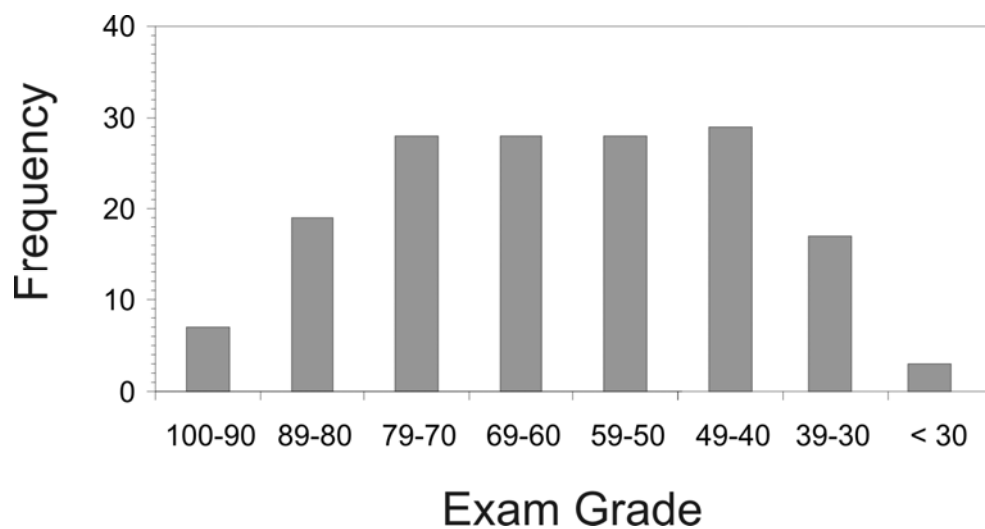
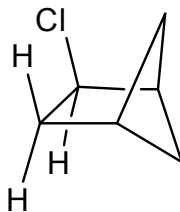
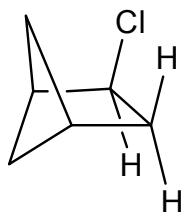


**Exam 2  
Answer Key**

Exam 2 Mean: 61  
Exam 2 Median: 60  
Exam 2 St. Dev.: 17



1. (12 pts) How would you describe the relationship between each of the pairs of structures below? Are they enantiomers or diastereomers, or are they just two ways of illustrating the same molecule? **Circle one answer** for each pair.



**ENANTIOMERS**

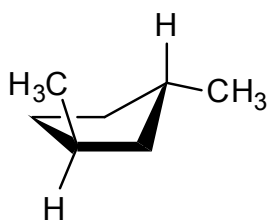
4

*or*

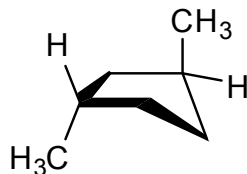
**DIASTEREOMERS**

*or*

**SAME MOLECULE**



*can also be drawn as*



*can also be drawn as*

**ENANTIOMERS**

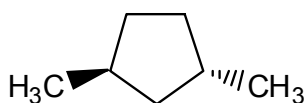
*or*

**DIASTEREOMERS**

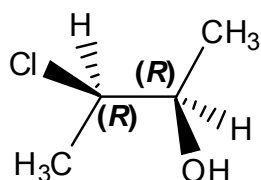
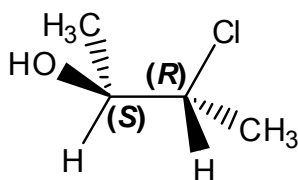
*or*

**SAME MOLECULE**

4



And these two are the same molecule.



**ENANTIOMERS**

*or*

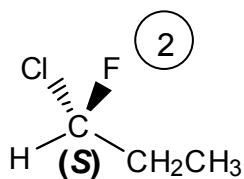
**DIASTEREOMERS**

4

*or*

**SAME MOLECULE**

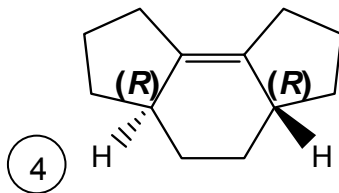
2. (19 pts) On the structures below, **label each chiral center** with its appropriate Cahn-Ingold-Prelog designation [(*R*) or (*S*)]. Make it clear which atom in the drawing you are labeling. Then, for each structure, **circle** whether you think the molecule is chiral or achiral.



*or*

**ACHIRAL ?**

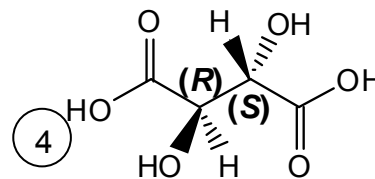
This molecule has one chiral center, so it must be chiral.



*or*

**ACHIRAL ?**

This molecule is (*R,R*), and so its mirror image would be (*S,S*)—a different molecule. So, because the molecule is not the same as its mirror image, it's chiral.



**CHIRAL**

*or*

(3)  
**ACHIRAL ?**

A molecule is *meso* if the (*R*) and (*S*) centers have the same groups attached. That is the case here, so the molecule is achiral.

Rubric:

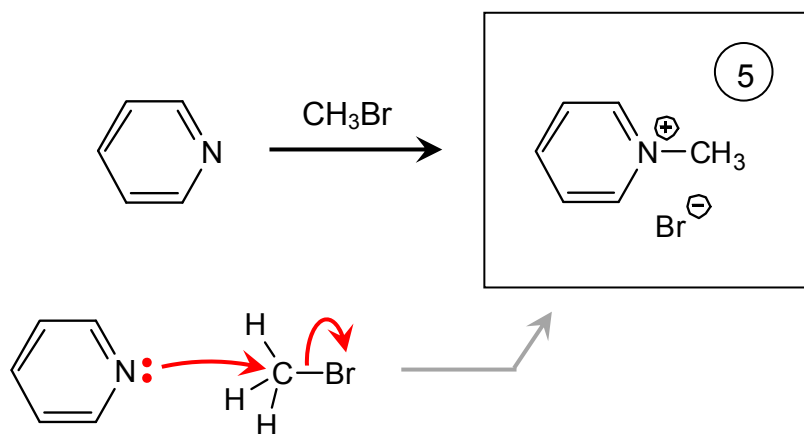
2 points for each labeled stereocenter.

*No partial credit for labeling correct center with incorrect letter.*

*-2 points for each achiral center labeled as chiral.*

3 points for each circle.

3. (20 pts) Draw the missing reactant or product in the empty boxes. For products, give the predominant, most favored product. Illustrate stereochemistry in your answer where appropriate. For reactions that yield multiple enantiomers, draw only one enantiomer in the box, and include the note "+ enantiomer".



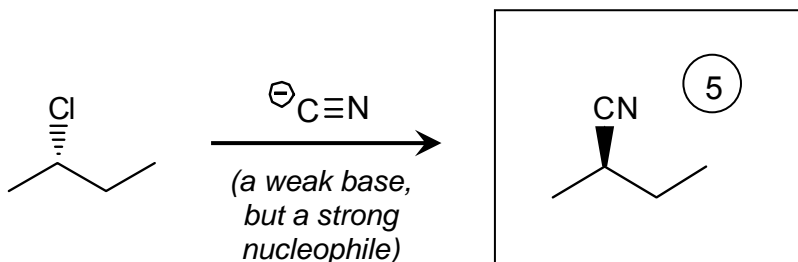
Rubric for this part:

5 points for organic part of structure (methylpyridinium).

*No need to include inorganic ( $\text{Br}^-$ ) part.*

*-1 point for writing "+ enantiomer"—product is achiral.*

*-2 points for each clearly trivial structure mistake. (Including omitting formal charge on nitrogen.)*



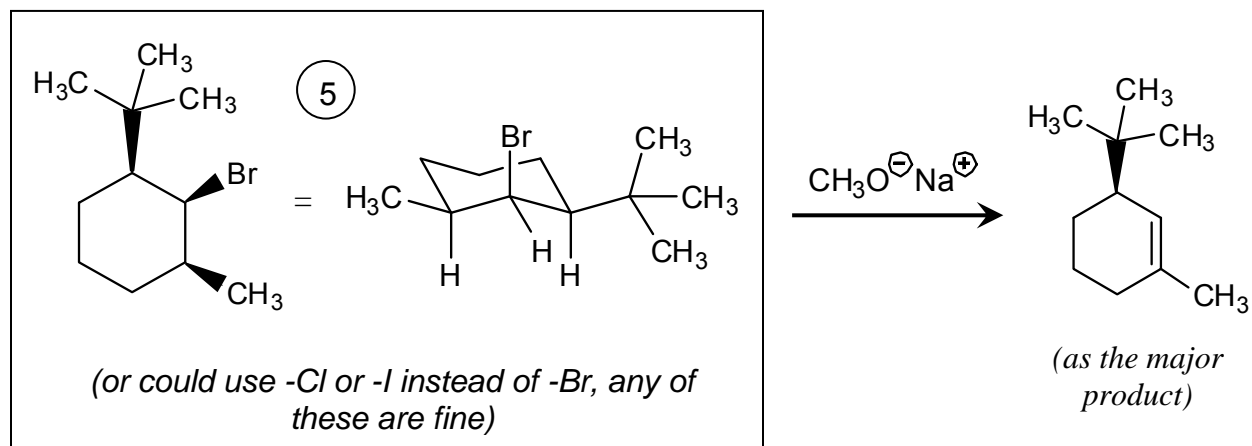
Rubric for this part:

5 points for correct structure.

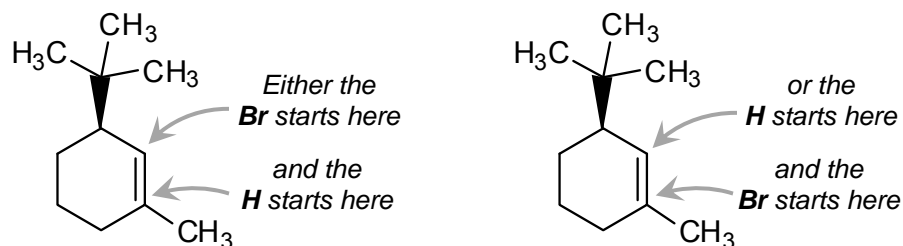
*3 points partial for opposite stereoisomer.*

*-1 point for writing "+ enantiomer" on correct answer—reaction generates one enantiomer only.*

*-2 points for each clearly trivial structure mistake.*



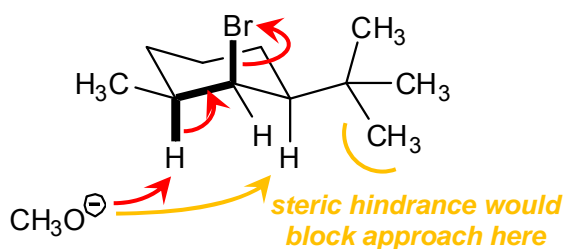
Our product, an alkene, would be made from an alkyl halide and methoxide anion—a strong base—by E2 elimination. Our starting material, a substituted cyclohexane, will need to have our halide leaving group—I'll use Br as my example, but Cl and I are also fine—at one of the positions that will become the double bond, and an H at the other position. That gives us two *regiochemical* possibilities:



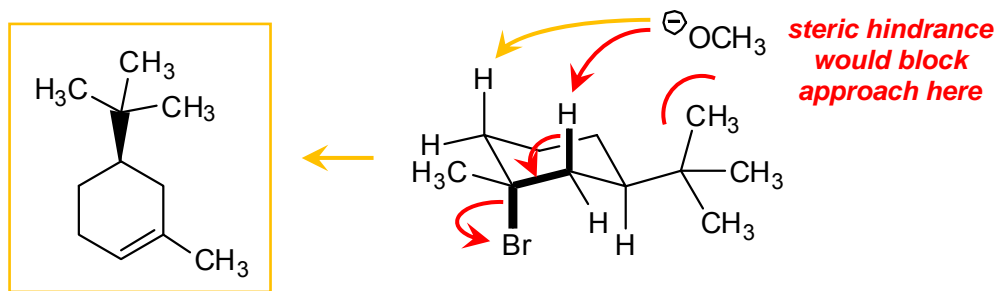
No matter where we put the H and the Br in the starting material, our cyclohexane starting material will have two additional geometric constraints:

1. The *tert*-butyl group is extremely large and sterically bulky, and will have a strong preference to be equatorial in the starting material. Even though cyclohexanes typically have two equilibrating chair conformers, this one will almost never be in the conformation that puts the *t*-butyl group axial.
2. The H and the Br shown above will have to be anti-periplanar for E2 to succeed (because this is a requirement of E2).

That means we've only got two possible starting materials:



In this potential starting material, the base has two different anti-periplanar protons it could take to eliminate the Br leaving group. The H on the right—the one that leads to the wrong product—is sterically protected by the *tert*-butyl group. That means that this starting material will selectively react to form the product we want.



In the other possible starting material, once again, there are two possible H's that our base could take. However, in this case, the *tert*-butyl group blocks the reaction we want, and encourages the base to take a proton distant from the *tert*-butyl group to preferentially generate a product we don't want.

We gave partial credit to this answer.

Rubric for this part:

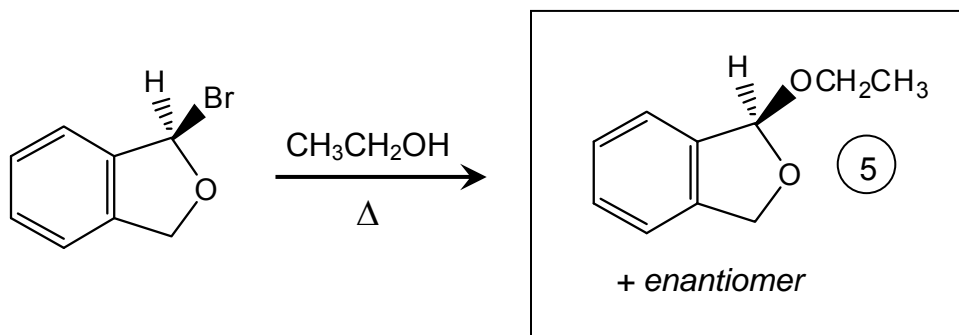
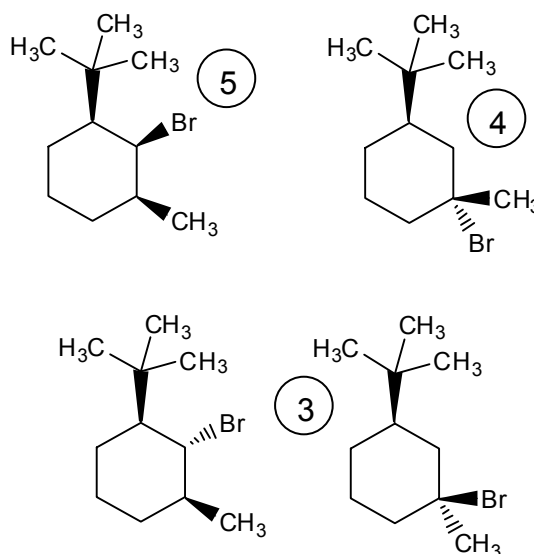
5 points for correct structure.

4 points partial for second starting material above.

3 points partial for any other starting material with -Br on same carbon as CH<sub>3</sub> or between CH<sub>3</sub> and *t*-butyl groups.

-1 point for writing "+ enantiomer" on correct answer—reaction generates one enantiomer only.

-2 points for each clearly trivial structure mistake. This does not include putting -Br



The conditions in the problem are for E1 and S<sub>N</sub>1. In this case, there are no H atoms one carbon away from the Br leaving group, so this starting material can only react via S<sub>N</sub>1. S<sub>N</sub>1 produces a racemic mixture of products.

Rubric for this part:

5 points for correct structure and either (a) including "+ enantiomer" or (b) not drawing wedge or dash illustrating stereochemistry (which infers racemate).

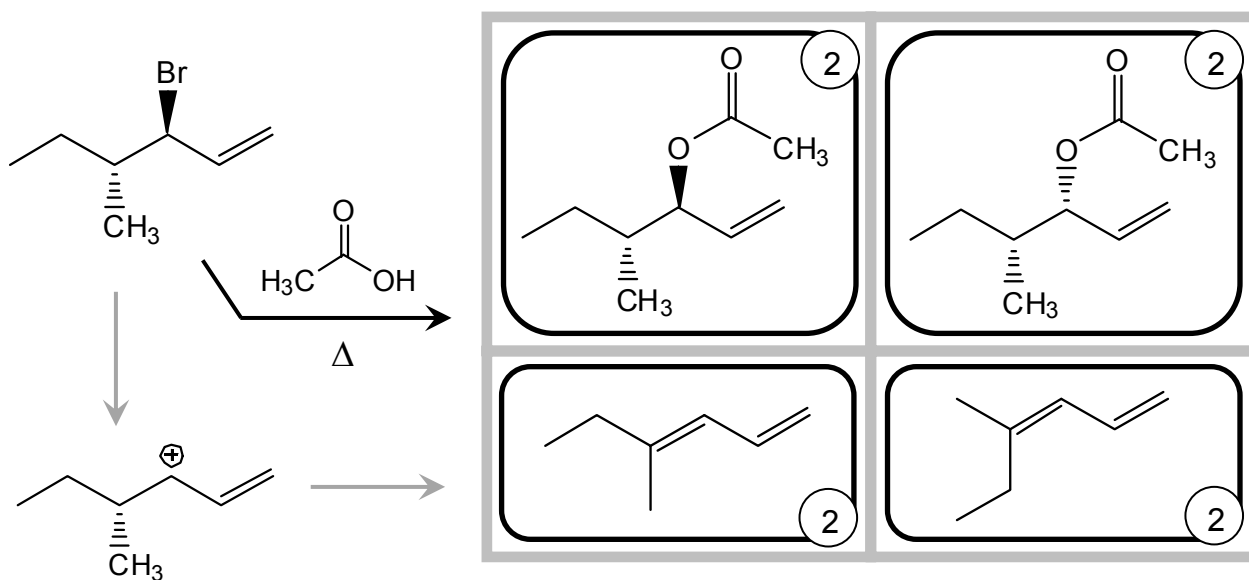
4 points partial for omitting "+ enantiomer".

3 points partial for inversion of stereochemistry only (as if reaction were  $S_N2$ ).

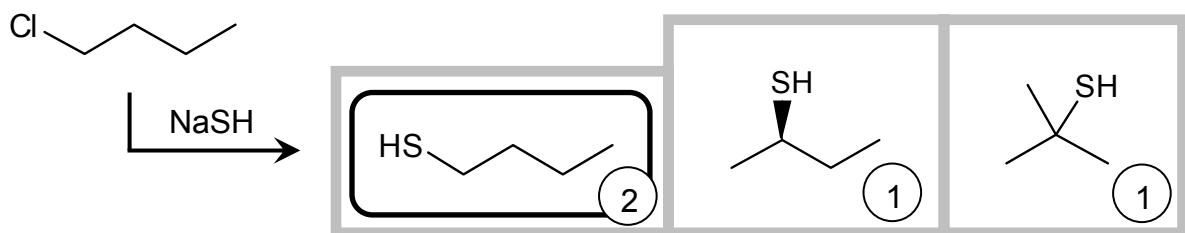
-2 points for each clearly trivial structure mistake.

4. (12 pts) For each reaction shown below, **circle all potential products**. Keep in mind that, for each case, you might circle one, multiple, or no molecules.

Rubric: 2 points for each box with a correctly circled product.  
1 point for each box with an incorrect product *not* circled.

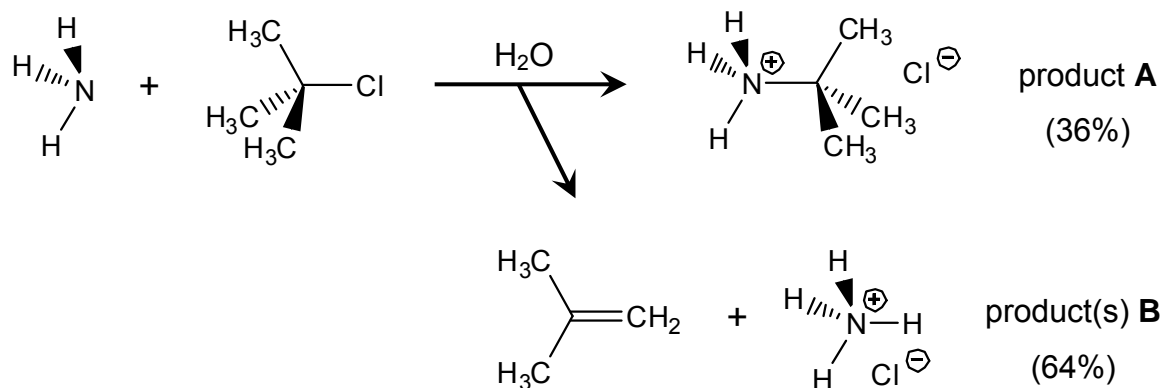


These reaction conditions correspond to a combination of  $S_N1$  and  $E1$  reactions through the cation shown. The top two are  $S_N1$  products, and the bottom two are  $E1$  products.

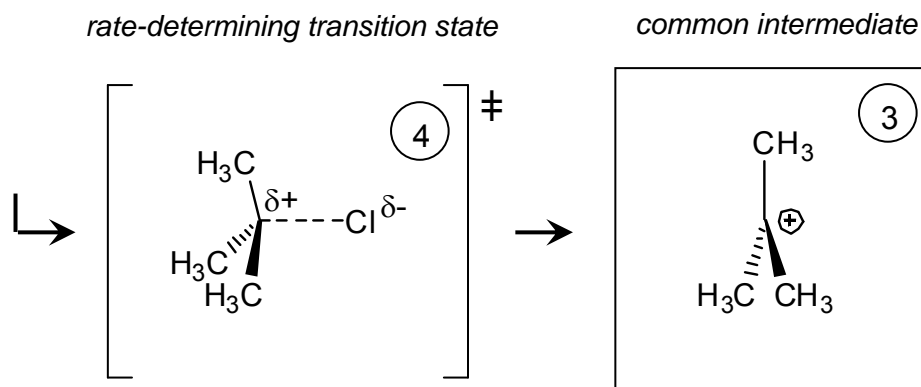


$\text{SH}^-$  is a strong nucleophile, and the leaving group is attached to a primary carbon, so the reaction will go exclusively  $S_N2$ . The other two products could result from rearrangement of an intermediate carbocation, but there won't be an intermediate carbocation at a primary site.

5. (23 pts) Ammonia reacts with *tert*-butylchloride to yield two sets of products:



(a) The two products are made from the same rate-determining transition state, and through the same reactive intermediate. What are the structures of those two states?



No need to draw these in 3D like I did.

Rubric for part (a):

4 points for transition state structure.

1 point partial for *S<sub>N</sub>2* or *E2* TS.

-1 point for each incorrect partial charge.

-1 point for incorrect partial bond.

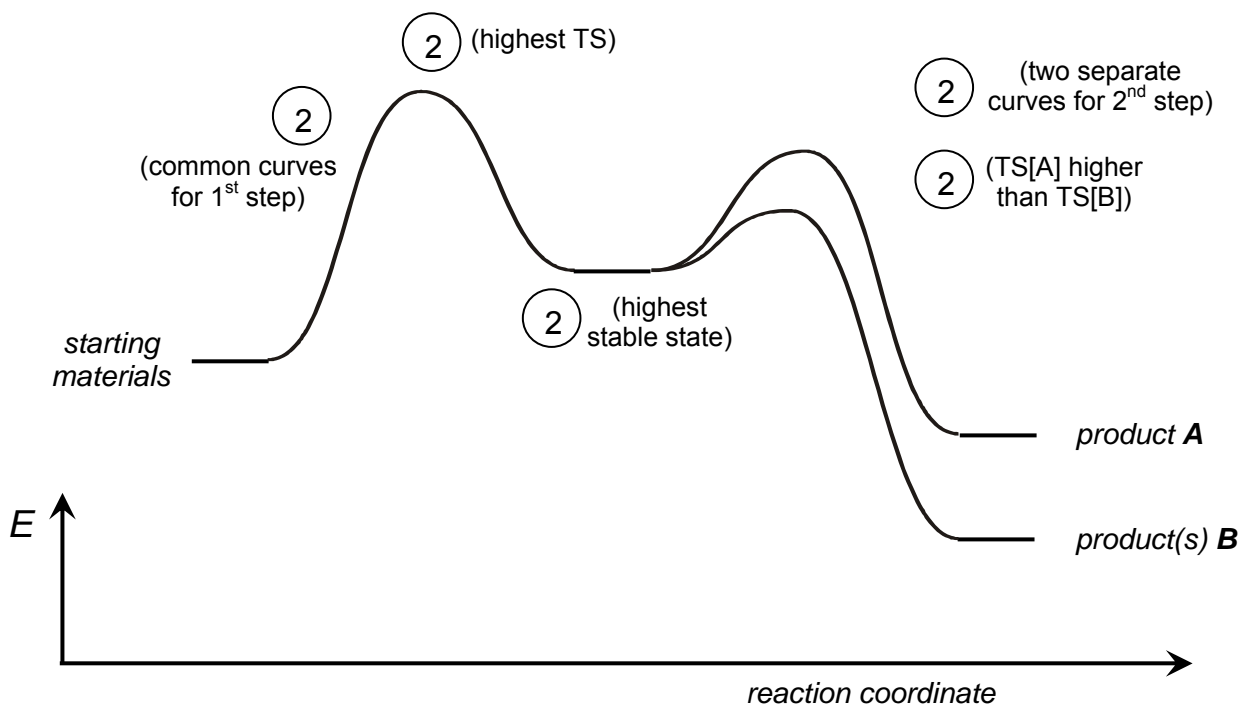
3 points for carbocation.

-1 point for each trivial error.



(b) On the diagram on the next page, **draw potential energy curves that describe the formation of each of your two products.** For each curve:

- Draw energy levels for all transition states and intermediates, and connect them with curves. You do not need to draw any chemical structures, just energies.
- Energy levels for the starting material and the two products are given.
- Wherever your two paths share common intermediates or transition states, you only need to draw one curve; draw two separate curves only where the paths diverge.

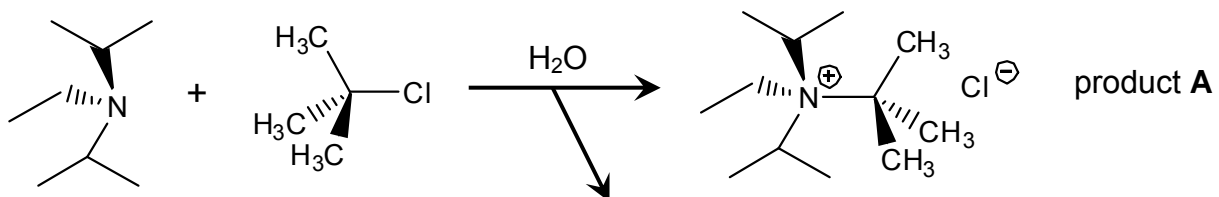


Rubric for part (b):

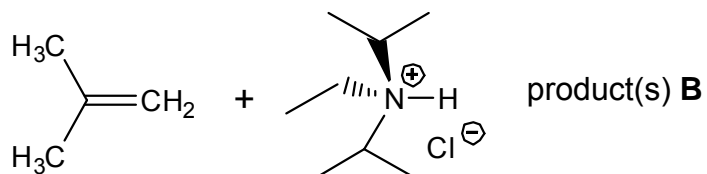
10 points total for potential energy diagram.

- 2 points partial for drawing a first step barrier in common for two curves.
- 2 points partial for putting intermediate higher in energy than starting materials.
- 2 points partial for having the first step have the higher activation energy (for making the first step rate-limiting).
- 2 points partial for drawing separate second steps with different activation energies.
- 2 points for making second barrier to product A higher than barrier to product B. (This is indicated by product ratio.)

How would the reaction change if ammonia was replaced with diisopropylethylamine (DIPEA)?



(c) Would the overall rate of reaction—the combined rate of making products **A** and **B**—change? Would the product ratio **A/B** change? (Circle one answer for each question.)



Using DIPEA would make the overall reaction

**FASTER**

**SLOWER**

proceed at the  
**SAME RATE**

3

Using DIPEA would make the product ratio **A/B**

**INCREASE**  
(favor **A** over **B**)

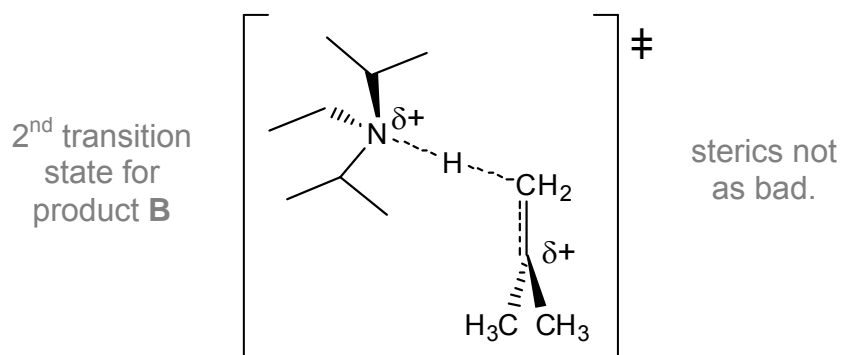
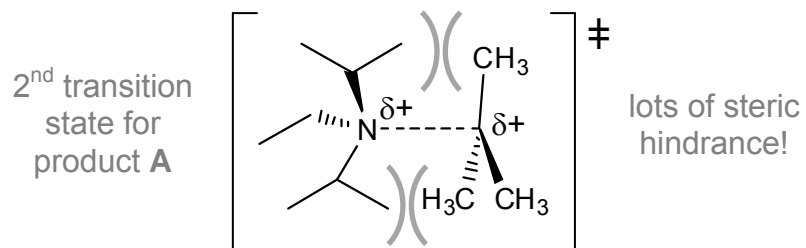
**DECREASE**  
(favor **B** over **A**)

**STAY THE SAME**

3

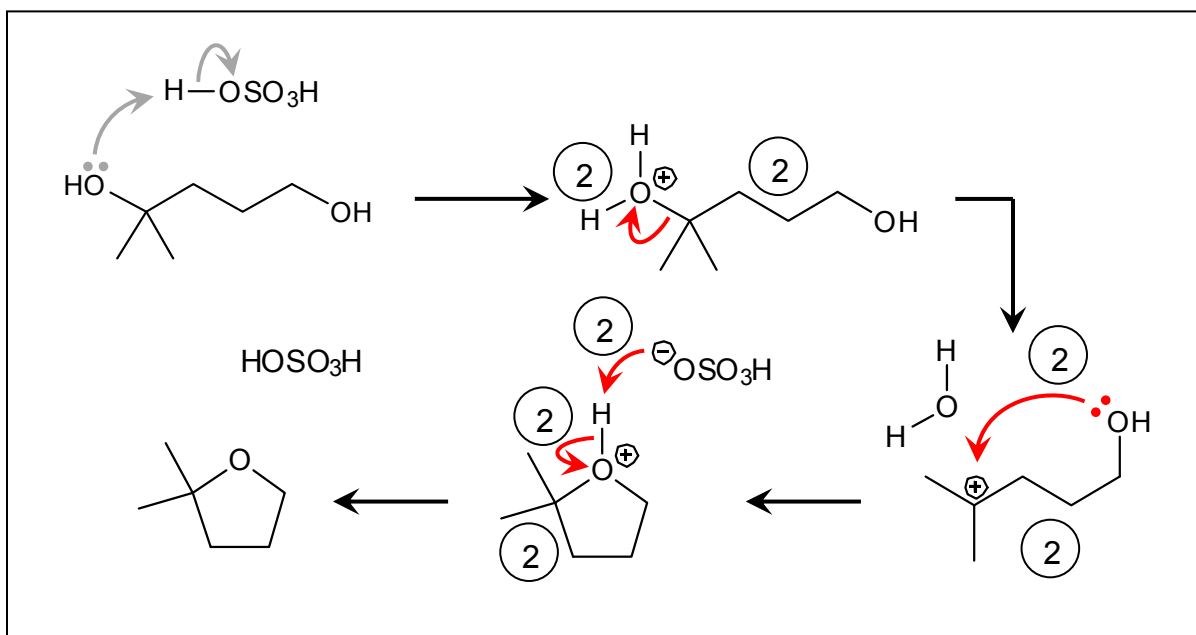
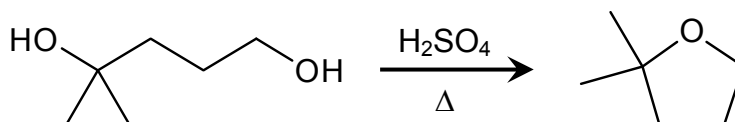
The two products represent competing  $S_N1$  and  $E1$  mechanisms, both of which proceed through a common carbocation intermediate and a common rate-determining transition state. The rate-determining transition state does not involve the nucleophile or base in either case, so the overall rate of the reaction would **not** be affected by changing  $NH_3$  to DIPEA. However, the product ratio could be affected, if the new nucleophile/base interacted with the second set of transition states differently.

We said in class that nucleophilic substitution ( $S_N$ ) reactions are generally more sensitive to steric interactions between nucleophile and electrophile than elimination ( $E$ ) reactions; a pendant H is usually easier to get to than a hindered  $S_N$  site.



Both of these transition states would be more sterically hindered than if  $\text{NH}_3$  were the nucleophile/base, but just between these two, the  $\text{S}_{\text{N}}1$  (product **A**) TS is much worse. This should reduce the amount of  $\text{S}_{\text{N}}1$  product relative to the amount of E1 product.

6. (14 pts) For the reaction shown below, draw a mechanism that explains how the product is generated from the starting material. In your answer, make sure that you:
- Draw each step of the mechanism separately;
  - Use “electron pushing” to show where the electrons in each step go;
  - Use only the molecules that you are given; do not invoke reactants or solvents that aren't in the problem.



Rubric:

Overall notes:

Overall, the minimum score for each step is zero; errors in a step cannot earn you negative points that count against another, correct step.

Things that have left for good (e.g.,  $H_2O$ ) and spectators (e.g.,  $HO_3SO^-$ ) may be omitted.

2 points for each curved arrow shown above in each step. Arrow must start at an electron pair, and end at nucleus where electrons will newly interact.

Out of these 2 points, 0 points for each use of a generic or incorrect acid/base.

For example, in the last step you could use  $HO_3SO^-$  or  $H_2O$  as a base, but you couldn't invoke  $^-OH$  or any other base you may have used in other problems.

2 points for each intermediate structure.

-1 point for each minor error in charge, valency, structure, base, etc.; if error propagates, points are taken off only for initial error.

*Maximum half-credit for combining separate steps.*

Special notes:

**Step 1:**

*2 points for drawing the correct intermediate.*

**Steps 3/4:**

*-2 points (so, 8 points out of 10 if everything else correct) for reversing order of steps—for deprotonating first to form alkoxide, then adding to cation. Alkoxide would never be formed in  $H_2SO_4$ .*

*You can use either  $HO_3SO^-$  or  $H_2O$  as a base—both are basic enough to deprotonate here.*