

Name: Answer Key

**CHEM 633: Advanced Organic Chemistry: Physical
Midterm 2**

Please answer the following questions clearly and concisely.

You may write your answers in the space provided and/or on additional pages.

Please write your initials on each page you wish to turn in.

There are 15 total pages to this exam. Please be sure your copy has 15 pages before you begin.

Molecular models and calculators are allowed.

Problem	Points
1	____/21
2	____/10
3	____/14
4	____/16
5	____/6
6	____/12
7	____/21
TOTAL	____/100

Potentially Useful Constants

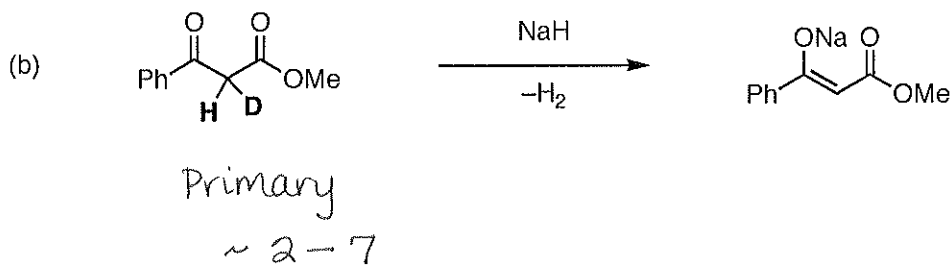
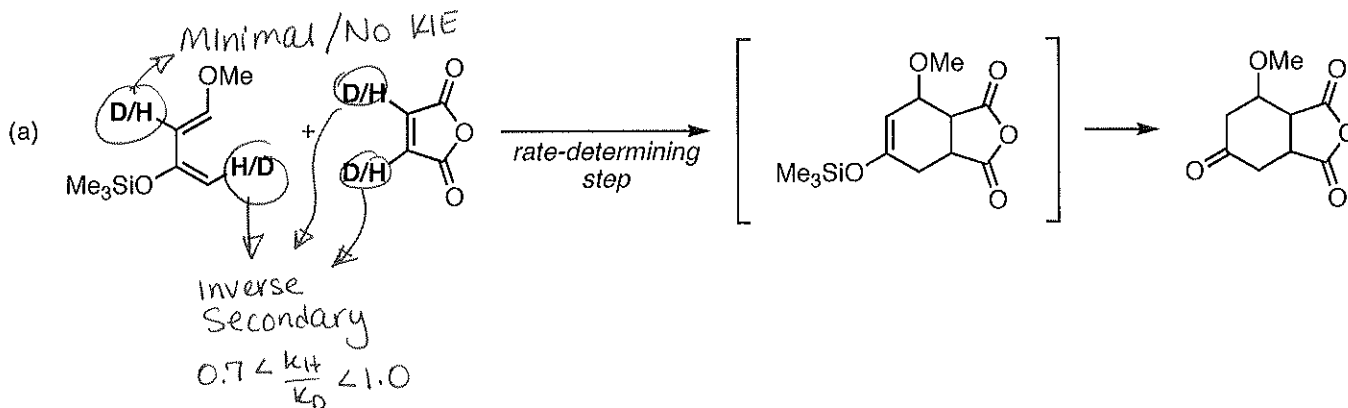
$$k_B/h = 2.083 \times 10^{10} \text{ s}^{-1}\text{K}^{-1}$$

$$\kappa = 1 \text{ (kappa)}$$

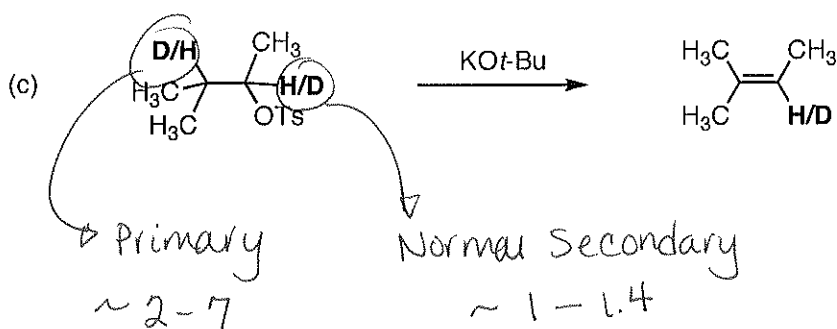
$$R = 1.98 \text{ cal/mol}\cdot\text{K}$$

3 points each (2 pts for naming, 1 for range)

1. (21 points) Please predict the kinetic isotope effect (if any) that would be observed at the marked positions (in bold) for the following reactions. Please specify the **type** (primary, secondary, inverse, etc) and the **range of magnitudes**. No explanation is necessary.



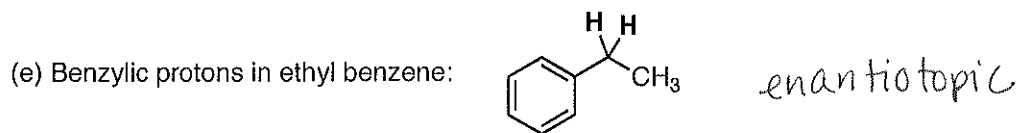
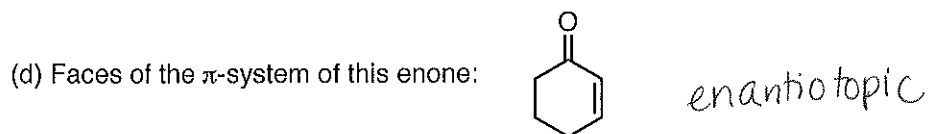
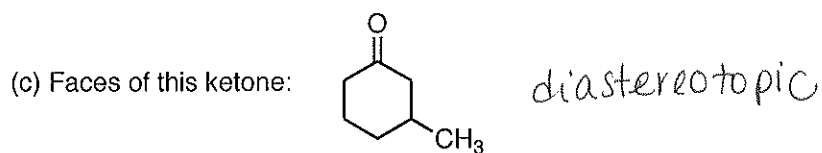
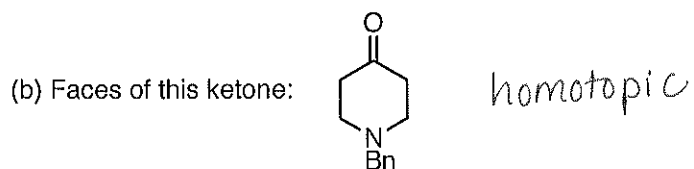
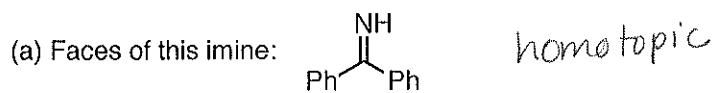
+2 if don't realize it's an intramolecular RIE expt.



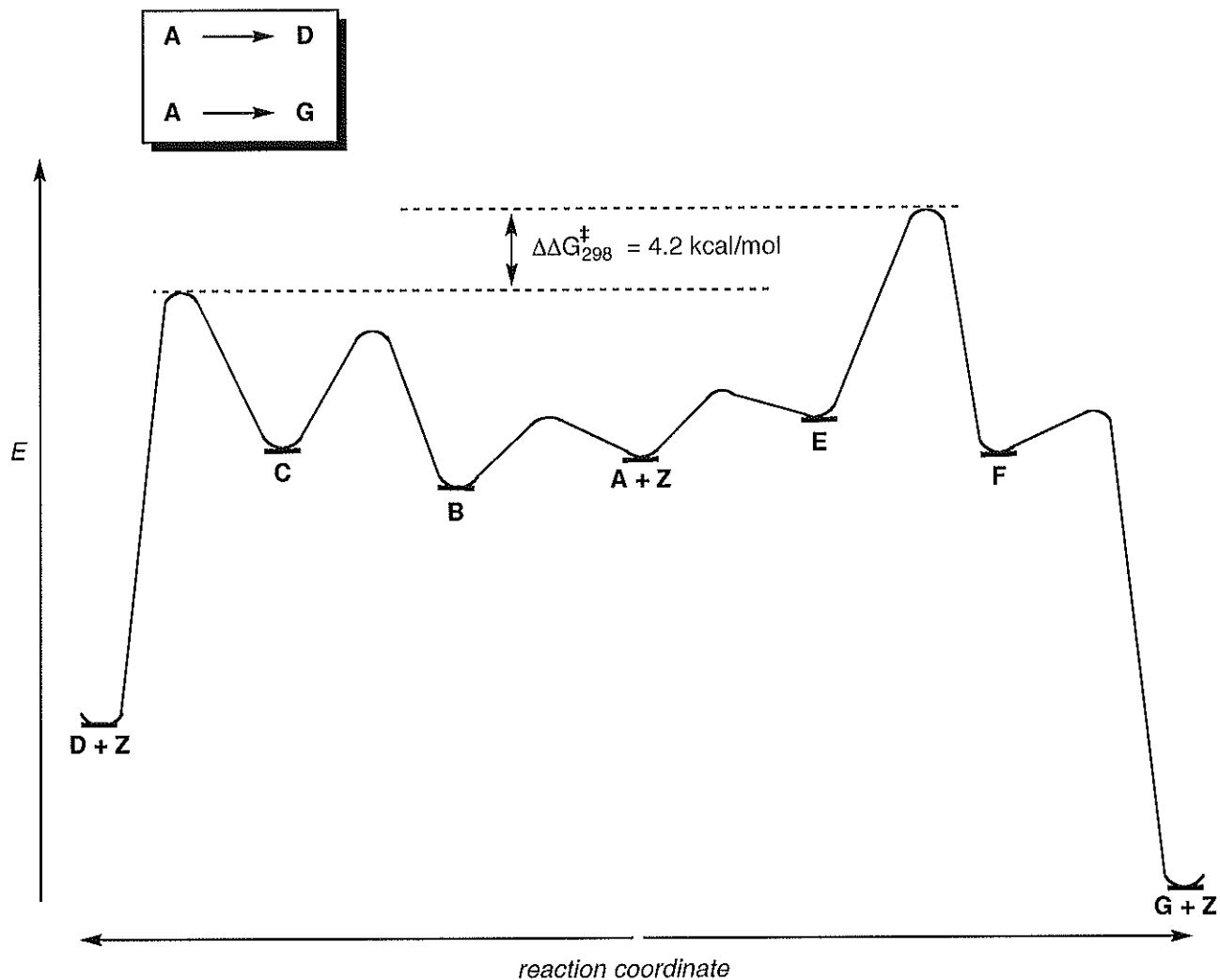
2 points each

3

2. (10 points) Please label the following "groups" as homotopic, enantiotopic or diastereotopic.



3. (14 points) Consider the following generic reaction coordinate diagram, which illustrates the competing reaction pathways for substrate **A** to form either product **D** or product **G**. You may assume that the overall transformations are irreversible.



(a) Will **D** or **G** be the major product?
(2 points)

D

(b) Predict the relative ratio of **D** : **G** that will be formed.
(2 pts)

1000 : 1 99.9 : 0.1

(c) Which intermediate will you observe during the reaction?
(2 pts)

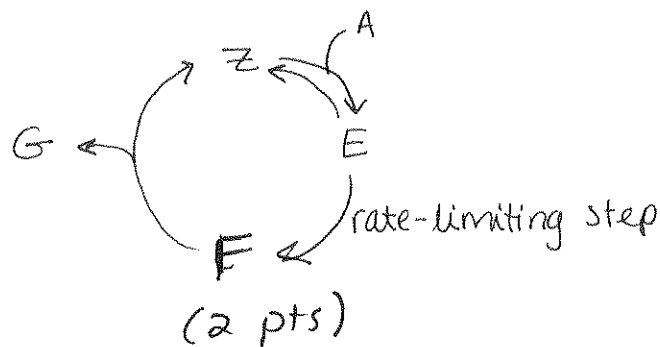
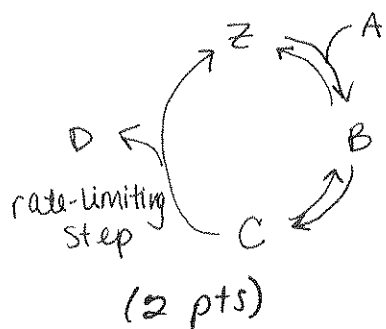
B

(3-continued)

(d) Are **D** and **G** enantiomers? *No*
(2 pts)

(e) Please identify the catalyst in this reaction. *Z*
(2 pts)

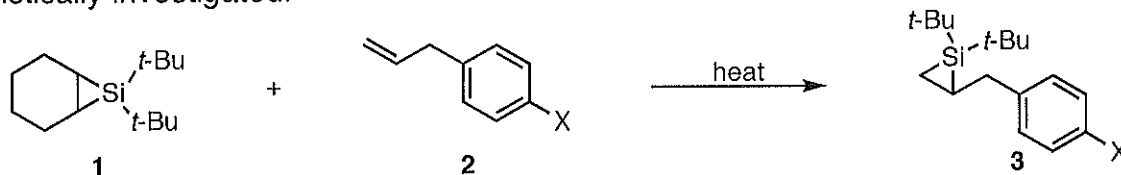
(f) Draw catalytic cycles to represent both transformations. Please label the rate-limiting step of each catalytic cycle and clearly show whether each step is reversible or irreversible.



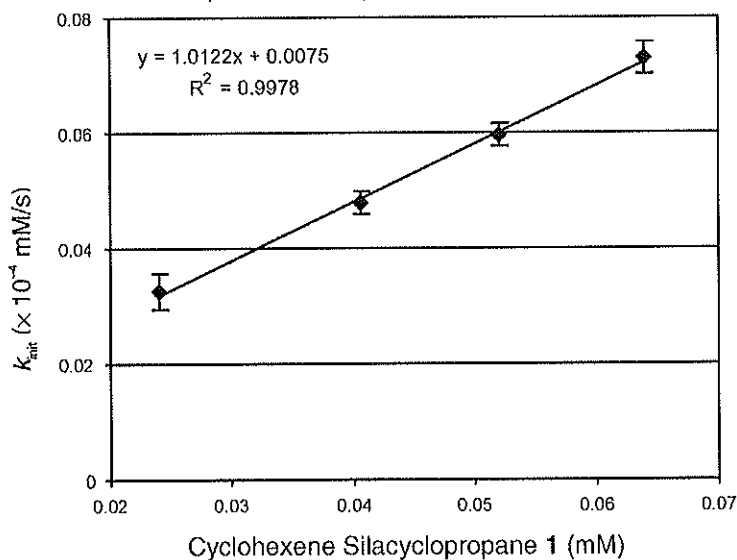
Only +1 if irreversible/reversible is wrong.

Only +1 if rls is not marked or is wrong.

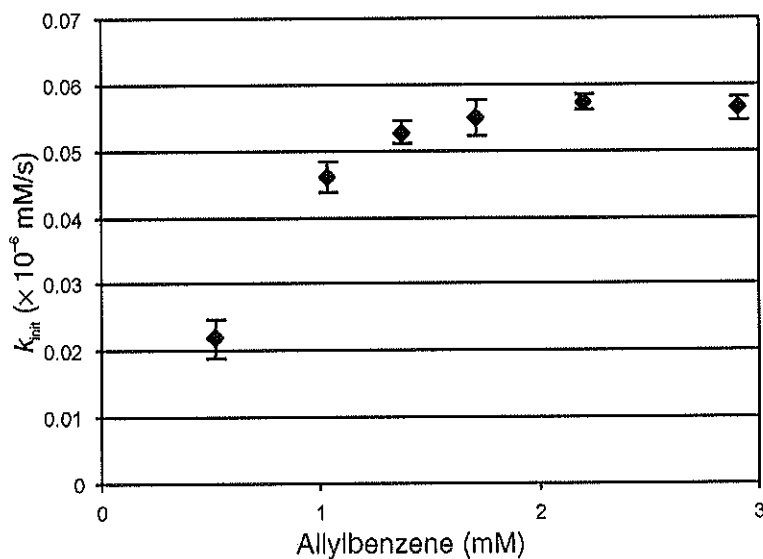
4. (16 points) Silylene transfer from silacyclopropane **1** to allylbenzene **2** ($X = H$) has been mechanistically investigated.



(a) Using initial rate data, the following correlations between rate and the concentration of **1**, **2** and cyclohexene have been determined (you may treat k_{init} as equivalent to initial rate). Please state the rate dependence (first order, second order, etc) on each of these species.

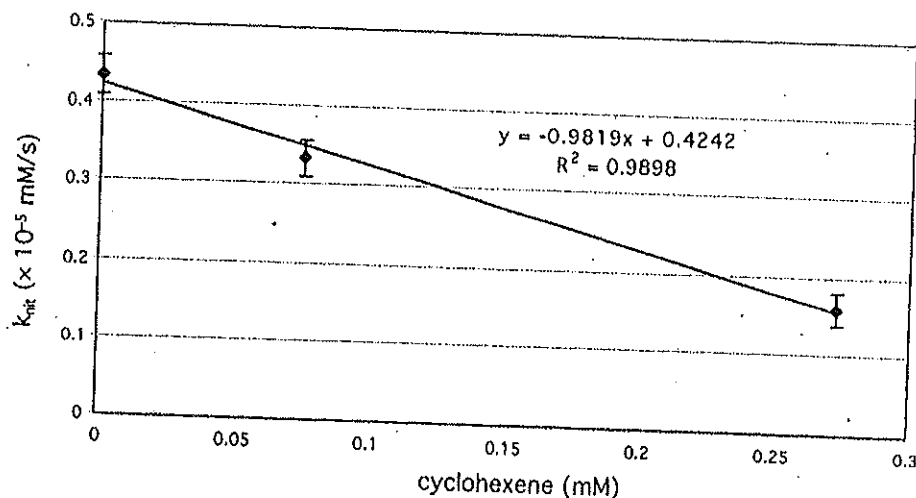


first order
in 1 (1 pt)



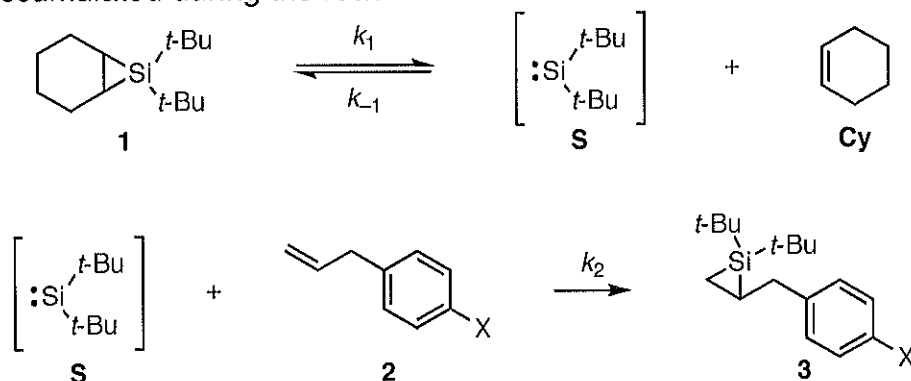
saturation w/ allylbenzene
(2)
(2 pts)

(4-continued)



Inverse first order
in Cyclohexene.
(1 pt)

(b) Based on this data, the following mechanism was proposed. Derive a rate law for this proposed mechanism, using the steady-state approximation where appropriate. Your rate law should only include terms that are experimentally quantifiable. Please note that no observable intermediates accumulated during the reaction.



$$\text{rate} = k_2 [\text{S}][\text{2}]$$

$$\text{SSA: } \frac{d[\text{S}]}{dt} = 0 = k_1 [\text{1}] - k_{-1} [\text{S}][\text{Cy}] - k_2 [\text{S}][\text{2}]$$

$$[\text{S}] = \frac{k_1 [\text{1}]}{k_{-1} [\text{Cy}] + k_2 [\text{2}]}$$

only +3 if missing [Cy].

$$\text{rate} = \frac{k_1 k_2 [\text{1}][\text{2}]}{k_{-1} [\text{Cy}] + k_2 [\text{2}]}$$

4 pts

(4-continued)

(c) Explain why this reaction exhibits nonlinear dependence on the concentration of allylbenzene ([2]).

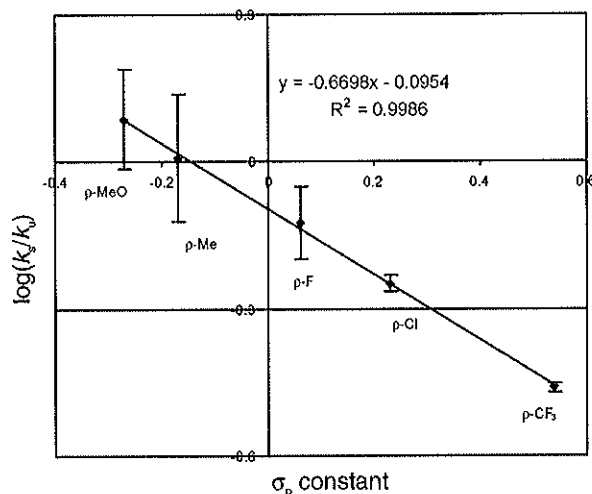
2pts At low [2], $\text{rate} = \frac{k_1 k_2 [1][2]}{k_{-1}[Cy]} \Rightarrow 1^{\text{st}} \text{ order in } [2]$
 $(k_{-1}[Cy] \gg k_2 [2])$

2pts At high [2], $k_{-1}[Cy] \ll k_2 [2]$, so
 $\text{rate} = \frac{k_1 k_2 [1][2]}{k_2 [2]} = k_1 [1] \Rightarrow 0\text{-order in } [2]$

+2

points for defining what saturation is.

(d) The relative rates of substituted allylbenzene derivatives were measured to give the following Hammett plot.

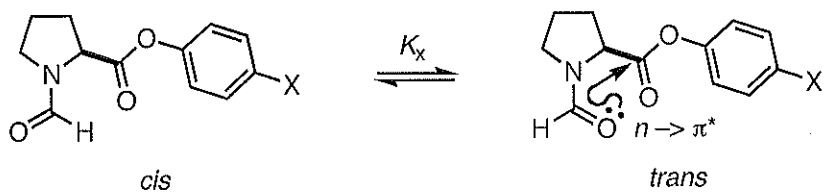


What does this plot tell you about the transition state of silylene transfer to the allylbenzene?

negative ^{2pts} $\rho \Rightarrow$ build-up of \oplus charge
 on allyl fragment

↑
2pts

5. (6 points) As a model for interactions in a polypeptide, Hodges and Raines have studied the following *N*-formylproline phenylesters, which exist as an equilibrium ratio of *cis/trans* isomers. They found that there was a linear free energy relationship between the isomeric ratio and σ_p (graph A = experimental data; graph B = computational data) and proposed that this LFER suggests that the *trans* isomer is stabilized by an $n \rightarrow \pi^*$ interaction.

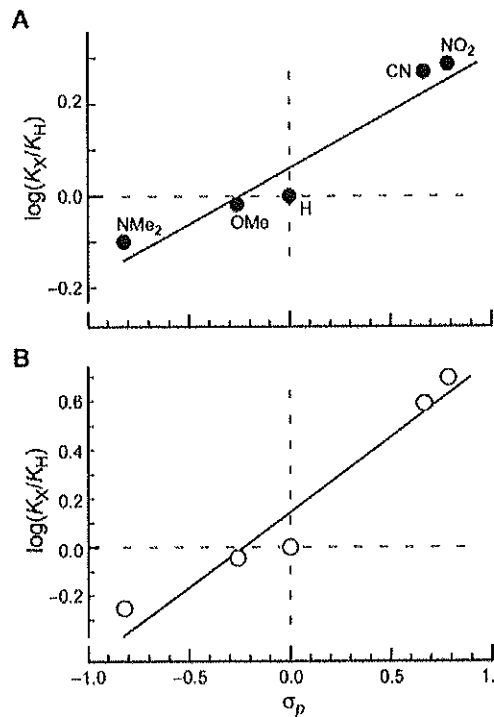


Please *briefly* explain how the LFER suggests the proposed $n \rightarrow \pi^*$ interaction.

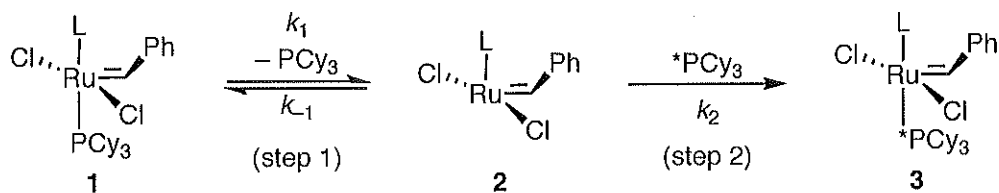
2pts Hammett plot has \oplus slope $\Rightarrow \oplus \rho$.

2pts So more negative charge in the *trans* conformation (electron-withdrawing substituents stabilize *trans* conformation).

2pts Negative charge is from $n \rightarrow \pi^*$ donation.



6. (12 points) Dissociation of PCy_3 is an important step of olefin metathesis reactions. Studies of this dissociation have been performed by analyzing the exchange of PCy_3 with a labeled $^*\text{PCy}_3$.



(a) Derive a rate expression for this sequence, assuming that step 2 is rate-determining. Use the steady-state approximation where appropriate. You may assume that no observable intermediates accumulate during the reaction. Your rate expression should only contain terms that are experimentally quantifiable.

3 pts

$$\text{rate} = k_2 [2] [^*\text{PCy}_3]$$

$$\text{SSA: } \frac{d[2]}{dt} = 0 = k_1 [1] - k_{-1} [2] [\text{PCy}_3] - k_2 [2] [^*\text{PCy}_3]$$

$$[2] = \frac{k_1 [1]}{k_{-1} [\text{PCy}_3] + k_2 [^*\text{PCy}_3]}$$

$$\text{rate} = \frac{k_2 k_1 [1] [^*\text{PCy}_3]}{k_{-1} [\text{PCy}_3] + k_2 [^*\text{PCy}_3]}$$

(b) Derive a rate expression for this sequence, assuming that step 1 is rate-determining. Use the steady-state approximation where appropriate. You may assume that no observable intermediates accumulate during the reaction.

3 pts

$$\text{rate} = k_1 [1]$$

(6-continued)

(c) Kinetic studies determined that the reaction rate had zero-order dependence on $[\text{PCy}_3]$ and $[\text{*PCy}_3]$. Does this data allow you to distinguish between the two possible rate-determining steps (step 1 or step 2)? If so, which step is rate-determining?

1 pts yes

2 pts Step 1 is rate-determining.

(d) The activation parameters of this reaction were also determined for $\text{L} = \text{PCy}_3$: $\Delta H^\ddagger = 23.6$ kcal/mol; $\Delta S^\ddagger = 12$ eu. Are these values consistent with your proposed rate-determining step? Please *briefly* explain your reasoning.

YES (2 pts)

$\Delta S^\ddagger = 12$ eu \Rightarrow Entropically favorable.

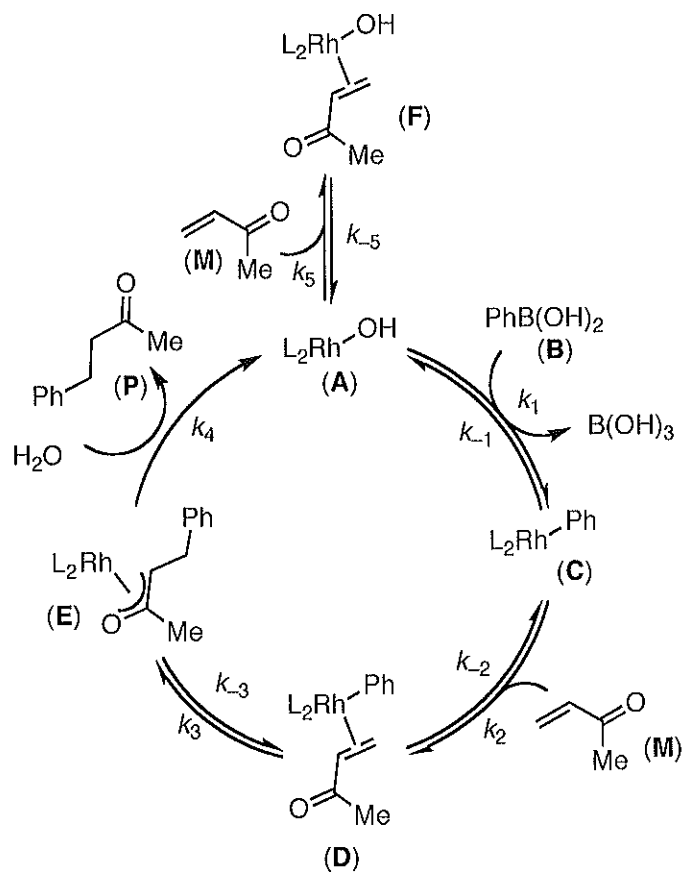
2 pts

Consistent w/ dissociation being rate-determining.

1 molecule \rightarrow 2 molecules
 \uparrow
 more disordered.

(+1 for saying $\oplus\Delta S^\ddagger = \text{more disorder in T.S.}$)

7. (21 points) Consider the Rh(I)-catalyzed conjugate addition of boronic acids to α,β -unsaturated ketones. The catalytic cycle below has been proposed.



(a) Write down a "one plus" catalytic rate expression for this catalytic cycle. You may use generic observable constants for each of the terms in the rate law (C_1 , C_2 , etc.). Be sure that your rate expression accounts for species both within and outside the catalytic cycle.

$$\text{rate} = \frac{k_4 C_1 C_2 C_3 [\text{Rh}]_{\text{tot}} [\text{B}][\text{M}][\text{H}_2\text{O}]}{1 + C_1[\text{B}] + C_1 C_2 [\text{B}][\text{M}] + C_3 [\text{M}]}$$

+ 2 is ~~is~~ C_2 instead
of $[\text{Rh}]_{\text{tot}}$

(-1/each error)

(7-continued)

3pts (b) Provide a simplified "1+" rate law assuming that the step **A** → **C** is rate-limiting, and all subsequent steps to regenerate **A** are fast and irreversible.

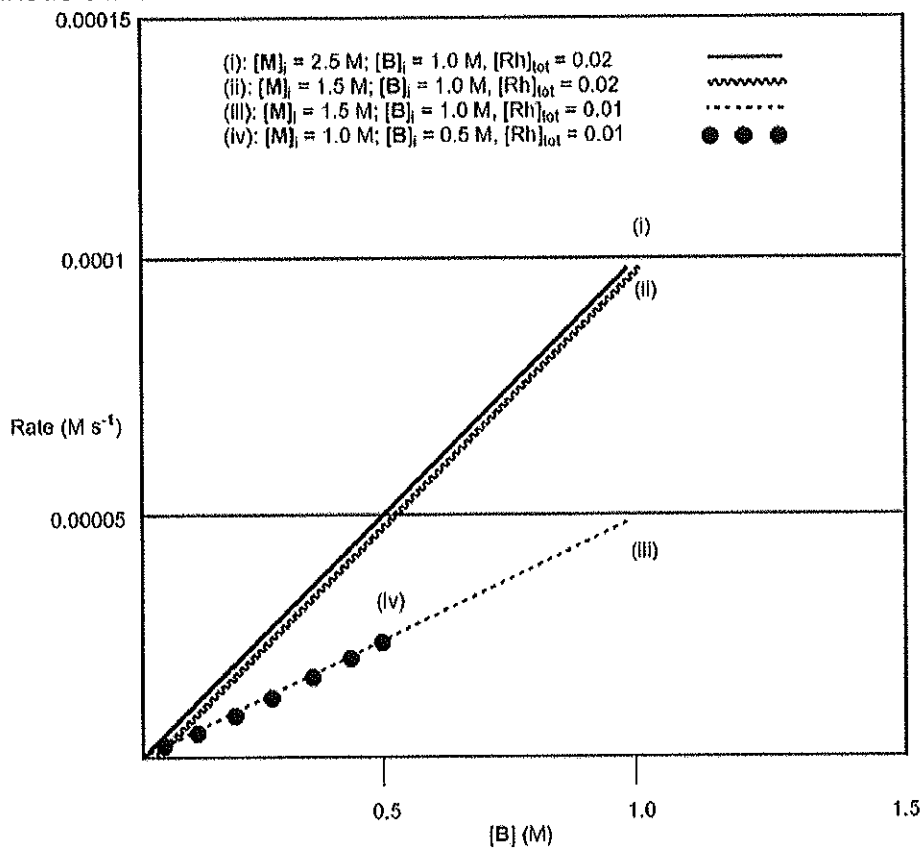
$$\text{rate} = \frac{k_1 [\text{Rh}]_{\text{tot}} [\text{B}]}{1 + C_4 [\text{M}]}$$

3pts (c) Provide a simplified rate law assuming that **D** → **E** is rate-limiting, and all subsequent steps to regenerate **A** are fast and irreversible.

$$\text{rate} = \frac{k_3 C_1 C_2 [\text{Rh}]_{\text{tot}} [\text{B}] [\text{M}]}{1 + C_1 [\text{B}] + C_1 C_2 [\text{B}] [\text{M}] + C_3 [\text{M}]}$$

(7-continued)

The following kinetic data were collected for this transformation.



(d) What can be concluded from comparison of curves (i) and (ii)?

3pts Rate has 0-order dependence on $[M]$.

(e) What can be concluded from comparison of curves (ii) and (iii)?

3pts 1st order in $[Rh]_{\text{total}}$

(7-continued)

(f) What can be concluded from comparison of curves (iii) and (iv)?

3 pts

Rxn is well behaved.

(Same excess experiment)

(g) Evaluate whether the kinetic data shown above allow you to distinguish between the possible rate-limiting steps in (b) and (c). If not, propose an additional experiment that will allow you to distinguish between these possibilities.

3 pts

$$(b) \text{ rate} = \frac{k_1 [\text{Rh}]_{\text{tot}} [\text{B}]}{1 + C_3 [\text{M}]}$$

If C_3 is small, then

$$\text{rate} = k_1 [\text{Rh}]_{\text{tot}} [\text{B}]$$

$$(c) \text{ rate} = \frac{k_3 C_1 C_2 [\text{Rh}]_{\text{tot}} [\text{B}] [\text{M}]}{1 + C_1 [\text{B}] + C_1 C_2 [\text{B}] [\text{M}] + C_3 [\text{M}]}$$

If C_1 & C_2 are small &
 C_3 is large, then

$$\text{rate} = \frac{k_3 C_1 C_2 [\text{Rh}]_{\text{tot}} [\text{B}] [\text{M}]}{C_3 [\text{M}]}$$

$$\text{rate} = \frac{k_3 C_1 C_2 [\text{Rh}]_{\text{tot}} [\text{B}]}{C_3}$$

So, either mechanism could be 0th order in $[\text{M}]$ & 1st order in $[\text{Rh}]_{\text{tot}}$. Available data is insufficient.

In (b), catalyst resting state is A.
In (c), catalyst resting state is E.
} Can distinguish spectroscopically.

+1 for saying data is insufficient.