Chemistry 386J
Anslyn
Dec 13, 2013
**Final Exam**

Name: _____

1. _____ (22 pts)
2. _____ (10 pts)
3. _____ (6 pts)
4. _____ (23 pts)
5. _____ (24 pts)
6. _____ (4 pts)
7. _____ (12 pts)
8. _____ (10 pts)
9. _____ (6 pts)
10. _____ (15 pts)
11. _____ (18 pts)
12. _____ (9 pts)
13. _____ (12 pts)
14. _____ (6 pts)
15. _____ (10 pts)
16. _____ (5 pts)
17. _____ (10 pts)

TOTAL (202 pts) _____

1. (22 points) Let's make meth(anol)!

   .planar

   a) Draw the Walsh diagram for pyramidal CH_3. You can draw the ~~linear~~ form if it helps you, but it is not necessary. Mix the two highest energy orbitals that have the same symmetry and populate the orbitals for methyl radical. (8 points)

same symmetry, mix
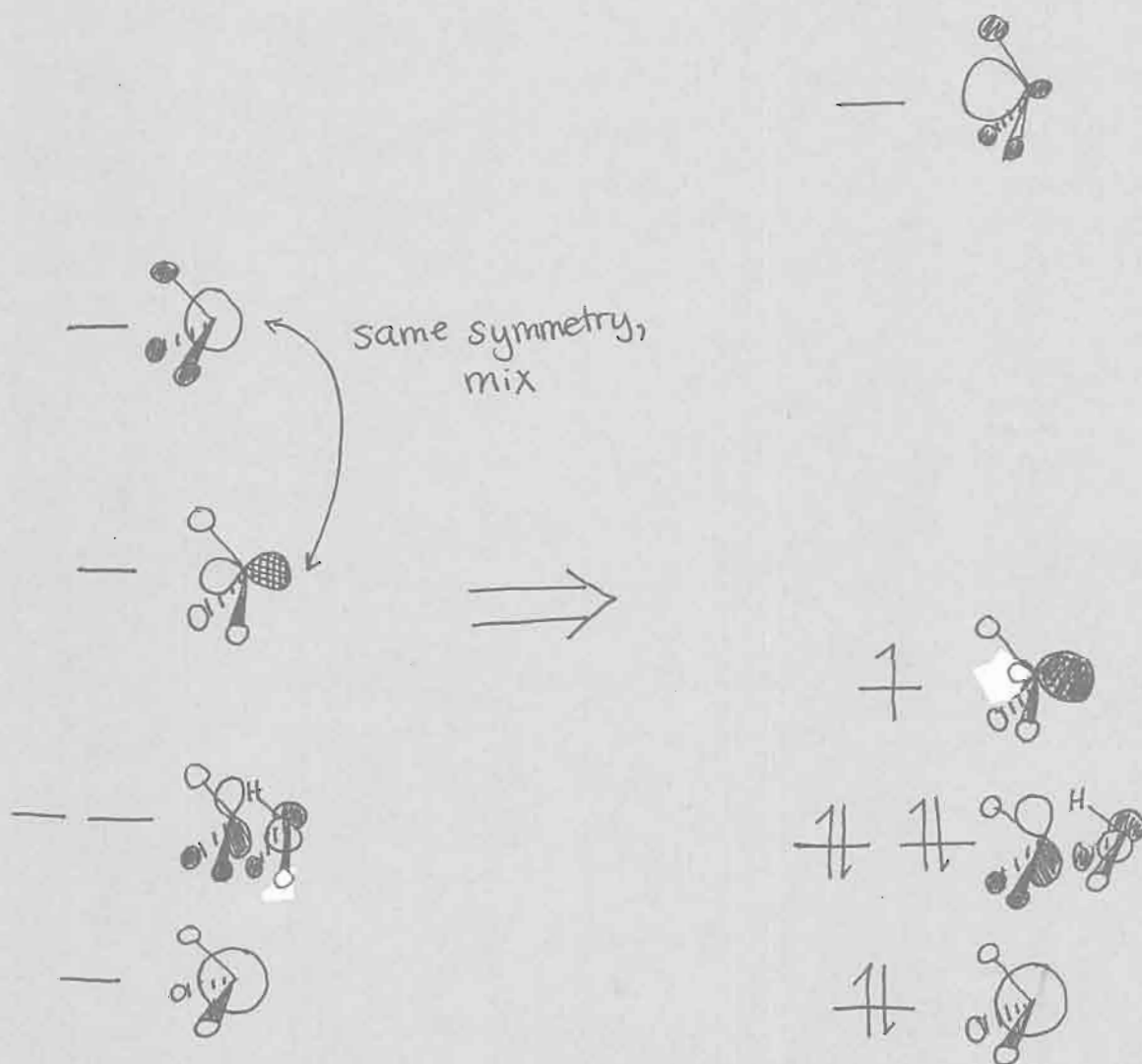
b) Draw the occupied orbitals from part a) on the left side of the diagram below. Consider the mixing of the orbitals as indicated and fill in the diagram with the appropriate amount of electrons. (14 points)

Draw the $\cdot CH_3$ orbitals here

B

G

z   x

y

D

C

A

F

E
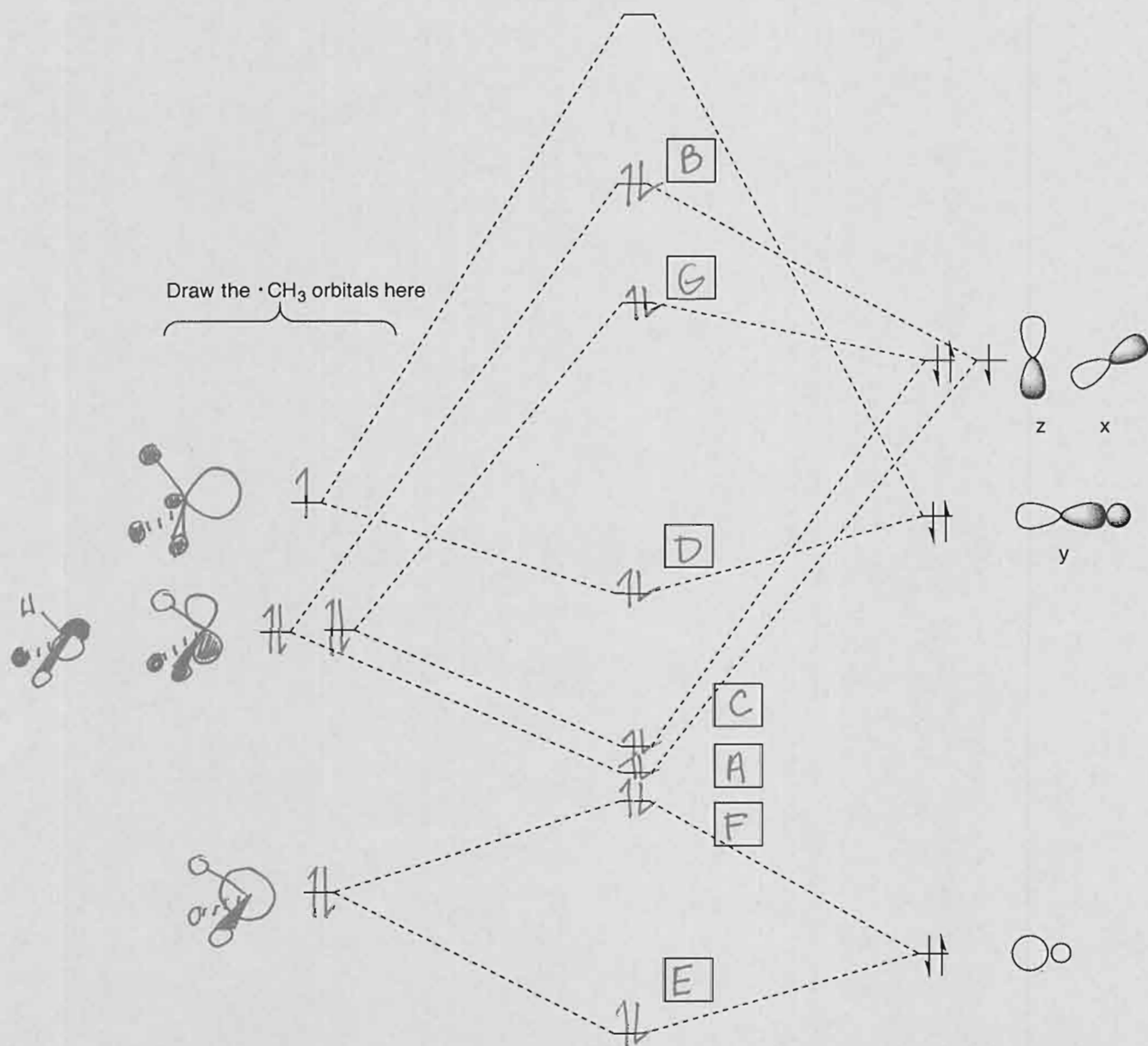
c) The calculated wavefunctions for all of methanol's **occupied** orbitals are shown below. Match each orbital to its correct energy level on the above diagram by filling in the appropriate letter in the boxes above.
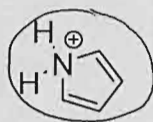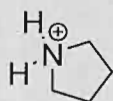
A.   B.   C.   D.   E.   F.   G.
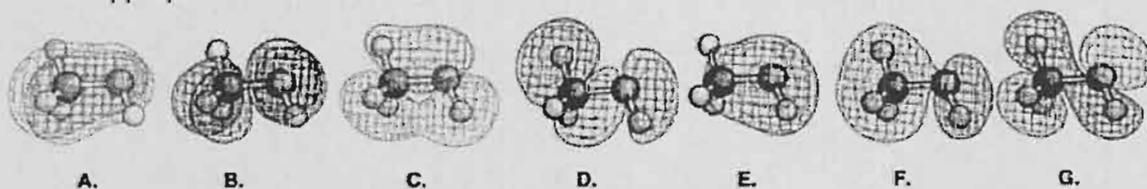
2. (10 points)

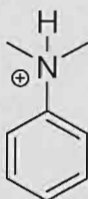a) Circle the strongest acid for the following pairs of compounds and briefly explain your choice. (6 pts)
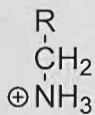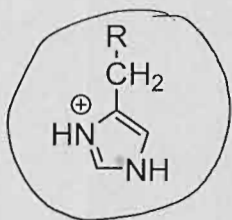
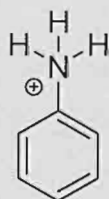Sp² is more acidic than sp3 hybridized nitrogen

Loss of proton restores aromaticity

b) Indicate which of the following compounds would be the strongest acid in the gas phase. Explain your choice. (2 pts)
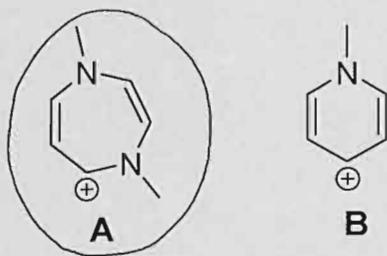
A   **B**

B is the strongest acid because it doesn't have as many electron donor groups as A has.

c) In solution the order reverses. Briefly explain why. (2 pts)

A is the strongest acid because it can't be solvated as much as B. Better solvated, less acidic.
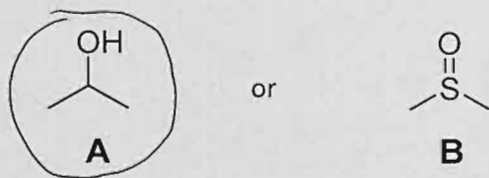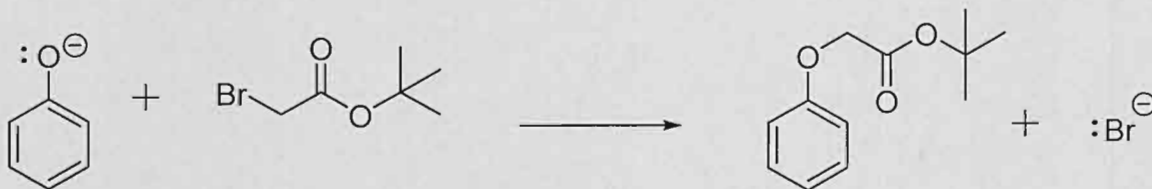
3. (6 points)

a) Circle the structure that has a higher hydride affinity value, and explain your choice. (3 pts)

A   B

A has a higher hydride affinity
because it is an antiaromatic structure,
whereas B is a stable aromatic
System.

b) Circle the solvent that will give the slowest rate of the following S_N2 reaction, and explain your choice. (3 pts)

OH

A   or   B

A is more polar solvent than DMSO.
A solvates the negative charge of
the $Nu^{\ominus}$ through H-bonding,
decreasing the rate of the S_N2 rxn.

4. (23 points) Four parts on stereochemistry:

a) Circle any chiral molecules in the set below (6 points):
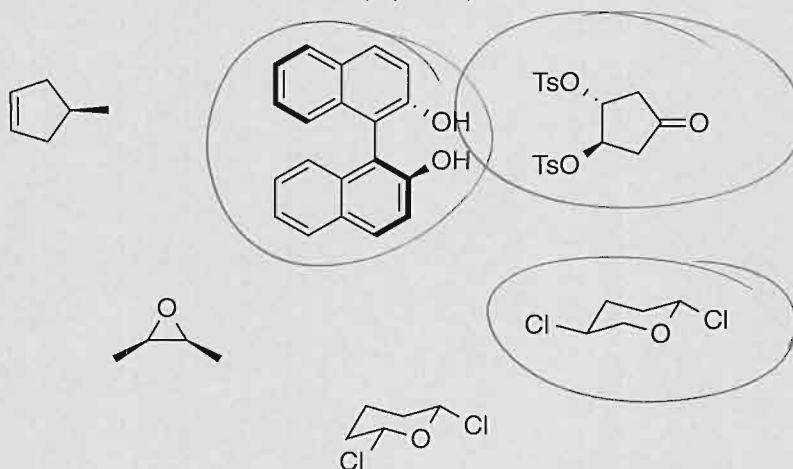
b) Label the indicated groups as homotopic, enantiotopic, or diastereotopic (8 points):

i. faces of alkene → diastereotopic

ii. homotopic

iii. enantiotopic

iv. homotopic
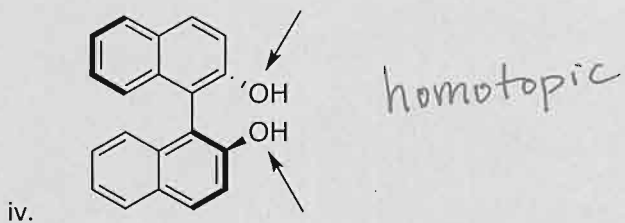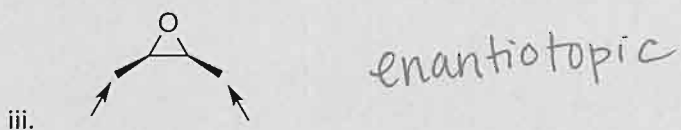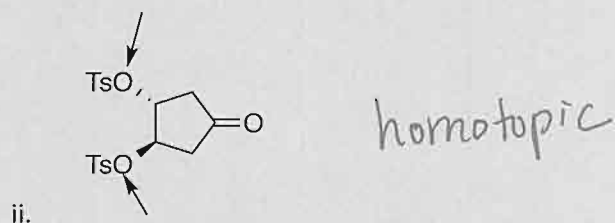
c) For the following reactions, fill in the box with the appropriate term (enantiomers, diastereomers, same molecule) that defines the stereochemical relationship between the two indicated molecules (5 points).

i.

enantiomers   enantiomers

diastereomers

ii.

diastereomers

iii.

same molecule
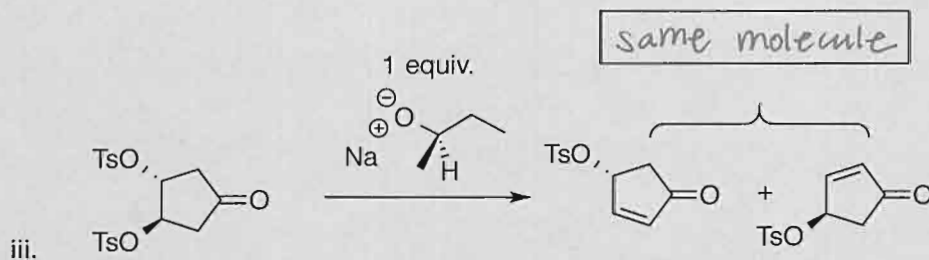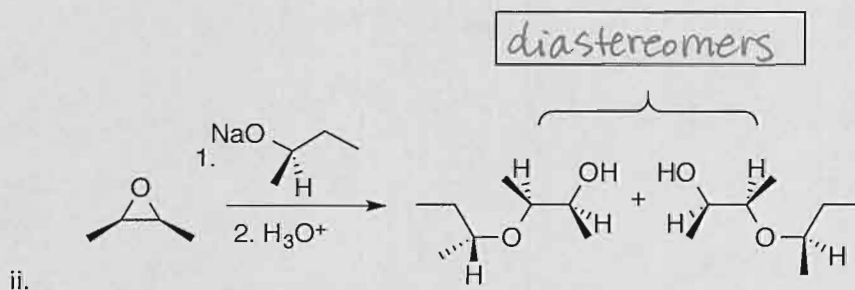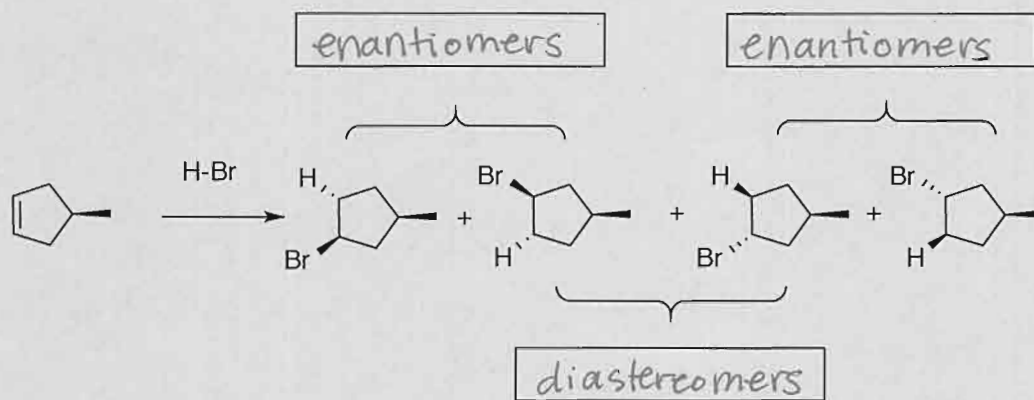
d) Define the sets of reactions below as stereospecific, stereoselective, or both stereoselective and stereospecific (4 points).

i.

stereoselective
& stereospecific

ii.

stereoselective
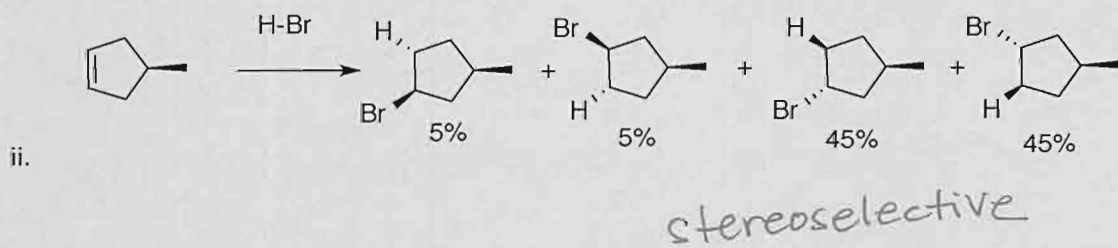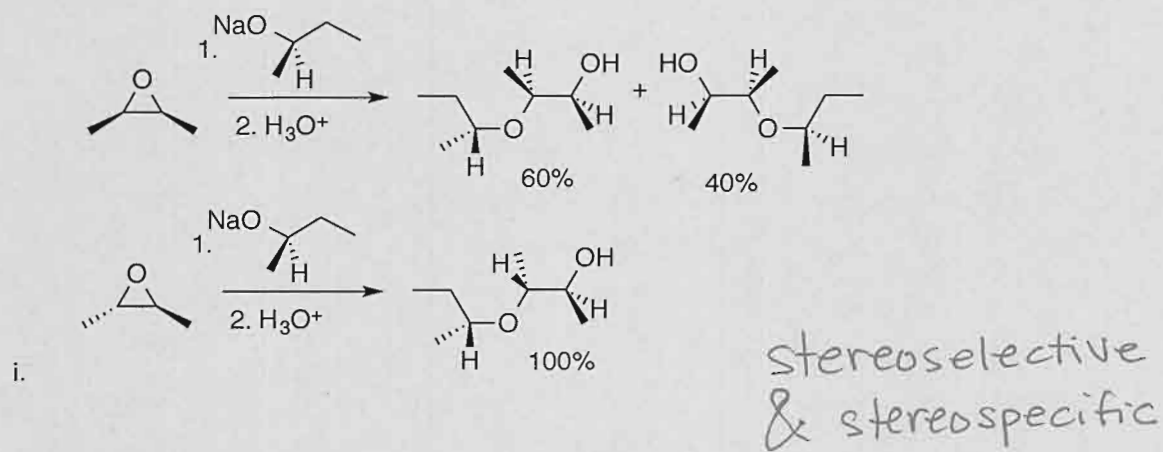
5. (24 points) Mannose is a diastereomer, specifically a C2 epimer, of glucose. In solution, the alpha anomer of D-mannose dominates over the beta form. This is in contrast to glucose, where the beta anomer is preferred.
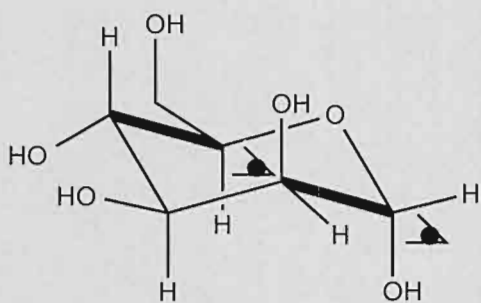
α-D-mannose
67%

β-D-mannose
33%

α-D-glucose
45%

β-D-glucose
55%

5. (continued)

Let's explain why mannose has a *smaller* preference for the beta anomer (33% β) compared to glucose (55% β).

a) Fill in the following Newman projections for α-D-mannose and β-D-mannose looking down the highlighted bonds on the previous page. The anomeric carbon should be on the left. Count the total number of gauche interactions in each, keeping in mind each gauche interaction with an atom in the ring counts for two gauche. (6 points)
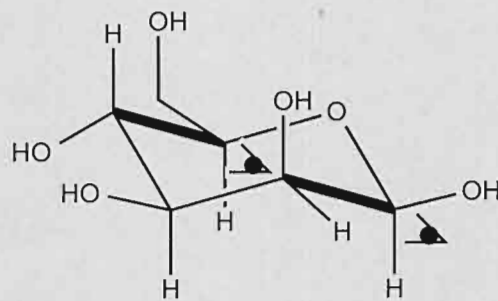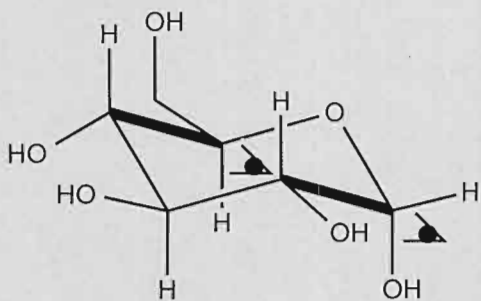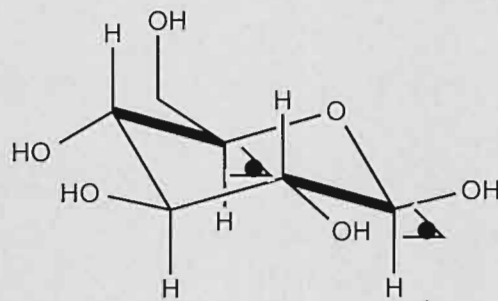
Hint: Once you have filled in one Newman projection, you should be able to quickly construct the next by only switching two groups of one stereocenter to create the epimer.

α-D-mannose   # gauche __5__

β-D-mannose   # gauche __4__
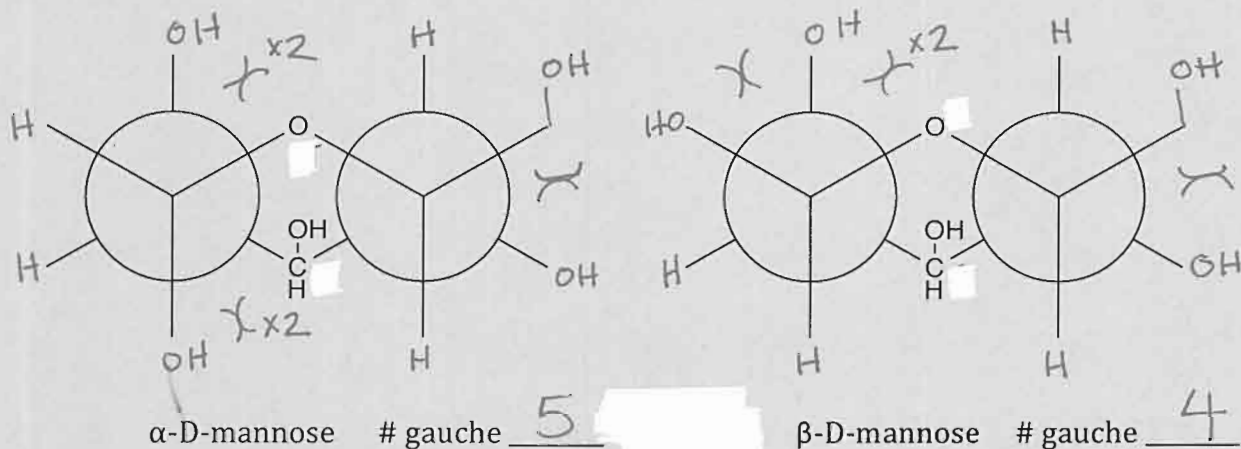
b) Draw the Newman projections of α-D-glucose and β-D-glucose. Again, you should be able to quickly construct them by switching two groups at one stereocenter. Count the total number of gauche interactions. (6 points)

α-D-glucose   # gauche __4__

β-D-glucose   # gauche __2__
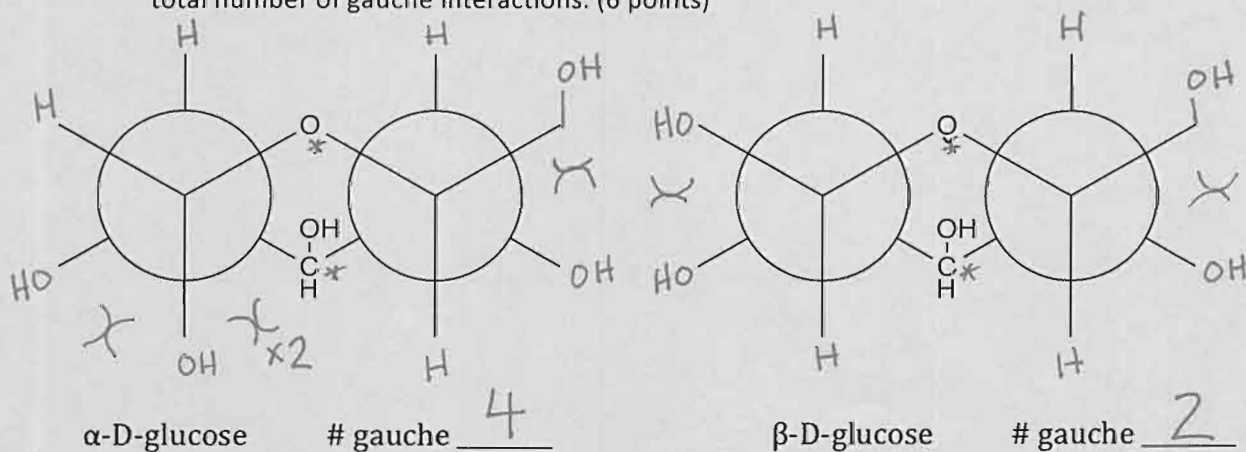
c) Based on the Newman projections you have just drawn, circle the preferred anomer of each pair below and write in their energy differences, assuming each gauche is worth the same value. (4 points)

α-D-mannose   or   β-D-mannose   energy difference: __0.9__ kcal/mol

α-D-glucose   or   β-D-glucose   energy difference: __1.8__ kcal/mol

d) Use the energy differences from part c) to estimate the ratios of the alpha and beta anomers of both sugars at equilibrium. Which sugar, mannose or glucose, has the higher preference for the beta anomer (prefers the alpha anomer to a lesser extent)? (5 points)

α-D-mannose : β-D-mannose   1 : ~6

α-D-glucose : β-D-glucose   1 : ~30

glucose

e) Experimental evidence shows that the alpha anomer of D-mannose is preferred over the beta 67:33. Draw the relevant orbitals to help explain why α-D-mannose is preferred. Comment on how your diagram affects any gauche interactions you identified in the Newman projections. (3 points)
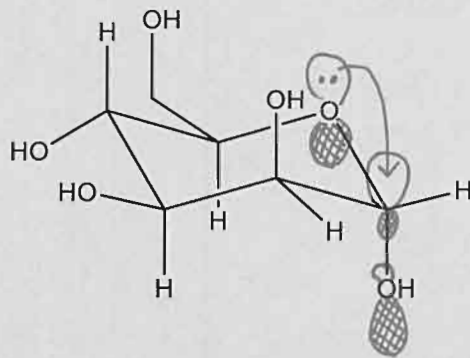
donation of LP e⁻ into σ* of C–OH due to donor/acceptor alignment (anomeric effect). Populating an anti-bonding orbital leads to lengthening of C–OH bond and LESS steric interaction when –OH is axial.

6. (4 points)The following rearrangement can occur via radical or carbocation intermediates shown below.
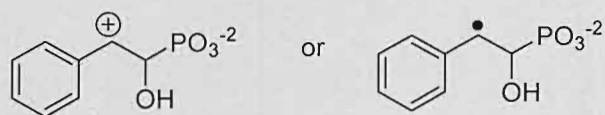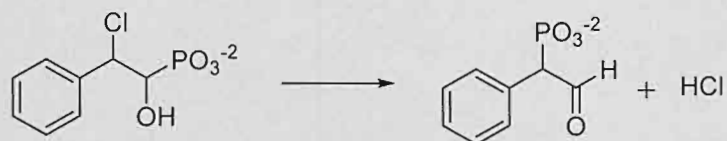
a) Propose two experiments to distinguish between these mechanisms.

1) Hammett plots

2) Radical clock

7. (12 points) The following reaction shows a 1,4-addition of a thiol to an enone in basic conditions.

a) What type of catalysis does the reaction above show? (1 pt)

General-base-catalysis
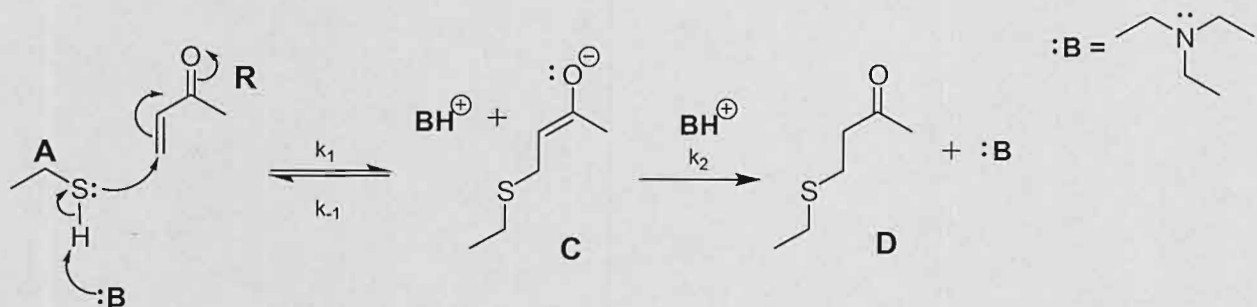
b) For the above mechanism, write the rate law for the formation of "**D**" using the steady state approximation. Use the letters provided to write the rate law. (4 pts)

$$\frac{d[C]}{dt} = 0 = k_1[A][R][B] - k_{-1}[C][BH^+] - k_2[C][BH^+]$$

$$[C] = \frac{k_1[A][R][B]}{k_{-1}[BH^+] + k_2[BH^+]}$$

$$\frac{d[P]}{dt} = k_2[C][BH^+]$$

$$\frac{d[P]}{dt} = \frac{k_1 k_2 [A][R][B][BH^+]}{k_{-1}[BH^+] + k_2[BH^+]}$$

$$\frac{d[P]}{dt} = \frac{k_1 k_2 [A][R][B]}{k_{-1} + k_2}$$

c) Does this reaction have any kinetic dependence on **BH**⊕? Briefly explain why. (2 pts)

NO, BH+ drops out the equation, and there is zero kinetic dependance

d) Does this reaction have any kinetic dependence on the base (:B)? Briefly explain why. (2 pts)

Yes, B stays part of the rate law as it is seen in general-base catalysis

e) Given your answer in part (d), and the pKa of triethylamine, is this reaction going to be faster at pH 7 or 12? Briefly explain your answer. (3 pts)

Formation of the product depends on [B]. If the pH is around 12, above the pKa of TEA, it means that all the base required in the reaction has been formed above pH=10, ∴ the reaction goes faster at pH=12.

8. (10 points) The effect of varying the substituent, X, on the rate-determining chloride departure in the S_N1 reaction of the starting materials below was measured using Hammett plots.

This is reference for σ^+!
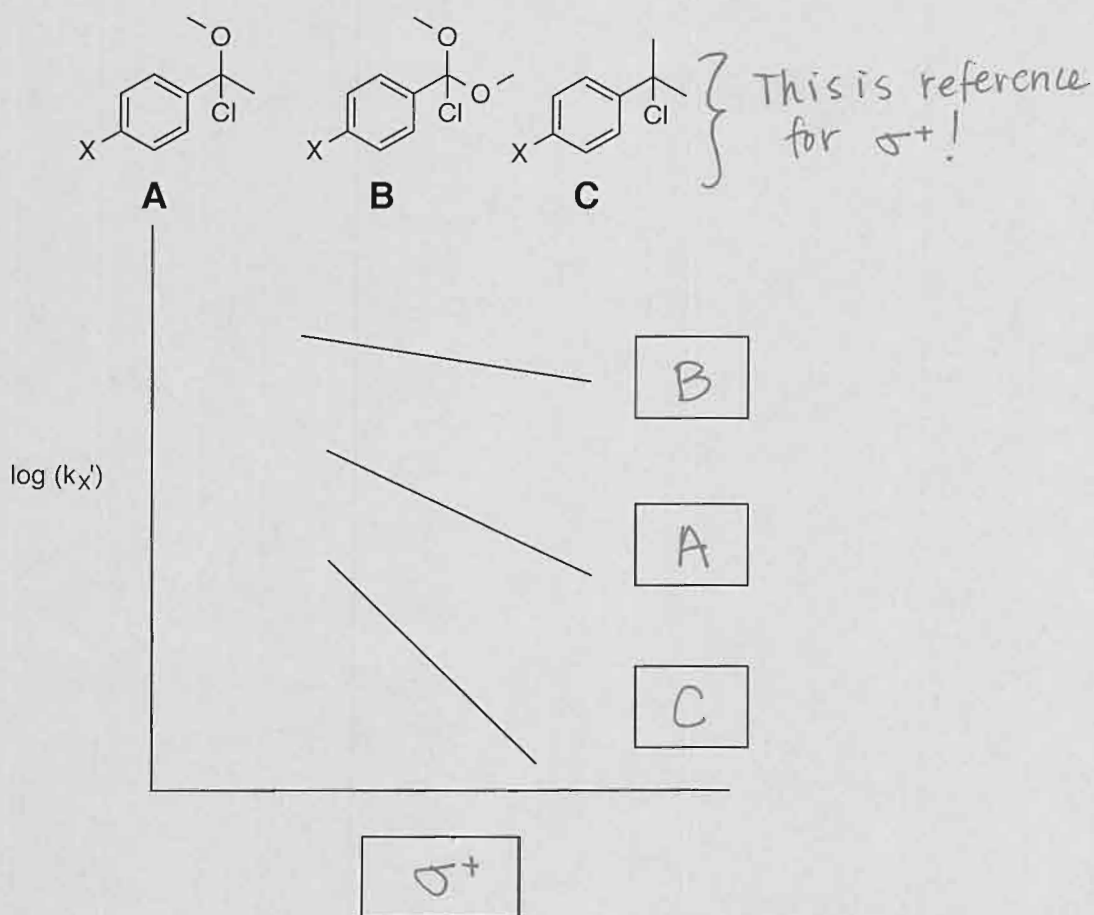
a) Fill in the missing x-axis for the Hammett plot above. Which parameter did you choose, σ, $\sigma+$, or $\sigma-$, and why? (2 points)

σ^+

b) Why are the slopes in this plot all negative? (2 points)

slope $= \rho$ value   when ρ is $\ominus$, means rxn builds $\oplus$ charge

c) Assign the letters corresponding to the starting materials to each of the three lines in the plot. Justify your choice for each starting material. (6 points)

C → slowest rate blc no additional stabilization from methyl groups. Highest sensitivity to substituent where slope = 1 blc it's the reference rxn.

B → least sensitive to substituent, smallest slope. Has additional resonance stabilization of cation by forming 2x oxonium.

A → sensitivity is in between B+C. only 1x oxonium.

9. (6 points, 2 each) Describe the kinetic isotope effects you would expect to observe for the following reactions using the terms primary, secondary, normal, and inverse.

a)

(D)H
(D)H

⟶

H(D)
H(D)

2° inverse

b)

H(D)Br

⟶

(D)H
Br

1° normal

≡—H(D)

2 HBr

⟶

Br
Br
H(D)
''H
H

2° inverse
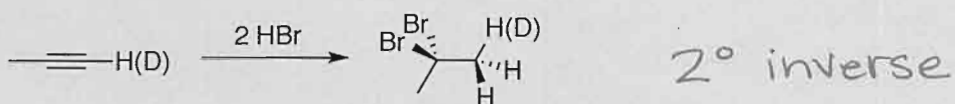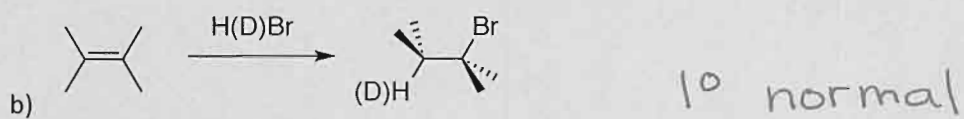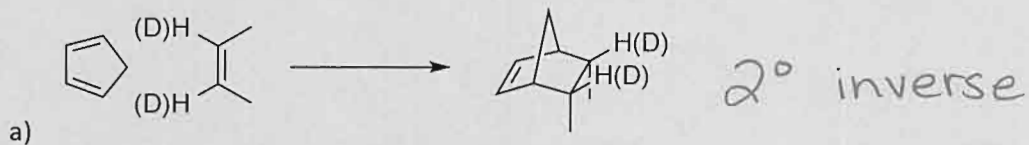
10. (15 points) The decomposition of aryl-substituted acetophenone methyl hemiacetal was studied under base-catalyzed conditions with an added base (A:$^{\ominus}$) and its conjugate acid (HA).

A   B   C
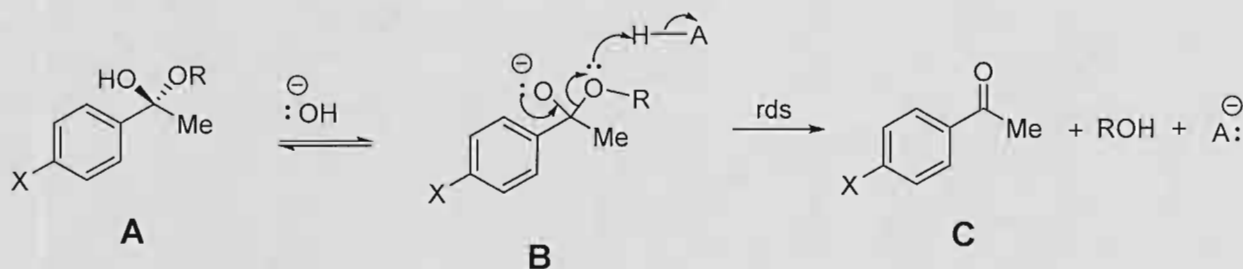
To understand the transition state, the following Bronsted plot was generated by varying the pKa of HA and measuring the rate of decomposition of the hemiacetal group.

$\beta = 0.61$

y-axis: $\log(k_A/q)$

x-axis: $pK_a + \log(p/q)$
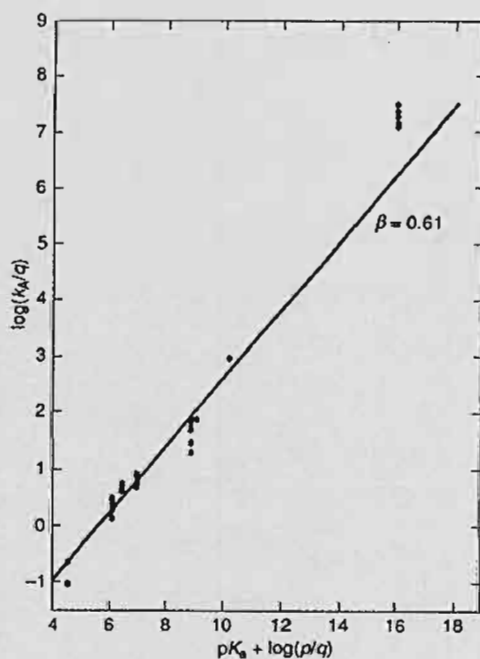
a) What kind of catalysis will the kinetics of the above mechanism indicate? (2 pts)
   Hint: the rate determining step uses a general acid after prior equilibrium deprotonation.

The above mechanism indicates general-base catalysis which kinetic equivalency is specific base followed by general acid

b) Does the Bronsted plot support your answer to part (a)? (1 pt)

Yes

c) Now, we teach you that $\alpha + \beta = 1$ in general catalyzed reactions. So given this information and β = 0.61, what is the α-value for the rds in the mechanism given above? (1 pt)

$$\alpha = 0.39$$

d) For the rds, fill in the remaining corners and axes on the More O'Ferrall-Jencks plot with the correspondent species. (4 pts)

e) Approximate the placement of the transition state using the answer that you found on part (c) and a β_{LG} of -0.3, labeling this point as "**E**". (1 pt)
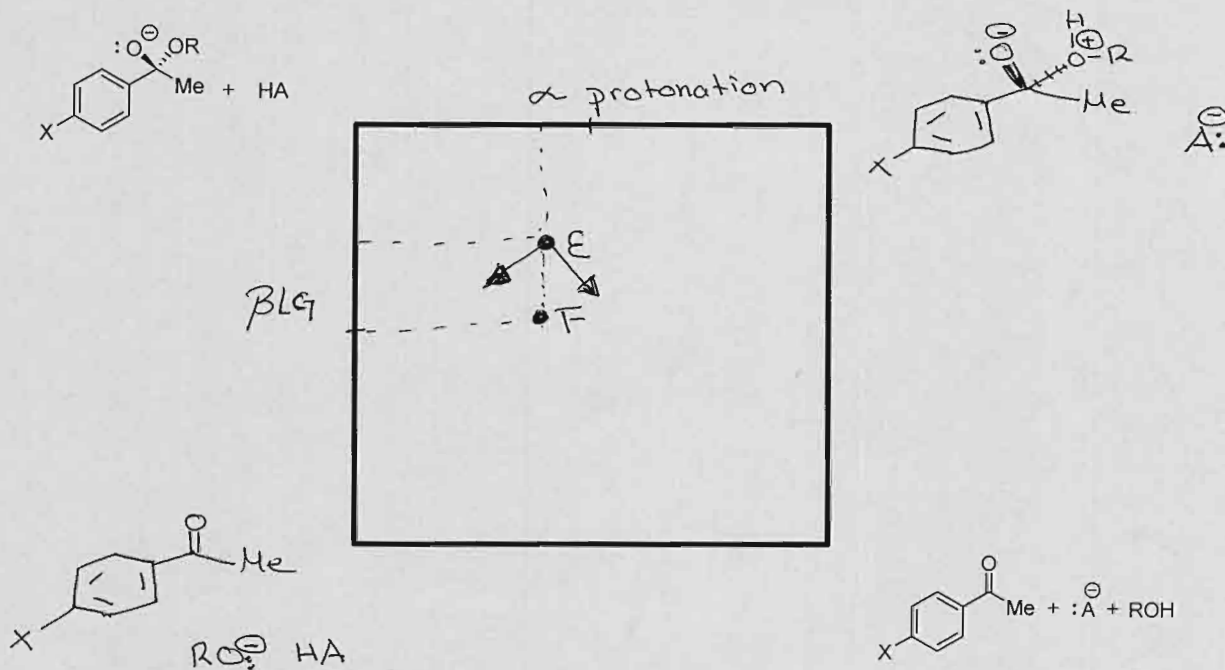

f) Starting from "**E**", how would the transition state change using a stronger base? Label this new transition state as "**F**". (2 pts)

g) With a stronger base, how would the extent of protonation by its conjugate acid change in the rds? (2 pts)

Same

h) With a stronger base, how would the extent of β_{LG} change in the rds? Why does this make sense? (2 pts)

Extent of β_{LG} is more because with a stronger base means we have a weaker acid, ∴ more LG departure is needed at the transition state

11. (18 points, 6 each) The following three reactions follow either specific base, general base, or no catalysis.
a. Predict which corresponds to each mechanistic alternative. (1 pt)
b. Draw the transition state of the rate-determining step for each reaction in the brackets given. (3 pts)
c. Draw the corresponding reaction coordinate diagram for each mechanistic alternative, where you include all intermediates. (2 pts)
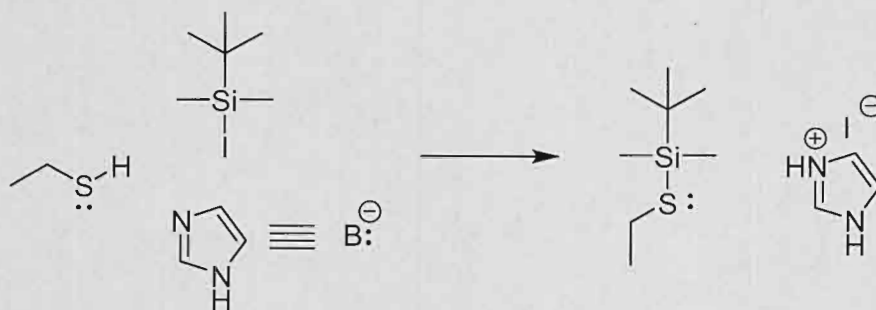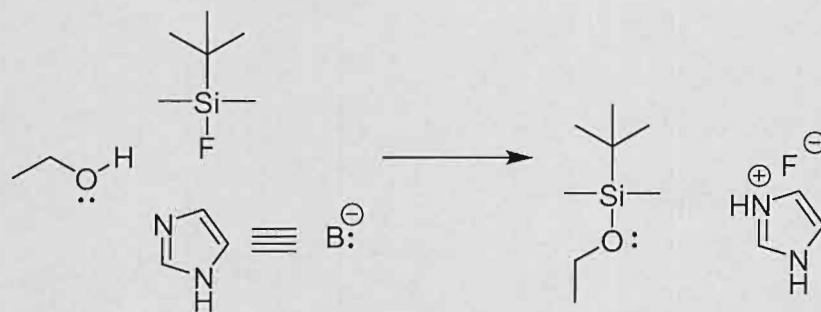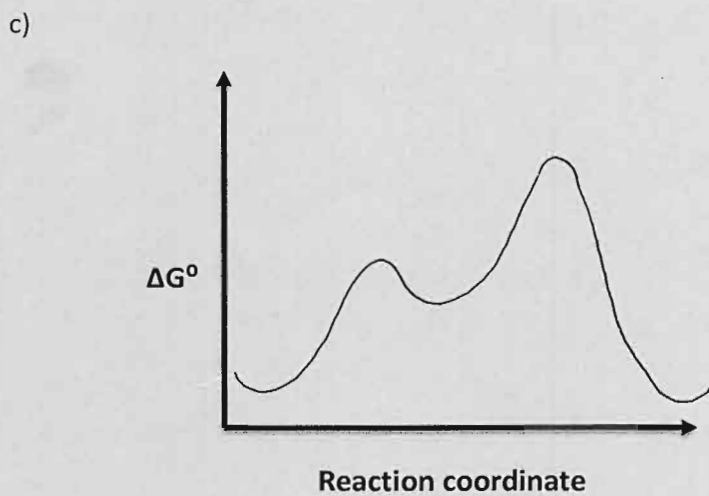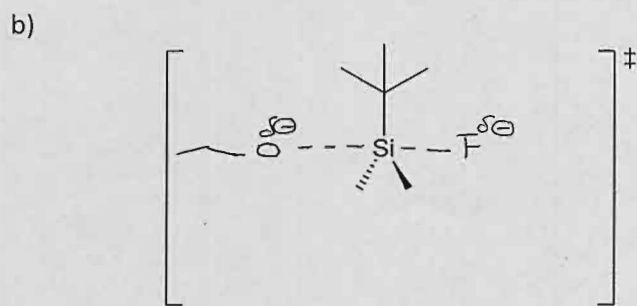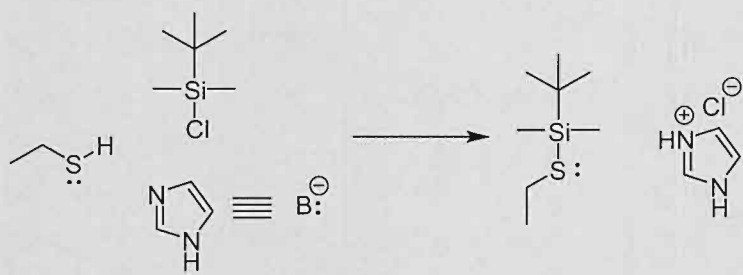

a) Reaction 1: No catalysis

b)

c)

Reaction coordinate
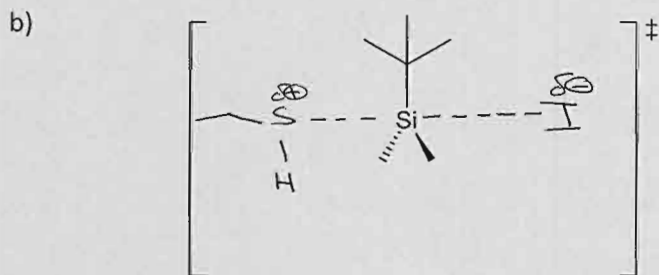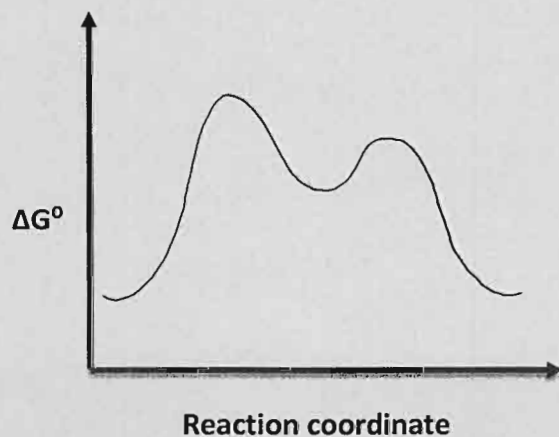
a) Reaction 2: _specific-base catalysis_
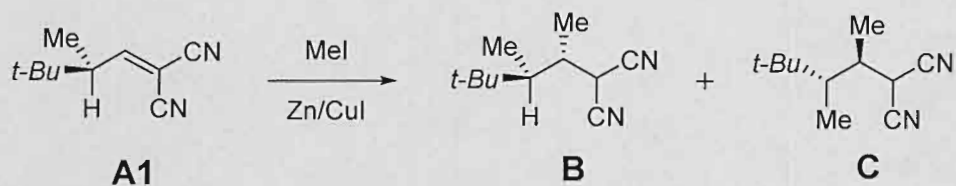
b)

c)

Reaction coordinate

a) Reaction 3: <u>General-base catalysis</u>

b)

c)

ΔG°

Reaction coordinate
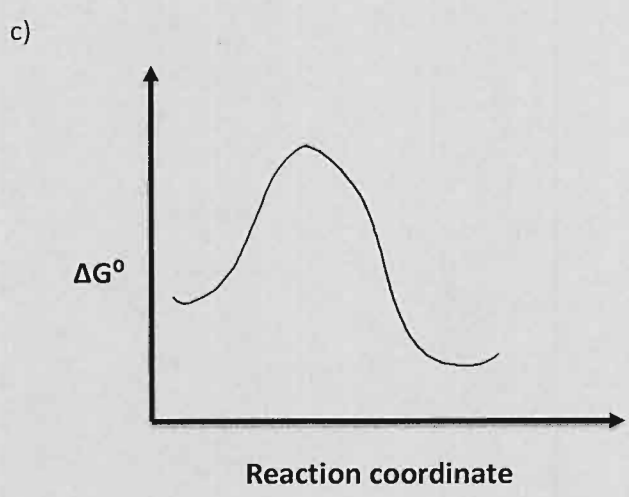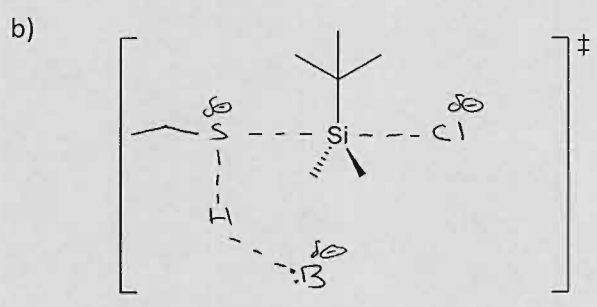
12. (9 points)The following methylation reaction proceeds through a radical mechanism. This reaction produces two different products, where **B** is the favored product.

A1 → (MeI, Zn/CuI) → **B** + **C**

a) Using the one conformer of **A1** given above, draw all three conformers and label the two new ones as **A2** and **A3**. (5 pts)
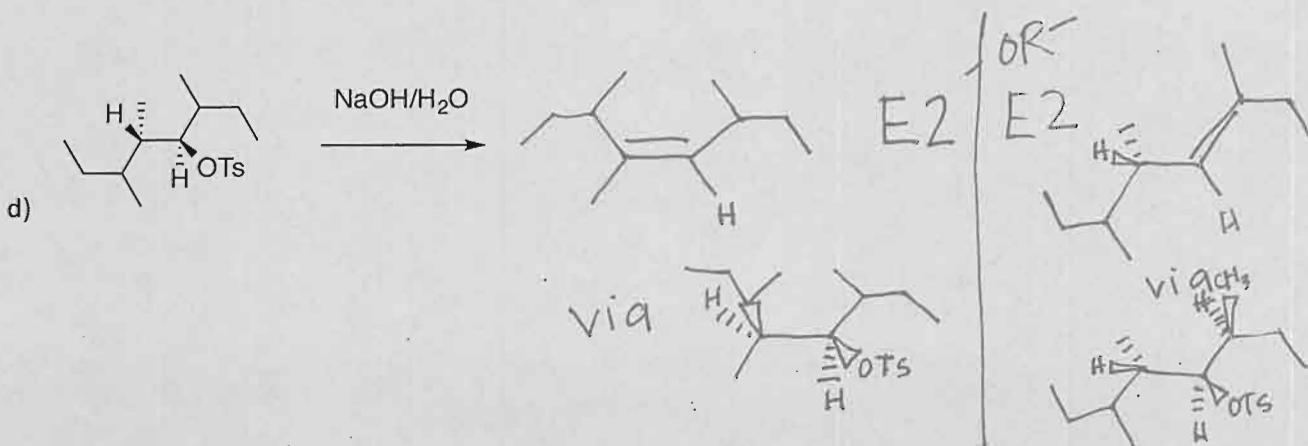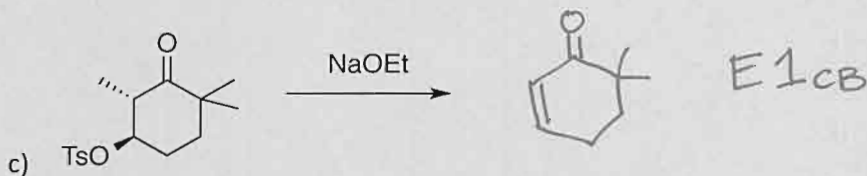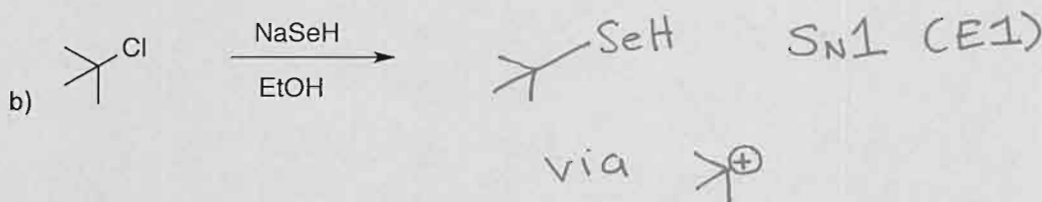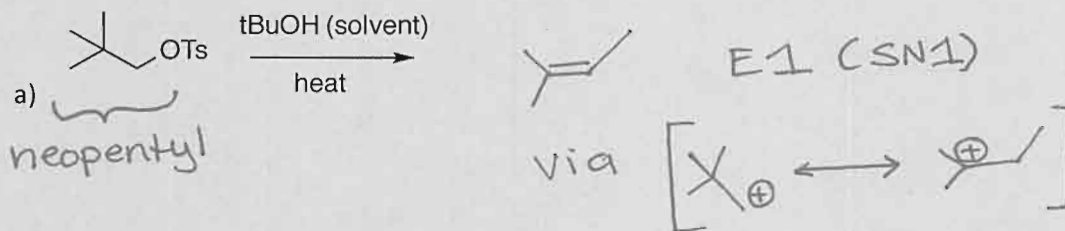

A1   A2   A3
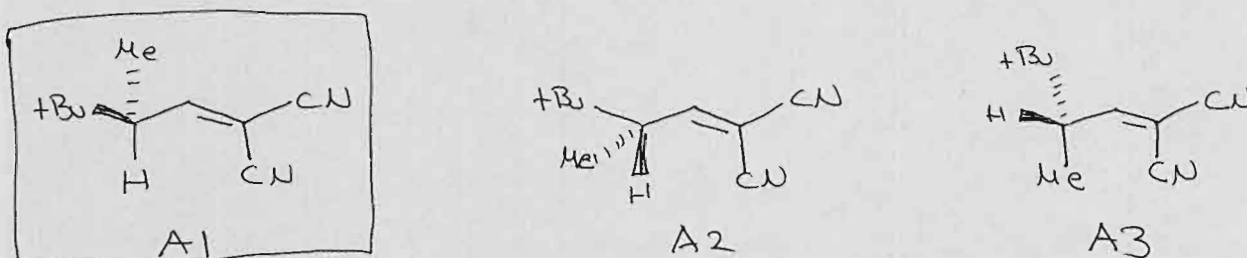
b) Circle the lowest energy conformer in part (a), and briefly explain the type of strain that is minimized in this conformer. (2 pts)

A strain

c) What is the postulate or principle that you should consider when attempting to explain the product ratios observed in the reaction? (2 pts)

Curtin-Hammett postulate

13. (12 pts, 3 each) Draw the predominant product for each of the following reactions. State whether you expect the reaction to proceed by an $S_N1/E1$, S_N2, E2, or $E1_{CB}$ mechanism.

a)

neopentyl

tBuOH (solvent) / heat

E1 (SN1)

via $[X_\oplus \longleftrightarrow \oplus]$

b)

NaSeH / EtOH

SeH S_N1 (E1)

via $\oplus$

c) TsO

NaOEt

$E1_{CB}$

d)

NaOH/H_2O

E2 | OR⁻ E2

via H⋯OTs / H

vi a ctₛ

14. (6 pts) The rate of S_N2 reactions was found to reverse depending on the counter ion of the nucleophile used for the following S_N2 reaction:

$$H_3C-O-\overset{\overset{O}{\|}}{\underset{\underset{O}{\|}}{S}}-O-\text{—⟨benzene⟩—}Br \;+\; \overset{\ominus}{X}: \longrightarrow CH_3X \;+\; :\overset{\ominus}{O}-\overset{\overset{O}{\|}}{\underset{\underset{O}{\|}}{S}}-O-\text{—⟨benzene⟩—}Br$$

a) Circle the halogen that will react the fastest when the counter ion is Li^+. Explain your choice. (3 points)

Cl^- Br^- $(\,I^-\,)$
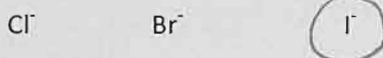
Weakest ion pairing between $Li^\oplus$ and $I^\ominus$ due to size and electronegativity. This means $I^\ominus$ is more available to act as a nucleophile.

b) Circle the halogen that will react the fastest when the counter ion is tetrabutylammonium. Explain your choice. (3 points)

$(\,Cl^-\,)$ Br^- I^-
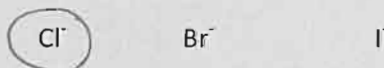
The larger tetrabutylammonium cation does not interact strongly with these anions. $Cl^\ominus$ is the most nucleophilic as it is the most basic anion in the series.

15. (10 points) In the following 4 + 2 cyclization, the *endo* product dominates. Let's figure out why!

endo   exo
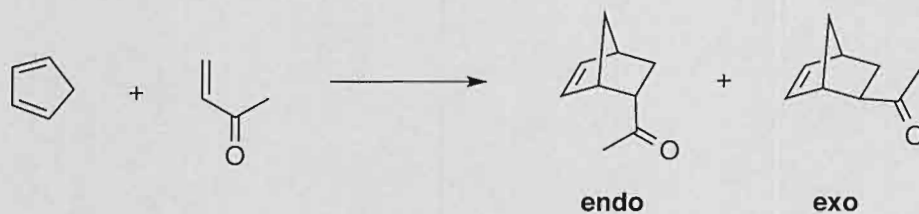
cyclopentadiene

a) Fill in the correct phasing for the HOMO of ~~cyclobutadiene~~ on the following diagram (2 points):

HOMO
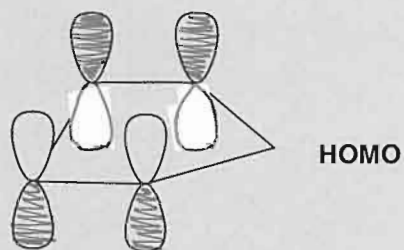
b) Treat the dienophile, methyl vinyl ketone, as though it were butadiene. Draw the correct phasing for the LUMO on the following two diagrams that are simply different conformers of the same dienophile (2 points):


LUMO   LUMO
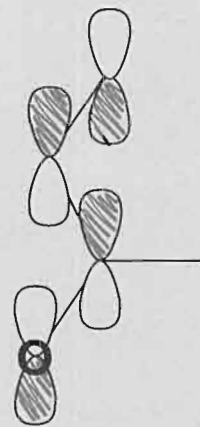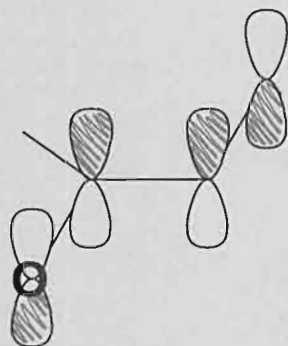
c) Use the phasing from parts a) and b) to fill in the orbital diagrams below to show the reaction is indeed allowed for both endo and exo. (4 points)
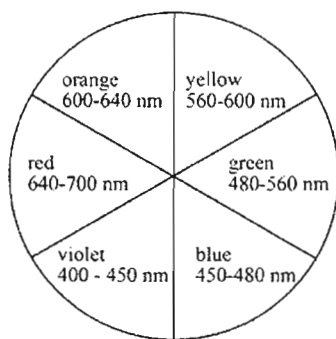

endo

exo
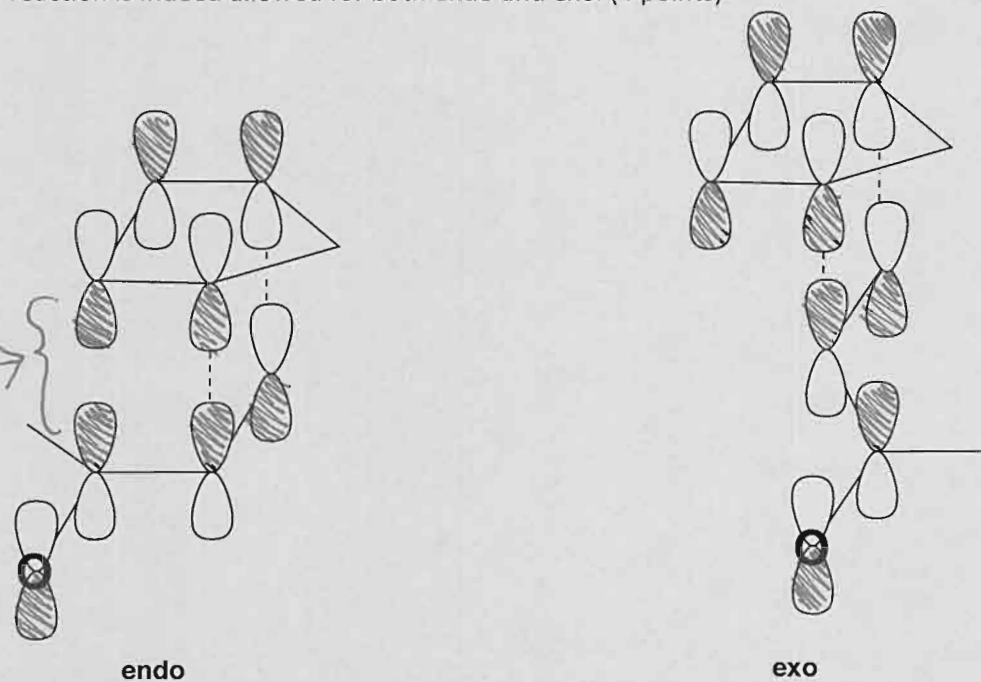
d) Use the orbital diagrams from part c) to explain why the *endo* product is preferred for Diels-Alder cyclization. (2 points)

There is an additional interaction between the HOMO & LUMO when the *endo* product is formed. This is stabilizing.

16.2 15. Your TA Alex uses a variety of dyes to create her rainbow hair. One of these dyes is Brilliant Blue FCF a dye approved for food, drug, and cosmetic use:
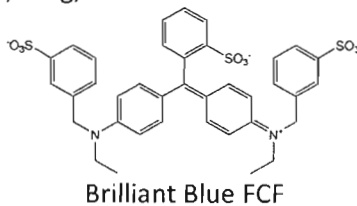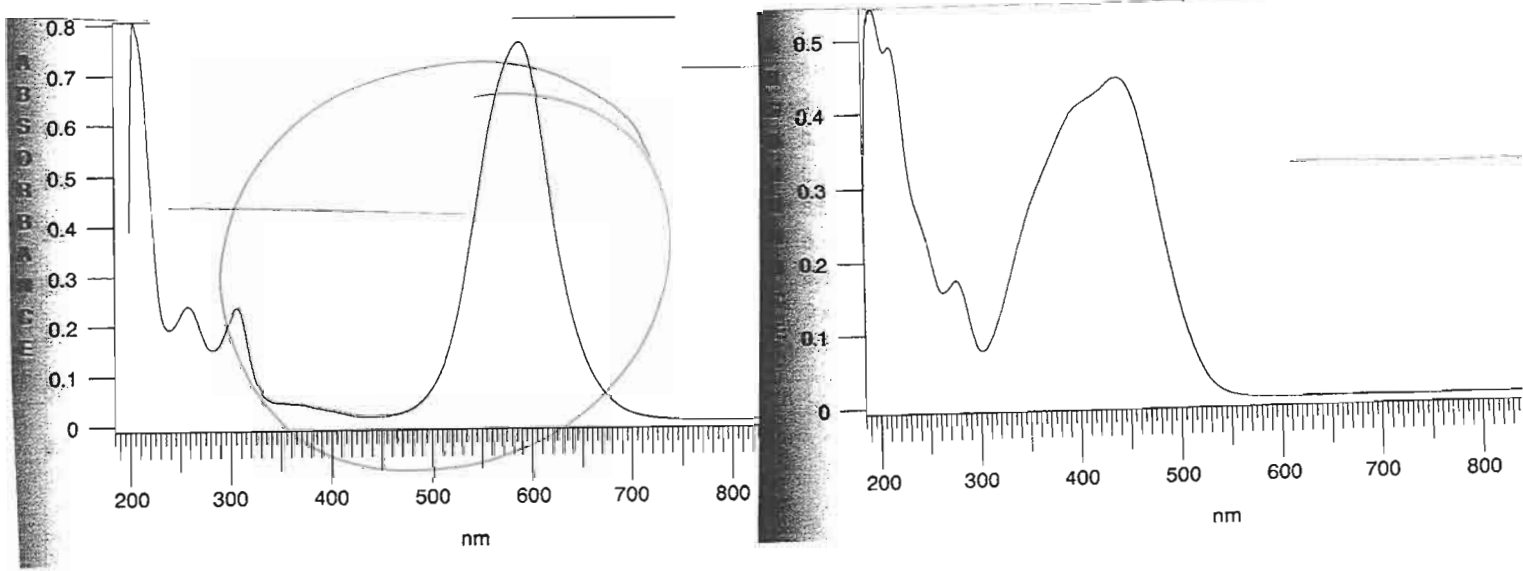

Brilliant Blue FCF

a) Given that the dye appears blue, use the color wheel to determine the wavelengths of light it absorbs.

orange 600-640 nm
yellow 560-600 nm
red 640-700 nm
green 480-560 nm
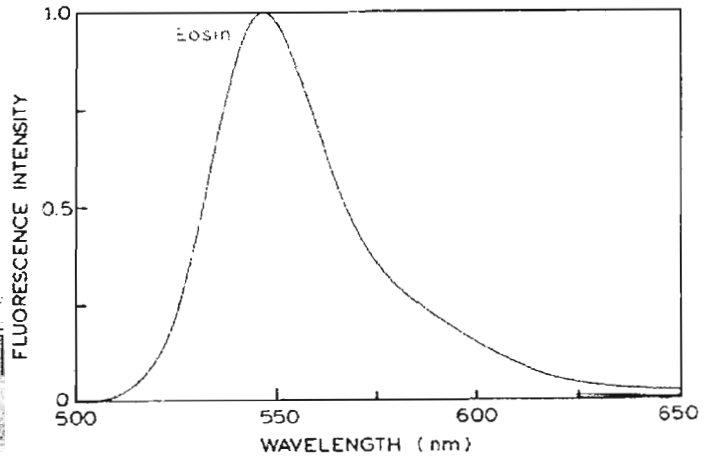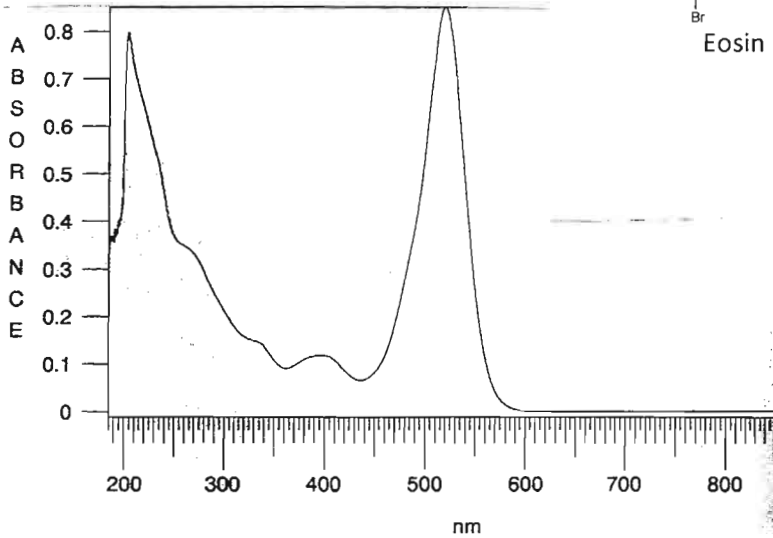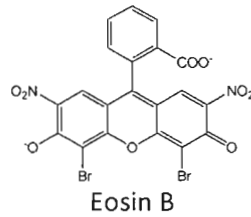violet 400 - 450 nm
blue 450-480 nm

600-640nm

b) From the choices below, circle the absorption spectrum that best corresponds to that of Brilliant Blue FCF

The majority of Alex's hair is dyed pink using Eosin B. This dye emits via fluorescence when exposed to UV radiation.

Eosin B

c) Use the color wheel and the given absorption/emission spectra of Eosin B to determine what color Alex's hair appears when excited using a UV lamp.

emits ~550nm ⟶ green

BONUS!   See reflected light PLUS emitted
        light
              pink (red) + green = orange!

17. (10 points) This is simply an arrow-pushing problem. Starting from the imine, push arrows correctly to make the following indole. Make sure to draw all lone pairs, proton transfers, and relevant arrows and steps. There is one step that involves a [3,3] sigmatropic shift and one step that involves a 5-exo-trig cyclization.

H_2SO_4/H_2O

+ $H_2\ddot{O}$ + $\ddot{N}H_3$

imine

$H-O-H$

$H-\overset{\oplus}{O}-H$ [3,3]

5-exo-trig

$H-\ddot{O}-H$

$H-\overset{\oplus}{O}-H$

$H_2N:$

$H-\overset{\oplus}{O}-H$

$\ddot{N}H_3$