Chapter 5

Functional Group Transformations: Carbon-Carbon π Bonds

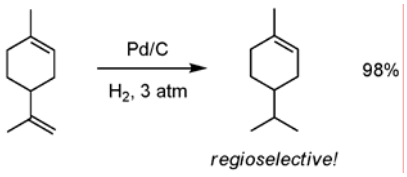
5.1 – Reactions of Carbon-Carbon Double Bonds

- Hydrogenation reactions
- Hydration of Alkenes
- Oxymercuration – demercuration
- Epoxidation of Alkenes
- Epoxidation of Allylic Alcohols
- Dihydroxylation of Alkenes
- Halolactonization
- Cleavage of C-C Double Bonds

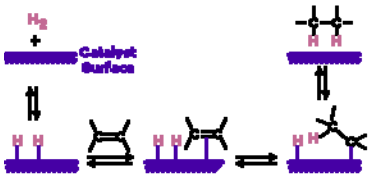
5.2 – Reactions of Carbon-Carbon Triple Bonds (Selected)

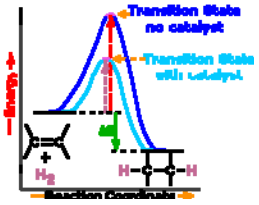
5.1 – Hydrogenation of Carbon-Carbon Double Bonds

Catalytic Hydrogenation



Proposed Mechanism

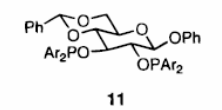




http://www.cem.msu.edu/~reusch/VirtualText/addene2.htm#add4

5.1 – Hydrogenation of Carbon-Carbon Double Bonds

Asymmetric Hydrogenation – Chiral ligands



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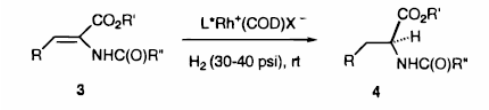
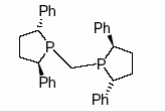
Rajanbabu, T. V. et. al. *J. Org. Chem*. **1997**, *62*, 6012-6028

Used as "L" in:



3 4

Up to 100% conversion and 99% e.e.



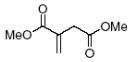
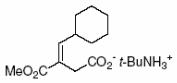
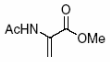
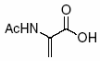
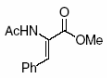
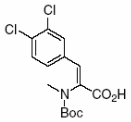
4 (*R*,*R*)-Ph-BPM

Jackson, M.; Lennon, I. C. *Tetrahedron Lett*. **2007**, *48*, 1831-1834

See next slide for application

5.1 – Hydrogenation of Carbon-Carbon Double Bonds

Table 1. Hydrogenation using [(*R*,*R*)-Ph-BPM Rh(COD)]BF_4

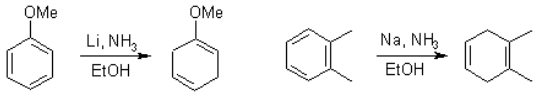
Entry	Substrate	S/C	Conditions	Conv. (%)	ee (%)
1		10,000	MeOH, 30 °C, 10 bar H_2, 15 min	100	99.5 (*R*)
2		1000	MeOH, 30 °C, 10 bar H_2, 6 h	100	91 (*R*)
3		5000	MeOH, 30 °C, 6 bar H_2, 1 h	>99	>99 (*S*)
4		5000	MeOH, 30 °C, 6 bar H_2, 75 min	>99	>99 (*S*)
5		3000	MeOH, 30 °C, 10 bar H_2, 18 h	>99	99 (*S*)
6		200	MeOH, 30 °C, 10 bar H_2, 18 h	96%	95 (*R*)

Jackson, M.; Lennon, I. C. *Tetrahedron Lett*. **2007**, *48*, 1831-1834

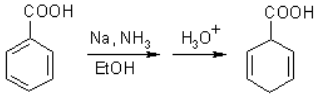
5.1 – Hydrogenation of Carbon-Carbon Double Bonds

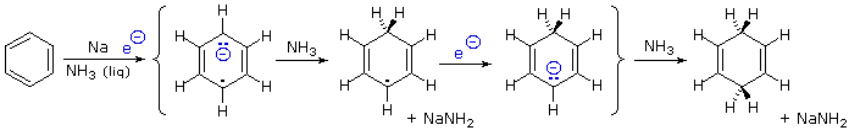
Dissolving Metal Reductions – The Birch Reduction

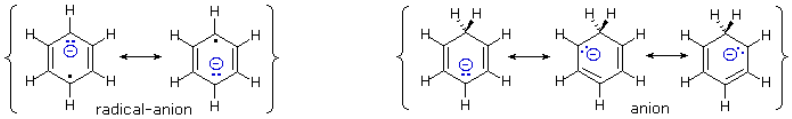
ED-groups



EWG-groups

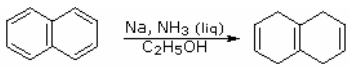






5.1 – Hydrogenation of Carbon-Carbon Double Bonds

1.



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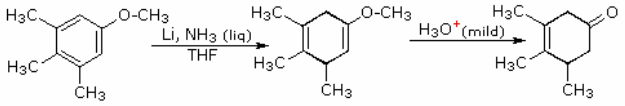

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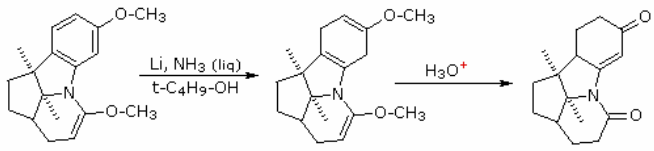
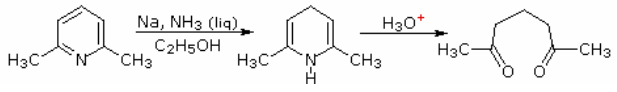
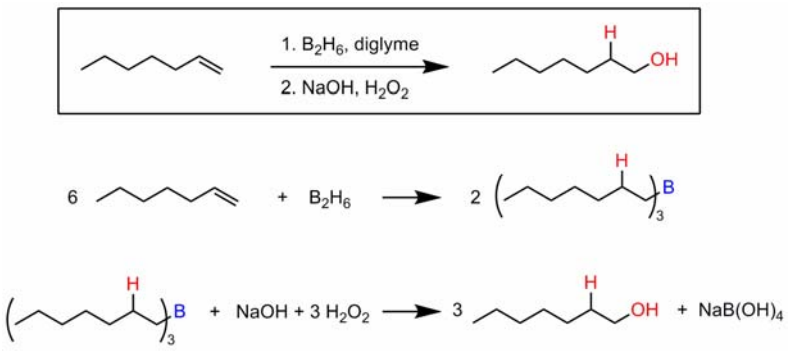


5.



5.1 – Hydration of Alkenes – Hydroboration

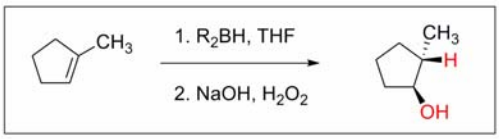


Reaction is *regioselective* and *stereoselective*

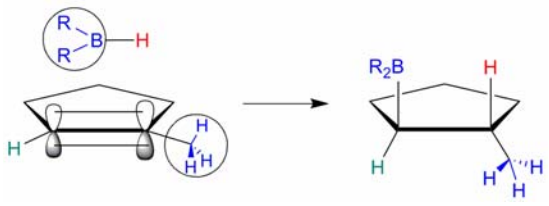
Addition of R_2B-H is a ***concerted syn* addition**

Oxidation step ***retains the stereochemistry* from first step**

5.1 – Hydration of Alkenes – Hydroboration



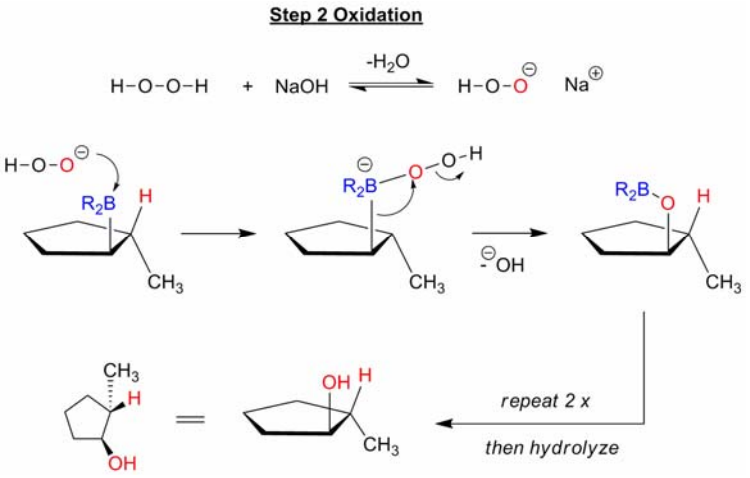
Step 1 *Syn* Addition



Larger BR_2 group adds to less substituted end of the alkene

Reaction is then *regioselective*

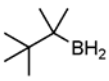
5.1 – Hydration of Alkenes – Hydroboration



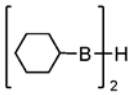
The oxidation features a ***concerted alkyl migration* so the ***syn stereochemistry is retained*** from the R_2B-H addition in the first step.**

5.1 – Hydration of Alkenes – Hydroboration

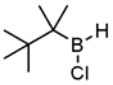
Hydroboration Reagents



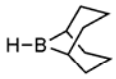
thexylborane ($ThxBH_2$)



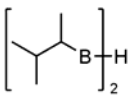
Dicyclohexylborane (Chx_2BH)



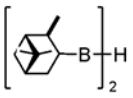
thexylchloroborane (ThxBClH)



9-Borabicyclo[3.3.1]nonane (9-BBN)



Disiamylborane (Sia_2BH)



Diisopinocampheylborane (Ipc_2BH)

Most are now commercially available

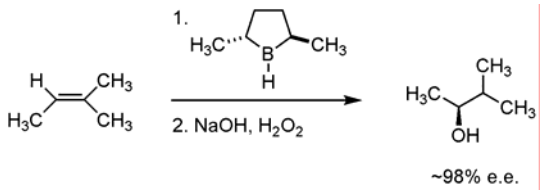
5.1 – Hydration of Alkenes – Hydroboration

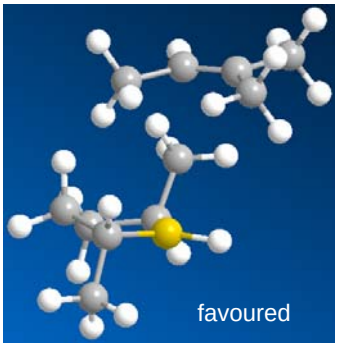
	$RCH{=}CH_2$	$i\text{-}PrCH{=}CHCH_3$	$(CH_3)_2C{=}CHCH_3$	$PhCH{=}CH_2$
BH_3.THF	6 : 94	43 : 57	2 : 98	19 : 81
Sia_2BH	1 : 99	3 : 97		2 : 98
9-BBN	1 : 99	1 : 99		2 : 98

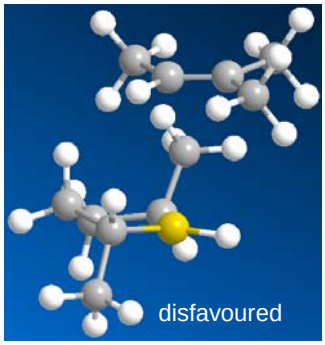
Regioselectivity improves with increasing bulk of R groups

5.1 – Hydration of Alkenes – Hydroboration

Asymmetric Variant – 2,5-Dimethylborolane

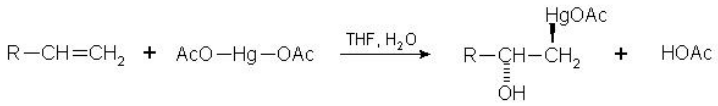




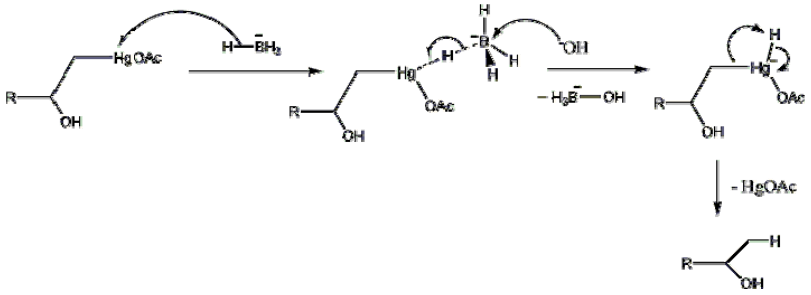


5.1 – Hydration of Alkenes – Oxymercuration/demercuration

Oxymercuration

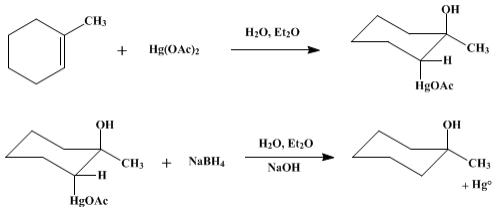


Demercuration



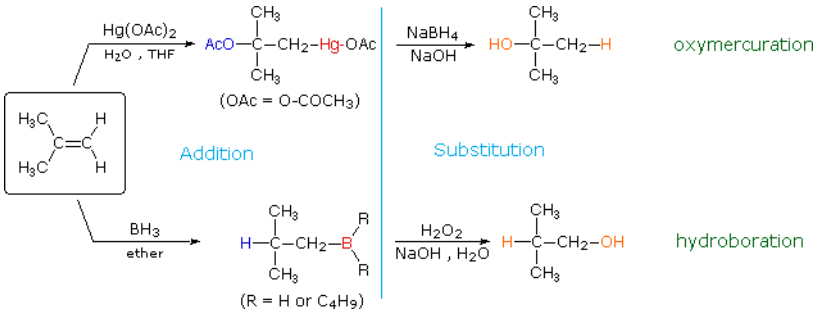
5.1 – Hydration of Alkenes – Oxymercuration/demercuration

Org. Syn. prep

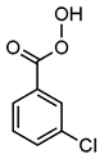


Org. Syn. Coll. Vol. 6 **1998**, 766

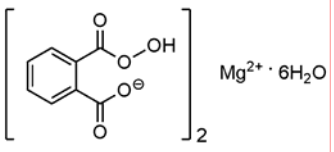
Regioselectivity



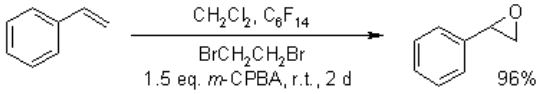
5.1 – Epoxidation of Alkenes



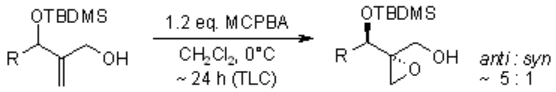
m-chloroperoxybenzoic acid
(*m*-CPBA)



magnesium(monoperoxyphthalate)$_2$
(MMPP)



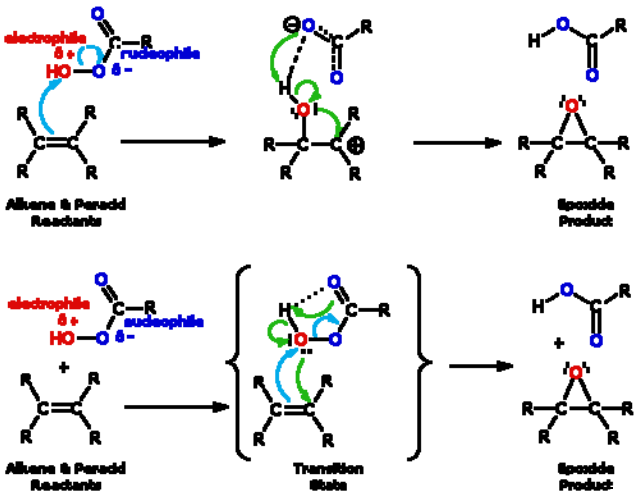
N. K. Jana, J. G. Verkade, *Org. Lett.,* **2003**, *5*, 3787-3790.



R. S. Porto, M. L. A. A. Vasconcellos, E. Ventura, F. Coelho, *Synthesis*, **2005**, 2297-2306.

5.1 – Epoxidation of Alkenes

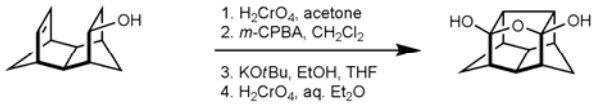
Mechanistic Possibilities



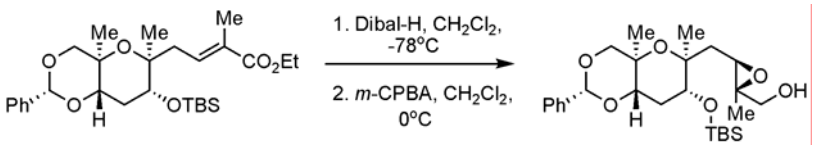
http://www.cem.msu.edu/~reusch/VirtualText/addene2.htm#add3c

5.1 – Epoxidation of Alkenes

Oxidation, peroxidation, epoxide opening with enolate, oxidation and hemiacetal formation



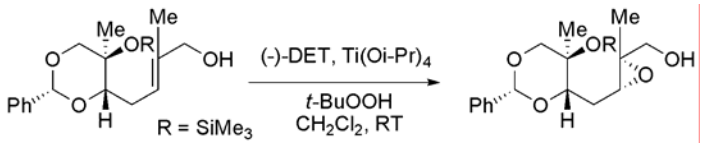
Woodward, R.B.; Fukunaga, T.; Kelly, R.C. *J. Am. Chem. Soc.* **1964**, *86*, 3162

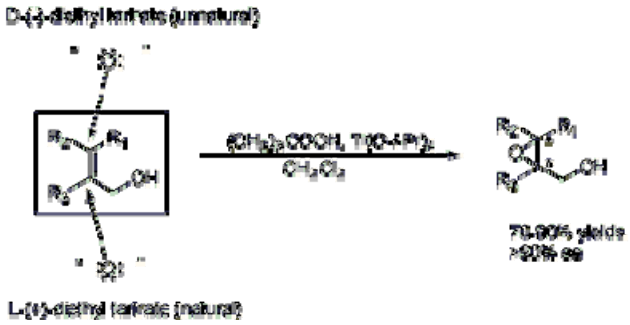


Nicolaou, K.C.; Theodorakis, E.A.; Rutjes, F.P.J.T.; Tiebes, J.; Sato, M.; Untersteller, E.; Xiao, X.Y., *J. Am. Chem. Soc.*, **1995**, *117*, 1171.
Nicolaou, K.C.; Rutjes, F.P.J.T.; Theodorakis, E.A.; Tiebes, J.; Sato, M.; Untersteller, E., *ibid*, **1995**, *117*, 1173.

5.1 – Epoxidation of Alkenes

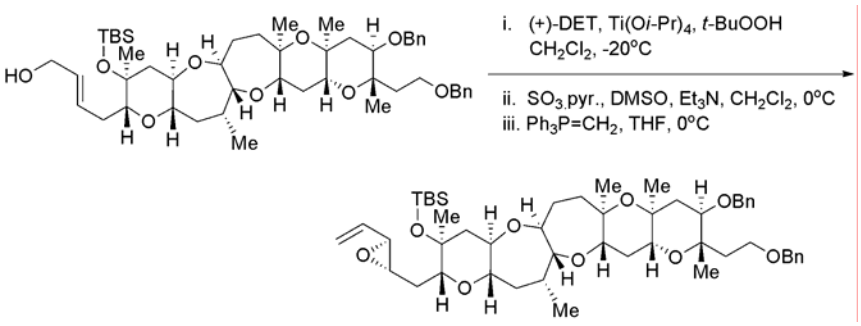
Sharpless asymmetric epoxidation





5.1 – Epoxidation of Alkenes

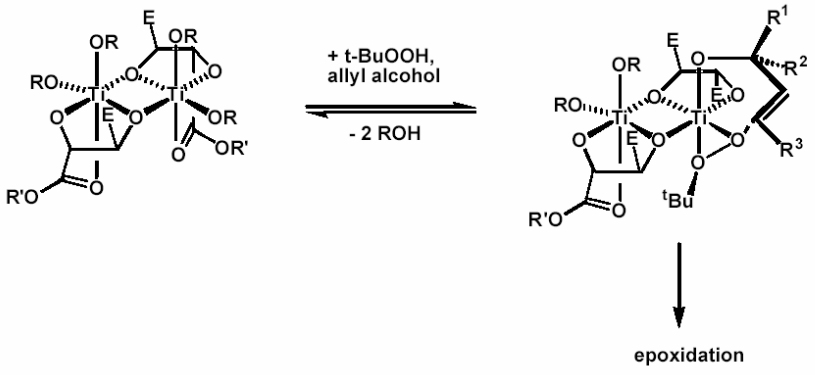
Sharpless asymmetric epoxidation



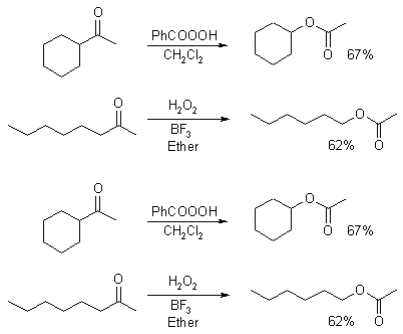
Nicolaou, K.C.; Theodorakis, E.A.; Rutjes, F.P.J.T.; Tiebes, J.; Sato, M.; Untersteller, E.; Xiao, X.Y., *J. Am. Chem. Soc*., **1995**, *117*, 1171.
Nicolaou, K.C.; Rutjes, F.P.J.T.; Theodorakis, E.A.; Tiebes, J.; Sato, M.; Untersteller, E., *ibid*, **1995**, *117*, 1173.

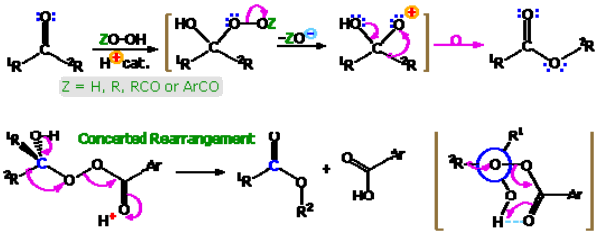
5.1 – Epoxidation of Alkenes

Active catalyst is believed to be a dimer

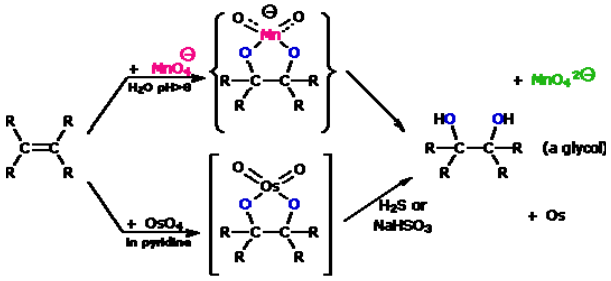


5.1 – Baeyer-Villiger Reaction

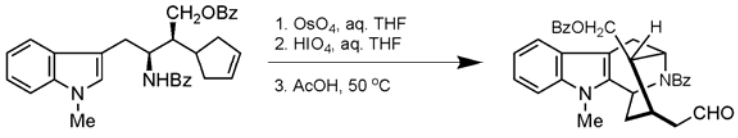




5.1 – Dihydroxylation of Alkenes

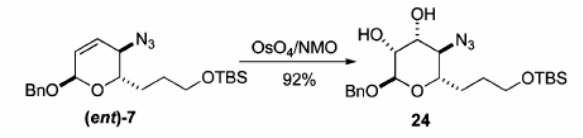


Olefin cleavage, aminal formation, intramolecular Friedel-Crafts acylation with iminium ion

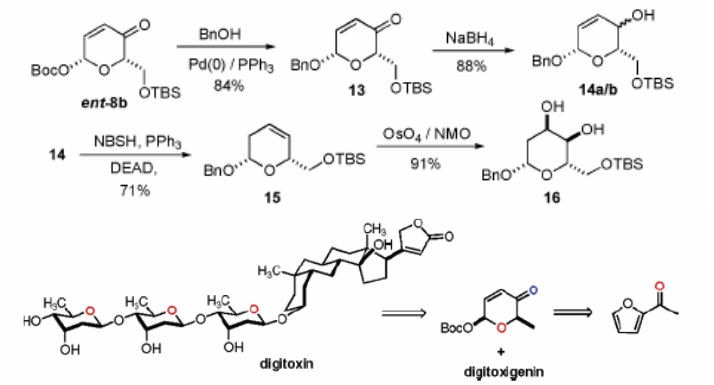


Masamune, S.; Ang, S.K.; Egli, C.; Nakatsuka, N.; Sarkar, S.K.; Yasunari, Y. *J. Am. Chem. Soc.* **1967**, *89*, 2506.

5.1 – Dihydroxylation of Alkenes

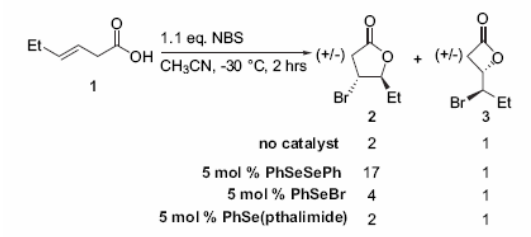


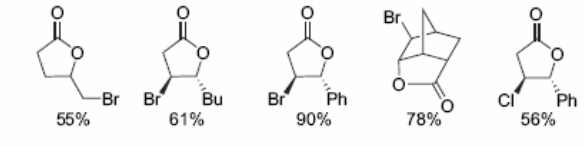
Guo, H.; O'Doherty, G. A. *Org. Lett*. **2006**, *8*, 1609-1612



Zhou, M.; O'Doherty, G. A. *Org. Lett*. **2006**, *8*, 4339-4342

5.1 – Halolactonization of Alkenes

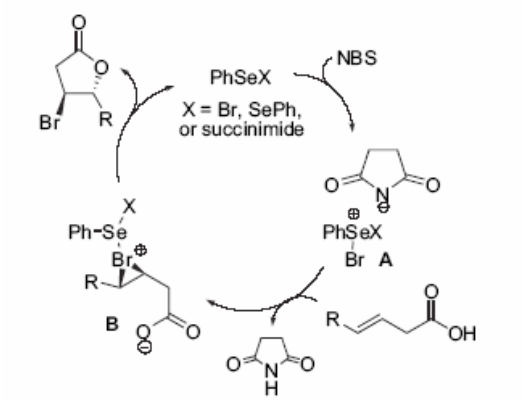




Tunge, J. A. *et. al*. *Org. Lett*. **2006**, *62*, 7191-7198

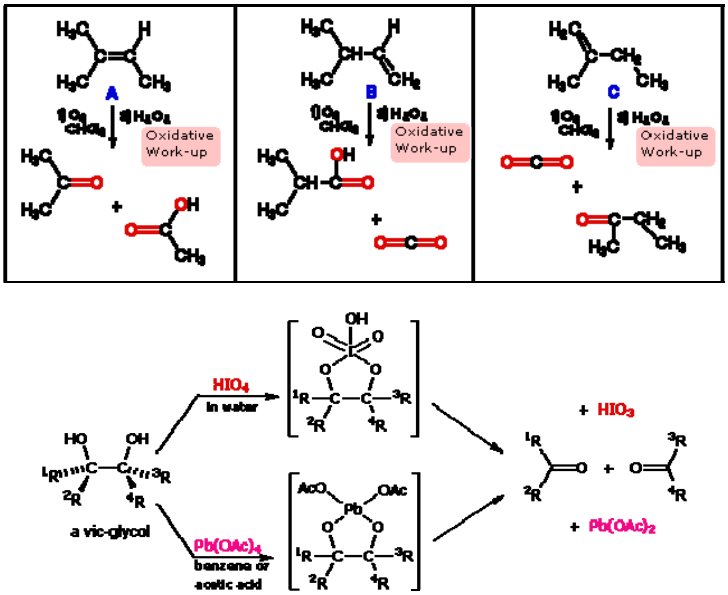
5.1 – Halolactonization of Alkenes

Proposed catalytic cycle using selenium additive



Tunge, J. A. *et. al. Org. Lett.* **2006**, *62*, 7191-7198

5.1 – Oxidative Cleavage of Alkenes



5.2 – Selected Reactions of Alkynes