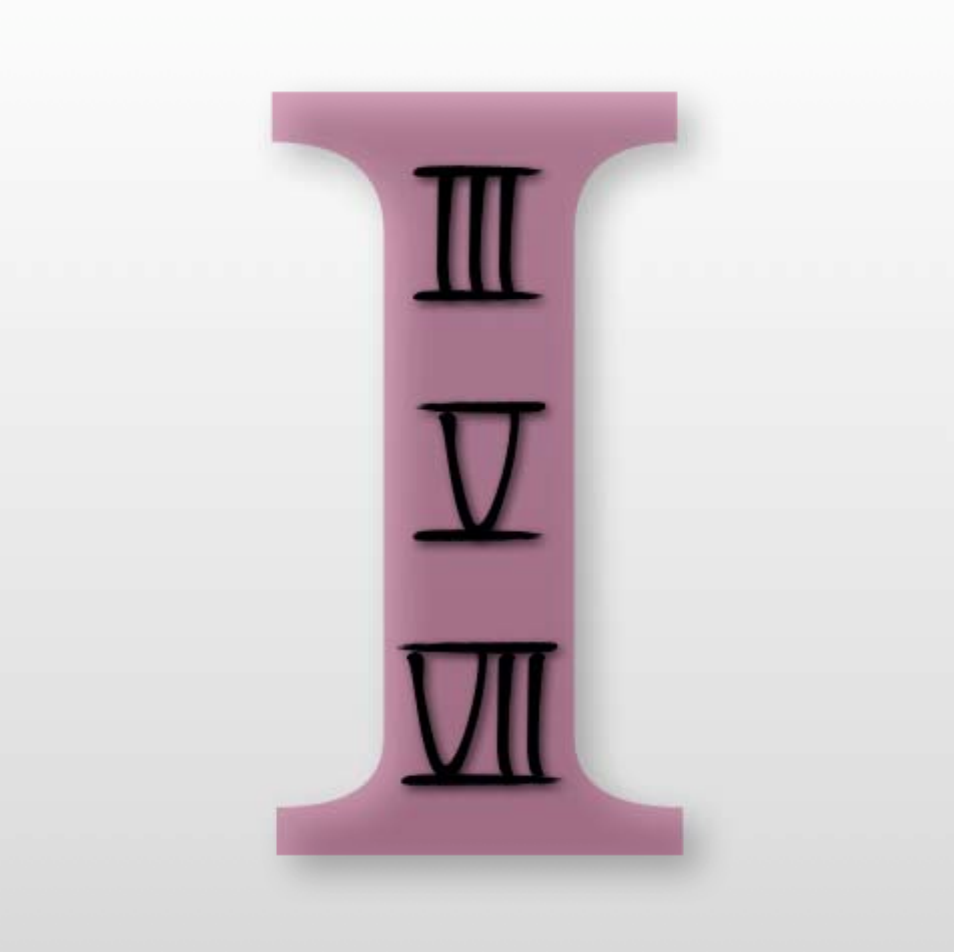
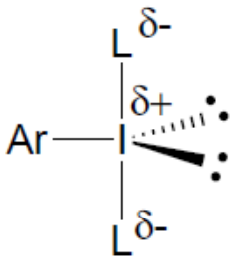
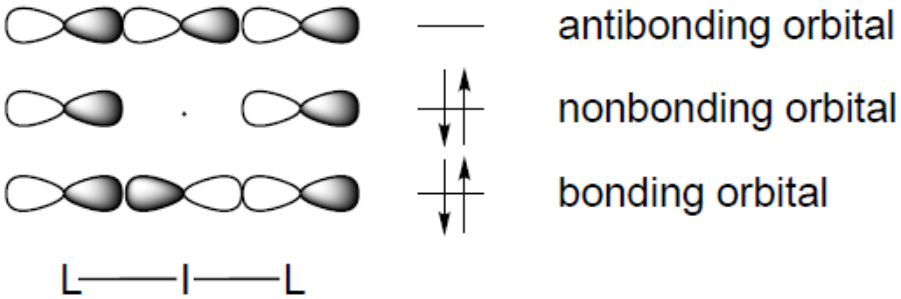
Hypervalent Iodine(III): Property and Reactivity

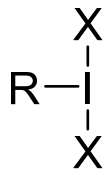


Penghao Chen
Dong Group Seminar
October, 21st, 2015

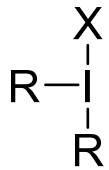
Structure and Nomenclature





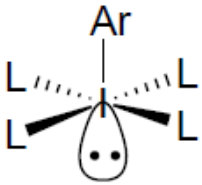


Oxidative Process



R group transfer

Aryl- λ³-iodanes:
L-I-L : hypervalent bond with a pure 5p orbital
Ar-I : typical bond with sp² hybridized orbital

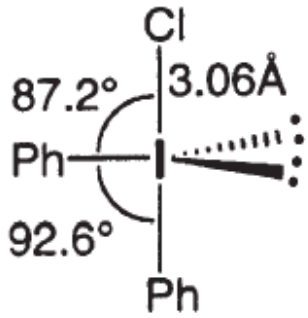


Aryl- λ⁵-iodanes
L-I-L : hypervalent bond with two pure 5 p orbitals
Ar-I : typical bond with sp hybridized orbital

Iodanes with oxidation state of IV or higher generally undergoes oxidative processes

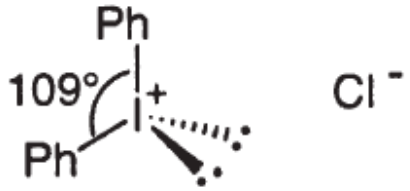
Ochiai, *Top. Curr. Chem.* **2002**, *224*, 1.

Structure and Nomenclature



1 10-I-3
chloro(diphenyl)-λ^3-iodane

[N-X-L]



2 8-I-2
diphenyliodonium chloride

N: valence electron. X: central atom. L: ligand
λ^N: nonstandard bonding number

Ochiai, *Top. Curr. Chem.* **2002**, *224*, 1.

General Reactivity Property

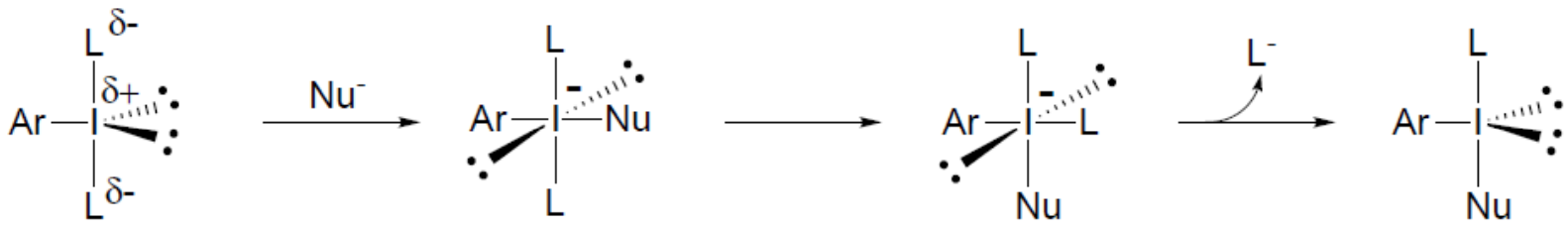
Ligand Exchange

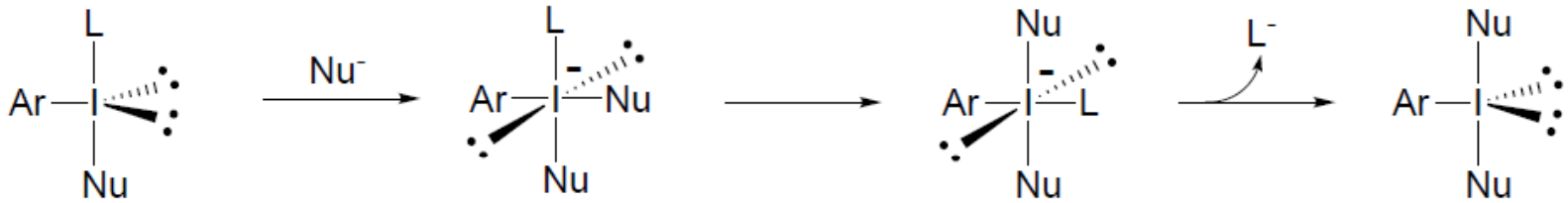
associative pathway

$$ArIL_2 \xrightarrow{Nu^-} [ArIL_2Nu]^- \longrightarrow ArILNu + L^-$$

dissociative pathway

$$ArIL_2 \longrightarrow ArI^+L + L^- \xrightarrow{Nu^-} ArILNu$$

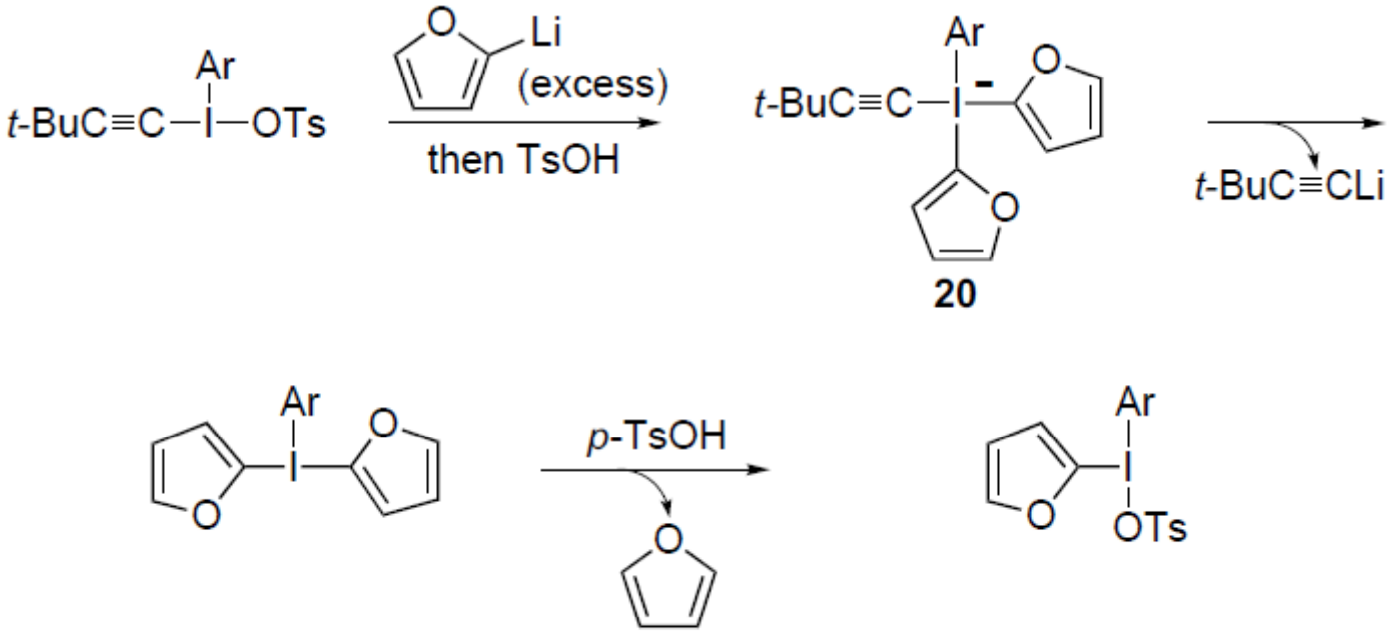




Ochiai, *Top. Curr. Chem.* **2002**, *224*, 1.

General Reactivity Property

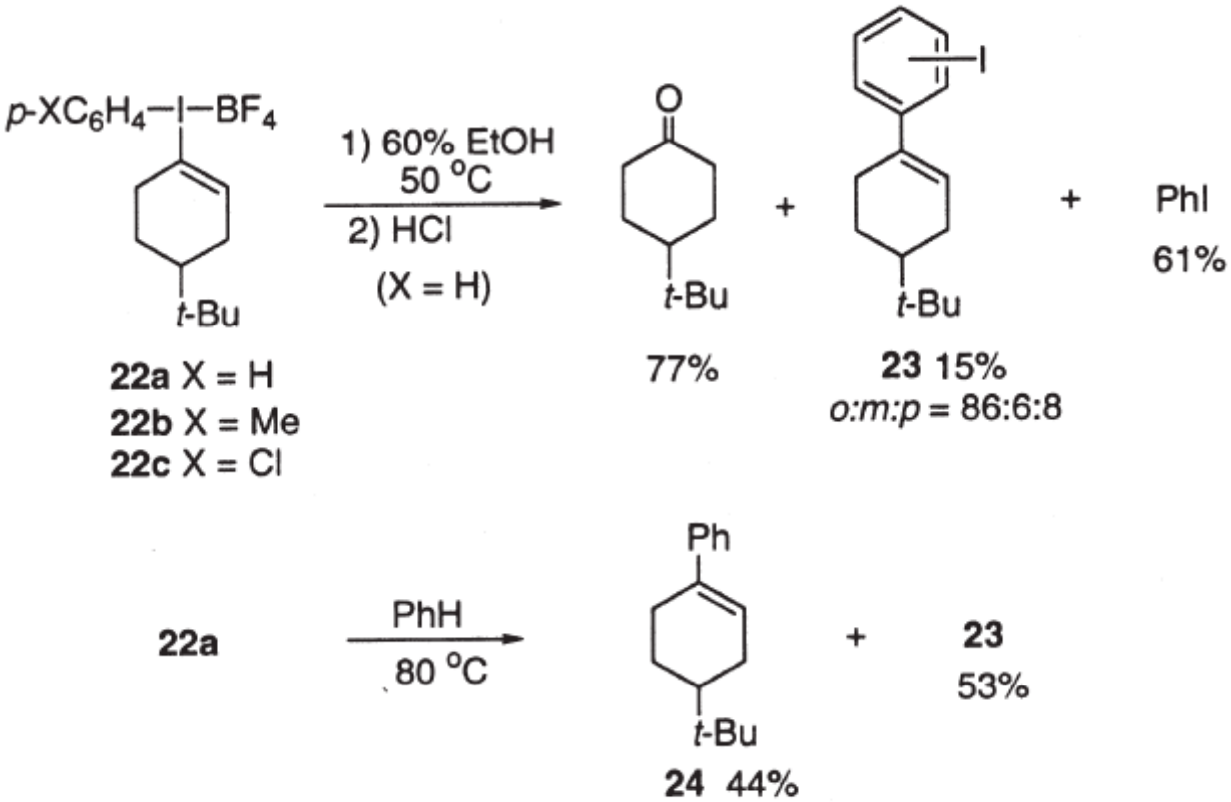
Ligand Exchange



Ochiai, *Top. Curr. Chem.* **2002**, *224*, 1.

General Reactivity Property

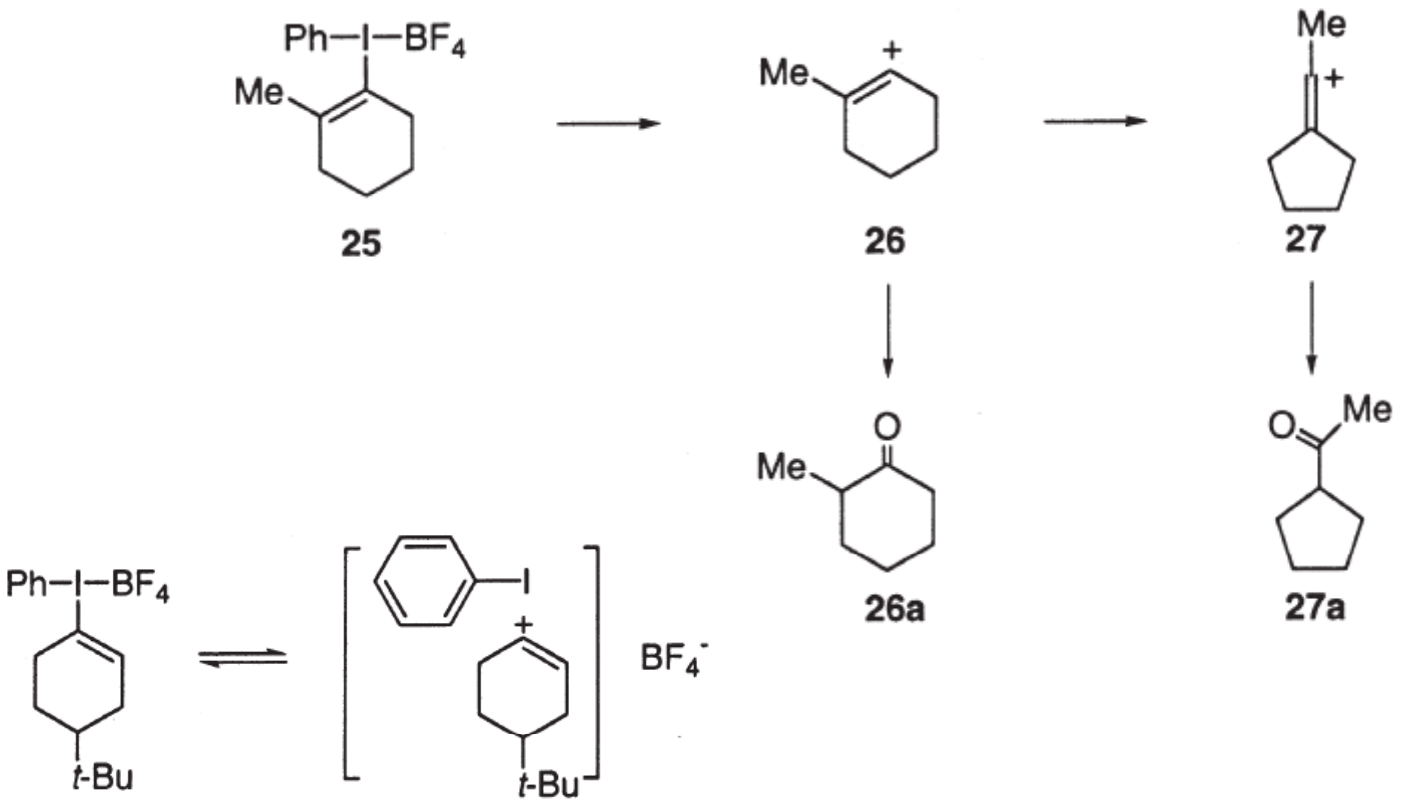
Hypernucleofuge: Reductive Elimination



Okuyama and Ochiai, *J. Am. Chem. Soc.* **1995**, *117*, 3360.
Ochiai and Nagao, *J. Chem. Soc., Chem. Commun.* **1986**, 1382.

General Reactivity Property

Hypernucleofuge: Reductive Elimination



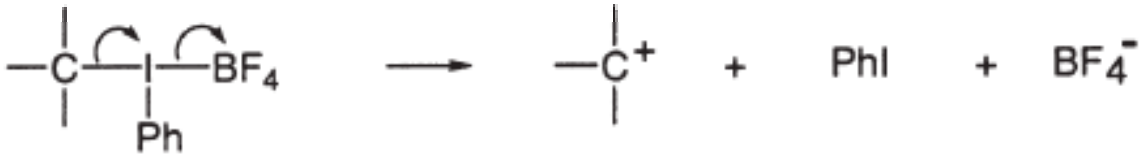
Okuyama and Ochiai, *J. Am. Chem. Soc.* **1995**, *117*, 3360.
Ochiai and Nagao, *J. Chem. Soc., Chem. Commun.* **1986**, 1382.

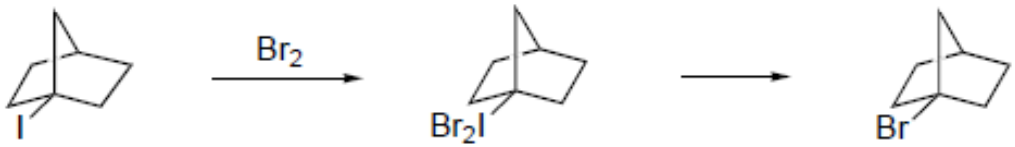
General Reactivity Property

Hypernucleofuge: Reductive Elimination

Relative leaving group abilities

Nucleofuge	k_{rel}	Nucleofuge	k_{rel}
AcO	1.4×10^{-6}	I	9.1×10
F	9.0×10^{-6}	MsO	3.0×10^{4}
Me_2S^+	5.3×10^{-2}	TsO	3.7×10^{4}
Cl	1.0	TfO	1.4×10^{8}
F_3CCO_2	2.5	p-MePh(BF_4)I	6.2×10^{13}
NO_3	7.2	Ph(BF_4)I	1.2×10^{14}
Br	1.4×10	p-ClPh(BF_4)I	2.9×10^{14}

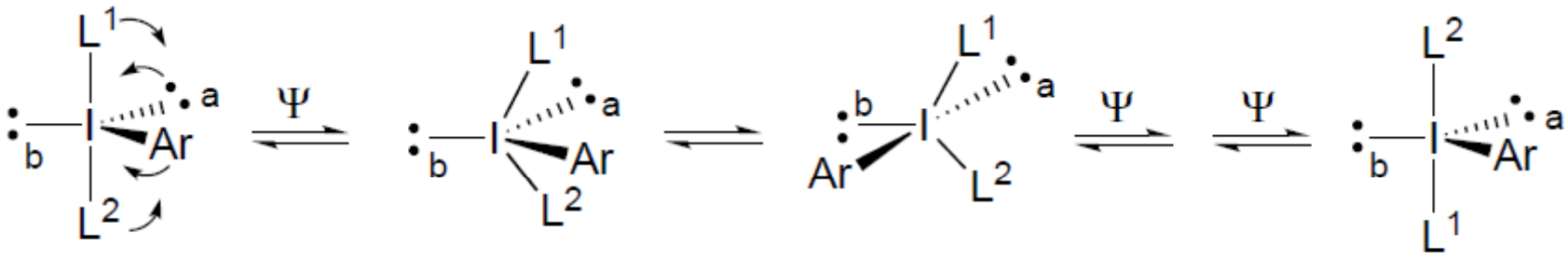


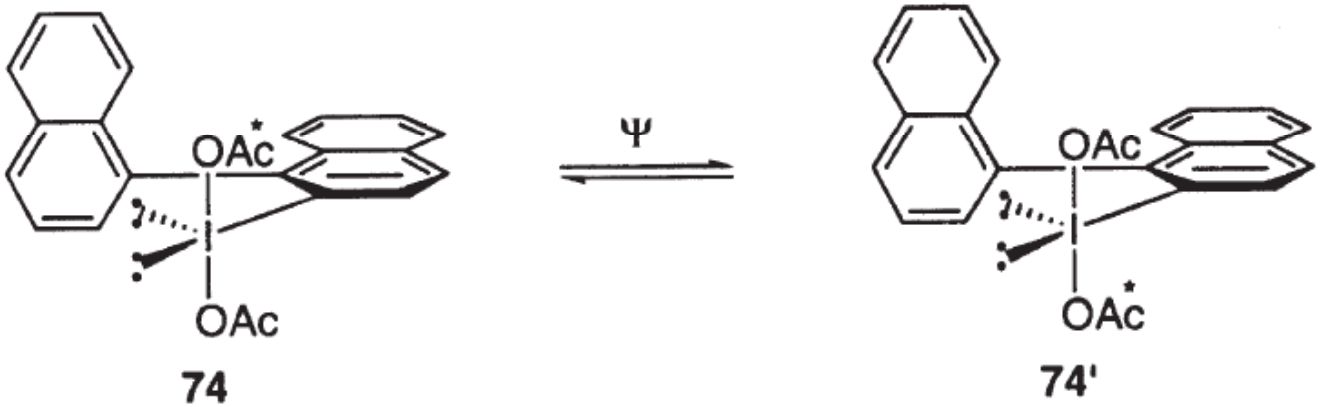


Okuyama and Ochiai, *J. Am. Chem. Soc.* **1995**, *117*, 3360.
Ochiai and Nagao, *J. Chem. Soc., Chem. Commun.* **1986**, 1382.
Wiberg, *J. Org. Chem.* **1982**, *47*, 2720.

General Reactivity Property

Pseudorotation of λ³-Iodane

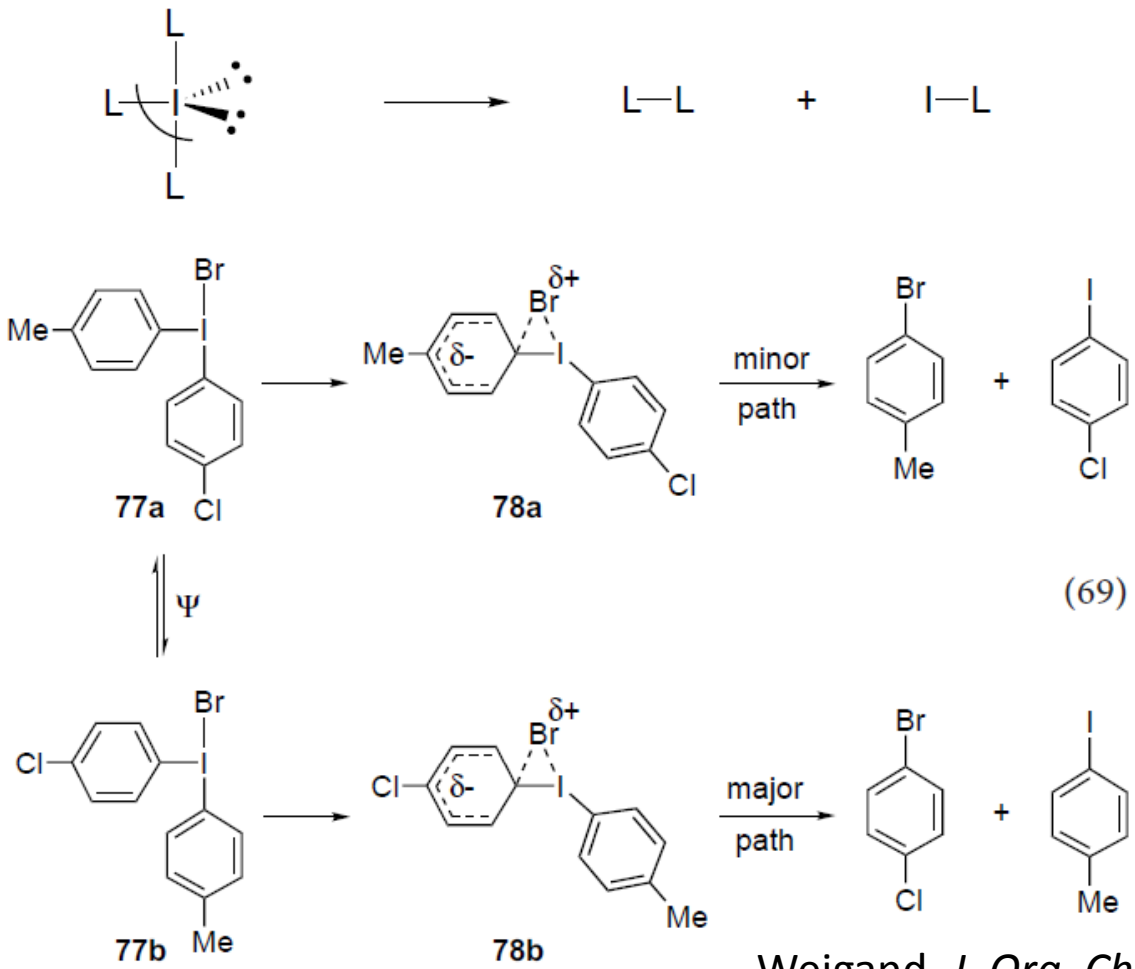




Berry, *J. Chem. Phys.* **1960**, *32*, 933.
Ochiai, *J. Am. Chem. Soc.* **1990**, *112*, 5677.

General Reactivity Property

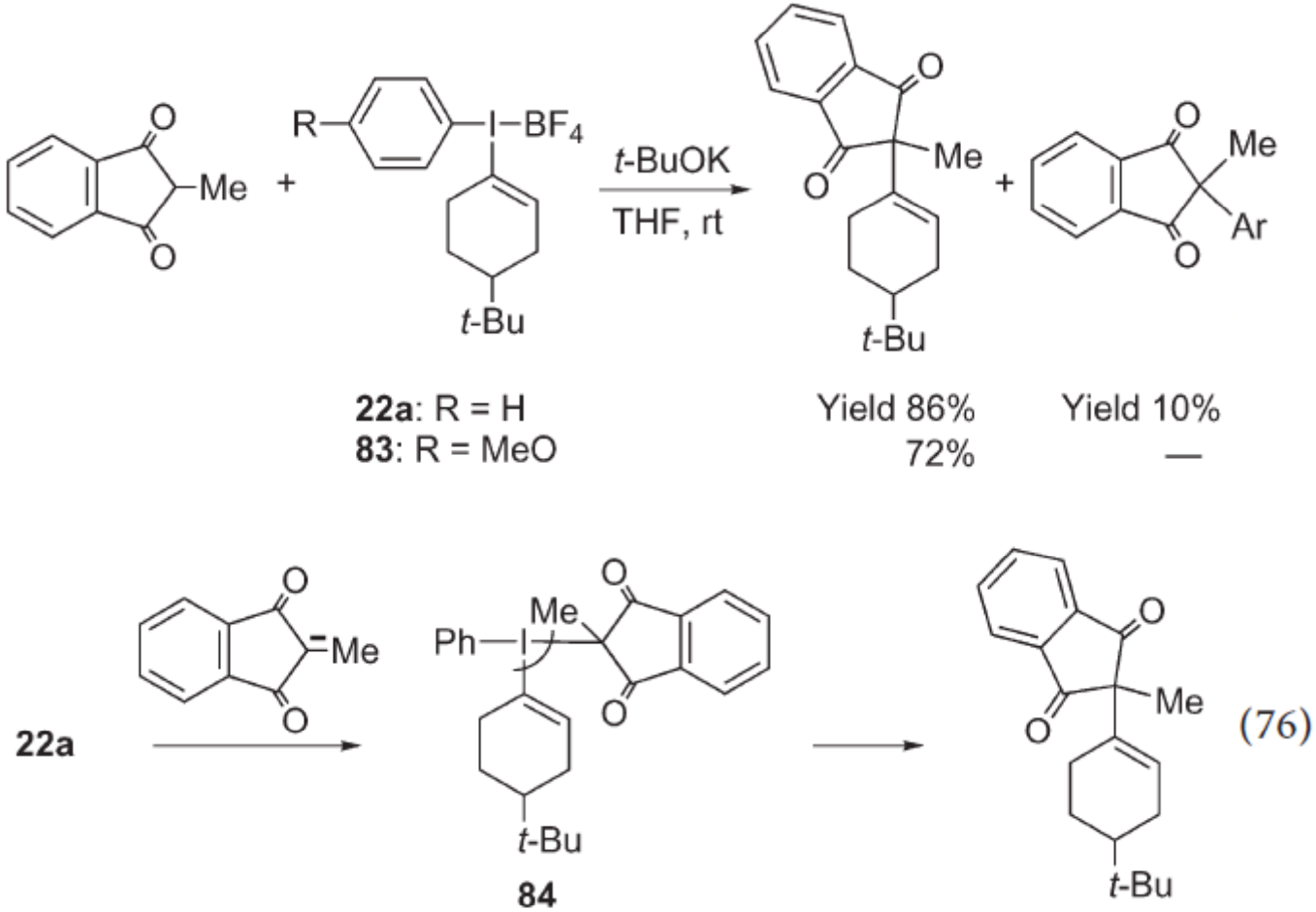
Ligand Coupling on Iodine (III)



Weigand, *J. Org. Chem.* **1976**, *41*, 3360.
Okawara, *Bull. Chem. Soc. Jpn.* **1974**, *47*, 3179.
Okawara, *Bull. Chem. Soc. Jpn.* **1972**, *45*, 1860.

General Reactivity Property

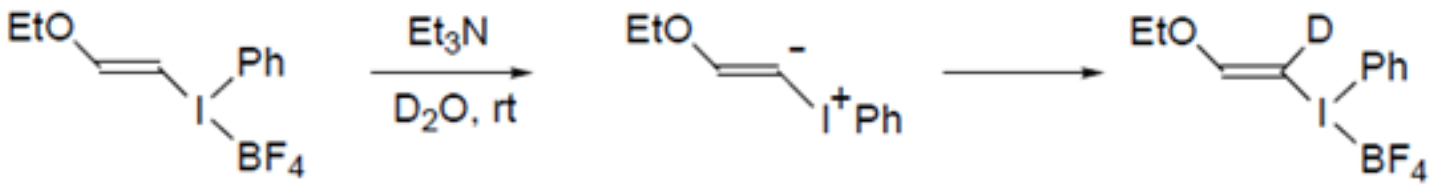
Ligand Coupling on Iodine (III)



Ochiai, *J. Org. Chem.* **1997**, *62*, 2130.

General Reactivity Property

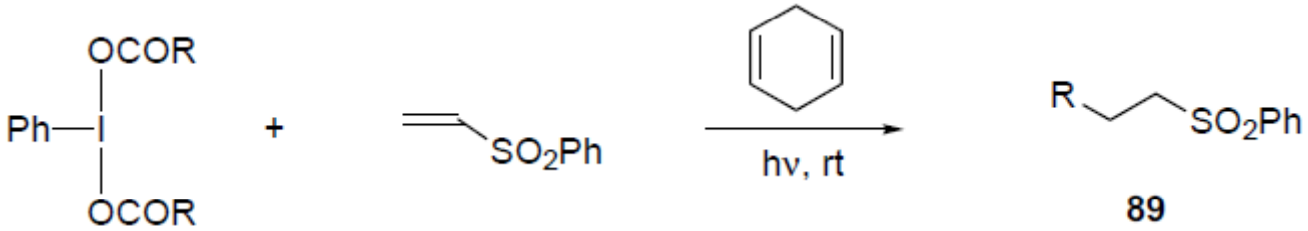
Electronic Nature



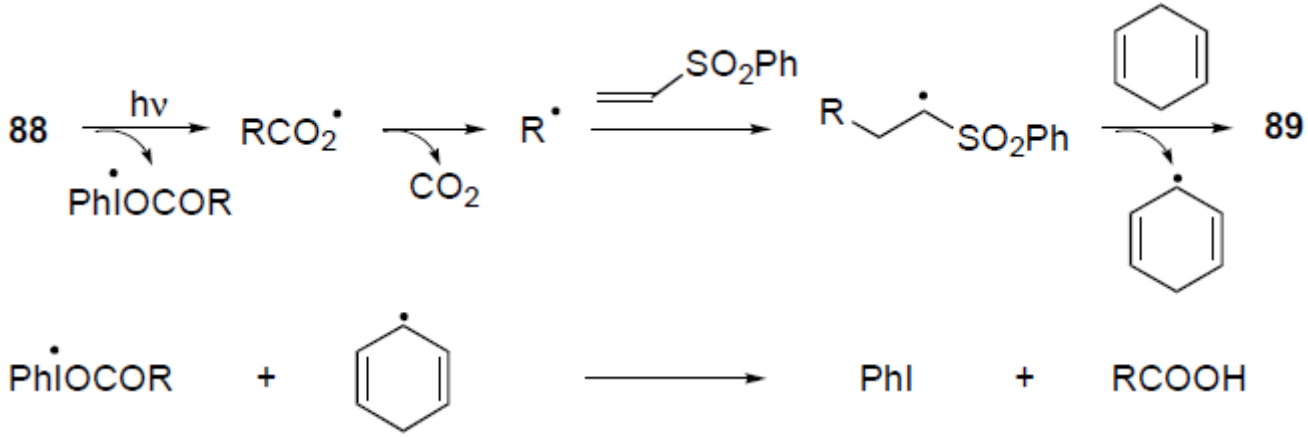
Ochiai and Nagao, *J. Chem. Soc., Chem. Commun.* **1988**, 1076.

General Reactivity Property

Homolytic Cleavage



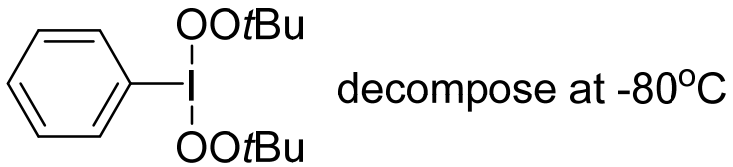
88 R = 1-adamantyl, *c*-C_6H_{11}, 2-phenethyl

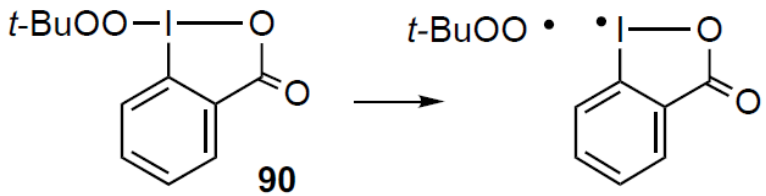


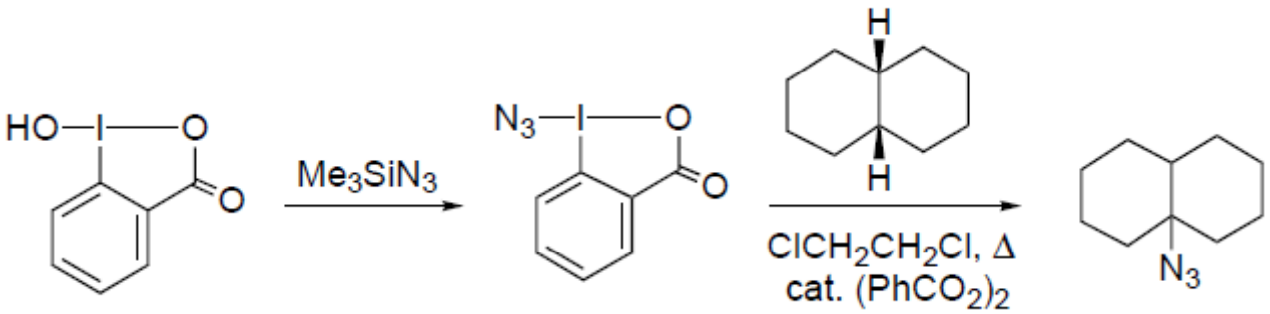
Togo, *Synlett.* **2001**, 565.
Zhdankin, *Rev. Heteroatom Chem.* **1997**, *17*, 213.

General Reactivity Property

Homolytic Cleavage



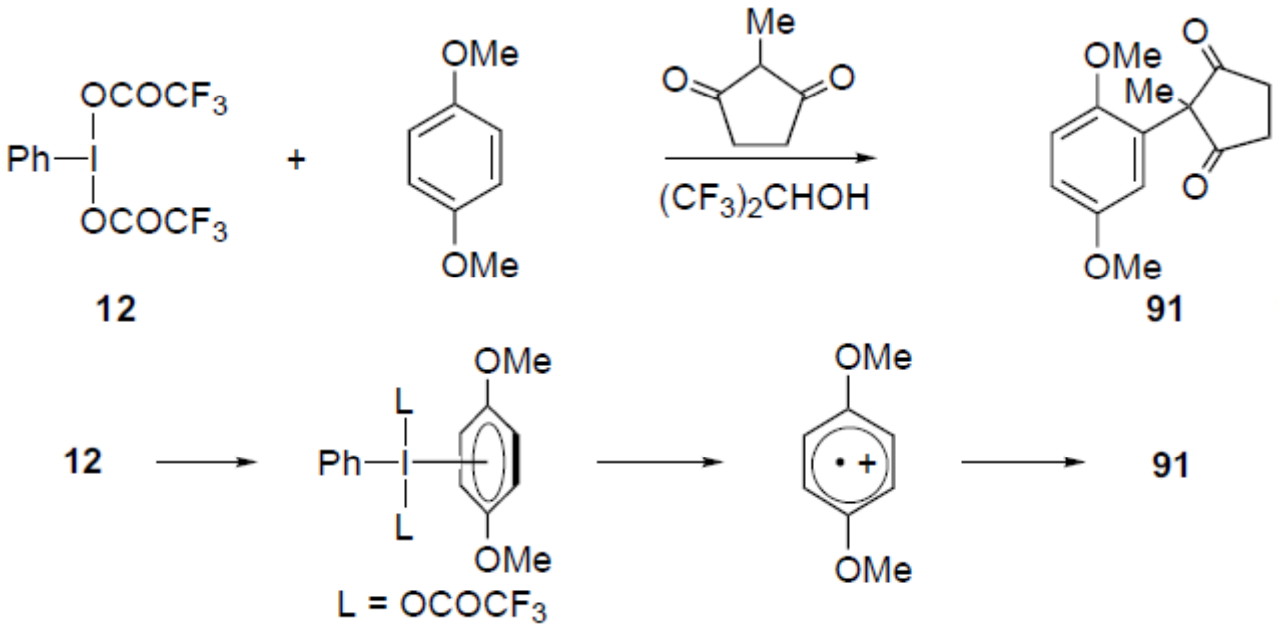




Plesnicar, *J. Am. Chem. Soc.* **1968**, *90*, 4450.
Ochiai, *J. Am. Chem. Soc.* **1992**, *114*, 6269.
Zhdankin, *J. Am. Chem. Soc.* **1996**, *118*, 5192.

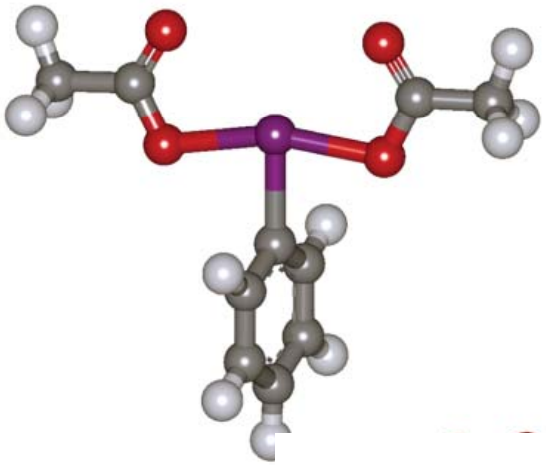
General Reactivity Property

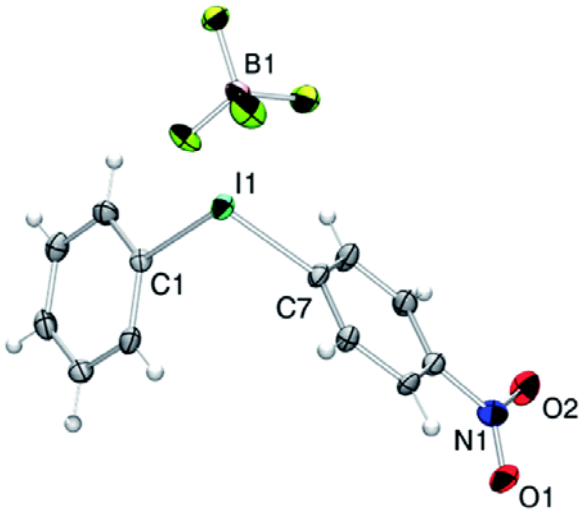
Single-Electron Transfer



Kita, *J. Am. Chem. Soc.* **1994**, *116*, 3684.
Kita, *Tetrahedron* **2001**, *57*, 345.

General Reactivity Property





Transformation-RIL$_2$

Oxidation to form Multiple Bonds

Reductive Elimination with Substitution

Reductive Elimination with Rearrangement

Activation of Multiple Bonds

Oxidative Dearomatization

Radical

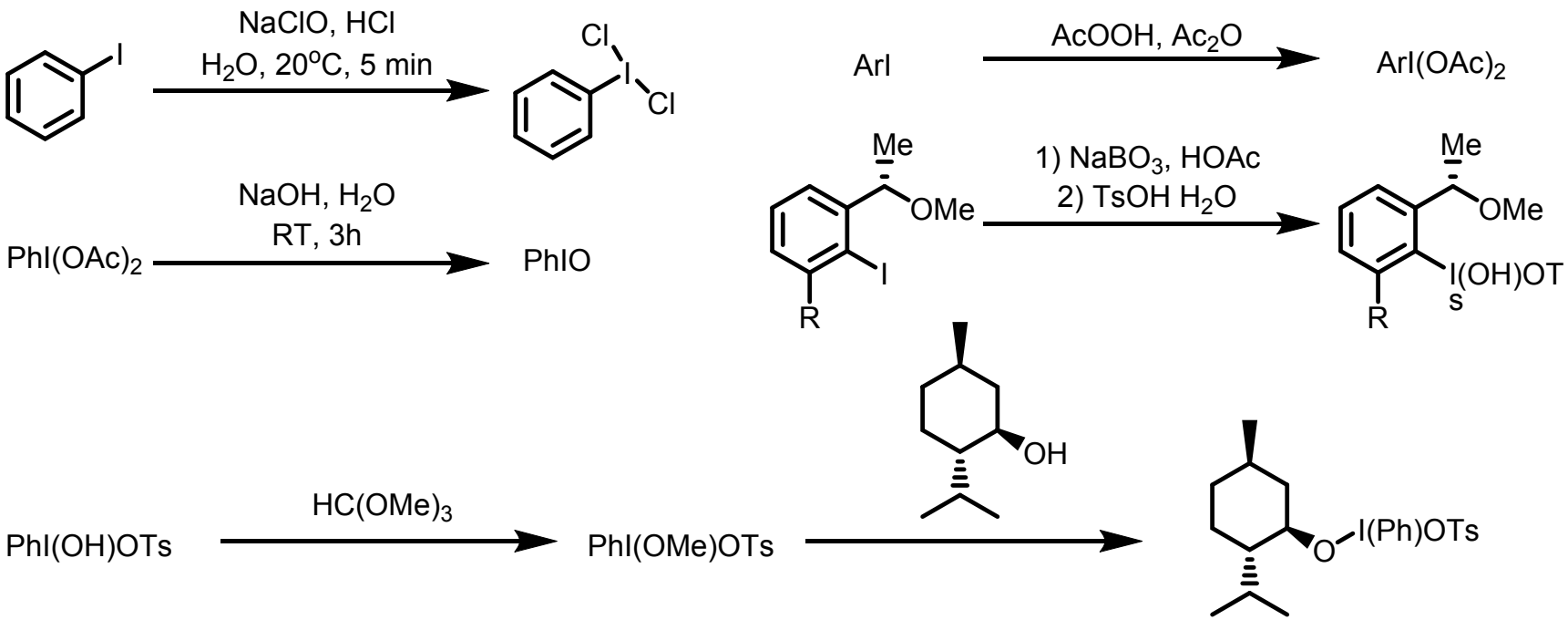
Transformation-R$_2$IL

Alkyl(aryl)-IL

Alkenyl(aryl)-IL

Alkynyl(aryl)-IL

Preparation-RIL_2



Zhang, *Synthesis*, **2009**, *14*, 2324.

Dauban and Fleurat-Lessard, *J. Org. Chem.*, **2015**, *80*, 1414.

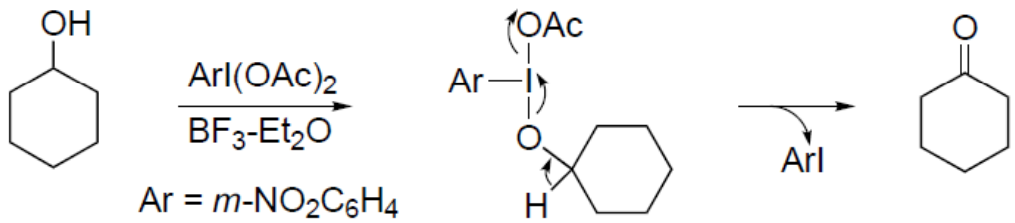
Saltzman, *Org. Synth. Coll.*, **1973**, *5*, 660.

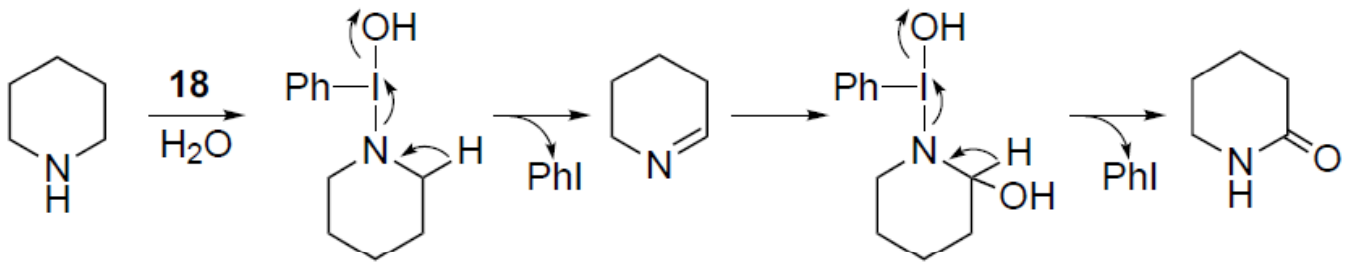
Wirth, *Eur. J. Org. Chem*. **2001**, 1569.

Koser, *J. Am. Chem. Soc.* **1990**, *112*, 5672.

Transformation-RIL_2

Oxidation to form Multiple Bonds

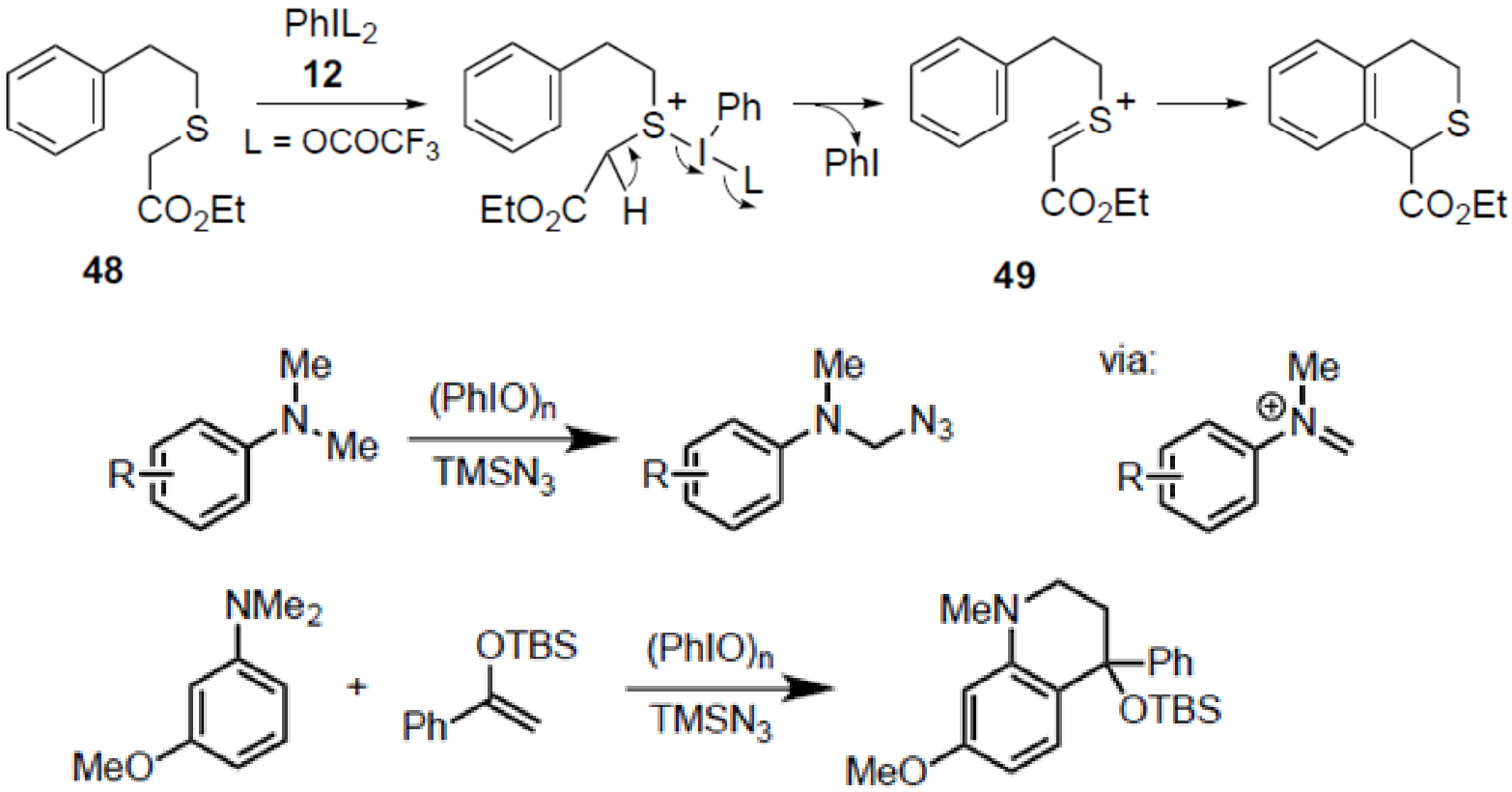




Kitamura, *Heterocyclic Commun.* **1998**, *4*, 205.
Nagao, *Tetrahedron Lett.* **1988**, *29*, 6913.

Transformation-RIL_2

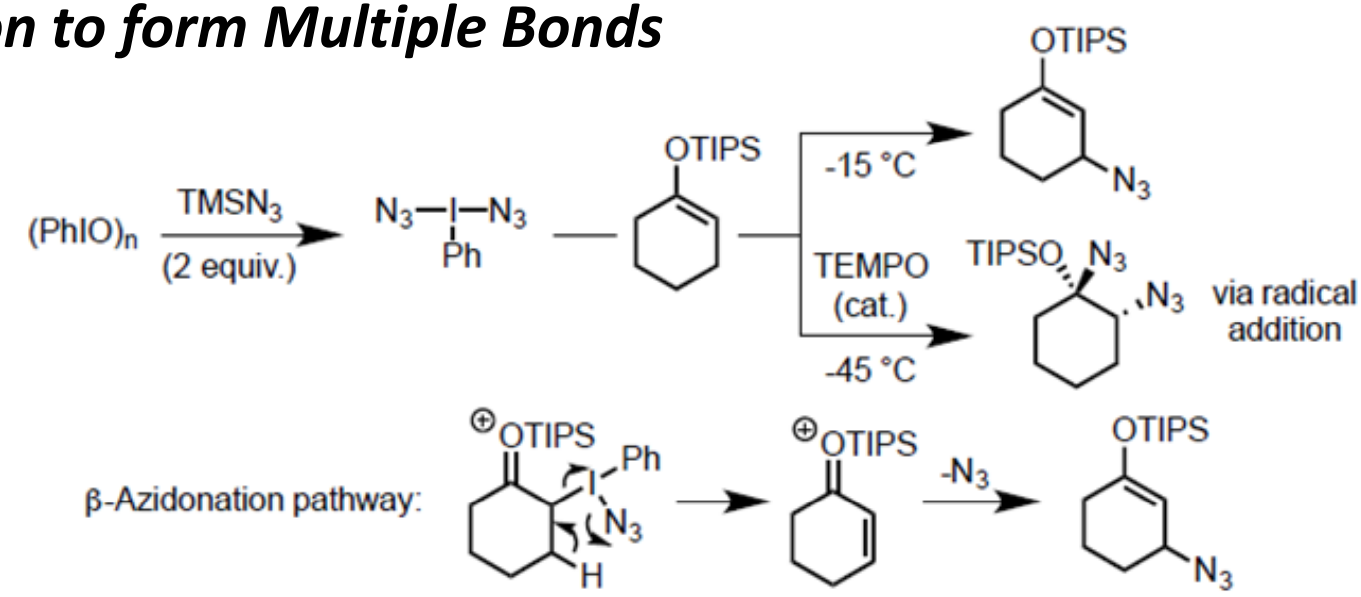
Oxidation to form Multiple Bonds

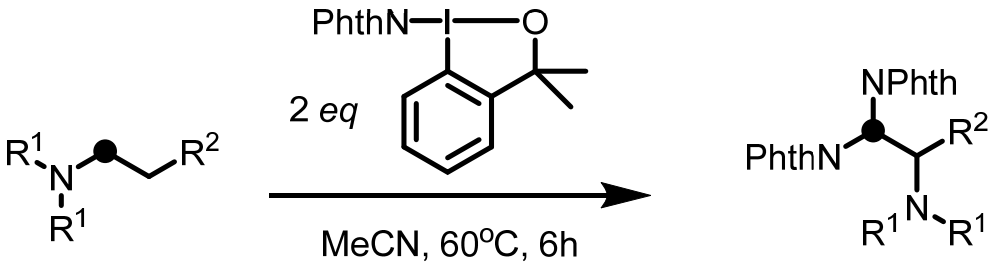


Kita, *J. Chem. Soc., Chem. Commun.* **1998**, 173.
Magnus, *Synthesis.* **1998**, 547.

Transformation-RIL$_2$

Oxidation to form Multiple Bonds



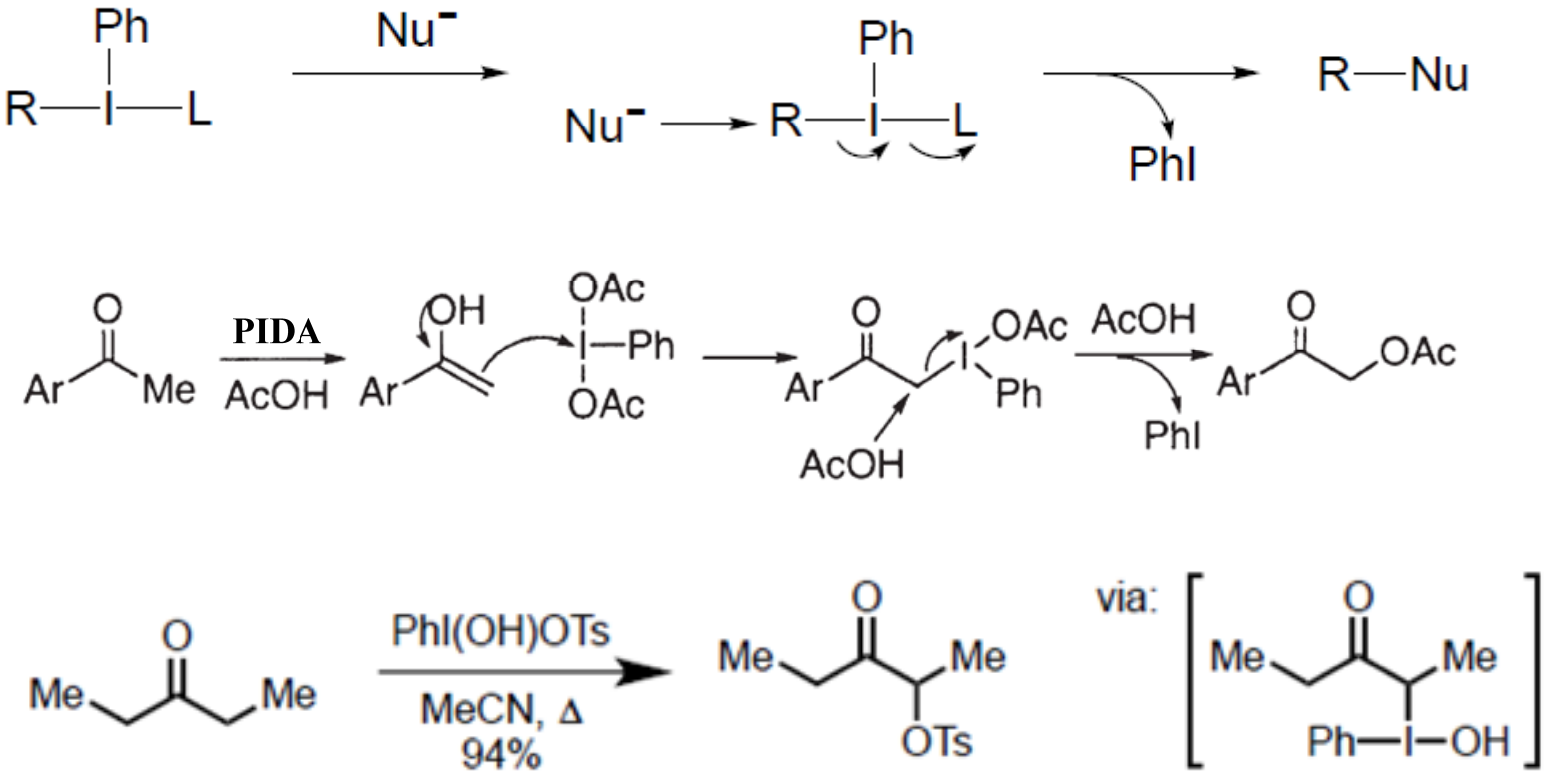


20 - 71%

Magnus, *J. Am. Chem. Soc.* **1992**, *114*, 767.
Kiyokawa and Minakata, *Angew. Chem. Int. Ed.* **2015**, *54*, ASAP.

Transformation-RIL_2

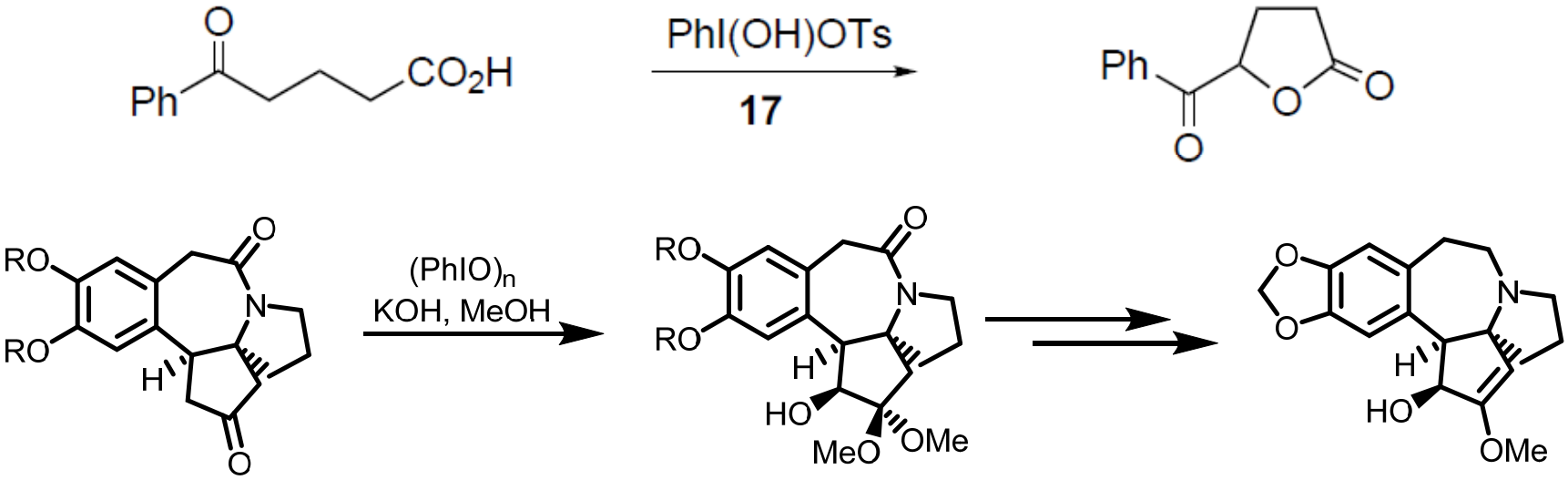
Reductive Elimination with Substitution



Imamura, *Bull. Chem. Soc. Jpn.* **1978**, *51*, 335.
Koser, *J. Org. Chem.* **1982**, *47*, 2487.

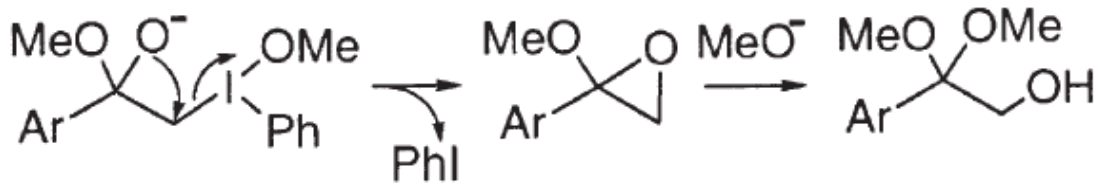
Transformation-RIL_2

Reductive Elimination with Substitution



80% R = Me
79% R = $-CH_2CH_2-$

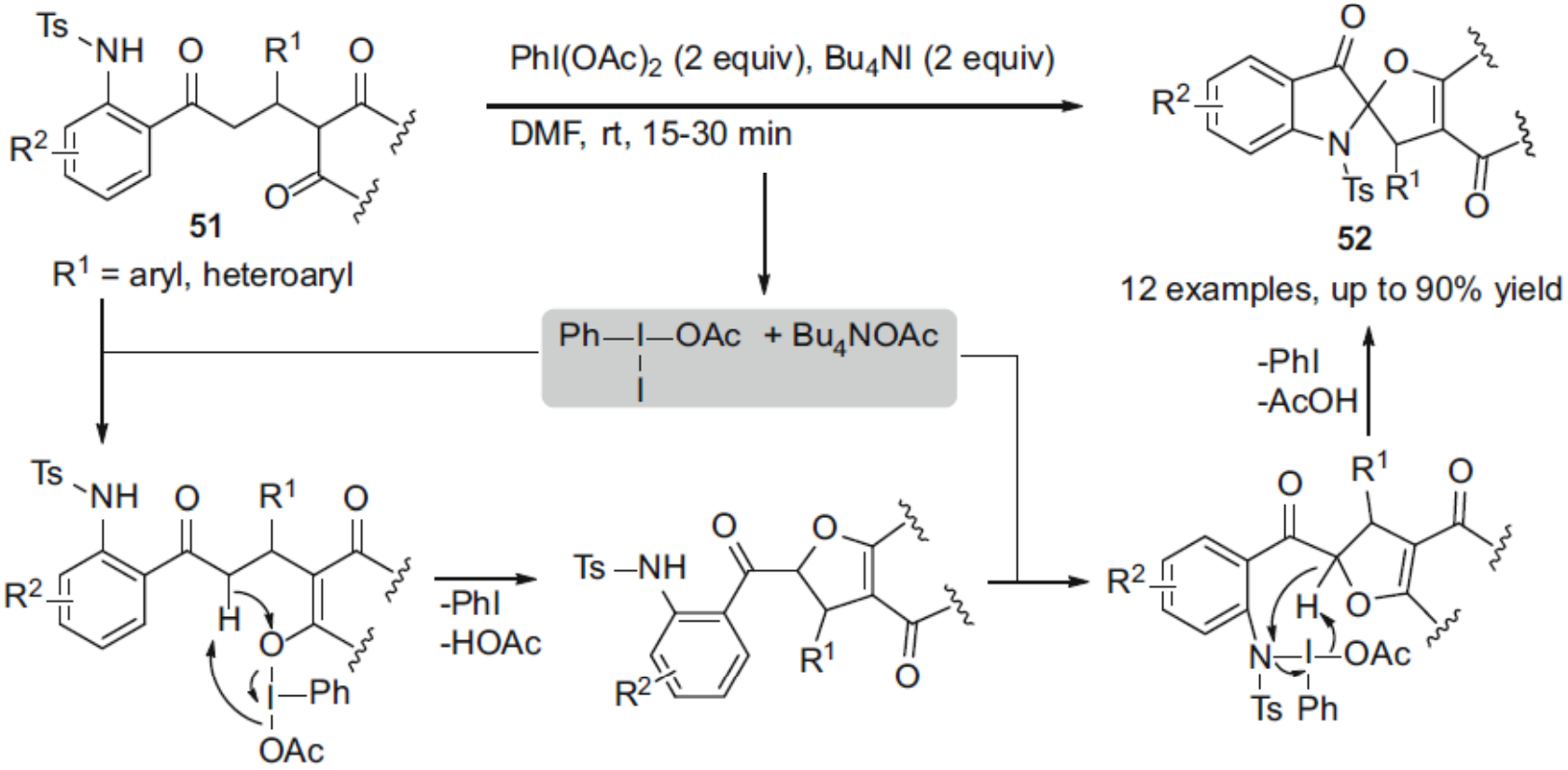
(+/-)-cephalotaxine



Moriarty, *Tetrahedron Lett.* **1990**, *31*, 201.
Hanaoka, *Tetrahedron Lett.* **1986**, *27*, 2023.

Transformation-RIL$_2$

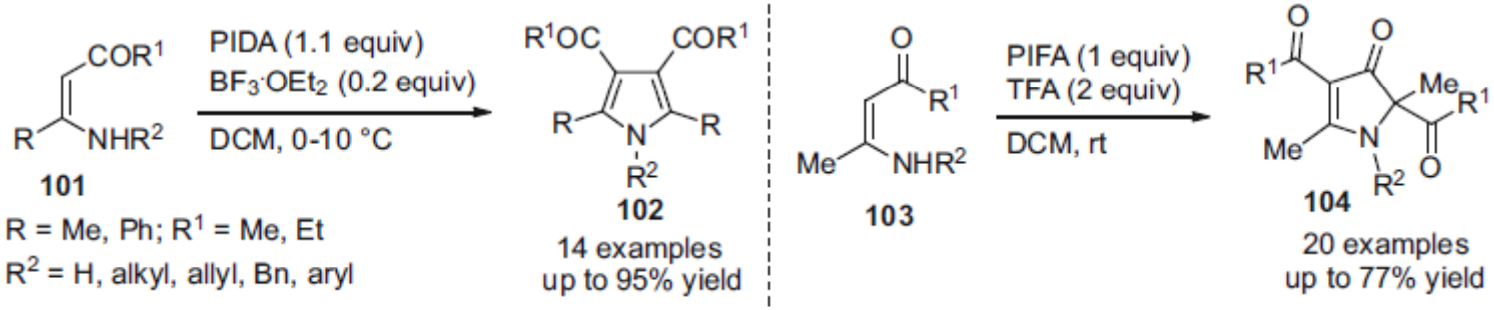
Reductive Elimination with Substitution

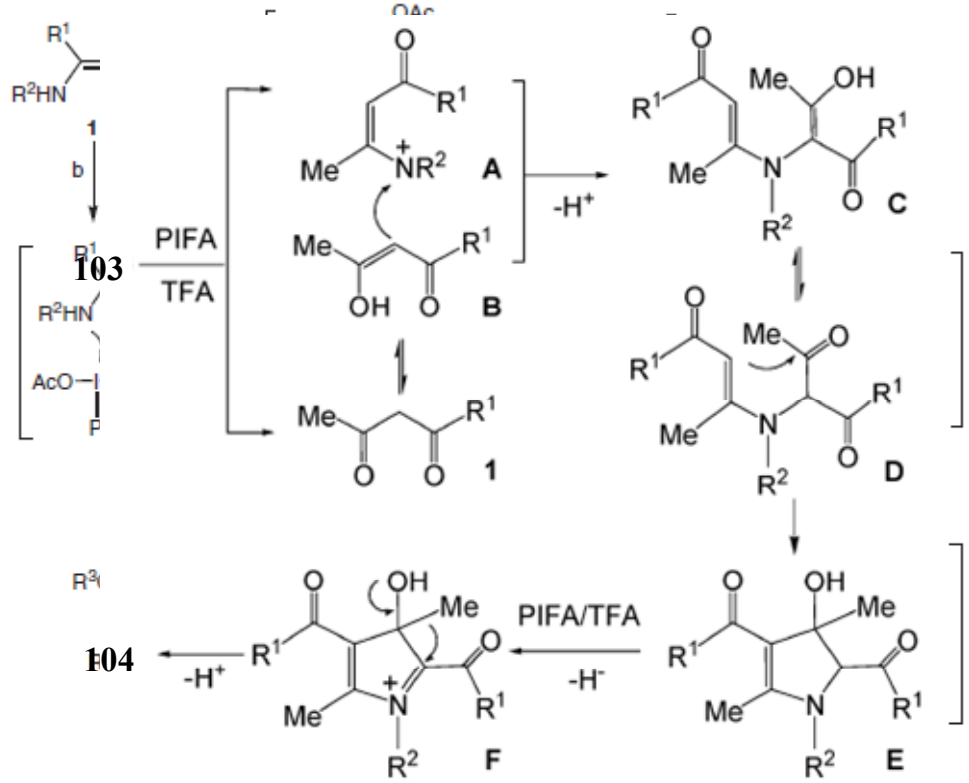


Taschner and Koser, *Tetrahedron Lett.* **1986**, *27*, 4557.

Transformation-RIL$_2$

Reductive Elimination with Substitution

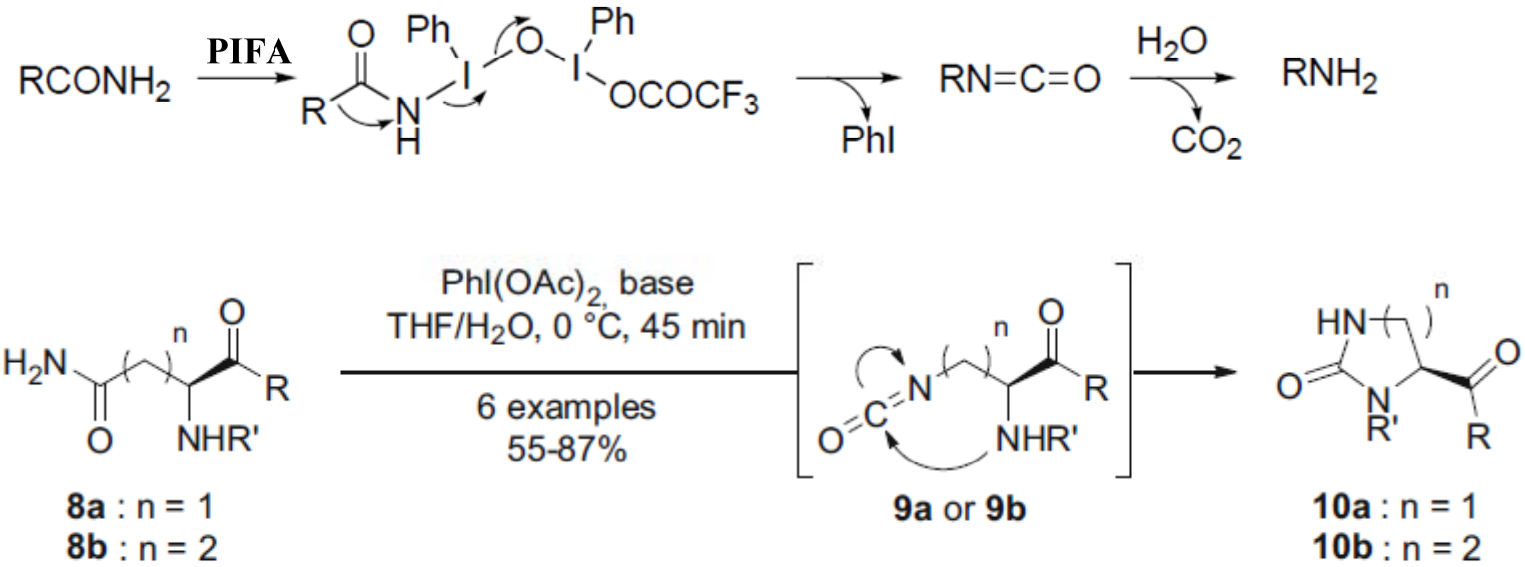




Wang, *Synlett*, **2009**, 2529.
Dong, *Org. Lett.* **2007**, *9*, 5345.

Transformation-RIL$_2$

Reductive Elimination with Rearrangement

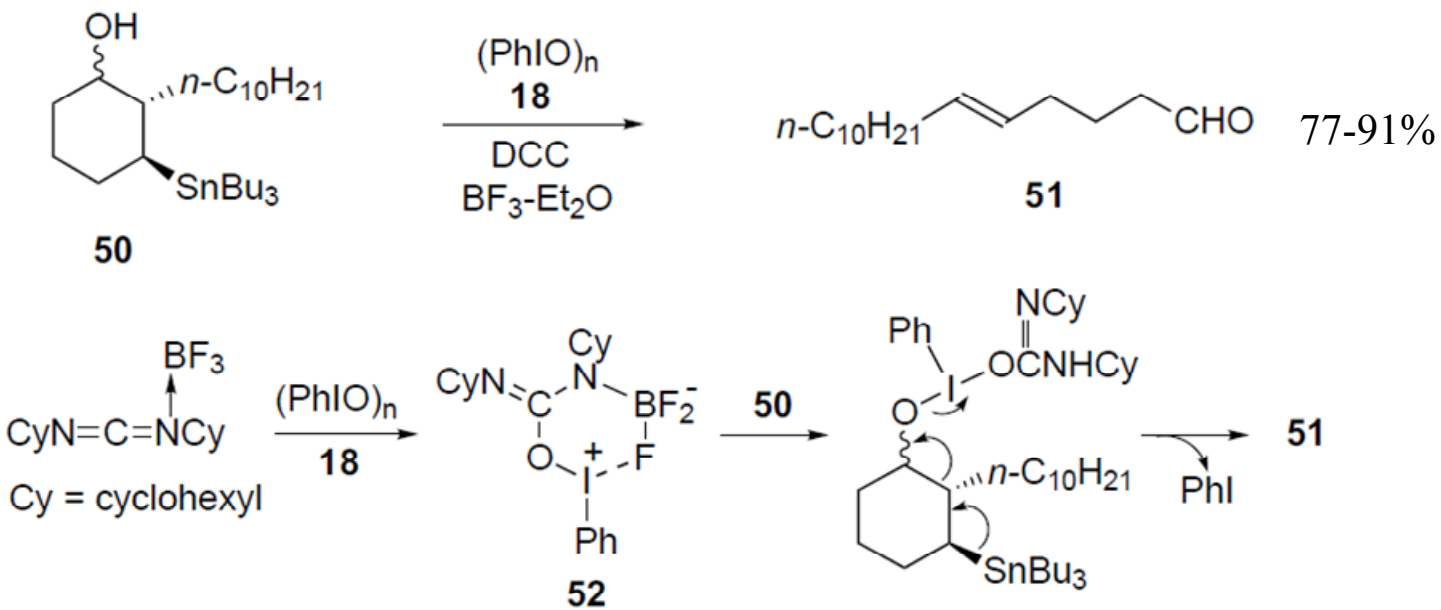


Base = DBU, DIEA
R = OMe, OBn, L-Ala-OBn
R' = Cbz, Boc, Ac

Loudon, *J. Org. Chem.* **1984**, *49*, 4277.
Tomasini, *Org. Biomol. Chem.* **2008**, *6*, 1849.

Transformation-RIL_2

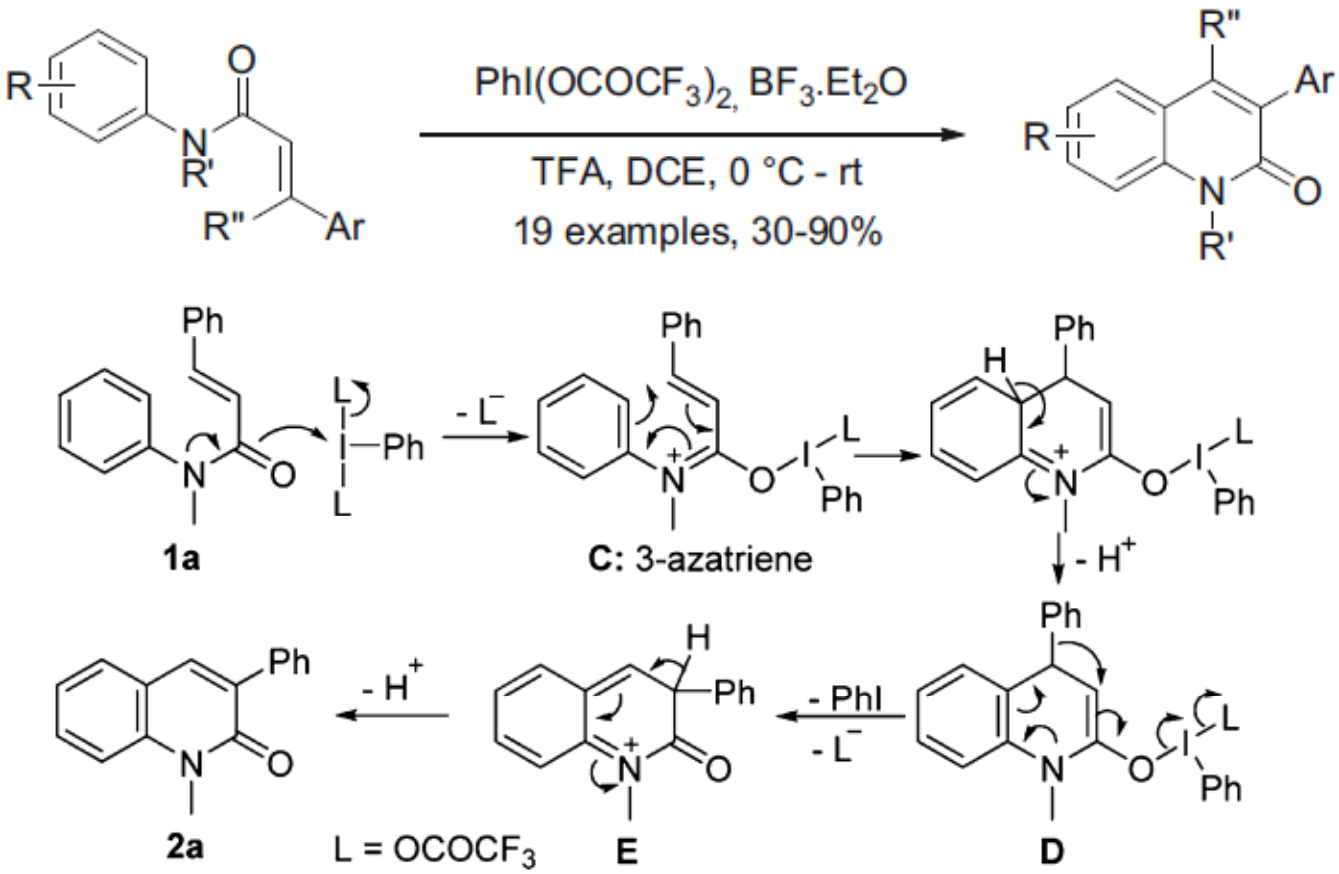
Reductive Elimination with Rearrangement



Ochiai and Fujita, *J. Org. Chem.* **1989**, *54*, 4832.

Transformation-RIL$_2$

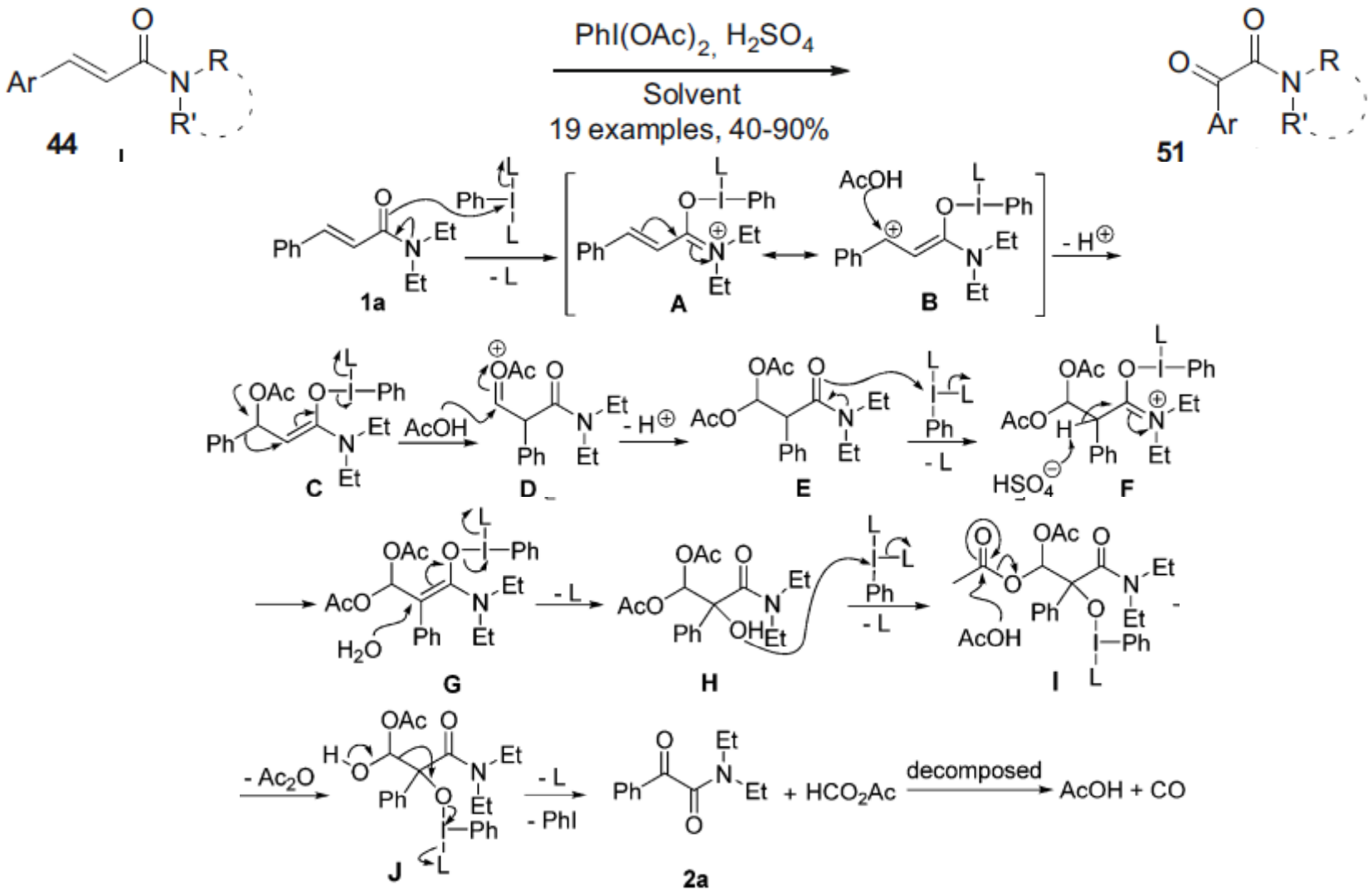
Reductive Elimination with Rearrangement



Du and Zhao, *Org. Lett.* **2013**, *15*, 2906.

Transformation-RIL$_2$

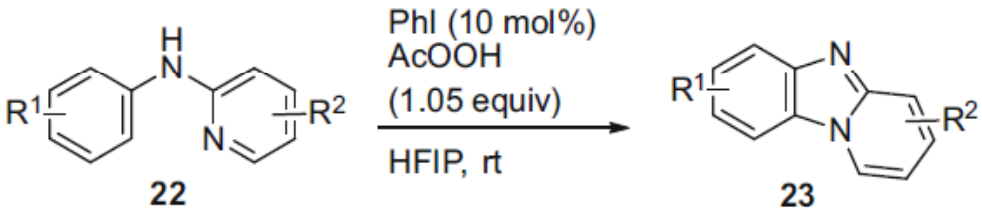
Reductive Elimination with Rearrangement



Du and Zhao, *Org. Lett.* **2014**, *16*, 5772.

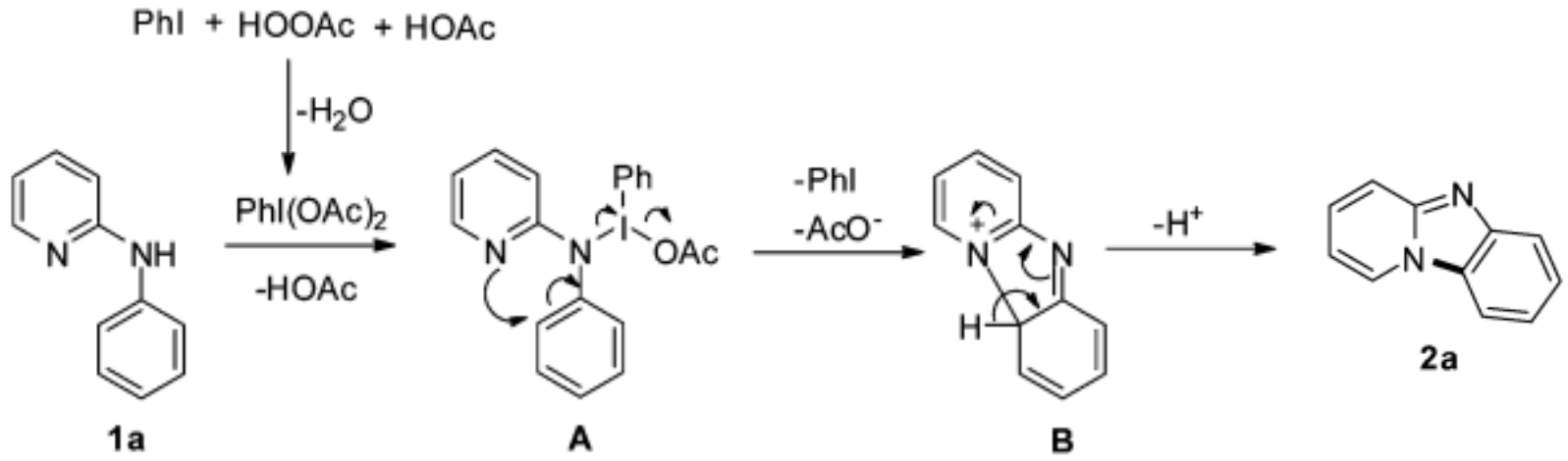
Transformation-RIL_2

Reductive Elimination with Rearrangement



25 examples, 39-99% yield

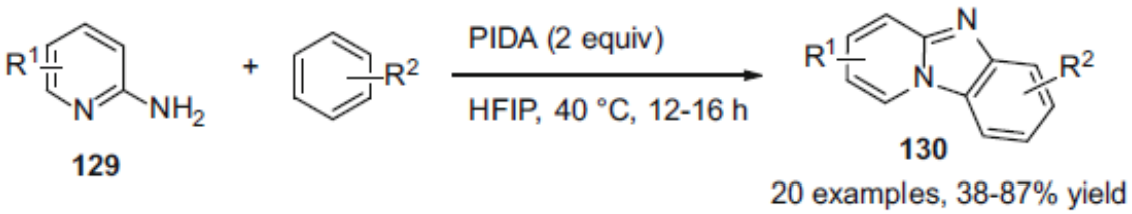
R^1, R^2 = alkyl, halogens

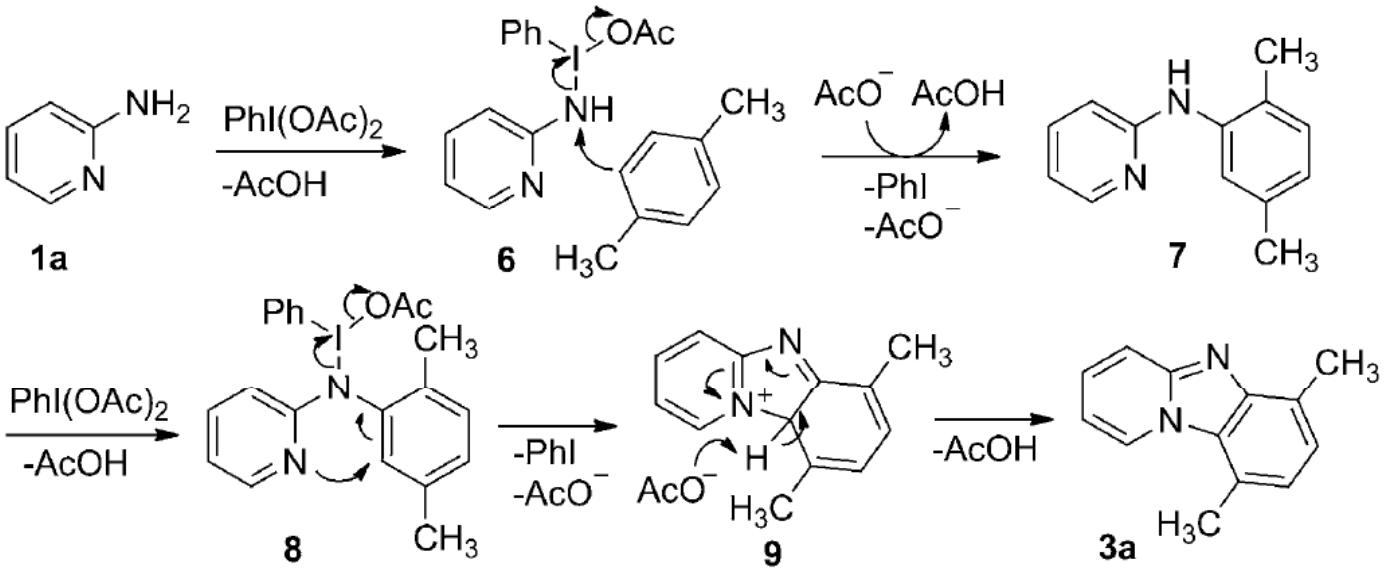


Zhu, *Chem. Commun.* **2013**, *49*, 7352.
Zhu, *Org. Lett.* **2013**, *15*, 3476.

Transformation-RIL$_2$

Reductive Elimination with Rearrangement

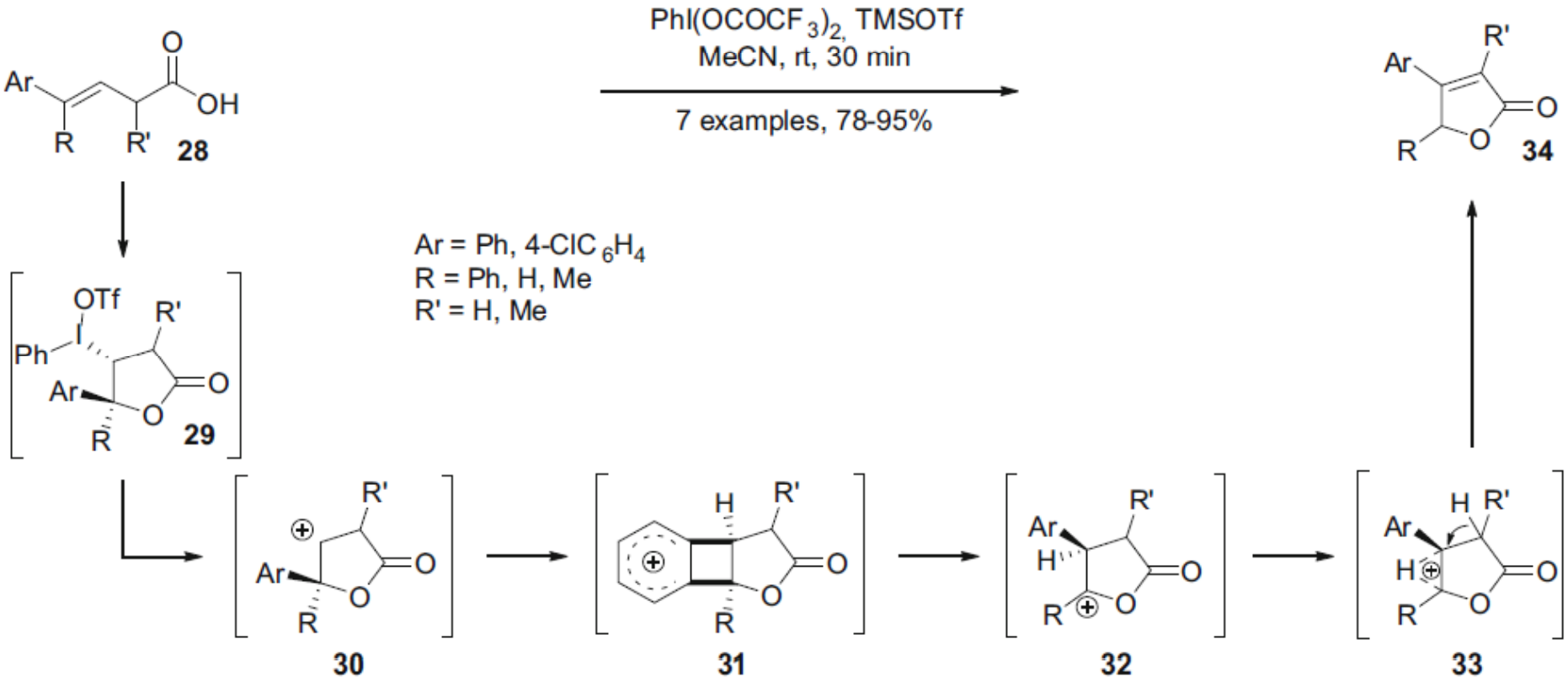




Antonchick, *Angew. Chem. Int. Ed.* **2014**, *53*, 8163.

Transformation-RIL$_2$

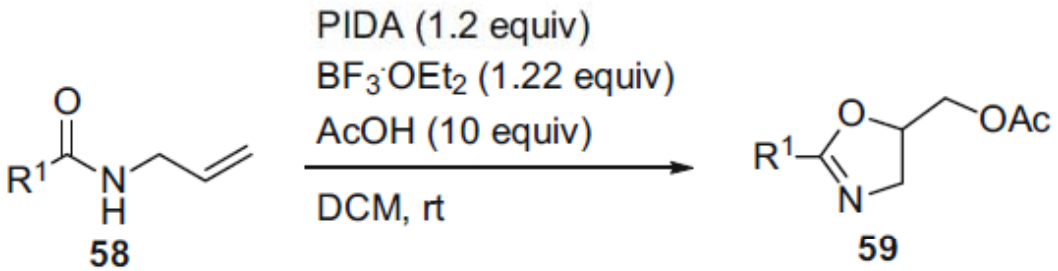
Activation of Multiple Bonds



Wirth, *ChemistryOpen*, **2012**, *1*, 245.

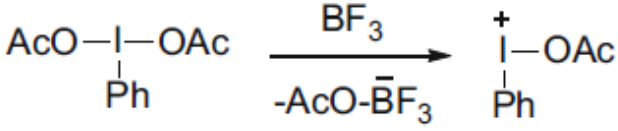
Transformation-RIL_2

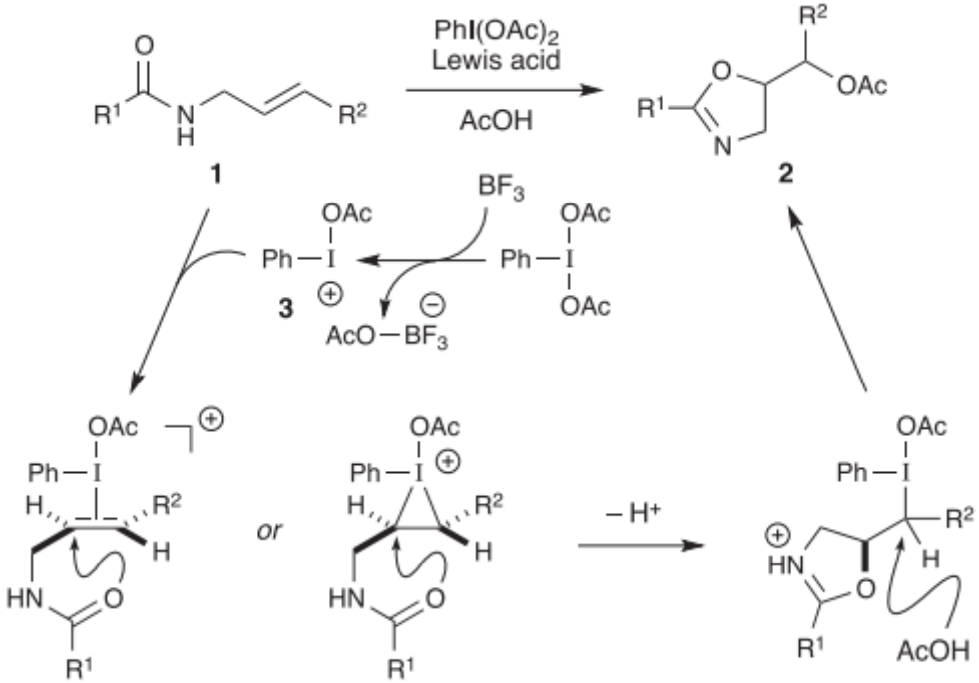
Activation of Multiple Bonds



R^1 = Me, *t*-Bu, aryl

9 examples, up to 85% yield

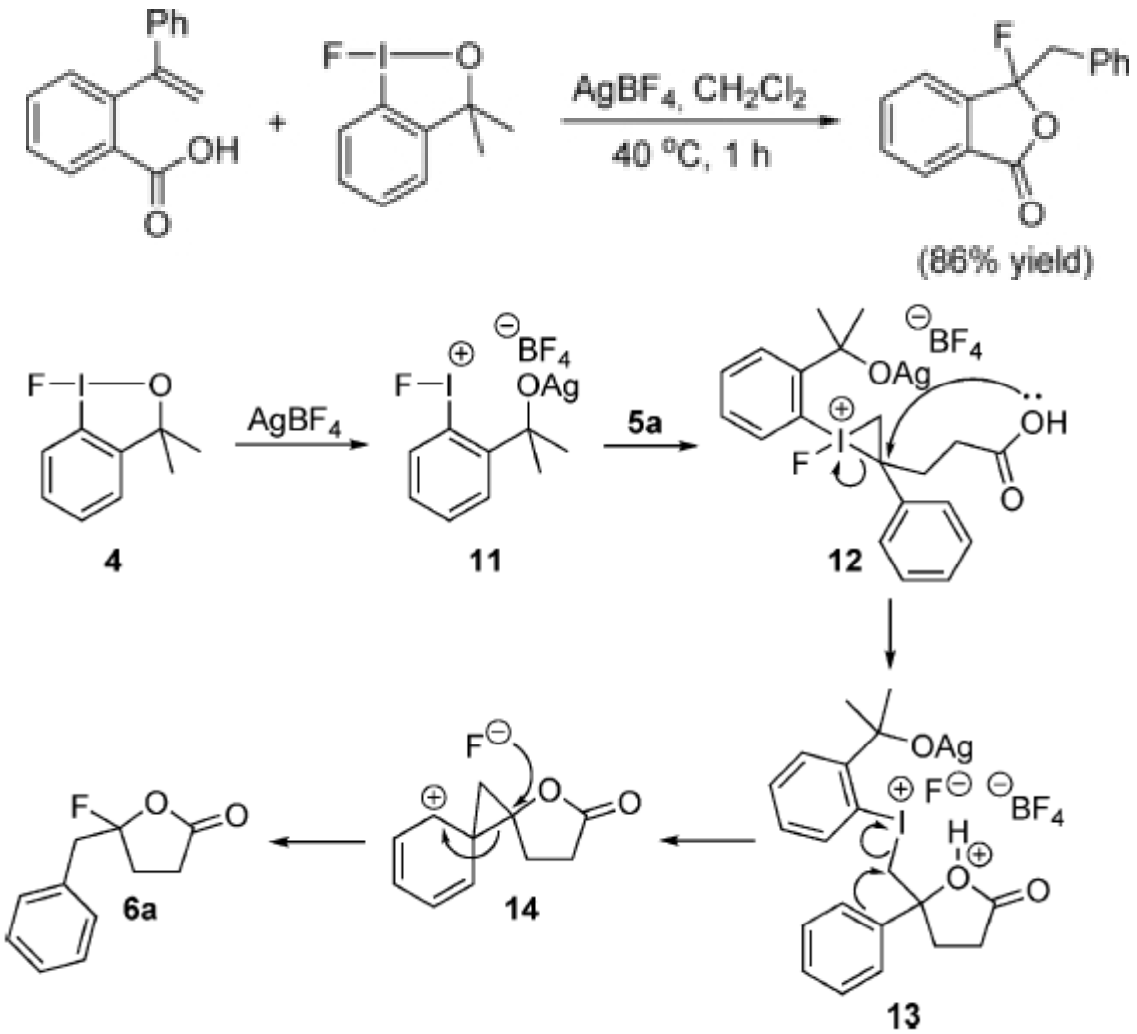




Moon, *Tetrahedron Lett.* **2013**, *54*, 2960.
Wirth, *Synthesis*, **2012**, *44, 1171.*

Transformation-RIL_2

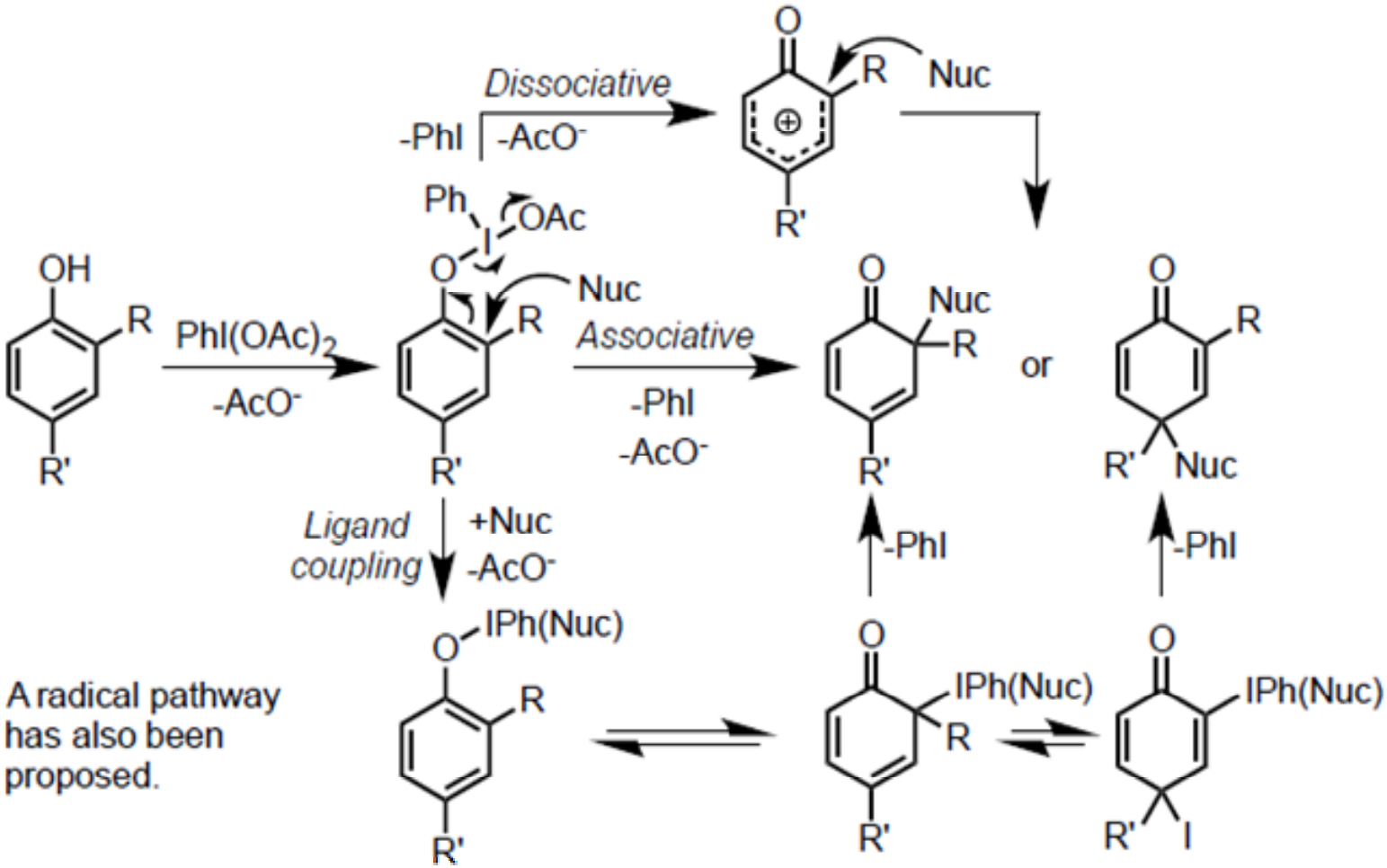
Activation of Multiple Bonds



Stuart, *Angew. Chem. Int. Ed.* **2015**, *54*, ASAP.

Transformation-RIL$_2$

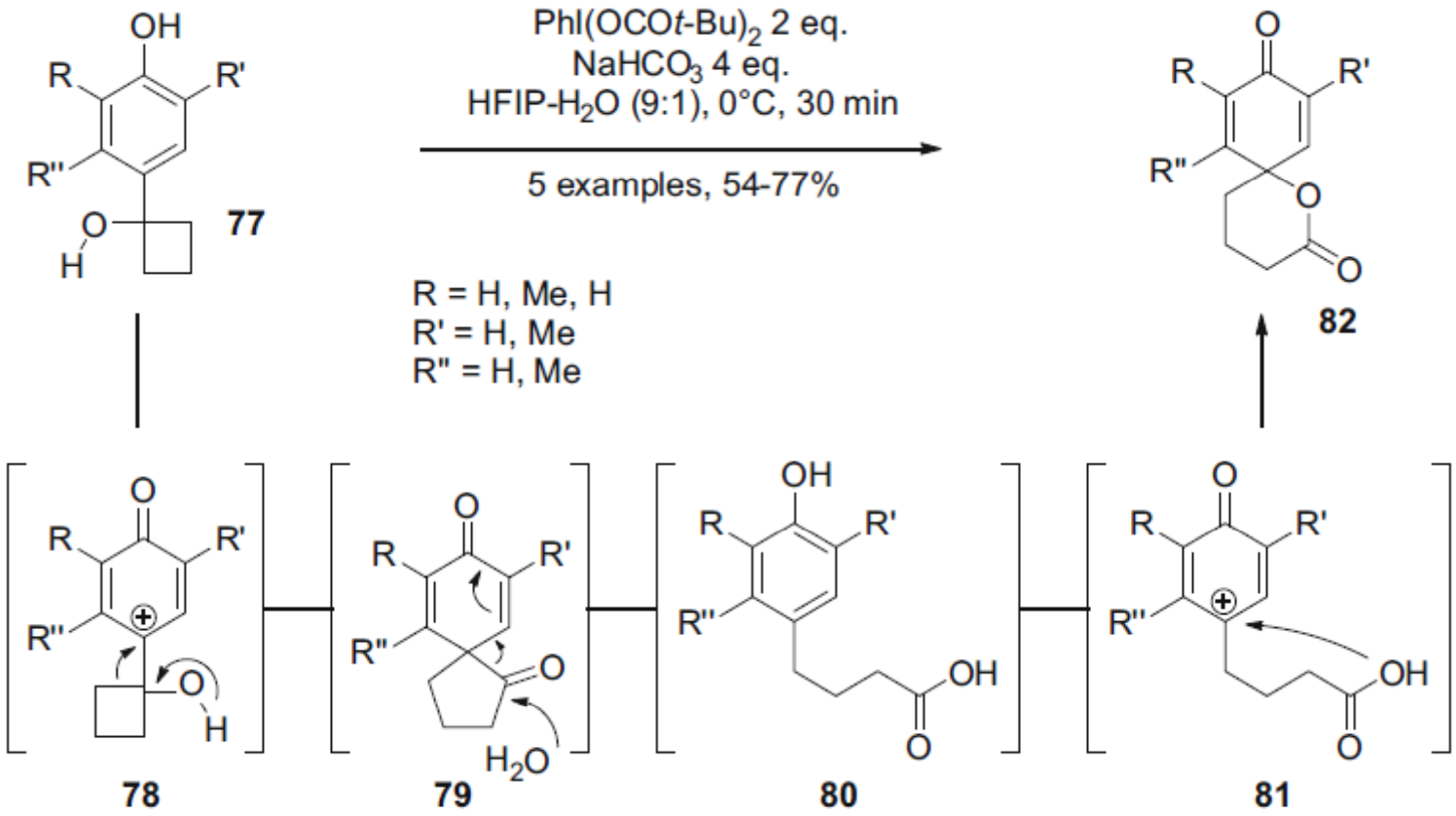
Oxidative Dearomatization



Quideau, *Tetrahedron* **2010**, *66*, 2235.

Transformation-RIL$_2$

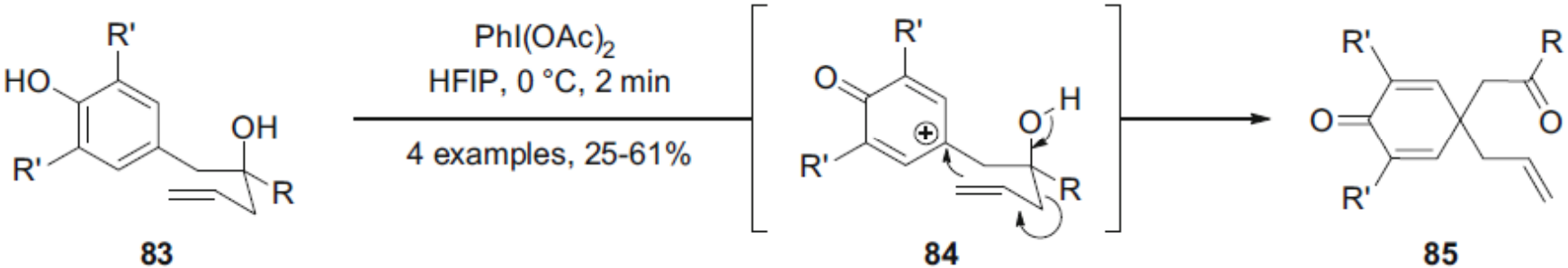
Oxidative Dearomatization



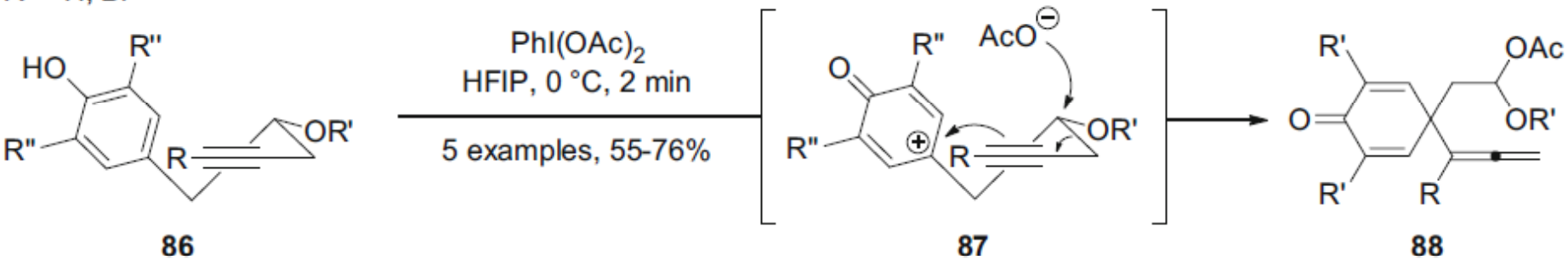
Fujioka and Kita, *Chem. Commun.* **2010**, *46*, 4133.

Transformation-RIL$_2$

Oxidative Dearomatization



R = allyl, CH_2SO_2Me, H
R' = H, Br

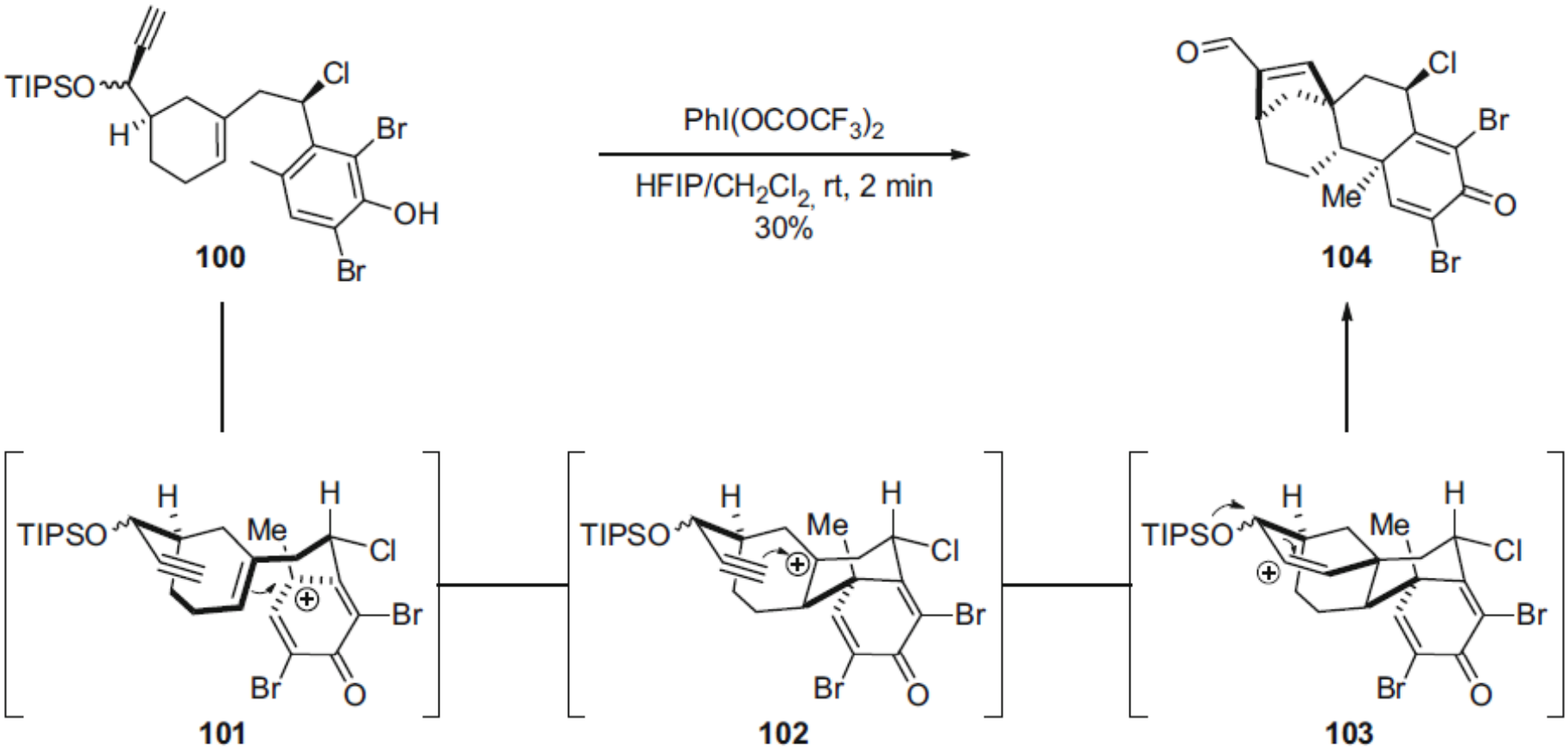


R = H, TMS
R' = TBDMS, TIPS
R'' = H, Br

Canesi, *Org. Lett.* **2009**, *11*, 4756.

Transformation-RIL$_2$

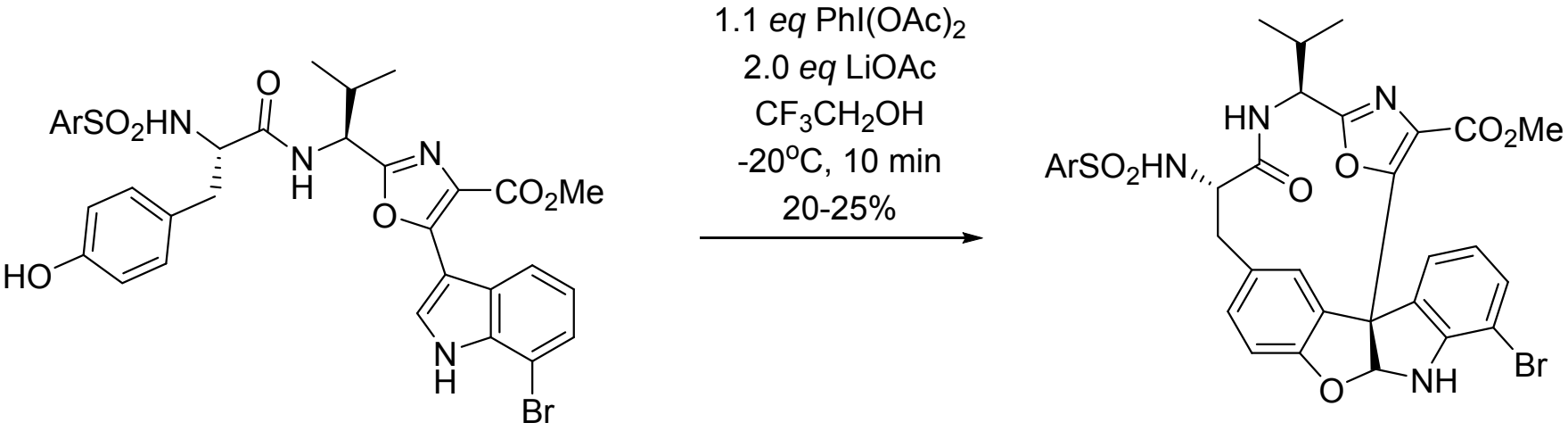
Oxidative Dearomatization



Canesi, *Org. Lett.* **2014**, *16*, 4928.

Transformation-RIL$_2$

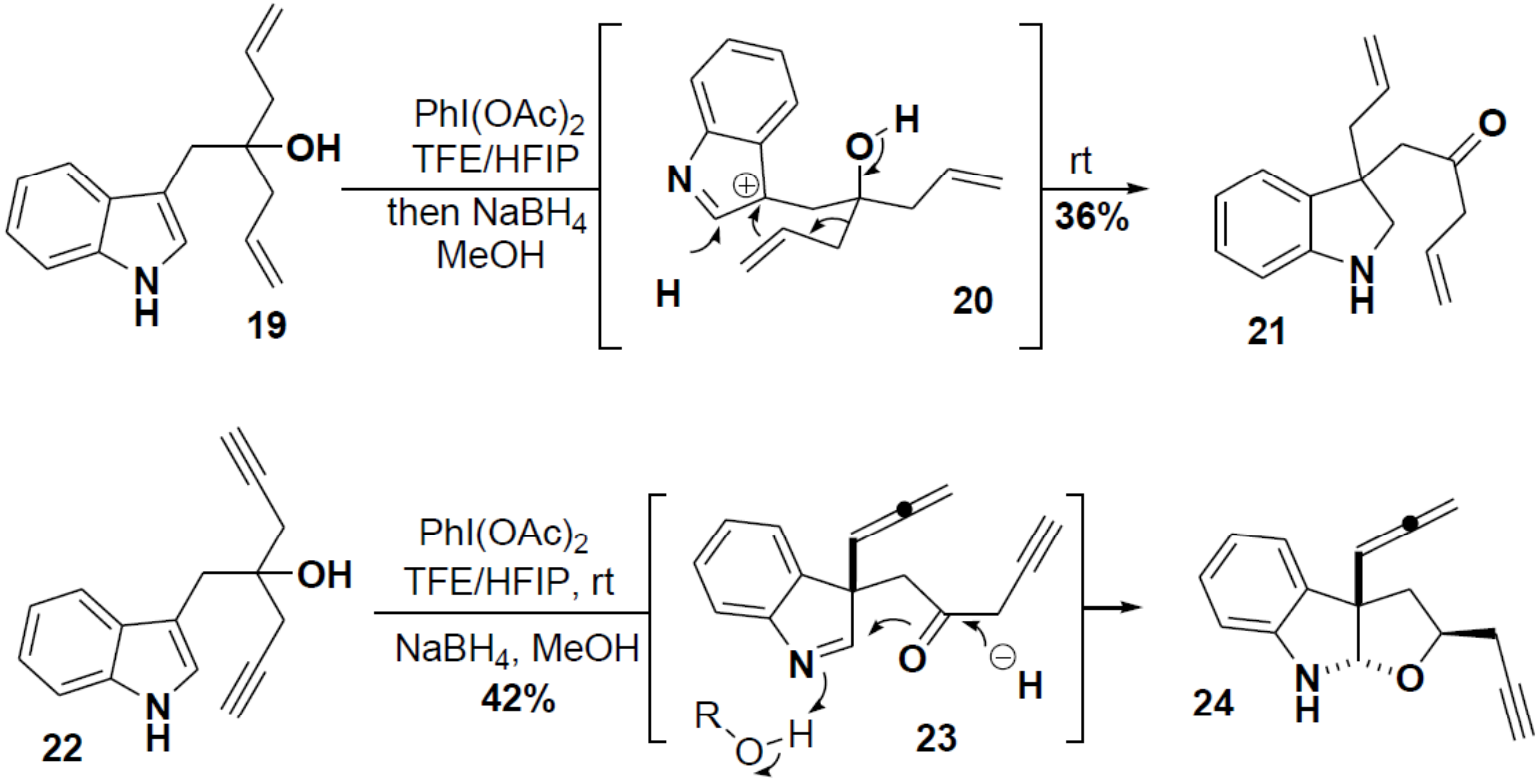
Oxidative Dearomatization



Harran, *Angew. Chem. Int. Ed.* **2003**, *42*, 4961.

Transformation-RIL$_2$

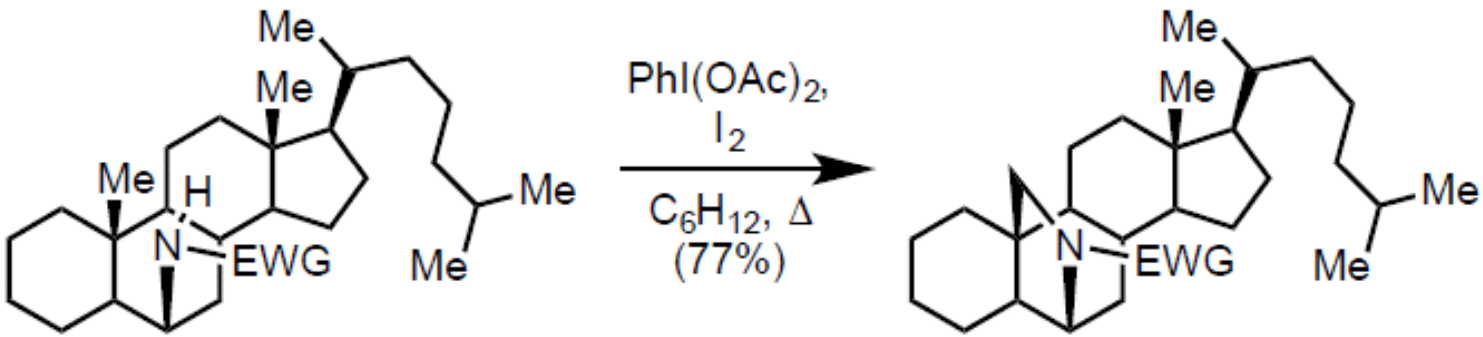
Oxidative Dearomatization

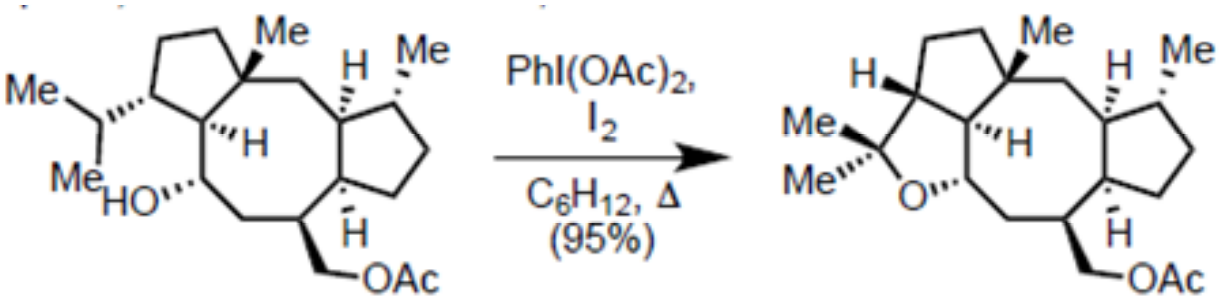


Canesi, *Chem. Eur. J.* **2015**, *21*, ASAP.

Transformation-RIL$_2$

Radical

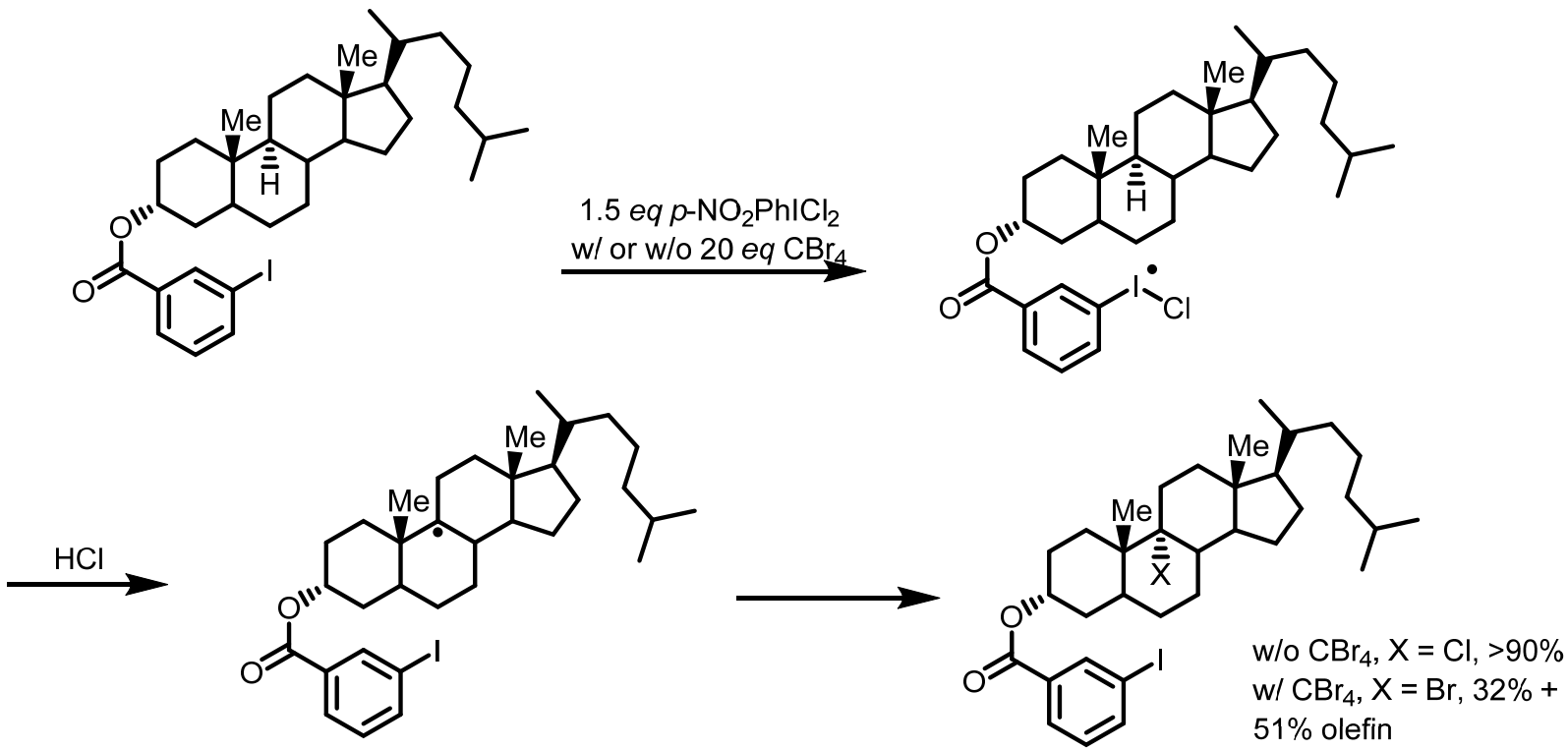




Suarez, *Tetrahedron Lett.* **1985**, *26*, 2493.
Paquette, *Tetrahedron Lett.* **1997**, *38*, 195.

Transformation-RIL$_2$

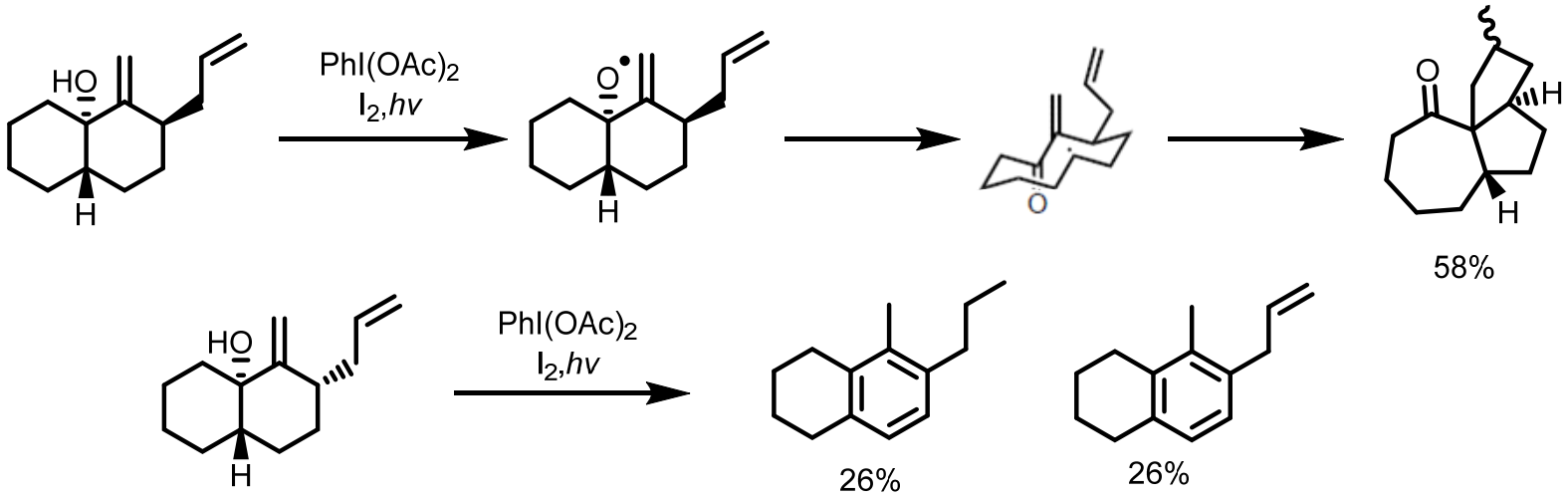
Radical

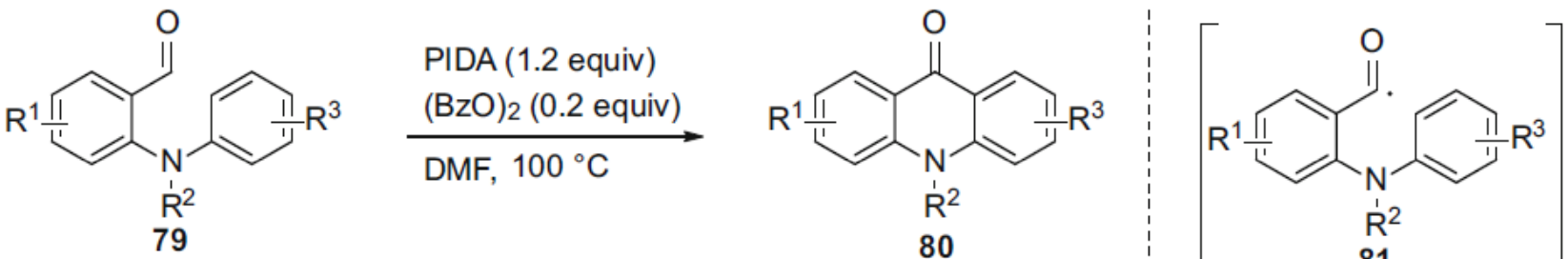


Breslow, *J. Am. Chem. Soc.* **1991**, *113*, 8977.

Transformation-RIL$_2$

Radical





R^1, R^3 = H, Me, OMe, halogens etc.
R^2 = Me, Bn

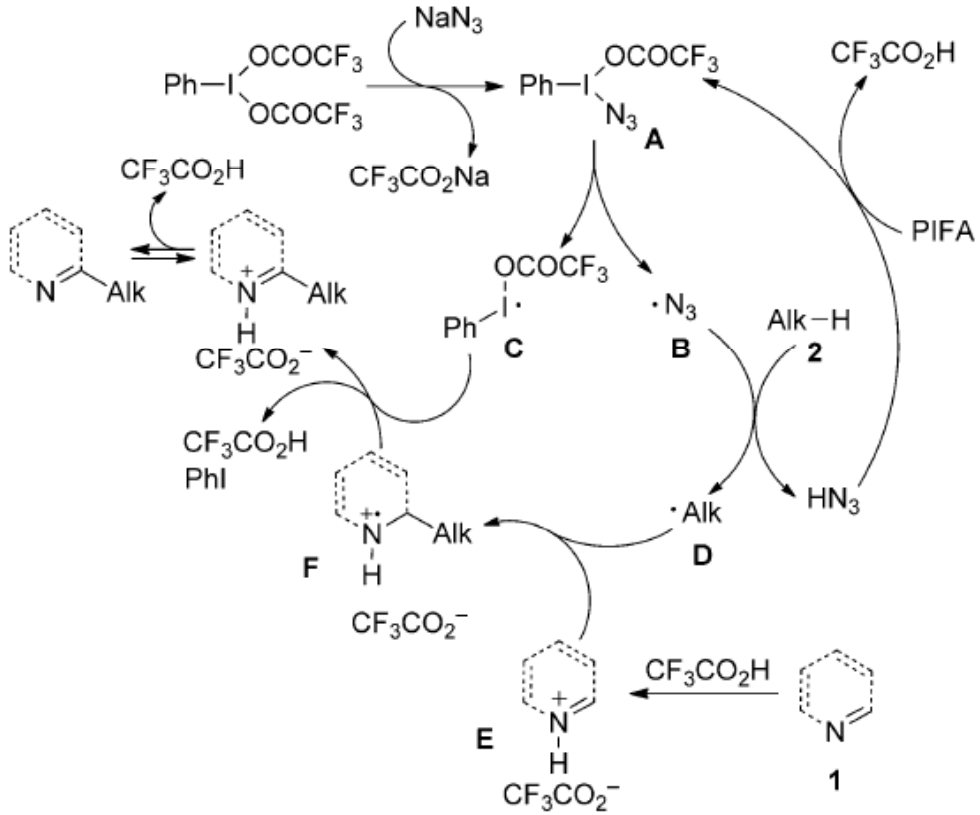
17 examples
40-82% yields

Pattenden, *Tetrahedron Lett.* **1993**, *34*, 127.
Zhao and Du, *J. Org. Chem.* **2014**, *79*, 7451.

Transformation-RIL$_2$

Radical

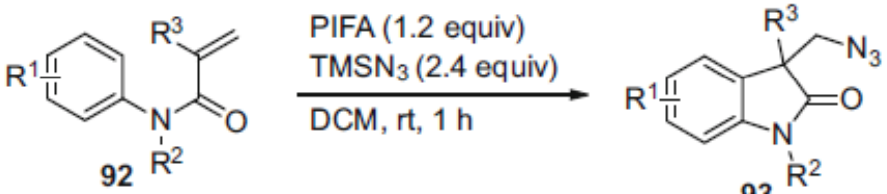
44 examples,
31 - 91 %



Antonchick, *Angew. Chem. Int. Ed.* **2013**, *52*, 3267.

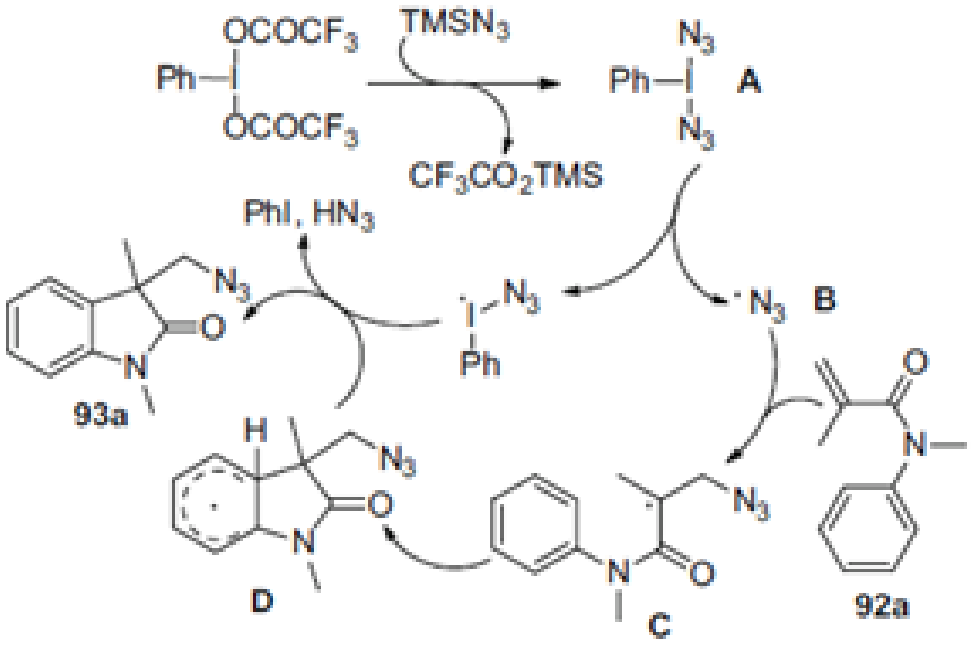
Transformation-RIL$_2$

Radical



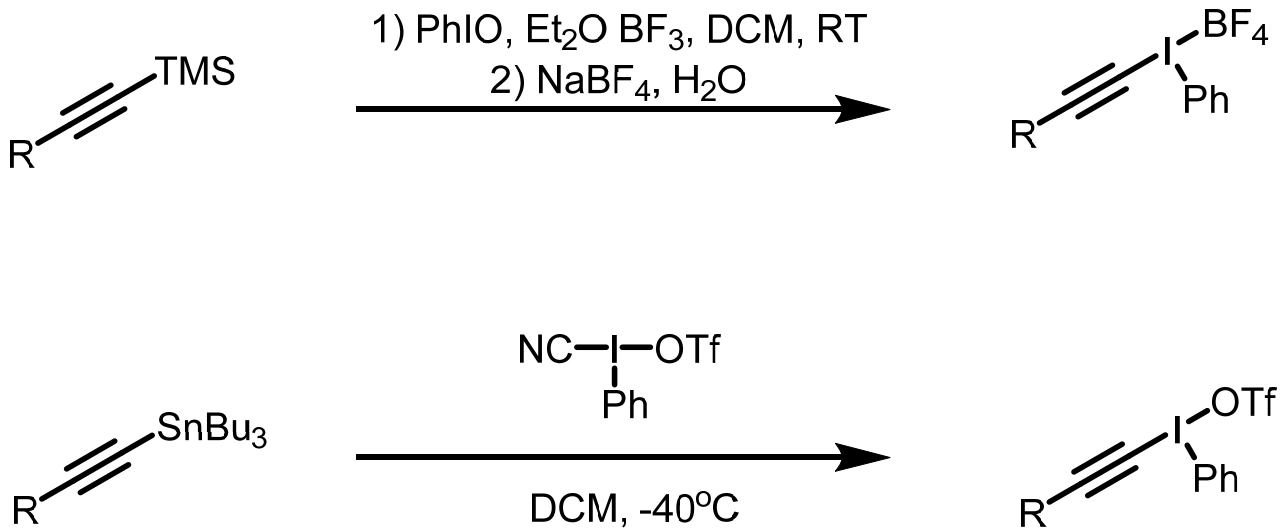
R^1 = H, Me, OMe, CF_3, NO_2 etc.
R^2 = alkyl, aryl, benzyl etc.
R^3 = H, Me, CH_2OMe, CH_2OTMS etc.

25 examples, 32-90% yield



Antonchick, *Angew. Chem. Int. Ed.* **2013**, *52*, 7985.

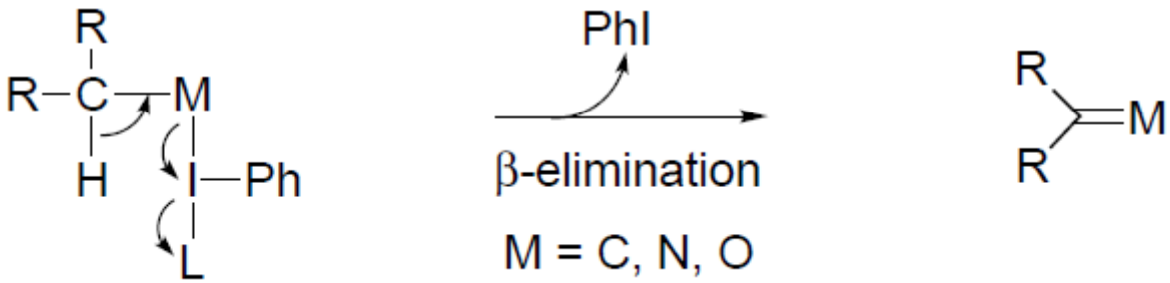
Preparation-R_2IL

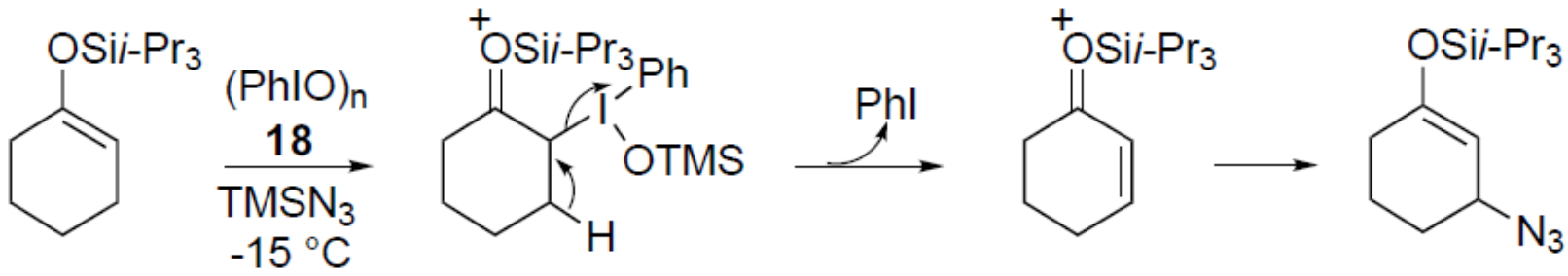


Fujita, *Tetrahedron Lett.* **1985**, 4501.
Stang, *J. Am. Chem. Soc.* **1994**, *116*, 93.

Transformation-R_2IL

Alkyl(aryl)-IL



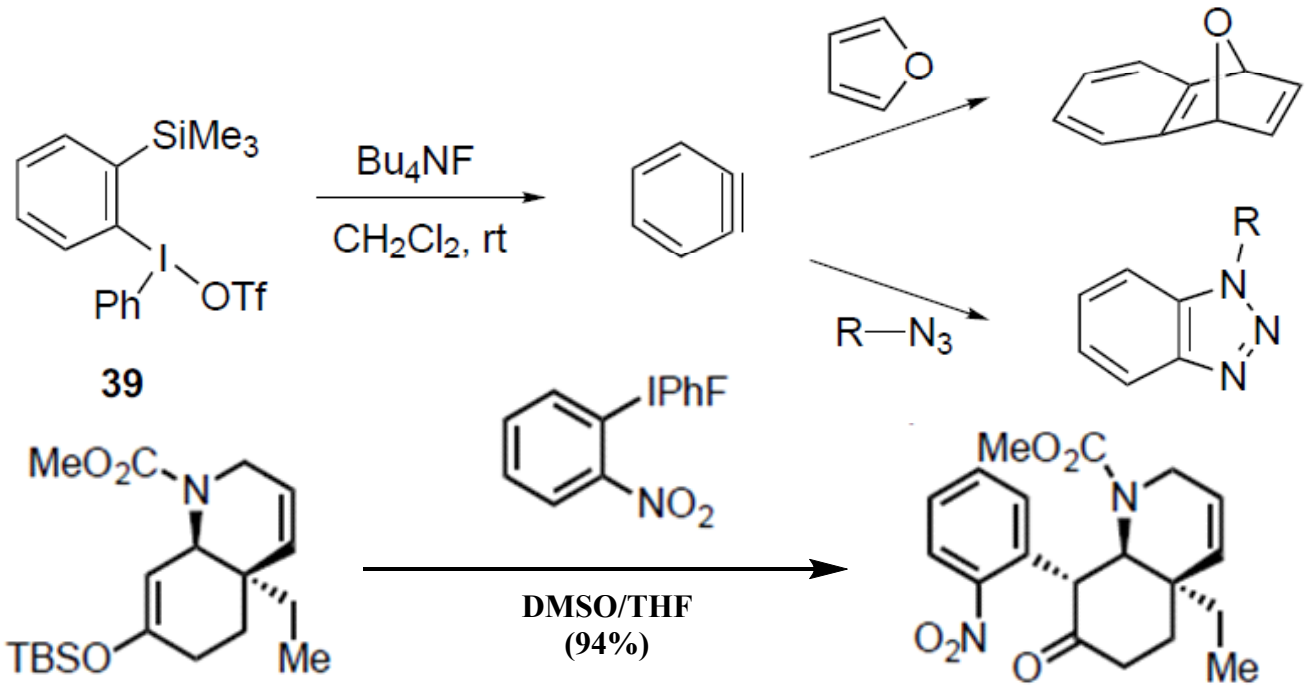


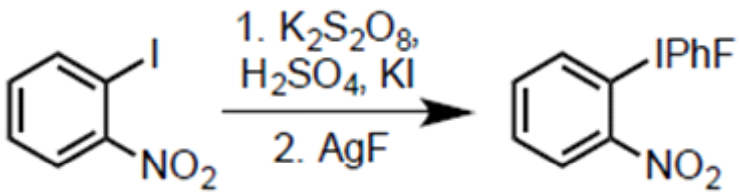
37 **38**

Reich, *J. Am. Chem. Soc.* **1978**, *100*, 4888.
Magnus, *J. Am. Chem. Soc.* **1992**, *114*, 767.

Transformation-R_2IL

Alkyl(aryl)-IL

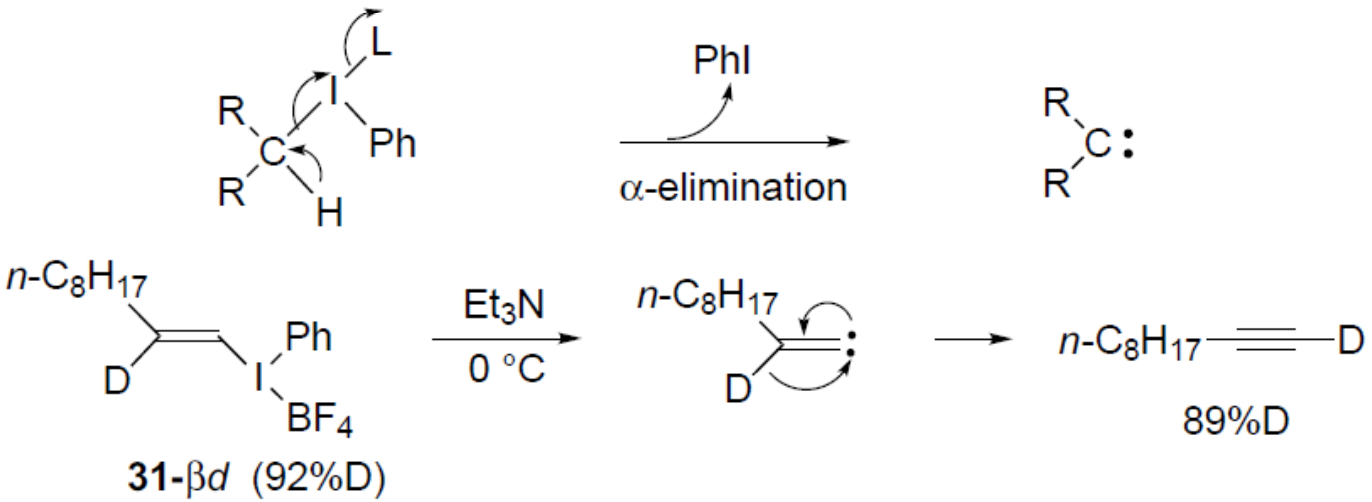




Kitamura, *J. Am. Chem. Soc.* **1999**, *121*, 11674.
Rawal, *J. Am. Chem. Soc.* **1998**, *120*, 13523.

Transformation-R_2IL

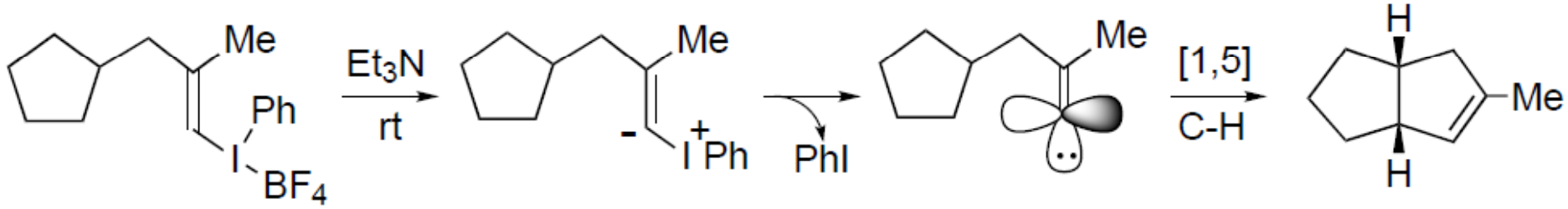
Alkenyl(aryl)-IL

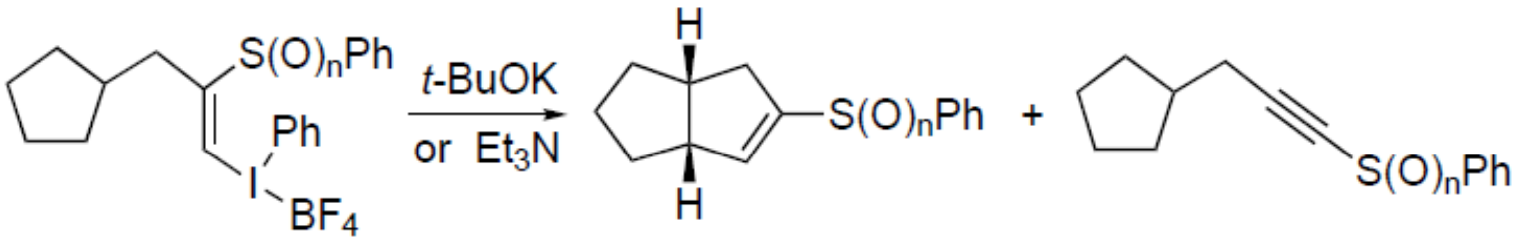


Ochiai, *J. Am. Chem. Soc.* **1988**, *110*, 6565.

Transformation-R_2IL

Alkenyl(aryl)-IL

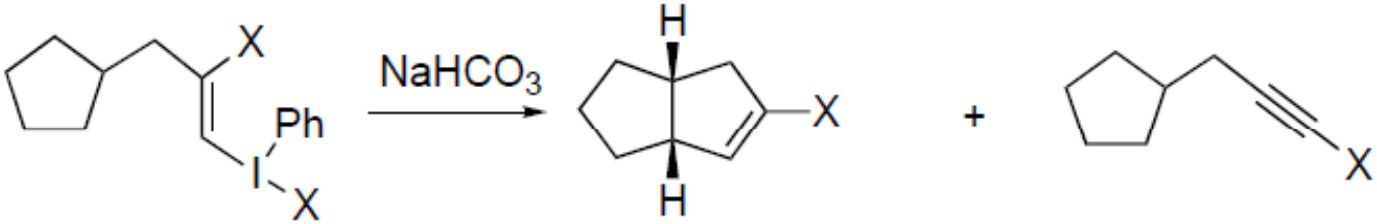




98 n = 0, 1, 2

n = 0, 1	0	:	100
n = 2	80	:	20

(95)



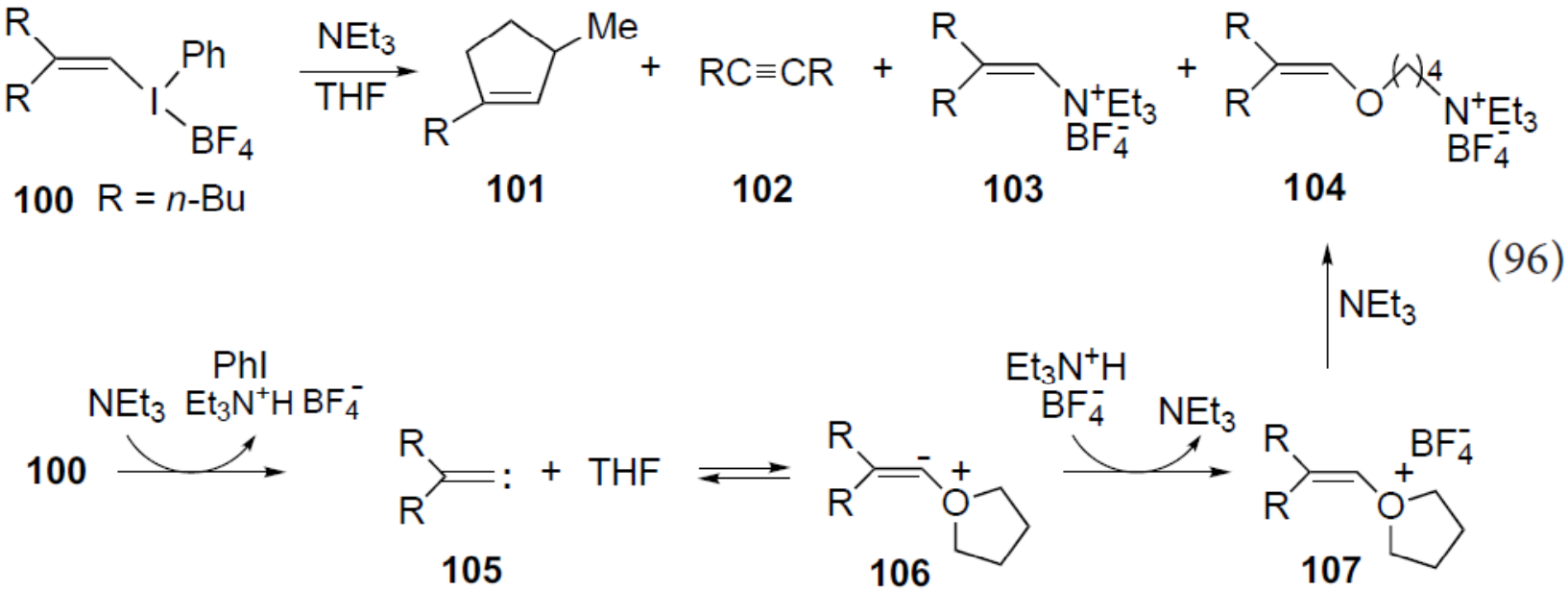
99 X = Br, Cl

X = Br	0	:	100
X = Cl	38	:	62

Ochiai, *J. Am. Chem. Soc.* **1991**, *113*, 3135.
Ochiai, *J. Am. Chem. Soc.* **1993**, *115*, 2528.

Transformation-R_2IL

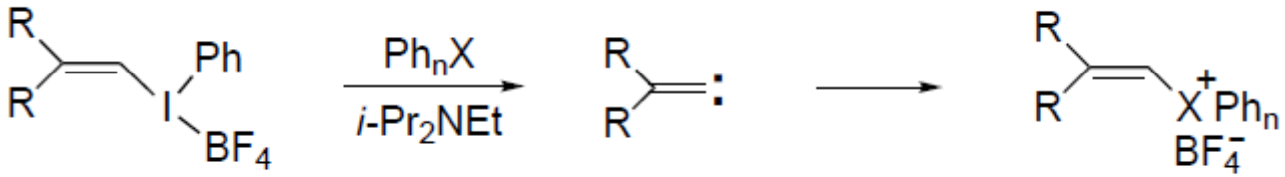
Alkenyl(aryl)-IL



Ochiai, *J. Am. Chem. Soc.* **1996**, *118*, 10141.

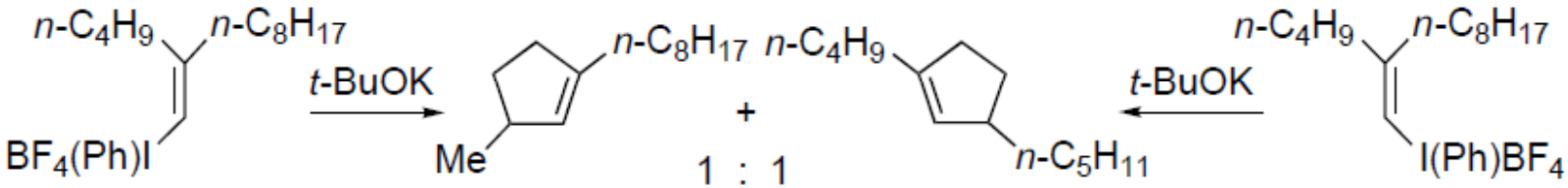
Transformation-R_2IL

Alkenyl(aryl)-IL

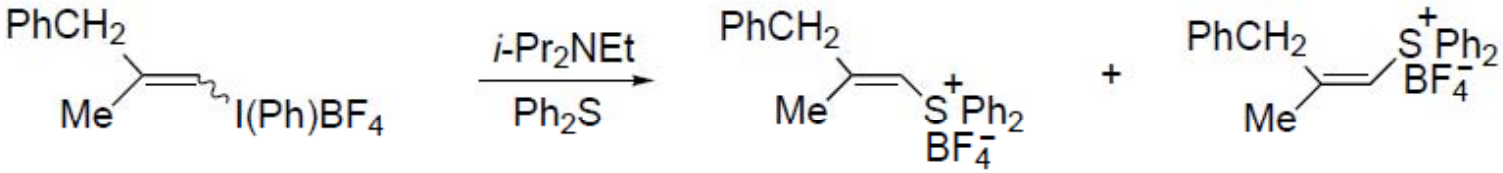


R,R = $(CH_2)_5$, or Me

Ph_nX = Ph_3P, Ph_3As, Ph_3Sb, Ph_2S, Ph_2Se, Ph_2Te



***E*-108** **Z-108**

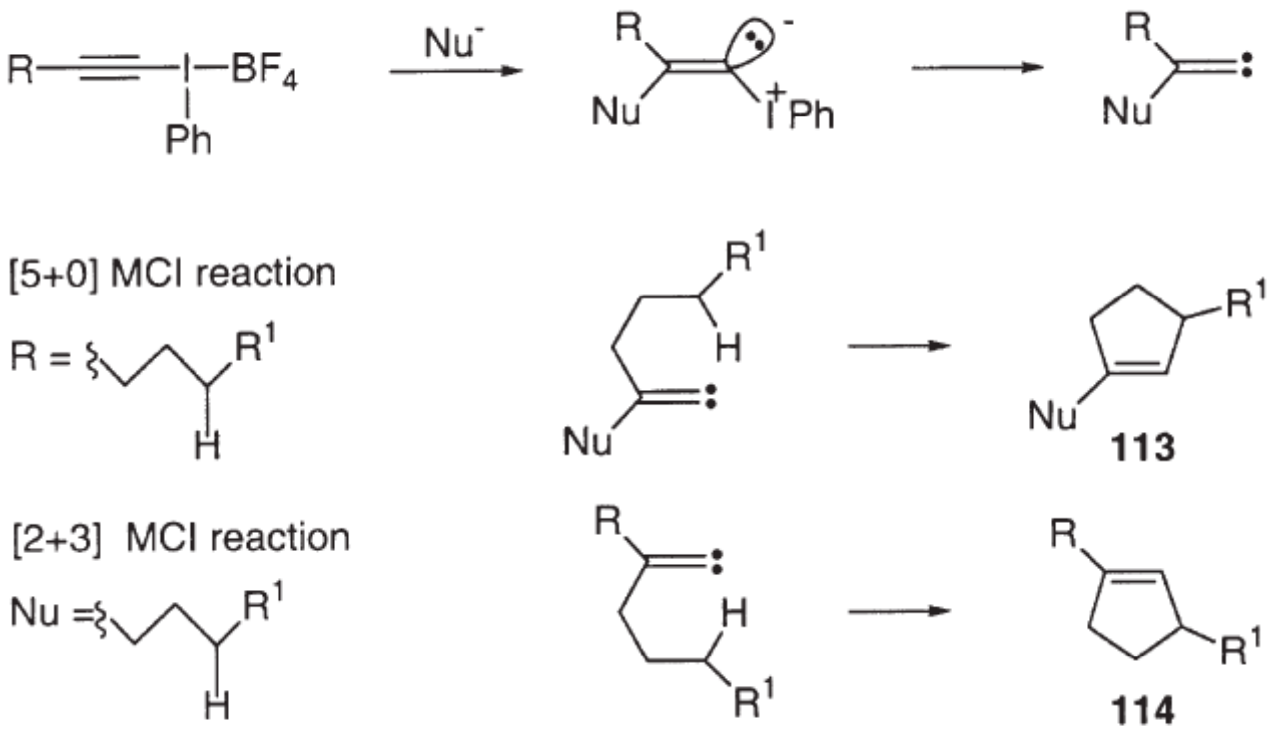


***E*-109**	69	:	31
***Z*-109**	71	:	29

Ochiai, *J. Org. Chem.* **1999**, *64*, 8563.
Ochiai, *J. Am. Chem. Soc.* **1996**, *118*, 10141.
Ochiai, *J. Am. Chem. Soc.* **1988**, *110*, 6565.

Transformation-R_2IL

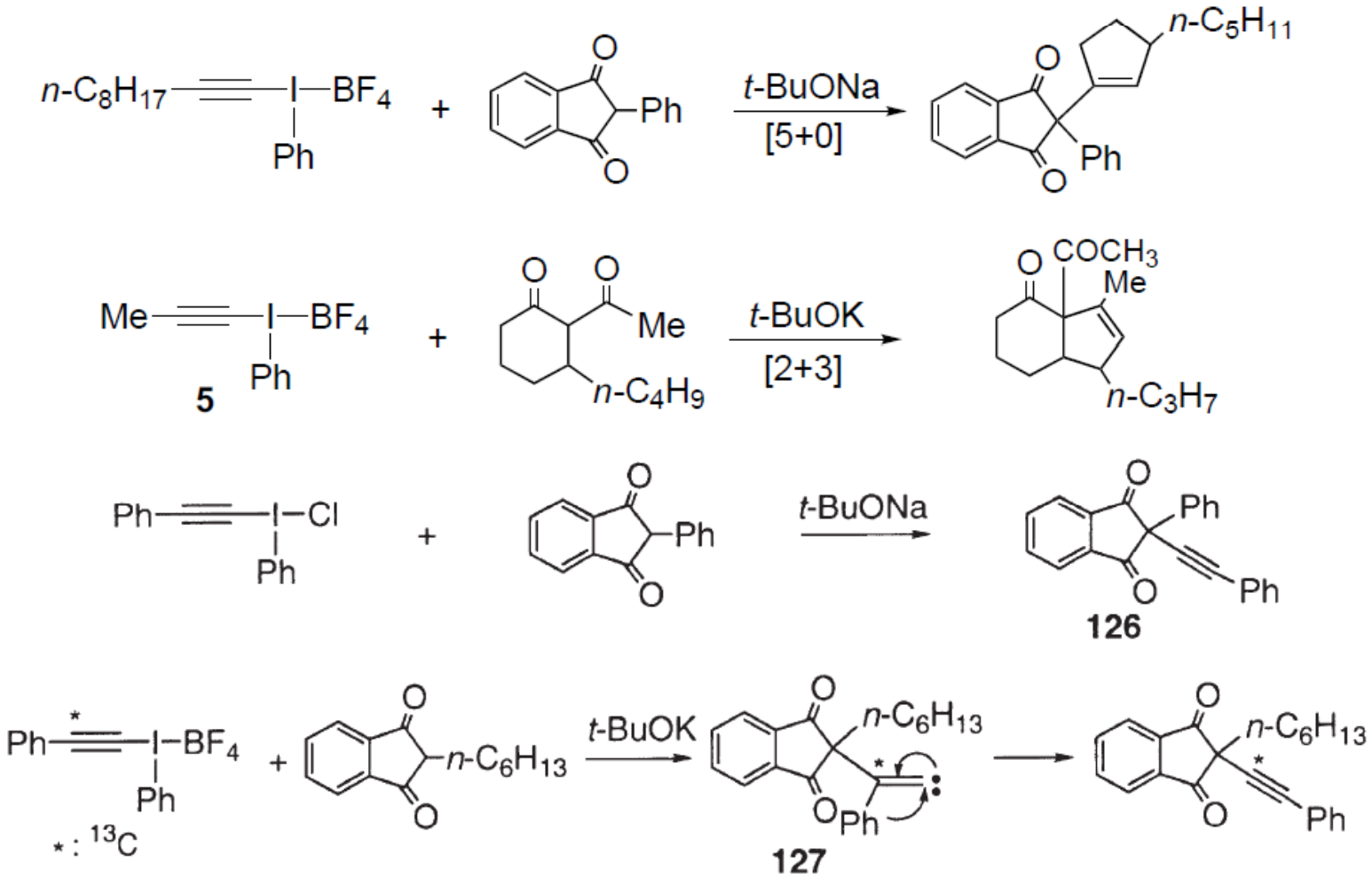
Alkynyl(aryl)-IL



Ochiai and Fujita, *J. Am. Chem. Soc.* **1986**, *108*, 8281.

Transformation-R_2IL

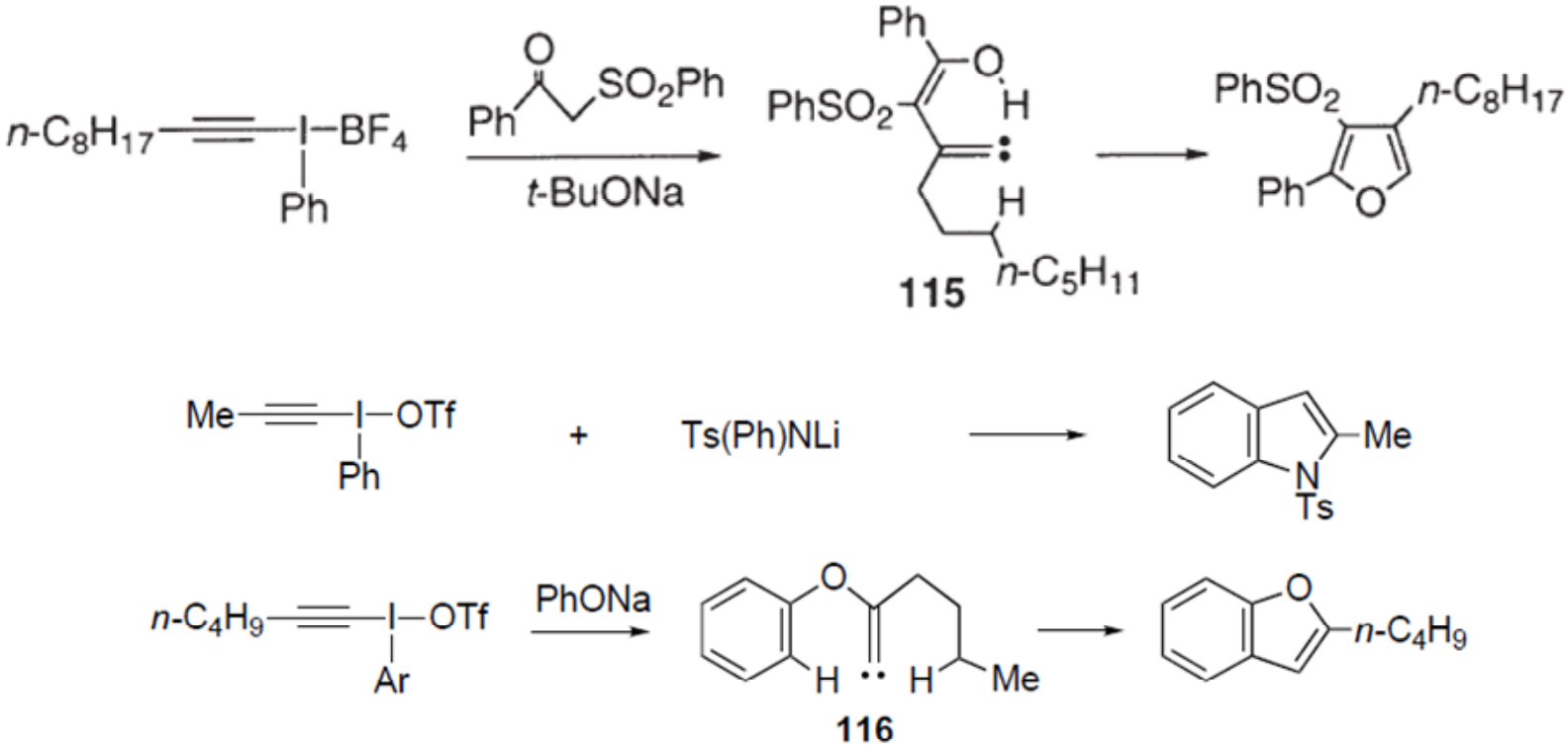
Alkynyl(aryl)-IL



Ochiai and Fujita, *J. Am. Chem. Soc.* **1986**, *108*, 8281.

Transformation-R_2IL

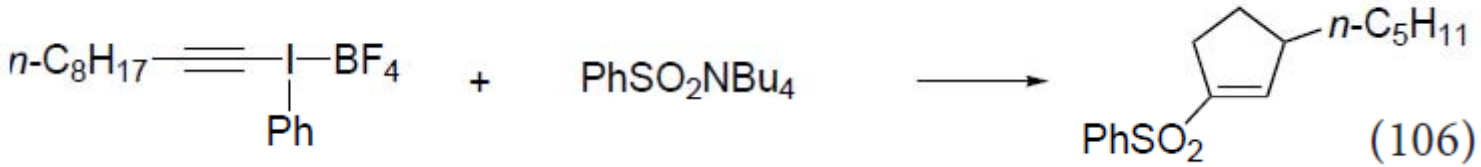
Alkynyl(aryl)-IL

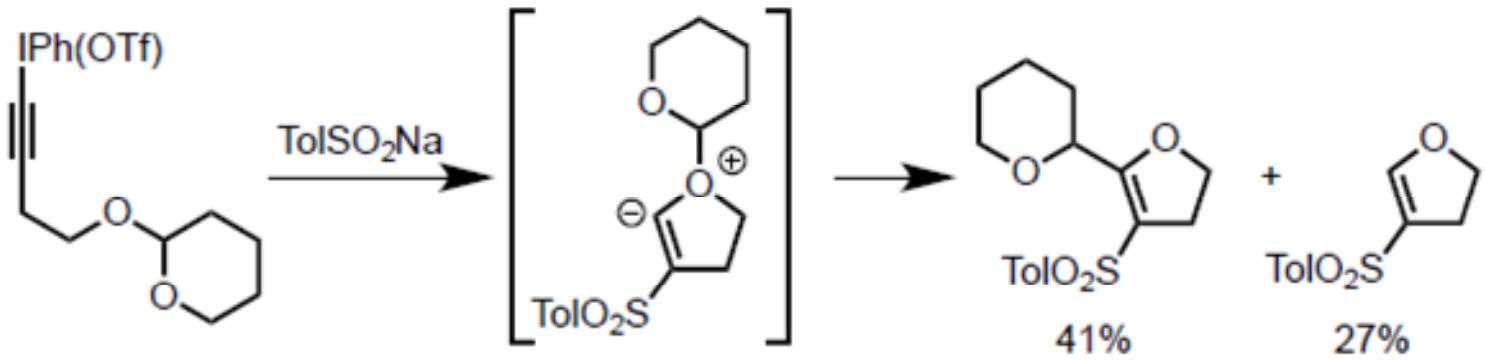


Ochiai, *J. Am. Chem. Soc.* **1991**, *113*, 3136.
Ochiai, *J. Am. Chem. Soc.* **1986**, *108*, 8281.
Feldman, *J. Org. Chem.* **1995**, *60*, 7722.

Transformation-R_2IL

Alkynyl(aryl)-IL



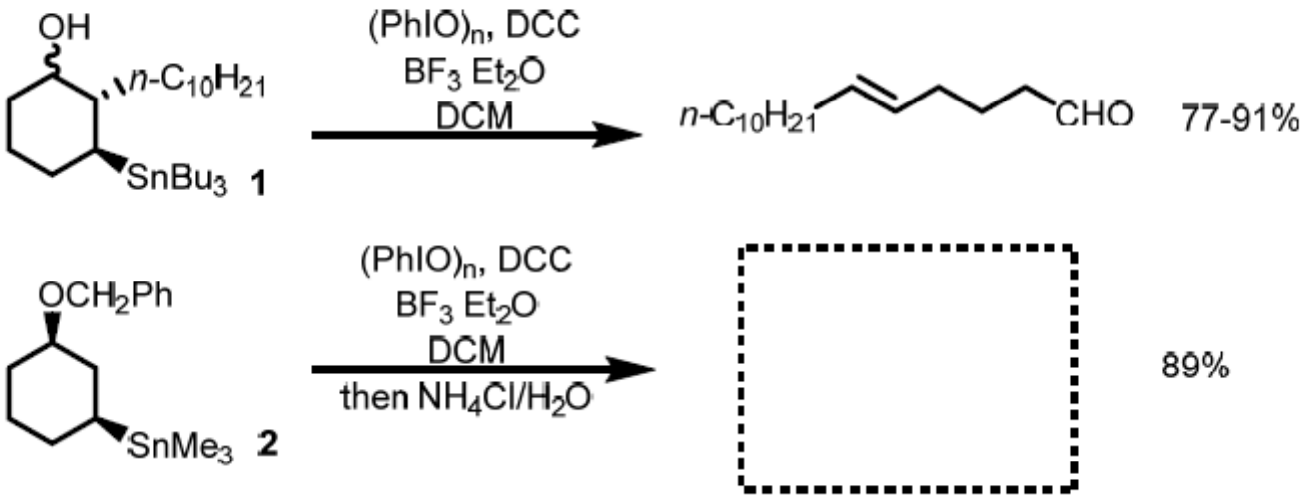


Stang, *J. Am. Chem. Soc.* **1994**, *116*, 93.
Feldman, *Org. Lett.* **2000**, *2*, 2603.

Acknowledgement-Welcome Marshall!!

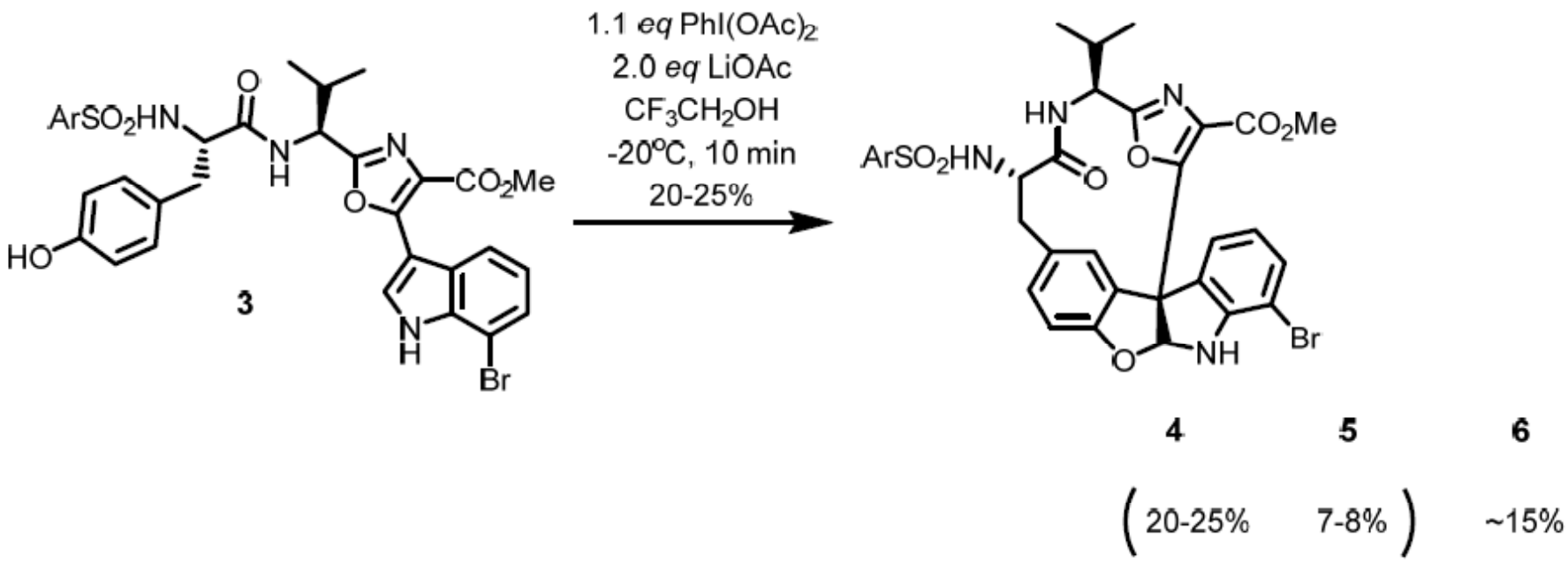
Q1

Q1. In Ochiai and Fujita's work, contol experiment was carried to illustrate the mechanism. However, when compound **2** was used, another hypervalent product was formed. Please provide the structure.



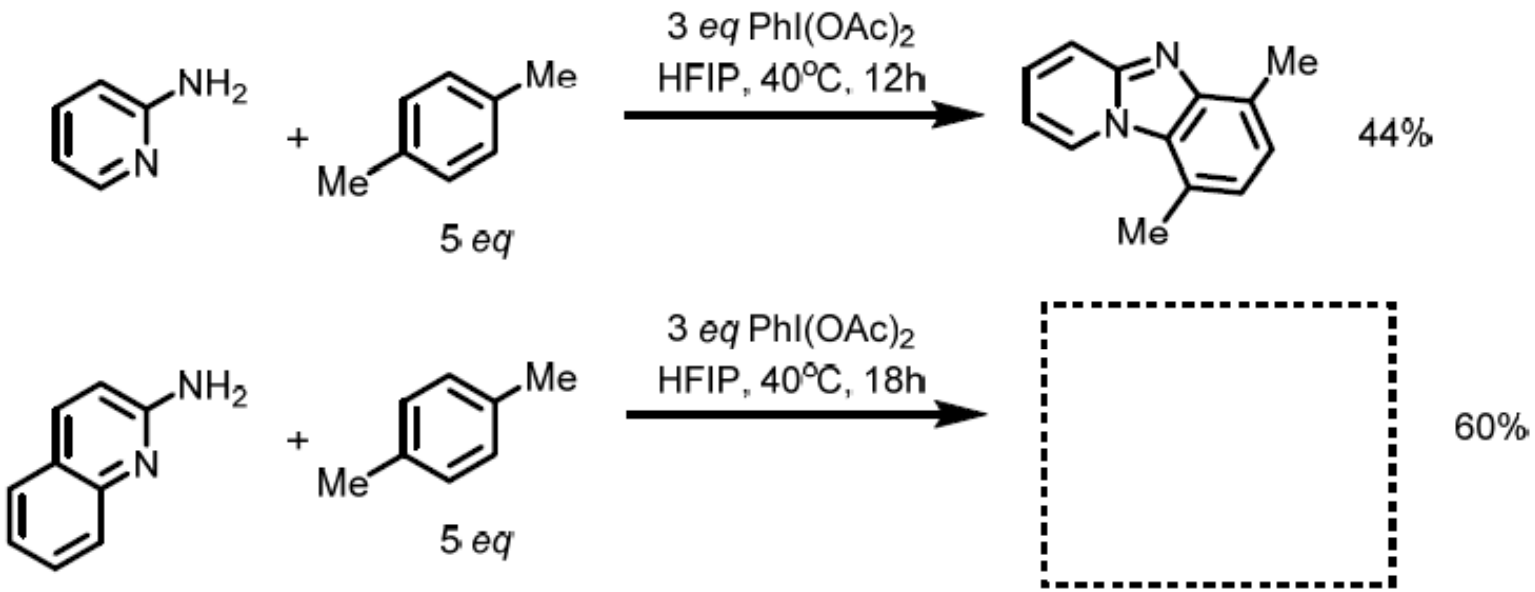
Q2

Q2. In Harran's synthesis, other than the desired molecule, two other by-products, **5** and **6** were obtained with comparable yields. Please provide the structures of the two by-products.

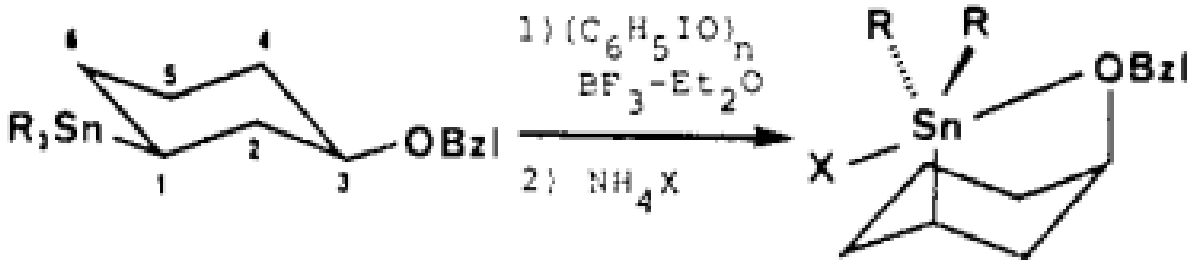


Q3

Q3. In Antonchick's work, when they used 2-aminoquinoline, a different product was obtained with decent yield. Please provide the structure of this "weird" product.



A1

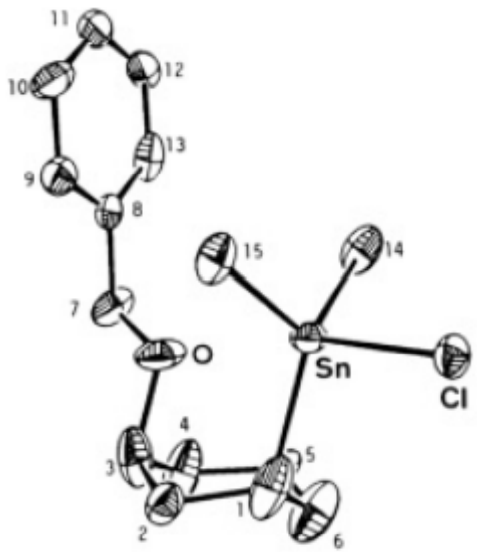


1a R = Me

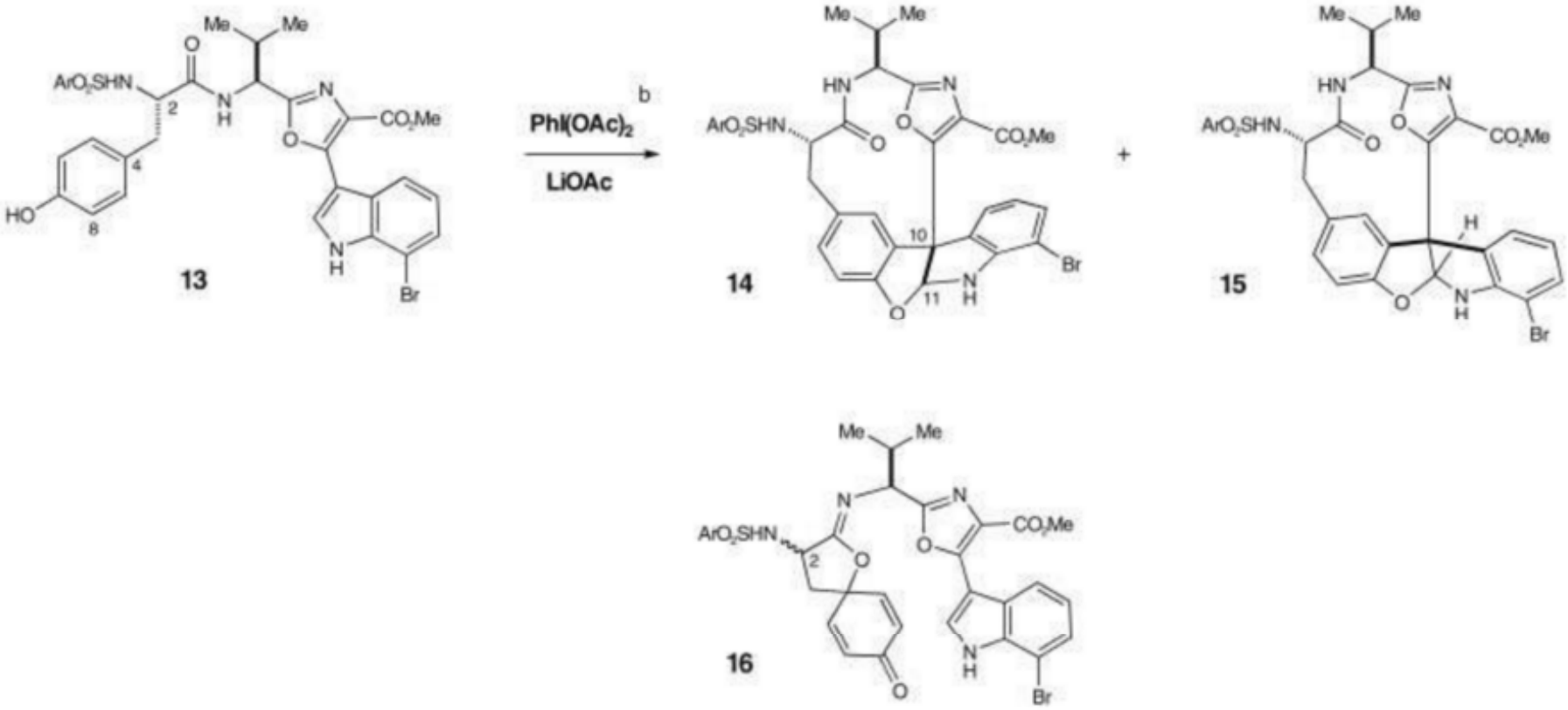
1b R = Bu

2a R = Me, X = F, Cl, Br

2b R = Bu, X = Cl

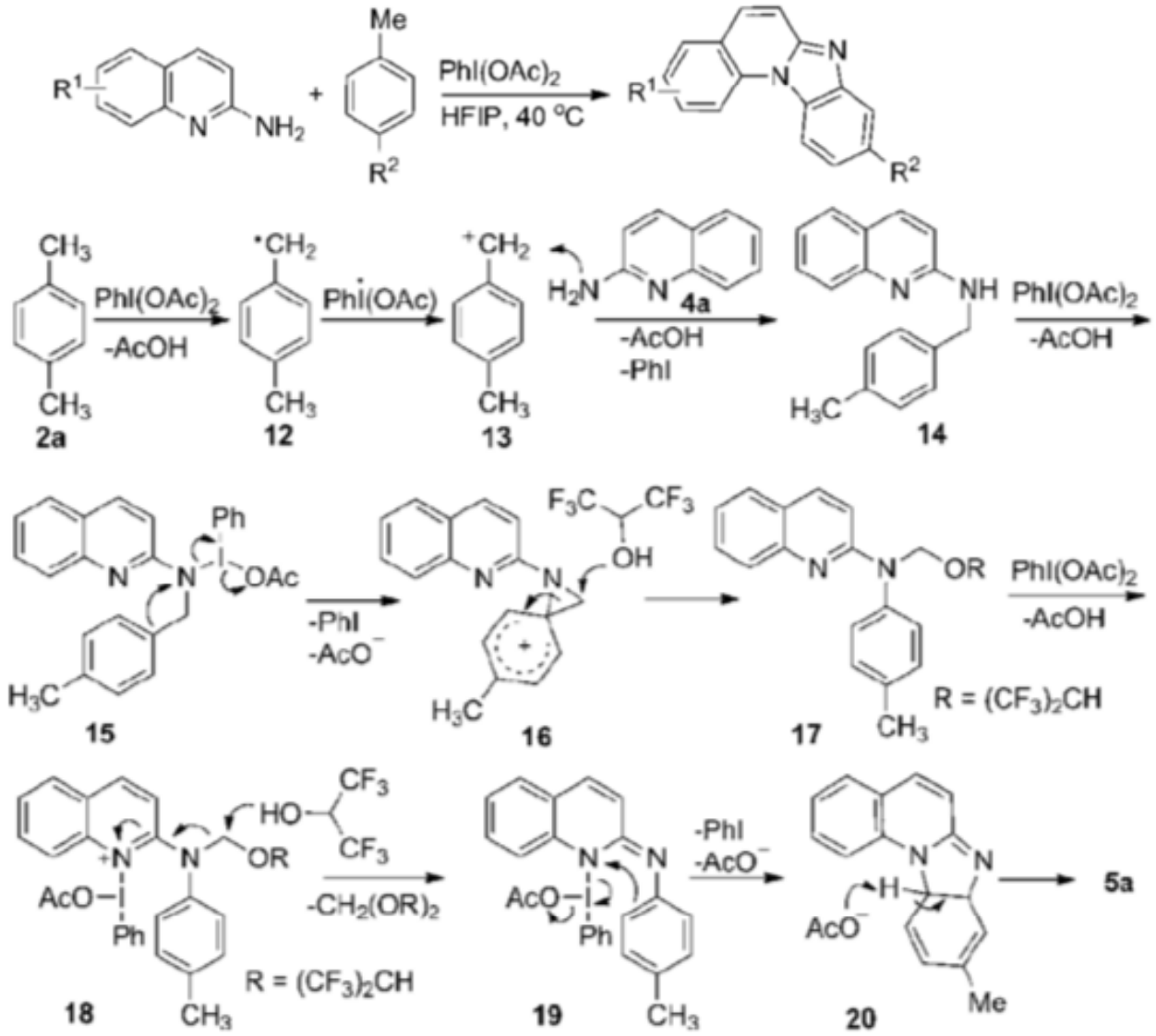


A2



(20–25% **14**, 7–8% **15**, ~15% **16** (1:1))

A3


PhI(OAc)2
HFIP, 40 °C
-AcOH
-PhI
-AcO⁻
-CH2(OR)2
R = (CF3)2CH
2a
12
13
4a
14
15
16
17
18
19
20
5a