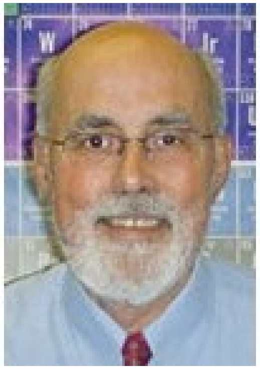
Major contributors in the field of hypervalent iodine chemistry

Anastasios Varvoglis

Masahito Ochiai

Viktor V. Zhdankin



Gerald F. Koser

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Antonio Togni

Jerome Waser

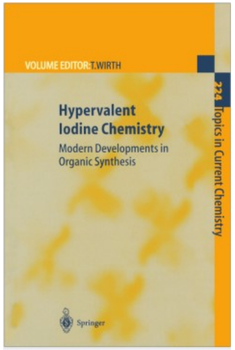
Robert M. Moriarty

Thomas Wirth

Hypervalent Iodine Chemistry

Introduction

- Oxidation states of iodine compounds: -1, +1**, +3, +5, +7**
- Elemental iodine oxidation state: 0
- Hypervalent compounds: molecules containing atoms bearing more electrons than the octet in the valence shell
- Hydrogen iodide (HI) AKA iodane
- IUPAC λ (lambda) nomenclature for compounds with nonstandard bond numbers
- λ^3-iodane = "H_3I", λ^5-iodane = "H_5I", aryl-λ^3-iodane = $ArIL_2$ (L is a ligand), etc.



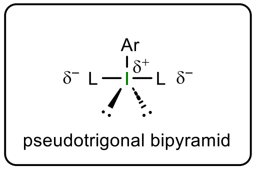
Wirth T. *Hypervalent Iodine Chemistry*. **2002.**
https://doi.org/10.1007/3-540-46114-0

Iodine oxidation states and selected examples

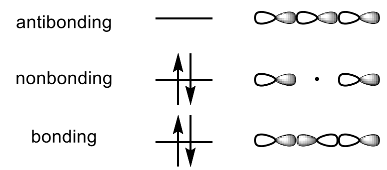
-1	+1	+3	+5	+7
HI, NaI	MeI, PhI, AcOI, ICl	$PhCl_2$, PhIO, PIDA, PIFA, HTIB	DMP, IBX	$NaIO_4$, HIO_4, H_5IO_6

Structure of aryl-λ^3-iodanes

- Pseudotrigonal bipyramid geometry
- L – I – L; 3-center-4-electron bond
- Nonbonding orbital has electron density at its termini
- Iodine has δ^+
- Ligands (preferably more electronegative, e.g. Cl, OH, OAc, OTs) have δ^-
- EN ligands prefer to be in apical positions, Ar & lone pairs in equatorial positions

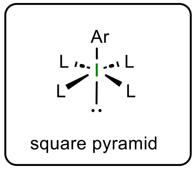


pseudotrigonal bipyramid



Structure of aryl-λ^5-iodanes

- Square pyramid geometry
- Two orthogonal 3-center-4-electron L – I – L bonds
- Ligands are in the basal position, aryl group is in the apical position



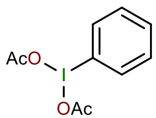
square pyramid

Other books and reviews

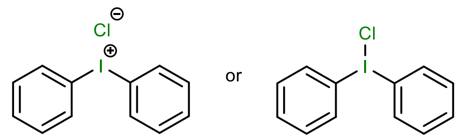
Wirth T. *Hypervalent Iodine Chemistry*. **2016.**
https://doi.org/10.1007/978-3-319-33733-3

Zhdankin V. V. *Chem. Rev.* ***2016***, *116*, 3328.
https://doi.org/10.1021/acs.chemrev.5b00547

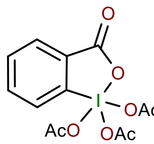
Structure of selected hypervalent iodine compounds in solid state



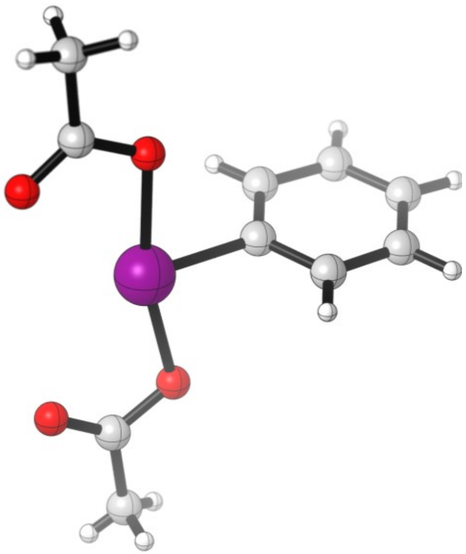
PIDA

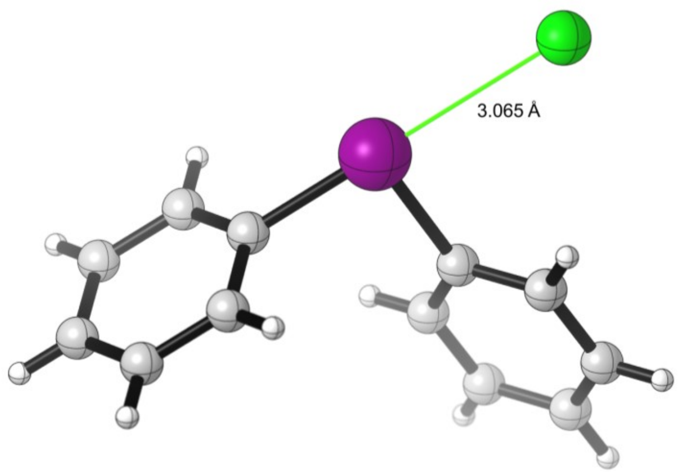


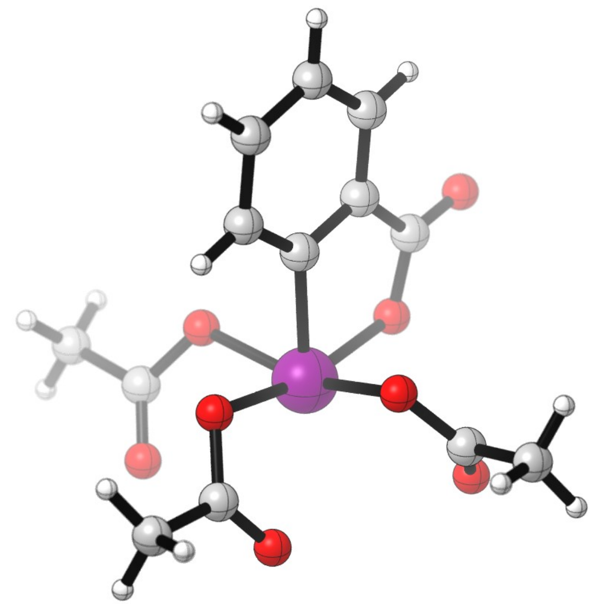
diphenyliodonium chloride or chloro(diphenyl)-λ^3 –iodane



DMP







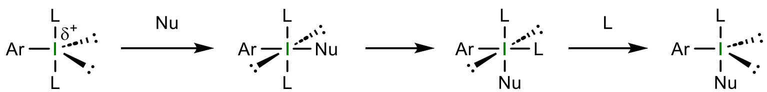
Wirth T. *Angew. Chem. Int. Ed.* **2018**, *57*, 8306.
https://doi.org/10.1002/anie.201804642

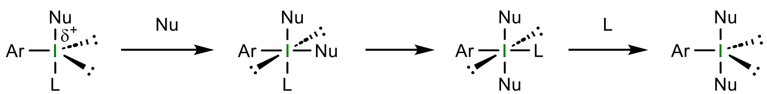
Countryman R. M. *J. Chem. Soc. Dalton Trans.* **1977**, *3*, 217.
https://doi.org/10.1039/DT9770000217

Trauner D. *Beilstein J. Org. Chem.* **2012**, *8*, 1523.
https://doi.org/10.3762/bjoc.8.172

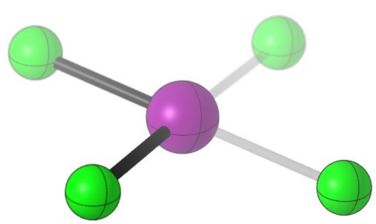
General reactivity patterns

- Aryl λ^3-iodanes of type $ArIL_2$ are oxidants
- First ligand gets displaced in the ligand exchange step, second ligand in reductive elimination step
- Ligand exchange: associative pathway
- $ArIL_2 + Nu^- \rightarrow [ArIL_2Nu]^- \rightarrow ArINuL + L^-$





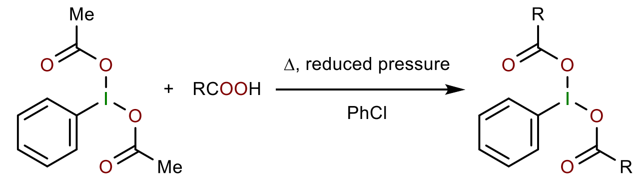
- Ligand exchange: dissociative pathway
- $ArIL_2 \rightarrow [ArIL]^+ + L^- \rightarrow ArINuL$
- Isolation of ICl_4^- salts favours the associative pathway hypothesis

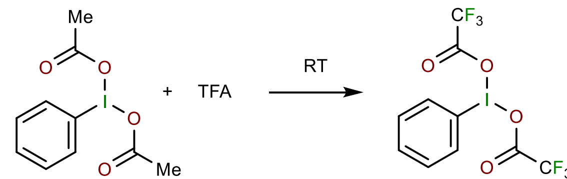


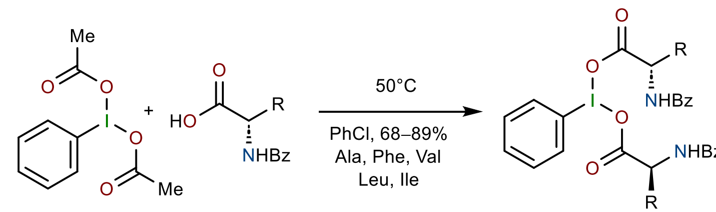
Edwards A. J. *Chem. Soc. Dalton Trans.* ***1978***, *12*, 1723.
https://doi.org/10.1039/DT9780001723

- Aryl λ^3-iodanes of type Ar_2IL can transfer one of the Ar groups to a nucleophile

Ligand exchange examples

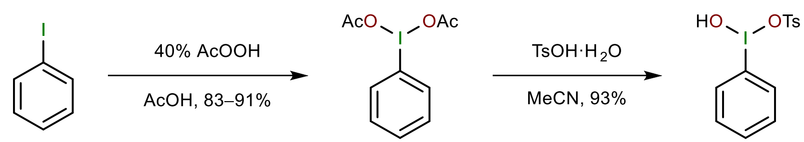






Zhdankin V. V. *Org. Lett.* ***2004***, *6*, 3613.
https://doi.org/10.1021/ol0484714

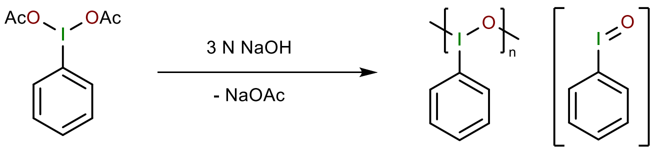
Synthesis of PIDA and Koser's reagent (HTIB)



Saltzman. H. *Org. Syn.* **1963**, *43*, 62.
https://doi.org/10.15227/orgsyn.043.0062

Koser G. F. *J. Org. Chem.* **1977**, *42*, 1476.
https://doi.org/10.1021/jo00428a052

Preparation of iodosyl benzene



Fieser & Fieser's Reagents for Oganic Synthesis
https://doi.org/10.1002/9780471264194.fos05913.pub5

Oxidation of alcohols with DMP, IBX, TEMPO/PIDA, allylic oxidations, C–H oxidations, unsaturation of carbonyls not covered, see Chem 534 notes

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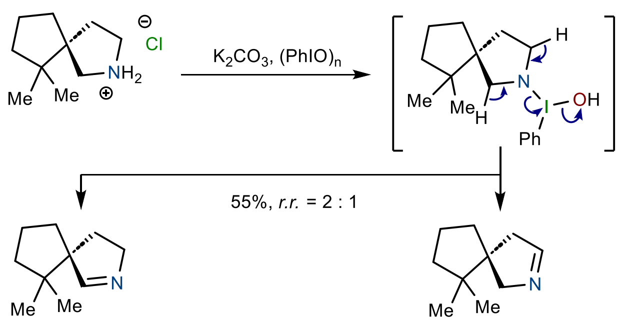
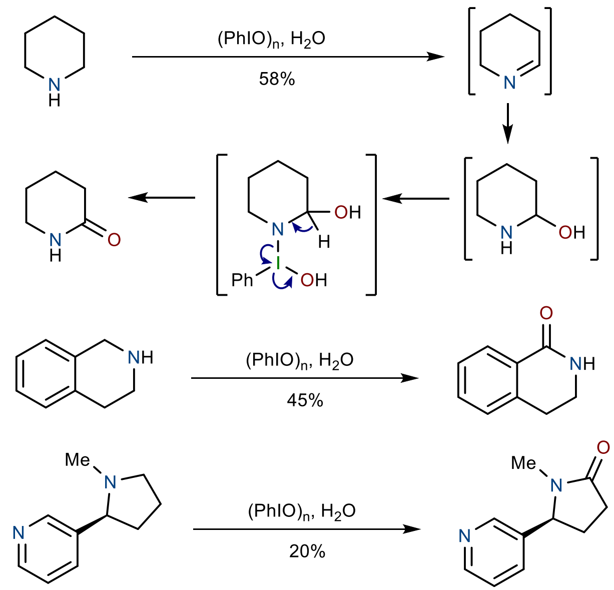
Oxidation of amines



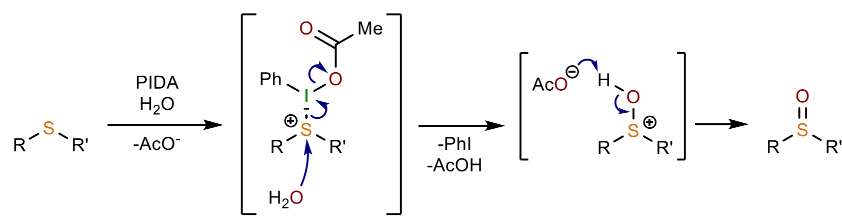
polyzonimine

Kiguchi T. *Nat. Prod. Lett.* **1993**, *2*, 309.
https://doi.org/10.1080/10575639308043827

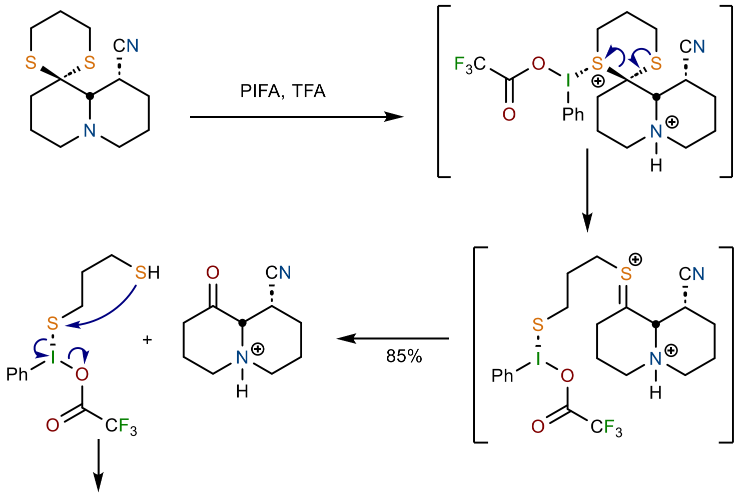


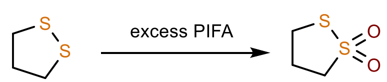
Moriarty R. M. *Tetrahedron Lett.* **1998**, *29*, 6913.
https://doi.org/10.1016/S0040-4039(00)88473-7

Oxidation of sulfdes



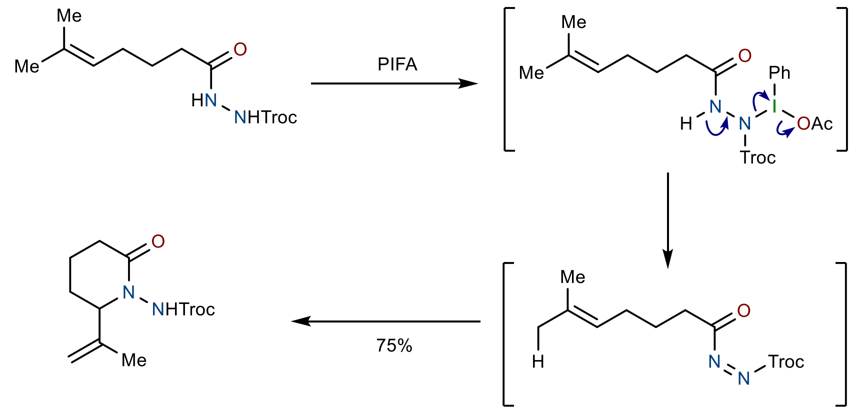
Kuthalingam P. *J. Org. Chem.* **1982**, *47*,428.
https://doi.org/10.1021/jo00342a010



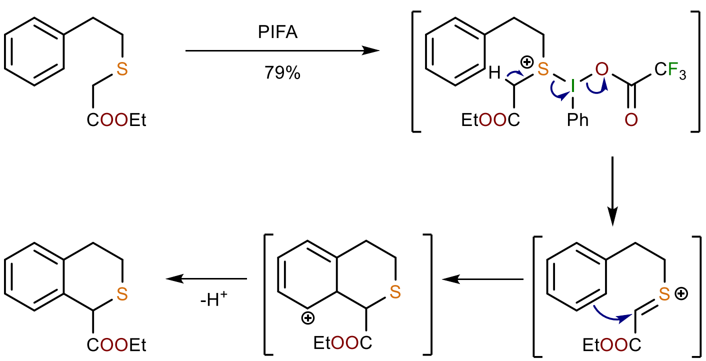


Tu Y. *J. Org. Chem.* **2001**, *66*, 6052.
https://doi.org/10.1021/jo0157829

Oxidation of acylhydrazides

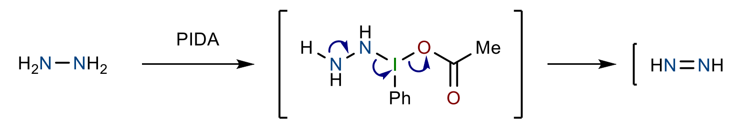


Leblanc Y. *Tetrahedron Lett.* **1992**, *33*, 5717.
https://doi.org/10.1016/0040-4039(92)89014-4

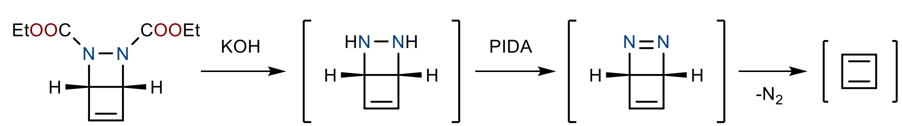


Haruta J. *Chem. Pharm. Bull.* **1986**, *34*, 1061.
https://doi.org/10.1248/cpb.34.1061

Oxidation of hydrazines and generation of diimide

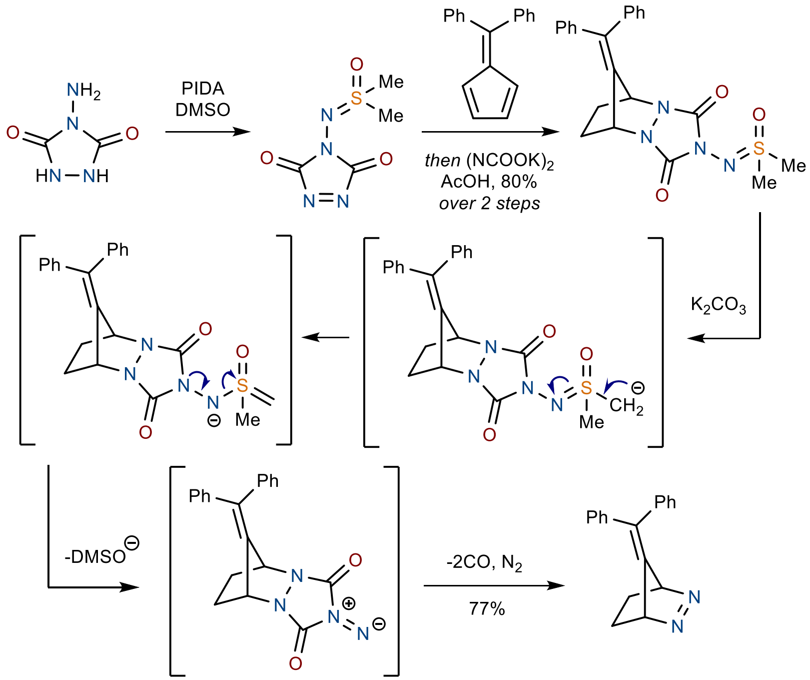


Moriarty R. M. *Synth. Commun.* **1987**, *17*, 703.
https://doi.org/10.1080/00397918708075744

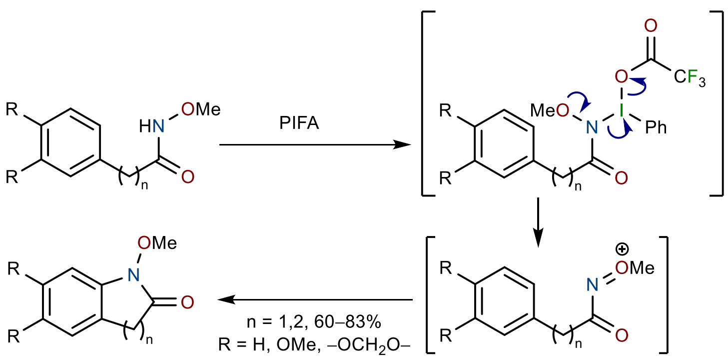


Burns. N. Z. *J. Am. Chem. Soc.* **2023**, *145*, 5631.
https://doi.org/10.1021/ja00086a007

Hypervalent Iodine Chemistry

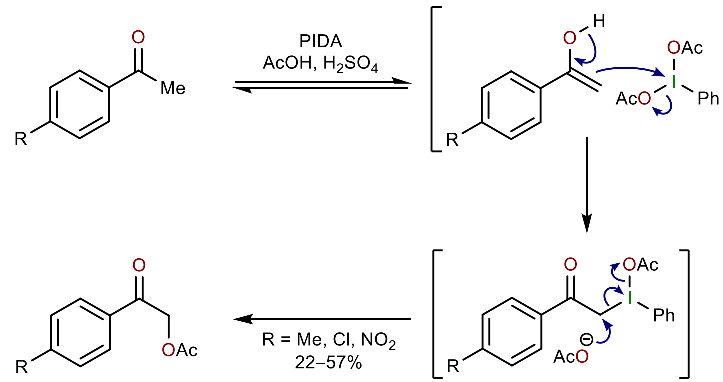


Little R. D. *J. Org. Chem.* **1997**, *62*, 3779. https://doi.org/10.1021/jo970011j

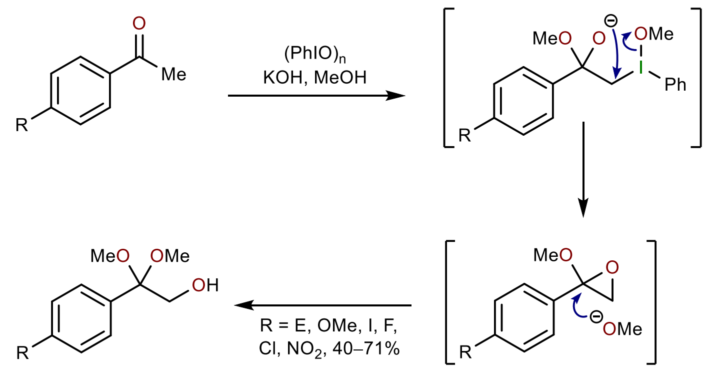


Kikugawa Y. *Chem. Lett.* **1990**, *19*, 581. https://doi.org/10.1246/cl.1990.581

α-functionalization of ketones

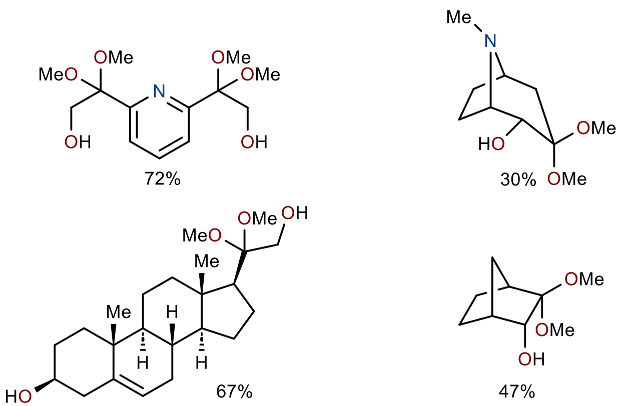


Imamura J. Bull. *Chem. Soc. Jpn.* **1978**, *51*, 335.
https://doi.org/10.1246/bcsj.51.335



Gupta S. C. *Tetrahedron Lett.* **1985**, *22*, 1283.
https://doi.org/10.1016/S0040-4039(01)90297-7

Extended substrate scope



Moriarty R. M. *J. Chem. Soc. Chem. Commun.* **1981**, *13*, 641.
https://doi.org/10.1039/C39810000641

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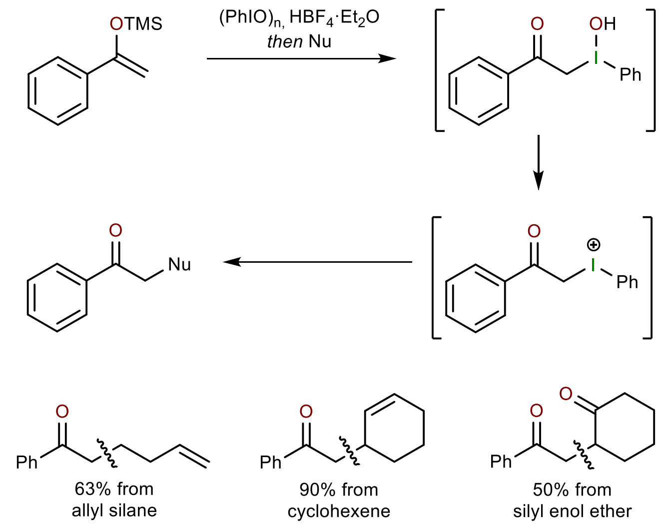
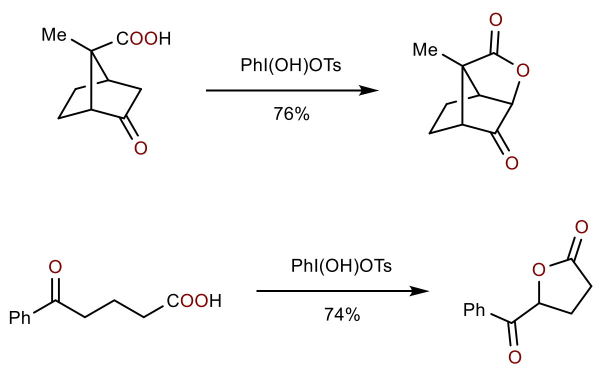
https://doi.org/10.1016/S0040-4039(01)81508-2

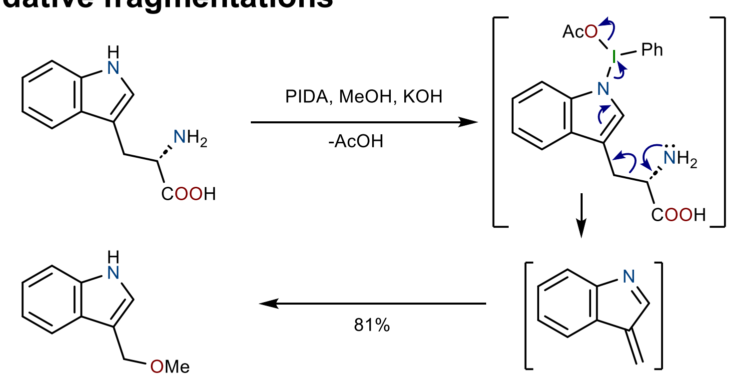


Zhdankin V.V. *J. Org. Chem.* **1989**, *54*, 2605.
https://doi.org/10.1021/jo00272a028



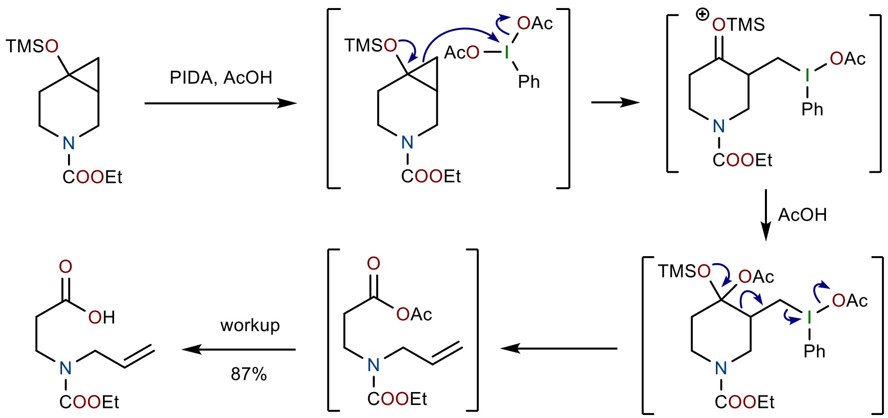
Moriarty R. M. *Tetrahedron. Lett.* **1990**, *31*, 201.
https://doi.org/10.1016/S0040-4039(00)94370-3

Oxidative fragmentations



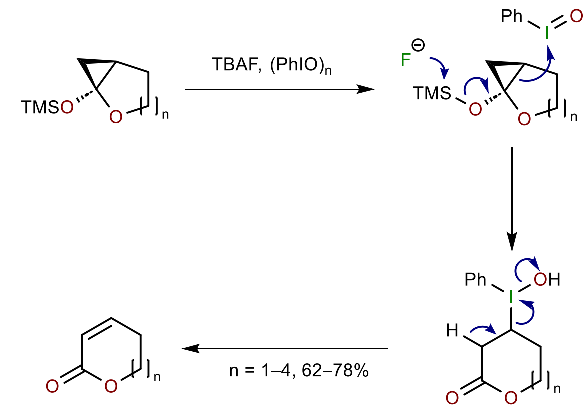
Moriarty R. M. *J. Am. Chem. Soc.* **1985**, *107*, 4559.
https://doi.org/10.1021/ja00301a039

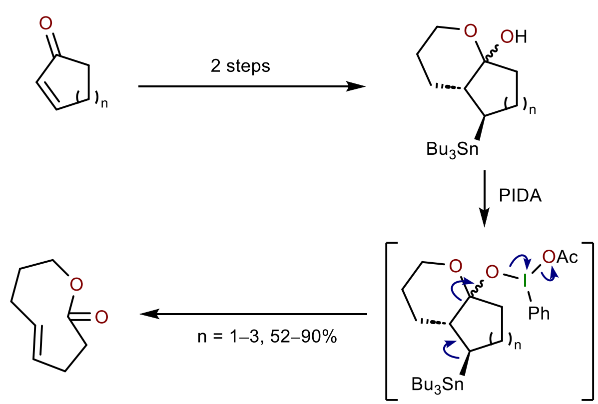
Hypervalent Iodine Chemistry



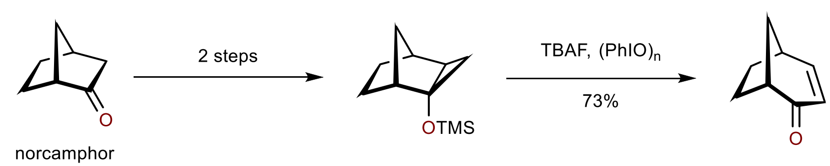
Kirihara M. *Tetrahedron Lett.* **1998**, *54*, 13943.
https://doi.org/10.1016/S0040-4020(98)00862-X

Synthesis of homologated unsaturated ketones / lactones



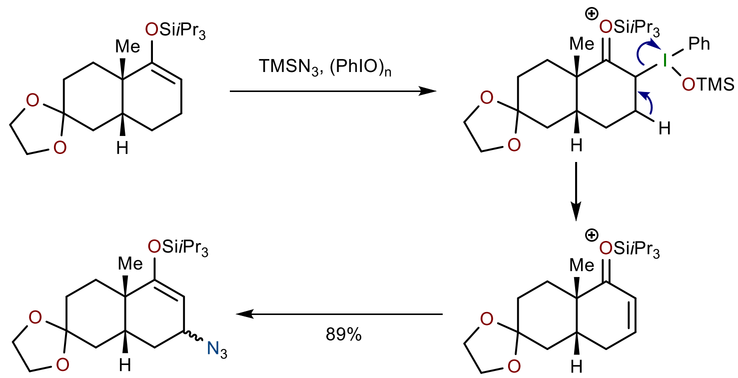


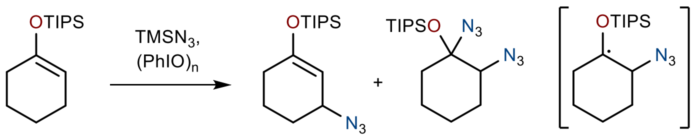
Ochiai M. *Chem. Lett.* **1997**, *16*, 133.
https://doi.org/10.1246/cl.1987.133



Moriarty R. M. *Tetrahedron Lett.* **1990**, *31*, 197.
https://doi.org/10.1016/S0040-4039(00)94369-7

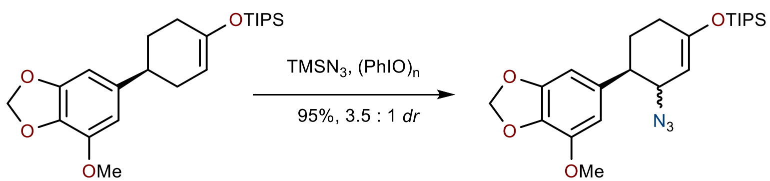
Azidation of TIPS enol ethers





-78 °C	1 : 9
0 °C	99 : 1

Magnus P. *J. Am. Chem. Soc.* **1996**, *118*, 3406.
https://doi.org/10.1021/ja953906r

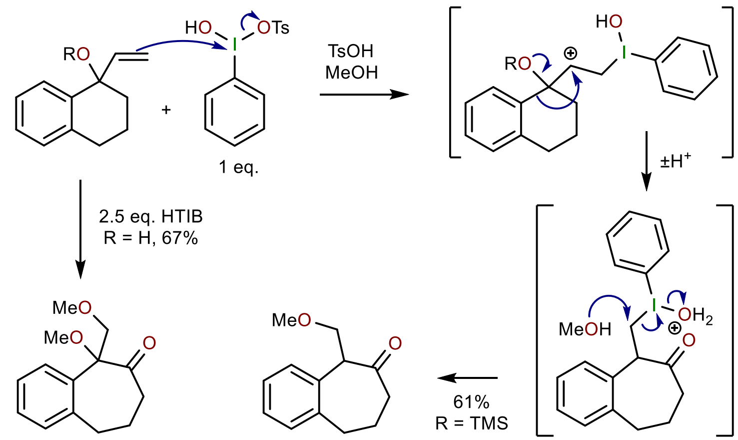


Magnus P. *J. Am. Chem. Soc.* **1998**, *120*, 5341.
https://doi.org/10.1021/ja980407s

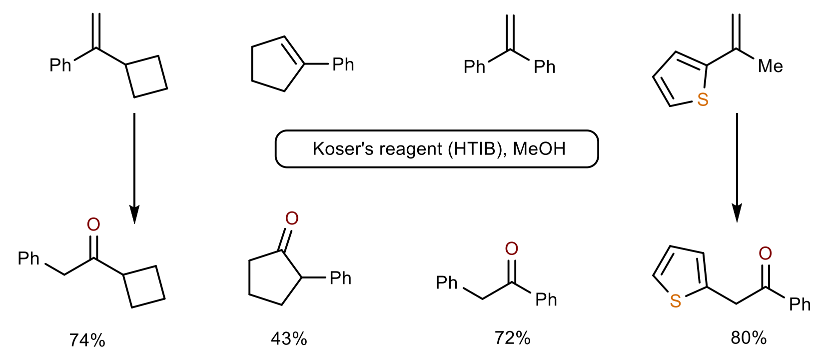
Reactions with olefins

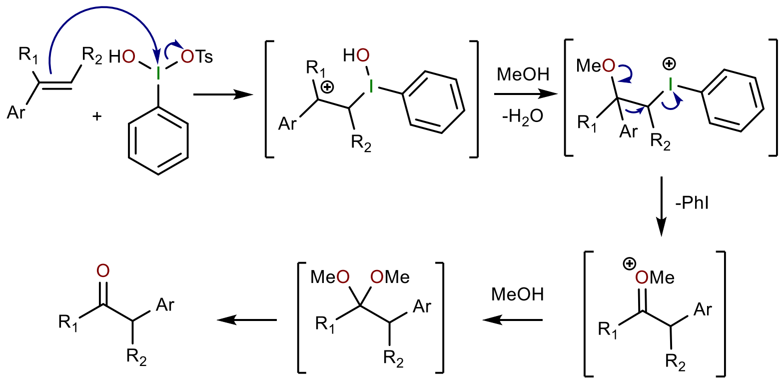
- "Reactions of simple alkenes with $PhI(OAc)_2$ are not synthetically useful because of formation of multiple products."

Moriarty R. M. *(Diacetoxyiodo)benzene. EROS.* **2006.**
https://doi.org/10.1002/047084289X.rd005m.pub2



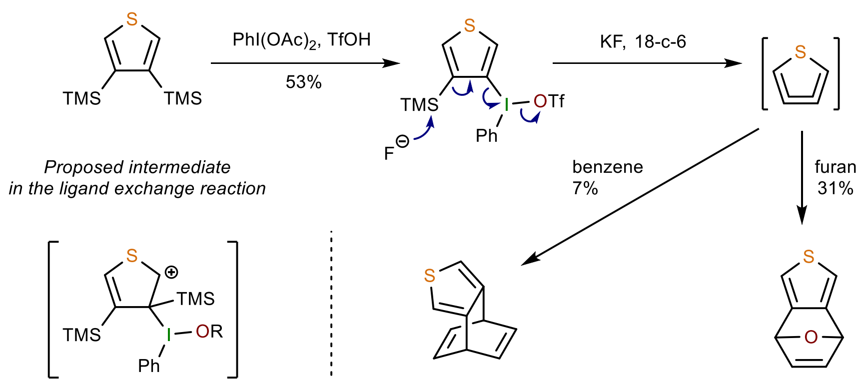
Silva L. F. *Org. Lett.* **2008**, *10*, 1017.
https://doi.org/10.1021/ol800048f





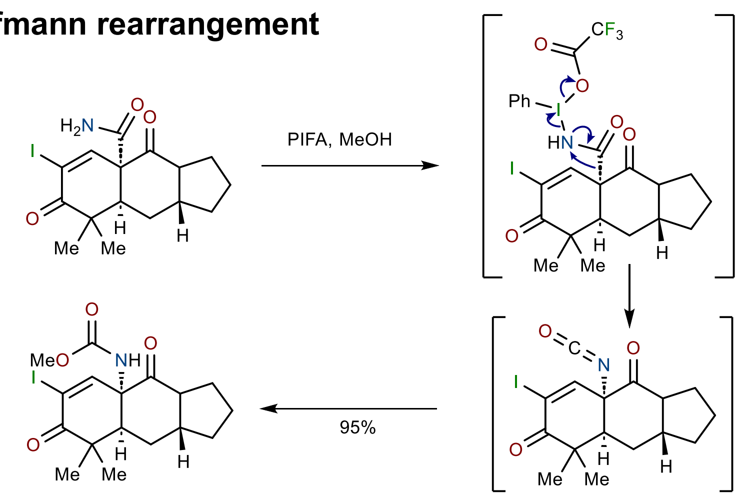
Koser G. F. *Tetrahedron Lett.* ***2004***, *45*, 6159.
https://doi.org/10.1016/j.tetlet.2004.06.029

Generation of arynes

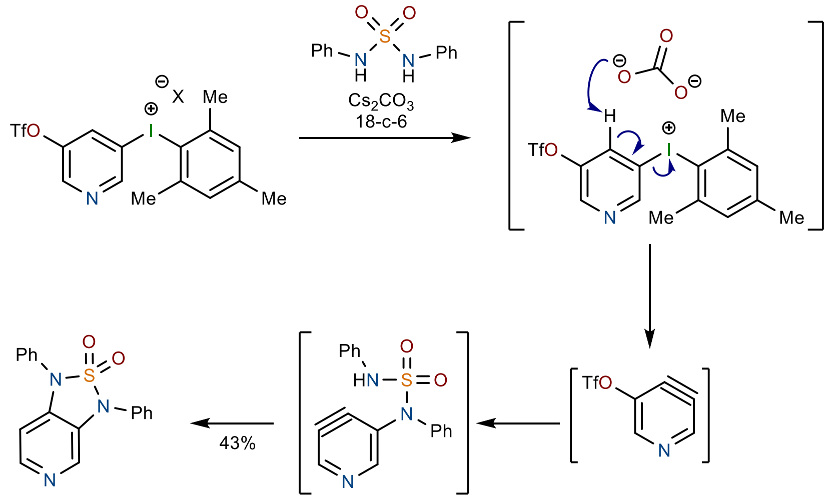


Magnus P. *J. Am. Chem. Soc.* **1996**, *118*, 3406.
https://doi.org/10.1021/ja953906r

Hofmann rearrangement



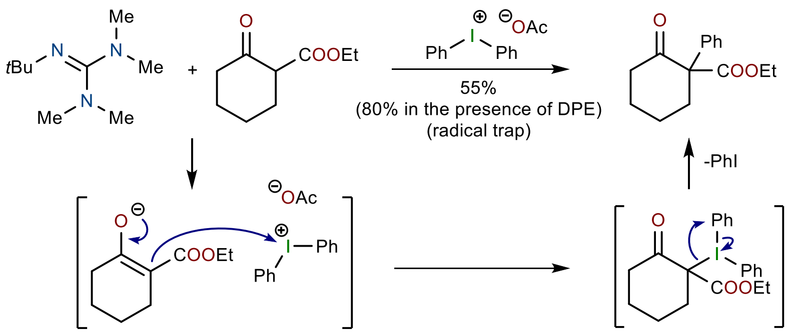
Sarpong R. *Nature.* **2014**, *509*, 318.
https://doi.org/10.1038/nature13273



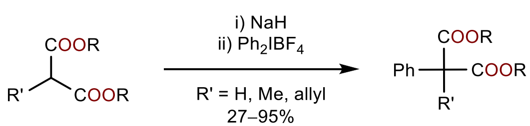
Li Y. *Nat. Commun.* **2023**, 14, 1841.
https://doi.org/10.1038/s41467-023-37196-3

The SARLAH Group

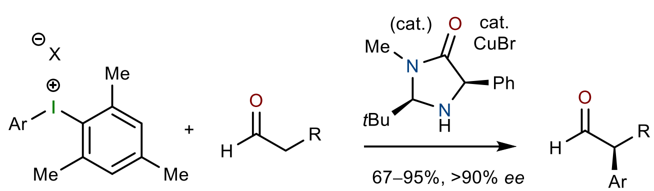
Arylation of 1,3-dicarbonyls

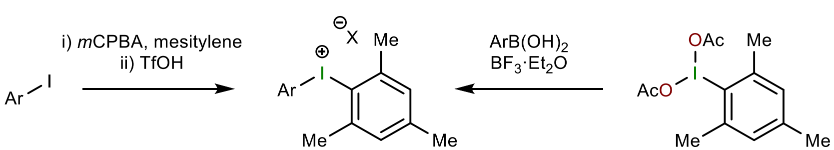


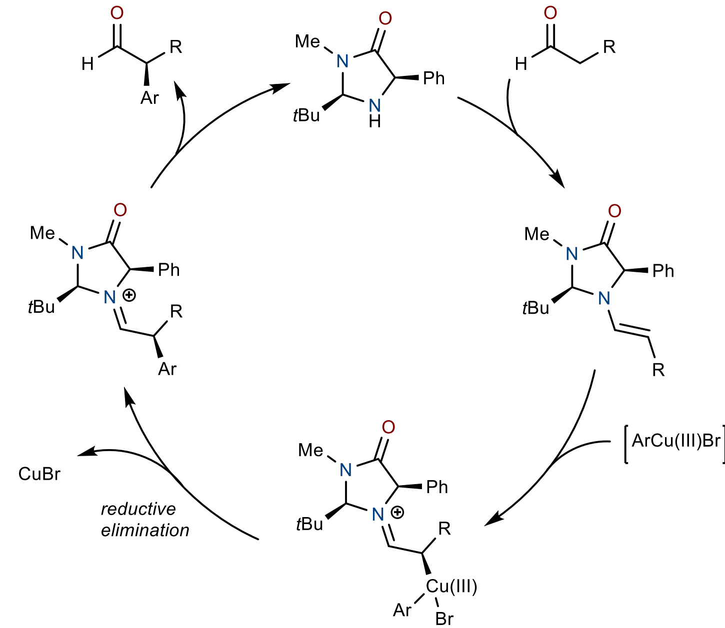
Barton D. H. R. *J. Chem. Soc. Chem. Perkin Trans. 1.* **1987**, *0*, 241.
https://doi.org/10.1039/P19870000241

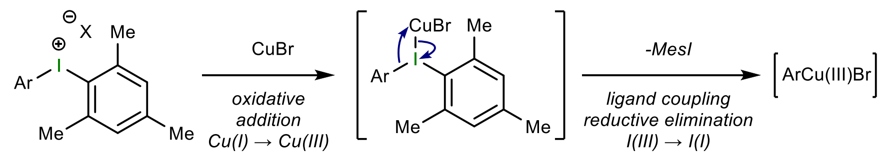


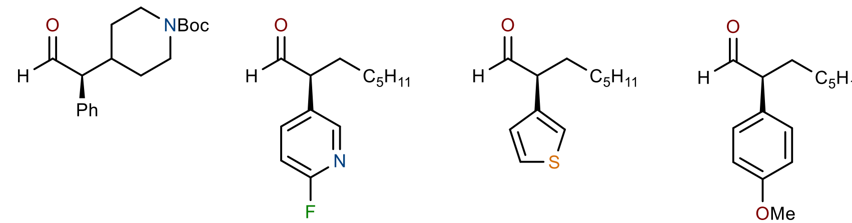
Jung H. H. *J. Org. Chem.* **1990**, *64*, 1338.
https://doi.org/10.1021/jo981065b











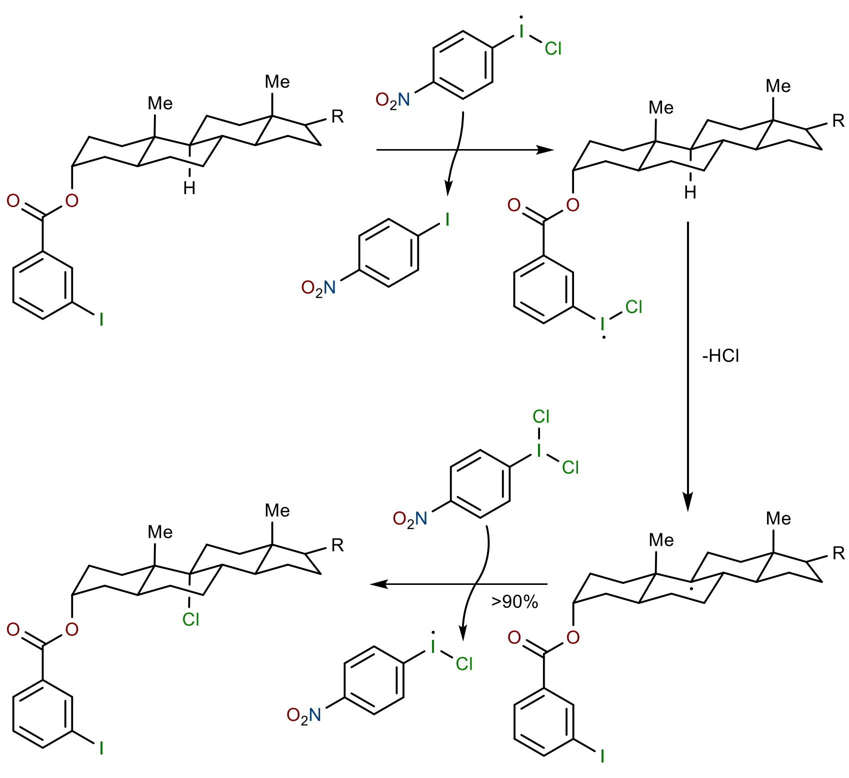
81%, 93% *ee* | 70%, 93% *ee* | 81%, 92% *ee* | 88%, 91% *ee*

Macmillan D. W. C. *J. Am. Chem. Soc.* ***2011***, *133*, 4260.
https://doi.org/10.1021/ja2008906

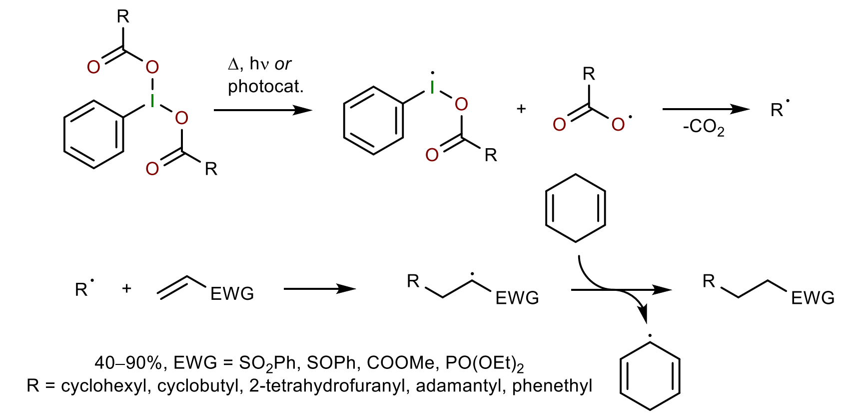
The SARLAH Group

Radical reactions of hypervalent iodine compounds

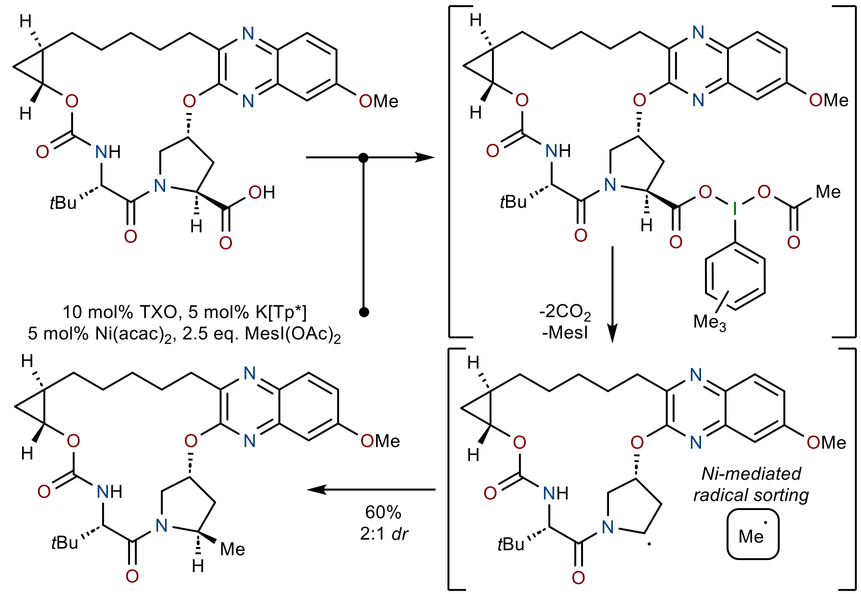
- BDE of organoiodine(I) compounds: 40–65 kcal/mol
- BDE(organoiodine(III) compounds) < BDE(organoiodine(I) compounds)
- Breslow's example of photolytic cleavage: $ArICl_2 \rightarrow ArICl^{\cdot} + Cl^{\cdot}$



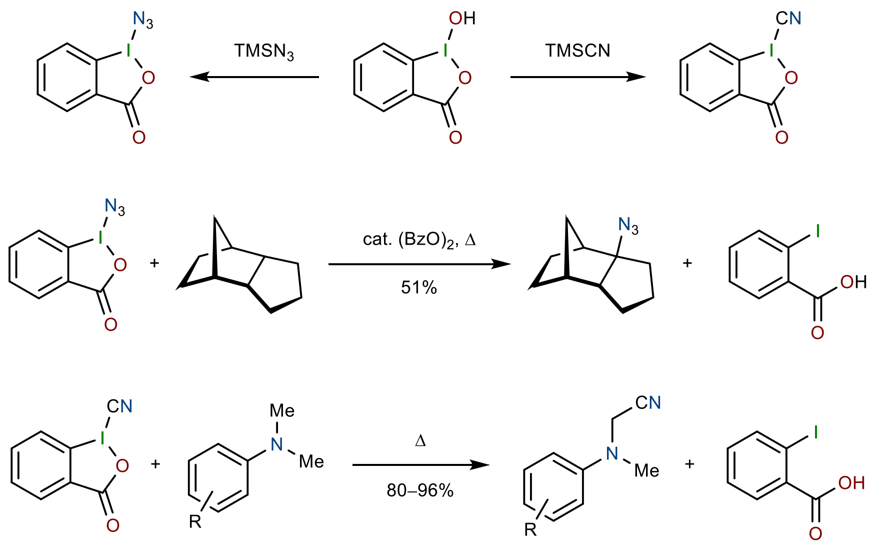
Breslow. R. *J. Am. Chem. Soc.* **1991**, *113*, 8977.
https://doi.org/10.1021/ja00023a074



Togo H. *Tetrahedron Lett.* **1993**, 49, 8241.
https://doi.org/10.1016/S0040-4020(01)88042-X



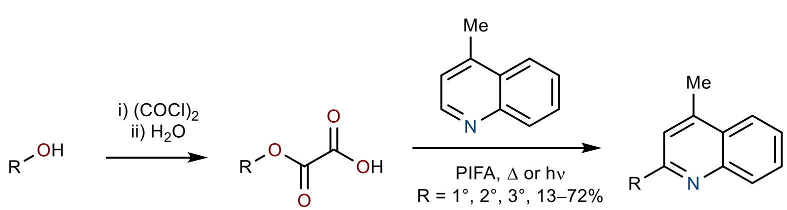
Macmillan D. W. C. *J. Am. Chem. Soc.* **2022**, *144*, 21278.
https://doi.org/10.1021/jacs.2c08989



Zhdankin V. V. *Tetrahedron Lett.* **1995**, *36*, 7975.
https://doi.org/10.1016/0040-4039(95)01720-3

Zhdankin V. V. *J. Am. Chem. Soc.* **1996**, *118*, 5192.
https://doi.org/10.1021/ja954119x

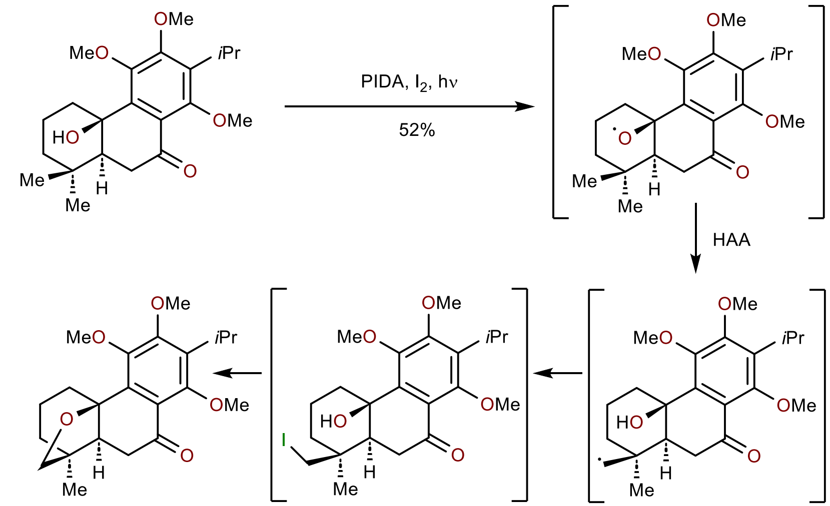
- Alcohols as radical precursors



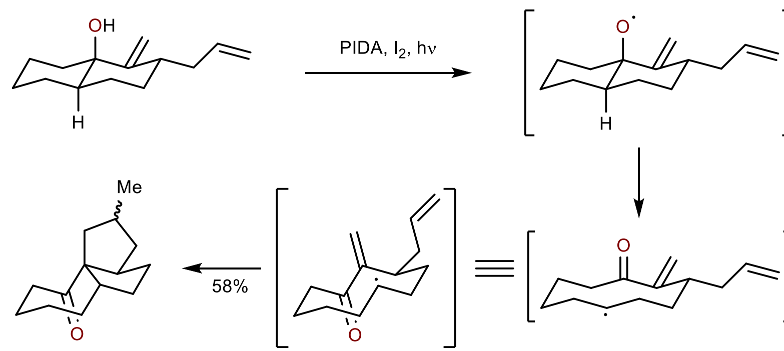
Yokohama M. *J. Chem. Soc. Perkin Trans. 1* **1993**, *20*, 2417.
https://doi.org/10.1039/P19930002417

Suárez reaction

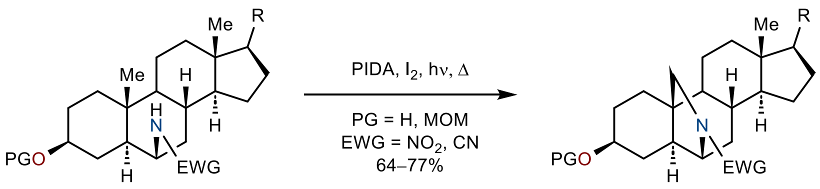
- $PhI(OAc)_2 + I_2 \rightarrow PhI + 2AcOI$ (acetyl hypoiodite)



Wood J. L. *Angew. Chem. Int. Ed.* **2022**, *61*, e202210821.
https://doi.org/10.1002/anie.202210821

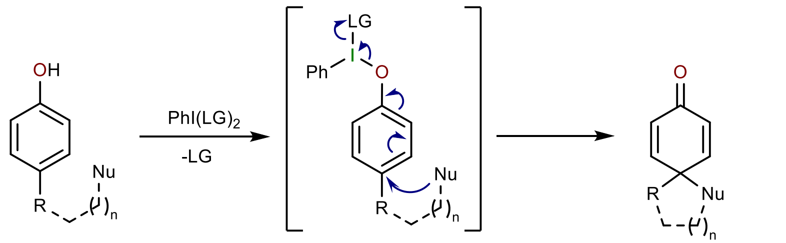


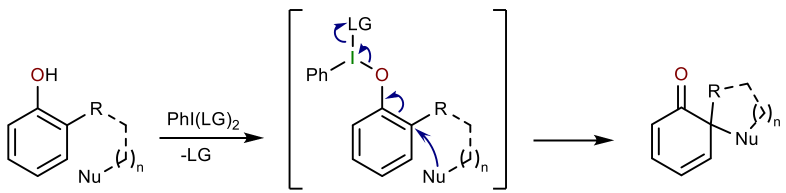
Pattenden G. *Tetrahedron Lett.* **1993**, *34*, 127.
https://doi.org/10.1016/S0040-4039(00)60074-6



Suárez, E. *Tetrahedron Lett.* ***1985***, *26*, 2493.
https://doi.org/10.1016/S0040-4039(00)94862-7

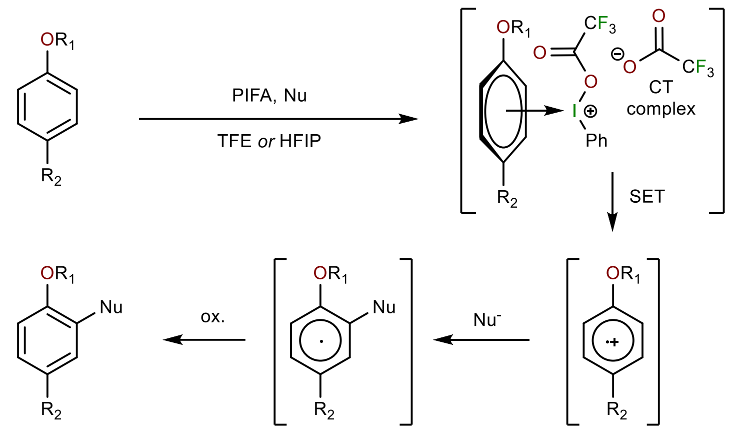
Oxidative phenol dearomatizations

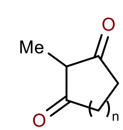




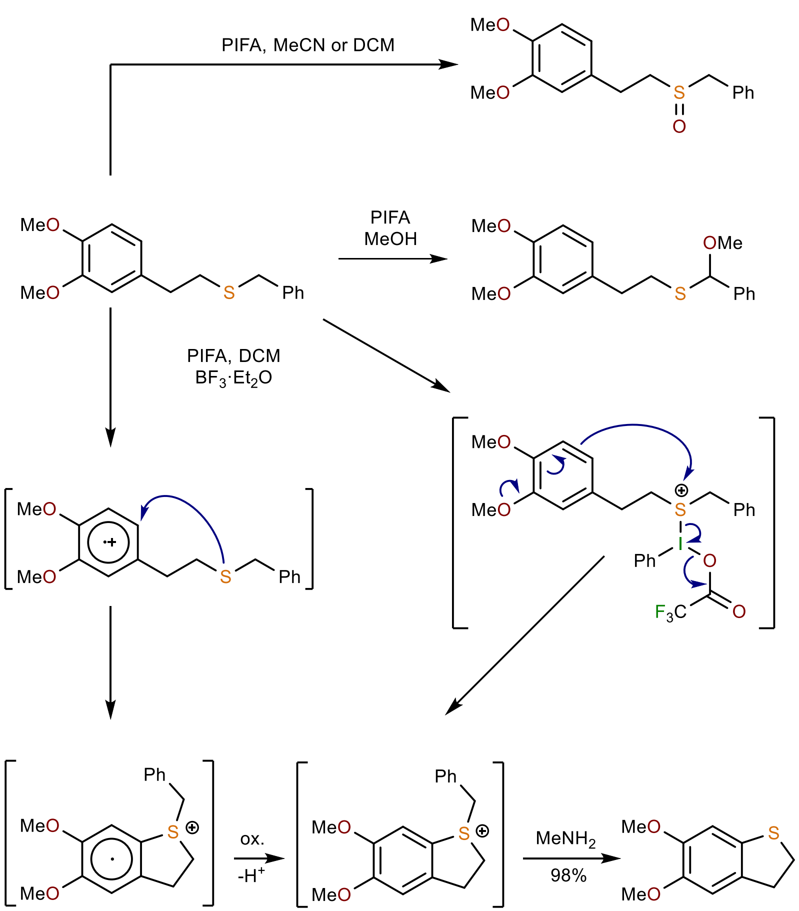
Nu = water, alcohol, carboxylic acid, fluoride, amide, vinylogous amide, sulfonamide, 1,3-dicarbonyl, enol ether, allyl silane, electron rich aromatic rings

Oxidative nucleophilic aromatic substitution

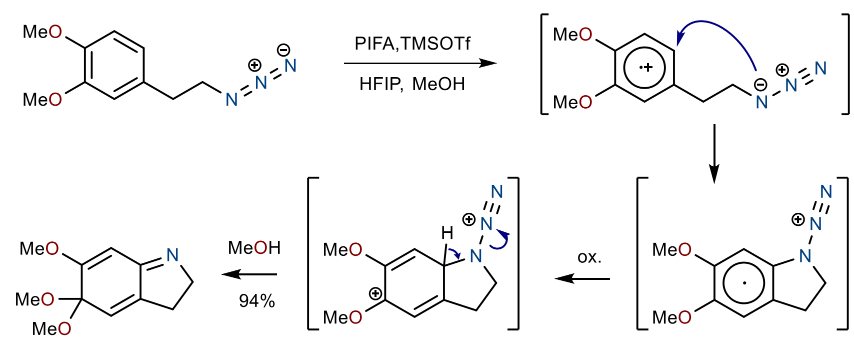


R_1	R_2	Nu	Yields	DOI
Me, Et, *i*Pr	*i*Pr, *t*Bu, OMe, OEt, Me	ArSH	55–91%	10.1021/jo00127a018
Me	*i*Pr, *t*Bu,Cl, Br, OMe, OEt, Me, CH_2COOMe	$TMSN_3$	31–68%	10.1021/ja00088a003
Me	OMe	TMSOAc	43%	10.1021/ja00088a003
Me, Et, *i*Pr	*i*Pr, *t*Bu, OMe, OEt, Me	TMSNC**S**	55–94%	10.1021/ja00088a003
Me, Et	OMe, OEt, *i*Pr		39–66%	10.1021/ja00088a003

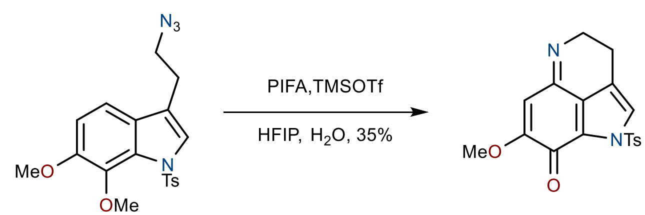
- Example of a divergent transformation with PIFA



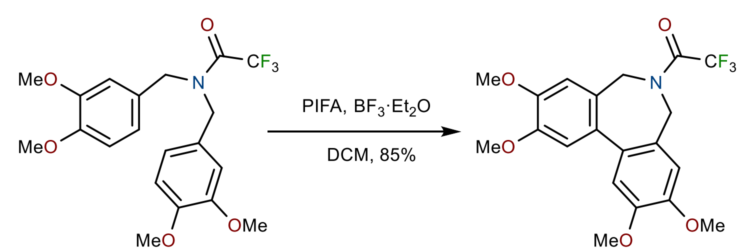
Kita Y. *Chem. Commun.* ***1996***, *19*, 2225.
https://doi.org/10.1039/CC9960002225



Kita Y. *Chem. Commun.* ***1996***, *13*, 1491.
https://doi.org/10.1039/CC9960001491

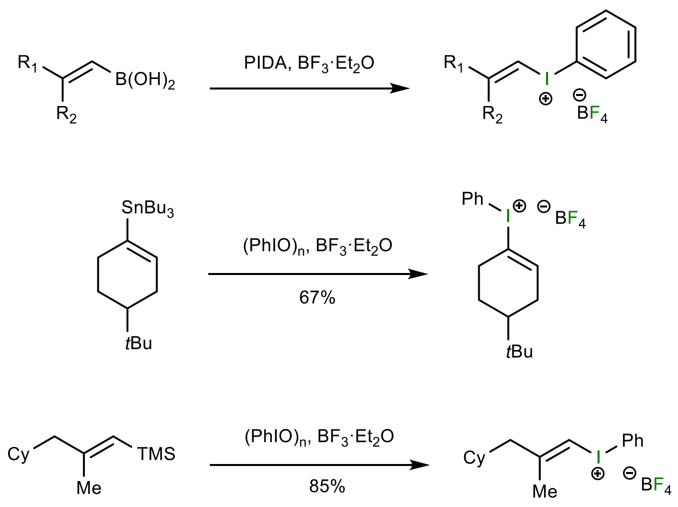


Tokuyama H. *J. Am. Chem. Soc.* ***2023***, *145*, 18233.
https://doi.org/10.1021/ja00227a048



Kita Y. *J. Org. Chem.* ***1998***, *63*, 7698.
https://doi.org/10.1021/jo980704f

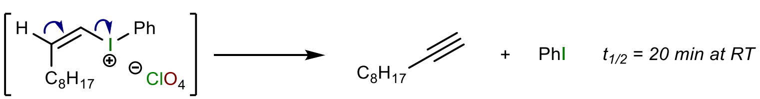
Alkenyl(phenyl)iodonium salts



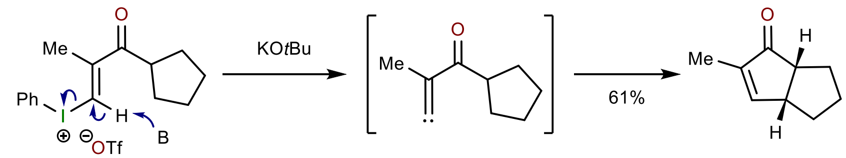
Okuyama T. *J. Am. Chem. Soc.* ***2001***, *123*, 8760.
https://doi.org/10.1021/ja010861n

Ochiai M. *J. Chem. Soc. Chem. Commun.* ***1991***, *13*, 869.
https://doi.org/10.1039/C39910000869

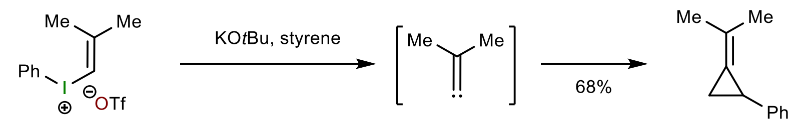
- *Z*-alkenyl(phenyl)iodonium salts are less stable and give alkynes



Ochiai M. *Tetrahedron.* ***1988***, *44*, 4095.
https://doi.org/10.1016/S0040-4020(01)86659-X



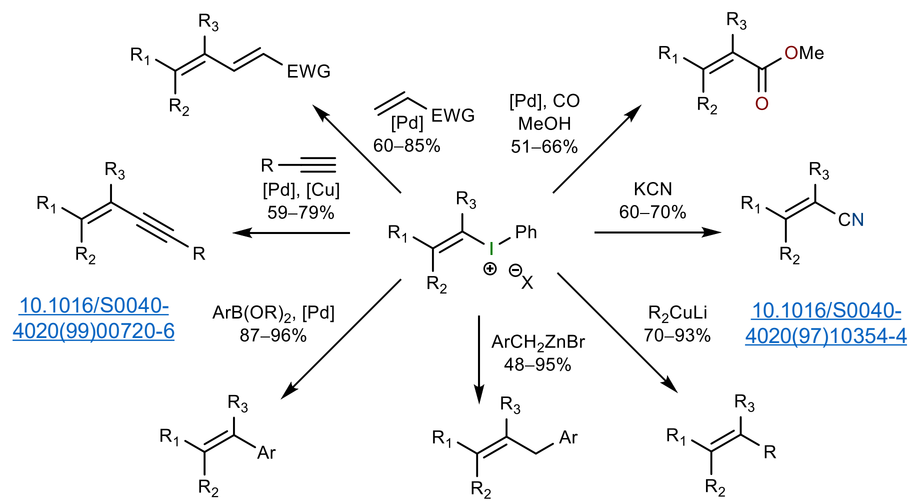
Ochiai M. *J. Am. Chem. Soc.* ***1988***, *110*, 6565.
https://doi.org/10.1021/ja00227a048



Ochiai M. *J. Org. Chem.* ***1995***, *60*, 2624.
https://doi.org/10.1021/jo00113a051

10.1021/ja00016a083

10.1016/S0040-4039(99)01626-3



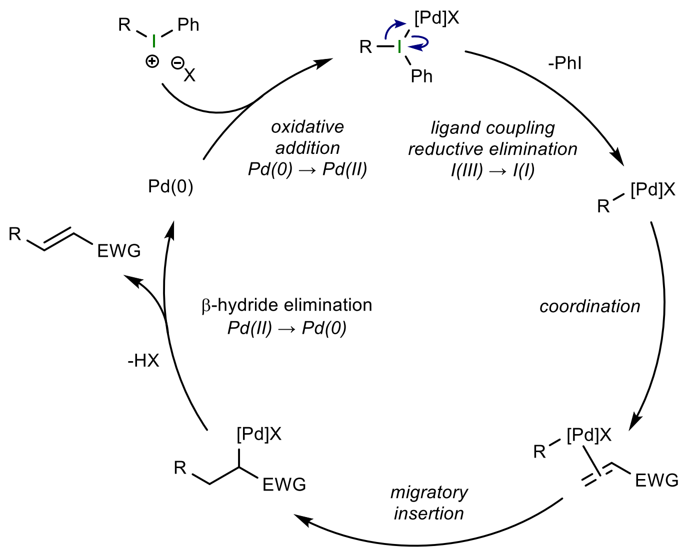
10.1021/jo960195m

10.1021/ol005682+

10.1016/S0040-4020(01)86659-X

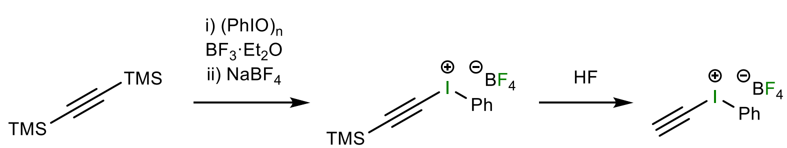
Hypervalent Iodine Chemistry

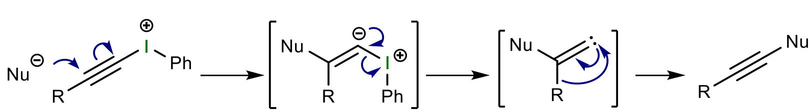
- Catalytic cycle of a Heck reaction with iodonium salts

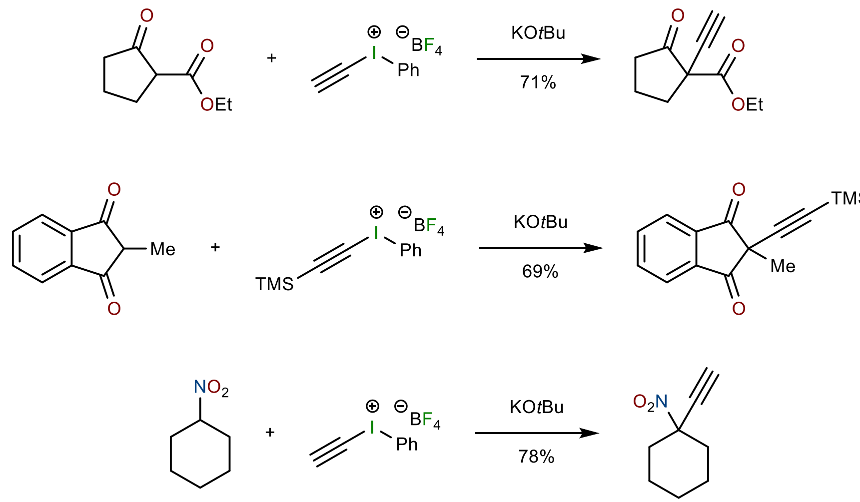


Moriarty R. M. *J. Am. Chem. Soc.* **1991**, *113*, 6315.
https://doi.org/10.1021/ja00016a083

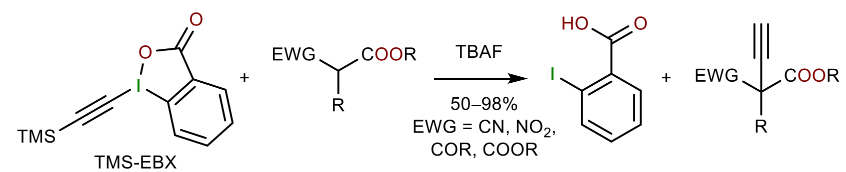
Alkynyl(phenyl)iodonium salts







Ochiai M. *J. Chem. Soc. Chem. Commun.* **1990**, *118*.
https://doi.org/10.1039/C39900000118

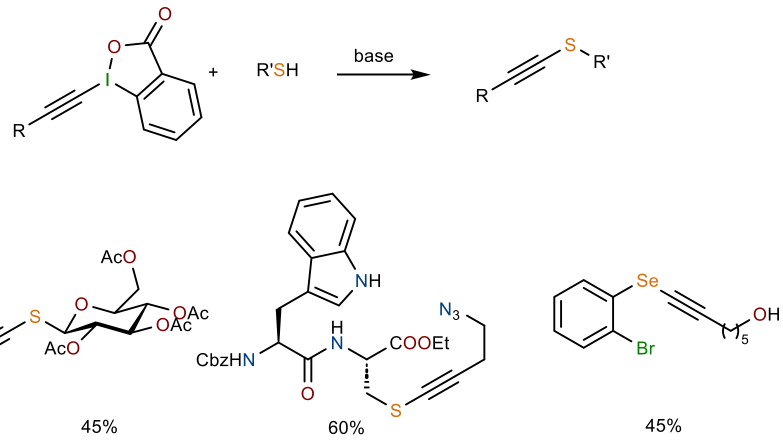


Waser J. *Eur. J. Org. Chem.* **2010**, *16*, 9457.
https://doi.org/10.1002/chem.201001539

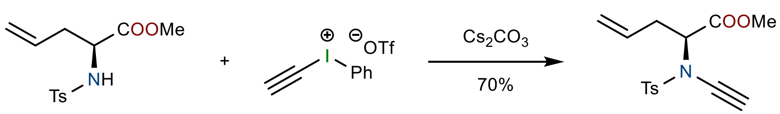
- TBAF acts both as an activating agent and a base
- EBX is formed in situ from TMS-EBX

- Review of other cyclic hypervalent iodine reagents

Waser J. *Acc. Chem. Res.* **2018**, *51*, 3212.
https://doi.org/10.1021/acs.accounts.8b00468

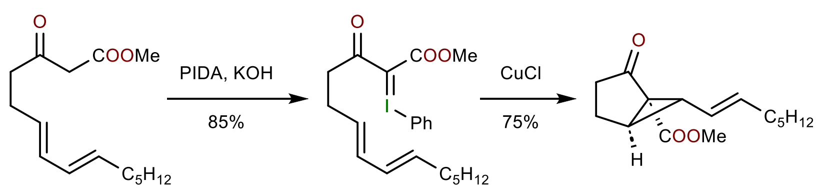


Waser J. *J. Am. Chem. Soc.* **2013**, *135*, 9620.
https://doi.org/10.1021/ja4044196

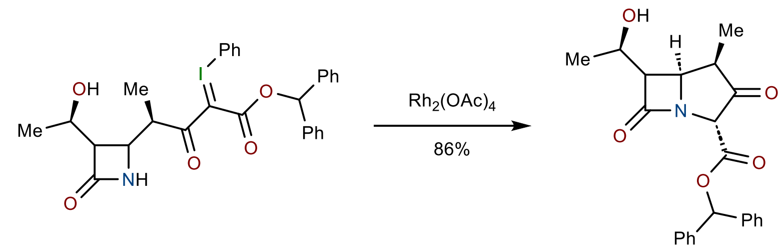


Witulski B. *Chem. Commun.* **1999**, *18*, 1879.
https://doi.org/10.1039/A905898B

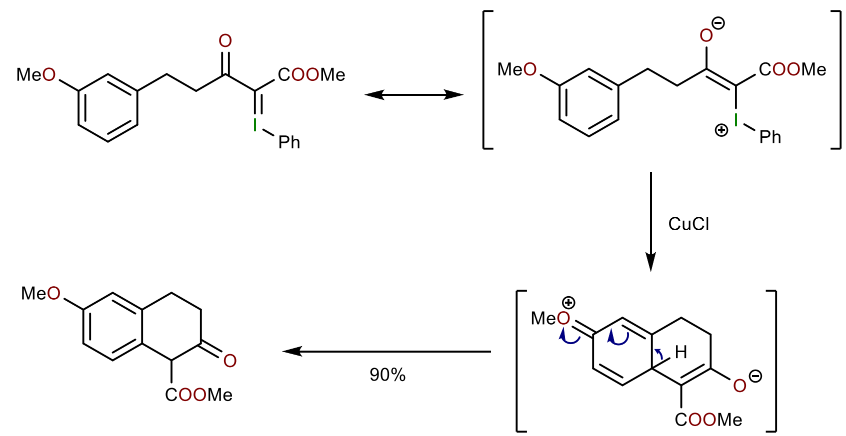
Iodonium ylides



Moriarty R. M. *Tetrahedron. Lett.* **1998**, *39*, 765.
https://doi.org/10.1016/S0040-4039(97)10620-7

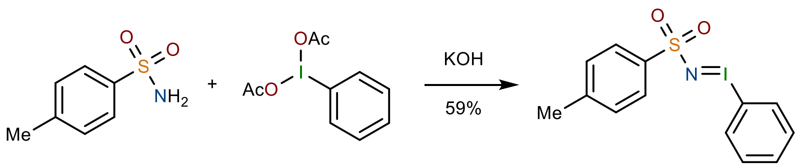


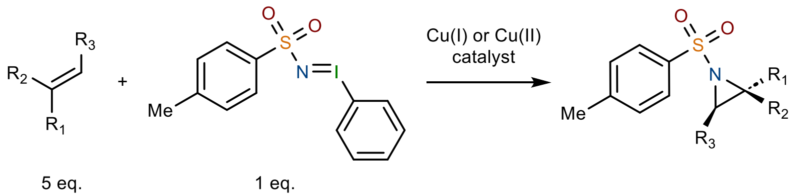
Kume M. *Tetrahedron. Lett.* **1995**, *36*, 9043.
https://doi.org/10.1016/0040-4039(95)01703-K

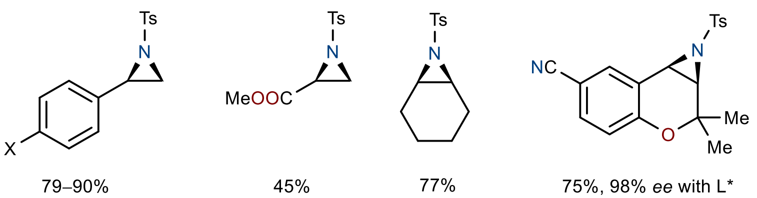


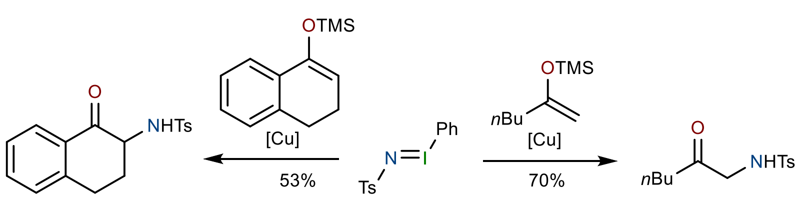
Moriarty R. M. *Tetrahedron. Lett.* **1997**, *38*, 4333.
https://doi.org/10.1016/S0040-4039(97)00967-2

Hypervalent iodine compounds as nitrene precursors

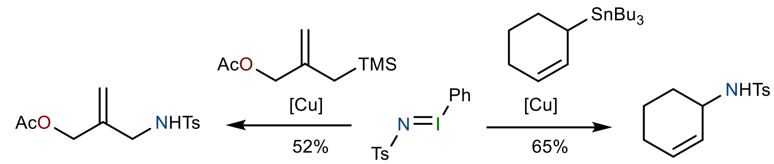




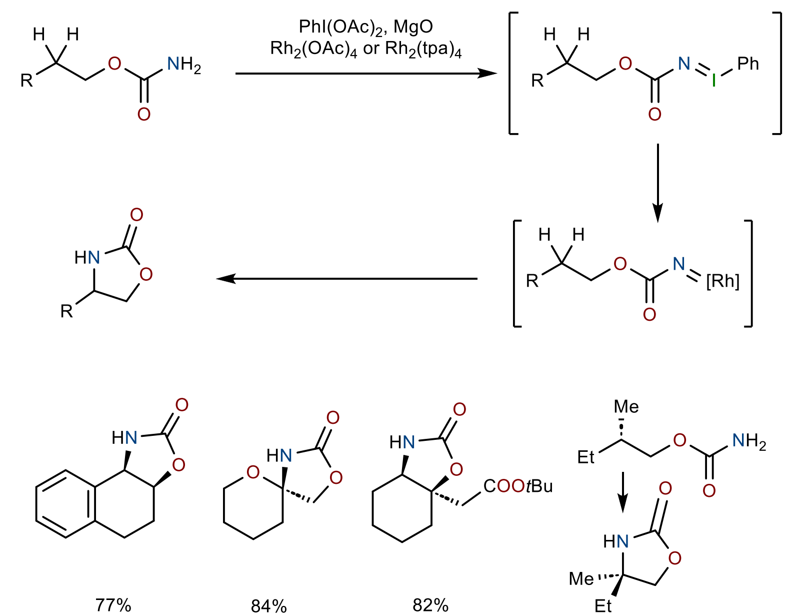




Evans D. A. *J. Am. Chem. Soc.* **1994**, *116*, 2742.
https://doi.org/10.1021/ja00086a007

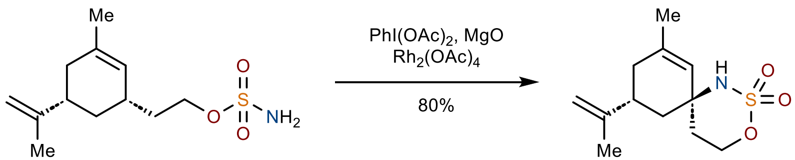


Lee K. *Bull. Korean Chem. Soc.* **2001**, *22*, 315.
https://doi.org/10.5012/bkcs.2001.22.3.315

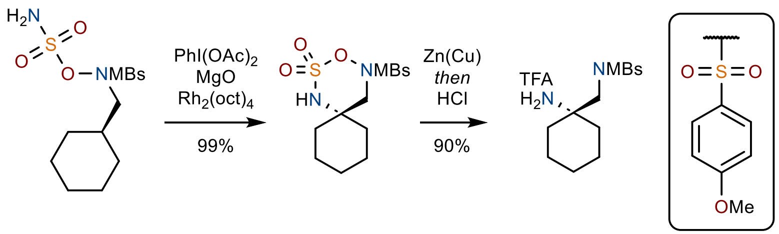


Du Bois. A. J. *Angew. Chem. Int. Ed.* **2001**, *40, 598.*
https://doi.org/10.1002/1521-3773(20010202)40:3%3C598::AID-ANIE598%3E3.0.CO;2-9

Hypervalent Iodine Chemistry

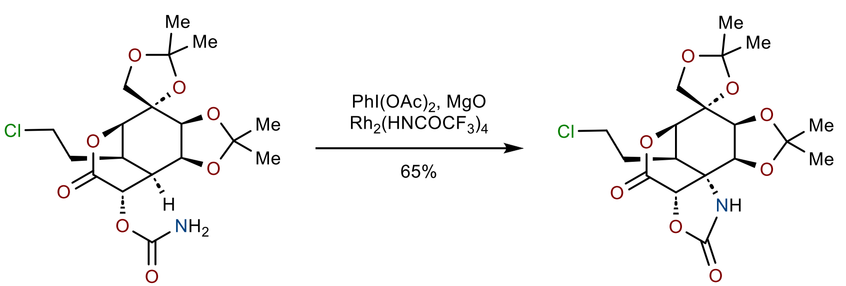


Du Bois. J. *J. Am. Chem. Soc.* **2001**, *28, 6935*.
https://doi.org/10.1021/ja011033x



Du Bois. J. *J. Am. Chem. Soc.* **2008**, *130, 11248*.
https://doi.org/10.1021/ja803344v

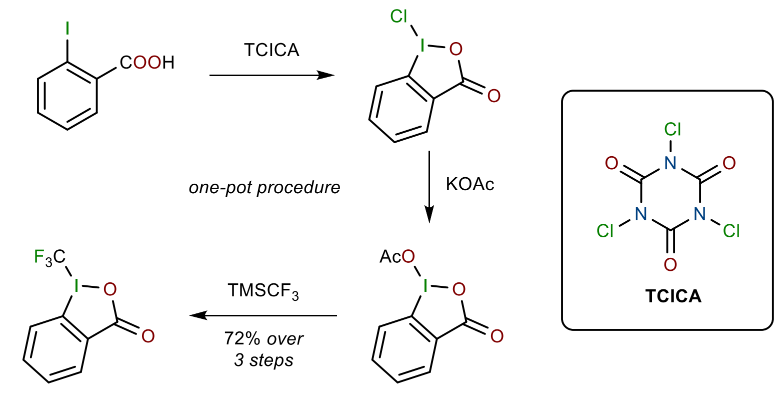
- Example of nitrene insertion in total synthesis



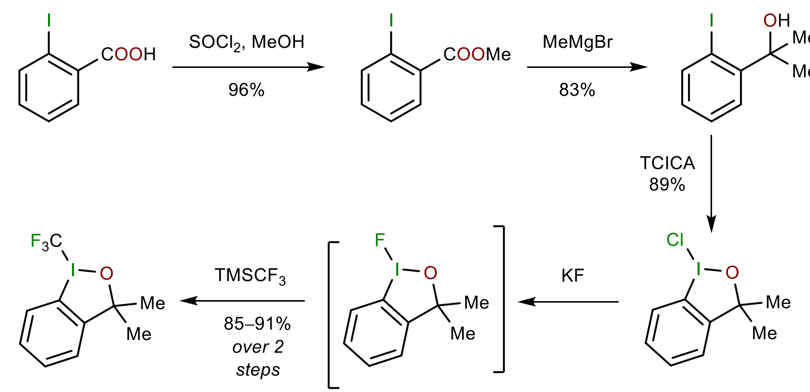
Du Bois. J. *J. Am. Chem. Soc.* **2003**, *125, 11510*.
https://doi.org/10.1021/ja0368305

Hypervalent iodine for electrophilic trifluoromethylation

- Synthesis of Togni's reagents



Togni's reagent I



Togni's reagent II

Togni A. *J. Org. Chem.* **2013**, *78*, 6763.
https://doi.org/10.1021/jo400774u

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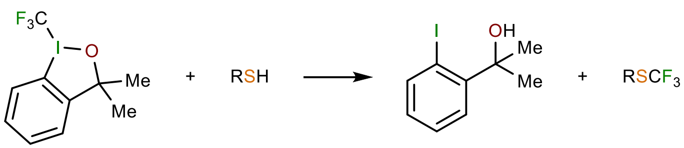
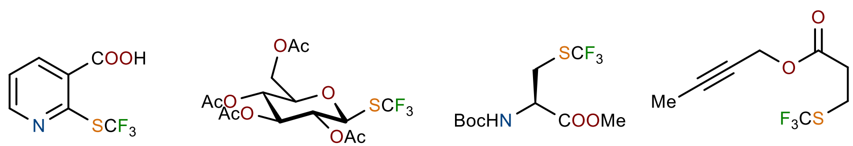
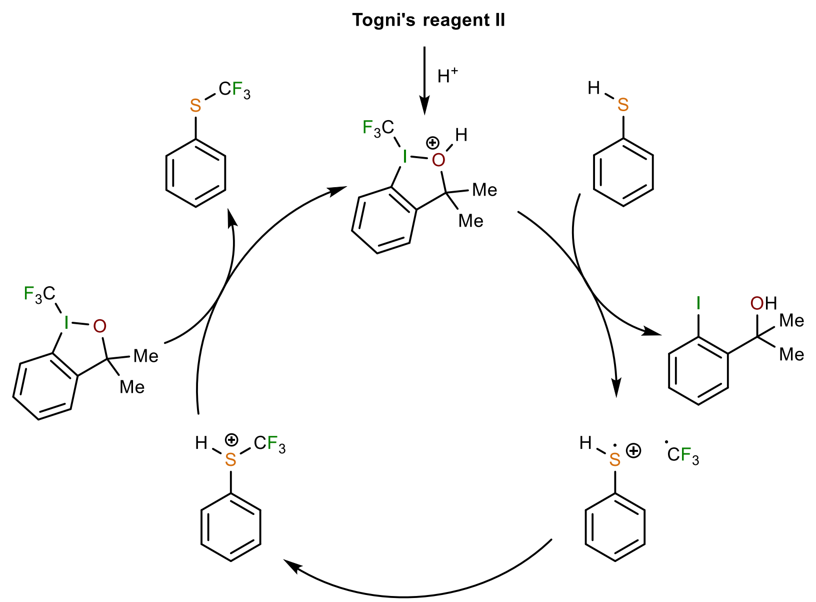
Trifluoromethylation of thiols and 1,3-dicarbonyls

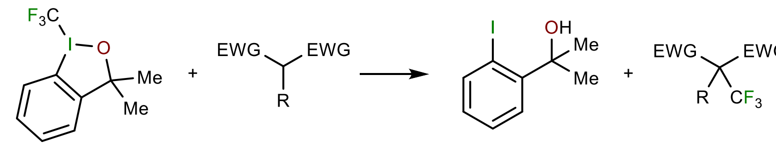


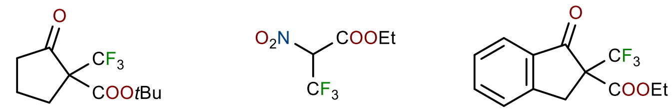


95% 90% 82% 53%

- Proposed mechanism for thiol trifluoromethylation

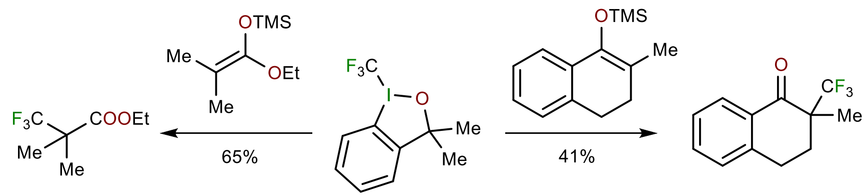




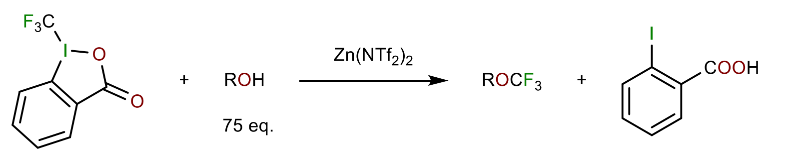


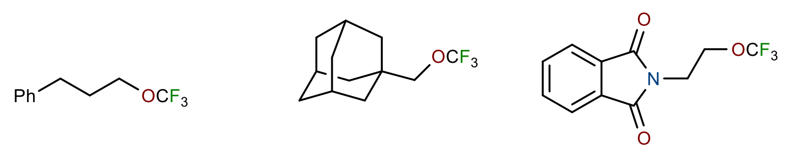
46% 89% 67%

Togni A. *Angew. Chem. Int. Ed.* **2007**, *46*, 754.
https://doi.org/10.1002/anie.200603497



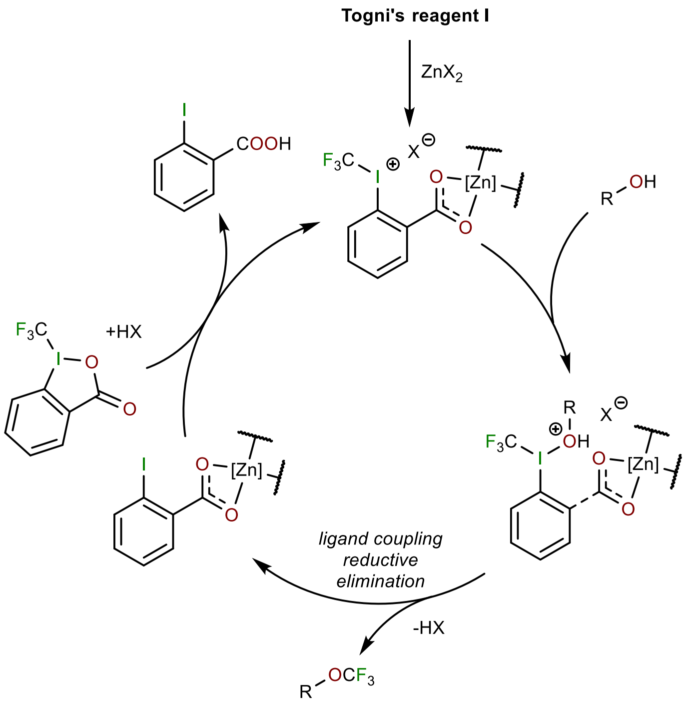
Togni A. *Chimia.* **2008**, *62*, 260.
https://doi.org/10.2533/chimia.2008.260





99% 55% 27%

- Proposed mechanism for alcohol trifluoromethylation



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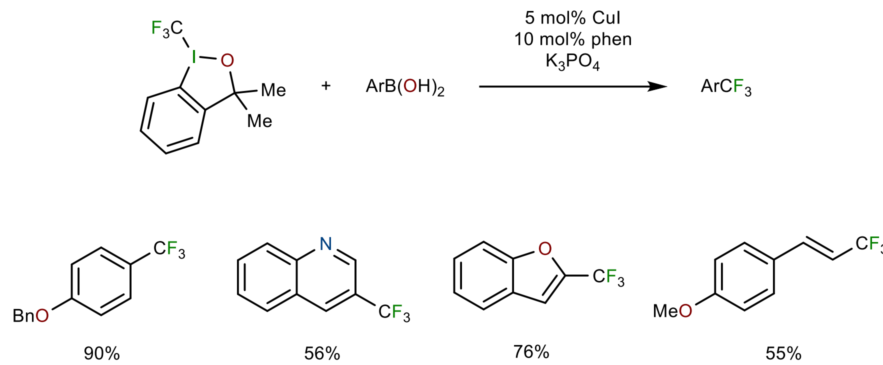

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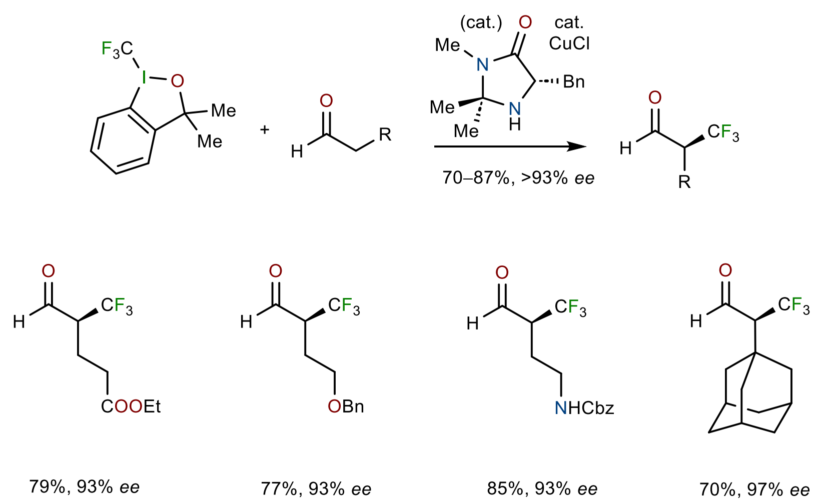

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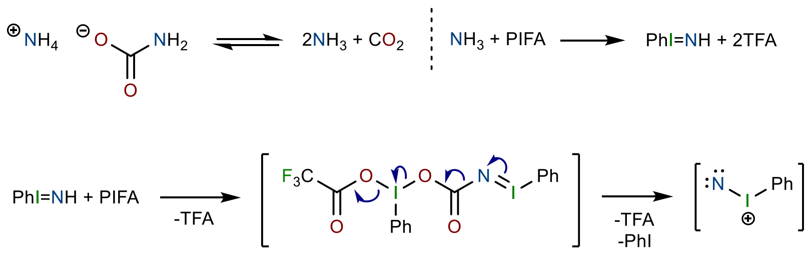
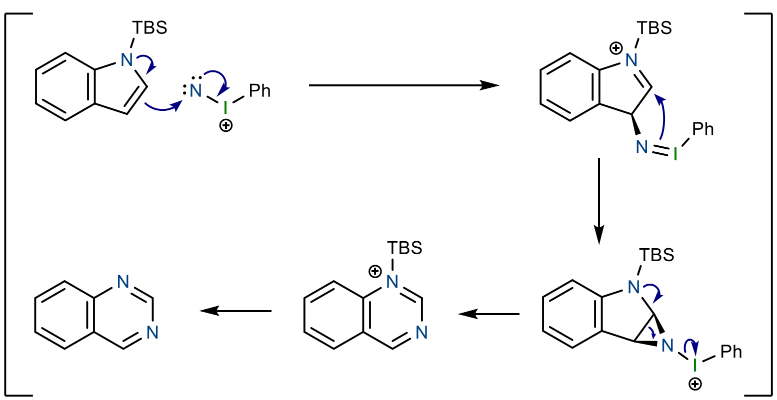
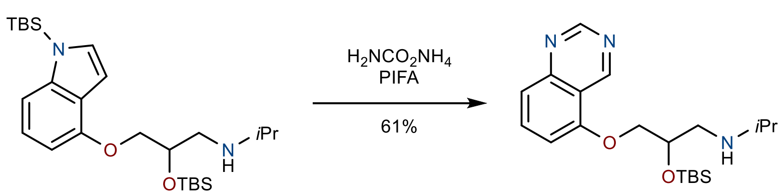
Hypervalent Iodine Chemistry







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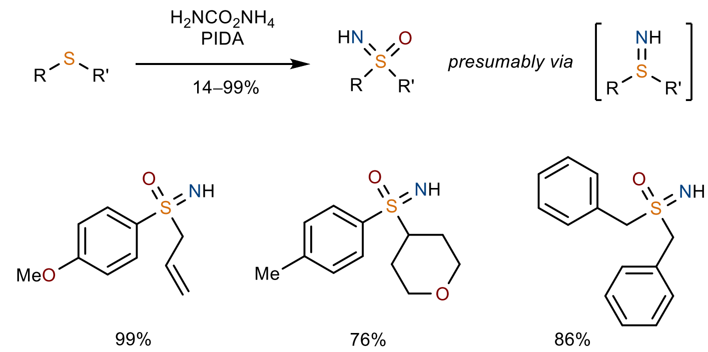
- Synthesis of NH-sulfoximines



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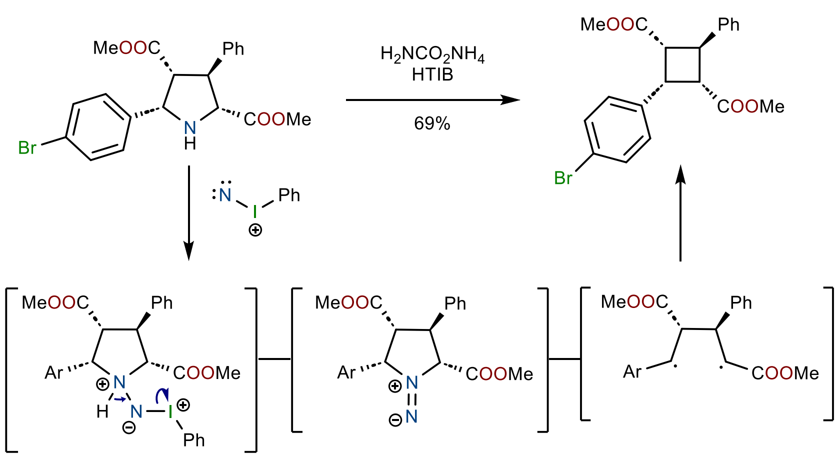

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