2c) [28,29]. Although good product yields were obtained for the oxidation of sulfides, the ees were very low.

New classes of chiral hypervalent iodine reagents were obtained by the introduction of chiral alcohols directly to the iodine reagent through ligand exchange. Koser et al. used (+)- or (−)-menthol as a source of chirality during their synthesis of the new chiral iodine reagent 5 [30]. Chiral sulfoxides 24 (having $R^1$ = $p$-Tol, $t$-Bu, Bn and $R^2$ = Me) were obtained for the first time with excellent enantioselectivity (Scheme 2d). Another class of chiral I(V) reagents 6 was synthesized by Wirth et al. who synthesized the desired compounds through esterification between chiral alcohols and the I(I)-substituted aromatic acids followed by oxidation with dimethyldioxirane (Scheme 2e) [31]. A summary of chiral hypervalent iodine reagents used in the asymmetric oxidation of sulfides is sketched below (Scheme 2).

**Asymmetric oxidative dearamatization, alkene functionalization and rearrangement strategy**

**Oxidative dearamatization**

Asymmetric oxidative dearamatizations and the use of dearamatized products to generate chiral complex molecular scaffolds in a short and efficient way is one of the attractive strategies used in chiral hypervalent iodine chemistry. Kita et al. for the first time developed a new chiral I(III) catalyst 7 having a rigid spirocyclic backbone. They applied it for the enantioselective oxidative dearamatization of phenolic derivatives 25 (spirolactonization) which is known as Kita oxidation to yield spirocyclic compounds 26 with good enantioselectivity [32]. The indication of an associative mechanism was also confirmed due to an increased enantioselectivity observed in polar solvents. Further, they were able to improve the enantioselectivity by implying steric effects at the ortho/ortho' (R = Et in 7) positions of the aromatics (Scheme 3) [33]. The regeneration of the catalyst was achieved by $m$-CPBA converting iodine compound 7$^*$ to chiral catalyst 7. The authors predicted a plausible mechanism and transition-state model 27 for the formation of the major isomer through the attack of the carboxylic acid group to the ipso position of the naphthol ring from the less sterically hindered Re-face of the substrate 25. It is worth mentioning that very recently they have introduced a new kind of binaphthyl-based chiral I(III) prereagent 19 with the 8 and 8' positions of the naphthalene substituents being occupied by iodide. Here they have observed that this chiral hypervalent iodine reagent 19 in the presence of co-oxidant $m$-CPBA is very useful for the dearamatizing spirocyclization of naphthol carboxylic acid [34].

Later Birman et al. reported a new variation of a chiral I(V) reagent, namely 2-(o-iodoxyphenyl)oxazoline derivative 28 [35]. The reagent was applied to an asymmetric [4 + 2] Diels–Alder dimerization of phenolic derivatives 29 to construct tricyclic derivatives 30 with moderate enantiose-
Scheme 1: An overview of different chiral iodine reagents or precursors thereof.
lectivity (Scheme 4). Although modest ees were obtained, this chiral oxazoline-based compound demonstrated encouraging potential as a new class of chiral hypervalent iodine reagent.

Fujita et al. synthesized non $C_2$-symmetric chiral iodoarene reagents 9a derived from lactic acid derivatives and utilized them in stoichiometric fashion for the synthesis of chiral tetrahydrofuran derivatives [36]. A major breakthrough was achieved in this field by the discovery of a family of conformationally flexible $C_2$-symmetric chiral iodoarene reagents. Ishihara et al. thoughtfully designed a new class of $C_2$-symmetric chiral iodoarene precatalyst 8a using ($-$)-ethyl lactate as a chiral linker with the aromatics attached followed by its successful conversion to the amide derivative to generate precatalyst 8a [37,38]. Application of this precatalyst 8a was employed for the Kita oxidation [32] with a high level of enantioselectivity. Naphthol derivatives 31 were converted to spirocyclic lactones.
Scheme 3: Oxidative dearomatization of naphthol derivatives by Kita et al.

Later, this dearomatization strategy was further reinvestigated by the Ishihara group using a new chiral iodine precatalyst derived from a chiral 2-aminoalcohol [39]. Its application in the oxidative dearomatization of phenol [33] and the subsequent reaction of the so-obtained dienes [34] with different dienophiles furnished Diels–Alder adducts [35] with excellent enantioselectivity. Intramolecular H-bonding and the presence of an achiral alcohol as additive helped them to achieve outstanding enantioselectivity (up to 99%) even when using very low catalyst loadings (1–10 mol %, Scheme 6).

Ciufolini et al. further carefully modified precatalyst [30] to generate a new chiral iodine precatalyst [40]. They critically altered the chiral center next to the amide NH group to achieve

Scheme 4: [4 + 2] Diels–Alder dimerization reported by Birman et al.

Scheme 5: m-CPBA guided catalytic oxidative naphthol dearomatization.
a high catalyst efficiency (Scheme 7). The crucial point is the better hydrogen-bonded conformation of 11 which imparted superior reactivity compared to Ishihara’s system without the need of achiral alcohols as an additive. Profitable results were obtained regarding the oxidative cyclization of phenolic derivatives 36 to spirocyclic compounds 37.

Chiral hypervalent iodine reagents having binaphthyl backbones were used by Quideau et al. for the α-hydroxylation of phenolic derivatives via oxygenative dearomatization. Quideau et al. showed that iodobiarene 38 was oxidized in situ by m-CPBA to generate the I(III) reagent which is responsible for the hydroxylative naphthol dearomatization affording the product in moderate enantioselectivity (Scheme 8 upper part). By this method naphthol 39 could be oxidized to chiral o-quinol 40 with 50% ee [41]. Varying the catalyst loading could alter the reaction outcome to afford either o-quinol 40 or epoxy o-quinol 41.
Recently, Pouységuy and Quideau et al. modified their iodo-biarenos to synthesize a new class of I(III) and I(V) reagents. These were applied for the hydroxylative dearomatization of phenolic derivatives followed by the successive use of the hydroxylated products as dienes in [4 + 2] cycloaddition reactions. This new reagent promoted oxygen transfer in phenol degradation, leading to the formation of cyclodimerization products with high enantioselectivity (up to 94% ee, Scheme 8 lower part).

**Alkene functionalization**

Nearly simultaneously to Ishihara’s work, Fujita et al. reported on the modification of their previously synthesized non C₂-symmetric reagent 9a to obtain a C₂-symmetric chiral iodoarene reagent 9b having an ester end group instead of an amide (as in case of Ishihara’s work). The enantioslective oxylation was achieved efficiently using stoichiometric amounts of chiral reagent 9b (Scheme 9). This lactate-derived I(III) reagent 9b was used successively for the synthesis of d-lactones 45 in a highly stereoselective manner starting from 44 [43]. The formation of cyclic iodonium 46 is the vital part of this difunctionalization process.

Wirth et al. were the first to introduce asymmetric dioxytosylation of styrene (47) using a new class of chiral hypervalent iodine reagents 49–52 to furnish 48 with moderate enantioselectivity (Scheme 10) [44–47]. Their constant efforts towards alkene dioxygenation helped them to discover new chiral hypervalent iodine reagents and also to reach up to 65% enantioselectivity using 52.

Fujita et al. further explored the difunctionalization strategy for the development of diacetoxylation of alkenes following a Prevost and Woodward reaction [48]. Recently, the same group used chiral iodine reagent 55 together with acid co-reagent for the intramolecular oxyarylation and aminoarylation of alkenes to produce 54 (Scheme 11). The presence of a silyloxy group is essential to achieve high enantioselectivity in case of the oxyarylation [49]. The Lewis acid activates the hypervalent chiral iodine reagent and then adds to the alkene system. The nucleophilic addition of the internal oxy/amino group followed by the nucleophilic addition of the aryl group delivers the desired products 54. The key to success also lies on the enantiotopic face discrimination of the alkene by the lactate-based chiral iodine reagent.
This difunctionalization strategy was further showcased by Muñiz et al. as intermolecular dianimation protocol of alkenes 56 using 9b (Scheme 12) [50]. This represented the first example of an asymmetric dianimation of simple nonfunctionalized alkenes to acquire dianimated products 57. The existence of an I(III)–N bond under ligand exchange conditions and the formation and ring opening of aziridinium intermediate 58 elucidate the product formation in this transformation [51].

Wirth et al. successfully employed I(III) reagent 8b in combination with trimethylsilyltriflate (TMSOTf) for the stereoselective oxyamination of 59 to furnish isourea 60 with >99% ee (Scheme 13) [52]. Both the Lewis acid and solvent used play an important role in this transformation. This method was applied to the synthesis of other isourea derivatives 62–64 with moderate enantioselectivity. The reactions were triggered by the activation of olefins followed by the formation of C–N bonds. The subsequent intramolecular substitution reaction of intermediate 61 having hypervalent iodine as a good leaving group yielded the required heterocycles.

After Wirth’s report, Nevado et al. discovered a newly modified chiral iodine reagent 13 analogous to lactate-based chiral iodoarenes [53]. They have utilized this chiral difluoriodo-
nium salt 13 for the asymmetric synthesis of aminofluorinated compounds 66 from 65 (Scheme 14). In addition to this, they extended this methodology for the regioselective intermolecular aminofluorination of styrenes with a racemic catalyst. The nucleophilic attack of the nitrogen atom onto the alkene (intermediate 67) to generate aziridinium ion 68 is the crucial step in this transformation.

Recently, Jacobsen et al. developed a highly stereoselective difunctionalization method for the synthesis of chiral fluorine-containing molecules and the 1,2-difluorination, 1,1-difluorination and fluorolactonization protocols appeared almost simultaneously (Scheme 15). The lactate-based $C_2$-symmetric chiral iodine precatalysts 73, 76, and 79 were used to deliver chiral fluorinated scaffolds from alkene starting materials 69 in the
presence of pyr-HF as a nucleophilic fluoride source. The reactions were guided by the formation of intermediate 70. Anchimeric assistance via the phenonium ion intermediate 71 and subsequent ring-opening rearrangement delivered the 1,1-difluorinated products 72 in the presence of catalyst 73 [54]. On the other hand the anchimeric assistance via participation of the amide carbonyl group (intermediate 74) dictated the formation of 1,2-difluorinated products 75 and catalyst 76 was identified as the optimal catalyst for this transformation. The 1,2-difluorinated products 75 can also be obtained with high diastereoselectivity by an anchimeric assistance of an \( o \)-NO\(_2\) group present in the aryl ring [55]. The authors cleverly replaced the \( o \)-NO\(_2\)-substituent with a \( CO_2R \) group (R = H or Me). With this modification they were able to obtain fluorolactonization products with high enantioselectivity using 79 as a catalyst, via the intramolecular displacement of the aryl iodide by the \( CO_2R \) group in 77 leading to chiral lactones of type 78 [56].

**Rearrangement strategy**

Wirth et al. used I(III) reagent 8b for the development of a stereoselective oxidative rearrangement method to synthesize \( \alpha \)-arylated carbonyls 81 from \( \alpha,\beta \)-unsaturated carbonyls 80 (Scheme 16, upper part) [57,58]. The reaction proceeds via the formation of the phenyliodinate intermediate 82 followed by a stereoselective 1,2-aryl migration. Elegantly, they utilized the 1,2-aryl migration approach to develop an enantioselective oxidative rearrangement of 1,1-disubstituted olefins 83 leading to the formation of valuable \( \alpha \)-arylated ketones 84. In this reaction...
I(III) reagent 9b gave the best reaction outcome. Key to the success of the reaction is the formation of the cyclic iodonium ion intermediate 85 (Scheme 16, below part) [59,60].

**Asymmetric α-functionalization strategy**

Methods for carbonyl α-functionalizations are still considered as highly demandable in synthetic organic chemistry. In this regard transition metals have been successfully applied and even allow accomplishing such transformations asymmetrically. On the other hand, diaryliodonium salts are known to transfer aryl groups ultimately leading to α-arylated products. This part of the review focuses on the development of α-functionalization strategies based on chiral diaryliodonium reagents having either an axially chiral backbone or that can be considered analogous to the $C_2$-symmetric iodoarene moiety. For this purpose various chiral iodine reagents were synthesized having an axially chiral biaryl backbone. In this part, we mainly focused on the transformations using chiral iodine reagents instead of achiral iodine reagents in a combination with other chiral sources [61].

More than one century after Pribam discovered diphenyliodonium tartrate [23], Ochiai et al. realized the introduction of chirality through incorporation of binaphthyl backbones [62] and they synthesized new classes of chiral hypervalent iodine reagents 15. Later, to ensure asymmetric transformations, the same group developed the synthesis of more effective chiral iodonium salts 16 which were used for the α-arylation of β-ketoester 86 to deliver α-arylated β-ketoesters 87 with moderate enantioselectivity (Scheme 17) [63]. This was the first example of an asymmetric α-arylation of β-ketoesters using hypervalent iodine reagents. A more reactive organostannane derived Sn–I(III) exchange in the presence of BF$_3$·Et$_2$O was the crucial step in the synthesis of the chiral iodonium salts from 88.
In view of developing asymmetric α-arylations of carbonyls, Olofsson et al. independently synthesized a new class of diaryliodonium salts 14 with different stereoelectronic properties by using aliphatic alcohols as a sole source of chirality [64]. Olofsson and Wirth et al. also jointly reported the synthesis of new structurally distinct chiral reagents 20 considering their interest towards asymmetric metal-free arylation [65].

In 1997, Wirth et al. for the first time reported an asymmetric α-oxytosylation of propiophenone using hypervalent iodine reagents 49,50 [45]. Later they improved the enantioselectivity by a structurally modified catalyst 51 to obtain up to 28% ee [46]. After a further few years, in 2001, they came up with a modified catalyst 52 which allowed them to reach up to 40% ee [47]. A catalytic variant of this methodology was developed by the same group using m-CPBA as co-oxidant together with catalyst 89 to get up to 39% ee [66] (Scheme 18).

In 2013, Berthiol and Einhorn et al. demonstrated an intermolecular asymmetric α-oxytosylation of ketones by using a new
family of chiral hypervalent iodine catalyst 21 with up to 46% ee [67]. The investigation of the reaction mechanisms revealed that the steric crowding around the iodine center improves the enantioselectivity (Scheme 18).

Asymmetric oxygenation and nitrogenation reactions of carbonyls were established by Wirth et al. Nucleophile transfer from silyl enol ethers 90 delivered α-functionalized carbonyls 91 with good enantioselectivity [68]. “Umpolung” reactivity and silyl-tethered enol ethers allowed the delicate synthesis of α-functionalized carbonyls (Scheme 19). C2-symmetric I(III) reagent 8b was used to obtain high enantioselectivity.

Ishihara et al. appealingly reported an oxidative cycloetherification of ketophenols 92 in the presence of an in situ generated chiral quaternary ammonium (hypo)iodite salt 94, with hydrogen peroxide as an oxidant to deliver chiral dihydrobenzofuran derivatives 93 as α-functionalized products of ketophenols 92 (Scheme 20) [69]. The substituents at the 3,3′-position of the binaphthyl moiety of the salt 94 played a crucial role to achieve high enantioselectivities up to 96%.

Very recently, Gong et al. developed an asymmetric oxidative intramolecular cross-coupling of C–H bonds in 95 using catalytic chiral iodine 12 for the synthesis of a diverse array of
spirooxindoles 96. Ishihara’s catalyst was modified by using an (S)-proline derivative to achieve a high level of enantioselectivity in the presence of peracetic acid (Scheme 21) [70]. They postulated the formation of possible intermediate 97 which favored the nucleophilic attack of the aryl ring from the less sterically hindered side. Later, Du et al. used this same precata-

---

**Scheme 20:** Asymmetric α-functionalization of ketophenols using chiral quaternary ammonium (hypo)iodite salt reported by Ishihara et al.

**Scheme 21:** Oxidative Intramolecular coupling by Gong et al.
lyst 12 to obtain spirofurooxindole derivatives with high enantioselectivity through cascade cross-coupling sequences [71].

Latterly, Masson et al. reported a new chiral iodoarene pre-reagent 22 which they have used for the direct oxygenation of carbonyls 98. They were able to get α-sulfonyls and α-phosphoryl oxyketones 99 with moderate ees (Scheme 22) [72]. A new type of non C2-symmetric chiral hypervalent reagent was utilized for the asymmetric α-oxygenation of carbonyls. Nucleophilic attack of the oxygen nucleophile to the intermediate 100 or alternatively a reaction pathway through O-enolate intermediate 101 can explain the desired product formation.

In 2014, Kita and Shibata reported a catalytic, enantioselective, nucleophilic fluorinating technique of β-keto esters 102 using 106/HF/m-CPBA as a catalytic system to access fluorinated β-keto esters 103 with moderate enantioselectivity [73]. β-Keto esters having sterically hindered adamantyl or menthyl groups lead to good selectivity. However, no further enhancement of ee could be achieved even by using a 50 mol % catalyst loading. A nucleophilic attack of the fluoride ion to the intermediate 104 or a possible ligand coupling pathway via 105 could justify the product formation (Scheme 23).

Waser et al. developed an asymmetric alkylation of β-ketoesters and amides 107 catalyzed by a phase-transfer catalyyst [74]. Their previous findings on the same reaction using a Cinchona-based phase-transfer catalyst [75] was further improved by using Maruoka’s binaphthyl-derived ammonium salt 110. The formation of intermediate 112 (chiral catalyst still attached to the substrate) from the enolate intermediate 111 followed by the generation of a C–C bond via conjugate addition

---

**Scheme 22:** α-Sulfonyl and α-phosphoryl oxylation of ketones reported by Masson et al.

**Scheme 23:** α-Fluorination of β-keto esters.
delivered intermediate carbene 113. A 1,2-hydrogen shift led to the formation of products 108 with enantioselectivities up to 79% (Scheme 24). Later, Maruoka et al. improved the enantioselectivity up to 95% ee for the alkynylation of β-ketoesters [76].

Pouységuy and Quideau et al. prepared new axially chiral biaryl I(III) reagents 18 assembled with alkynyl ligands. They were able to achieve alkynylation of β-ketoesters 114 as well as dearomative alkynylation of phenolic derivatives 118 to obtain derivatives 115 and 119, respectively, with decent enantioselectivity (Scheme 25) [77]. The formation of an alkylidene carbene 117 and its rapid rearrangement via 1,2-silyl shift (in case of R = silyl group) into the alkylated β-ketoesters 115 can fairly explain the reaction outcome. On the other hand, the ligand exchange/coupling sequence through the iodosyl intermediate 116 can be an alternative pathway for the formation of 115. Likewise, a C–C ipso-allyl ligand coupling via intermediate 120 from O-naphtholate 118 explains the formation of product 119.

Scheme 24: Alkynylation of β-ketoesters and amides catalyzed by phase-transfer catalyst.
Conclusion

To conclude, throughout this review we have seen substantial growth in the field of chiral hypervalent iodine reagents. This review points to a number of striking chiral hypervalent iodine reagents used in stoichiometric or in catalytic fashion for quite a number of useful organic transformations. Most importantly the oxidative chemistry can be done using catalytic amounts of chiral hypervalent iodine reagents in the presence of an external...
These environmentally friendly, cheap and readily available reagents will surely attract the attention of scientists towards a sustainable replacement of transition metals. The application of chiral hypervalent iodine reagents is expected to pave the way for new reactions and reagent design in the field of asymmetric synthesis and catalysis.

Acknowledgements

The authors highly acknowledge the financial assistance received from the Indian Institute of Technology, Ropar. S. G. and S. P. thank UGC, New Delhi and IIT Ropar, respectively, for their research fellowships. We thank Prof. Rano Ringo for proofreading the manuscript and valuable suggestions. We kindly acknowledge http://www.pexels.com/ from where we adapted our graphical abstract.

ORCID® IDs

Soumen Ghosh - https://orcid.org/0000-0002-0551-177X
Suman Pradhan - https://orcid.org/0000-0002-5942-3206
Indranil Chatterjee - https://orcid.org/0000-0001-8957-5182

References

1. Willgerodt, C. J. Prakt. Chem. 1886, 33, 154–160. doi:10.1002/prac.18860330117
2. Zhdankin, V. V.; Stang, P. J. Chem. Rev. 2002, 102, 2523–2584. doi:10.1021/cr010003+
3. Zhdankin, V. V.; Stang, P. J. Chem. Rev. 2008, 108, 5299–5358. doi:10.1021/cr080032c
4. Yoshimura, A.; Zhdankin, V. V. Chem. Rev. 2016, 116, 3328–3345. doi:10.1021/acs.chemrev.5b00547
5. Zhdankin, V. V. ARKIVOC 2009, No. i, 1–62. doi:10.3998/ark.5550190.0010.101
6. Zhdankin, V. V. J. Org. Chem. 2011, 76, 1185–1197. doi:10.1021/jo1024738
7. Yusubov, M. S.; Zhdankin, V. V. Curr. Org. Synth. 2012, 9, 247–272. doi:10.2174/15701791279829021
8. Merritt, E. A.; Olofsson, B. Angew. Chem., Int. Ed. 2009, 48, 9052–9070. doi:10.1002/anie.200904689
9. Küpper, F. C.; Feiters, M. C.; Olofsson, B.; Kaiho, T.; Yanagida, S.; Zimmermann, M. B.; Carpenter, L. J.; Luther, G. W.; III; Lu, Z.; Jonsson, M.; Kloo, L. Angew. Chem., Int. Ed. 2011, 50, 11598–11620. doi:10.1002/anie.201100028
10. Wirth, T. Synthesis 1999, 1261–1287. doi:10.1055/s-1999-3540
11. Wirth, T. Angew. Chem., Int. Ed. 2005, 44, 3656–3665. doi:10.1002/anie.200500115
12. Kitamura, T.; Fujiwara, Y. Org. Prep. Proced. Int. 1997, 29, 409–458. doi:10.1080/00304949709355217
13. Varvoglis, A. Tetrahedron 1997, 53, 1179–1255. doi:10.1016/S0040-4020(96)00970-2
14. Moriarty, R. M. J. Org. Chem. 2005, 70, 2893–2903. doi:10.1021/jo050117b
15. Kiprof, P. ARKIVOC 2005, No. iv, 19–25. doi:10.3998/ark.5550190.0006.403
16. Ochiai, M.; Sueda, T.; Miyamoto, K.; Kiprof, P.; Zhdankin, V. V. Angew. Chem., Int. Ed. 2006, 45, 8203–8206. doi:10.1002/anie.200603055
17. Saijth, P. K.; Suresh, C. H. Inorg. Chem. 2012, 51, 967–977. doi:10.1021/ic202047g
18. Gillespie, R. J.; Silivi, B. Coord. Chem. Rev. 2002, 233–234, 53–62. doi:10.1016/S0010-8545(02)00102-9
19. Akiba, K. y., Ed. Chemistry of Hypervalent Compounds; Wiley-VCH: New York, 1999.
20. Zhdankin, V. V. Hypervalent Iodine Chemistry; John Wiley & Sons Ltd.: New York, 2014.
21. Parra, A.; Reboredo, S. Chem. – Eur. J. 2013, 19, 17244–17260. doi:10.1002/chem.201302220
22. Berthiol, F. Synthesis 2015, 47, 587–603. doi:10.1055/s-0034-1379892
23. Priram, R. Justus Liebigs Ann. Chem. 1907, 351, 481–485. doi:10.1002/acs.jlac.1907351139
24. Immamoto, T.; Koto, H. Chem. Lett. 1986, 967–968. doi:10.1246/cl.1986.967
25. Tohma, H.; Takizawa, S.; Watanabe, H.; Fukuoka, Y.; Maegawa, T.; Kita, Y. J. Org. Chem. 1999, 64, 3519–3523. doi:10.1021/jo982885f
26. Hatzigrigoriou, E.; Varvoglis, A.; Bakola-Christianopoulou, M. J. Org. Chem. 1990, 55, 315–318. doi:10.1021/jo00288a053
27. Xia, M.; Chen, Z.-C. Synth. Commun. 1997, 27, 1321–1326. doi:10.1080/00397919708006060
28. Zhdankin, V. V.; Smart, J. T.; Zhao, P.; Kiprof, P. Tetrahedron Lett. 2000, 41, 5299–5302. doi:10.1016/S0040-4039(00)00836-4
29. Ladziata, U.; Carlson, J.; Zhdankin, V. V. Tetrahedron Lett. 2006, 47, 6301–6304. doi:10.1016/j.tetlet.2006.06.103
30. Ray, D. G., III; Koser, G. F. J. Am. Chem. Soc. 1990, 112, 5672–5673. doi:10.1021/ja00170a059
31. Altermann, S. M.; Schäfer, S.; Wirth, T. Tetrahedron 2010, 66, 5902–5907. doi:10.1016/j.tet.2010.05.079
32. Dohi, T.; Maruyama, A.; Takenaga, N.; Senami, K.; Minamitsuji, Y.; Fujikoa, H.; Caemmerer, S. B.; Kita, Y. Angew. Chem., Int. Ed. 2008, 47, 3787–3790. doi:10.1002/anie.200800464
33. Dohi, T.; Takenaga, N.; Nakae, T.; Toyoda, Y.; Yamasaki, M.; Shirō, M.; Fujikoa, H.; Maruyama, A.; Kita, Y. J. Am. Chem. Soc. 2013, 135, 4558–4566. doi:10.1021/ja401074u
34. Dohi, T.; Sasa, H.; Miyazaki, K.; Fujitake, M.; Takenaga, N.; Kita, Y. J. Org. Chem. 2017, 82, 11954–11960. doi:10.1021/acs.joc.7b02037
35. Boppisetti, J. K.; Birman, V. B. Org. Lett. 2009, 11, 1221–1223. doi:10.1021/ol8029092
36. Fujita, M.; Okuno, S.; Lee, H. J.; Sugimura, T.; Okuyama, T. Tetrahedron Lett. 2007, 48, 8691–8694. doi:10.1016/j.tetlet.2007.10.015
37. Uyanik, M.; Yasui, T.; Ishihara, K. Angew. Chem., Int. Ed. 2010, 49, 2175–2177. doi:10.1002/anie.200907352
38. Uyanik, M.; Yasui, T.; Ishihara, K. Y. Tetrahedron 2010, 66, 5841–5851. doi:10.1016/j.tet.2010.04.060
39. Uyanik, M.; Yasui, T.; Ishihara, K. Angew. Chem., Int. Ed. 2013, 52, 9215–9218. doi:10.1002/anie.201303559
