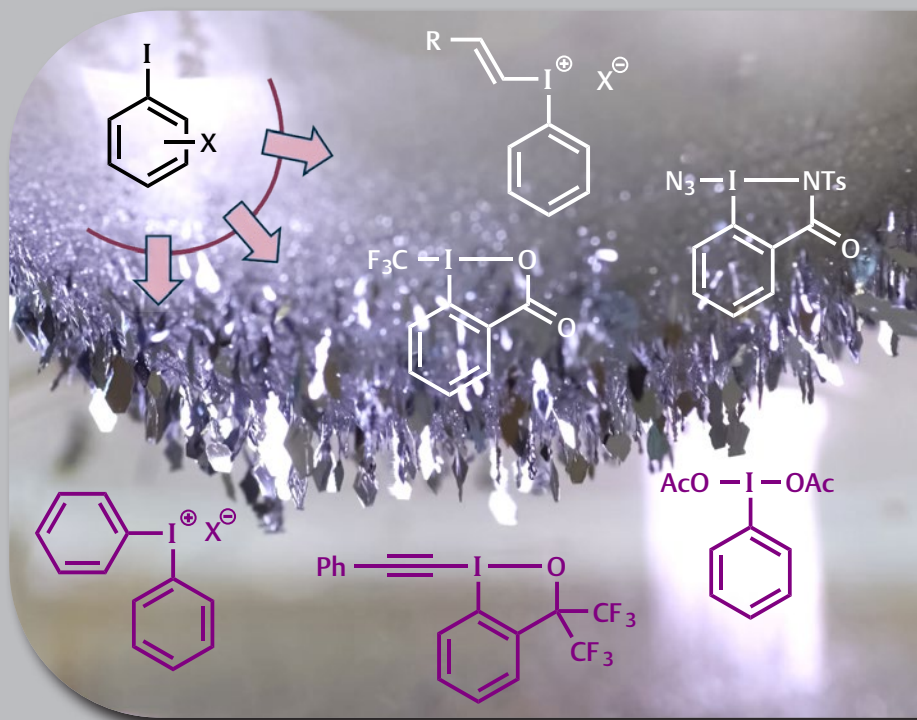




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Synthesis

Hypervalent Halogens in Organic Synthesis

Volume Editor
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Authors

Jan Balzer 

Prafulla Bera 

Tomas Bystron 

Yiyun Chen 

José C. Cunha 

Beatriz Dedeiras 

Toshifumi Dohi 

Xiaojuan Dong 

Yunfei Du 

Ya-Nan Duan 

Tanja Gulder 

Martin Jirasko 

Yasuyuki Kita 

Kensuke Kiyokawa 

Maria Manuel B. Marques 

Ana Cláudia R. Negrão 

Stefano Nicolai 

Bidisha Paroi 

Nitin T. Patil 

Hanzhang Qin 

Hiroataka Sasa 

Igors Sokolovs 

César R. Solorio-Alvarado 

Edgars Suna 

Markus Tost 

Jérôme Waser 

Dan Xiao

Naohiko Yoshikai 

Chi Zhang 



2026

Georg Thieme Verlag KG

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Georg Thieme Verlag KG
Oswald-Hesse-Straße 50, 70469 Stuttgart, Germany
www.sos.thieme.com

Cover design: © Thieme
background: © Ludmila/stock.adobe.com

General Partner: Dr. Albrecht Hauff

VAT ID number: DE 147 638 607

Legal structure: Limited Partnership

Domicile and Commercial Register:
Stuttgart, HRA 3499

Typesetting: Ziegler + Müller, Einhornstraße 21,
72138 Kirchentellinsfurt, Germany

Date of publication: December 10, 2025

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*Bibliographic Information published by
Die Deutsche Bibliothek*

Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available on the internet at <www.dnb.de>

Library of Congress Card No.: applied for

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISSN (online) 2566-7297

ISBN (PDF) 978-3-13-246039-3
DOI 10.1055/b000000995

Structure searchable version available at:
sos.thieme.com

ISBN 978-3-13-246039-3

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Preface

As the pace and breadth of research intensifies, organic synthesis is playing an increasingly central role in the discovery process within all imaginable areas of science: from pharmaceuticals, agrochemicals, and materials science to areas of biology and physics, the most impactful investigations are becoming more and more molecular. As an enabling science, synthetic organic chemistry is uniquely poised to provide access to compounds with exciting and valuable new properties. Organic molecules of extreme complexity can, given expert knowledge, be prepared with exquisite efficiency and selectivity, allowing virtually any phenomenon to be probed at levels never before imagined. With ready access to materials of remarkable structural diversity, critical studies can be conducted that reveal the intimate workings of chemical, biological, or physical processes with stunning detail.

The sheer variety of chemical structural space required for these investigations and the design elements necessary to assemble molecular targets of increasing intricacy place extraordinary demands on the individual synthetic methods used. They must be robust and provide reliably high yields on both small and large scales, have broad applicability, and exhibit high selectivity. Increasingly, synthetic approaches to organic molecules must take into account environmental sustainability. Thus, atom economy and the overall environmental impact of the transformations are taking on increased importance.

The need to provide a dependable source of information on evaluated synthetic methods in organic chemistry embracing these characteristics was first acknowledged over 100 years ago, when the highly regarded reference source **Houben–Weyl Methoden der Organischen Chemie** was first introduced. Recognizing the necessity to provide a modernized, comprehensive, and critical assessment of synthetic organic chemistry, in 2000 Thieme launched **Science of Synthesis, Houben–Weyl Methods of Molecular Transformations**. This effort, assembled by almost 1000 leading experts from both industry and academia, provides a balanced and critical analysis of the entire literature from the early 1800s until the year of publication. The accompanying online version of **Science of Synthesis** provides text, structure, substructure, and reaction searching capabilities by a powerful, yet easy-to-use, intuitive interface.

From 2010 onward, **Science of Synthesis** is being updated quarterly with high-quality content via **Science of Synthesis Knowledge Updates**. The goal of the **Science of Synthesis Knowledge Updates** is to provide a continuous review of the field of synthetic organic chemistry, with an eye toward evaluating and analyzing significant new developments in synthetic methods. A list of stringent criteria for inclusion of each synthetic transformation ensures that only the best and most reliable synthetic methods are incorporated. These efforts guarantee that **Science of Synthesis** will continue to be the most up-to-date electronic database available for the documentation of validated synthetic methods.

Also from 2010, **Science of Synthesis** includes the **Science of Synthesis Reference Library**, comprising volumes covering special topics of organic chemistry in a modular fashion, with six main classifications: (1) Classical, (2) Advances, (3) Transformations, (4) Applications, (5) Structures, and (6) Techniques. Titles will include *Stereoselective Synthesis*, *Water in Organic Synthesis*, and *Asymmetric Organocatalysis*, among others. With expert-evaluated content focusing on subjects of particular current interest, the **Science of Synthesis Reference Library** complements the **Science of Synthesis Knowledge Updates**, to make **Science of Synthesis** the complete information source for the modern synthetic chemist.

The overarching goal of the **Science of Synthesis** Editorial Board is to make the suite of **Science of Synthesis** resources the first and foremost focal point for critically evaluated information on chemical transformations for those individuals involved in the design and construction of organic molecules.

Throughout the years, the chemical community has benefited tremendously from the outstanding contribution of hundreds of highly dedicated expert authors who have devoted their energies and intellectual capital to these projects. We thank all of these individuals for the heroic efforts they have made throughout the entire publication process to make **Science of Synthesis** a reference work of the highest integrity and quality.

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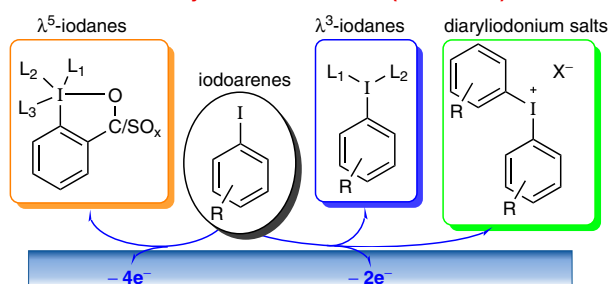
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2 Electrochemical Synthesis of Hypervalent Iodine Compounds

Tomas Bystron^{1b} and Martin Jirasko^{1b}

Hypervalent iodine compounds (or iodonanes) represent an interesting class of chemicals possessing a multivalent iodine atom. They are popular oxidation and ligand-transfer agents that are renowned for their versatility and selectivity, but also for their high cost and in some cases low stability. Compared to classical synthetic procedures, the electrochemical synthesis of these compounds offers significant benefits, such as increased safety, and potentially reduced cost and environmental impact. This review summarizes advances in the electrochemical synthesis of various iodonanes, and briefly mentions their applications for in-cell and ex-cell mediation.

Electrosynthesis of Iodonanes (1967–2024)



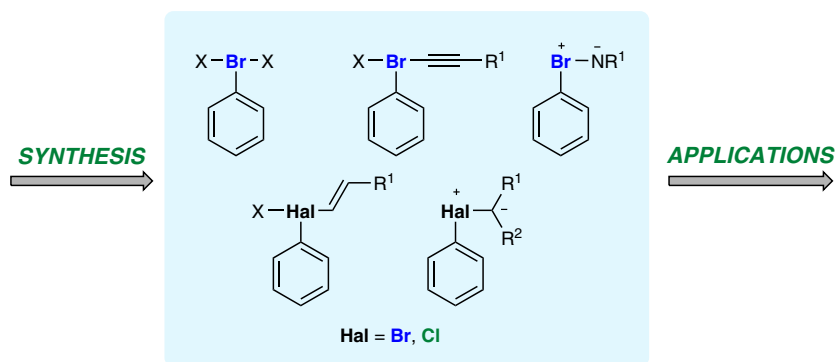
Keywords: hypervalent iodine compounds · electroorganic chemistry · iodonanes · iodoarene oxidation · iodonium salts · iodanyl radicals · benziodoxolone · iodobenzenes · electrochemical synthesis · electrolysis · electrosynthesis · anodic oxidation · mediation · flow reactors

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3 Synthesis and Applications of Aryl- λ^3 -bromanes and Aryl- λ^3 -chloranes

Igors Sokolovs^{1b} and Edgars Suna^{1b}

Hypervalent halogen compounds have emerged as powerful reagents in contemporary organic synthesis. Among these, λ^3 -bromanes and λ^3 -chloranes stand out as the most reactive species, enabling unique and unconventional synthetic transformations that underpin novel bond-forming strategies. This review provides a comprehensive overview of the synthesis and applications of monoaryl- λ^3 -bromanes and monoaryl- λ^3 -chloranes (including bromonium and chloronium ylides) as well as alkenyl(aryl)- and alkynyl(aryl)- λ^3 -bromanes and the corresponding λ^3 -chloranes.



Keywords: hypervalent halogens · λ^3 -bromanes · λ^3 -chloranes · bromonium ylides · chloronium ylides · nucleofugality · oxidation · rearrangements · C–H activation

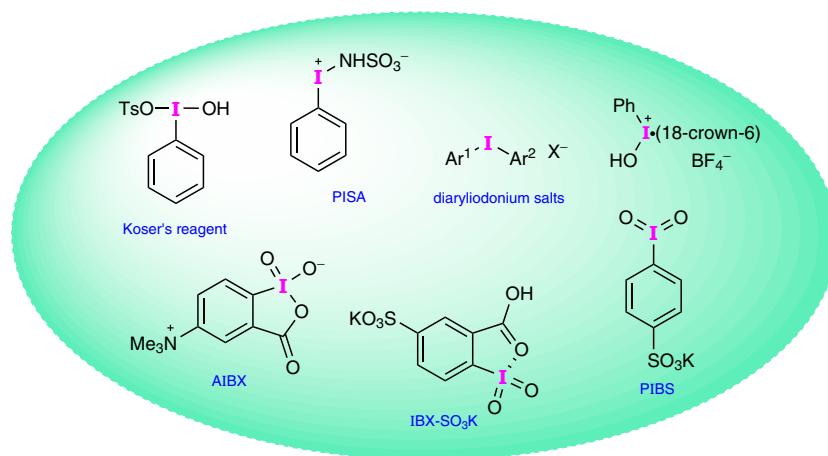
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Synthesis and Applications of Water-Soluble Hypervalent Iodine Reagents

Chi Zhang^{1b} and Ya-Nan Duan^{1b}

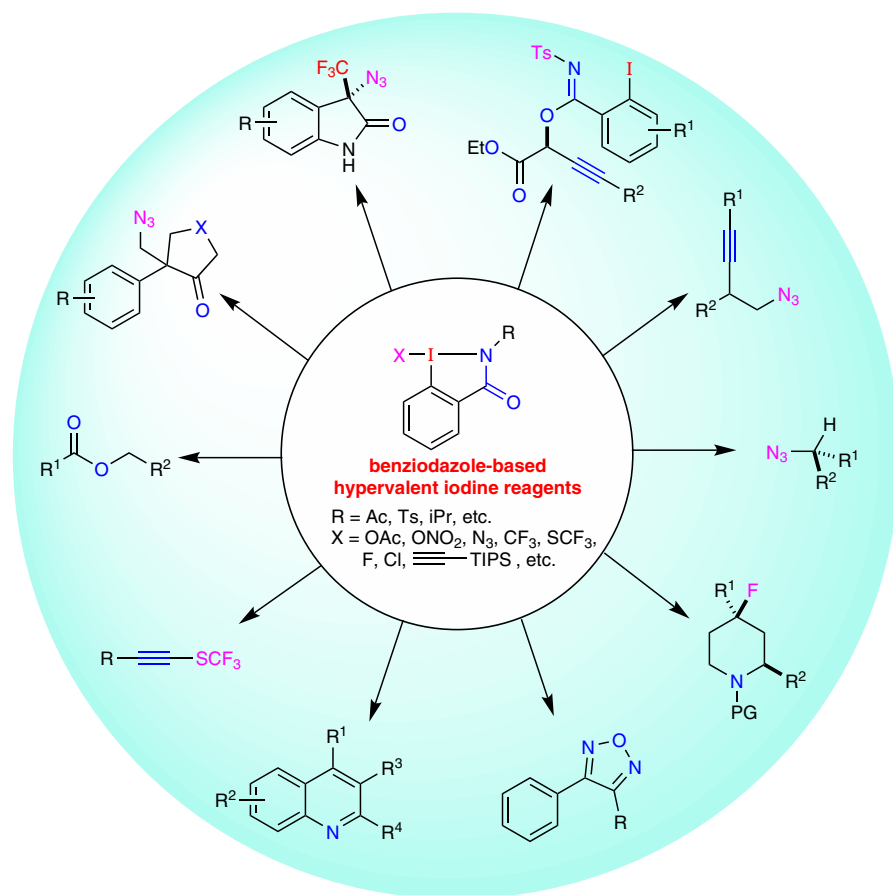
The development of water-soluble hypervalent iodine reagents represents a significant advancement in green chemistry, addressing the environmental concerns associated with traditional organic solvents. In this review, the synthesis and applications of water-soluble iodine(III) and iodine(V) reagents are comprehensively summarized. By leveraging hydrophilic ligands or functional groups, these reagents achieve high reactivity in water or mixed aqueous solvents, aligning with the principles of sustainable chemistry. This chapter underscores the potential of water-soluble hypervalent iodine reagents to replace conventional methods, offering scalable, more eco-friendly alternatives for diverse organic transformations.



Keywords: hypervalent iodine · iodine(III) reagents · iodine(V) reagents · Koser's reagent · PISA · diaryliodonium salts · AIBX · dehydrogenation · oxidative functionalization · water · aqueous media · sustainable chemistry · recyclable reagents

Synthesis and Applications of Benziodazole-Based Hypervalent Iodine ReagentsDan Xiao and Yunfei Du 

Hypervalent iodine compounds have found broad application in modern organic chemistry as either reagents or catalysts. Cyclic hypervalent iodine reagents based on the benziodazole heterocyclic system have higher stability compared to their acyclic and benziodoxole-based analogues, which makes possible the preparation and safe handling of the reagents with special ligands such as azido, ester, alkynyl and trifluoromethylsulfanyl groups. Certain benziodazole-based hypervalent iodine reagents have been utilized as reagents to transfer the substituent from the hypervalent iodine compound to an organic substrate. Reactions of these reagents can be classified into various categories, including the formation of esters, amides, azides, alkenes, alkynes, fluorides, and heterocyclic compounds. This review comprehensively summarizes the main progress in the synthesis and relevant application of benziodazole-based hypervalent iodine reagents.

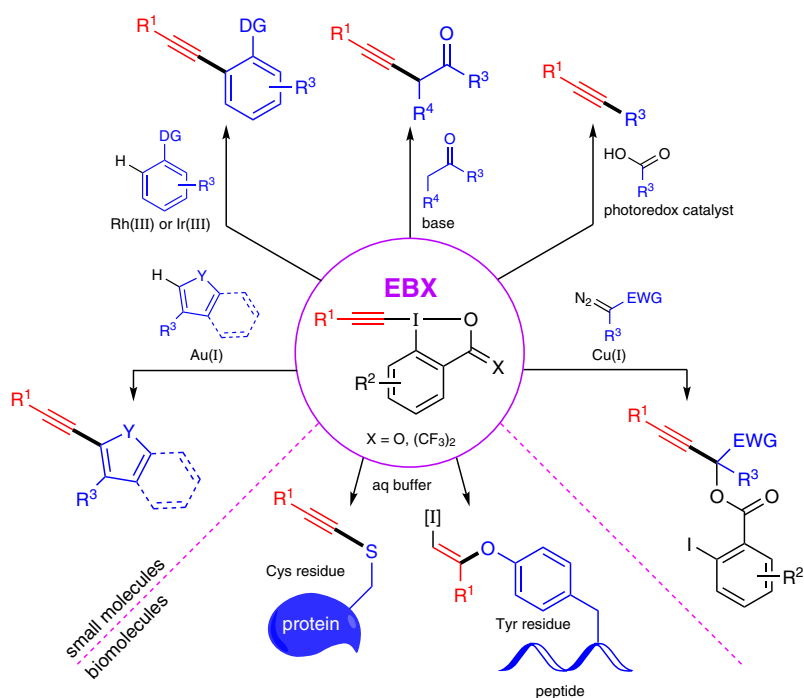


Keywords: hypervalent iodine reagents · benziodazoles · cyclic hypervalent iodine compounds · metal-free conditions · bond formation

6 Synthesis and Applications of Alkynylbenziodoxol(on)es

Stefano Nicolai^{id} and Jérôme Waser^{id}

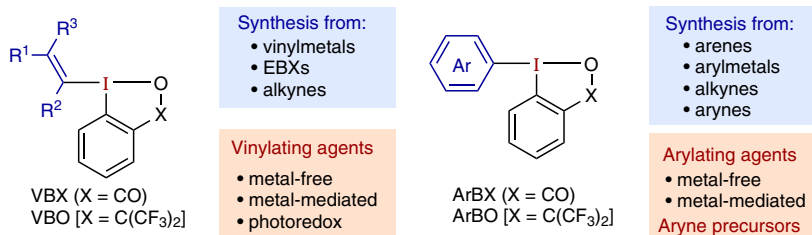
The synthetic value of the C≡C bond has prompted assiduous efforts to develop effective methods for the synthesis of acetylenes. First introduced in the 1990s and then rediscovered twenty years later, alkynylbenziodoxol(on)es (EBXs) have rapidly emerged as one of the most powerful class of alkynylating reagents. Easily accessed, bench stable and nontoxic, these compounds were initially employed for acetylene transfer onto nucleophilic substrates under a variety of conditions. However, they have later shown their great utility in the alkynylation of radicals. Key to their success is their cyclic structure, which provides them with enhanced stability and permits the fine-tuning of their reactivity through structural adjustments of the benziodoxol(on)yl core. After presenting the principal procedures for the preparation of EBXs, this review will summarize the most important synthetic applications of these reagents. The functionalization of small molecules is discussed first; following that, the more recently established methods for the labeling of biomolecules with EBXs are described.



Keywords: hypervalent iodine · ethynyl benziodoxolones · ethynyl benziodoxoles · alkynes · electrophilic alkynylation · somophilic alkynylation · transition-metal catalysis · photoredox catalysis · bioconjugation

7 **Synthesis and Applications of Vinyl- and Arylbenziodoxol(on)es**Naohiko Yoshikai 

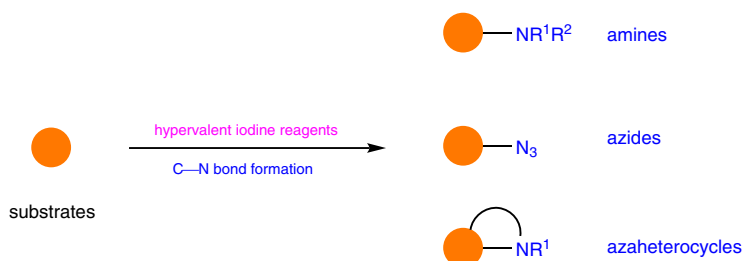
This chapter reviews the synthesis and applications of vinyl- and arylbenziodoxol(on)es as a distinct class of stable organoiodanes. Recent advancements have enabled their efficient preparation via multiple synthetic approaches, expanding their utility in vinylation and arylation reactions. These compounds have demonstrated unique versatility in metal-free, metal-mediated, and photoassisted transformations, underscoring their growing importance as group-transfer reagents in modern organic synthesis.



Keywords: hypervalent iodine · vinylation · arylation · metal-free reactions · cross coupling · C—H activation · photoredox catalysis · arynes · organoboron compounds · nucleophilic addition · alkynes · difunctionalization · cyclopropenes

8 **C—N Bond Forming Reactions with Hypervalent Iodine Reagents**Kensuke Kiyokawa 

Hypervalent iodine reagents containing transferable nitrogen functional groups, or the combined use of hypervalent iodine oxidants with aminating reagents, have proven to be powerful tools for oxidative amination, an umpolung strategy for introducing nitrogen functional groups into organic molecules. The discovery of new reactivities of hypervalent iodine reagents has expanded the scope of C—N bond formation reactions, and these advancements provide an efficient approach to synthesizing nitrogen-containing organic molecules, which serve as promising building blocks for the preparation of biologically active and medically significant compounds. This review highlights recent advances in C—N bond forming reactions using hypervalent iodine reagents.

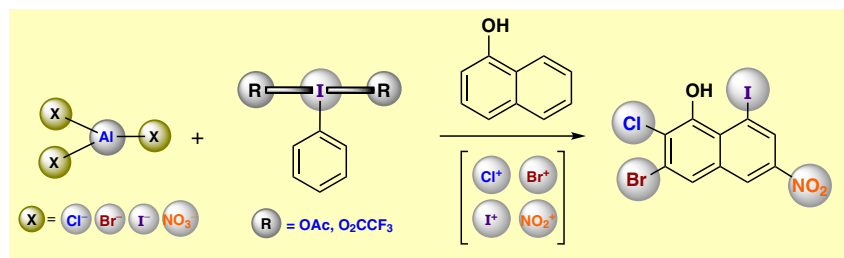


Keywords: amination · amines · anilines · azaheterocycles · azides · C—N bond formation · cyclization · iodine · hypervalent iodine · nitrogen-containing organic molecules · oxidation

9 Aromatic Halogenation and Nitration with Hypervalent Iodine Reagents

César R. Solorio-Alvarado 

Iodine(III) compounds have gained increasing prominence in organic synthesis due to their use as nontoxic and easy to handle reagents and more environmentally friendly nature. Their versatility as oxidants has been applied in the development of various methodologies for the functionalization of aromatic systems, allowing the introduction of various inorganic groups, including halogens and nitro groups. In this review, the most representative procedures for the halogenation of arene and hetarene systems using different iodine(III) reagents in combination with halide sources are described.

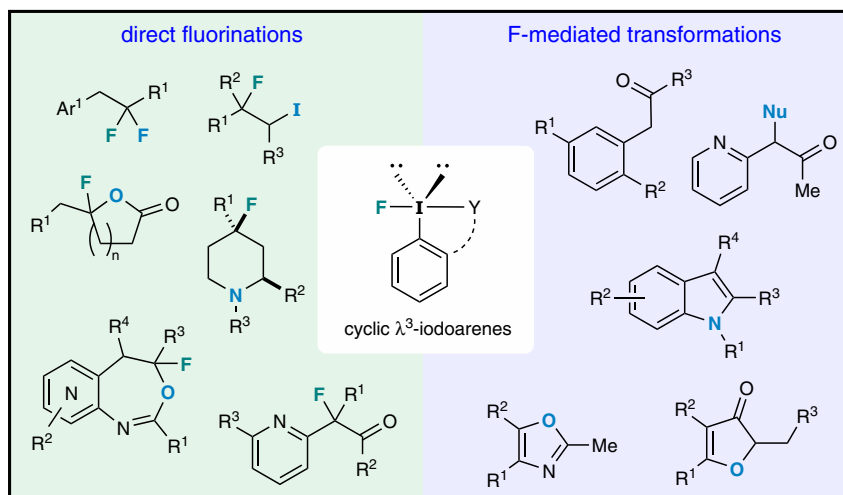


Keywords: hypervalent iodine · iodine(III) reagents · oxidative aromatic halogenation · arenes · aryl halides · nitroarenes · fluorination · chlorination · bromination · iodination · nitration

10 Reactions with Fluorinated Cyclic Hypervalent Iodine Reagents

Jan Balzer , Markus Tost , and Tanja Gulder 

Fluorinated cyclic hypervalent iodine reagents (fluoro- λ^3 -iodanes) have emerged as versatile fluorinating agents in organic synthesis. Their characteristic three-center-four-electron (3c–4e) bond imparts unusual stability and reactivity, enabling selective fluorination under mild conditions. In comparison, cyclic λ^3 -iodanes are more stable toward oxygen, moisture, and heat, but also less reactive than their linear analogues. An increased reactivity can be achieved by activation with Lewis acids and bases, Brønsted acids, or hydrogen bonding. Mechanistic studies have revealed iodine coordination, σ -metathesis, and aryl migration pathways that generate highly functionalized products. This review highlights their diverse applications in direct fluorination reactions of alkenes, oxyfluorinations, aminofluorinations, and cascade reactions toward fluorinated heterocycles and α -fluoro carbonyl compounds. Moreover, fluorine can also act as a traceless directing group, enabling the formation of heterocycles, Umpolung reactions, and oxidation processes through fluorinated reactive intermediates. The combination of high reactivity, tunable selectivity, and compatibility with catalytic activation makes cyclic hypervalent iodine reagents powerful tools for constructing C–F, C–O, C–N, and C–C bonds in complex molecules.



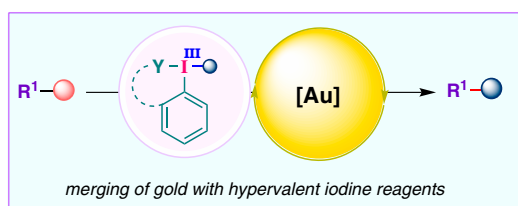
Keywords: hypervalent iodine · fluoro- λ^3 -iodanes · electrophilic fluorination · cyclic iodine reagents · C—F bond formation · C—C bond formation · C—O bond formation · C—N bond formation · aryl migration · Lewis acid activation · Lewis base activation

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11 Hypervalent Iodine Reagents in Gold Catalysis

Nitin T. Patil^{1d}, Prafulla Bera^{1d}, and Bidisha Paroi^{1d}

In the past two decades, hypervalent iodine(III) reagents in partnership with gold catalysts have found extensive application in achieving electrophilic functional-group-transfer reactions. A variety of transformations including alkynylation, arylation, acetoxylation, and cross-coupling reactions have been accomplished by leveraging different reactivity modes of gold catalysis. Presented in this review is an overview of these reactions, categorized based on the employed hypervalent iodine(III) reagents such as ethynylbenziodoxol(on)es (EBXs), (diacetoxyiodo)benzene, 1-(trifluoromethanesulfonyloxy)-1,2-benziodoxol-3-(1*H*)-one, diaryliodonium salts, and cyclopropenyl benziodoxoles.

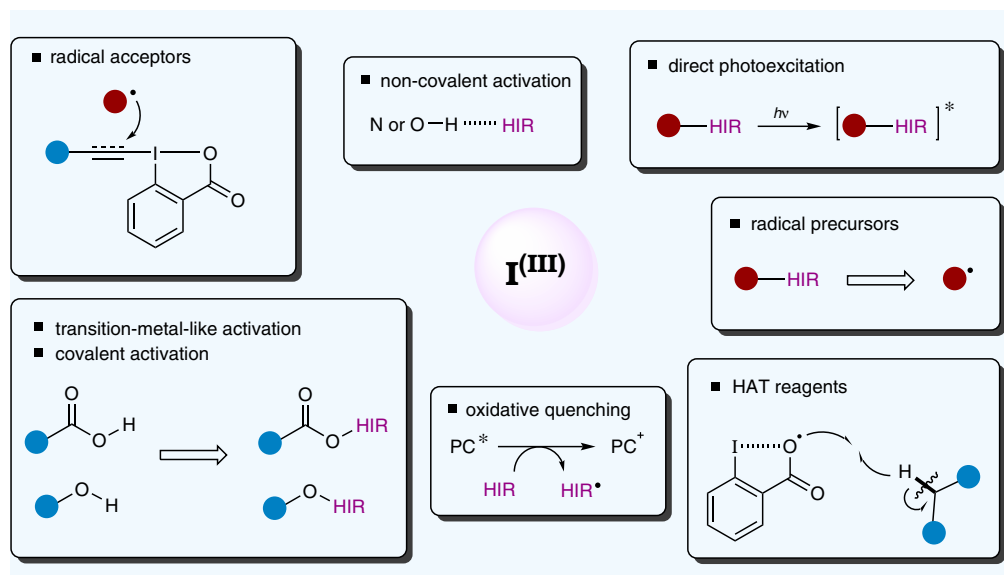


Keywords: hypervalent iodine reagents · ethynylbenziodoxoles · ethynylbenziodoxolones · (diacetoxyiodo)benzene · phenyliodonium diacetate · iodosylbenzoic acid triflate · diaryliodonium salts · cyclopropenyl benziodoxoles · gold catalysis · alkynylation · arylation · acetoxylation · cross coupling

12 Hypervalent Iodine Reagents in Photochemistry

Xiaojuan Dong , Hanzhang Qin , and Yiyun Chen 

Harnessing their unique three-center, four-electron bonding motif, hypervalent iodine compounds have emerged as powerful and versatile reagents in modern organic synthesis, with particularly significant applications in photochemical transformations. This review provides a systematic overview of recent advances that exploit these reagents in diverse photoredox roles, including direct photoexcitation, and their use as radical precursors, radical acceptors, hydrogen-atom-transfer (HAT) reagents, and redox-active agents. Furthermore, it explores their capacity to mimic transition-metal behavior through distinct covalent and non-covalent activation modes. By consolidating these multifaceted reactivities, the integral role of hypervalent iodine reagents in advancing the frontier of sustainable photochemical synthesis is underscored.

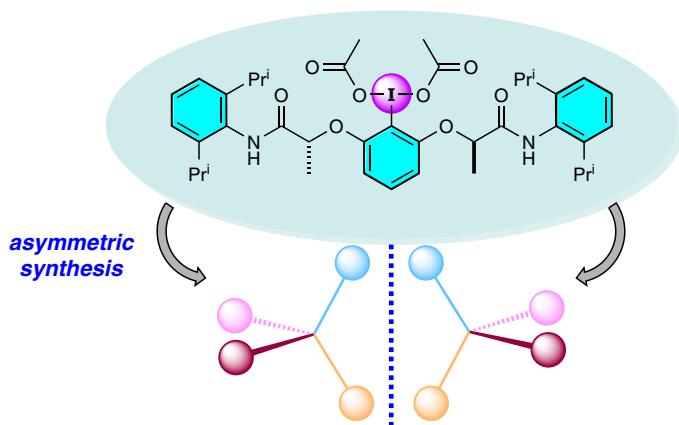


Keywords: hypervalent iodine · photochemistry · photoredox · homolysis · activation · catalysis · hydrogen-atom transfer (HAT) · radical processes

13

Hypervalent Iodine in Asymmetric Synthesis*José C. Cunha^{ID}, Beatriz Dedeiras^{ID}, Ana Cláudia R. Negrão^{ID}, and Maria Manuel B. Marques^{ID}*

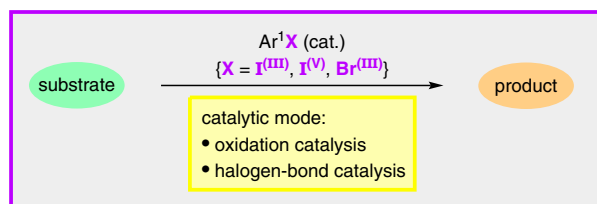
Hypervalent iodine compounds, particularly iodine(III) and iodine(V) species, have emerged as powerful, environmentally friendly reagents in asymmetric synthesis, combining strong oxidative ability with good functional-group tolerance and sustainability. Recent developments in chiral iodine-mediated asymmetric reactions have expanded the scope of oxidative rearrangements, phenol dearomatizations, and α -functionalizations of carbonyl compounds. Special emphasis is placed on C–C bond forming processes such as asymmetric [4 + 2] cycloadditions and nucleophilic additions to C=N bonds, which benefit from tunable C_2 -symmetric chiral iodine(III) scaffolds. This review highlights advances in the structural design, reactivity, and mechanistic understanding of chiral hypervalent iodine reagents, underscoring their growing role in enantioselective oxidative transformations and their potential in sustainable asymmetric catalysis.



Keywords: hypervalent iodine · asymmetric synthesis · chiral iodoarenes · iodine(III) · iodine(V) · oxidative coupling · enantioselective catalysis · sustainable synthesis · oxidative dearomatization · oxidative rearrangement · alkene functionalization · carbonyl α -functionalization · nucleophilic addition

14 Recent Advances in Hypervalent Halogen Catalysis*Hiroataka Sasa^{1b}, Yasuyuki Kita^{1b}, and Toshifumi Dohi^{1b}*

Over the past three decades, hypervalent halogen catalysis has demonstrated significant versatility in facilitating various organic transformations. This review categorizes these catalytic reactions into two main classifications: oxidation catalysis and halogen-bond catalysis. Oxidation catalysis involves the utilization of hypervalent iodine compounds with co-oxidants to promote catalytic oxidation processes. Conversely, halogen-bond catalysis encompasses reactions promoted by the Lewis acidity of iodonium or bromonium salts. The chapter presents selected examples from each category, elucidating the applicable substrates, reaction limitations, and detailed experimental protocols.



Keywords: hypervalent iodine · oxidation catalysis · organocatalysis · halogen-bond catalysis · hypervalent bromine · Lewis acids

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Chemical (cont.)

Name Used in Text	Abbreviation Used in Tables and on Arrow in Schemes	Abbreviation Used in Experimental Procedures
1,2-dimethoxyethane	DME	DME
dimethylacetamide	DMA	DMA
dimethyl acetylenedicarboxylate	DMAD	DMAD
2-(dimethylamino)ethanol	Me ₂ N(CH ₂) ₂ OH	2-(dimethylamino)ethanol
4-(dimethylamino)pyridine	DMAP	DMAP
dimethylformamide	DMF	DMF
dimethyl sulfide	DMS	DMS
dimethyl sulfoxide	DMSO	DMSO
1,3-dimethyl-3,4,5,6-tetrahydro- pyrimidin-2(1 <i>H</i>)-one	DMPU	DMPU
ethyl diazoacetate	EDA	EDA
ethylenediaminetetraacetic acid	edta	edta
hexamethylphosphoric triamide	HMPA	HMPA
hexamethylphosphorous triamide	HMPT	HMPT
iodomethane	MeI	MeI
<i>N</i> -iodosuccinimide	NIS	NIS
lithium diisopropylamide	LDA	LDA
lithium hexamethyldisilazane	LiHMDS	LiHMDS
lithium isopropylcyclohexylamide	LICA	LICA
lithium 2,2,6,6-tetramethylpiperidine	LTMP	LTMP
lutidine	lut	lut
methylaluminum bis(2,6-di- <i>tert</i> -butyl-4-methyl- phenoxide)	MAD	MAD
methyl ethyl ketone	MEK	methyl ethyl ketone
methylmaleimide	NMM	NMM
4-methylmorpholine <i>N</i> -oxide	NMO	NMO
1-methylpyrrolidin-2-one	NMP	NMP
methyl vinyl ketone	MVK	methyl vinyl ketone
petroleum ether	PE ^a	petroleum ether
<i>N</i> -phenylmaleimide	NPM	NPM
polyphosphoric acid	PPA	PPA
polyphosphate ester	PPE	polyphosphate ester
potassium hexamethyldisilazane	KHMDS	KHMDS
pyridine	pyridine ^b	pyridine
pyridinium chlorochromate	PCC	PCC
pyridinium dichromate	PDC	PDC
pyridinium 4-toluenesulfonate	PPTS	PPTS
sodium bis(2-methoxyethoxy)aluminum hydride	Red-Al	Red-Al
tetrabutylammonium bromide	TBAB	TBAB

^a Used to save space; abbreviation must be defined in a footnote.^b py used on arrow in schemes.

Chemical (cont.)

Name Used in Text	Abbreviation Used in Tables and on Arrow in Schemes	Abbreviation Used in Experimental Procedures
tetrabutylammonium chloride	TBACl	TBACl
tetrabutylammonium fluoride	TBAF	TBAF
tetrabutylammonium iodide	TBAI	TBAI
tetracyanoethene	TCNE	tetracyanoethene
tetrahydrofuran	THF	THF
tetrahydropyran	THP	THP
2,2,6,6-tetramethylpiperidine	TMP	TMP
trimethylamine <i>N</i> -oxide	TMANO	trimethylamine <i>N</i> -oxide
<i>N,N,N',N'</i> -tetramethylethylenediamine	TMEDA	TMEDA
tosylmethyl isocyanide	TosMIC	TosMIC
trifluoroacetic acid	TFA	TFA
trifluoroacetic anhydride	TFAA	TFAA
trimethylsilyl cyanide	TMSCN	TMSCN

Ligands

acetylacetonato	acac
2,2'-bipyridyl	bipy
1,2-bis(dimethylphosphino)ethane	DMPE
2,3-bis(diphenylphosphino)bicyclo[2.2.1]hept-5-ene	NORPHOS
2,2'-bis(diphenylphosphino)-1,1'-binaphthyl	BINAP
1,2-bis(diphenylphosphino)ethane	dppe (not diphos)
1,1'-bis(diphenylphosphino)ferrocene	dppf
bis(diphenylphosphino)methane	dppm
1,3-bis(diphenylphosphino)propane	dppp
1,4-bis(diphenylphosphino)butane	dppb
2,3-bis(diphenylphosphino)butane	Chiraphos
bis(salicylidene)ethylenediamine	salen
cyclooctadiene	cod
cyclooctatetraene	cot
cyclooctatriene	cte
η^5 -cyclopentadienyl	Cp
dibenzylideneacetone	dba
6,6-dimethylcyclohexadienyl	dmch
2,4-dimethylpentadienyl	dmpd
ethylenediaminetetraacetic acid	edta
isopinocampheyl	lpc
2,3- <i>O</i> -isopropylidene-2,3-dihydroxy-1,4-bis(diphenylphosphino)butane	Diop
norbornadiene (bicyclo[2.2.1]hepta-2,5-diene)	nbd
η^5 -pentamethylcyclopentadienyl	Cp*

Radicals

acetyl	Ac
aryl	Ar
benzotriazol-1-yl	Bt
benzoyl	Bz
benzyl	Bn
benzyloxycarbonyl	Cbz
benzyloxymethyl	BOM
9-borabicyclo[3.3.1]nonyl	9-BBN
<i>tert</i> -butoxycarbonyl	Boc
butyl	Bu
<i>sec</i> -butyl	<i>s</i> -Bu
<i>tert</i> -butyl	<i>t</i> -Bu
<i>tert</i> -butyldimethylsilyl	TBDMS
<i>tert</i> -butyldiphenylsilyl	TBDPS
cyclohexyl	Cy
3,4-dimethoxybenzyl	DMB
ethyl	Et
ferrocenyl	Fc
9-fluorenylmethoxycarbonyl	Fmoc
isobutyl	iBu
mesityl	Mes
mesyl	Ms
4-methoxybenzyl	PMB
(2-methoxyethoxy)methyl	MEM
methoxymethyl	MOM
methyl	Me
4-nitrobenzyl	PNB
phenyl	Ph
phthaloyl	Phth
phthalimido	NPhth
propyl	Pr
isopropyl	iPr
tetrahydropyranyl	THP
tolyl	Tol
tosyl	Ts
triethylsilyl	TES
triflyl, trifluoromethanesulfonyl	Tf
triisopropylsilyl	TIPS
trimethylsilyl	TMS
2-(trimethylsilyl)ethoxymethyl	SEM
trityl [triphenylmethyl]	Tr

General

absolute	abs
anhydrous	anhyd
aqueous	aq
boiling point	bp
catalyst	no abbreviation
catalytic	cat.
chemical shift	δ
circular dichroism	CD
column chromatography	no abbreviation
concentrated	concd
configuration (in tables)	Config
coupling constant	<i>J</i>
day	<i>d</i>
density	<i>d</i>
decomposed	dec
degrees Celsius	°C
diastereomeric ratio	dr
dilute	dil
electron-donating group	EDG
electron-withdrawing group	EWG
electrophile	E ⁺
enantiomeric excess	ee
enantiomeric ratio	er
equation	eq
equivalent(s)	equiv
flash-vacuum pyrolysis	FVP
gas chromatography	GC
gas chromatography-mass spectrometry	GC/MS
gas-liquid chromatography	GLC
gram	g
highest occupied molecular orbital	HOMO
high-performance liquid chromatography	HPLC
hour(s)	h
infrared	IR
in situ	in situ
in vacuo	in vacuo
lethal dosage, e.g. to 50% of animals tested	LD ₅₀
liquid	liq
liter	L
lowest unoccupied molecular orbital	LUMO
mass spectrometry	MS
medium-pressure liquid chromatography	MPLC
melting point	mp
milliliter	mL
millimole(s)	mmol
millimoles per liter	mM
minute(s)	min
mole(s)	mol
nuclear magnetic resonance	NMR
nucleophile	Nu ⁻
optical purity	op
phase-transfer catalysis	PTC
proton NMR	¹ H NMR