MAX-PLANCK-INSTITUT
FÜR KOLLOID- UND
GRENZFLÄCHENFORSCHUNG

WACKER- AND HECK-TYPE NUCLEOPALLADATION

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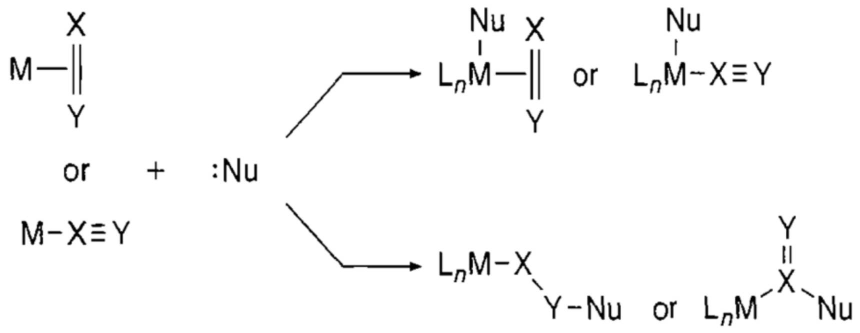
7.1 NUCLEOPHILIC ATTACK ON COORDINATED LIGANDS



i.e. ligand substitution intermediate

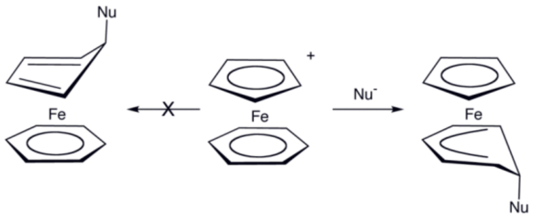
Nucleophilic attack on ligands

Attack at ligand favored by:

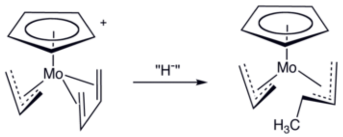
- Coordinatively saturated metal center
- E-poor metal center
- Cationic metal complexes
- Soft nucleophiles

7.1.1 GREEN–DAVIES–MINGOS RULES

1. Nucleophilic attack is preferred on even-numbered polyenes



2. Nucleophiles preferentially add to acyclic polyenes rather than cyclic polyenes



3. Nucleophiles preferentially add to even-hapticity acyclic polyene ligands at a terminal position. Nucleophiles preferentially add to odd-hapticity acyclic polyene ligands at a terminal position if the metal is highly electrophilic, otherwise they add at a lateral site

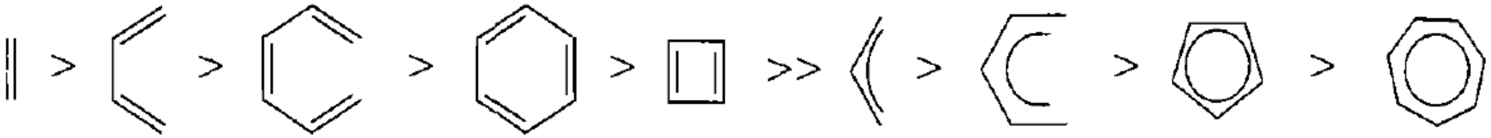
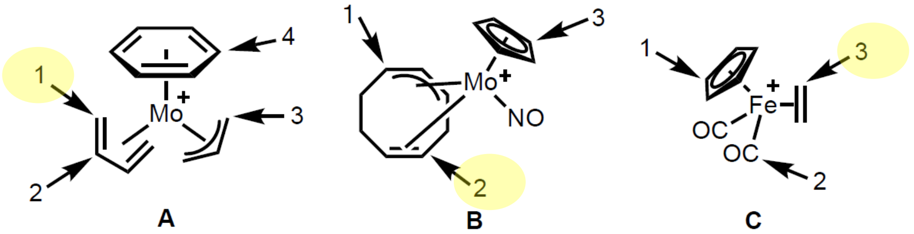


Figure 11.4. Order of reactivity of π-ligands according to the Davies–Green–Mingos rules.

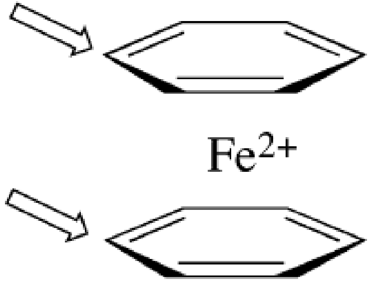
Davies Green Mingos, *Tetrahedron* **1978,** 34, 3047 DOI: dspjrq

POD #1

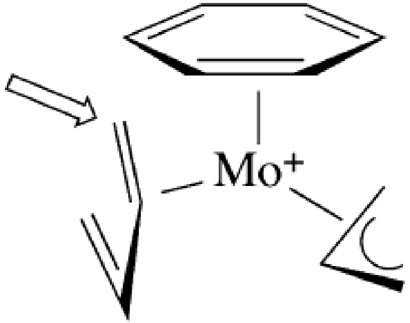
Consider the following three complexes A, B, and C. **Predict the site of nucleophilic attack (1 or 2 or 3..) according to Green–Davies–Mingos rules.**



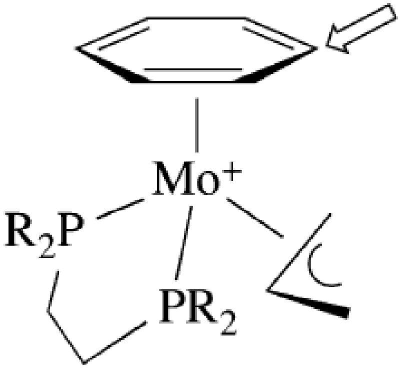
7.1.1 GREEN–DAVIES–MINGOS – MORE EXAMPLES



8.6



8.7



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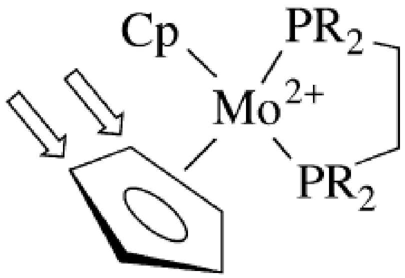
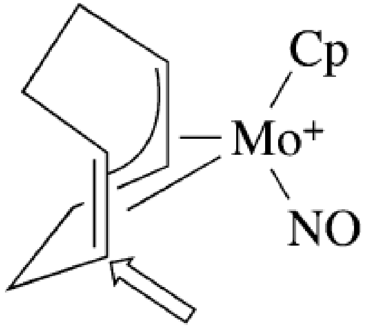
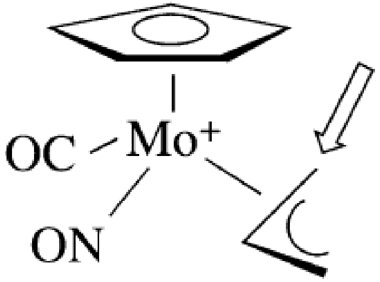
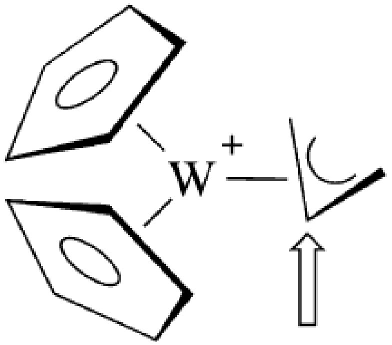
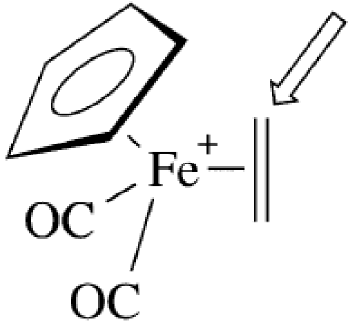


8.9



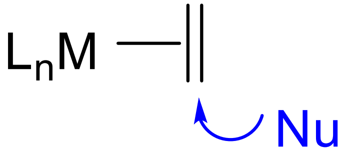






7.2 WACKER OXIDATION

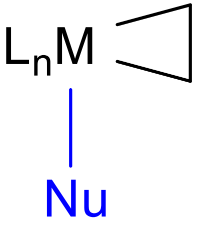
Two possible mechanism:



Outer-sphere

“nucleometalation”

Wacker-type



Inner-sphere

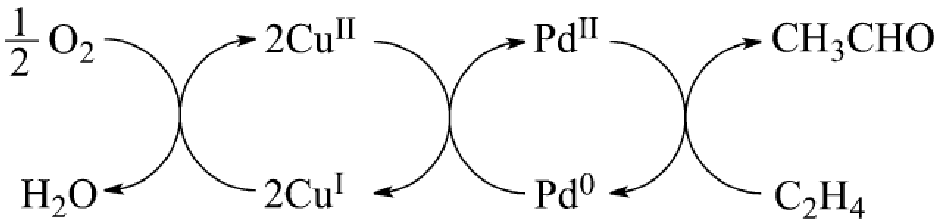
“migratory insertion”

Heck-type

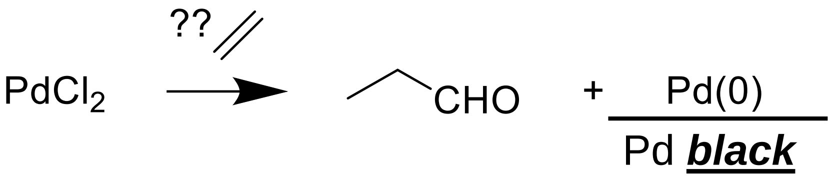
Metal
cationic, electron poor, high-valent

Metal
anionic, electron rich/neutral, low-valent

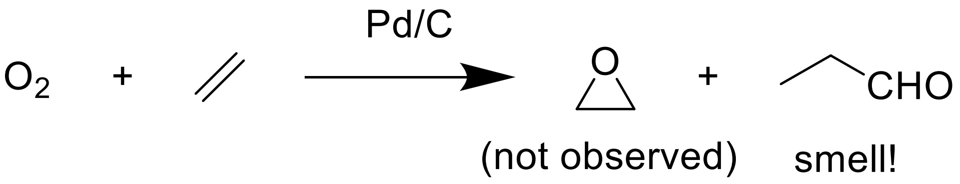
7.2 WACKER OXIDATION



Philips, 1894, colorimetric test for alkenes



- Walter Hafner (Wacker Chemie) 1950s
- Attempted reaction:



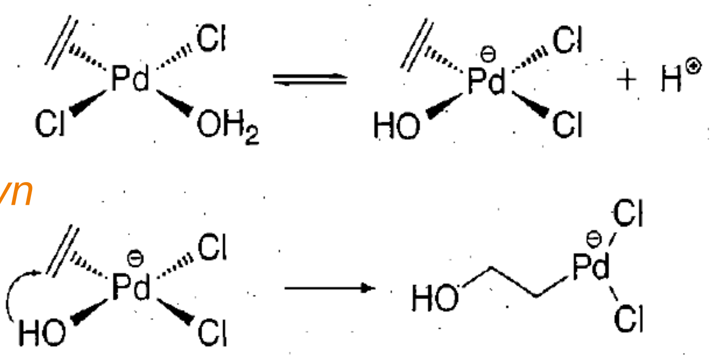
7.2.1 WACKER PROCESS - KINETICS

Industrially relevant conditions
(low Cl$^-$)

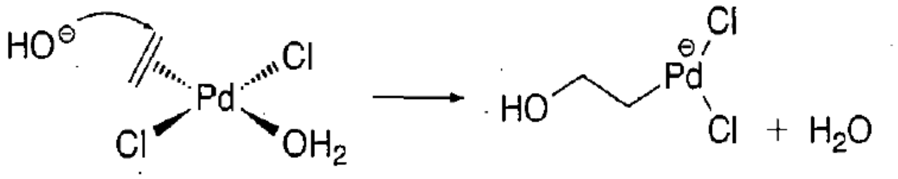
$$Rate = \frac{k[PdCl_4^{2-}][C_2H_4]}{[Cl^-]^2[H^+]}$$

lab conditions
(high Cl$^-$)

$$Rate = \frac{k[PdCl_4^{2-}][C_2H_4]}{[Cl^-]}$$

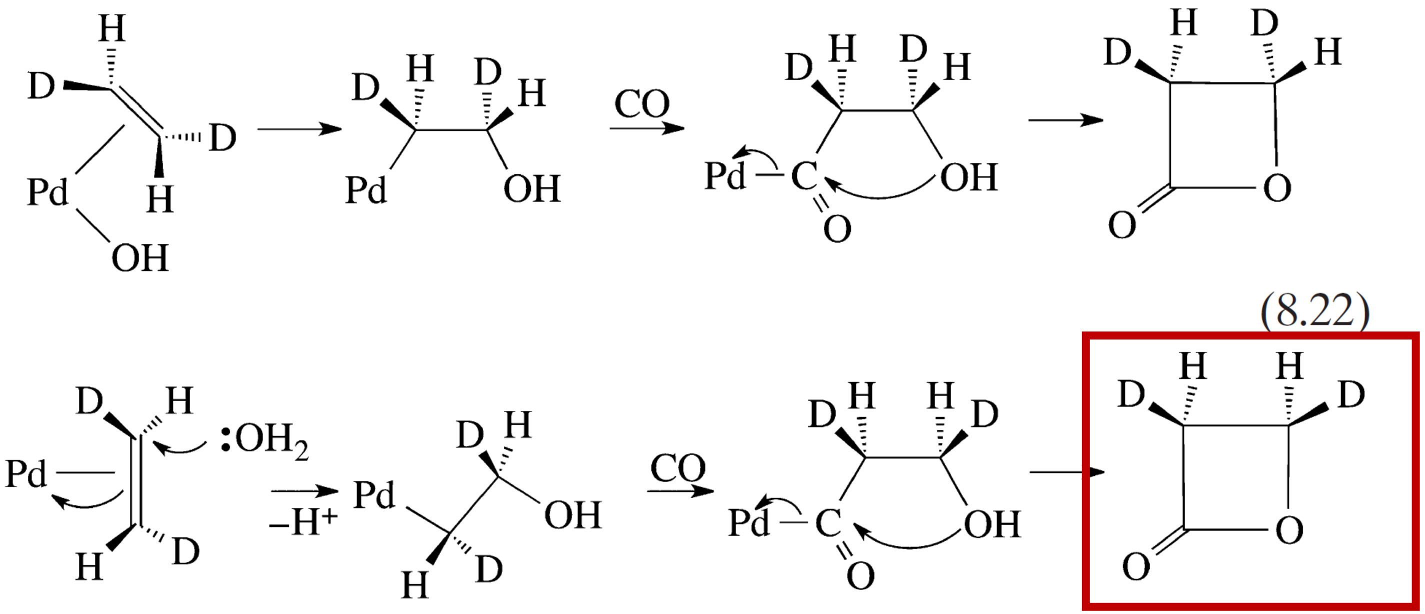


Inner sphere - syn



Outer sphere - anti

Stille 1978



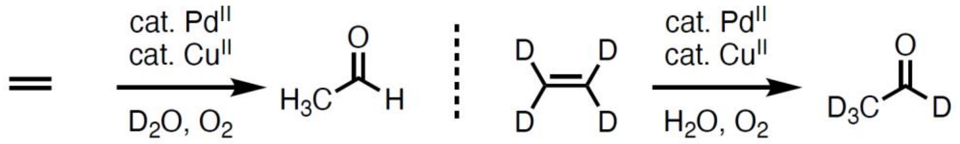
(8.22)

(8.23)

Stille *JACS* **1978** 100, 1303. DOI: 10.1021/ja00472a052
Bäckvall *JACS* **1979** 101, 2411. DOI: 10.1021/ja00503a029

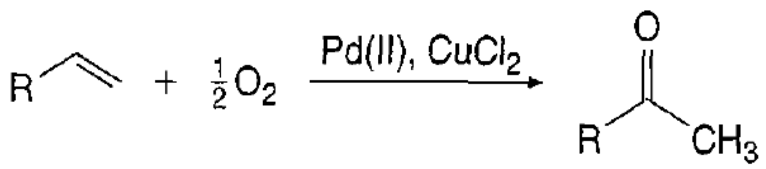
POD #2

Consider the following results from deuterium labeling experiments. **Propose a mechanism that is consistent with these results.**



7.2.2 WACKER-TYPE OXIDATIONS

Wacker-type oxidations -> Markovnikov selectivity

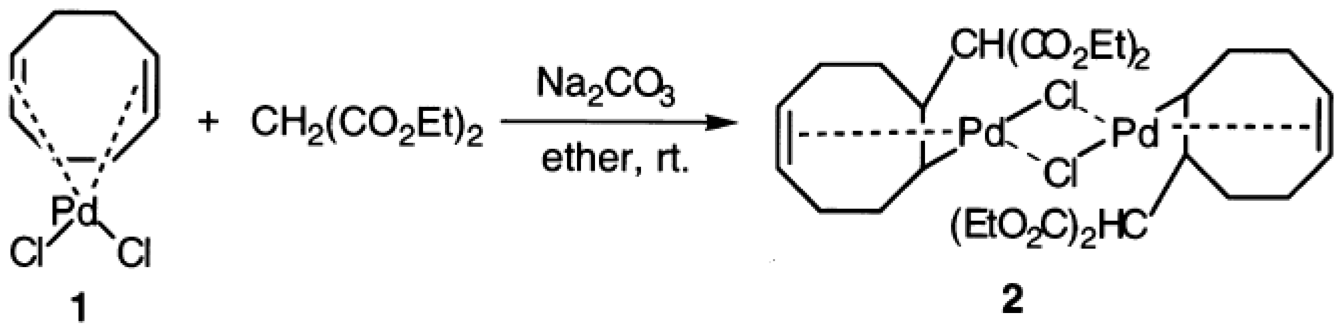


Anti-Markovnikov reported (ref below) but different mechanism

Grubbs, *Science* **2011** 333, 6049, 1609. DOI: 10.1126/science.1208685

7.3.1 OTHER NUCLEOPHILES - CARBON

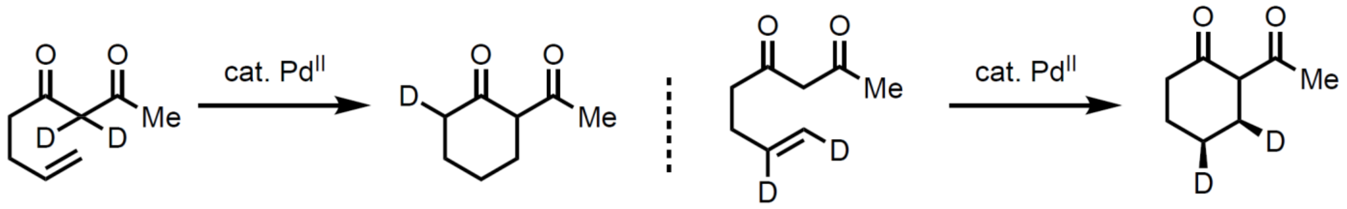
Tsuij, 1965 (stoichometric)



Tsuij, *JACS* **1965** 87, 3275. DOI:10.1021/ja01092a067

POD #3

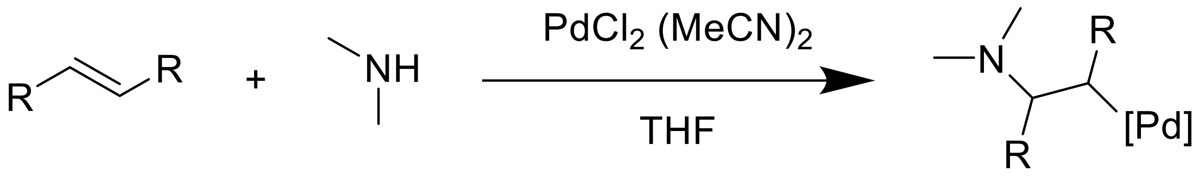
Widenhoefer performed several deuterium labeling experiments to elucidate the mechanism of a palladium(II)-catalyzed intramolecular hydroalkylation. **Based on the results below, propose a viable mechanism.**



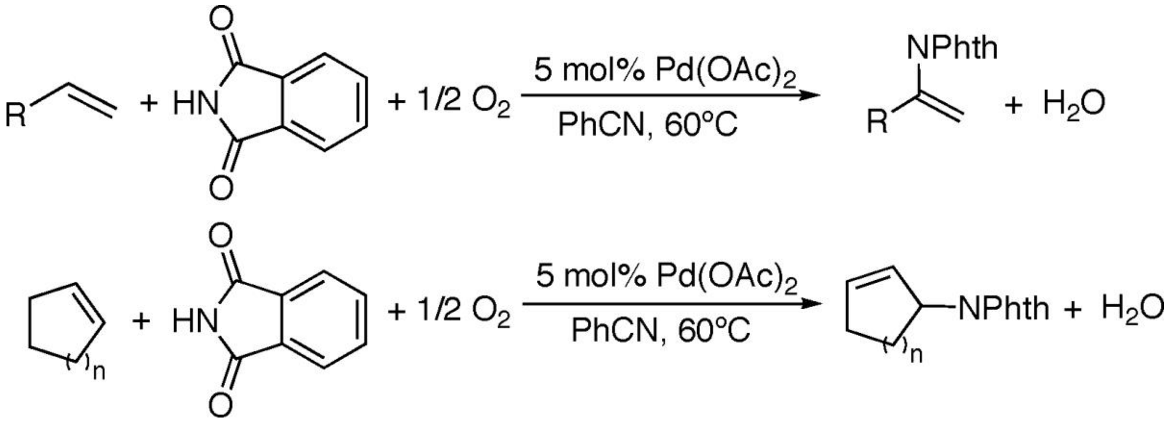
Widenhoefer, *JACS* **2003** 125, 8, 2056. DOI: 10.1021/ja0293002

7.3.2 OTHER NUCLEOPHILES – NITROGEN (AZA-WACKER-TYPE)

Åkermark (1974) - stoichometric



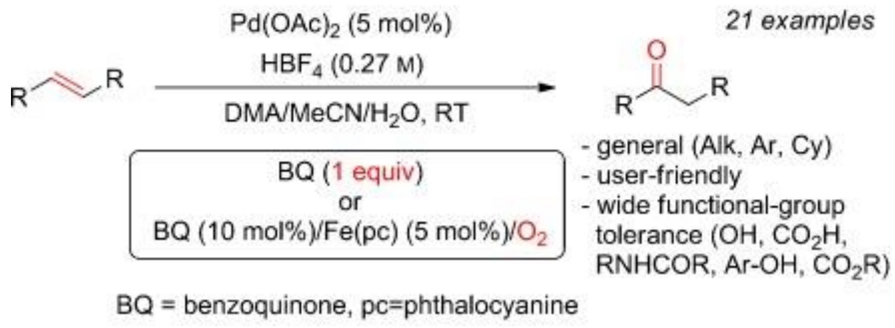
Stahl (2005) – catalytic



Tsuij, *JACS* **1968** 90, 20, 5518. DOI: 10.1021/ja01022a034

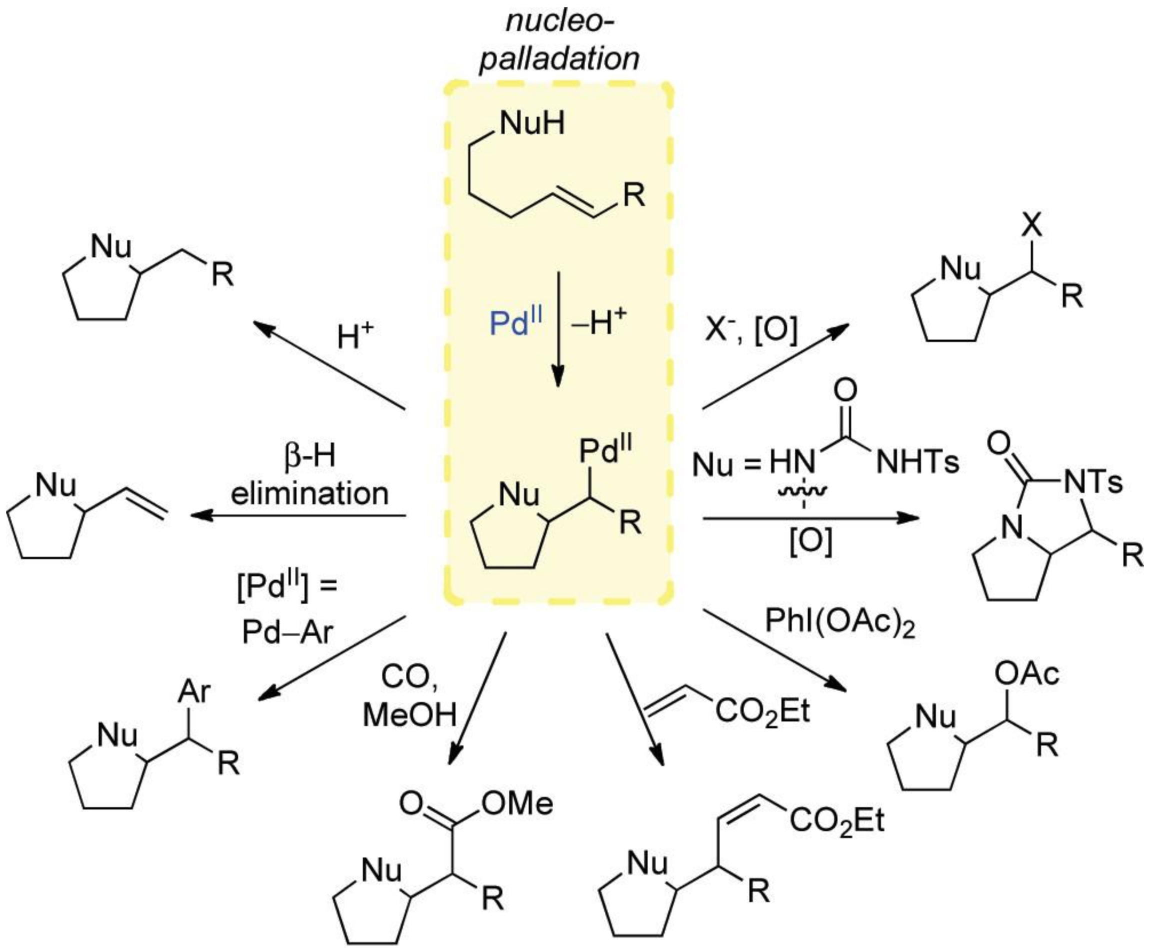
7.3.3 WACKER FOR INTERNAL ALKENES

Dicationic Pd(II) complex ($[Pd(MeCN)_4](BF_4)_2$ generated in-situ from $Pd(OAc)_2$ and HBF_4) necessary to increase the electrophilicity of the catalyst towards the less reactive internal double bonds



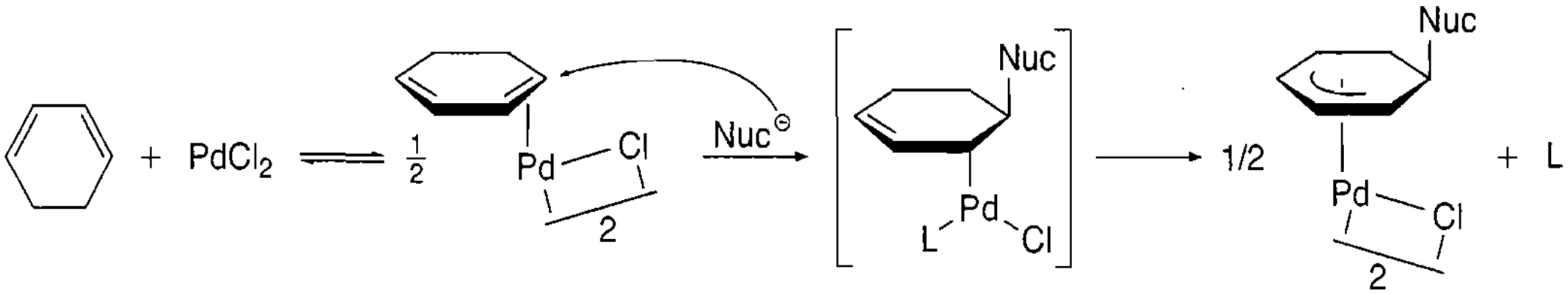
Morandi *ACIE* **2013** DOI: 10.1002/anie.201209541

7.4 INTERCEPTING NUCELOPALLADATE INTERMEDIATES



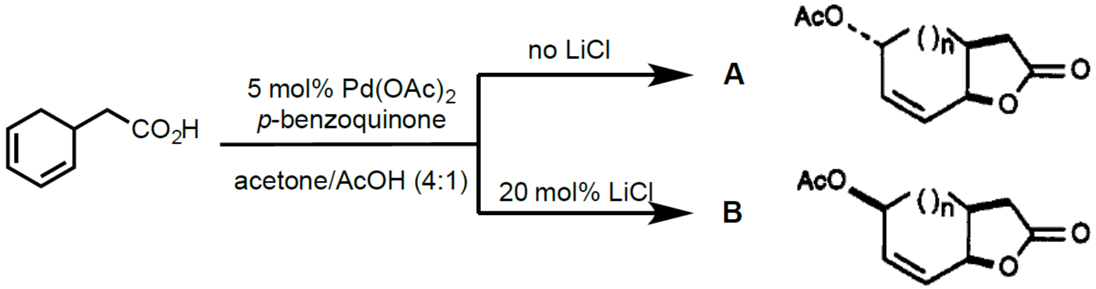
Stahl, *Chem Rev* **2011** 111, 4, 2981. DOI: 10.1021/cr100371y

7.5 NUCLEOPHILIC ATTACK ON DIENES

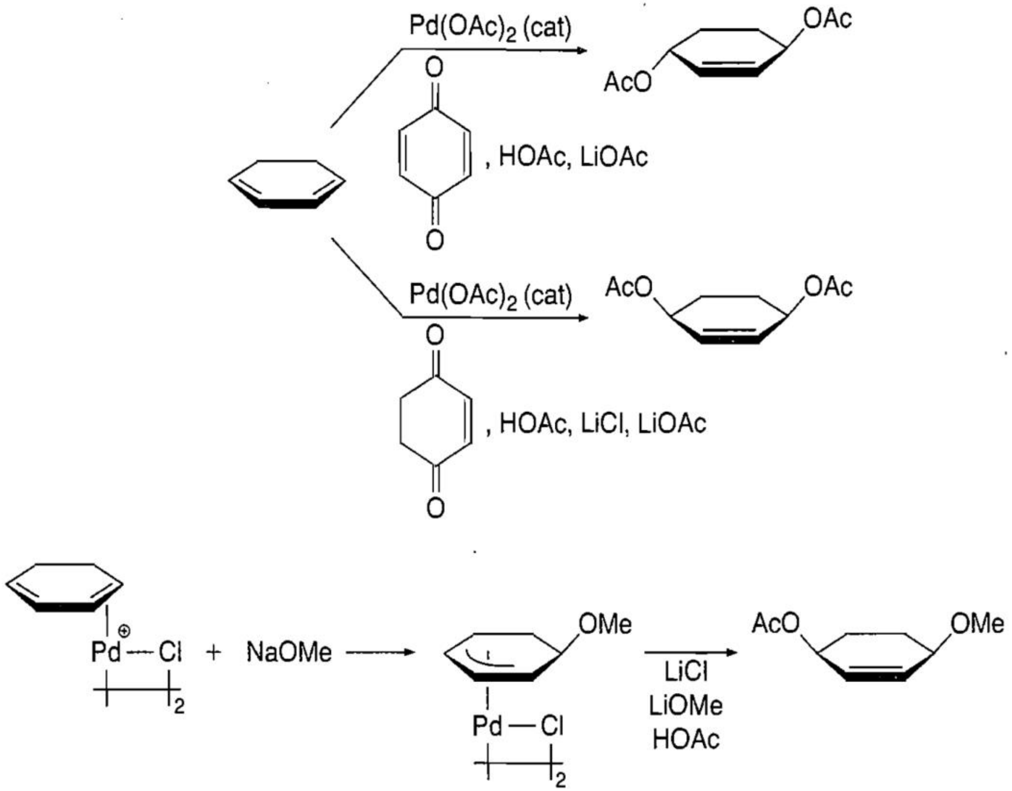


POD #1

The following catalytic system was found to give divergent outcomes in the presence or absence of LiCl (*JOC* 1993, *58*, 5445). **Predict the structures for products A and B, propose the mechanisms that account for product formation, and, explain the origin of the observed selectivity.**



7.5.2 NUCLEOPHILIC ATTACK ON Pd(II) DIENE COMPLEXES

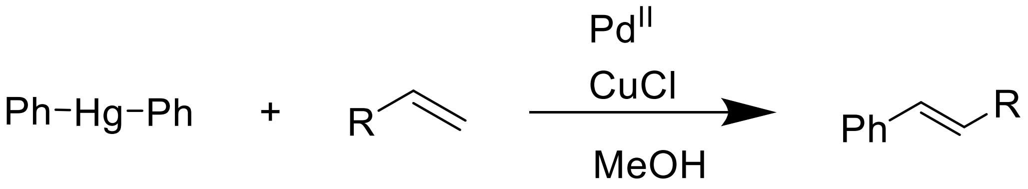


7.6.1 MIZOROKI-HECK REACTION – HISTORY

Fuijwara-Moritani

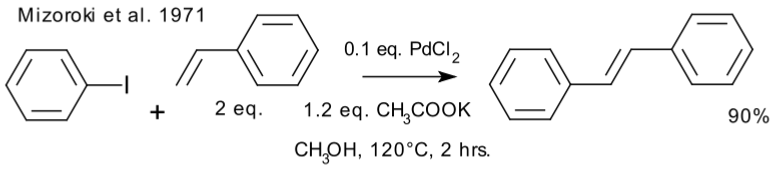
Moritani and Fuijwara *Tet Lett* **1967**, 11119 DOI: doi.org/cjpvnm

Oxidative Heck



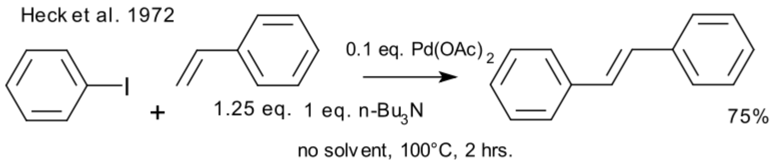
Heck, *JACS* **1968** 90, 5518. DOI: [10.1021/ja01022a034](10.1021/ja01022a034)

Mizoroki

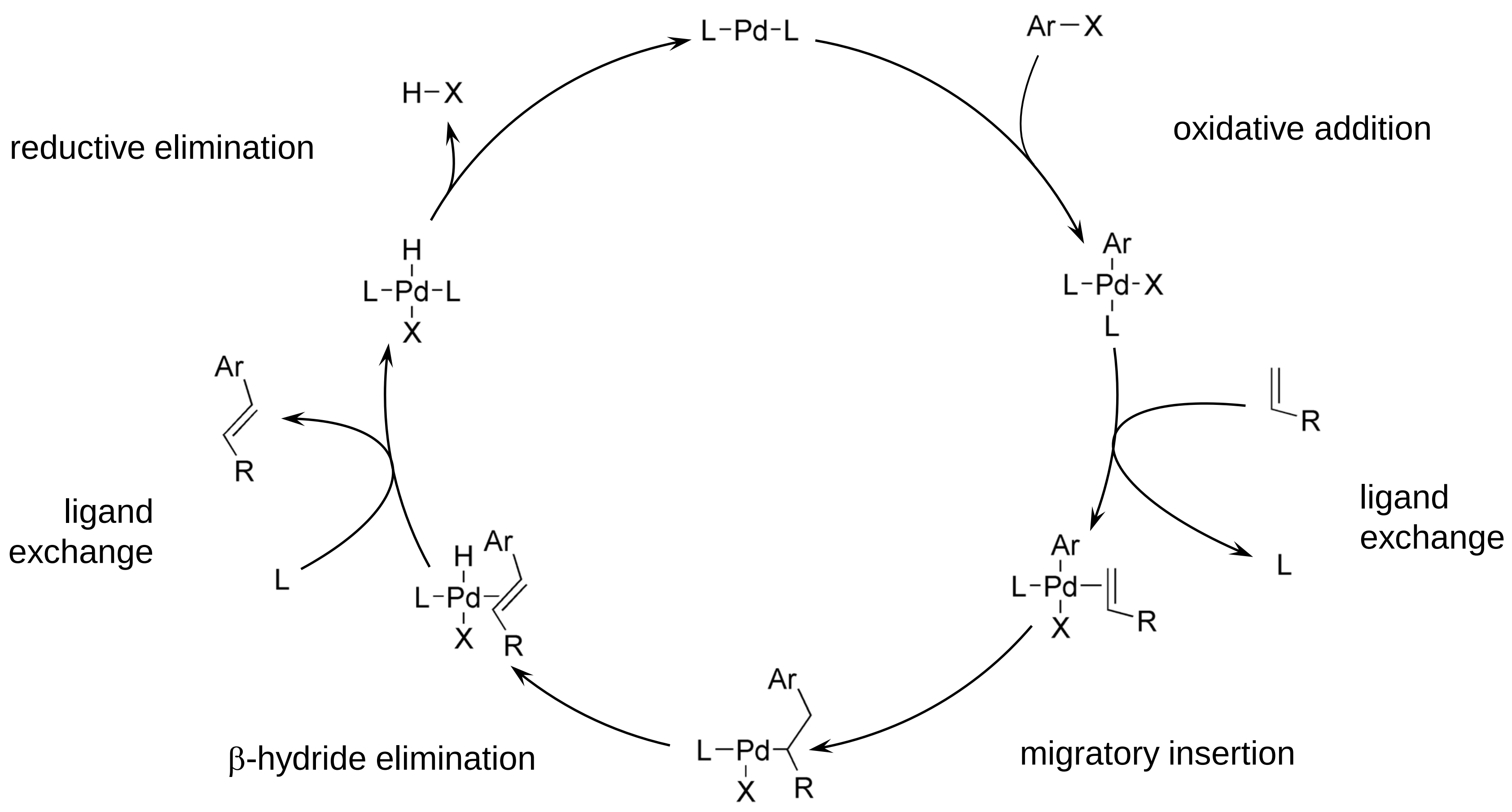


Mizoroki *Bull Chem Soc Jpn* **1971** 44, 581. DOI: 10.1246/bcsj.44.581

Heck

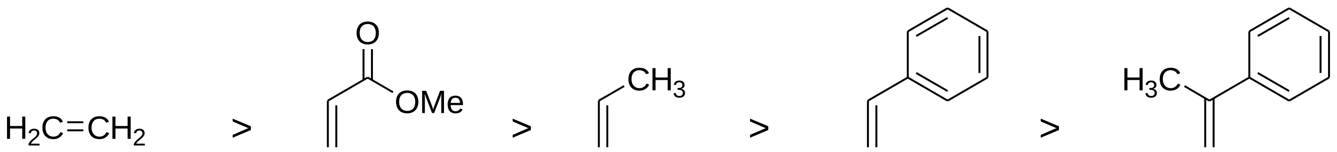


7.6.2 MIZOROKI-HECK REACTION – MECHANISM



7.6.3 MIZOROKI-HECK REACTION – REACTIVITY

Olefin



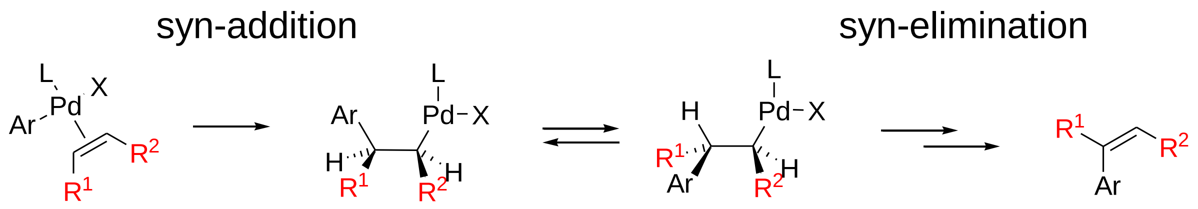
14000   970   220   42   1

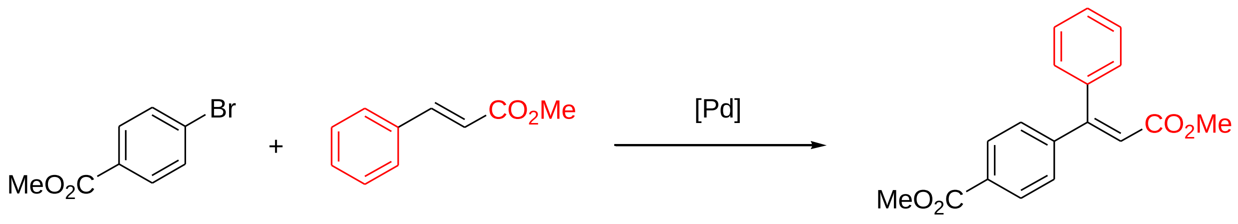
relative rates
from competition
experiments

Ar-X

X = $N_2^{\oplus}$ > I >> OTf ~ Br > Cl > OTs >> F > OMe

7.6.4 MIZOROKI-HECK REACTION – STEREOCHEMISTRY

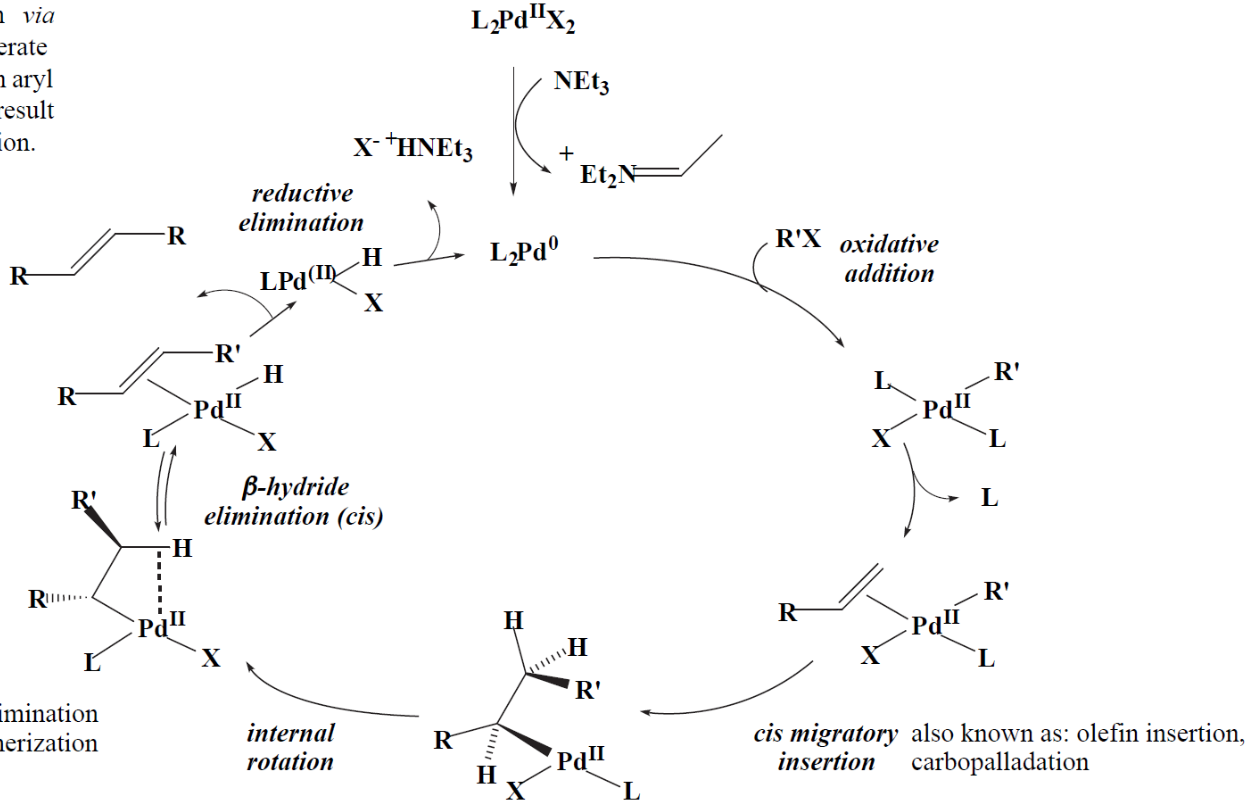


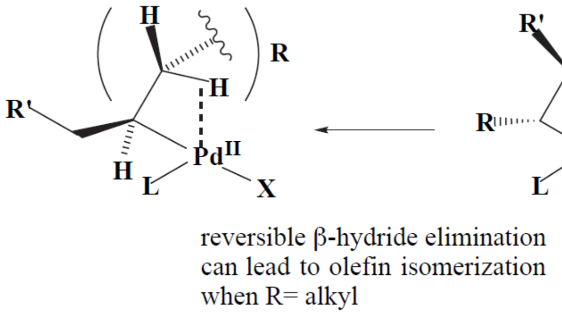


7.6. MIZOROKI-HECK REACTION – NEUTRAL MECHANISM

Neutral mechanism: coordination of olefin *via* dissociation of a neutral ligand. Thought to operate when X = strong σ-donor (*i.e.* Cl, Br or I). When aryl or vinyl halides are used, bidentate ligands can result in a partial or complete suppression of the reaction.

The reaction is stereoselective for the *E* olefin because the corresponding TS leading to the *cis* olefin involves energetically unfavorable R'/R eclipsing interactions.

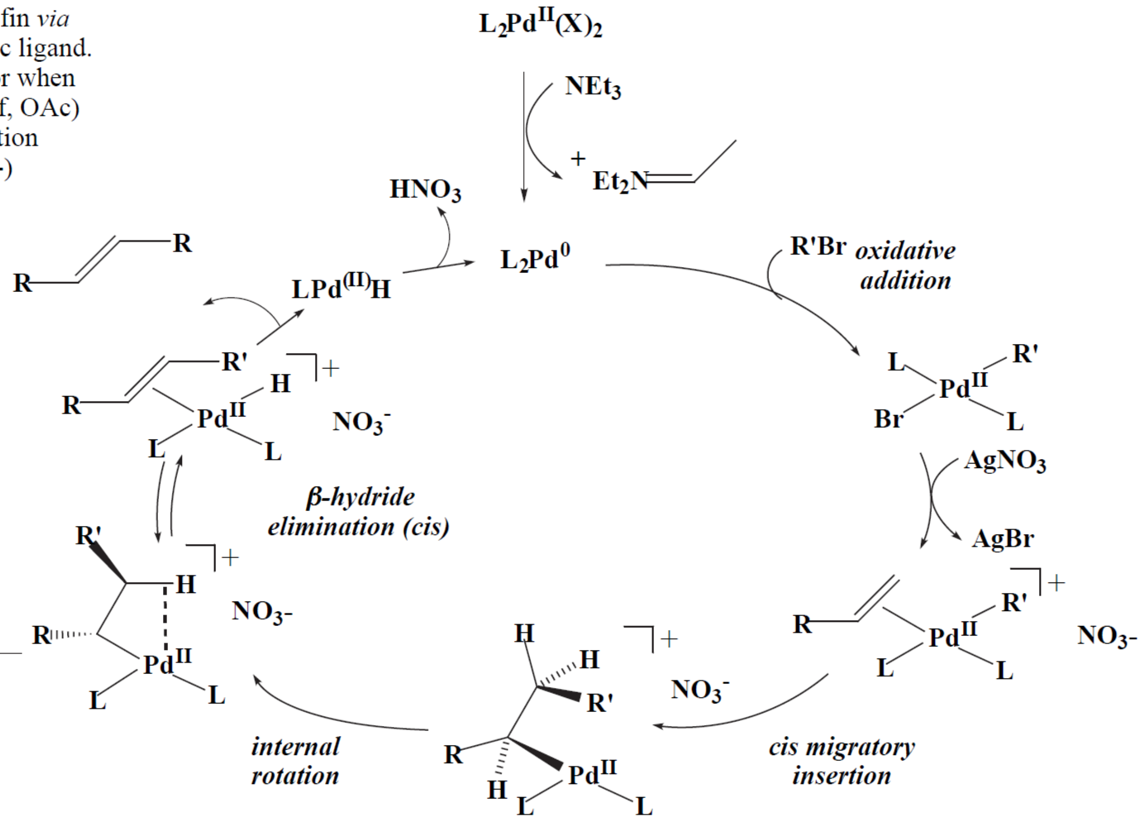


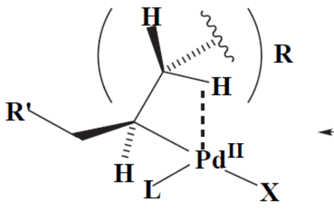


7.6. MIZOROKI-HECK REACTION – CATIONIC MECHANISM

Cationic mechanism: coordination of olefin *via* dissociation of a weakly associated anionic ligand. Thought to operate when X = OTf, OAc or when Ag or Tl salts (AgY or TlY; Y= CO3, OTf, OAc) are used that are capable of halide abstraction (metathesis- see Structure & Bonding -12-)

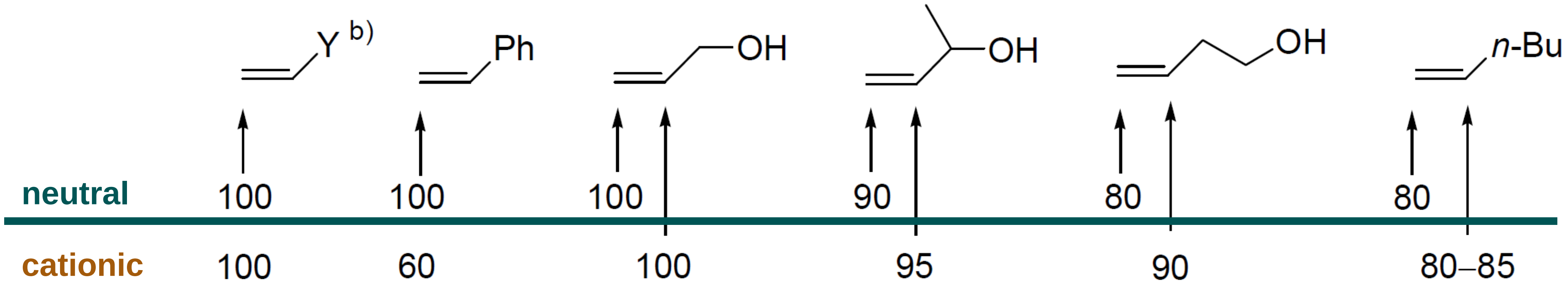
Faster dissociation of the olefin leads to less β-hydride elimination.





Cabri *Acc. Chem. Res.* **1995** (28) 2.
Beletskaya *Chem. Rev.* **2000** (100) 3009

7.6. MIZOROKI-HECK – MECHANISM AND REGIOCHEMISTRY



Cabri *Acc Chem Res* **1995** *28* 2
Hallberg *TH* **1994** *50* 285
JOC **2000** *65* 7235