Pd-catalyzed meta-selectivity C-H bond activation with a nitrile-containing template: computational study on mechanism and origins of selectivity

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2013-12-23

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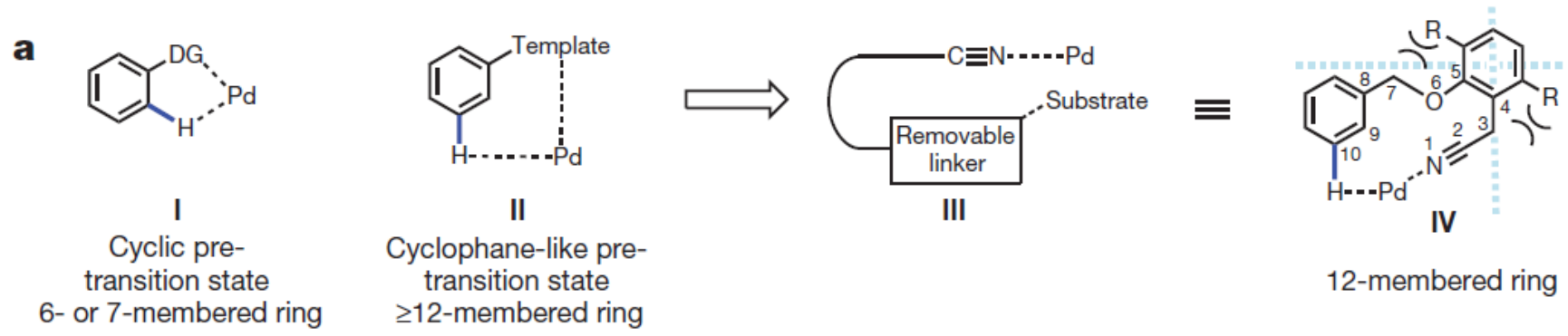
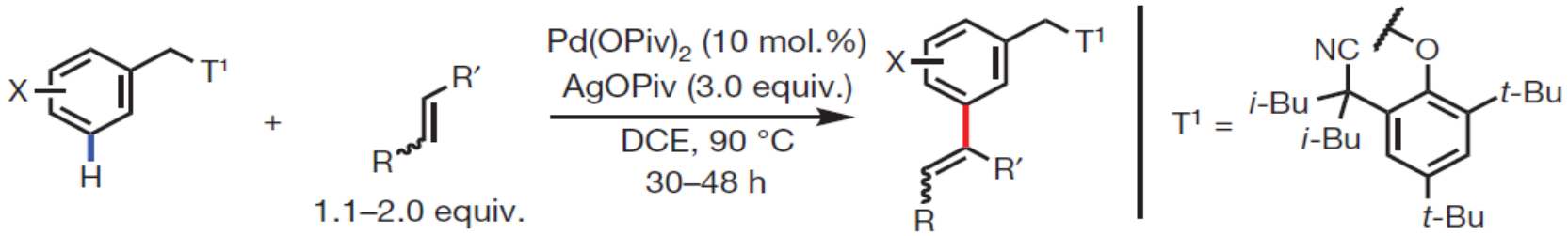
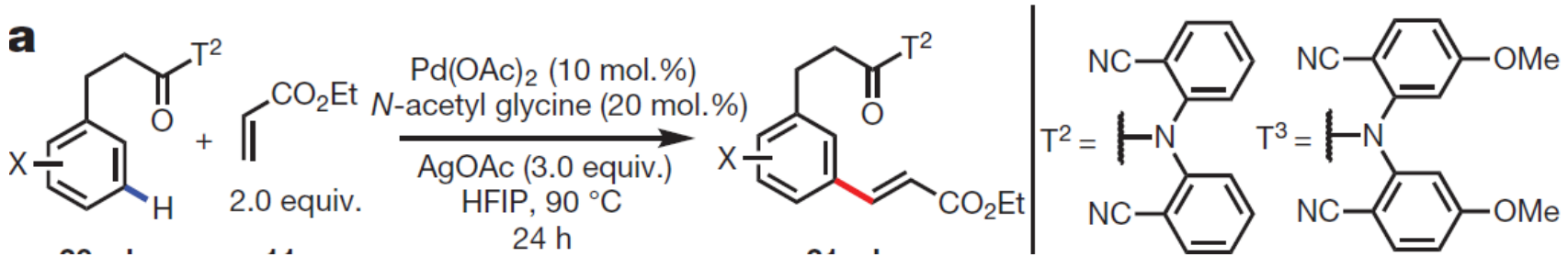
Introduction



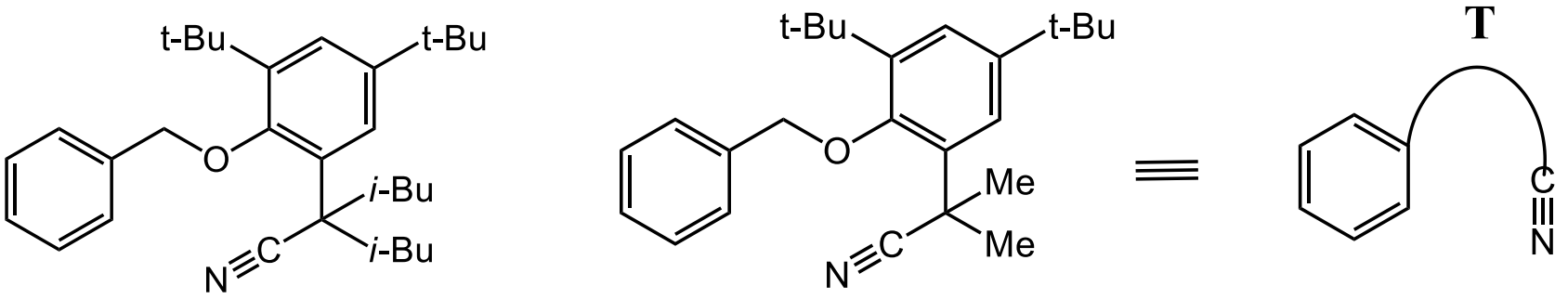




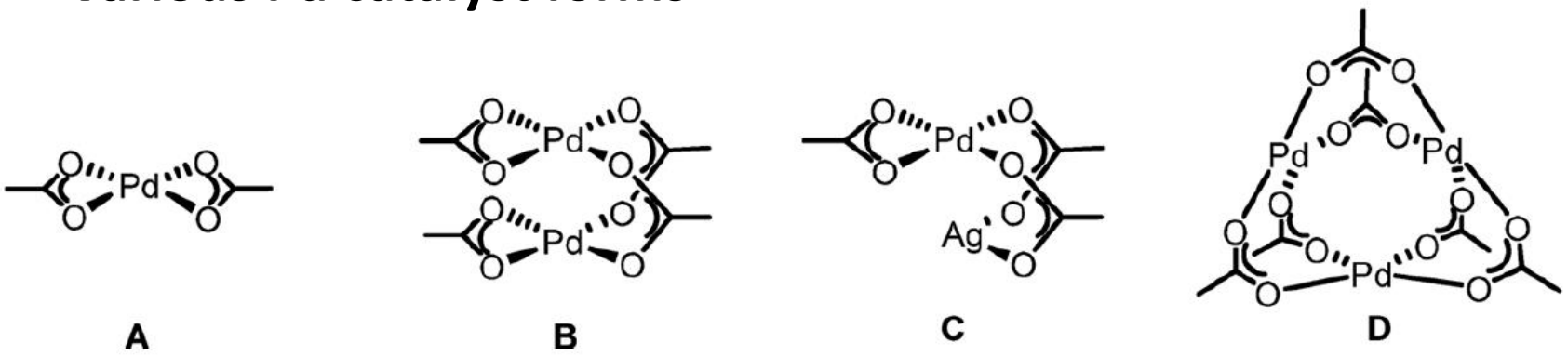
(1) Leow, D.; Li, G.; Mei, T.-S.; Yu, J.-Q. *Nature* **2012**, *486*, 518.

Introduction

The mechanism and the origins of meta-selectivity, the effects of template length and bulky *t*-Bu and *i*-Bu



Various Pd catalyst forms



Introduction

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Article

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Palladium-Catalyzed *Meta*-Selective C–H Bond Activation with a Nitrile-Containing Template: Computational Study on Mechanism and Origins of Selectivity

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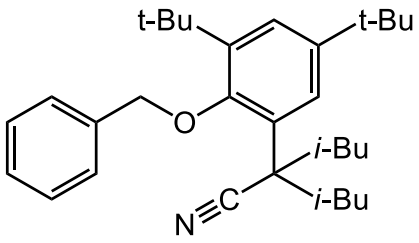
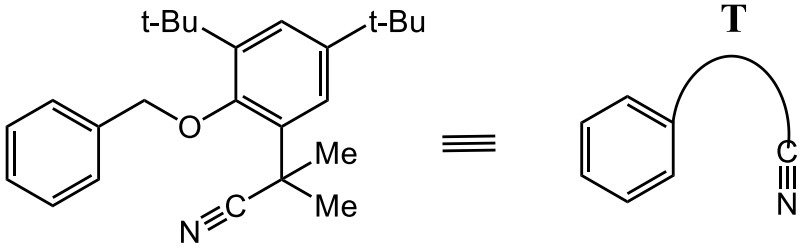
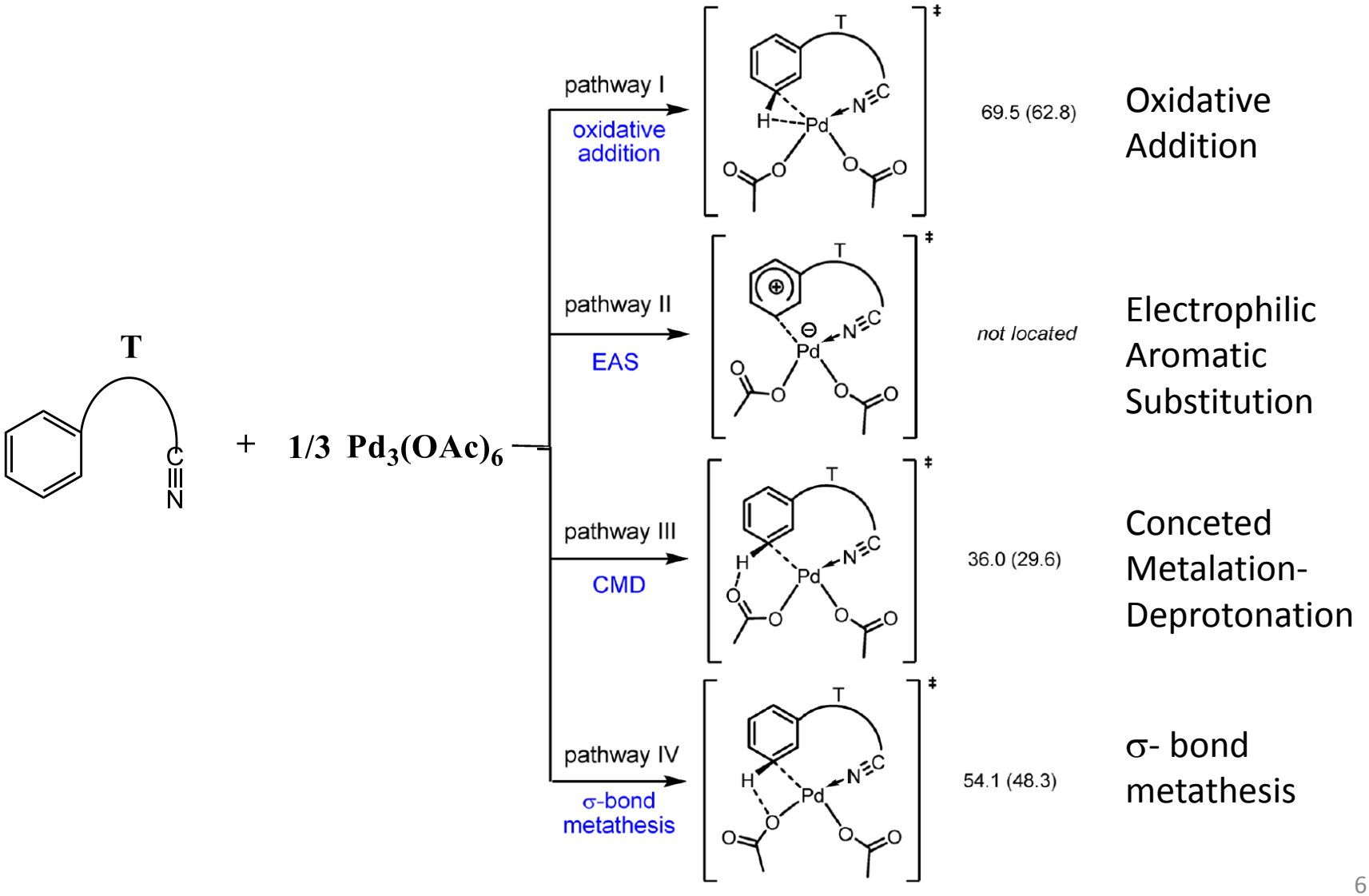
Supporting Information

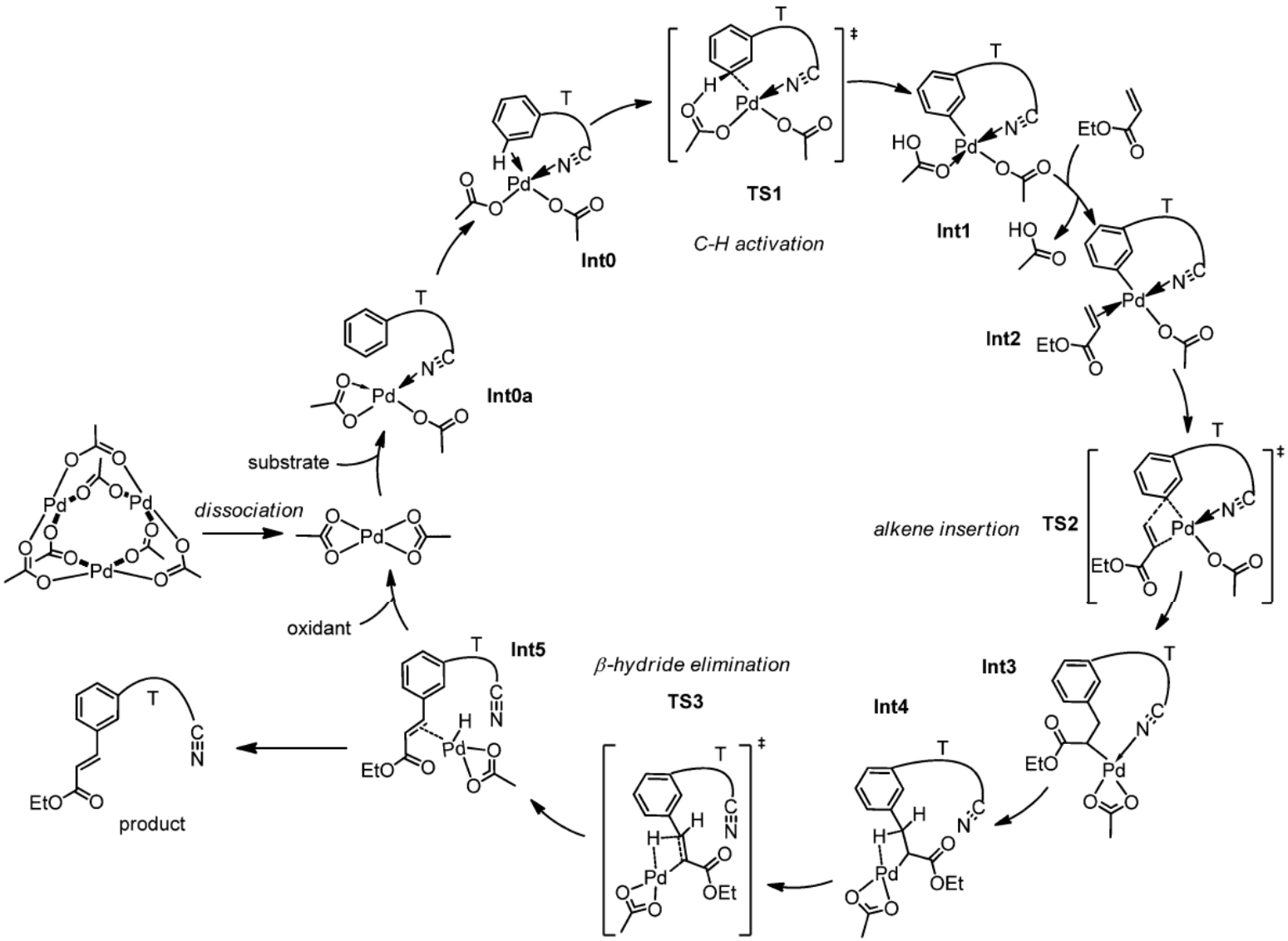




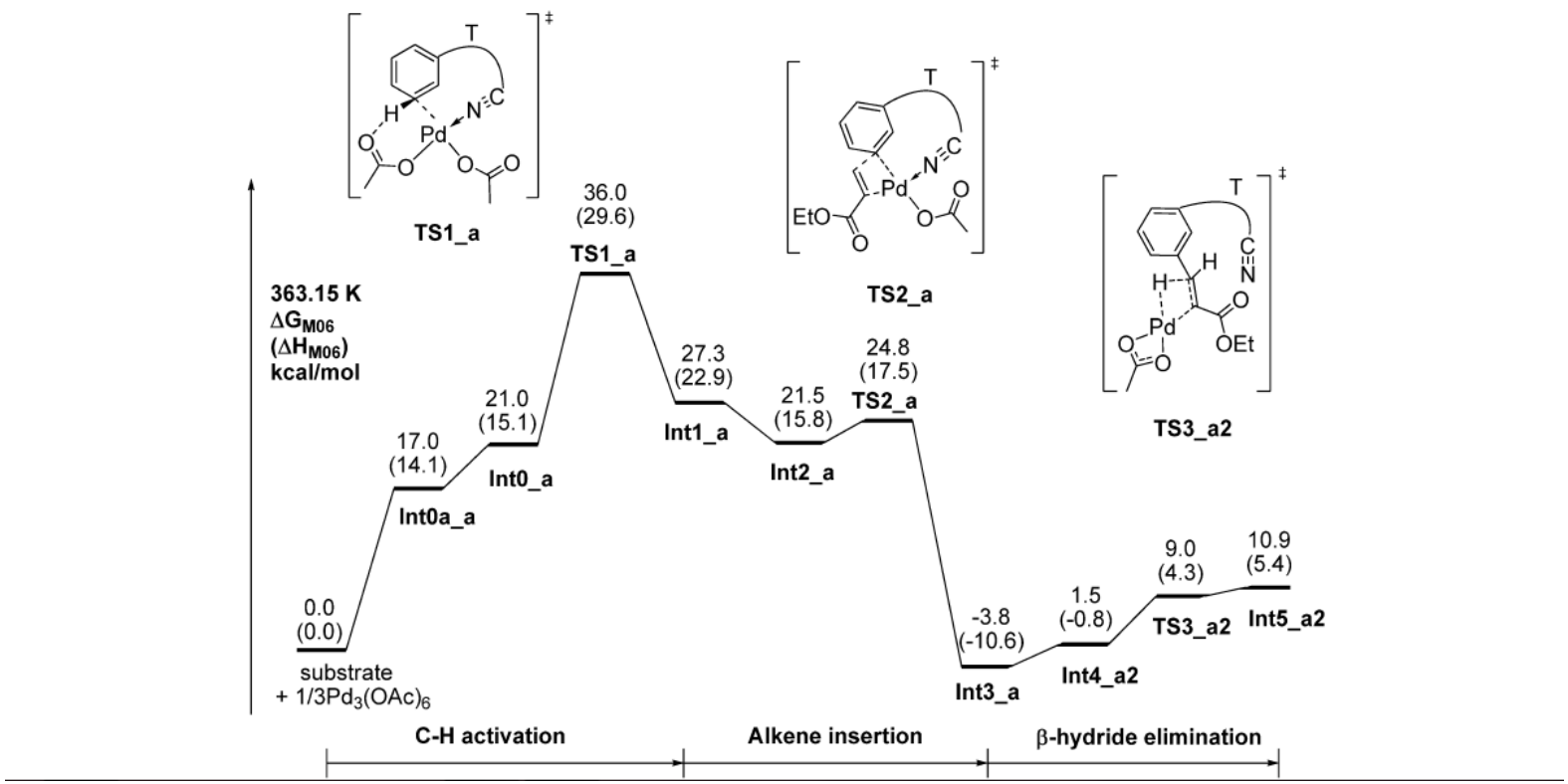
Monomeric C-H activation pathways and computed activation energies

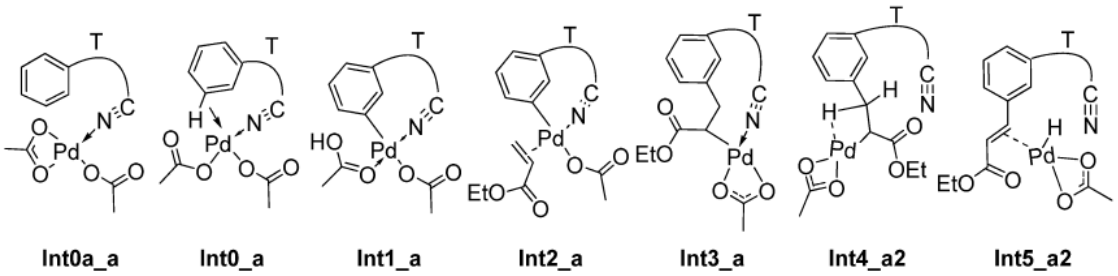


Catalytic cycle of Pd monomeric mechanism



Energy profile for the meta pathway in the monomeric $Pd(OAc)_2$ mechanism

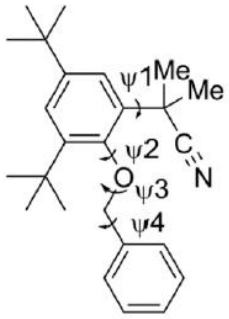




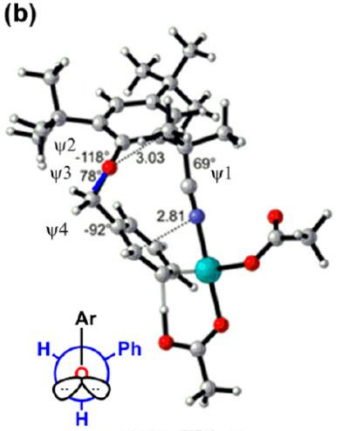
Regioselectivity

Transition states with nitrile coordinated to Pd

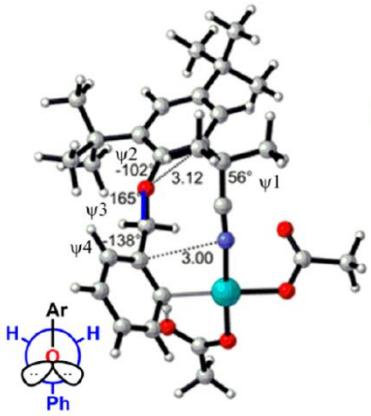
(a)



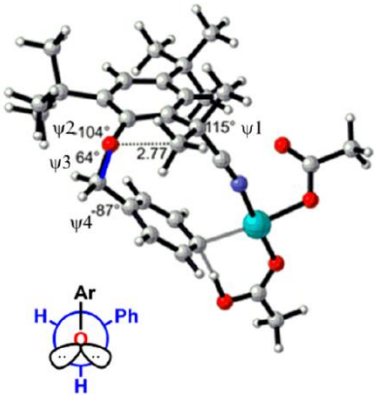
(b)



meta_TS1_a
36.0 kcal/mol



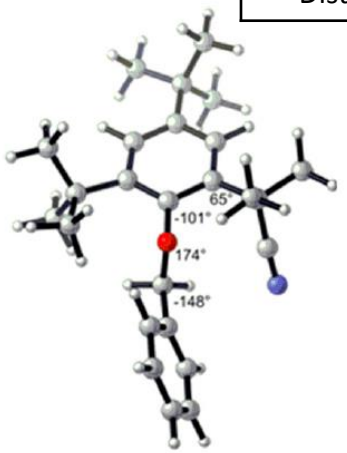
ortho_TS1_a
30.1 kcal/mol

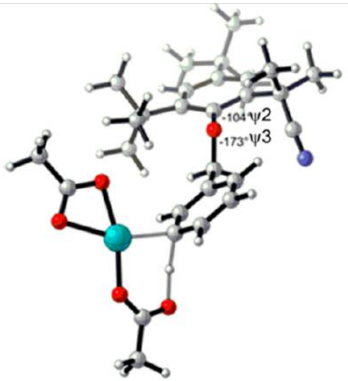


para_TS1_a
35.3 kcal/mol

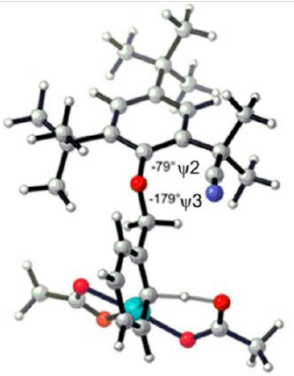
Distortion E	36.7	44.1	43.2	Kcal/mol

Transition states without nitrile coordinated to Pd

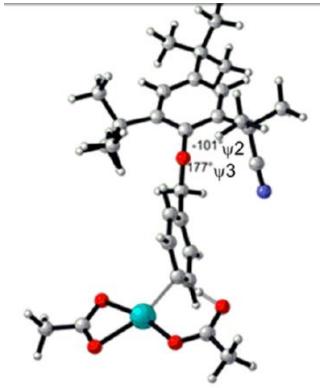




meta_TS1_a2
36.0 kcal/mol



ortho_TS1_a2
34.2 kcal/mol

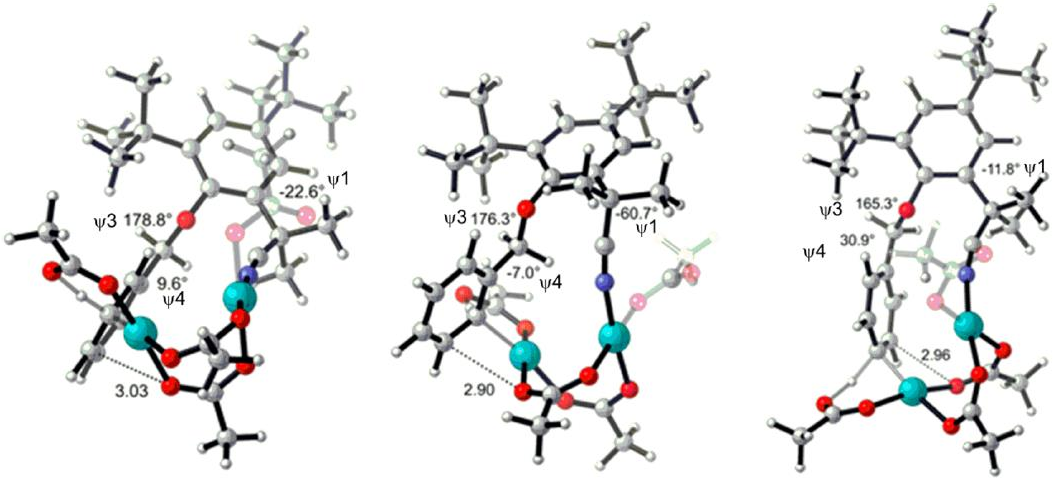


para_TS1_a2
35.0 kcal/mol

$Pd_2(OAc)_4$ Dimeric Mechanism

- ***Four major factors considered***
  - ***1, dihedral angles ψ1 and ψ2***
  - ***2, dihedral angles ψ3 and ψ4***
  - ***3, dihedral angles ψ5***
  - ***4, relative position of the nitrile coordination site and C-H bond activation site***

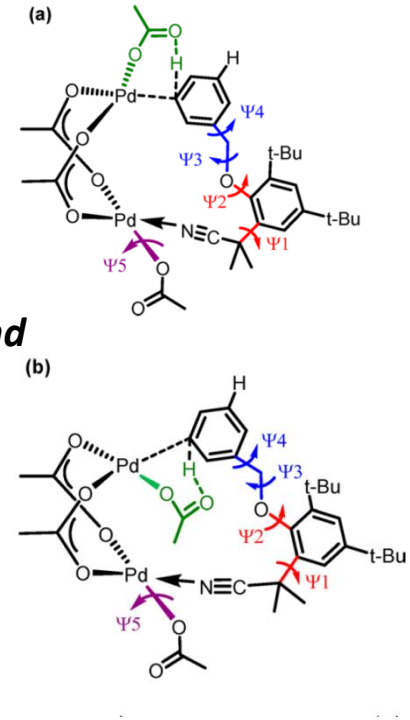
Eight conformations within 2 kcal/mol.



meta_TS1_b
29.3 kcal/mol

ortho_TS1_b
29.7 kcal/mol

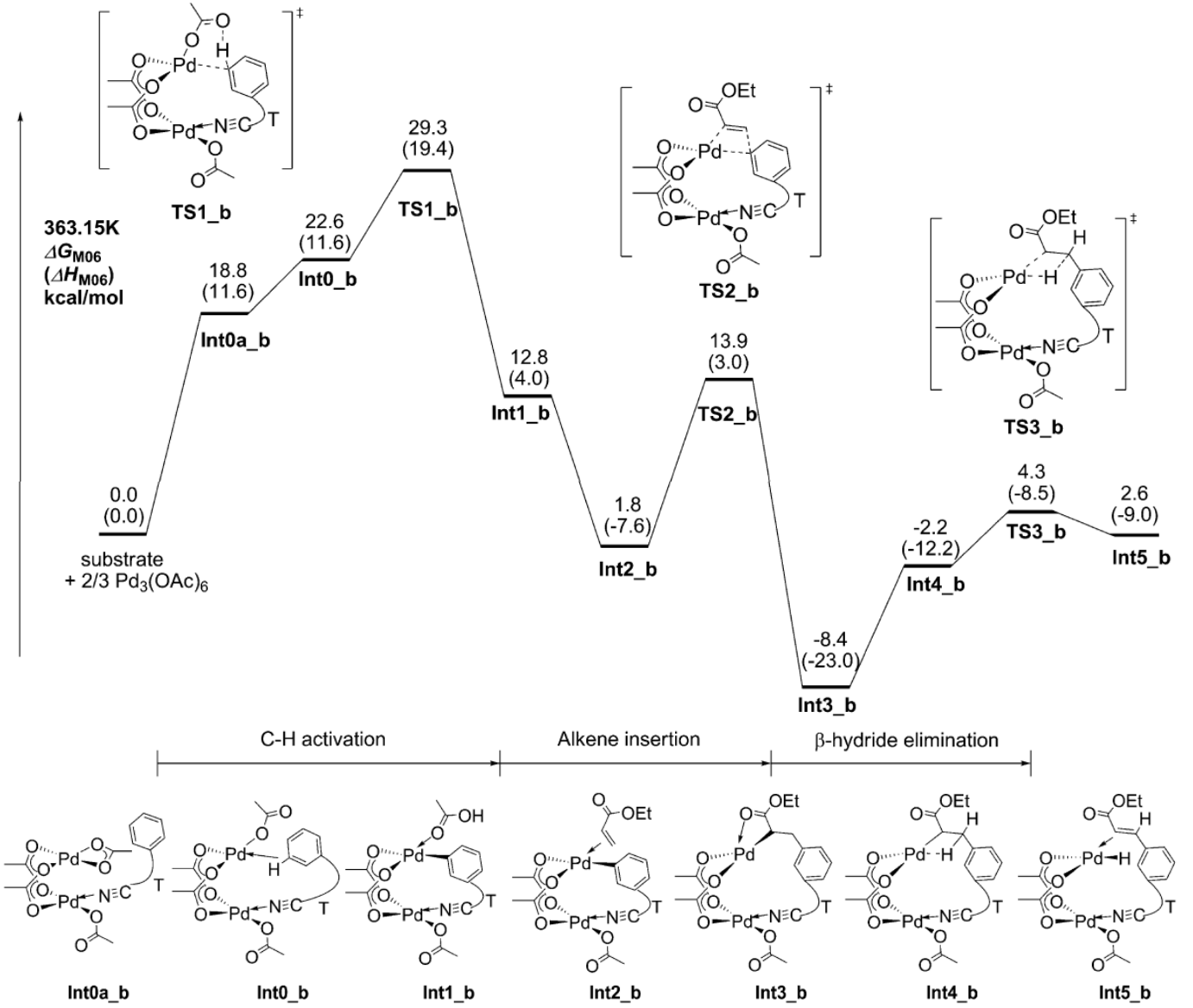
para_TS1_b
33.4 kcal/mol



(a)Two acetate groups are on different sides.
(b) two acetate groups on the same side

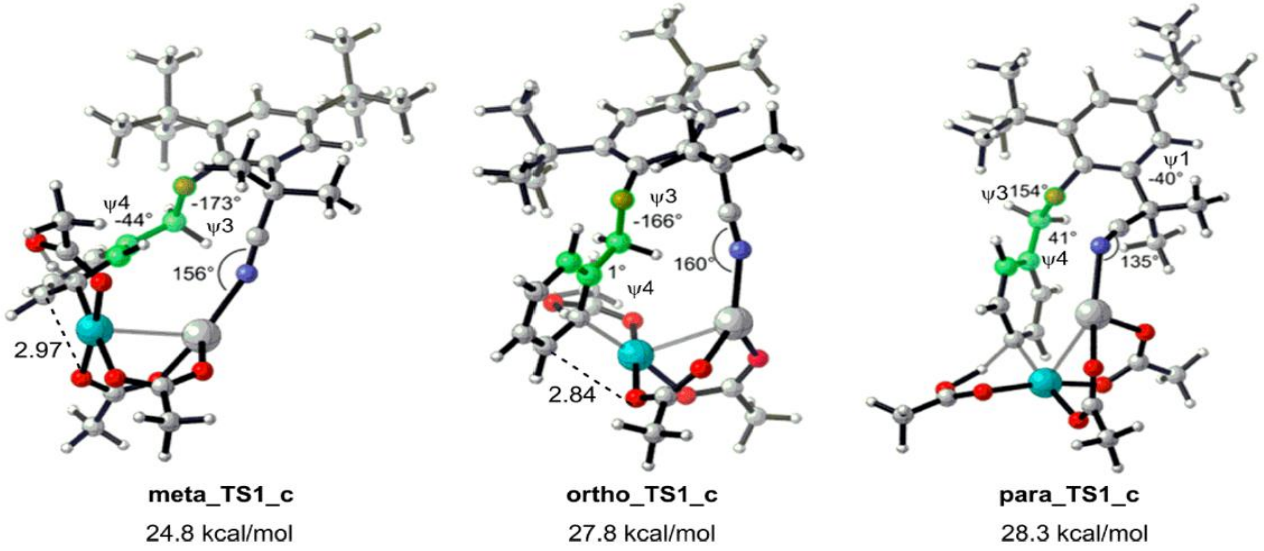
Boltzaman distribution indicate Metapathway is more favorable ratio 73: 27

$Pd_2(OAc)_4$ Dimeric Mechanism



$PdAg(OAc)_3$ Heterodimeric Mechanism

Ag^+ could play a dual role in this reaction. Oxidant and coordinate with nitrile



meta_TS1_c
24.8 kcal/mol

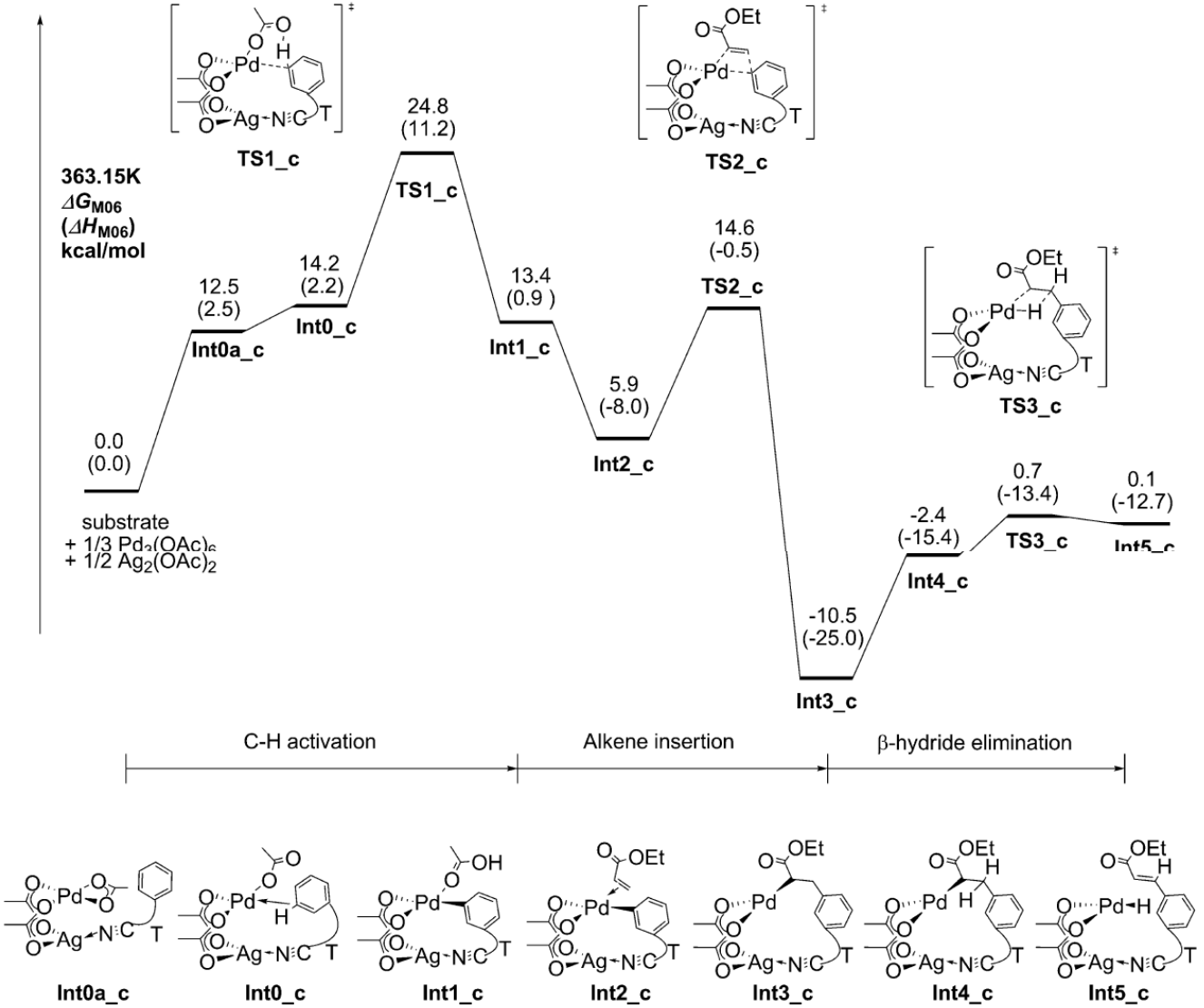
ortho_TS1_c
27.8 kcal/mol

para_TS1_c
28.3 kcal/mol

Distortion Energy analysis of C-H activation transition states of $PdAg(OAc)_3$ Mechanism

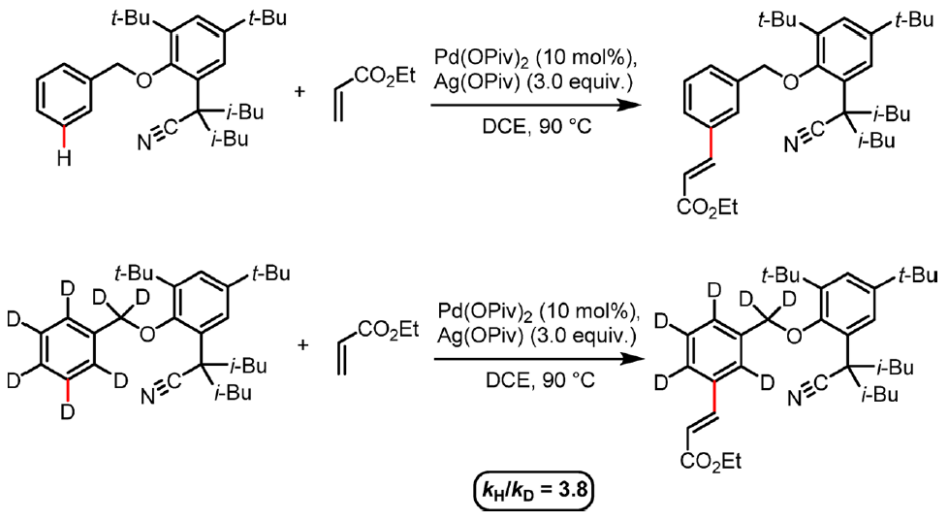
Distortion	Meta-Ts1-C	ortho-Ts1-C	para-Ts1-C
Ecat(kcal/mol)	35.2	36.3	36.3
Esub(kcal/mol)	33.3	37.7	35.6
Etotal(Kcal/mol)	68.5	74.0	71.9

$PdAg(OAc)_3$ Heterodimeric Mechanism

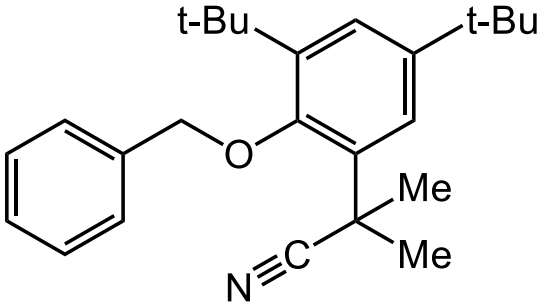


Kinetic Isotope Effects in C-H Olefination

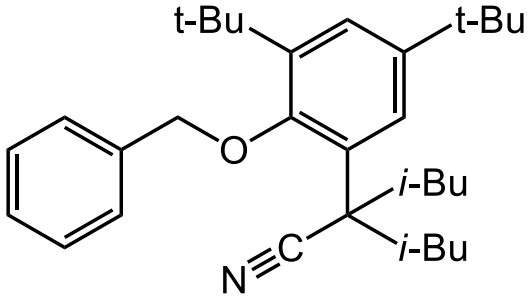
Experimental KIE



Theoretical KIE



$Pd(OAc)_2$ **Meta-TS1-a**: 3.6
$Pd_2(OAc)_4$ **Meta-TS1-b**: 4.1
$PdAg(OAc)_3$ **Meta-TS1-b**: 3.8



$Pd(OAc)_2$ **Meta-TS1-a**: 3.6
$Pd_2(OAc)_4$ **Meta-TS1-b**: 4.1
$PdAg(OAc)_3$ **Meta-TS1-b**: 3.9

Summary

- ***Multiple C-H activation Mechanism studied***
  - ***Monomeric Pd, Dimeric Pd-Pd and Pd-Ag, Trimeric Pd complex***
- ***C-H activation occurs via CMD Mechanism***
  - ***Experimentally and theoretically***
- ***Results***
  - ***Monomeric Pd mechanism is ortho-selective dimeric mechanism is meta-selective, trimeric mechanism is ruled out in this transformation.***
  - ***AgOAc as both oxidant or heternuclear active species***