

NAME (Print): \_\_\_\_\_

Chemistry 320M/328M

Dr. Brent Iverson

Final Exam

December 12, 2025

EID \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

**Please print the  
first three letters  
of your last name  
in the three boxes**

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**Please Note:** Please take your time. We are giving you three hours to take this exam. The idea is to give you enough time to show us what you know, not how fast you can draw structures. Please take all the time you need to draw the best possible structures that you can!

**FINALLY, DUE TO SOME UNFORTUNATE RECENT INCIDENTS YOU ARE NOT ALLOWED TO INTERACT WITH YOUR CELL PHONE IN ANY WAY. IF YOU TOUCH YOUR CELL PHONE DURING THE EXAM YOU WILL GET A "0" NO MATTER WHAT YOU ARE DOING WITH THE PHONE. PUT IT AWAY AND LEAVE IT THERE!!!**

And to help with scanning the exams before grading **DO NOT TEAR OUT ANY PAGES** from your exam!

## **Student Honor Code for the University of Texas at Austin**

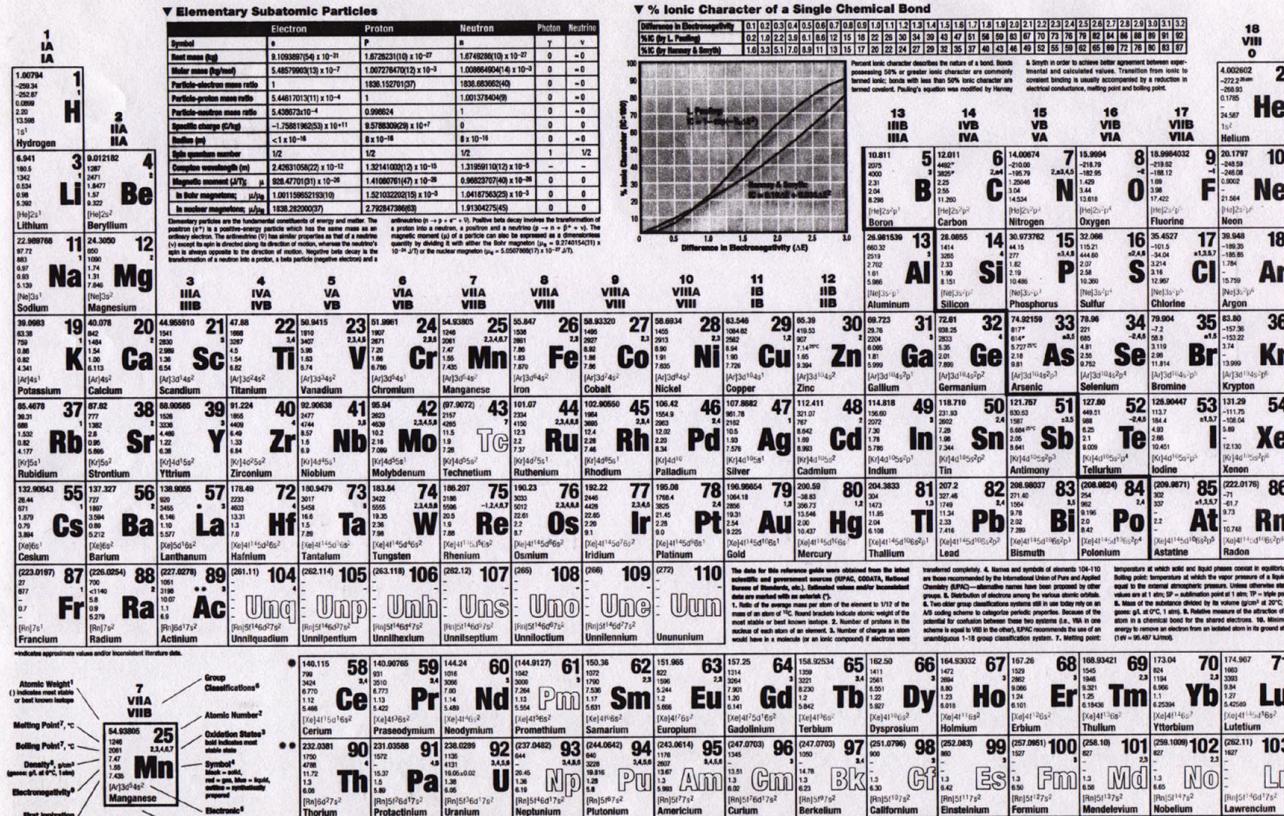
“I pledge, as a member of The University of Texas at Austin community, to do my work honestly, respectfully, and through the intentional pursuit of learning and scholarship.”

## Elaboration

1. I pledge to be honest about what I create and to acknowledge what I use that belongs to others.
2. I pledge to value the process of learning in addition to the outcome, while celebrating and learning from mistakes.
3. This code encompasses all of the academic and scholarly endeavors of the university community.

**(Your signature)**

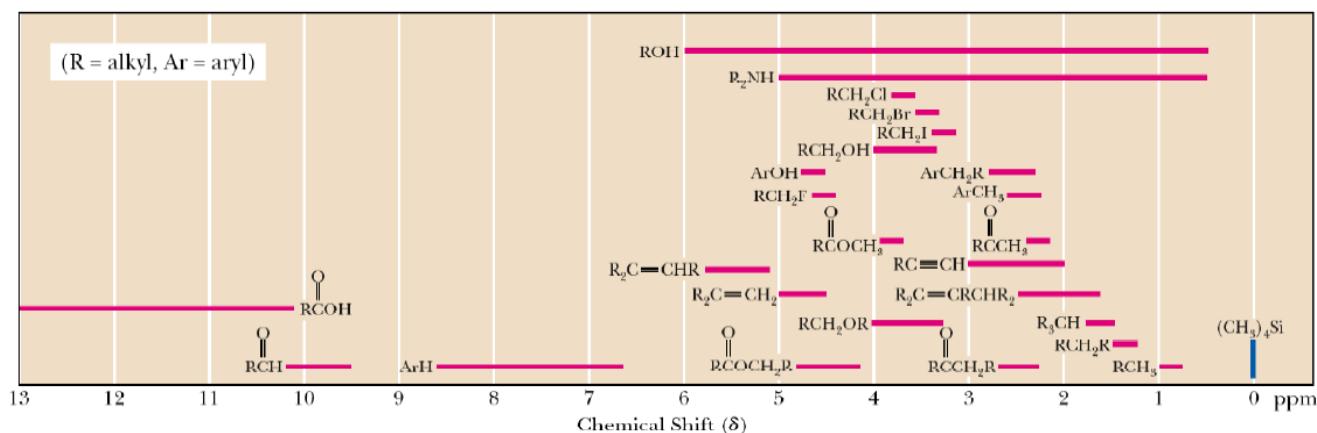
# PERIODIC TABLE OF THE ELEMENTS



Compound		pK <sub>a</sub>
Hydrochloric acid	H-Cl	-7
Protonated alcohol	RCH <sub>2</sub> <sup>+</sup> OH <sub>2</sub>	-2
Hydronium ion	H <sub>3</sub> O <sup>+</sup>	-1.7
Carboxylic acids	R-CO-H	3-5
Thiols	RCH <sub>2</sub> SH	8-9
Ammonium ion	H <sub>4</sub> N <sup>+</sup>	9.2
β-Dicarbonyls	RC(=O)-CH <sub>2</sub> -CR'	10
Primary ammonium	H <sub>3</sub> N <sup>+</sup> CH <sub>2</sub> CH <sub>3</sub>	10.5
β-Ketoesters	RC(=O)-CH <sub>2</sub> -COR'	11
β-Diesters	ROC(=O)-CH <sub>2</sub> -COR'	13
Water	HOH	15.7
Alcohols	RCH <sub>2</sub> OH	15-19
Acid chlorides	RCH <sub>2</sub> -COCl	16
Aldehydes	RCH <sub>2</sub> -CHO	18-20
Ketones	RCH <sub>2</sub> -C(=O)R'	18-20
Esters	RCH <sub>2</sub> -COR'	23-25
Terminal alkynes	RC≡C-H	25
LDA	H-N(i-C <sub>3</sub> H <sub>7</sub> ) <sub>2</sub>	40
Terminal alkenes	R <sub>2</sub> C=C(H)-H	44
Alkanes	CH <sub>3</sub> CH <sub>2</sub> -H	51

Type of Hydrogen (R = alkyl, Ar = aryl)	Chemical Shift ( $\delta$ )*	Type of Hydrogen (R = alkyl, Ar = aryl)	Chemical Shift ( $\delta$ )*
$R_2\text{NH}$	0.5-5.0	$R\text{CH}_2\text{OH}$	3.4-4.0
$\text{ROH}$	0.5-6.0	$R\text{CH}_2\text{Br}$	3.4-3.6
$\text{RCH}_3$	0.8-1.0	$R\text{CH}_2\text{Cl}$	3.6-3.8
$\text{RCH}_2\text{R}$	1.2-1.4	$\begin{matrix} \text{O} \\ \parallel \\ \text{RCOCH}_3 \end{matrix}$	3.7-3.9
$\text{R}_3\text{CH}$	1.4-1.7	$\begin{matrix} \text{O} \\ \parallel \\ \text{RCOCH}_2\text{R} \end{matrix}$	4.1-4.7
$\text{R}_2\text{C}=\text{CRCH}_2\text{R}_2$	1.6-2.6	$\text{RCH}_2\text{F}$	4.4-4.5
$\text{RC}\equiv\text{CH}$	2.0-3.0	$\text{ArOH}$	4.5-4.7
$\begin{matrix} \text{O} \\ \parallel \\ \text{RCCH}_3 \end{matrix}$	2.1-2.3	$\text{R}_2\text{C}=\text{CH}_2$	4.6-5.0
$\begin{matrix} \text{O} \\ \parallel \\ \text{RCCH}_2\text{R} \end{matrix}$	2.2-2.6	$\text{R}_2\text{C}=\text{CHR}$	5.0-5.7
$\text{ArCH}_3$	2.2-2.5	$\begin{matrix} \text{H}_2\text{C} \\ \text{---} \\ \text{O} \\ \parallel \\ \text{CH}_2 \end{matrix}$	3.3-4.0
$\text{RCH}_2\text{NR}_2$	2.3-2.8	$\begin{matrix} \text{O} \\ \parallel \\ \text{RCH} \end{matrix}$	9.5-10.1
$\text{RCH}_2\text{I}$	3.1-3.3	$\begin{matrix} \text{O} \\ \parallel \\ \text{RCOH} \end{matrix}$	
$\text{RCH}_2\text{OR}$	3.3-4.0		10-13

\* Values are relative to tetramethylsilane. Other atoms within the molecule may cause the signal to appear outside these ranges.



Can you believe it, we are here: Your OChem 1 final. It has been quite the journey, from August until now. We started with hybridization and orbital overlap and have worked all the way through epoxide reactions and even NMR. And now, you are conquering synthesis problems!

I put the following on every final, but I hope that it has a special meaning for each one of you. We live in complex and confusing times, but you have incredibly bright futures in front of you. You should all be looking forward with optimism and big dreams. As one of my favorite poets of the 20<sup>th</sup> century put it, here is my truly sincere wish for every one of you:

*“May your wishes all come true.  
May you build a ladder to the stars  
and climb on every rung.  
May you stay forever young.*

*May you grow up to be righteous,  
May you grow up to be true,  
May you always know the truth  
And see the lights surrounding you  
May you always be courageous  
Stand upright and be strong  
May you stay forever young.*

*May your hands always be busy  
May your feet always be swift  
May you have a strong foundation  
When the winds of changes shift  
May your heart always be joyful  
May your song always be sung.  
And may you stay forever young.” BD*

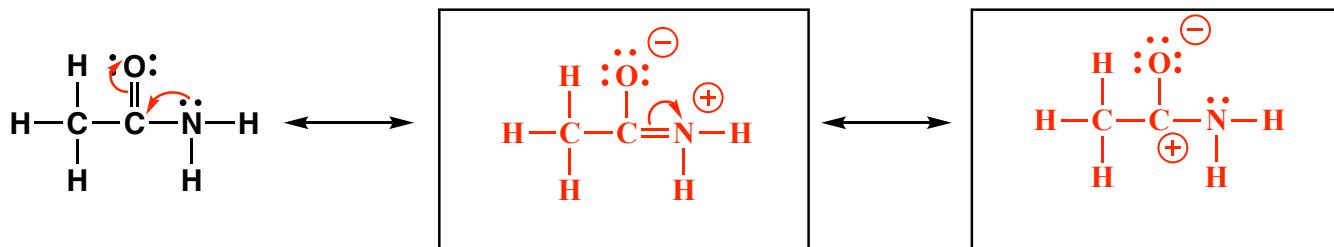
Remember, run every chance you get. Getting exercise is the very best way to overcome anxiety and stress. And, staying fit will also allow you to stay forever young. Now, go get it, show me all that you have learned as you crush this final!

Brent Iverson

1. (5 pts) What is the most important question in organic chemistry?

**Where are the electrons?**

2. (9 pts) Amides are best represented as the hybrid of three contributing structures. Draw the second and third important contributing structures in the spaces provided, including all lone pairs and formal charges. For the two structures on the left, use arrows to indicate the movement of electrons to give the structures you drew.

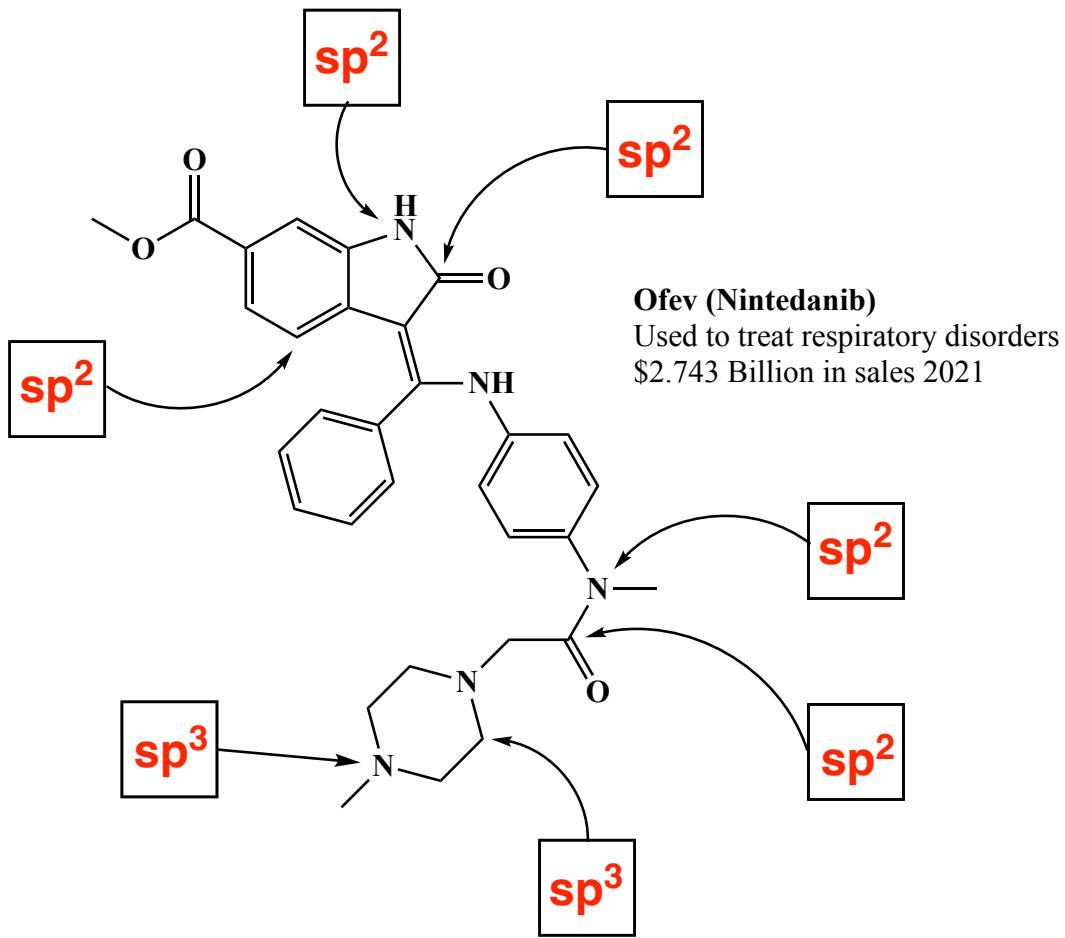


3. (1 pt each) Fill in each blank with the word that best completes the sentences. Yep, this is the MRI paragraph!

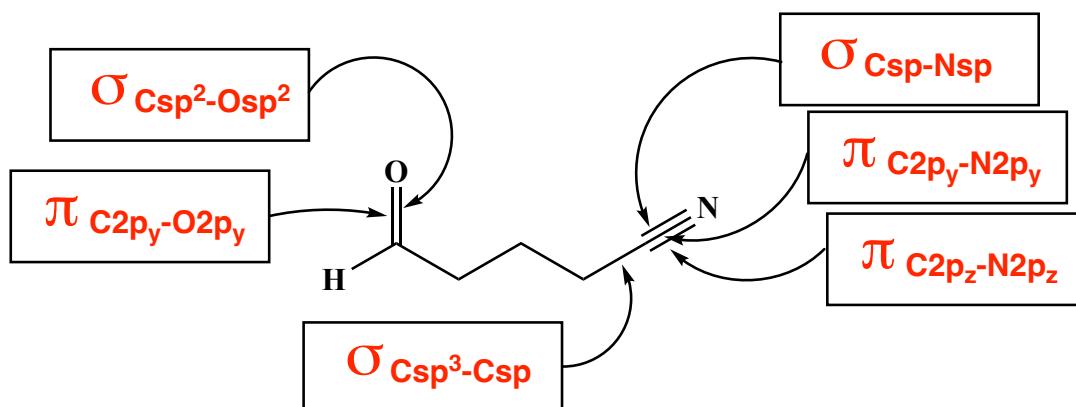
The popular 1. **medical** diagnostic technique of 2. **magnetic**

3. **resonance** 4. **imaging** (5. **MRI**) is based on the same principles as 5. **NMR**, namely the flipping (i.e. 6. **resonance**) of nuclear 7. **spins** of H atoms by radio 8. **frequency** 9. **irradiation** when a patient is placed in a strong 10. **magnetic** field. 11. **magnetic** field 11. **gradients** are used to gain 12. **imaging** information, and rotation of the 13. **gradient** around the center of the object gives imaging in an entire 14. **plane** (i.e. slice inside patient). In an MRI image, you are looking at individual 15. **slices** that when stacked make up the three-dimensional 16. **image** of relative amounts of H atoms, especially the H atoms from 17. **water** and 18. **fat**, in the different tissues.

4. (1 pt each) In the boxes provided, write the hybridization state of the atoms indicated by the arrow.

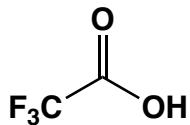
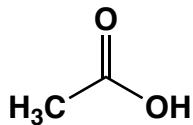


5. (2 pts each) Describe each bond indicated with an arrow as the overlap of orbitals. For example, an answer might be  $\sigma$  Csp<sup>3</sup>-Csp<sup>3</sup>



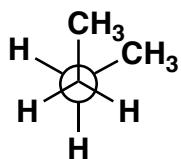
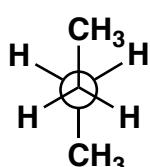
6. (22 pts) Fill in the circle to indicate which of each pair of molecules is more stable, more reactive or the stronger acid as appropriate. To the right under "Reason(s)" fill in every circle that **explains** which of the two molecules is more stable, more reactive or stronger acid. Notice that for some pairs of molecules the correct answer might require more than one circle filled in under "Reason(s)".

A)


 Stronger acid

 Stronger acid
**Reason(s)**

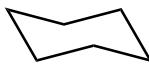
- Torsional strain
- Steric strain
- Angle strain
- Hyperconjugation
- Inductive effect

B)


 More stable

 More stable

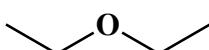
- Torsional strain
- Steric strain
- Angle strain
- Hyperconjugation
- Inductive effect

C)


 More stable

 More stable

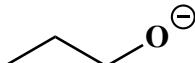
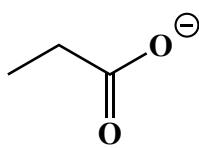
- Torsional strain
- Steric strain
- Angle strain
- Hyperconjugation
- Inductive effect

D)


 More reactive

 More reactive

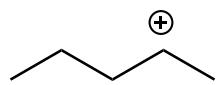
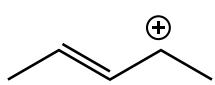
- Torsional strain
- Steric strain
- Angle strain
- Hyperconjugation
- Inductive effect

E)


 More stable

 More stable

- Difference in element electronegativity
- Delocalization of charge
- Pi electron delocalization (a "pi-way" is present)
- Hyperconjugation

F)


 More stable

 More stable

- Difference in element electronegativity
- Delocalization of charge
- Pi electron delocalization (a "pi-way" is present)
- Hyperconjugation

7. (2 pts each) Fill in the circle to indicate whether each statement is true or false as appropriate. You might recognize these as rules of the day.

A. Physics: Moving charge generates a magnetic field, and a moving magnetic field causes charges to move in a conductor.  True  False

B. For NMR we care about the nuclei  $^1\text{H}$  and  $^{13}\text{C}$  since these are commonly found in organic molecules and they have spin quantum numbers of 5/2.  True  False

C. The difference in energy between the +1/2 and -1/2 nuclear spin states is proportional to the strength of the magnetic field felt by the nucleus.  True  False

D. In NMR the process of absorbing energy and flipping nuclear spins from +1/2 to -1/2 is called "resonance".  True  False

E. For a  $^1\text{H}$  nuclear spin to flip, it needs to be exposed to electromagnetic radiation with an energy that is exactly the same as the energy difference between the +1/2 and -1/2 nuclear spin states.  True  False

F. For a  $^1\text{H}$  nuclear spin to flip, it needs to be exposed to electromagnetic radiation with an energy that is greater than or equal to the energy difference between the +1/2 and -1/2 nuclear spin states.  True  False

G. Electron density is induced to circulate in a strong external magnetic field, which, in turn, produces a magnetic field that aligns with and therefore reinforces the external magnetic field.  True  False

H. The splitting of a -CH<sub>2</sub>- group adjacent to a chiral center will condense into a single peak with no splitting.  True  False

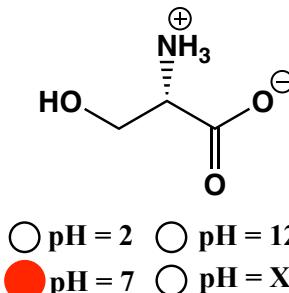
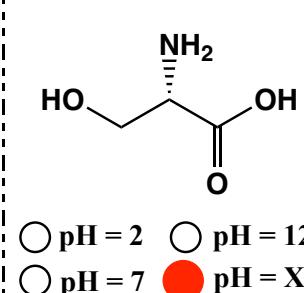
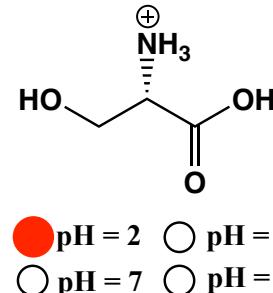
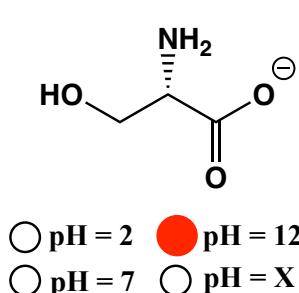
I. THEORY: When there are two sets of adjacent H atoms, the number of peaks multiply  $[(N+1) \times (N'+1)]$ .  True  False

J. WHAT YOU WILL SEE IN REALITY: For alkyl groups, complex splittings simplify to N+1 because coupling constants ("J") are all about the same when the C atoms can rotate freely.  True  False

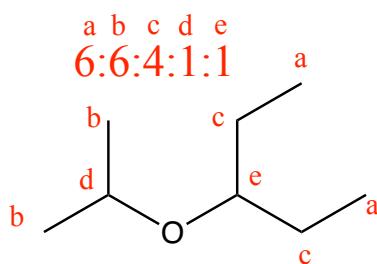
K. The H atoms of relatively acidic functional groups (alcohols, carboxylic acids, amines) exchange rapidly, so they often do not split the signals of adjacent hydrogen atoms, and they can be replaced (signal disappears) with deuterium by adding a drop of D<sub>2</sub>O to the NMR sample.  True  False

8. (8 pts.) Fill in the circle next to the pH value that corresponds the pH at which the structure drawn would be dominant. If the structure drawn cannot exist at any pH, fill in the circle next to the "pH = X"

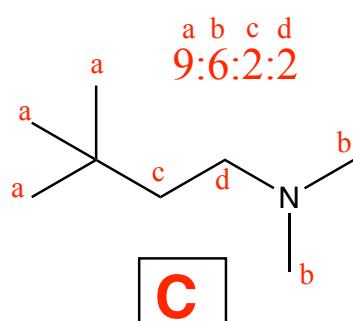
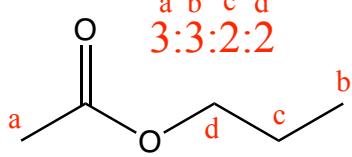
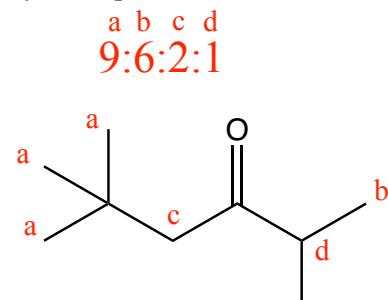
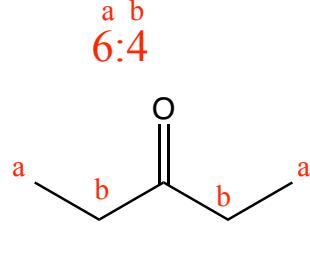
**The pK<sub>a</sub> of a carboxylic acid (RCO<sub>2</sub>H) is generally in the 4-5 range. The pK<sub>a</sub> of ammonium ions (RNH<sub>3</sub><sup>+</sup>) is in the 9-10 range.**



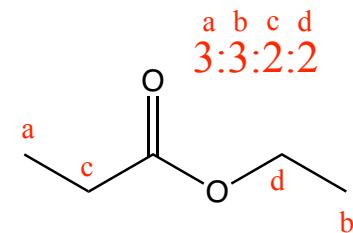
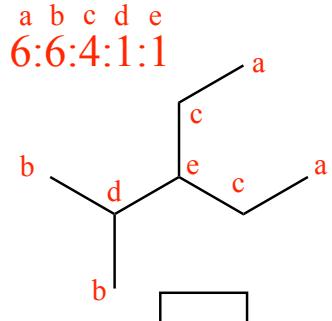
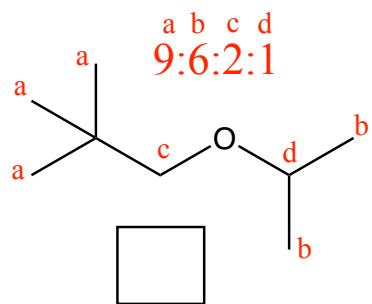
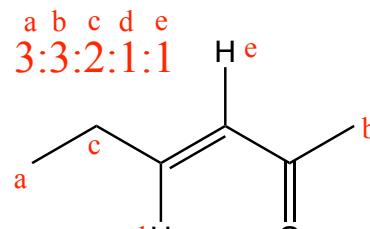
8. (24 pts total) On the following four pages there are NMR spectra. The relative integrations are given above each signal. Each NMR spectrum has a letter on it. **In the spaces provided, write the appropriate letter underneath the molecules that would produce that spectrum.** Notice that not all of the molecules below will have letters underneath them, as there are only four spectra but eleven molecules.



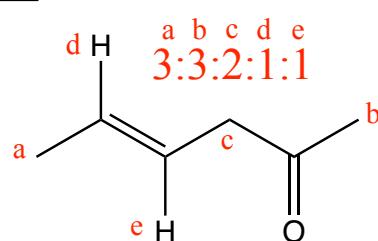
**B**



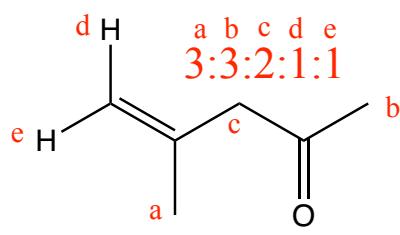
**C**



**A**



**D**

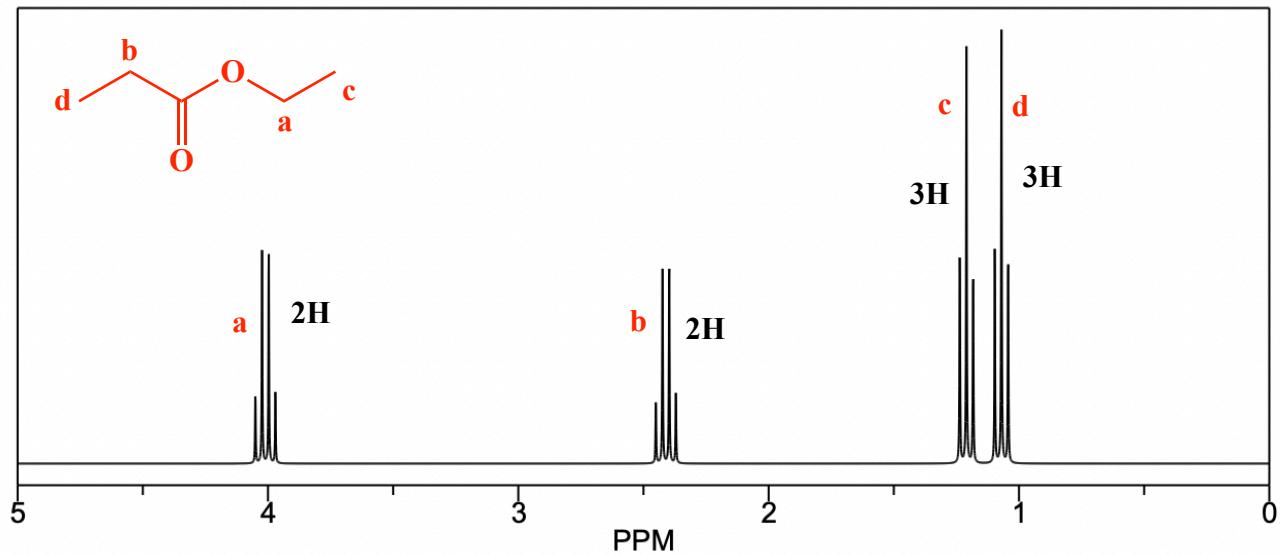


Signature \_\_\_\_\_

Pg 6 \_\_\_\_\_

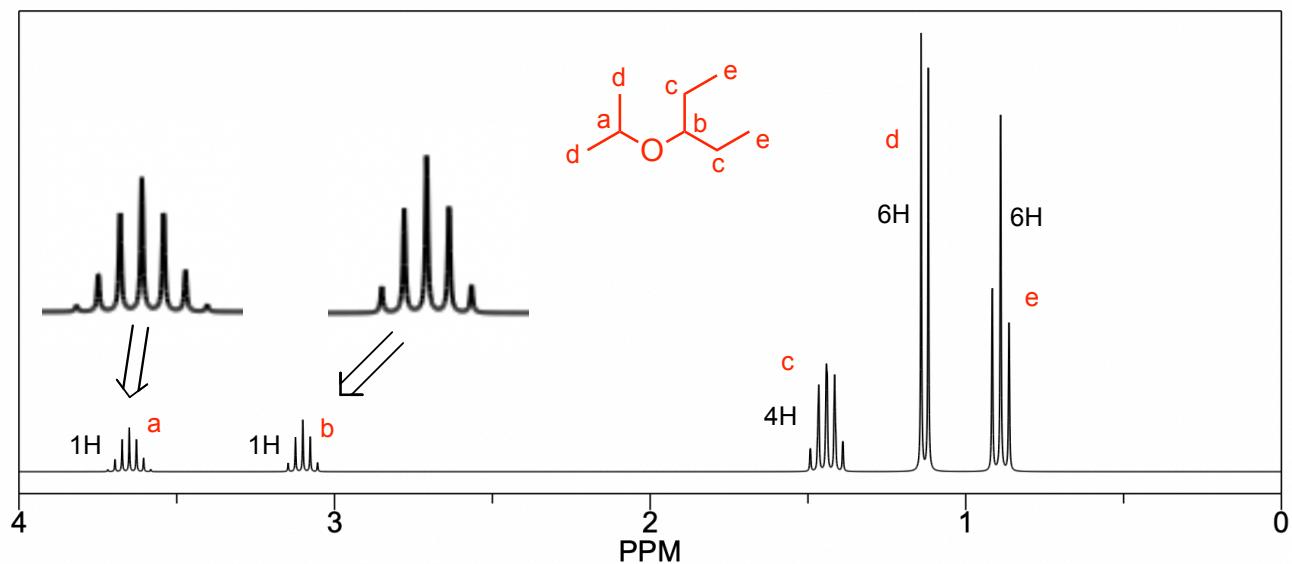
# Spectrum A

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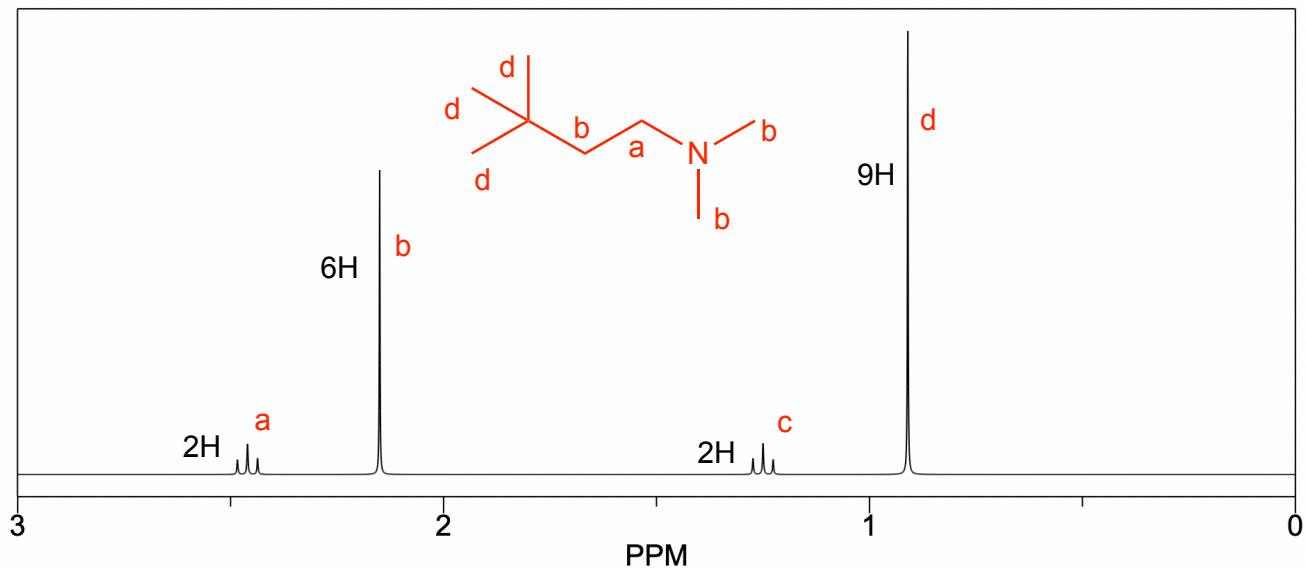
# Spectrum B

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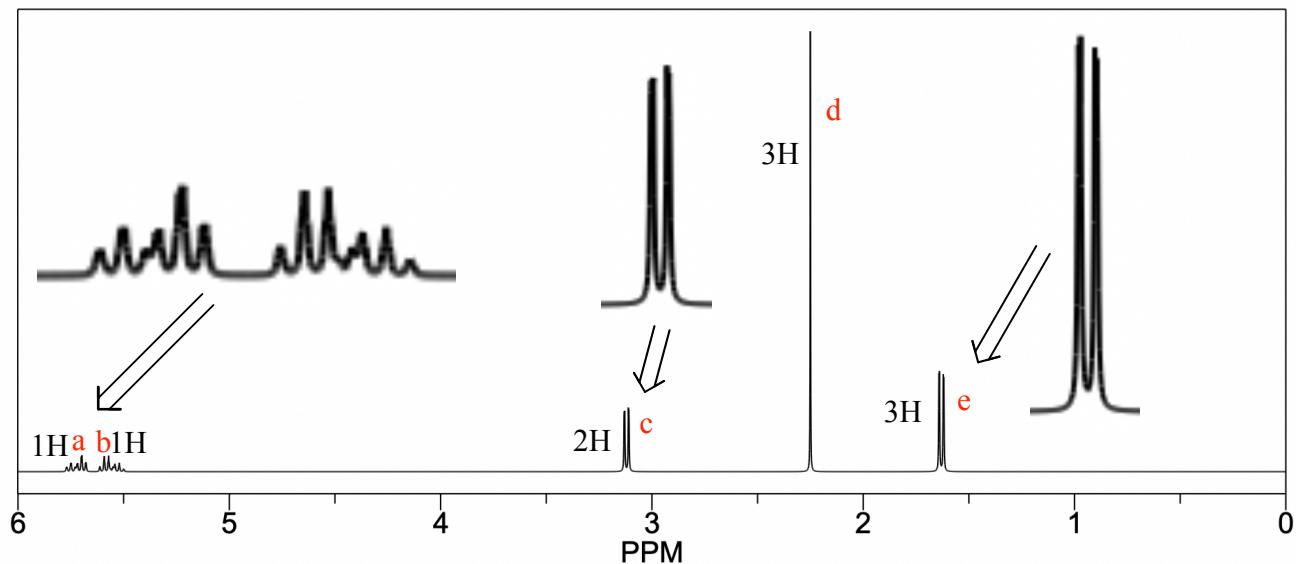
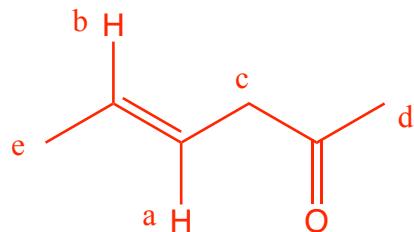
# Spectrum C

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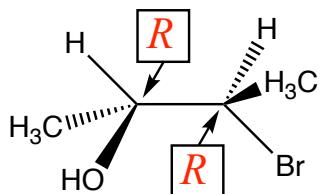


# Spectrum D

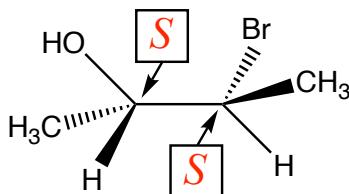
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9. (14 pts total) On the line provided, state the stereochemical relationship between each pair of molecules: **enantiomers, diastereomers, or the same molecule**. In each box assign R and S to each chiral center. **Fill in the circle under all meso compounds.**



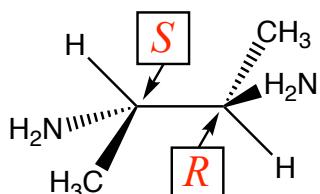
This is a meso compound



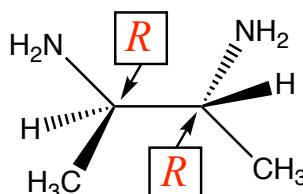
This is a meso compound

**Relationship**

enantiomers



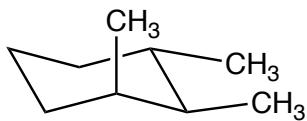
This is a meso compound



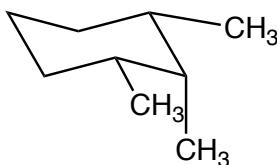
This is a meso compound

diastereomers

10. (4 pts) On the line provided, state the stereochemical relationship between this pair of molecules: **enantiomers, diastereomers, or the same molecule**. No need to assign R and S. **Fill in the circle under all meso compounds.**



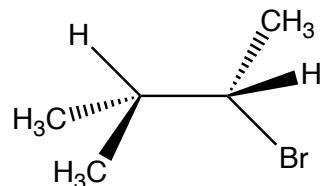
This is a meso compound



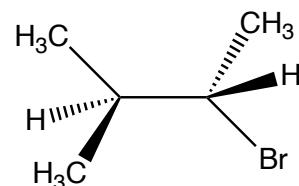
This is a meso compound

diastereomers

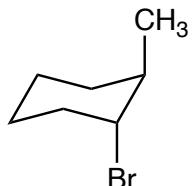
11. (4 pts) For the following pairs of structures, fill in the circle under the molecule of each pair that is in the correct conformation for an E2 reaction that gives the major product formed as predicted by Zaitsev's rule.



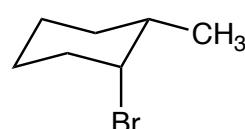
This is a reactive conformation for Zaitsev product



This is a reactive conformation for Zaitsev product

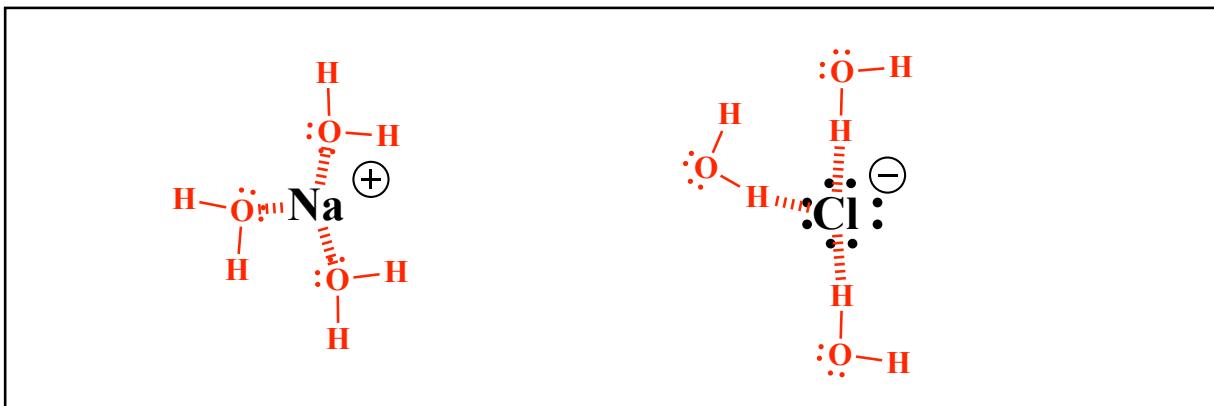


This is a reactive conformation for Zaitsev product

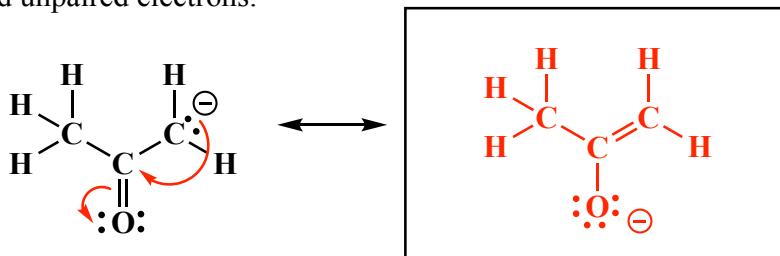


This is a reactive conformation for Zaitsev product

12. (12 pts.) Water is a polar protic solvent. We have drawn  $\text{Na}^+$  and  $\text{Cl}^-$  ions below. For each ion, place three water molecules around them, oriented exactly as you would expect based on the polarity of the -OH bonds in the water molecules. Details matter here! Next, for each ion, use dashed lines to indicate the most important interaction between the ion and specific atoms of each of the three water molecules you drew. There should be three dashed lines per ion. Please read these directions again!



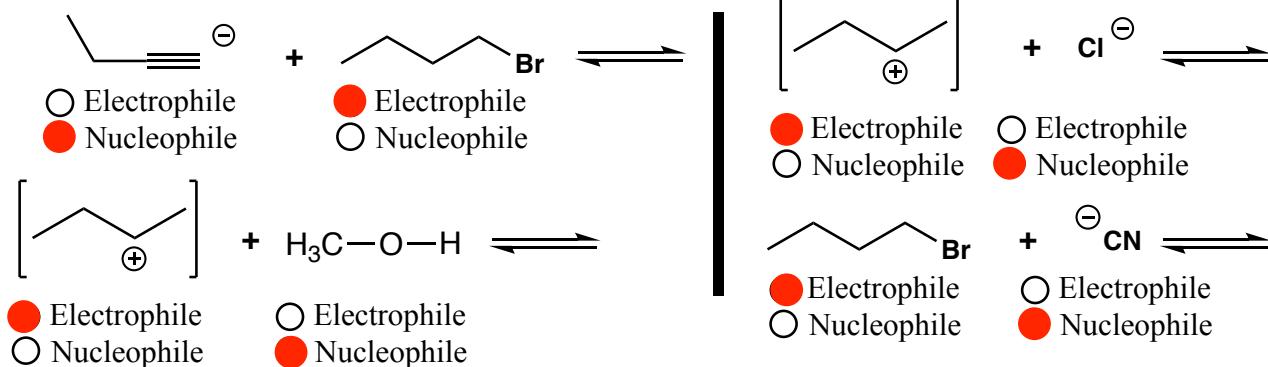
13. (7 pts.) Draw the other important contributing structure for this enolate anion. Draw arrows on the structure given that leads to the contributing structure you drew. Remember to include all formal charges and unpaired electrons.



Fill in the circle to indicate how many pi electrons are in the delocalized pi system ("pi-way") indicated by the two contributing structures

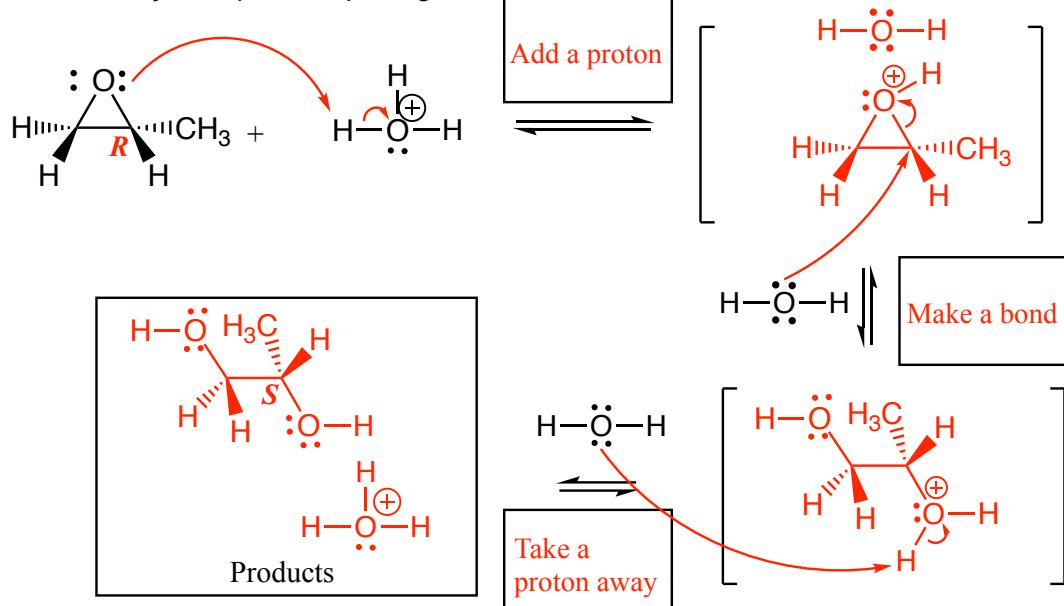
0  
 2  
 3  
 4

14. (4 pts each) For the following four pairs of reagents you have seen in various bond-making steps in mechanisms, fill in the circle to indicate which structure is acting as a nucleophile and which is an electrophile.

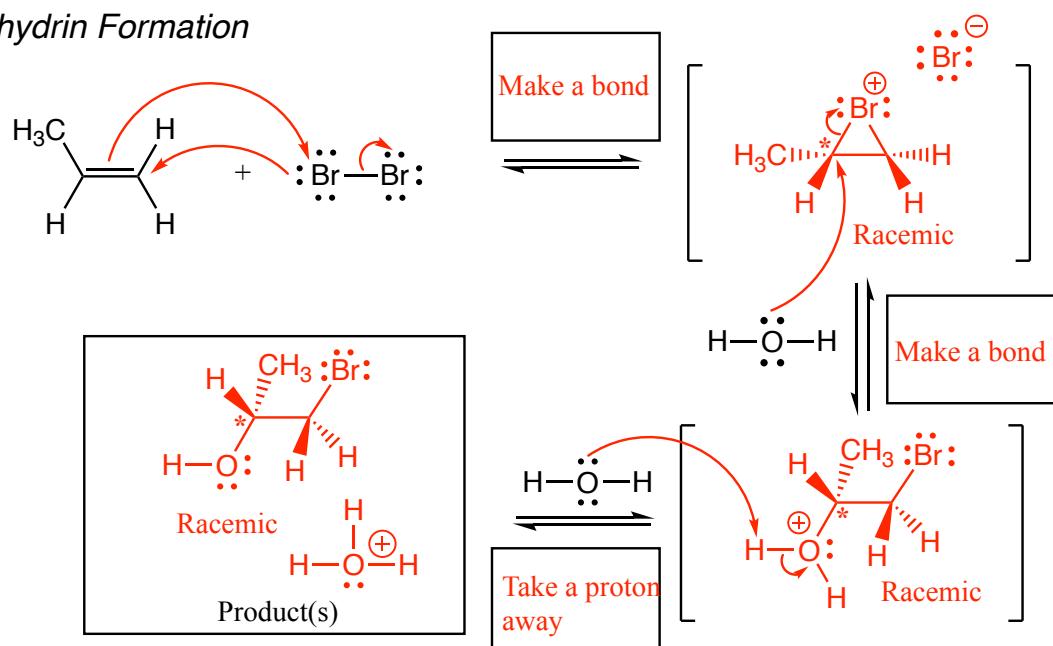


15. (35 pts) For these two mechanisms, use arrows to indicate movement of all electrons, write all lone pairs, all formal charges, and all the products for each step. Remember, I said all the products for each step. YOU MUST USE WEDGES AND DASHES TO INDICATE ALL STEREOCHEMISTRY. IF A NEW CHIRAL CENTER IS CREATED IN AN INTERMEDIATE OR PRODUCT YOU ONLY NEED TO DRAW ONE OF THE ENANTIOMERS AND YOU MUST MARK THE NEW CHIRAL CENTER WITH AN ASTERISK AND LABEL THE MOLECULE AS "RACEMIC" IF APPROPRIATE. In the boxes provided, write which of the 4 most common mechanistic elements describes each step (make a bond, break a bond, etc.).

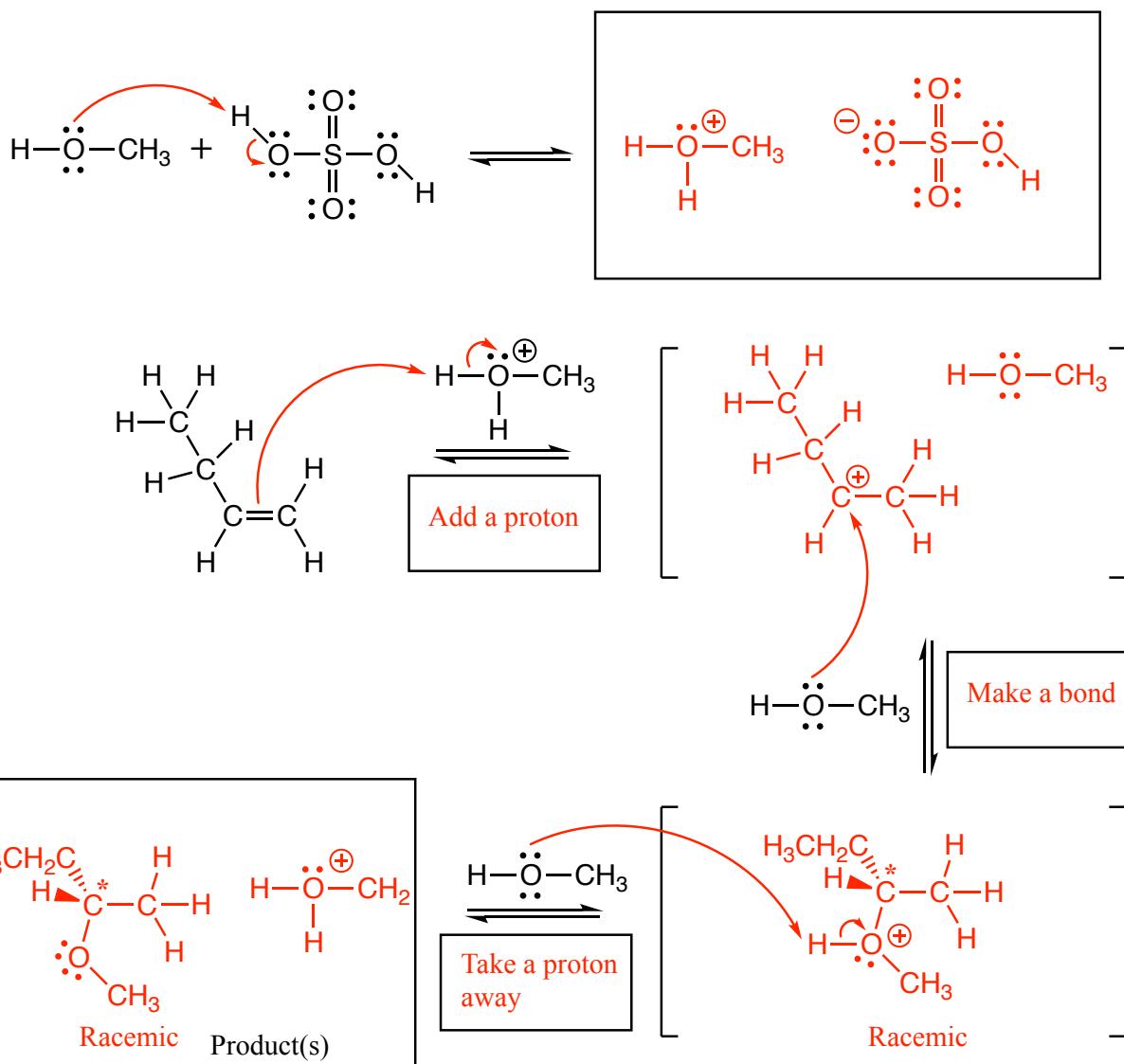
*Acid-catalyzed epoxide opening*



*Halohydrin Formation*



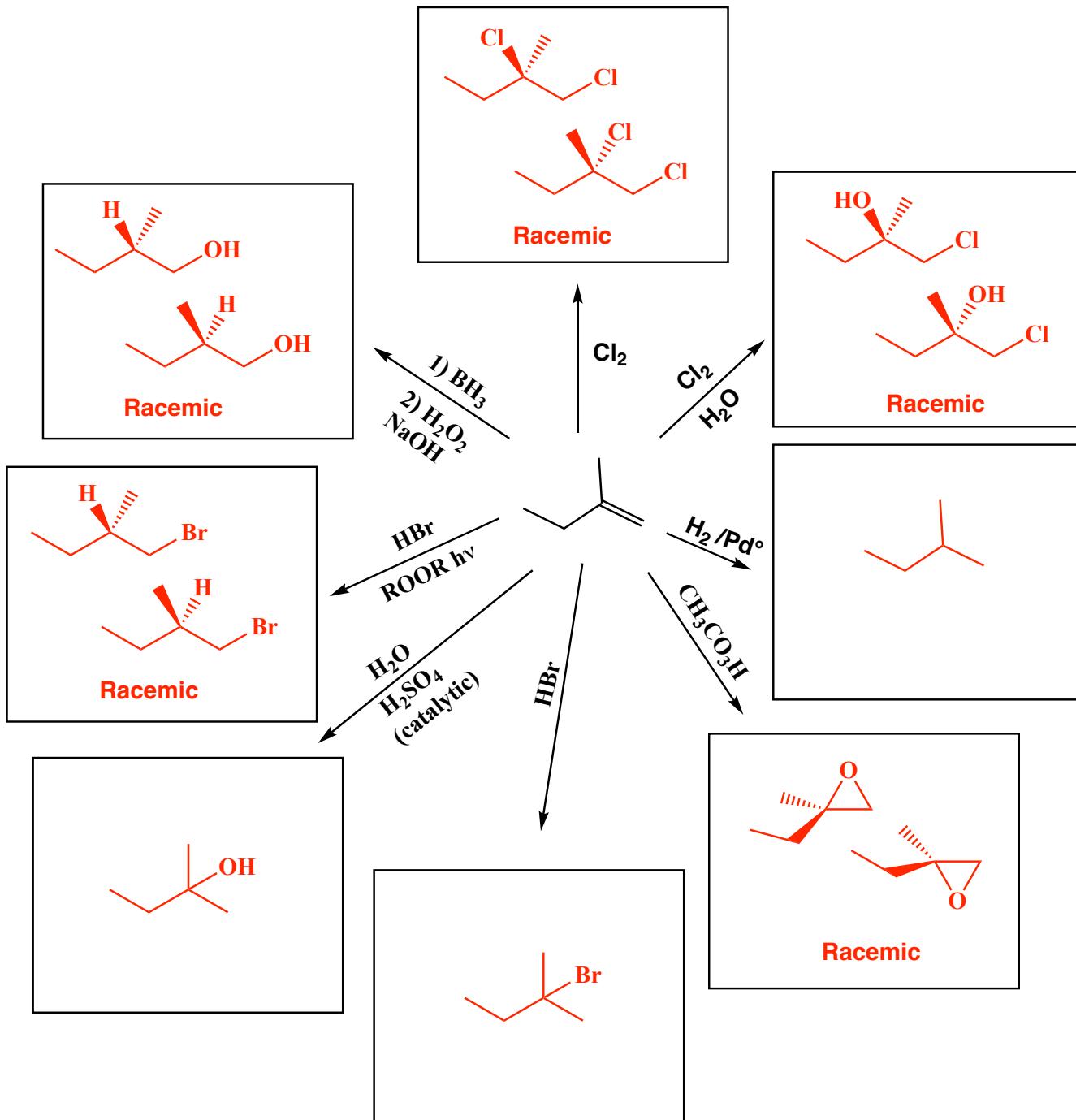
16. (32 pts) Complete the mechanism for the following reaction of an alkene with  $\text{CH}_3\text{OH}$  in the presence of catalytic amount of  $\text{H}_2\text{SO}_4$ . Use **arrows to indicate movement of all electrons, write all lone pairs, all formal charges, and all the products for each step**. Remember, I said all the products for each step. **YOU MUST USE WEDGES AND DASHES TO INDICATE ALL STEREOCHEMISTRY. IF A NEW CHIRAL CENTER IS CREATED IN AN INTERMEDIATE OR PRODUCT YOU ONLY NEED TO DRAW ONE OF THE ENANTIOMERS AND YOU MUST MARK THE NEW CHIRAL CENTER WITH AN ASTERISK AND LABEL THE MOLECULE AS "RACEMIC" IF APPROPRIATE.** In the boxes provided, write which of the 4 most common mechanistic elements describes each step (make a bond, break a bond, etc.).



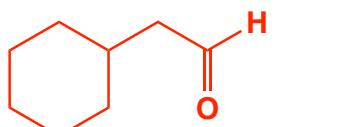
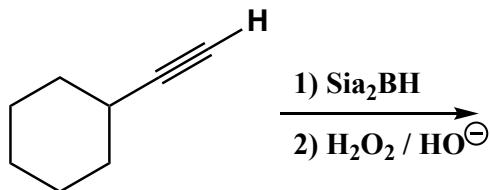
(2 pts) How many total stereoisomers are produced by this reaction? 2 (*R* and *S*)

(2 pts) As the reaction proceeds, does the pH of the solution increase, decrease, or stay the same? Stays the same

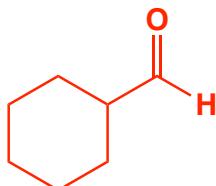
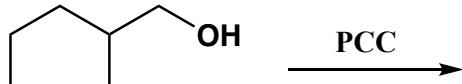
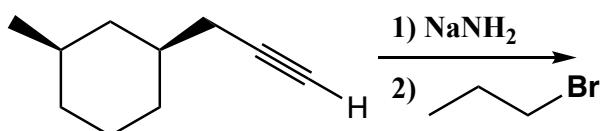
17. (3 or 5 pts) For the following, complete the reactions with the predominant carbon-containing product or products. You must indicate stereochemistry with wedges and dashes. You must draw all stereoisomers produced as predominant products and write "racemic" under the structures when appropriate. **Assume no rearrangements take place.**



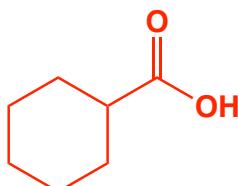
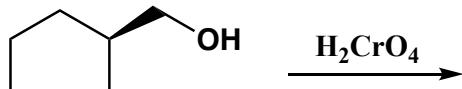
18. (3 or 5 pts each) For the following, complete the reactions with the predominant carbon-containing product or products. You must indicate stereochemistry with wedges and dashes. You must draw all stereoisomers produced as predominant products and write "racemic" under the structures when appropriate. Assume no rearrangements take place.



Not Chiral



Not Chiral

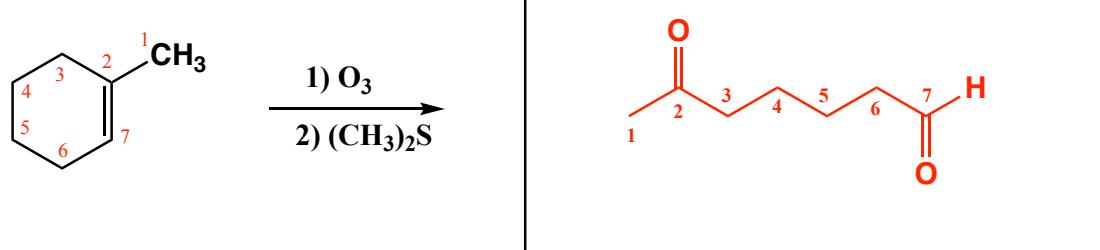
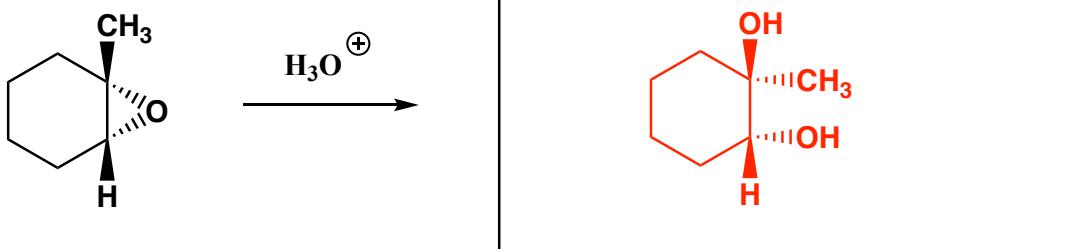
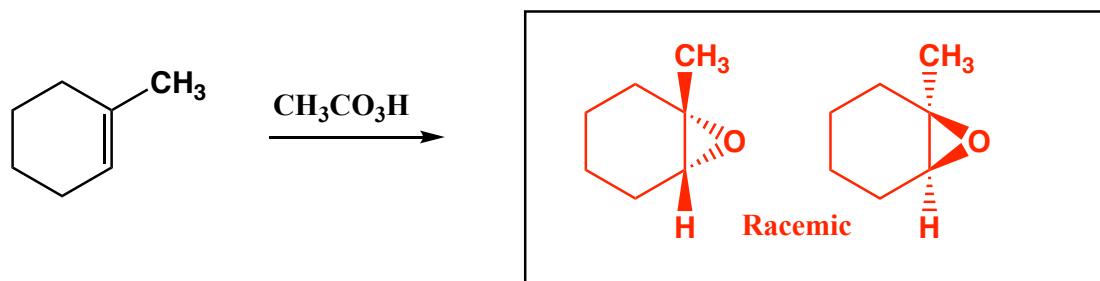
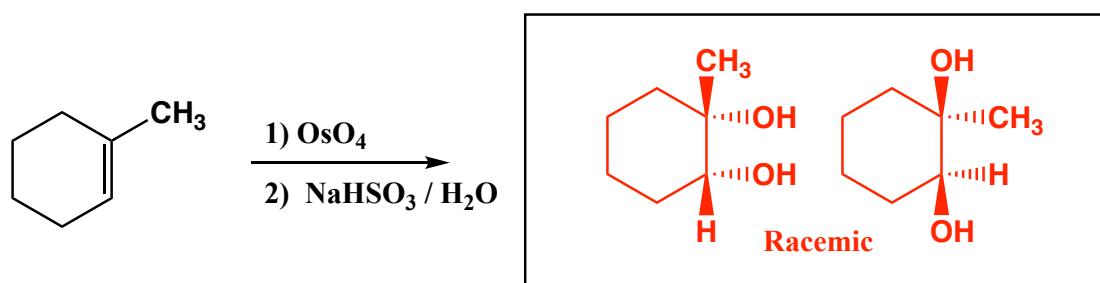
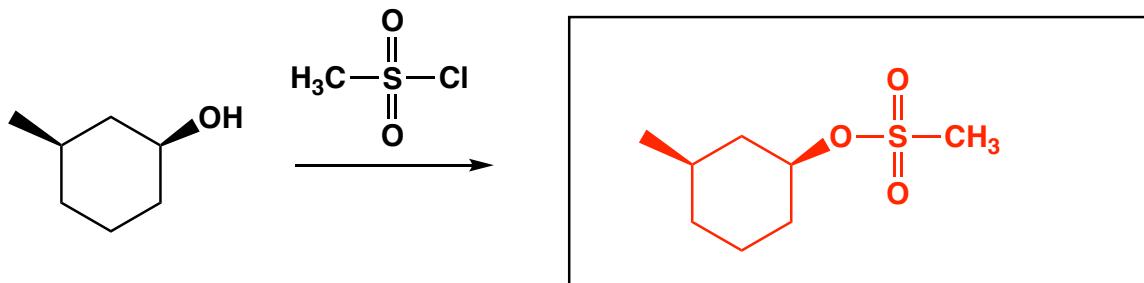


Not Chiral

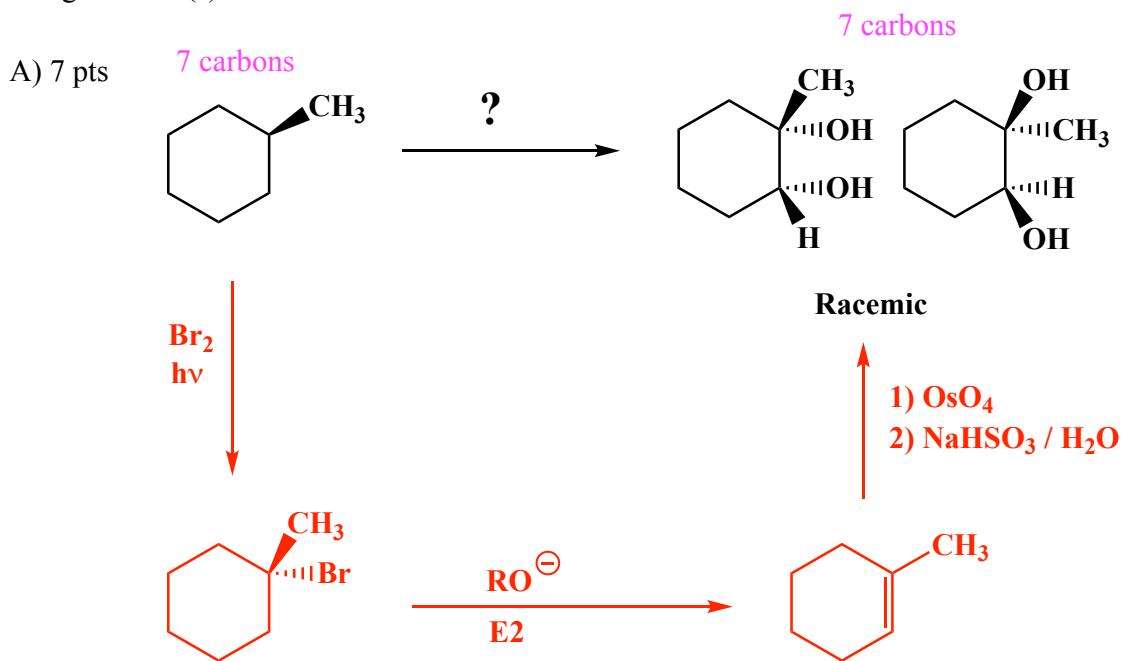


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18. (3 or 5 pts each) For the following, complete the reactions with the predominant carbon-containing product or products. You must indicate stereochemistry with wedges and dashes. You must draw all stereoisomers produced as predominant products and write "racemic" under the structures when appropriate. Assume no rearrangements take place.

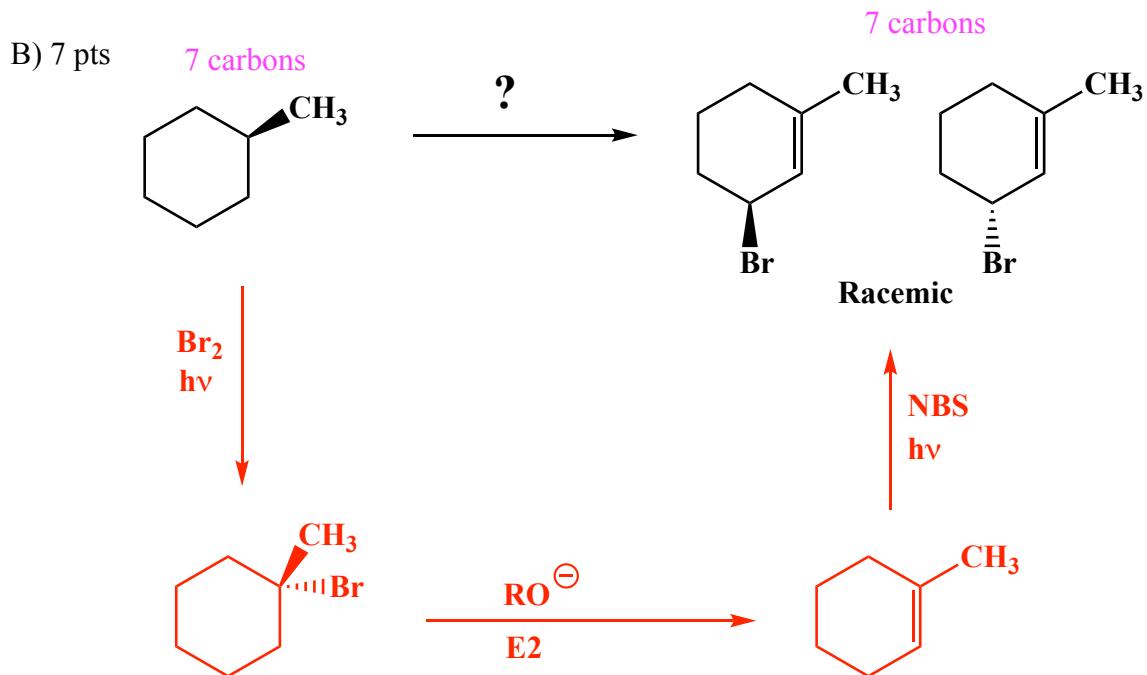


18. (7 pts) These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned. Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction because only predominant products can be used. All the carbon atoms of the product(s) must come from the starting material(s) shown.



**Recognize** the final product as being a *cis* vicinal diol, therefore assume the last step uses 1)  $\text{OsO}_4$  then 2)  $\text{NaHSO}_3 / \text{H}_2\text{O}$  and starts with the alkene shown. **Recognize** the alkene as a Zaitsev product of an E2 elimination of the 1-bromomethylcyclohexane. **Recognize** that the starting material is an alkane, and the only reaction you know that starts with an alkane is free radical halogenation using  $\text{Br}_2$  and  $\text{h}\nu$  to give the 1-bromomethylcyclohexane.

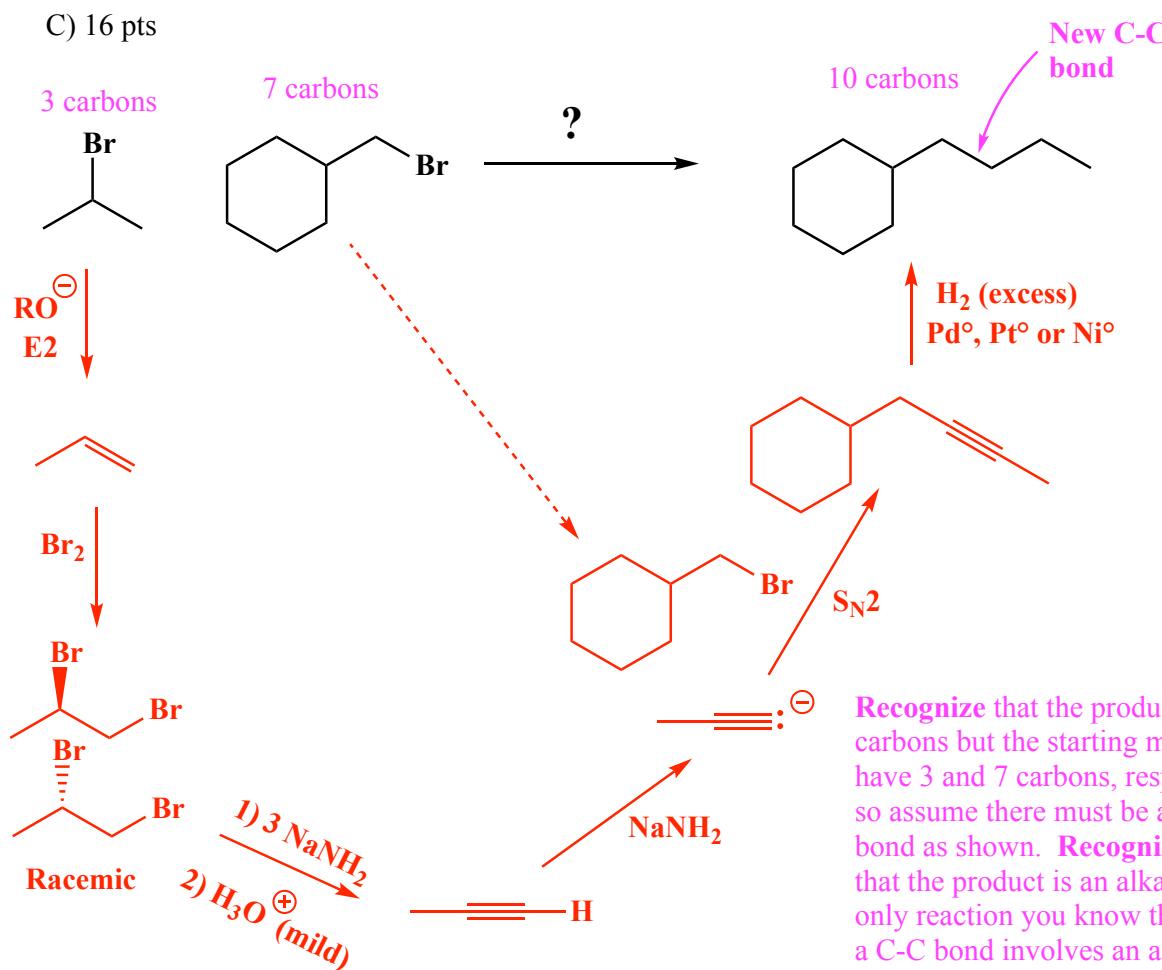
18. (7 pts) These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned. Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction because only predominant products can be used. All the carbon atoms of the product(s) must come from the starting material(s) shown.



**Recognize** the final product as being a bromoalkene, therefore assume the last step is a free radical allylic bromination reaction using NBS and light (hν) that starts from the alkene shown. This makes sense because the product has the most highly substituted alkene possible for the molecule, consistent with what is known about free radical allylic halogenation using NBS and light. **Recognize** the alkene as a Zaitsev product of an E2 elimination of the 1-bromomethylcyclohexane. **Recognize** that the starting material is an alkane, and the only reaction you know that starts with an alkane is free radical halogenation using Br<sub>2</sub> and hν to give the 1-bromomethylcyclohexane.

18. (16 pts) These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned. Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction because only predominant products can be used. All the carbon atoms of the product(s) must come from the starting material(s) shown.

C) 16 pts

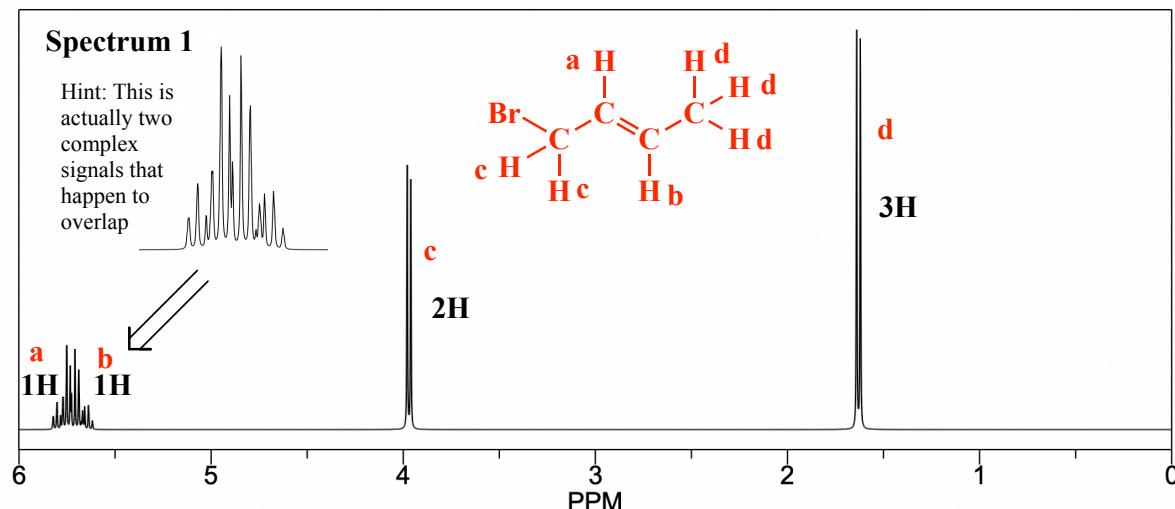
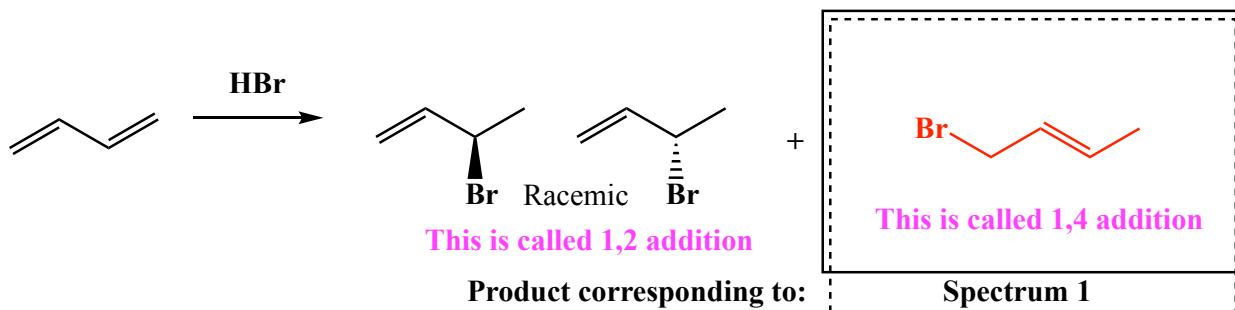


Recognize that the product has 10 carbons but the starting materials have 3 and 7 carbons, respectively, so assume there must be a new C-C bond as shown. Recognize further that the product is an alkane but the only reaction you know that makes a C-C bond involves an alkyne so assume the last step is reduction of the alkyne as shown.

Recognize that the bromoalkane with 7 carbons needed for the  $S_N2$  reaction is the 7-carbon starting material and the alkyne anion you need can be made from the terminal alkyne shown. Recognize that the terminal alkyne that you need can be made by going right up I-35 from the starting 2-bromopropane using an E2 reaction to give the alkene followed by halogenation to give the racemic vicinal dihalide. A double E2 reaction using 1) 3  $NaNH_2$  followed by 2) mild acid gives the terminal alkyne.



19. (11 pts) Here is a combination box problem plus NMR spectra! A chemist carries out the following reaction of 1,3-butadiene with HBr. She isolated three products. Two she expected, both R and S 3-bromo-1-butene as shown. In the empty box, draw the third product that corresponds to the NMR spectra below. Make sure to indicate stereochemistry with wedges and dashes as appropriate. Hint: if you are stuck you should try to answer the question at the bottom for inspiration.



When the chemist realized what the structures were for all the products she had made, she immediately knew what happened. **In the two boxes provided, draw both contributing structures of the intermediate involved in the reaction.**

