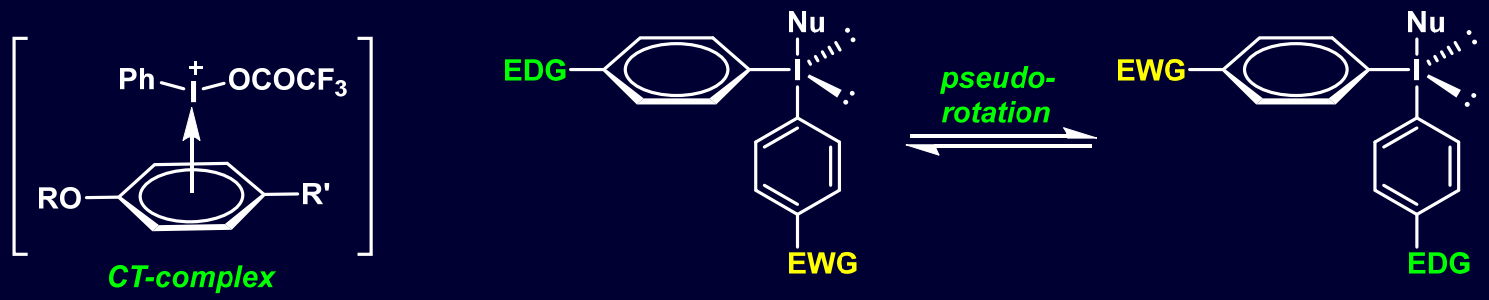
Hypervalent Iodine Chemistry



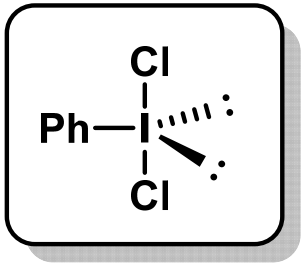
Nan Zhang
Peking-Tsinghua Center for Life Sciences
Academy for Advanced Interdisciplinary Studies
Peking University

Dec, 21st . 2019

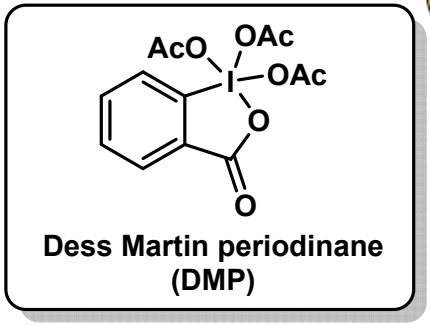
Content

Introduction

1811, B. Courtois
Isolated from ash of seaweed



1886, C. Willgerodt, $PhICl_2$
1st hypervalent organic iodine compound



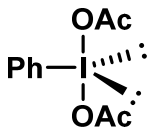
Dess Martin periodinane (DMP)

1980s - 1990s
New organic iodine compounds & useful synthetic applications

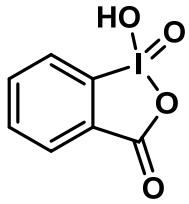
1814, Gay Lussac
ICl_3, KIO_3
Inorganic hypervalent Iodine derivatives

1914, C. Willgerodt,
More than 500 hypervalent Organic iodine compound

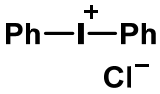
2000 – now
New organic iodine compounds & catalytic applications



Phenyliodo diacetate (PIDA)



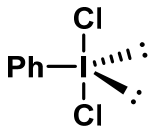
2-Iodoxybenzoic acid (IBX)



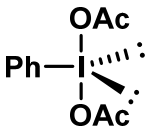
Chlorodiphenyliodonium (DPI)

Introduction

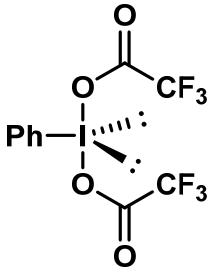
➢ Iodine(III) Compounds



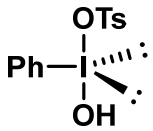
Iodosobenzene dichloride (IBD)



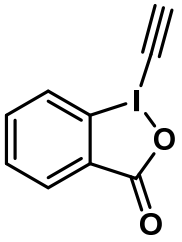
Phenyliodo diacetate (PIDA)



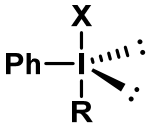
Phenyliodo bis(trifluoroacetate) (PIFA)



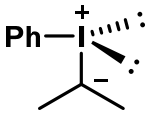
Hydroxy(tolsyloxy) iodo benzene (HTIB)



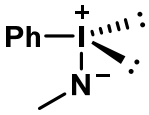
Ethynylbenziodoxol(on)es (EBX)



Iodonium salts

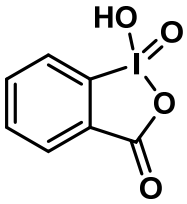


iodonium ylides

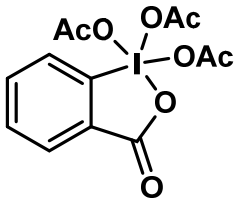


iodonium imides

➢ Iodine(V) Compounds



2-Iodoxybenzoic acid (IBX)

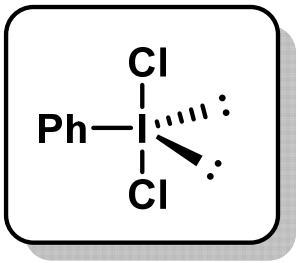


Dess Martin periodinane (DMP)

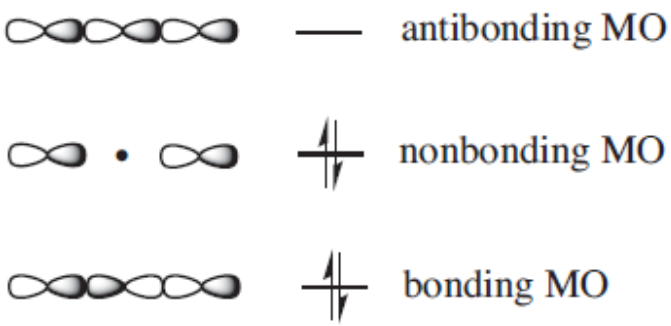
Why Ph- group??

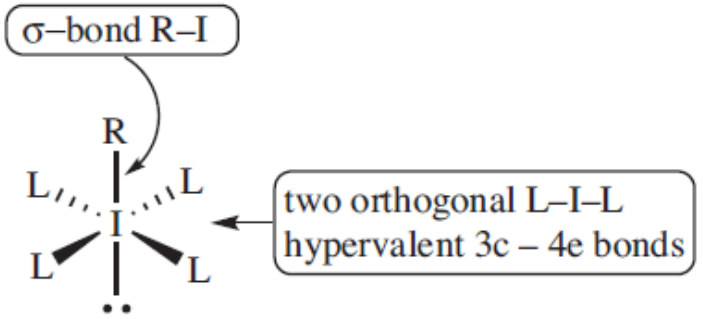
Introduction

- *Hypervalent bonding*
  - *Higher-lying d orbitals (dsp^3 or d^2sp^3)*
  - *New type of highly ionic orbital (3c-4e)*



- *3c-4e bond*
  - *G. C. Pimentel & R. E. Rundle in 1951*



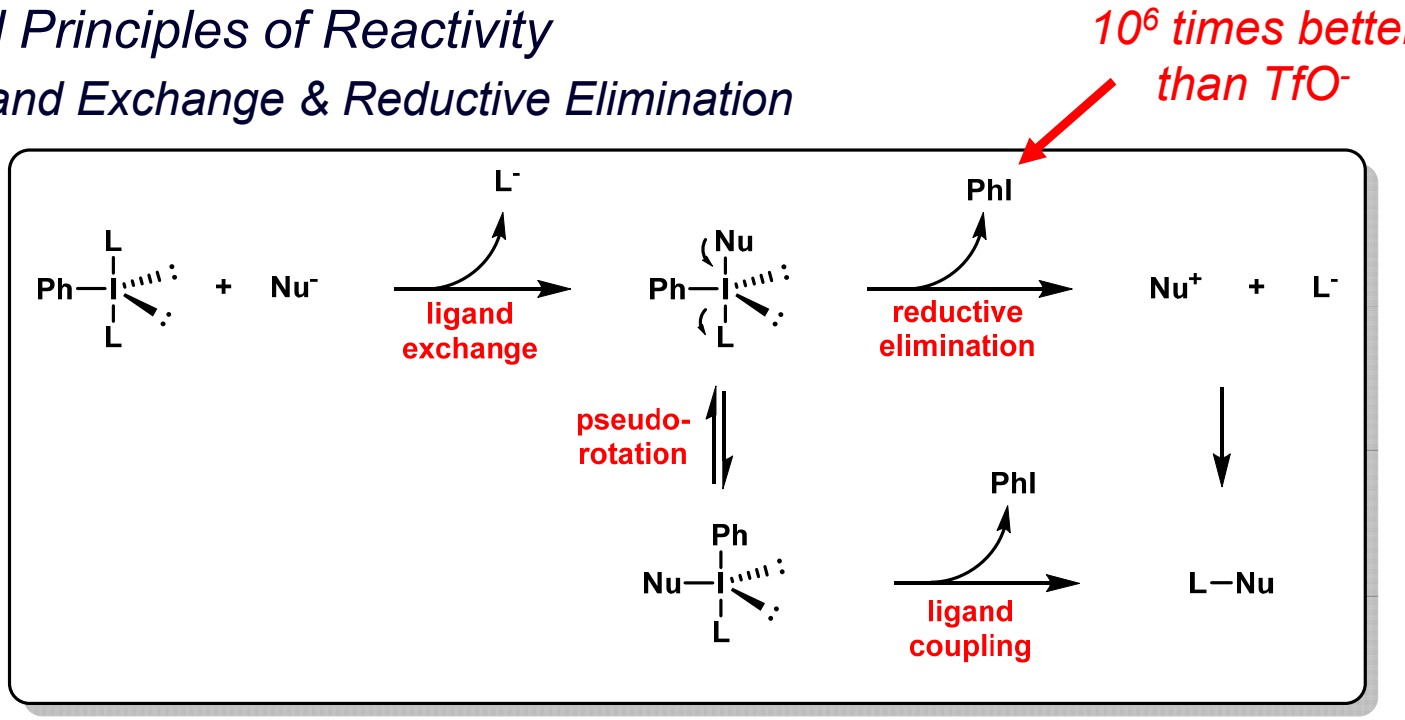


  - *6c-10e bond in iodine(VII) compound*
- *Similar to transition metal complexes*
  - *oxidative addition, reductive elimination, ligand exchange, ligand coupling*

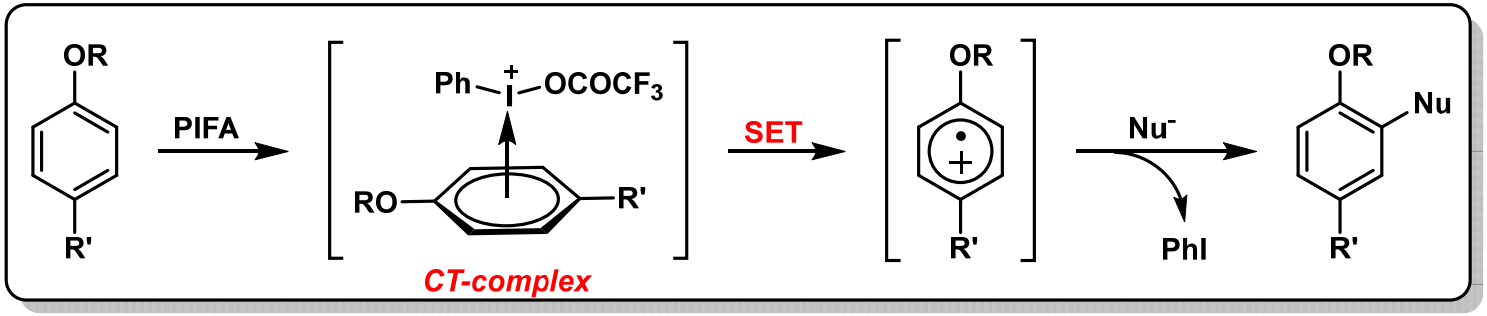
Pimentel, G. C. *J. Chem. Phy*, **1951**, *19*, 446.
Rundle, R. E. *J. Am. Chem. Soc*, **1951**, *73*, 4321.

Introduction

- *General Principles of Reactivity*
  - *Ligand Exchange & Reductive Elimination*



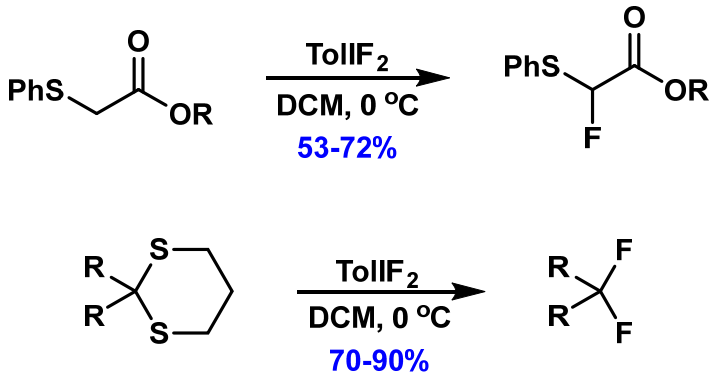
- *Single-Electron Transfer Reactions*



Content

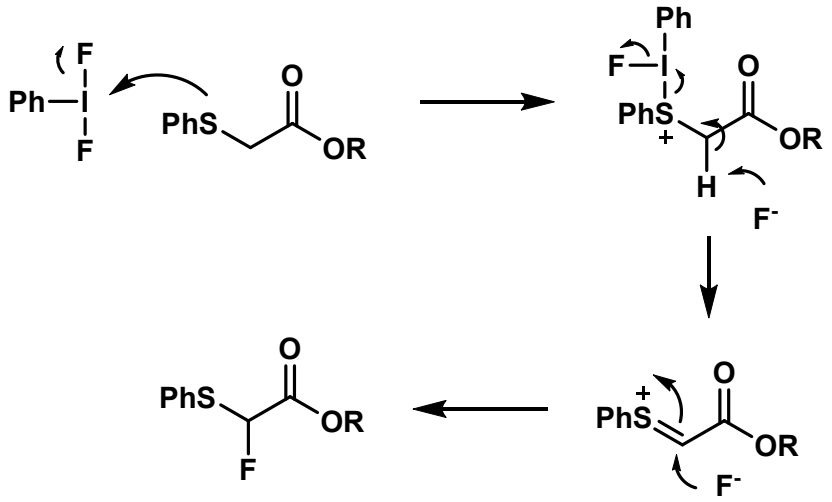
Iodine(III) Reagent

➢ Fluorinations

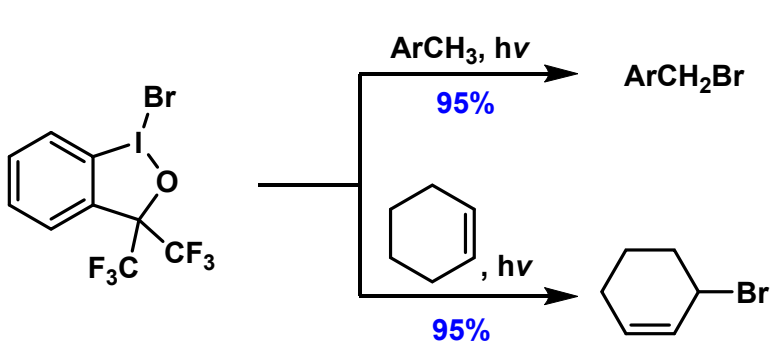


Synlett, **1991**, *3,* 191.

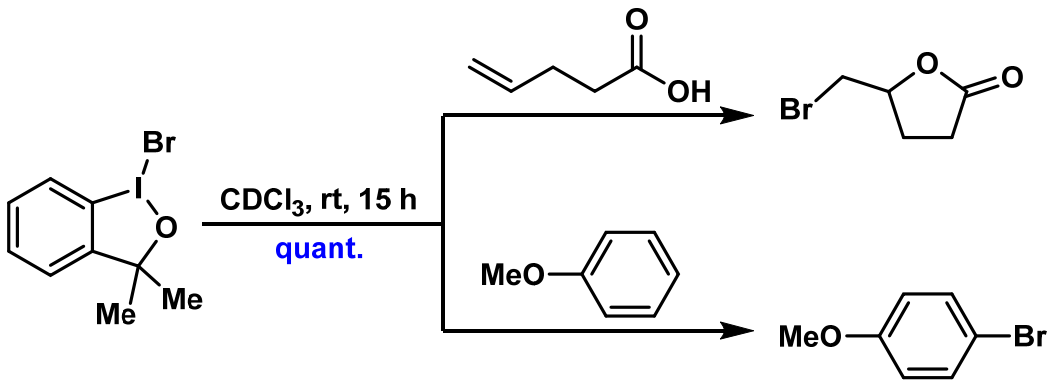
Pummerer-type reaction



➢ Brominations



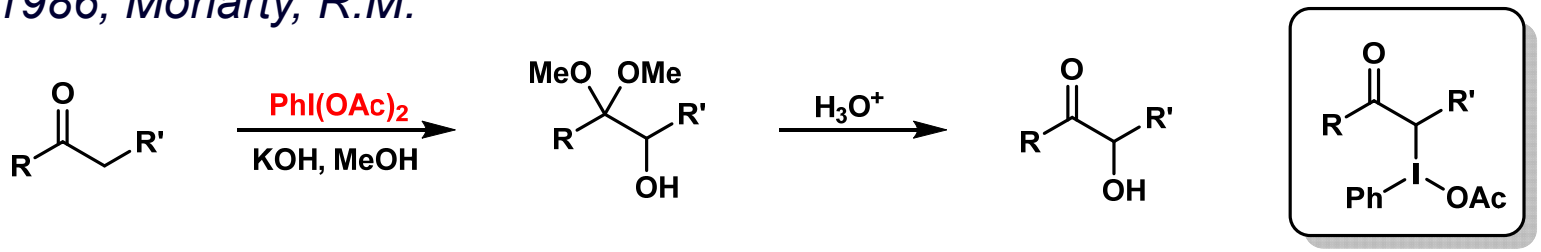
J. Org. Chem, **1979**, *44*, 1779.



Chem. Commun., **2006**, 1442.

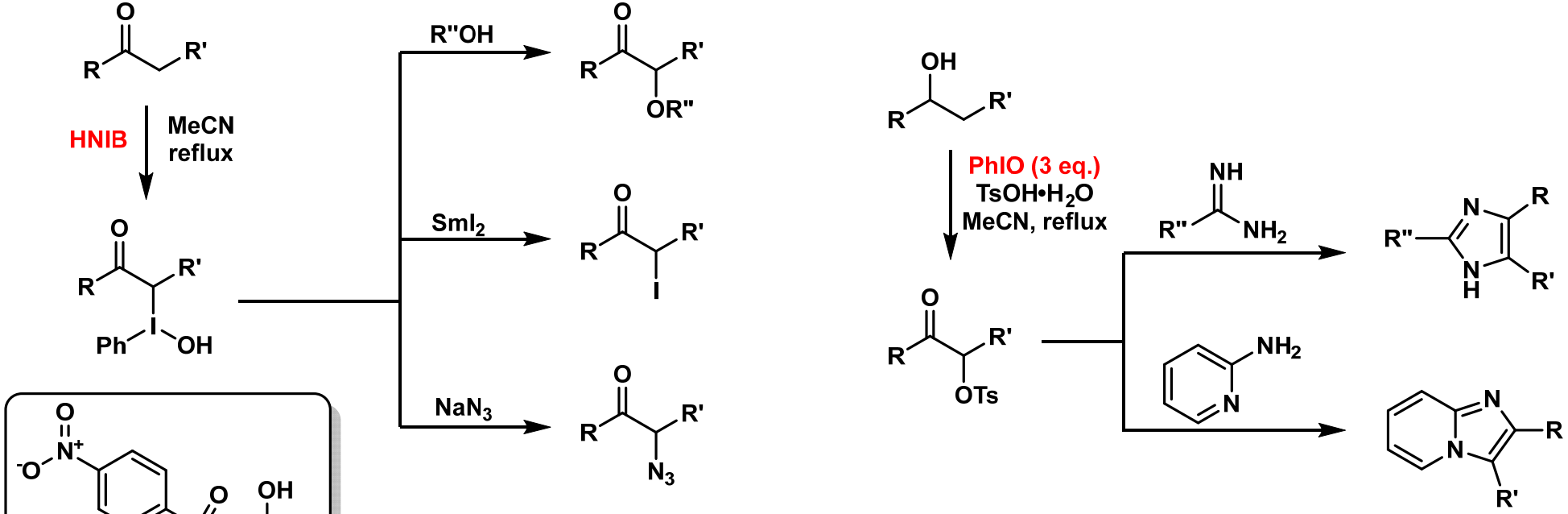
Iodine(III) Reagent

- *Oxidative Functionalization of Carbonyl Compounds*
  - *1986, Moriarty, R.M.*



Acc. Chem. Res. **1986**, *19*, 244.

  - *α-substituted ketones*

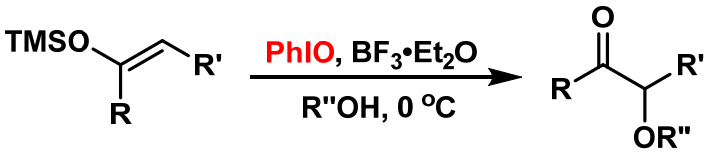


Synth. Commun, **1997**, *27*, 4085.
Synth. Commun, **1999**, *29*, 2769.
Synth. Commun, **2000**, *30*, 4271.

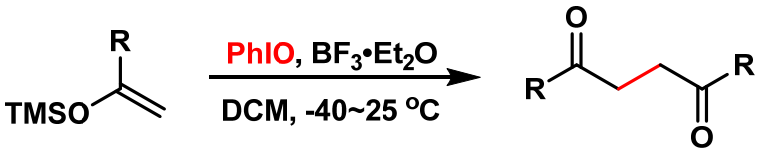
J. Org. Chem, **2003**, *68*, 6424.

Iodine(III) Reagent

➢ Oxidative Functionalization of Silyl Enol Ethers

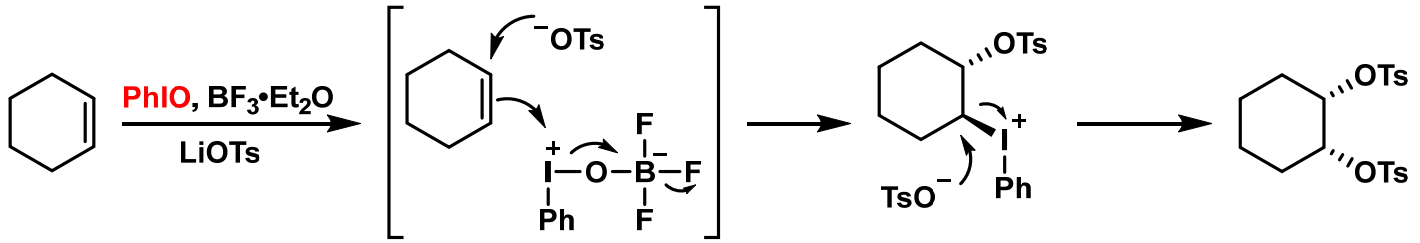


J. Chem. Soc., Perkin Trans. 1, **1987**, 1781.



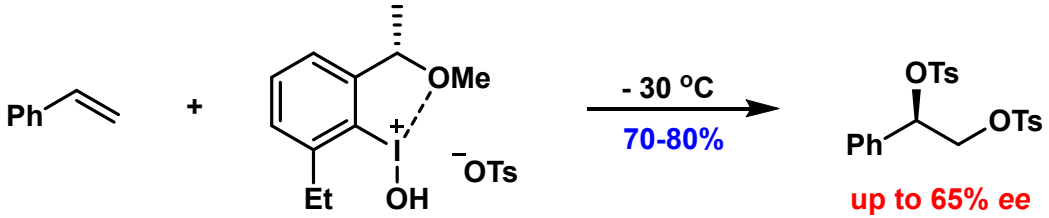
J. Chem. Soc., Perkin Trans. 1, **1987**, 559.

➢ Oxidative Functionalization of Alkene



Tetrahedron Lett. **1986**, *27*, 3971.

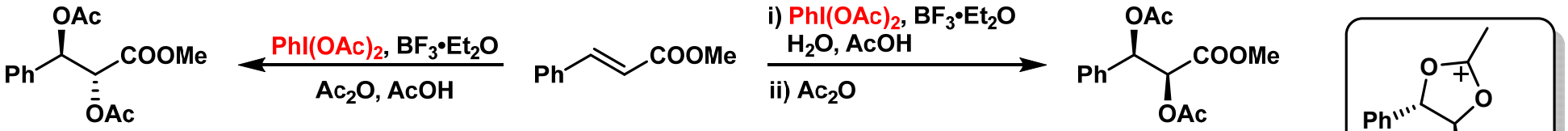
➢ Asymmetric Version



Eur. J. Org. Chem, **2001**, *8*, 1569.

Iodine(III) Reagent

- *Oxidative Functionalization of Alkene*
  - *Reversal of syn/anti selectivity*

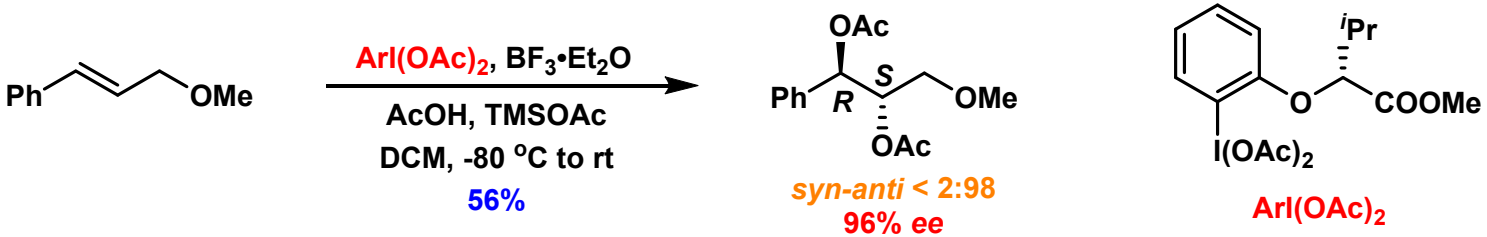


93%
anti:syn = 8.3:1

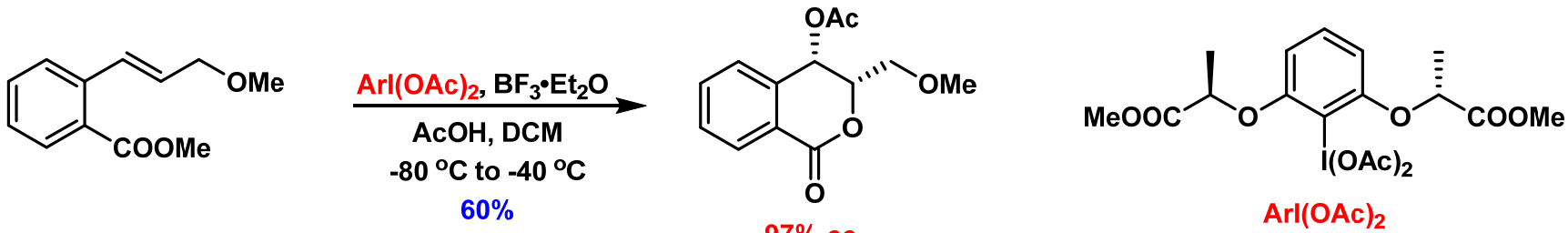
97%
anti:syn < 1:19

J. Org. Chem. ***2011****, 76*, 9997.

- *Asymmetric Version*



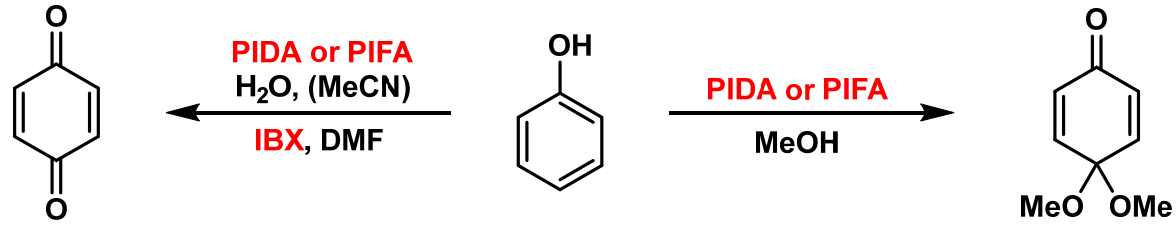
Chem. Commun, **2011**, *47*, 3983.



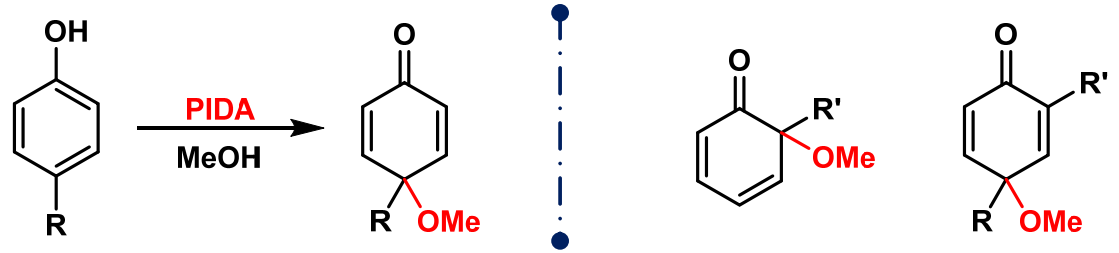
Angew. Chem. Int. Ed. **2010**, *49*, 7068.

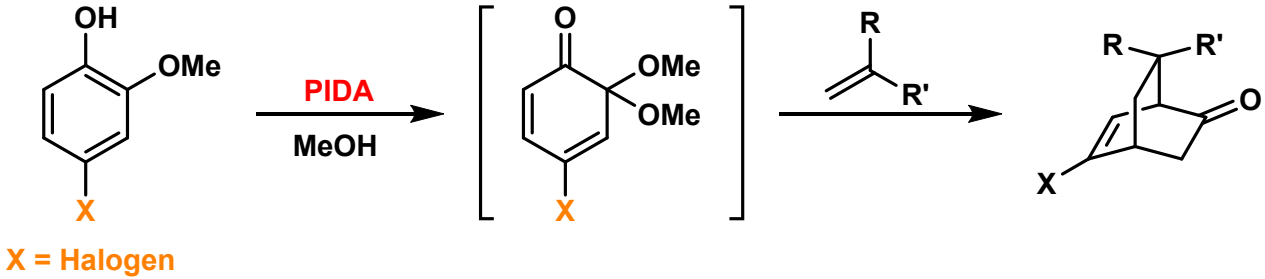
Iodine(III) Reagent

- *Oxidative De-aromatization*
  - *To Quinones & Quinone Monoketals*



  - *Substituted Phenol*



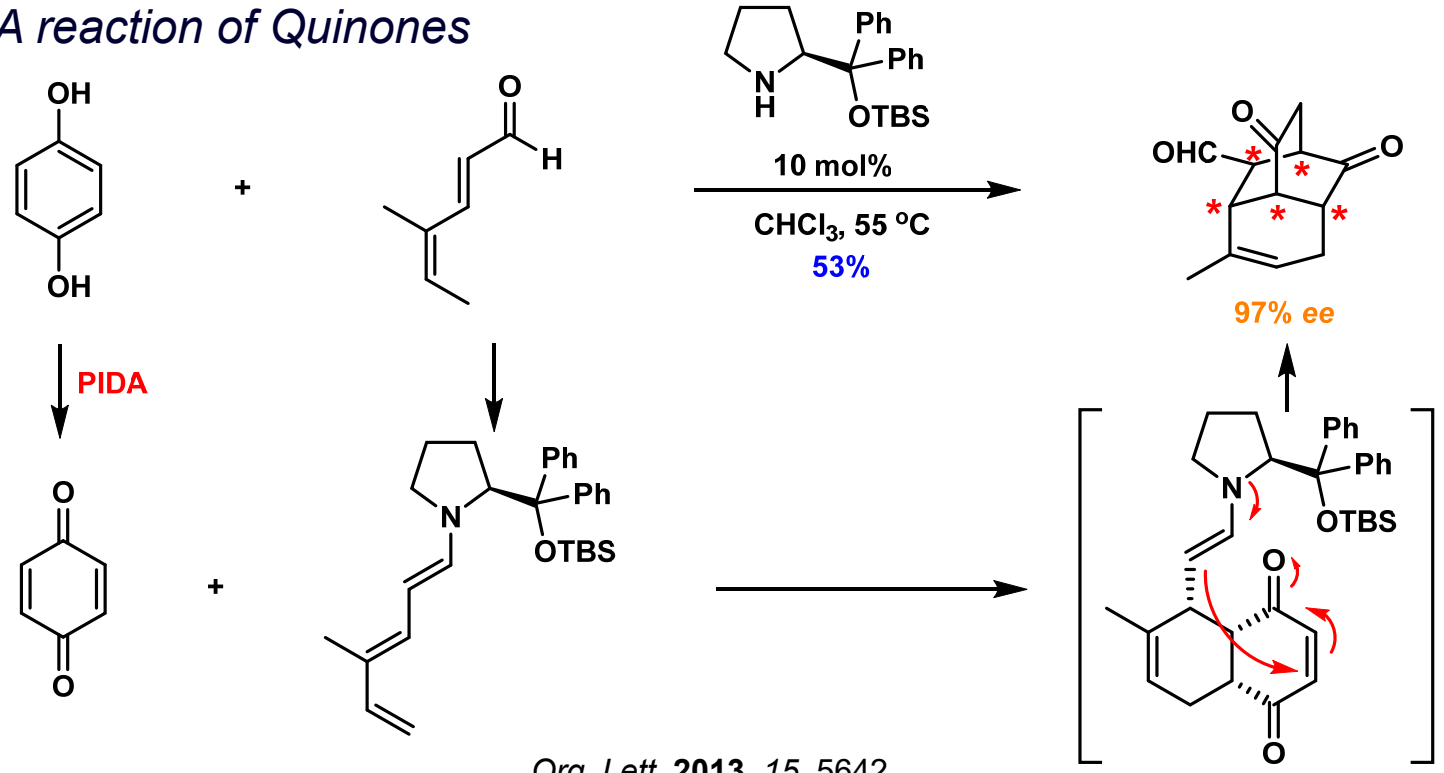


X = Halogen

Org. Biomol. Chem. **2014**, *12*, 5656.

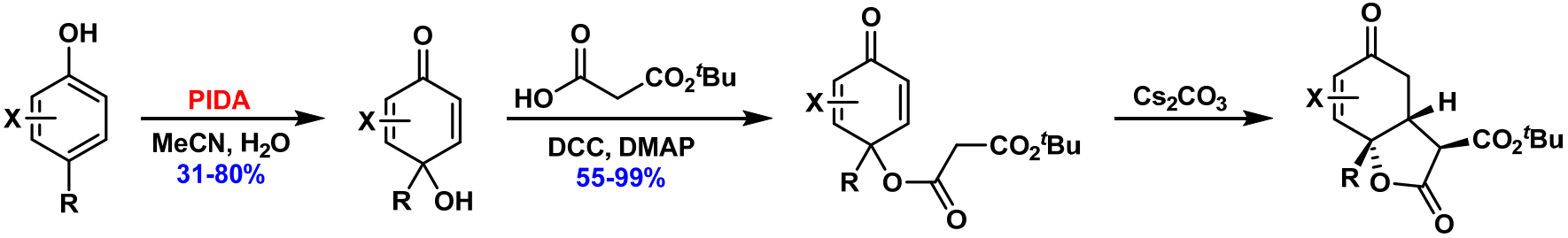
Iodine(III) Reagent

- *Oxidative De-aromatization to Quinones*
  - *D-A reaction of Quinones*



Org. Lett. **2013**, *15*, 5642.

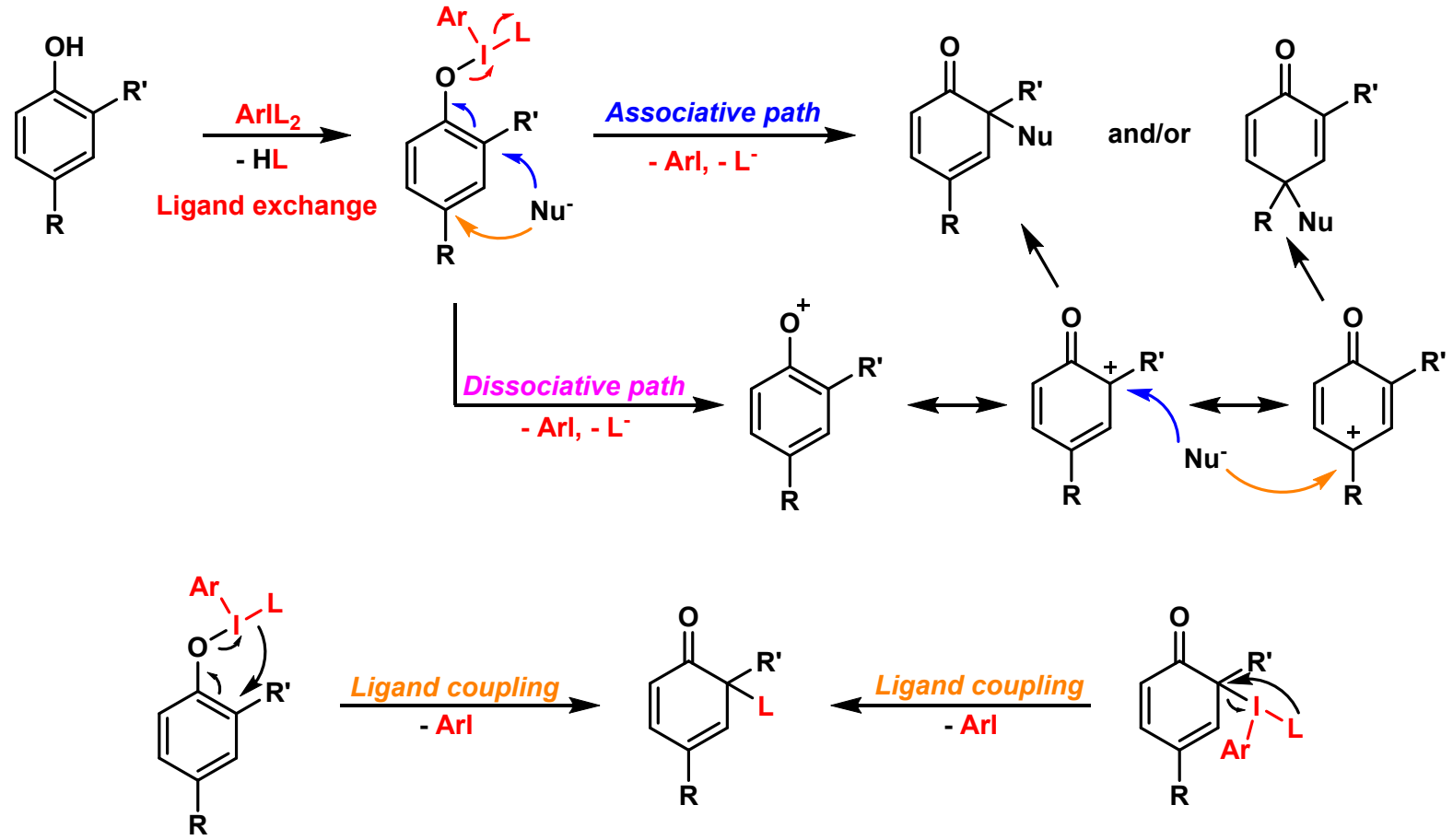
  - *Michael-type Addition*



Org. Biomol. Chem. **2011**, *9*, 7849.

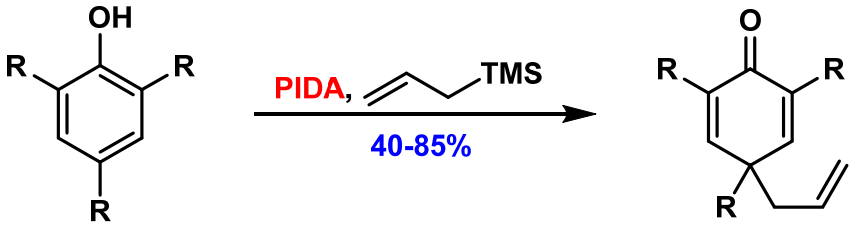
Iodine(III) Reagent

- *Oxidative De-aromatization*
  - *Possible mechanism options*

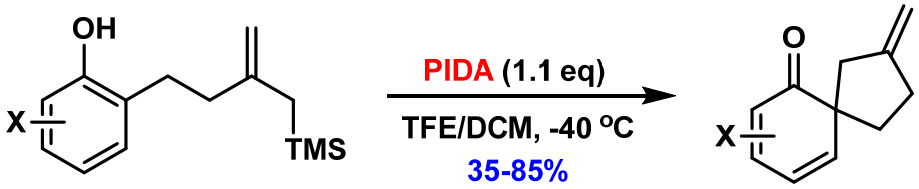


Iodine(III) Reagent

- *Oxidative De-aromatization*
  - *Trapped by C-Nucleophile*

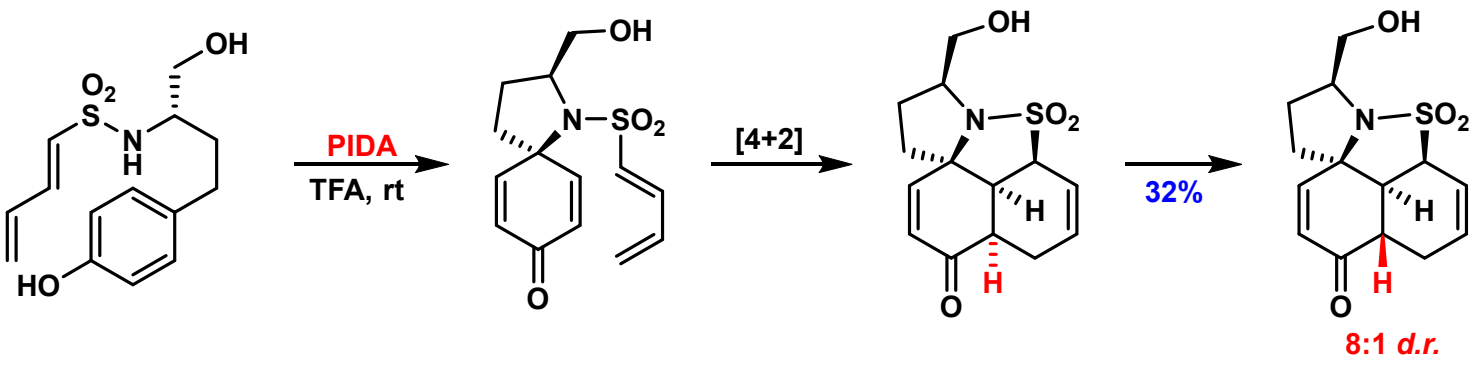


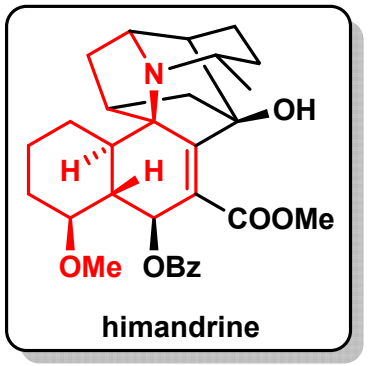
Synlett, **2008**, *20*, 3226.



Org. Lett. **2013**, *15*, 4046.

  - *Trapped by N-Nucleophile*

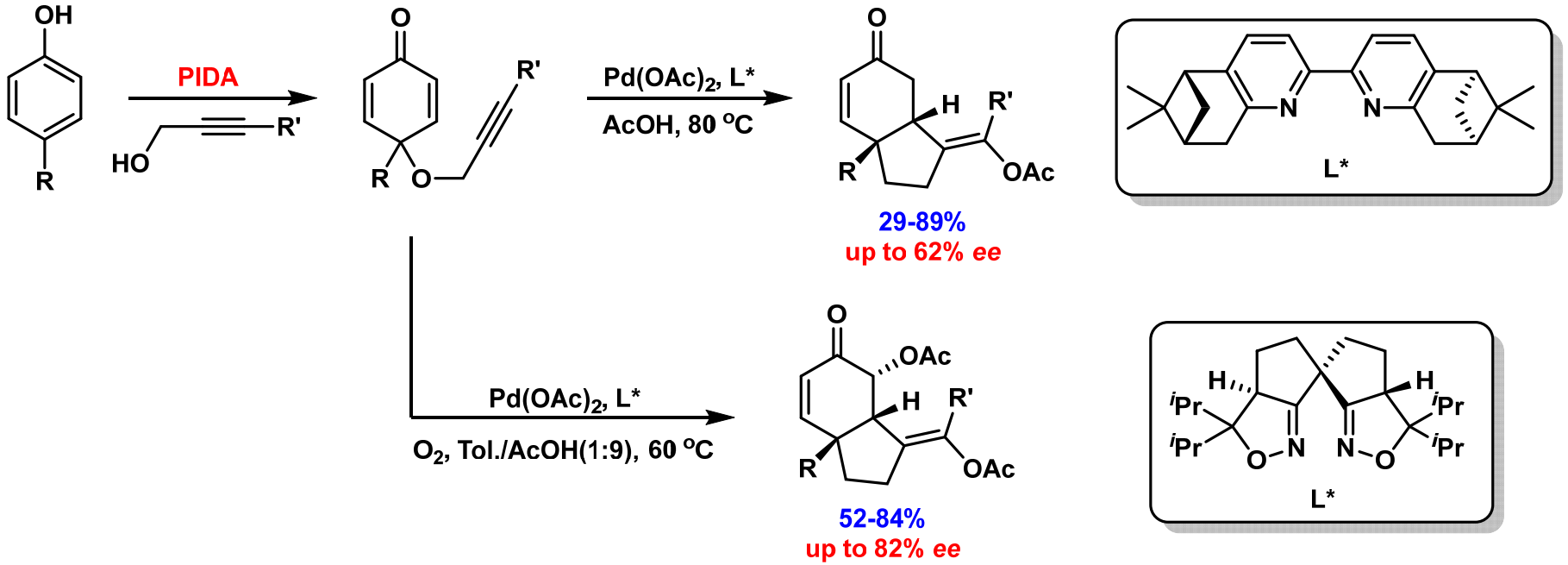


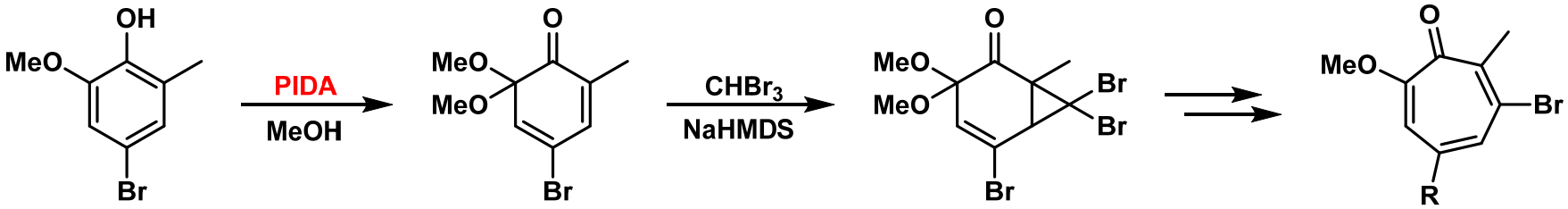


Org. Lett. **2010**, *12*, 1760.

Iodine(III) Reagent

- *Oxidative De-aromatization*
  - *Trapped by O-Nucleophile*

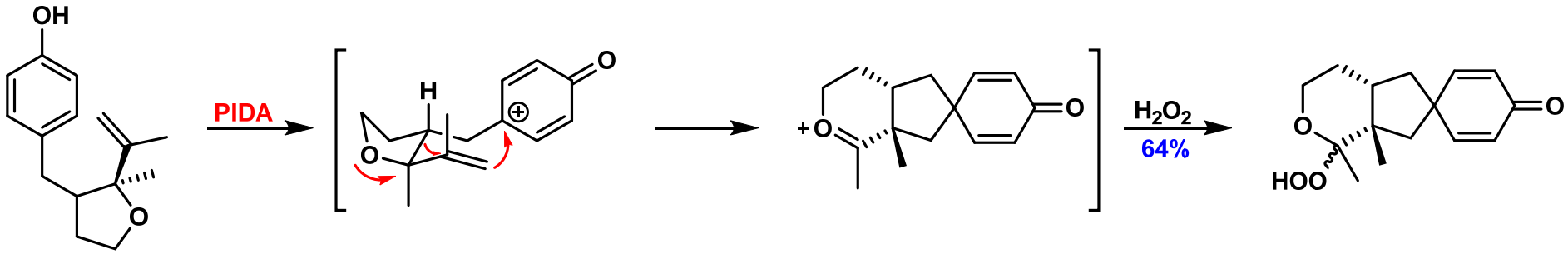




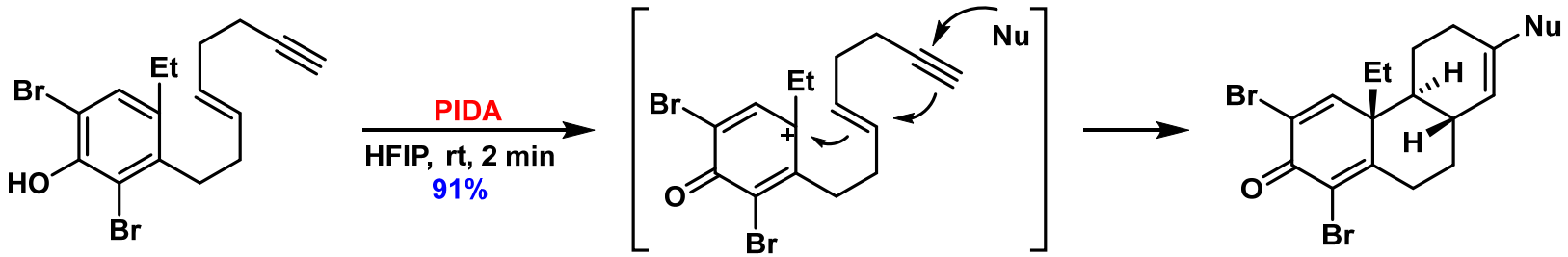
Org. Biomol. Chem., **2013**, *11*, 5596.
Angew. Chem. Int. Ed. **2014**, *53*, 4675.
Org. Lett. **2015**, *17*, 2030.

Iodine(III) Reagent

- *Oxidative De-aromatization*
  - *Induce Rearrangement*



Chem. Eur. J. **2010**, *16*, 11224.

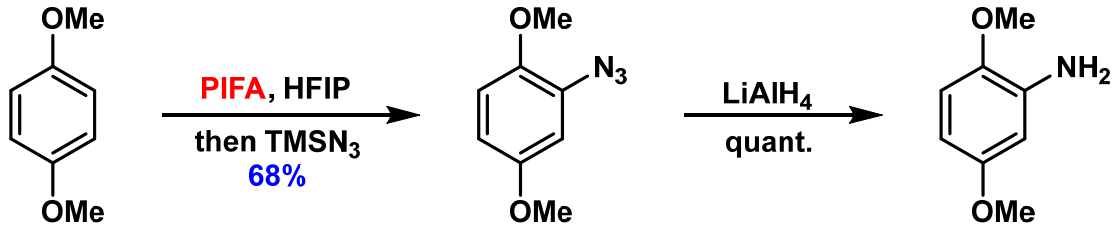


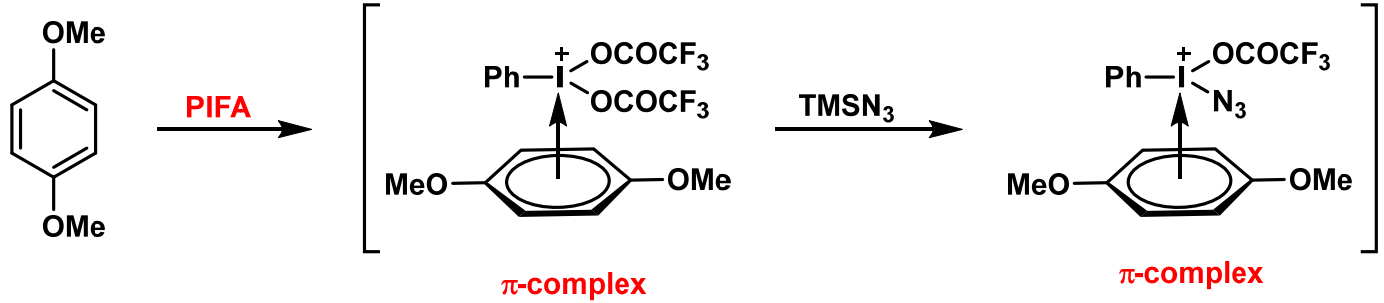
Org. Lett. **2011**, *13*, 3406.

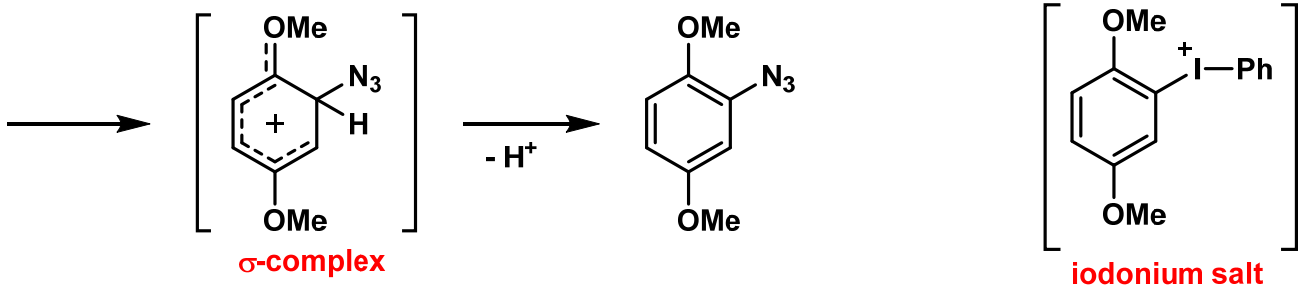
As of today, most mechanistic depictions given in the literature are based on chemists' interpretations of their experimental observations rather than on accurate potential energy-based examinations of reaction coordinates.

Iodine(III) Reagent

- *Oxidative Functionalization of Phenyl Ether*
  - *1991, Yasuyuki Kita*



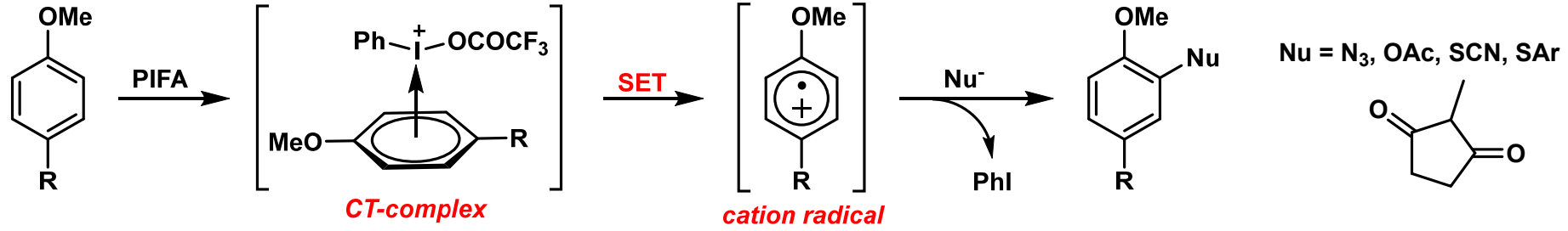




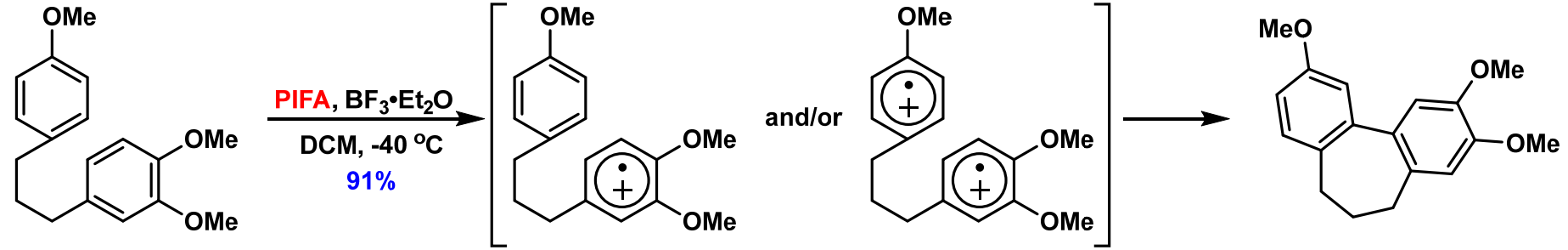
Tetrahedron Lett. **1991**, *31*, 4321.

Iodine(III) Reagent

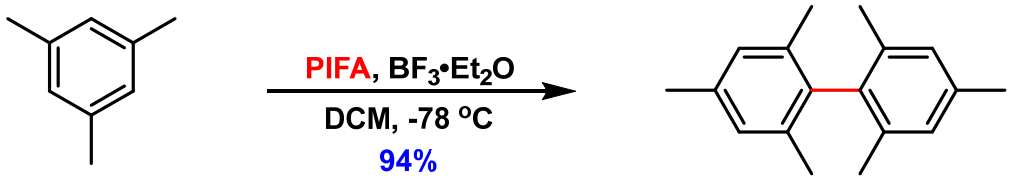
- *Oxidative Functionalization of Phenyl Ether*
  - *1994, Yasuyuki Kita, detected cation radical*



J. Am. Chem. Soc. **1994**, *116*, 3684.



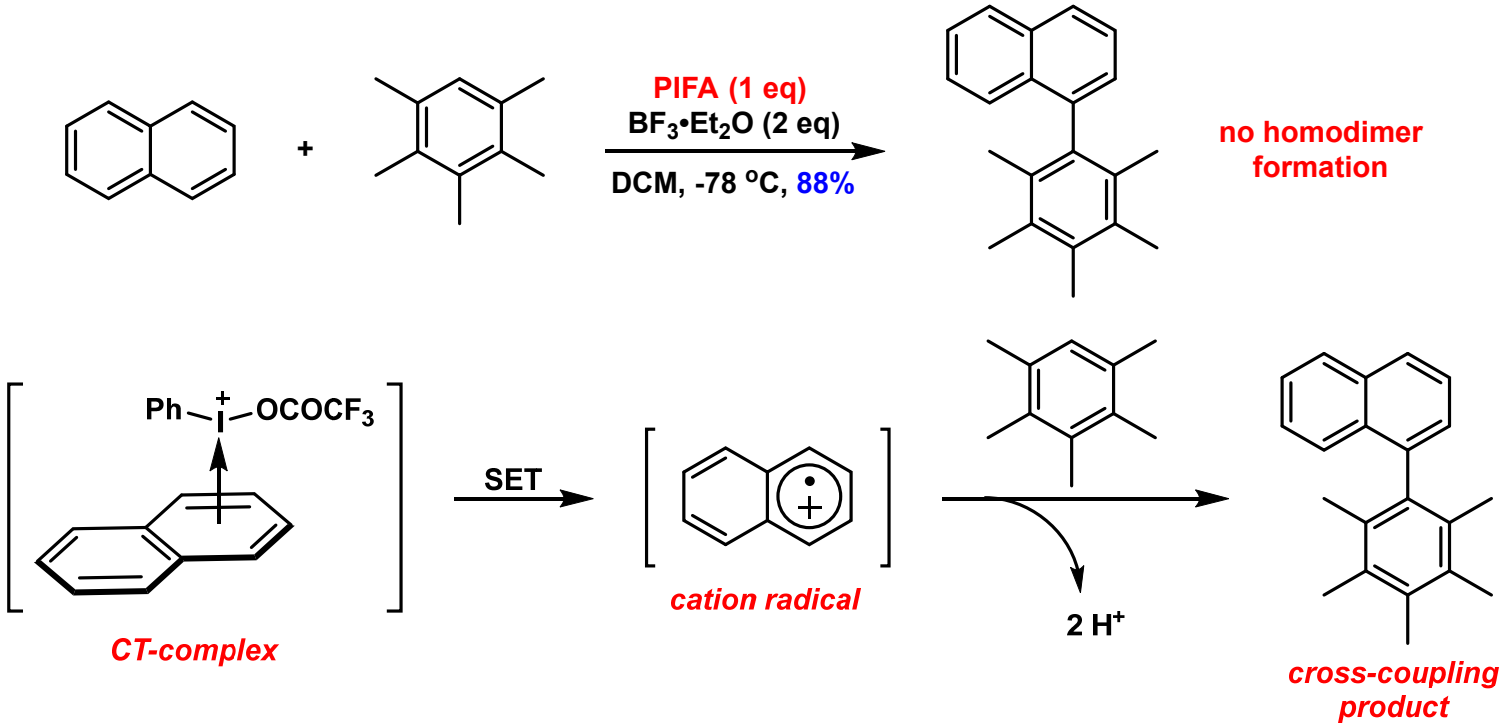
Chem. Commun. **1996**, 1481.

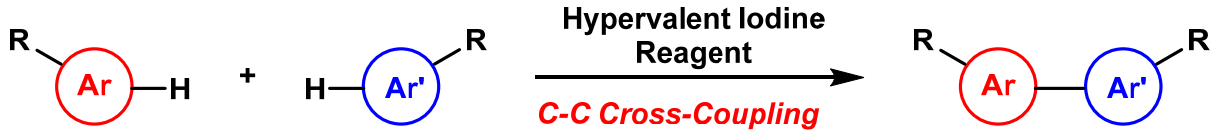


Tetrahedron Lett. **2002**, *43*, 9241.

Iodine(III) Reagent

- *Oxidative Coupling*
  - *First Met in 2008*

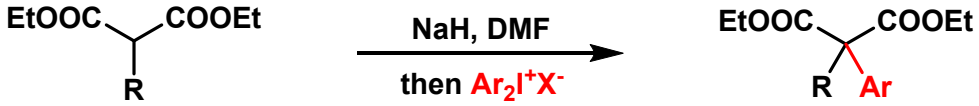




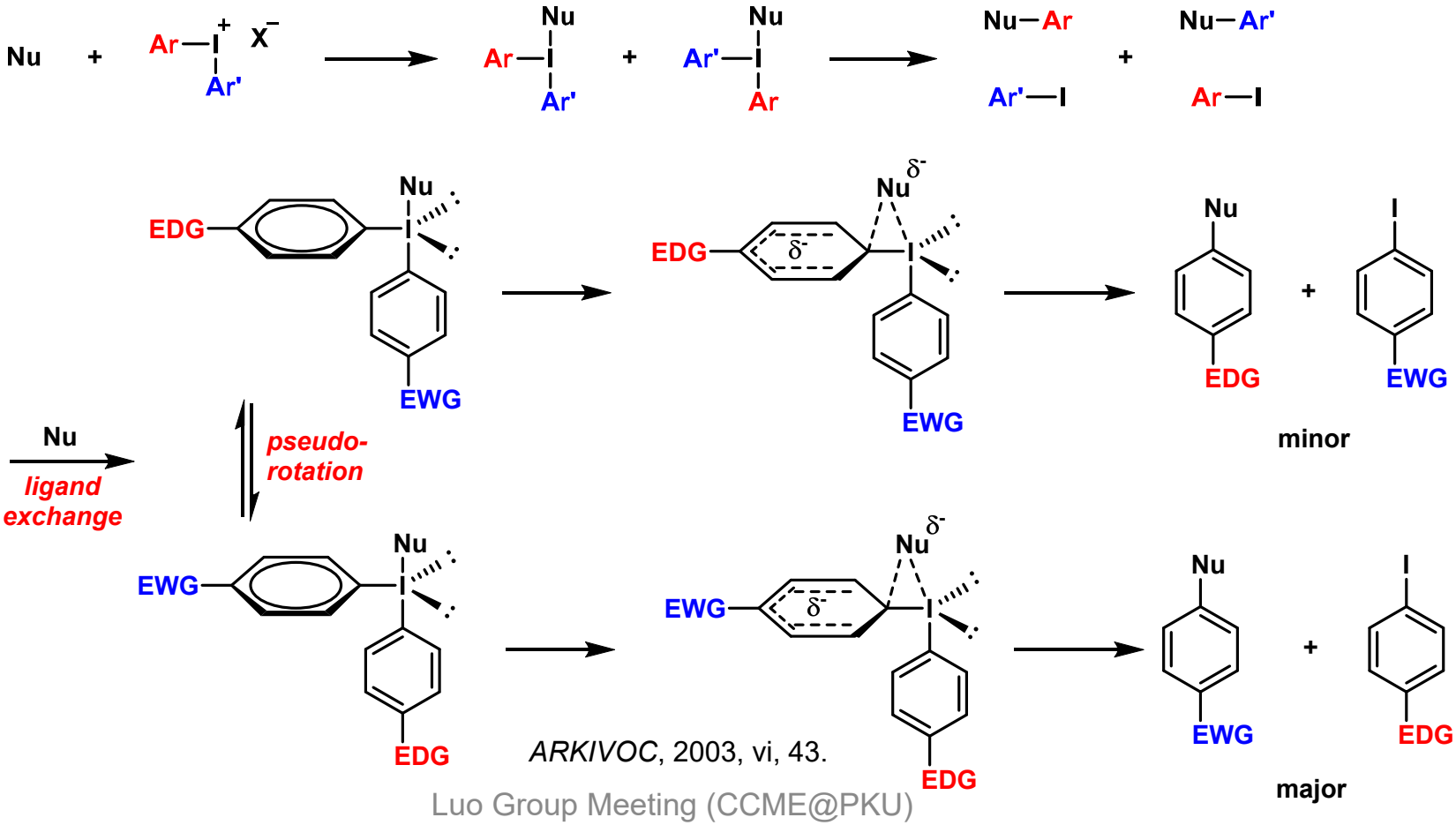
Angew. Chem. Int. Ed. **2008**, *47*, 1301.

Iodine(III) Reagent

➢ *Arylation*



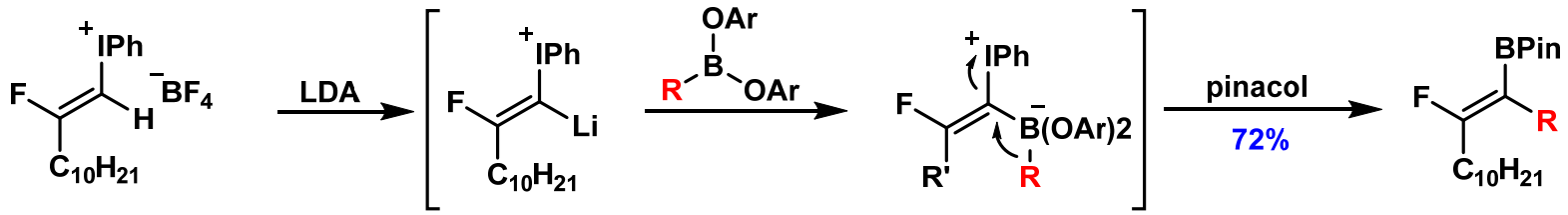
J. Org. Chem. **1999**, *64*, 1338.



ARKIVOC, 2003, vi, 43.

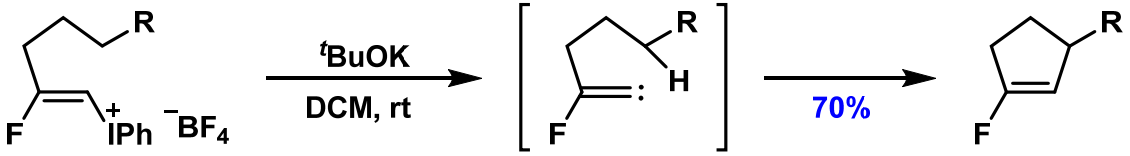
Iodine(III) Reagent

➢ Trans-Boronation



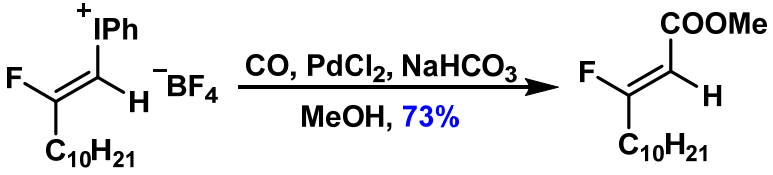
J. Org. Chem. **2007**, *72*, 9617

➢ 1,5-C-H bond insertion

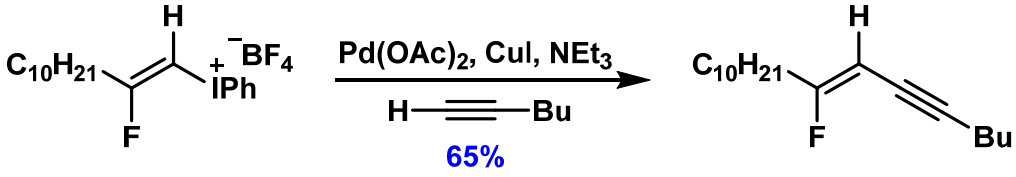


Tetrahedron Lett, **2007**, *49*, 76.

➢ Metal-Catalyzed Reaction



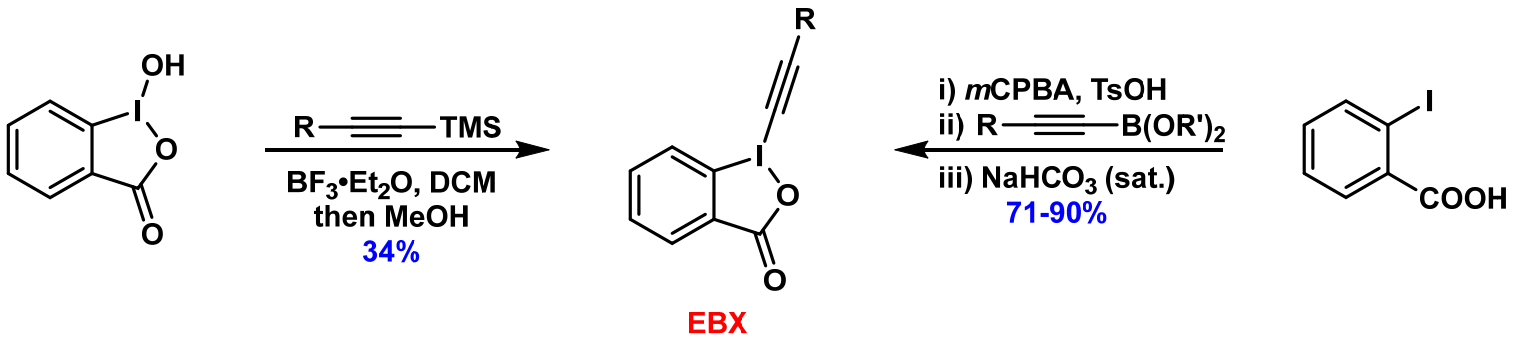
J. Fluo. Chem. **2004**, *125*, 527.



Org. Lett. **2003**, *5*, 573.

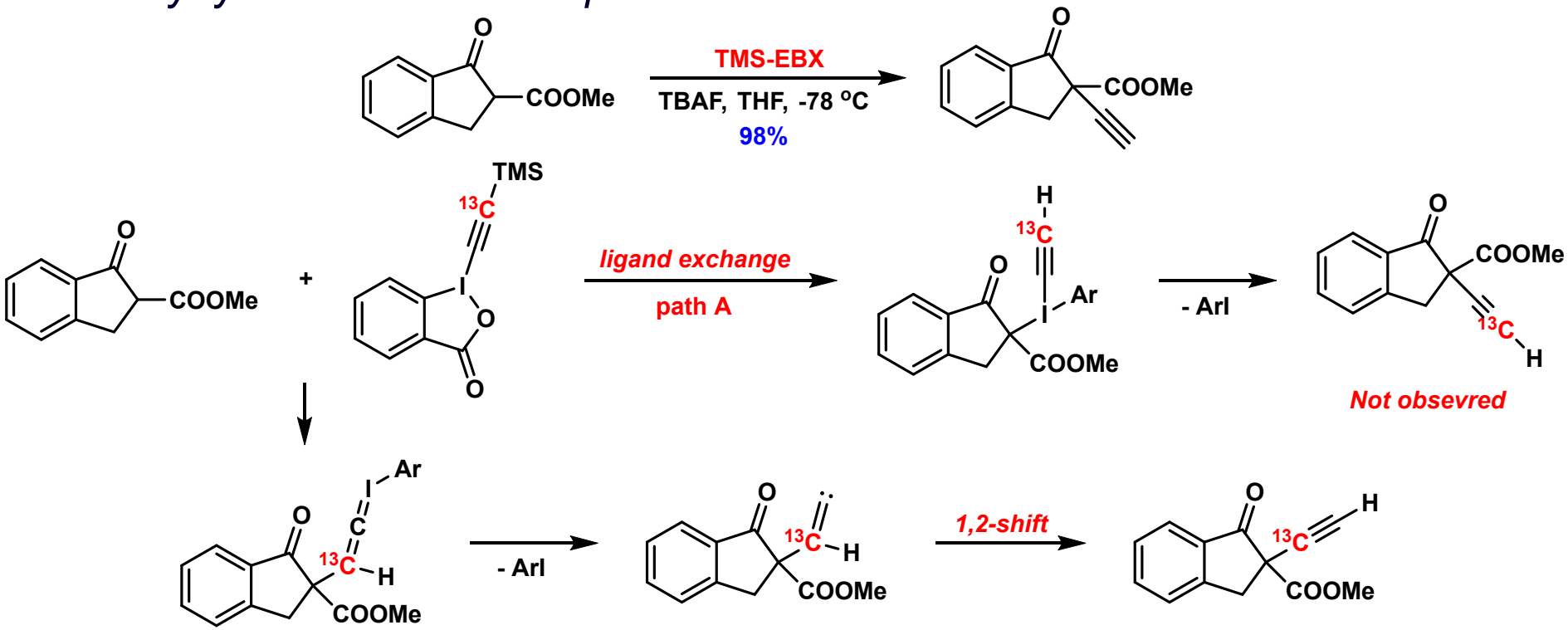
Iodine(III) Reagent

- *EBX*



J. Org. Chem. **1991**, *56*, 5511. *Chem. Eur. J.* **2012**, *18*, 14242.

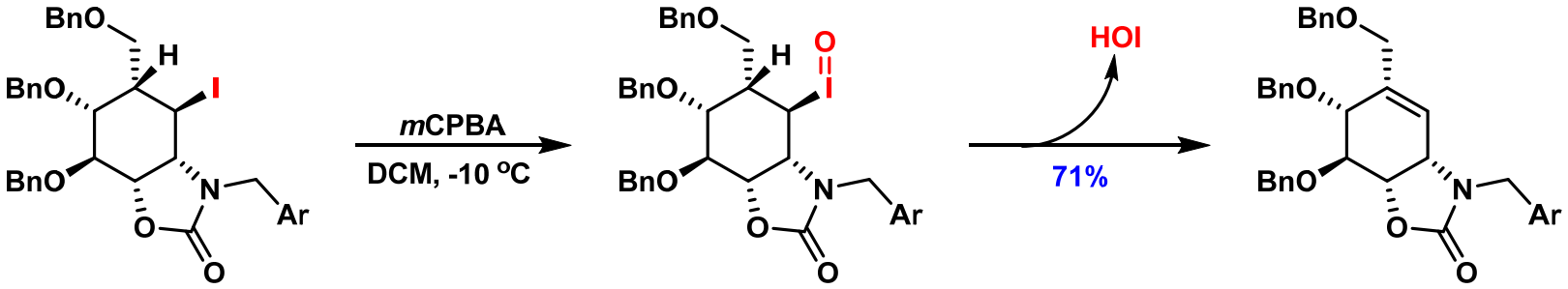
- *1st Alkynylation of C-Nucleophile*



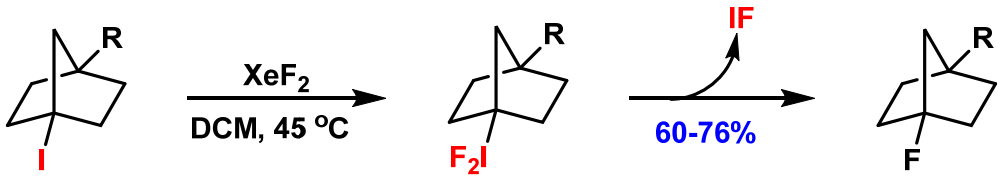
Chem. Eur. J. **2010**, *16*, 9457.

Iodine(III) Reagent

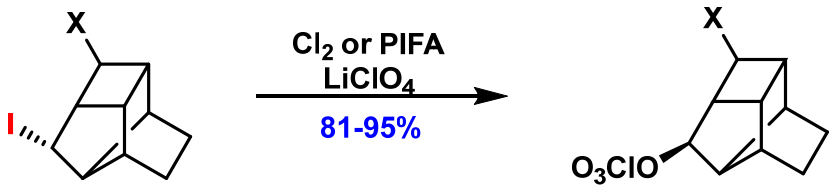
- *Reactions via Alkyliodine(III) Intermediatesn*



Tetrahedron Lett, **1992**, *33*, 1025.



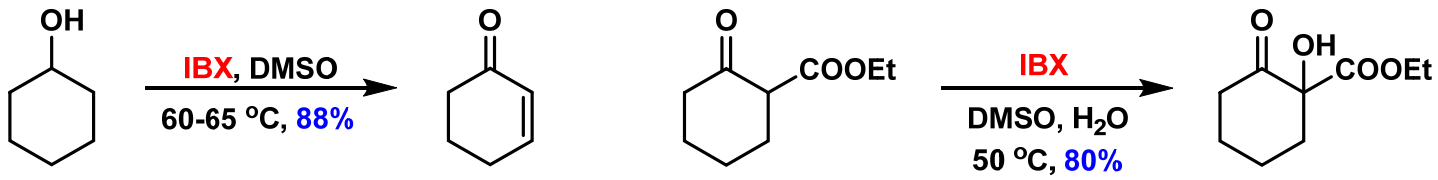
J. Org. Chem, **1992**, *57*, 2850.

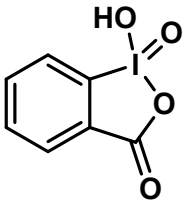


Tetrahedron Lett, **1986**, *27*, 1845.

Iodine(V) Reagent

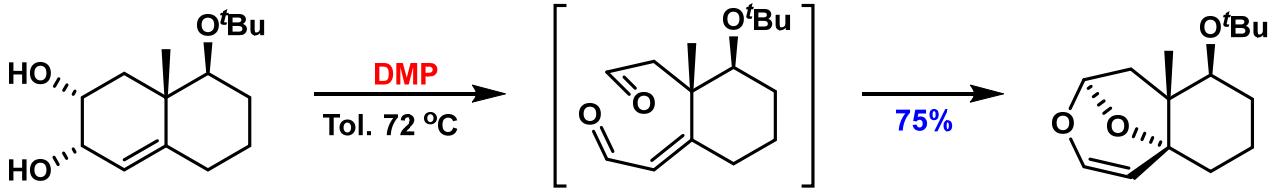
- *IBX*

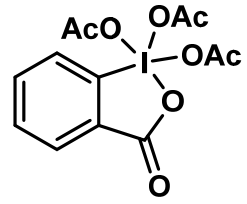




2-Iodoxybenzoic acid (IBX)

- *Dess Martin Periodiane*

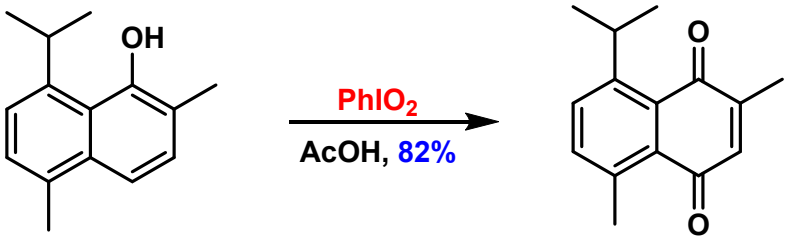




Dess Martin periodinane (DMP)

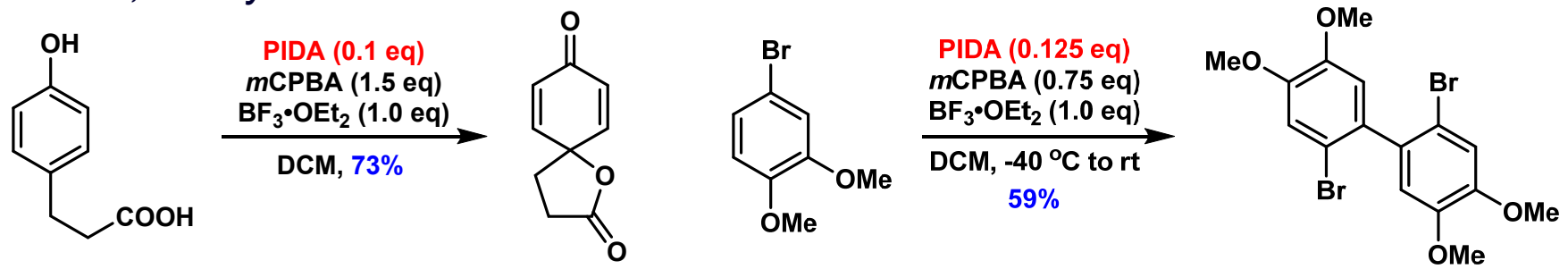
Synlett, **2001**, 597.

- *$PhIO_2$*



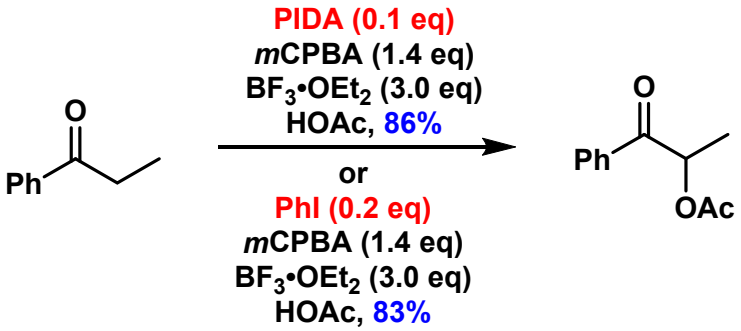
Catalytic application

- *Concept*
  - *2005, Yasuyuki Kita*



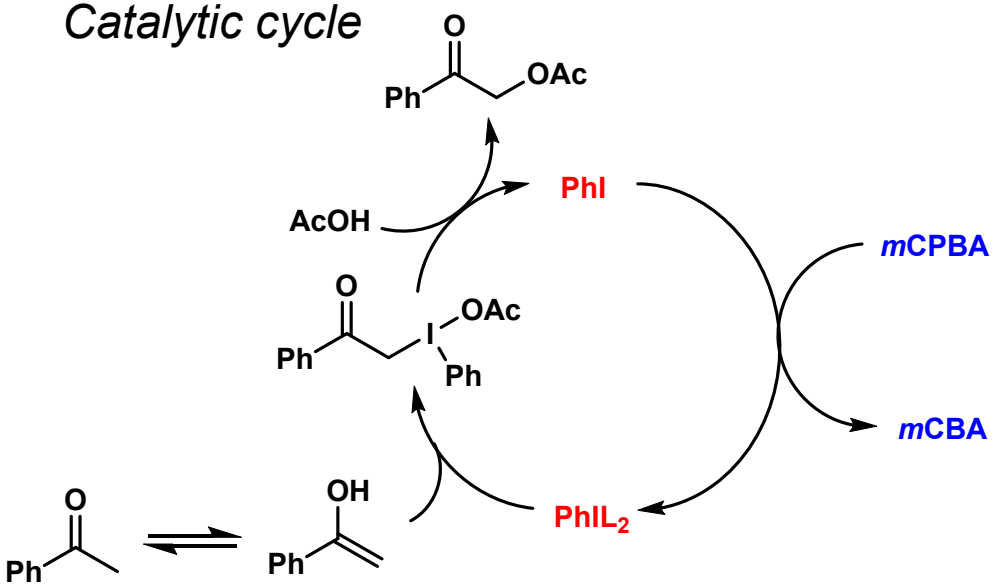
Angew. Chem. Int. Ed. **2005**, *44*, 6193.

  - *2005, Masahito Ochiai*



J. Am. Chem. Soc. **2005**, *127*, 12244.

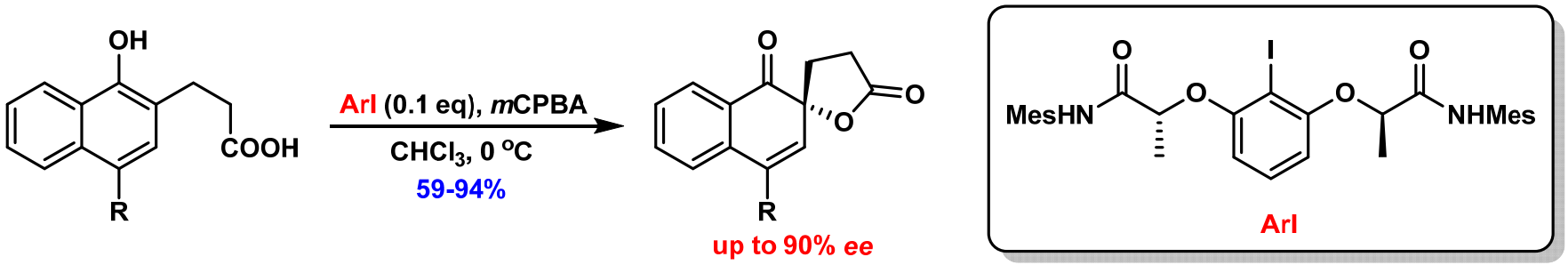
Catalytic cycle



Oxidant: *m*CPBA, Oxone®

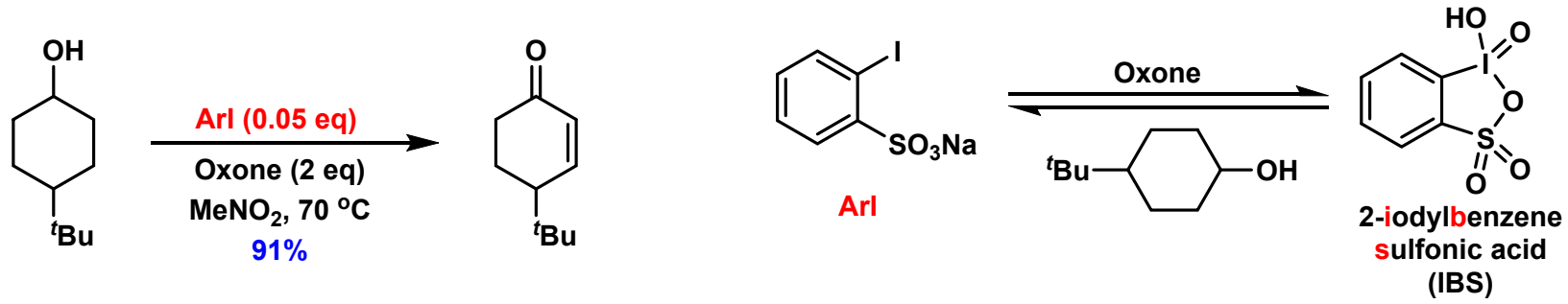
Catalytic application

- *Based on I(III) Species*



Angew. Chem. Int. Ed. **2010**, *49*, 2175.

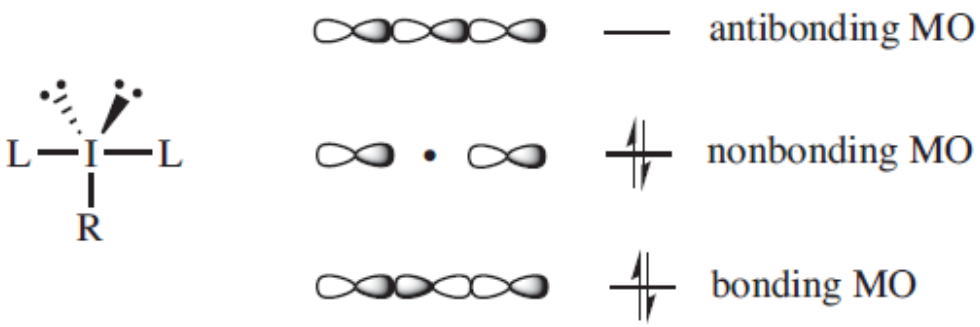
- *Based on I(V) Species*



J. Fluo. Chem, **2012**, *137*, 99.

Summary

- *3c-4e bond*



Similar to Transition Metals