Hydrogen Bond Catalysis in Synthesis

IBS 2May2009

Baran GM

I.B. Seiple

Hydrogen Bond Catalysis in Synthesis

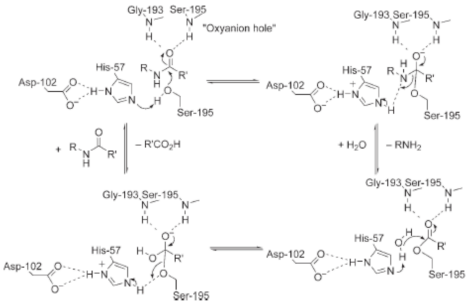
Baran Group Meeting
5/2/2009

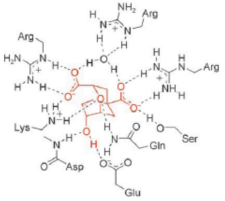
Background

For Reviews, see: Jacobsen/Taylor, ACIEE 2007, 45, 1520
Jacobsen/Doyle, Chem Rev 2007, 107, 5713
Connon, ChemComm, 2008, 2499
Takemoto, BCSJ 2008, 81, 785
Wang, Chem. Asian Journal 2008, 516

-Yates/Eaton reported $AlCl_3$ catalyzed DA in 1960, phenol accelerated was reported years earlier by Wassermann (1942).
-Lewis acid catalysis received ample attention throughout the 20th century, while H-Bonding catalysis was relatively forgotten until the 1980's
-H-bond catalysis vaulted onto the stage in 1981 when Wynberg reported asymmetric conjugate addition reactions with cinchona alkaloids bearing free OH's.
-concaminant repot by Inoue that diketopiperazines could catalyze the hydrocyanation of benzaldehydes asymmetrically.
- 1998 Jacobsen reported his first catalyst for asymmetric hydrocyanation of aliphatic and aromatic aldehydes, and everybody jumped on the train after this. The irony is, he was trying to design a ligand for a Lewis acid, but found no LA was necessary.

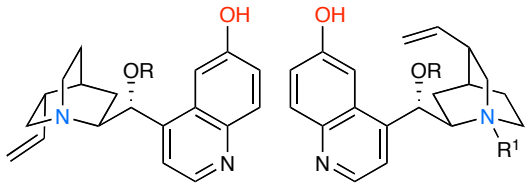
-H-bond can vary between 0.4 (CH••N) and 40 kcal/mol (NH••N in proton sponge), but is typically 4-15 kcal/mol
-H-bonds play crucial rolls in biology:
- H_2O bulk properties
- Protein folding
-DNA base pairing
-Ligand-Receptor binding



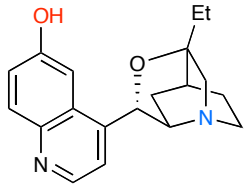


1. Selected Hydrogen Bond Donating Catalysts:

- Cinchona-alkaloid based:

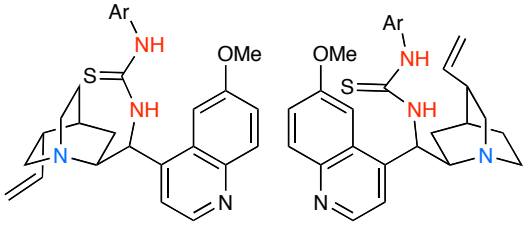


1 (R^1 = lone pair)**:** Wynberg, 1981 (conjugate addition)
2 (R^1 = *p*-CF_3-Bn, Br^- salt): Graboswski, 1984 (enolate alk.)
3 (R = OH): Deng, 2004 (conjugate addition)

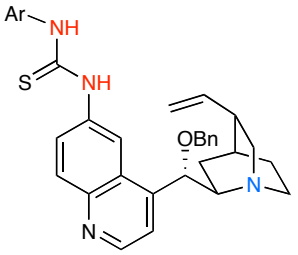


4: Hatakeyama, 1999 (B-H)

- Cinchona-alkaloid based (cont'd):

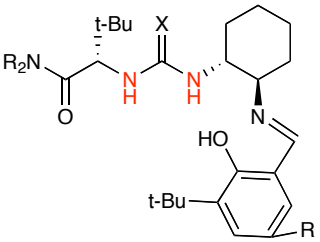


5 (Ar = 3,5-CF_3-Ph): Connon, Dixon, Soós, 2005 (conjugate addition, Mannich)

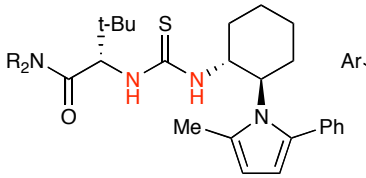


6 (Ar = 3,5-CF_3-Ph): Hiemstra, 2006 (Henry)

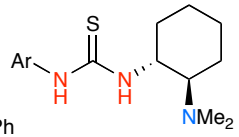
- Thiourea-based catalysts:



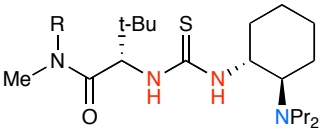
7 (R's = alk or Ar): Jacobsen, 1998 (Strecker, Mannich)



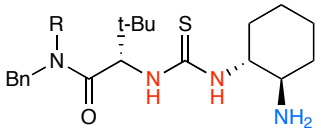
8 (R's = alk or Ar): Jacobsen, 2004, (P-S and Mannich)



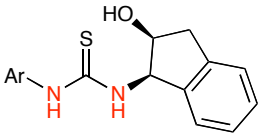
9 (Ar = 3,5-CF_3-Ph): Takemoto, 2003 (Nu- to nitroolefins)



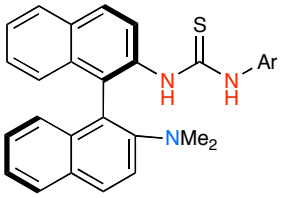
10 (R = H or Me): Jacobsen, 2005 (cyanohydrin formation) Berkessel, 2005 (res. of azalactones)



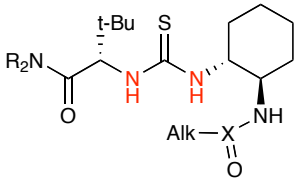
11 (R = H or Me): Jacobsen, 2006 (Nu- to nitroolefins)



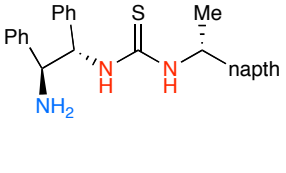
12 (Ar = 3,5-CF_3-Ph): Ricci, 2005, (F-C add'n to nitroolefins)



13: Wang, 2005 (B-H)



14: Jacobsen, 2005 (nitro Mannich)



15: Tsogoeva, 2006 (Nu- to nitroolefins)

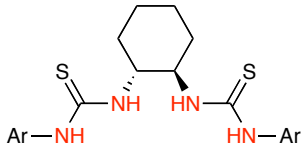
I.B. Seiple

Hydrogen Bond Catalysis in Synthesis

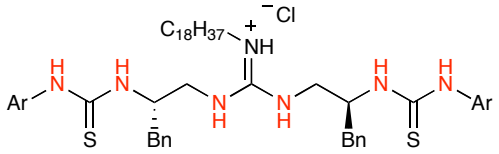
Baran Group Meeting
5/2/2009

Hydrogen Bond Donating Catalysts (cont'd):

- Dual activation thiourea catalysts:

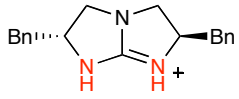


16 (Ar = 3,5-CF_3-Ph): Nagasawa, 2004 (B-H)

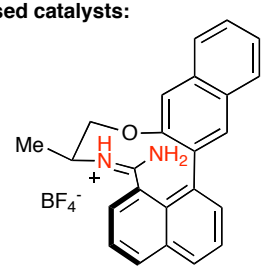


17 (Ar = 3,5-CF_3-Ph): Nagasawa, 2005 (Henry)

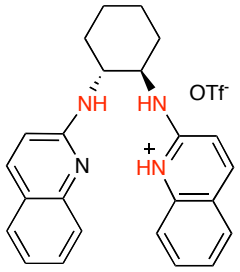
- Guanidine- and amidine-based catalysts:



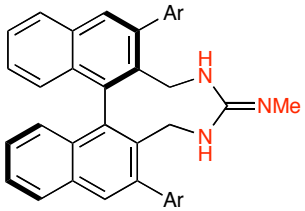
18: Corey, 1999 (Strecker)



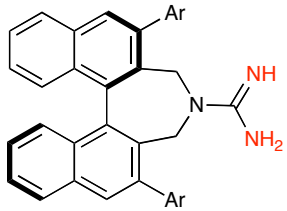
19: Göbel, 2000 (4+2)



20: Johnston, 2004 (Mannich)

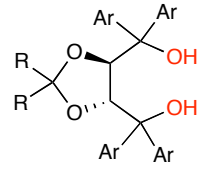


21 (Ar = 3,4-bis(3,5-di-tBu-Ph)-Ph): Tareda, 2006 (Nu- to nitroolefins)

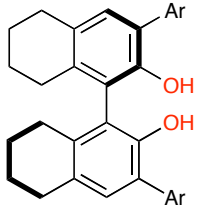


22 (Ar = 3,4-bis(3,5-di-tBu-Ph)-Ph): Tareda, 2006 (amination of malonates)

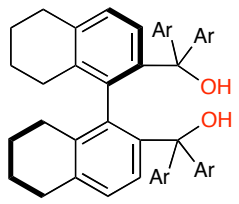
- Chiral (di)ol catalysts:



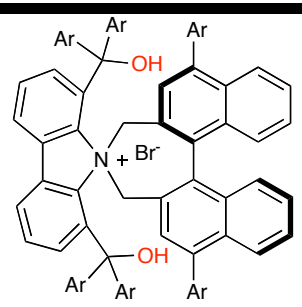
23 (Ar = napth, R = alk): Rawal, 2003 (4+2, aldol)



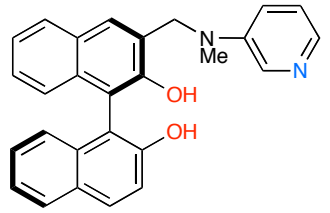
24 (Ar = 3,5-CF_3-Ph): Schaus, 2003 (B-H)



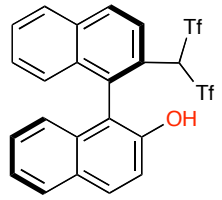
25 (Ar = 4-F-3,5-Et-Ph): Rawal/Yamamoto, 2005 (4+2)



26 (Ar = 3,5-Ph_2-Ph): Maruoka, 2004 (epoxidation)

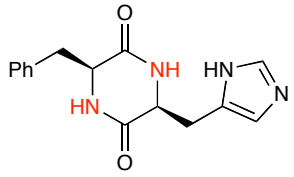


27: Sasai, 2005 (aza-B-H)

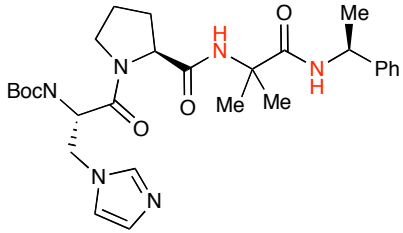


28: Yamamoto, 2006 (Mannich)

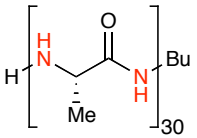
- Peptide-based catalysts:



29: Inoue, 1981 (cyanohydrins)

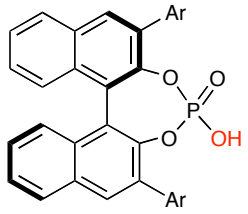


30: Miller, 1998 (acyl xfer)

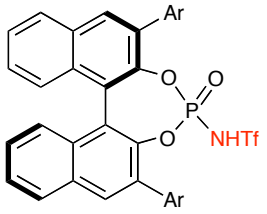


31: Julía, 1980 (epox'n)

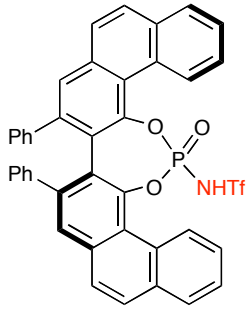
- Phosphoric (acid) catalysts:



32: Akiyama/Tareda, 2004 (Mannich)

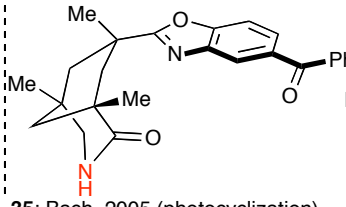


33: Yamamoto, 2006 (4+2)

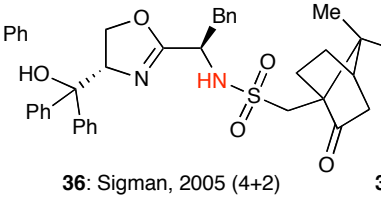


34: Antilla, 2005 (Imine Amidation)

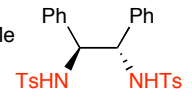
- Miscellaneous catalysts



35: Bach, 2005 (photocyclization)



36: Sigman, 2005 (4+2)



37: Mikami, 2005 (4+2)

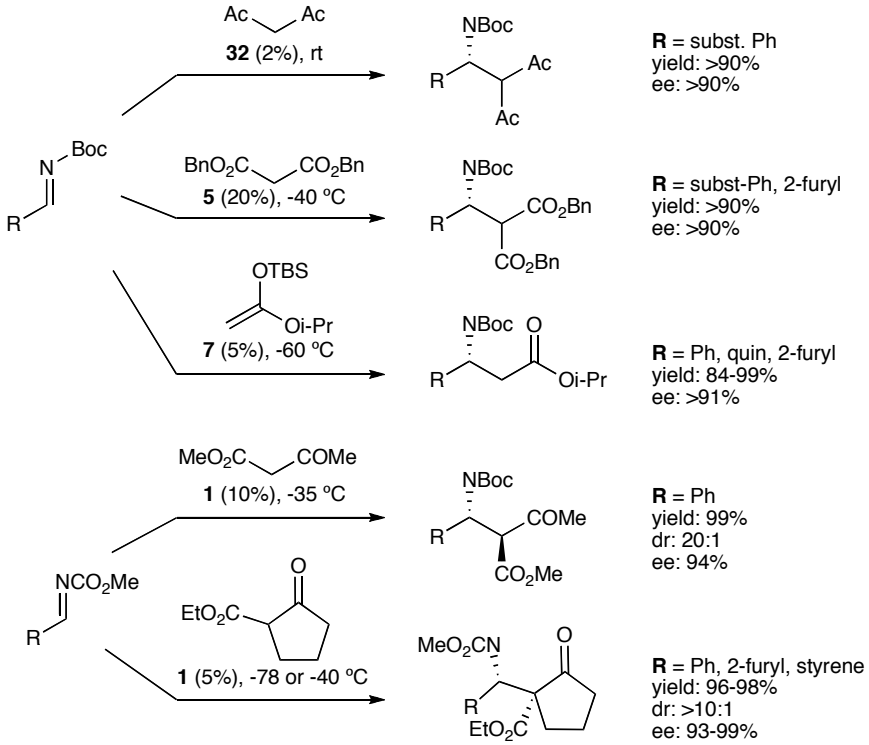
I.B. Seiple

Hydrogen Bond Catalysis in Synthesis

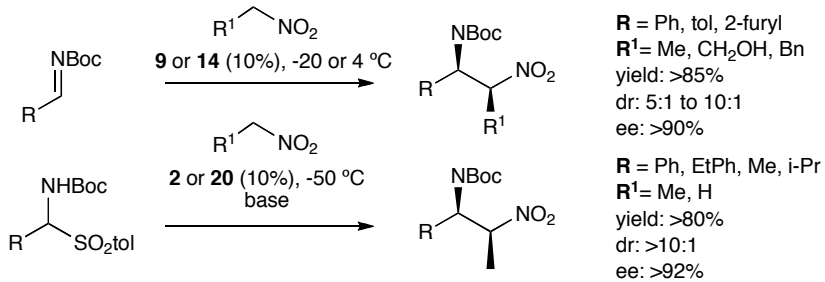
Baran Group Meeting
5/2/2009

2. Addition to Imines

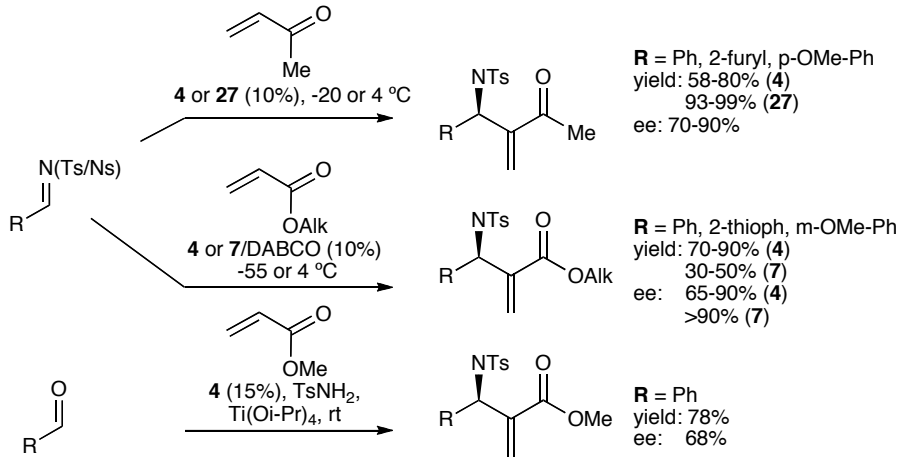
A. Mannich Reaction



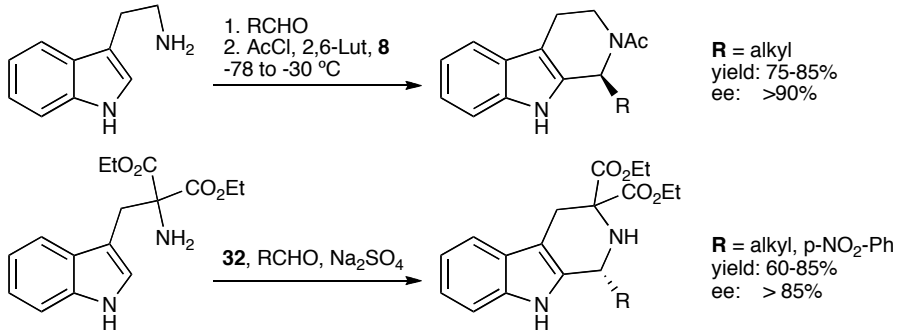
B. Nitro Mannich:



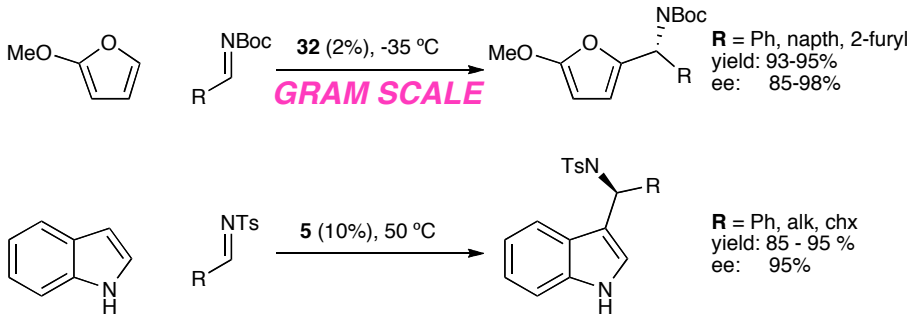
C. Aza-Baylis-Hillman:



D. Pictet–Spengler:



E. Friedel–Crafts

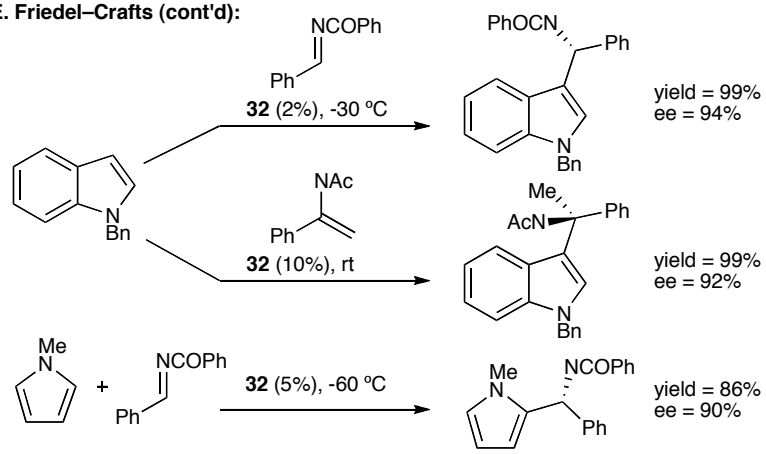


I.B. Seiple

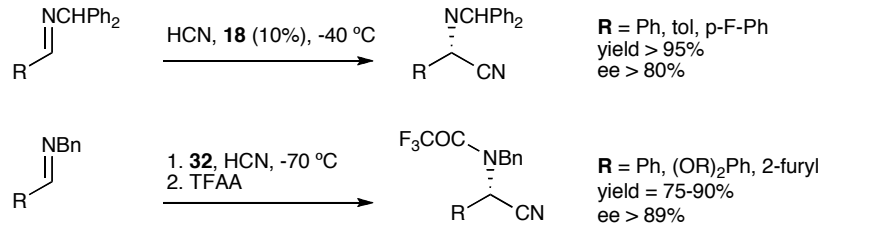
Hydrogen Bond Catalysis in Synthesis

Baran Group Meeting
5/2/2009

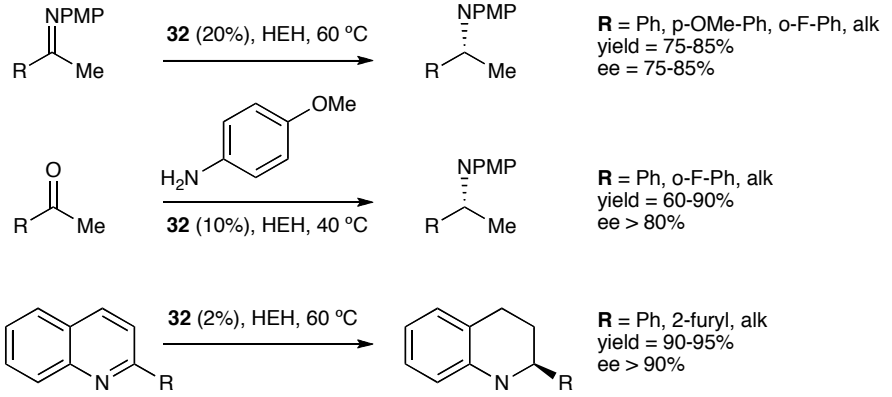
E. Friedel–Crafts (cont'd):

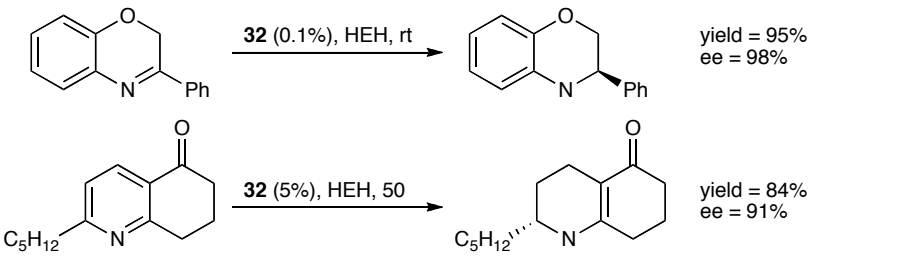


F. Strecker:

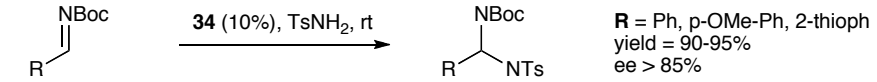


G. Reduction:

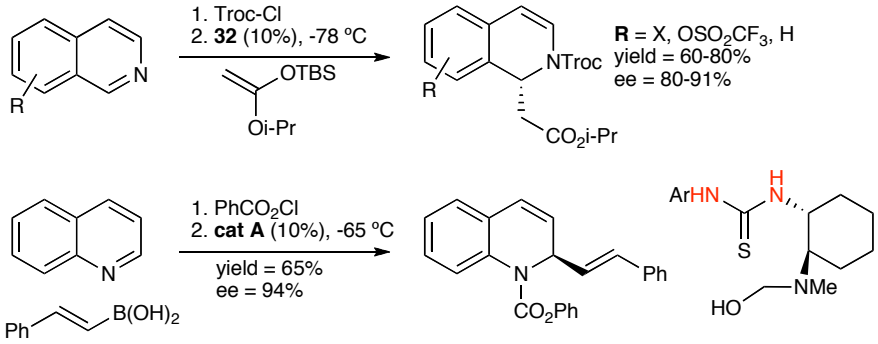




H. Amidation:



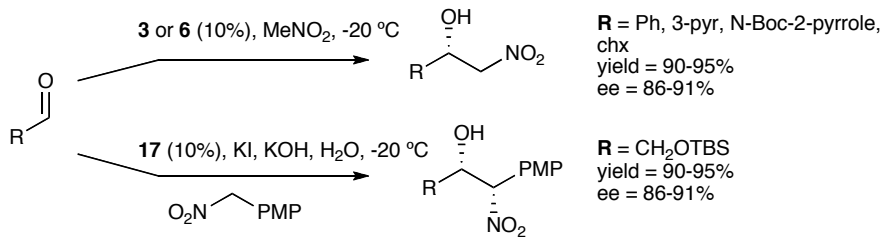
I. Addition to N-Acyl Iminiums:



3. 1,2-Addition to Carbonyls

A. Aldol Reactions: These reactions all involve proline catalysis. This constitutes a group meeting of its own, and will not be covered in this group meeting.

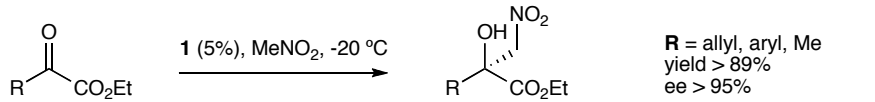
B. Nitro-Aldol (Henry):



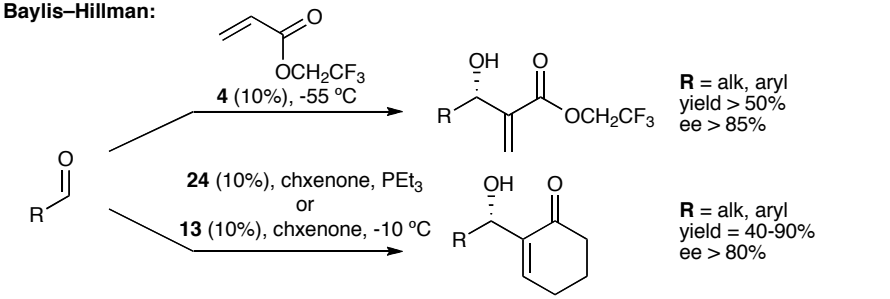
I.B. Seiple

Hydrogen Bond Catalysis in Synthesis

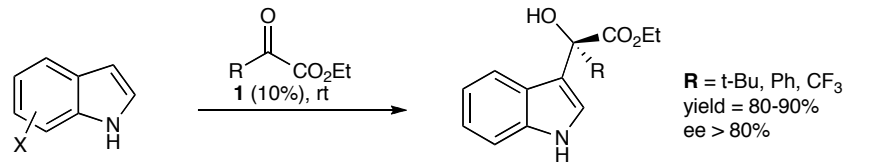
Baran Group Meeting
5/2/2009



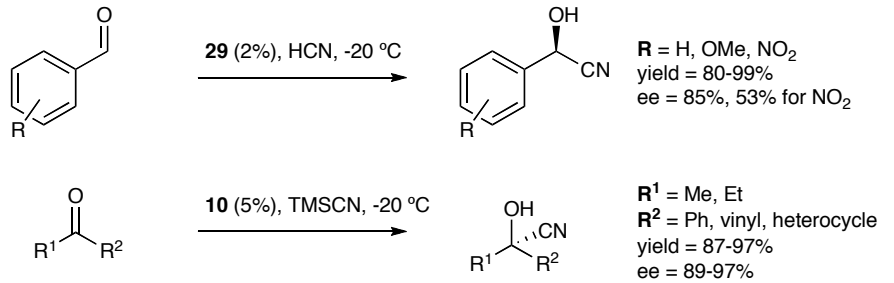
C. Baylis–Hillman:



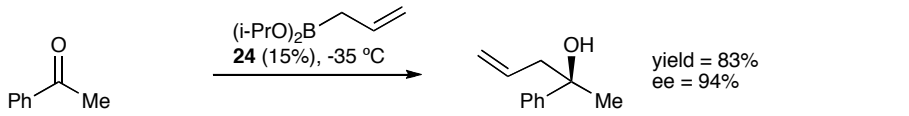
D. Friedel–Crafts:



E. Cyanation:

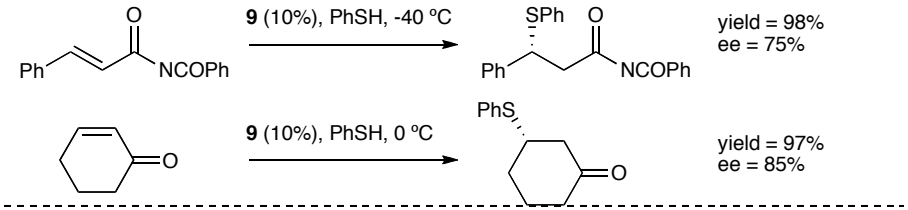


E. Metallo-addition:

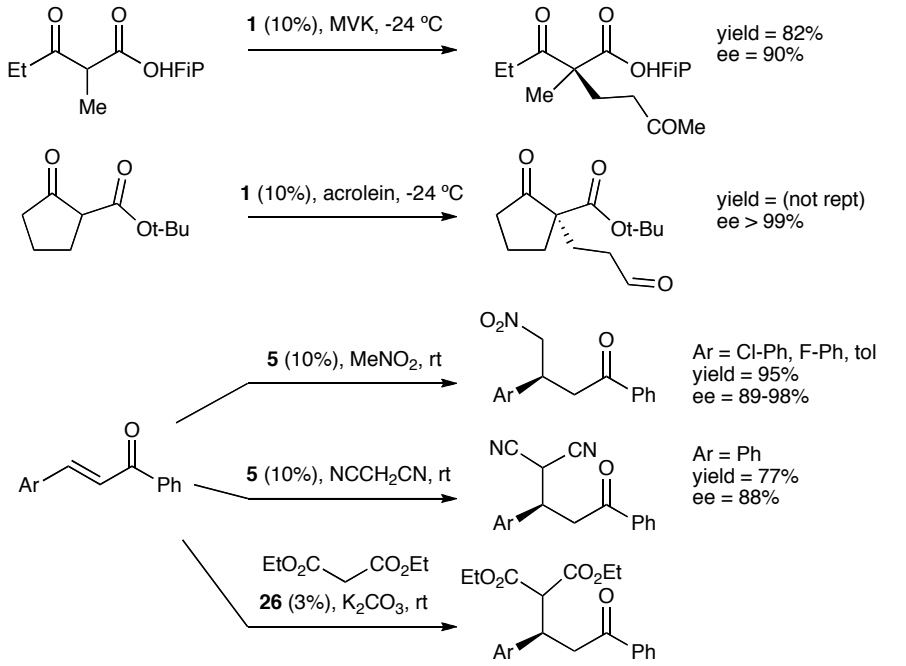


4. Conjugate (1,4) Addition

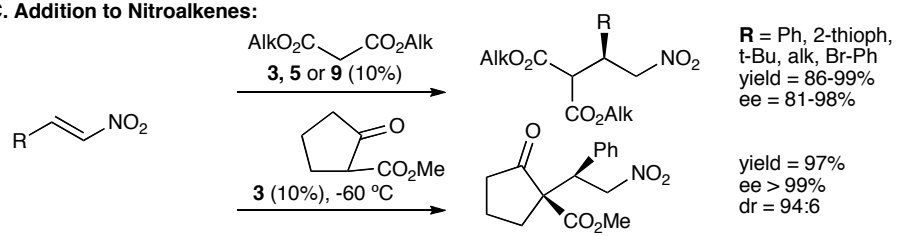
A. Heteroatom Addition to eneones:



B. Michael Addition:



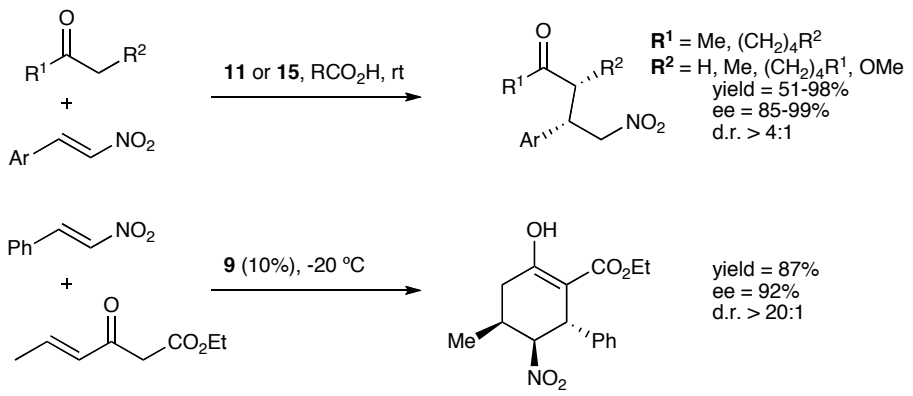
C. Addition to Nitroalkenes:



I.B. Seiple

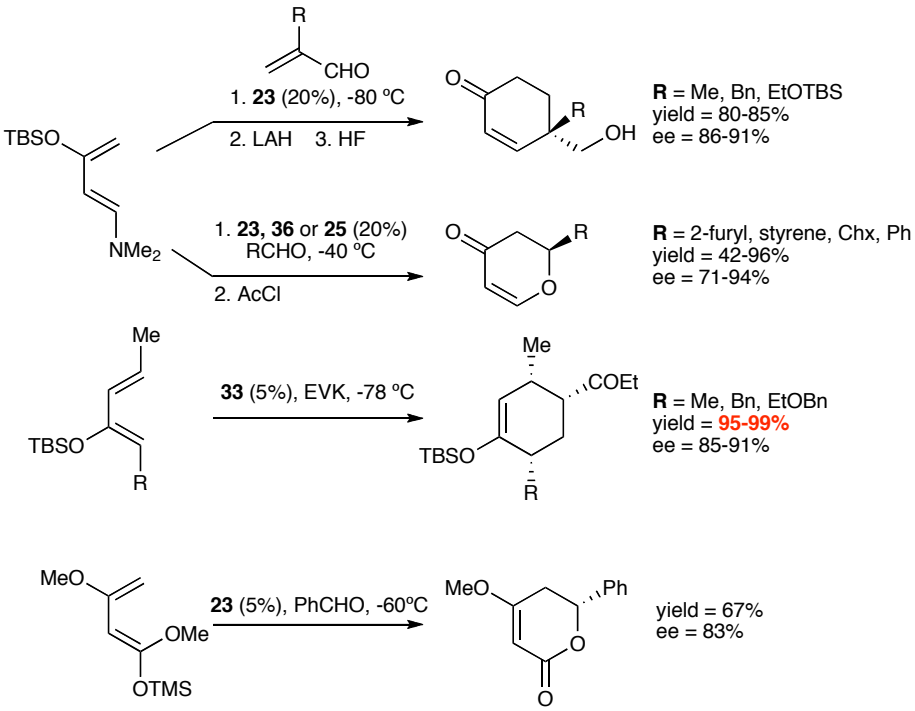
Hydrogen Bond Catalysis in Synthesis

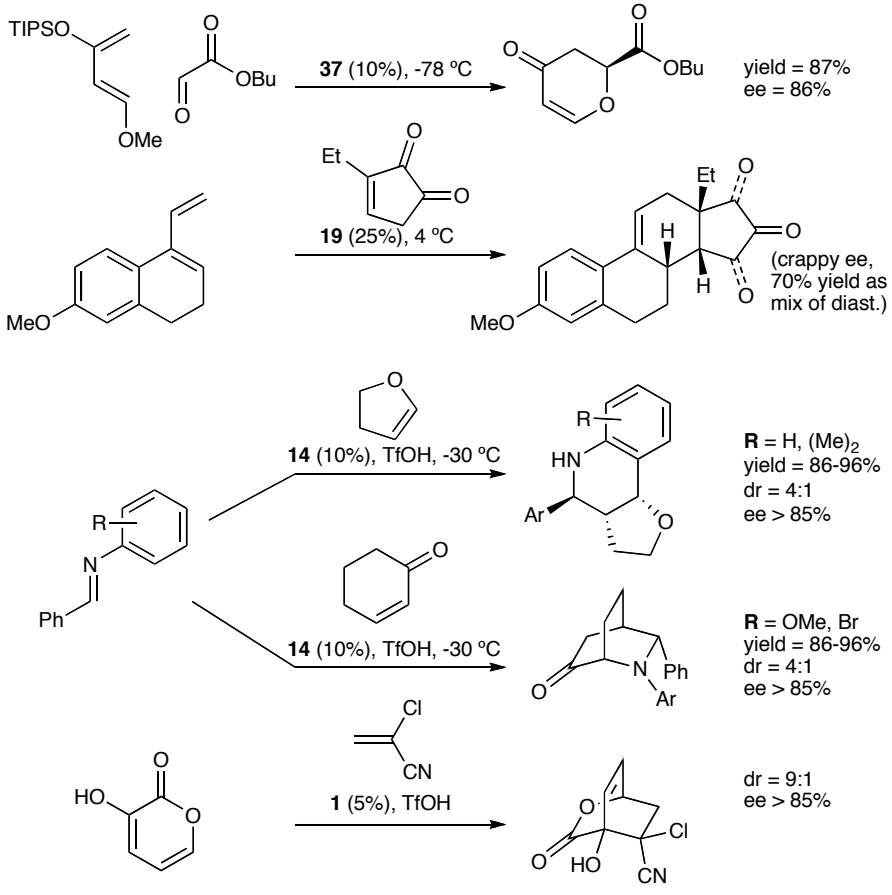
Baran Group Meeting
5/2/2009



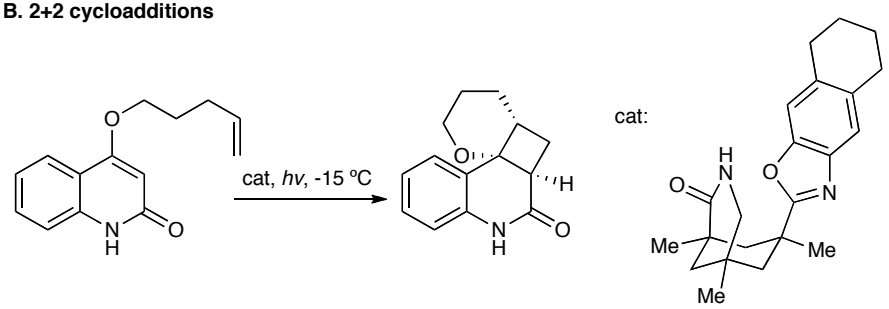
5. Cycloadditions

A. 4+2 (Diels–Alder) Cycloadditions





B. 2+2 cycloadditions

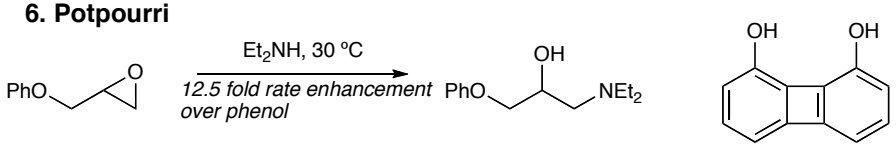


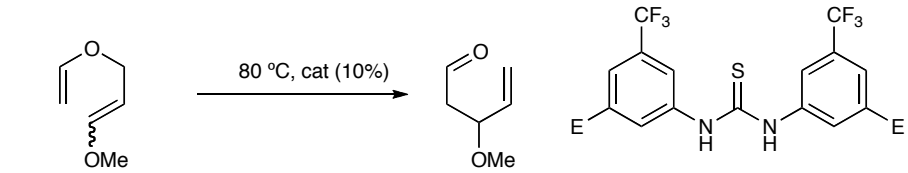
I.B. Seiple

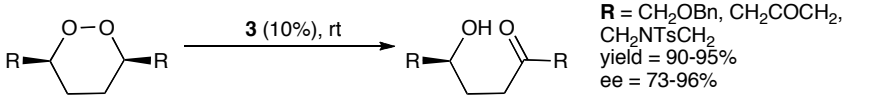
Hydrogen Bond Catalysis in Synthesis

Baran Group Meeting
5/2/2009

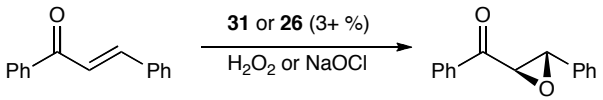
6. Potpourri

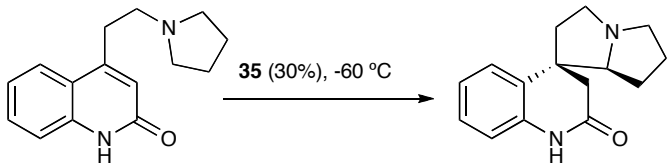






R = CH_2OBn, CH_2COCH_2, CH_2NTsCH_2
yield = 90-95%
ee = 73-96%

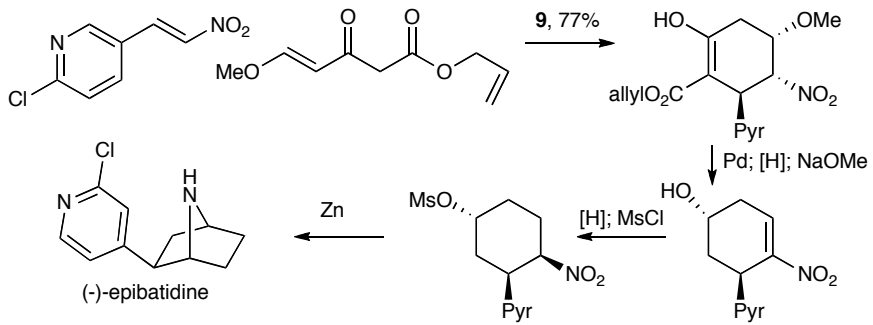




yield: 64%
ee = 70%

7. Application to Synthesis

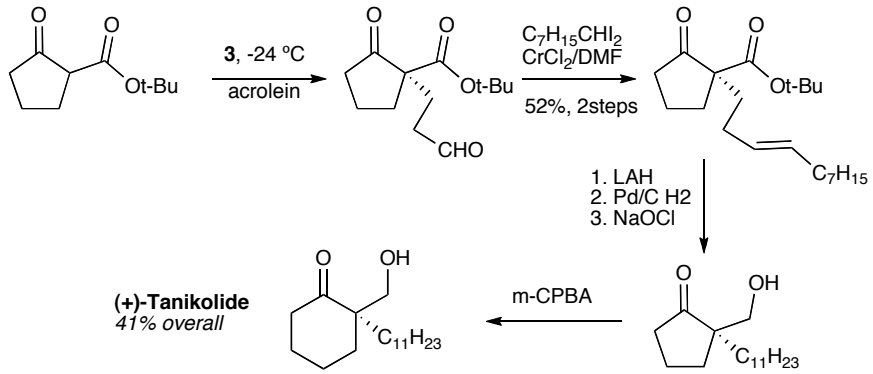
A. (-)-epibatidine - Takemoto, Bull. Chem. Soc. Jpn. 81, 785



B. Manzacidin A - Deng, JACS 2006, 128, 3928

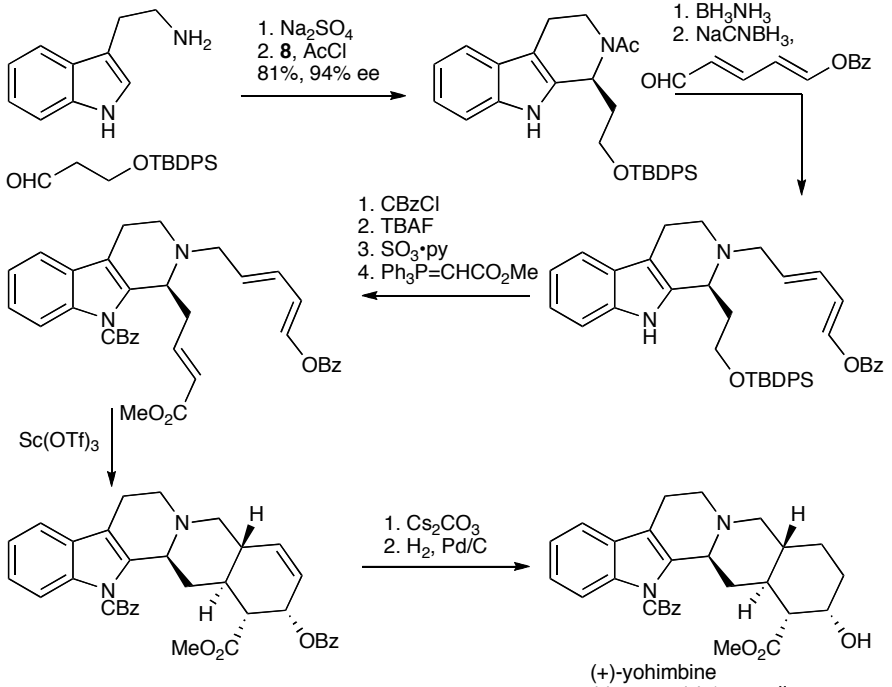
(not really worth drawing in)

C. (+)-Tanikolide - Deng, ACIEE, 2006, 45, 4301.



(+)-Tanikolide
41% overall

D. (+)-Yohimbine - Jacobsen, OL 2008, 10, 745



(+)-yohimbine
11 steps, 14% overall