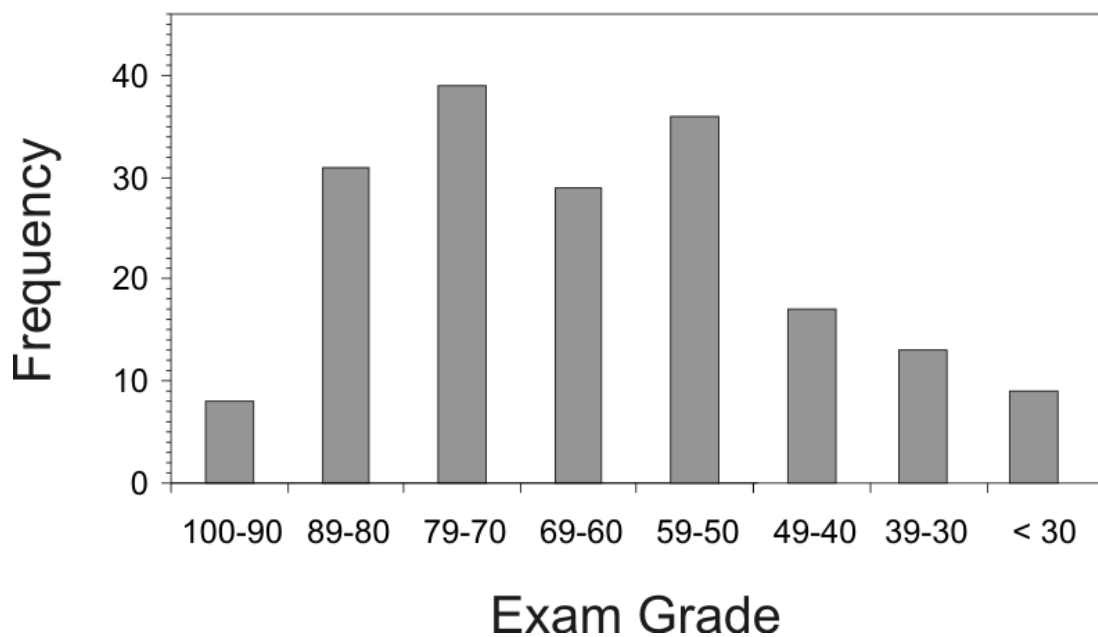


**Exam 2
Answer Key**

Exam 2 Mean: 63
Exam 2 Median: 65
Exam 2 St. Dev.: 18

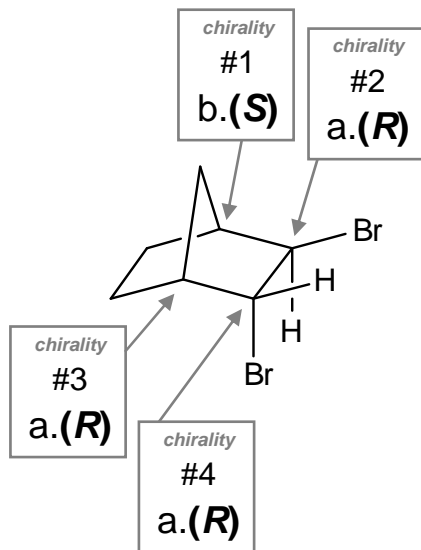


Multiple-Choice Problems

(2 pts each) For each of the molecules drawn below:

- For each atom marked “chirality”, indicate whether the atom would be labeled as (a) an (*R*)-chiral center, (b) an (*S*)-chiral center, or (c) not a chiral center, according to the Cahn-Ingold-Prelog classification system.
- Indicate whether the molecule would be chiral or achiral.

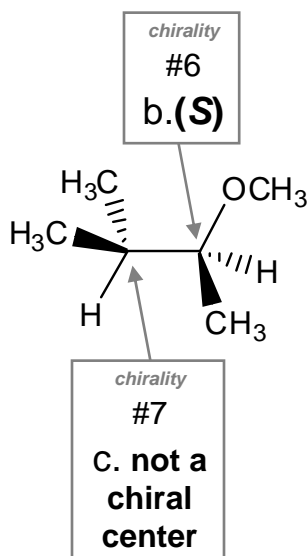
Mark each answer on the bubble sheet, with the problem number indicated inside each box.



5. Is this molecule

- a. chiral, or
b. achiral?

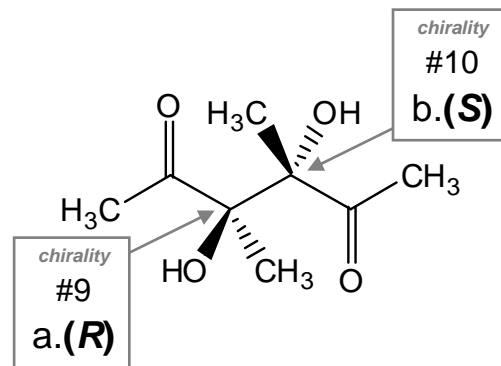
You could look at the mirror image and try to superimpose it, but this one was probably easier to answer by using *R* and *S* assignments. The molecule is (*R,R,R,S*), and so its mirror image would be (*S,S,S,R*)—by definition, a different molecule. So, because the molecule is not the same as its mirror image, it's chiral.



8. Is this molecule

- a. chiral, or
b. achiral?

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

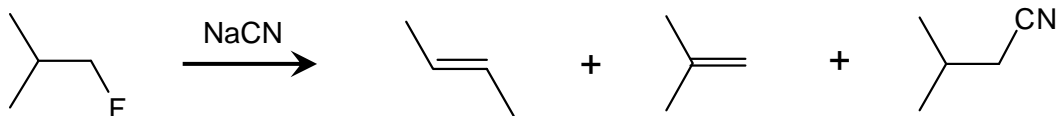


11. Is this molecule

- a. chiral, or
b. achiral?

This molecule is (*R,S*), so it may or may not be chiral. Because the molecule has opposite assignments at those two centers, and each center has the same things attached, the molecule is *meso*, and achiral.

(2 pts each) Each reaction below is drawn with multiple potential products. Of these products, which would you actually expect to observe? Keep in mind that, for each reaction, you might predict one, multiple, or none of the products shown.



Would you expect this product?

12. a. Yes, or

b. No?

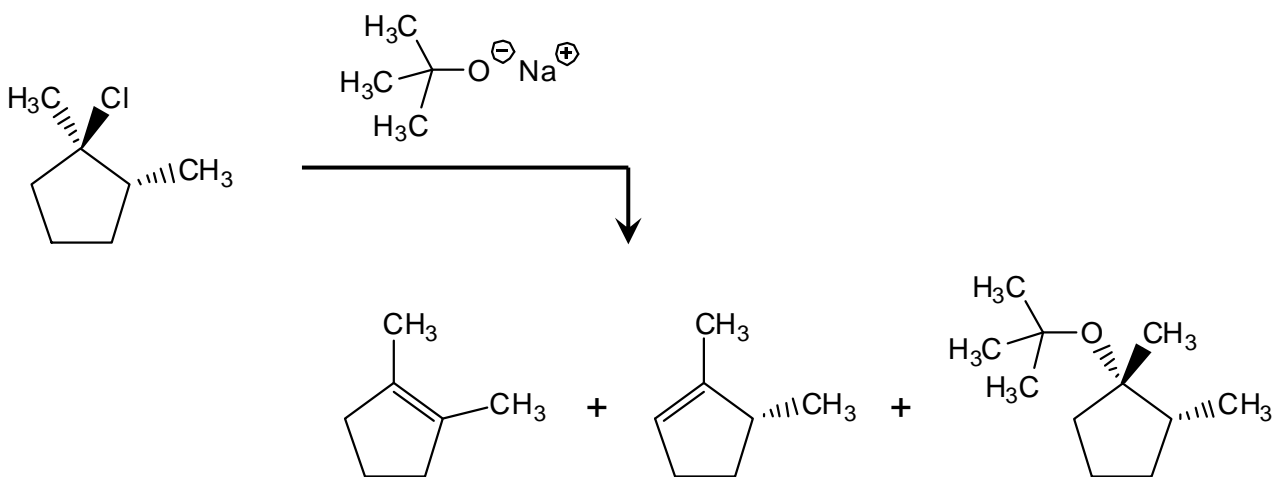
13. a. Yes, or

b. No?

14. a. Yes, or

b. No?

Fluoride (F⁻) is a terrible leaving group—it doesn't react by substitution or elimination. (This is the reason why 3M's perfluorinated chemicals, like PFOS, are so persistent in the environment. They do not degrade by the mechanisms that clear other functionalized molecules from wastewater.) None of the products would be formed.



Would you expect this product?

15. a. Yes, or

b. No?

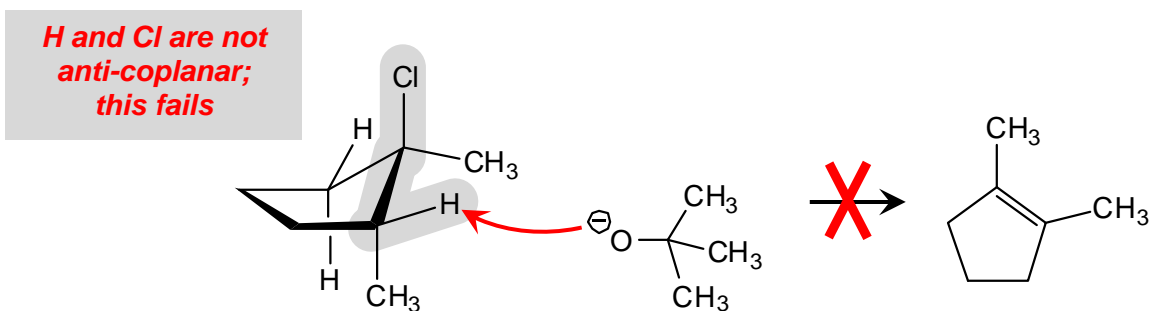
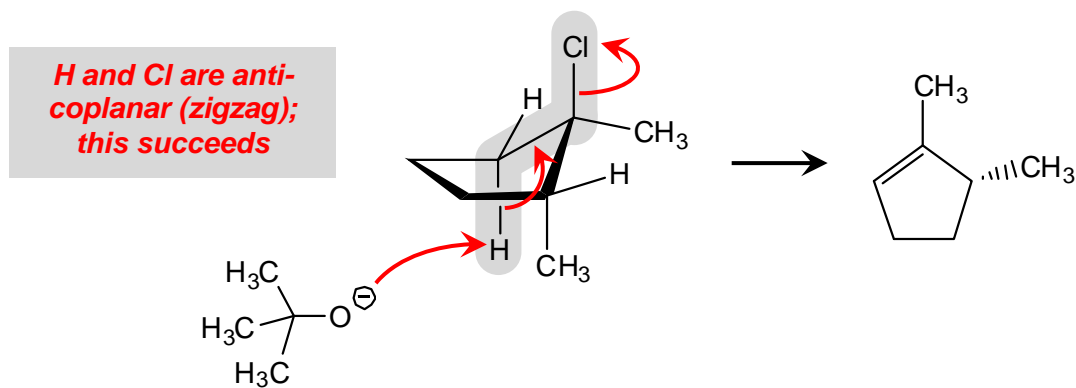
16. a. Yes, or

b. No?

17. a. Yes, or

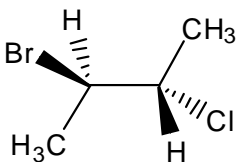
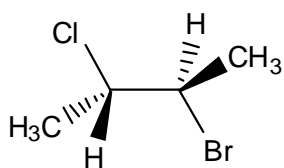
b. No?

tert-Butoxide [(CH₃)₃CO⁻] is a sterically hindered nucleophile, but a very strong base. It already strongly prefers E2 over S_N2, but here, the tertiary reaction center would make it impossible for S_N2 to occur, so the substitution product (#17) wouldn't be observed. In addition, product #15 would require that the base took a proton on the same side (*syn*) of the bond being changed as the leaving group, and we know that E2 elimination requires *anti*-coplanar arrangement of the proton and leaving group:



This means that only E2 product #16, and not E2 product #15, would be observed.

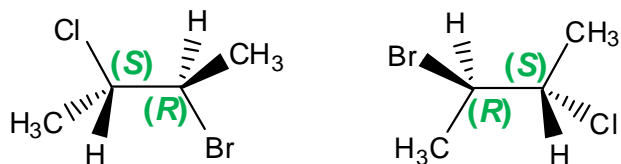
18. (3 pts) Are the two structures below



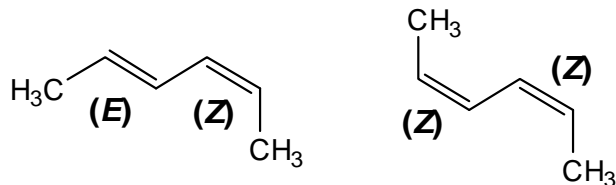
- a. enantiomers,
 b. diastereomers, or
 c. the same molecule?

In my opinion, the easiest way to do this problem was to use Cahn-Ingold-Prelog assignments to learn about the chirality of the Cl- and Br-containing centers, and compare them:

These two have the same (*R/S*) chirality assignments at the centers bearing the same substituents, so they're identical.



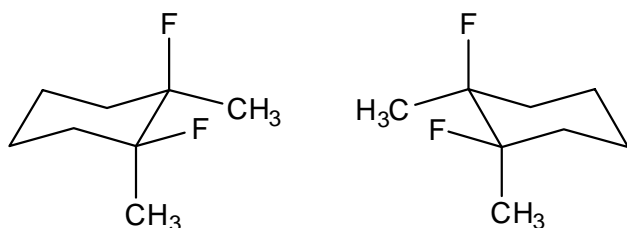
19. (3 pts) Are the two structures below



- a. enantiomers,
b. diastereomers, or
 c. the same molecule?

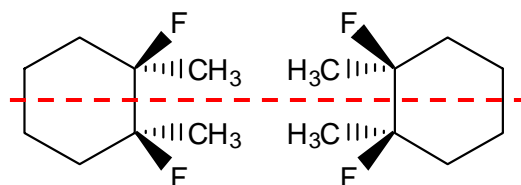
The alkenes on the left-hand side of each molecule have the same groups attached, but different spatial arrangements of those groups, so the two molecules are stereoisomers. The molecules are achiral (because they are flat, with a mirror plane of symmetry in the plane of the page), so they cannot be or have enantiomers. Two molecules that are stereoisomers, but not enantiomers, are by definition diastereomers.

20. (3 pts) Are the two structures below



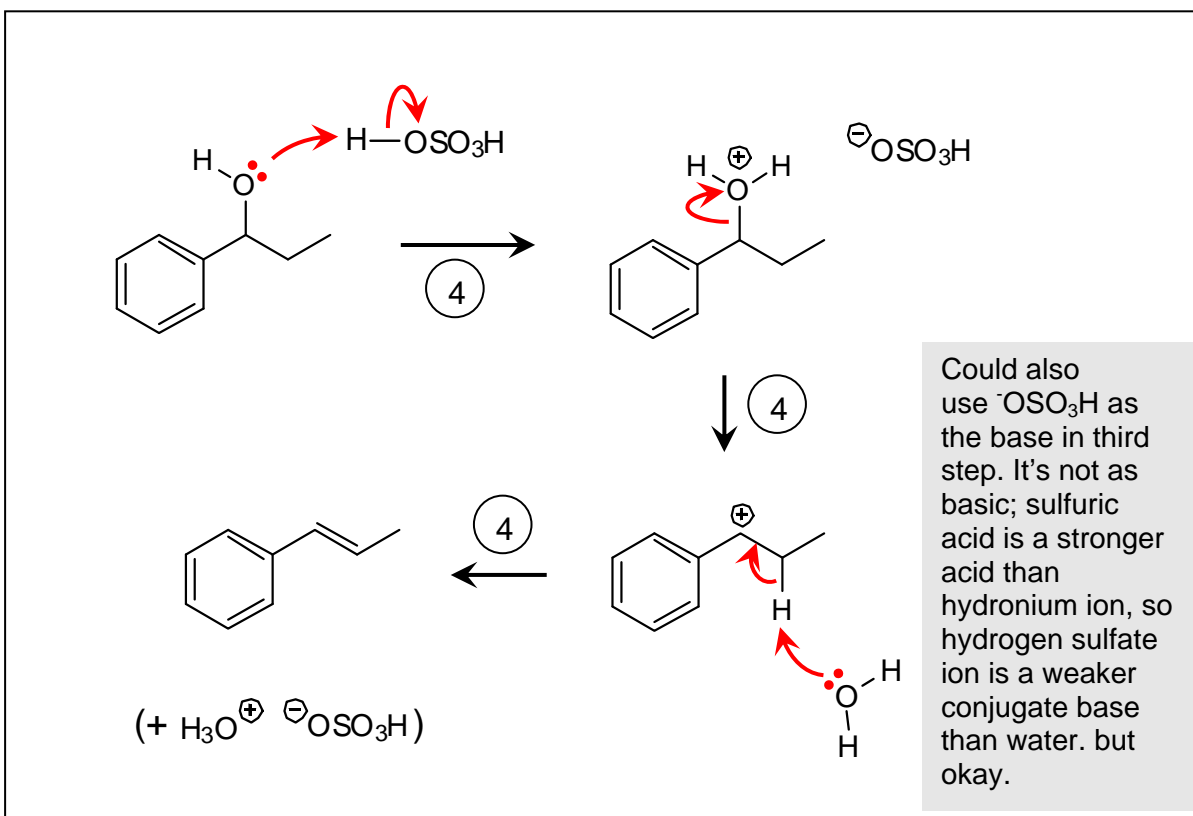
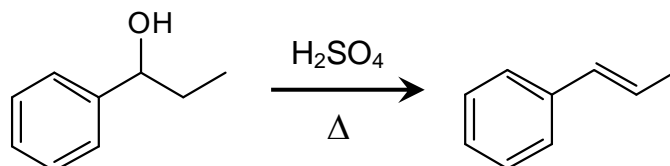
- a. enantiomers,
b. diastereomers, or
 c. the same molecule?

These structures look like mirror images--so does that mean they are enantiomers, or the same molecule? If we re-draw these molecules so that they are flat, we see that they are the same molecule (and achiral). "Flat" is admittedly not a very stable conformation for this molecule, which would much rather be a chair. But the rules of chirality say that if we can find any available conformation of the molecule that is achiral, the molecule must be achiral. The mirror image of an achiral molecule is the same molecule.



23. (12 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.



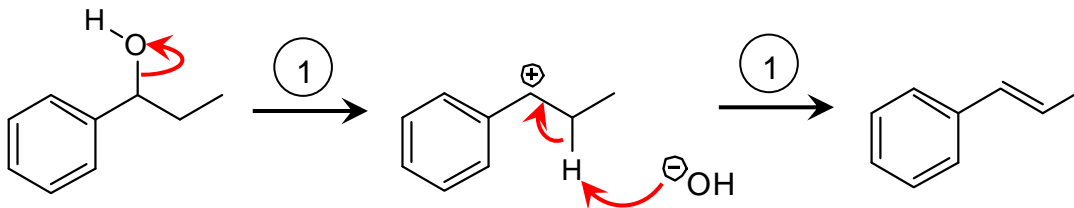
Rubric:

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.

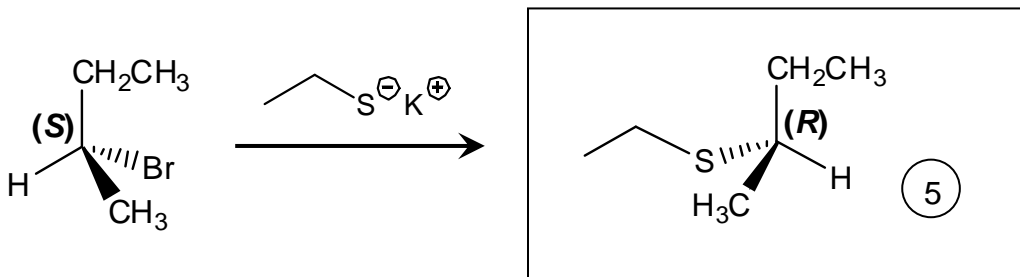
Things that have left for good (e.g., OSO_3H^- , H_3O^+) and spectators may be omitted.

- 2 points, for each arrow in each step, for errors in drawing arrows. Arrow must start at an electron pair, and end at nucleus or bond where electrons will newly interact. Can only lose points if you get them.
- 1 point for each minor error in charge, valency, structure, base, etc.; if error propagates, points are taken off only for initial error.
- 2 points for each step combined with another. (Say, initial leaving group leaving and proton transfer.) You lose the points on each step you combine; so two 4-point steps could be combined into a step that would be worth a maximum of 4 points total (out of 8).
- 2 points for each use of a generic or incorrect acid/base. For example, the amine is your only base.
- 3 points for each step in the wrong sequence. Correct sequence here was protonation \rightarrow leaving group departure \rightarrow deprotonation. If, however, you answered leaving group departure \rightarrow deprotonation, you would get a maximum of 2 points, as long as everything else was correct:



This would never happen. OH^- is a terrible leaving group, and would never exist in an acidic environment. Appropriate step here is to protonate first, then leave.

24. (15 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”.



EtS⁻ is a better nucleophile than base, so this reaction will go S_N2. (Secondary halides are fine for S_N2 as long as they don't have anything else wrong with them.) Inversion of stereochemistry gives the (R) product selectively.

Rubric:

5 points for correct structure.

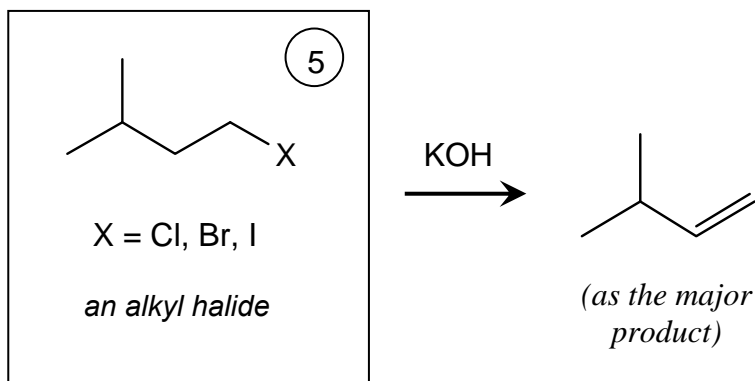
No need to put the “(R)” label on your answer. (We didn't grade it, even if you did put it in.)

4 points partial for “+ enantiomer” or drawing both stereoisomers (as if reaction was S_N1).

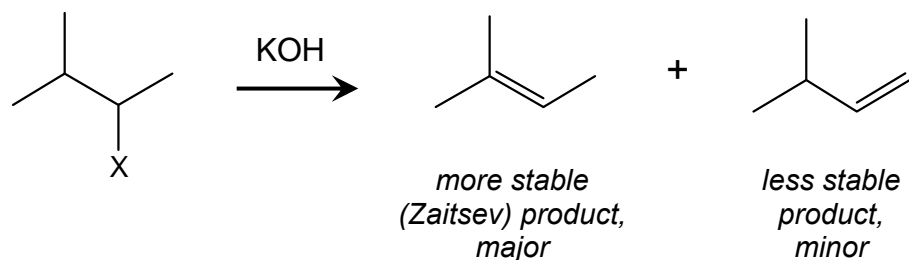
3 points partial for drawing (S) stereoisomer instead of (R), or for drawing no stereochemistry. You also got these three partial points for drawing no stereochemistry but labeling center “(R)”; instructions ask you to illustrate/draw the stereochemistry.

2 points partial for any butene (elimination product).

-2 points for each clearly trivial structure mistake. The answer that you intend needs to be clear for you to get these points.



E2 on any primary halide with the structure above will give this alkene as the major product. A secondary halide would give the product above as a minor product, and would yield the more substituted alkene as the major product:



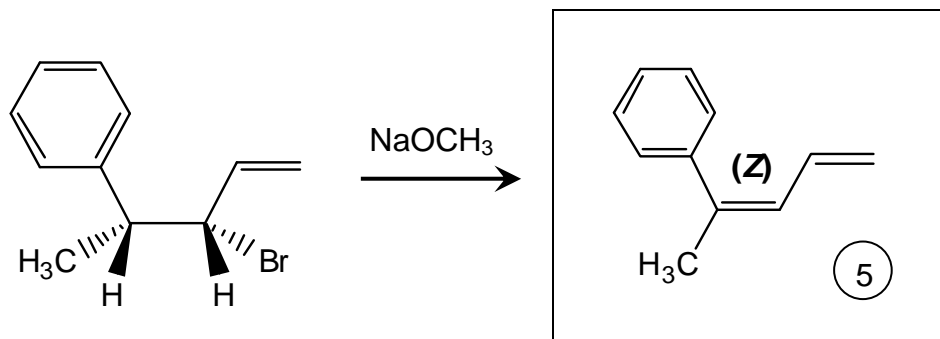
So this can't be the starting material.

Rubric:

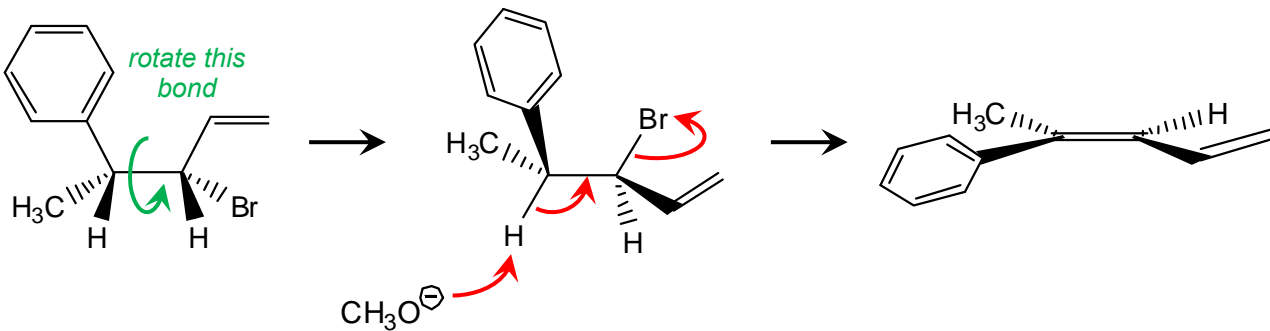
5 points for correct structure.

3 points partial for secondary halide.

-2 points for each clearly trivial structure mistake.



CH_3O^- is a better base than it is a nucleophile, so it will do E2. The starting material isn't drawn in a conformation that can react via E2; the H being taken and the leaving group have to be anti-coplanar. To get there, the central C-C bond has to rotate. My starting material is drawn in an eclipsed conformation, with neither the H nor the Br in the plane of the page, so I'll rotate both sides of the molecule to make things clear:



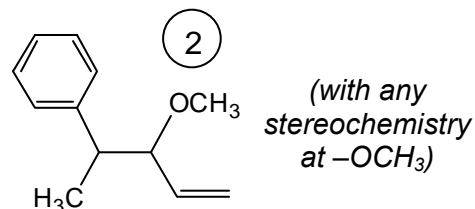
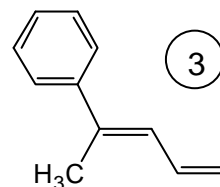
Rubric for this part:

5 points for correct structure.

3 points partial for bromine elimination product with wrong or unclear stereochemistry.

2 points partial for any bromine substitution product.

-2 points for each clearly trivial structure mistake.

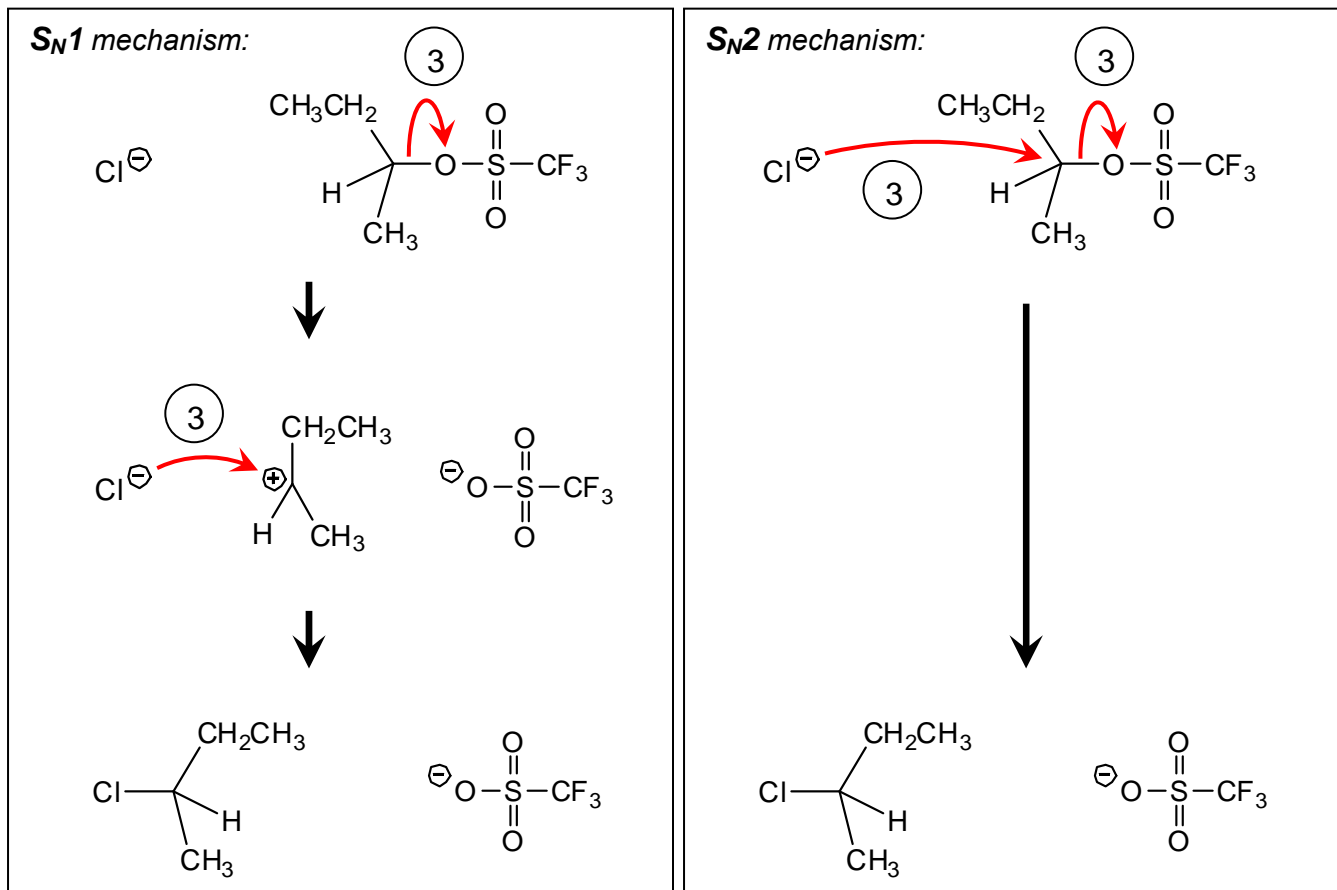


25. (24 pts)

a. In the boxes below, draw mechanisms that explain how the products above are generated from starting materials via S_N1 and S_N2 reactions. 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.

Feel free to add arrows, any necessary electron pairs, and intermediates directly to my drawings. Ignore stereochemistry for this part of the problem.



Rubric for (a): (12 points total for this part.)

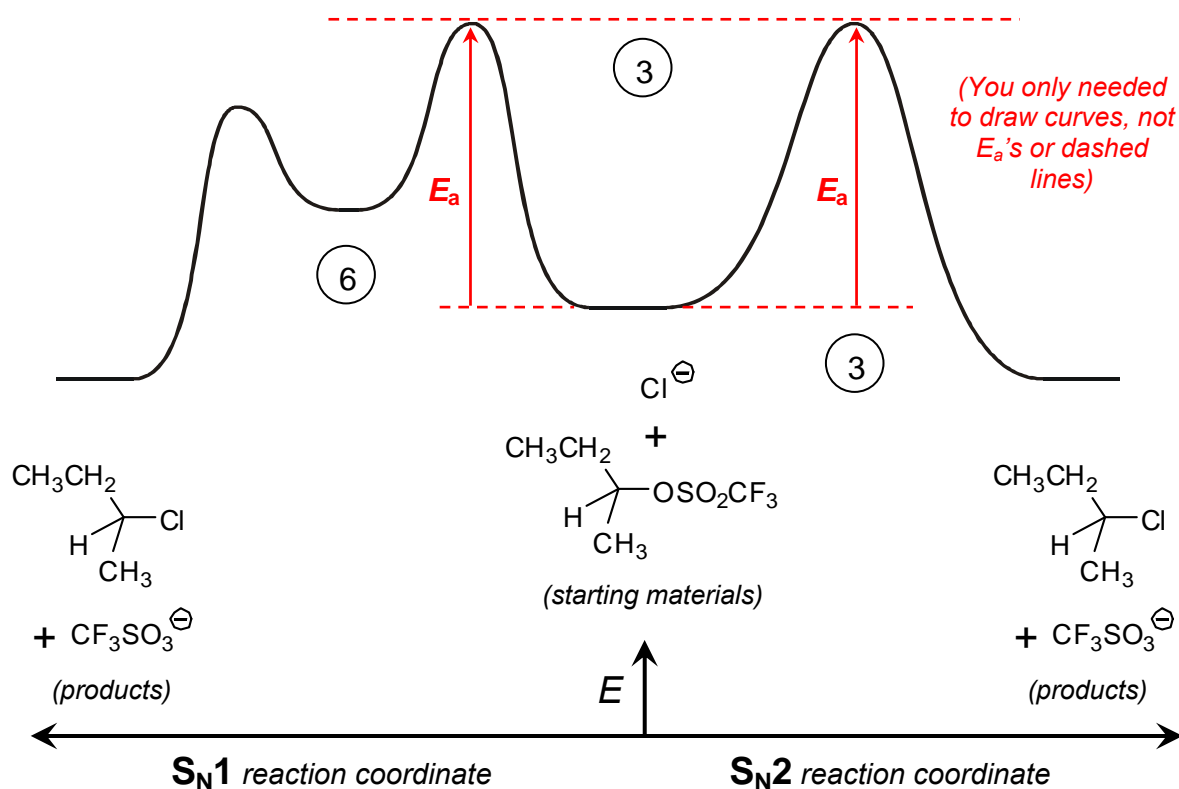
6 points for each mechanism; we broke this down to 3 points each arrow.

No partial credit for errors in drawing arrows. Arrow must start at an electron pair/negative charge, and end at nucleus or bond where electrons will newly interact.

No partial credit for incorrect mechanism. S_N1 must be stepwise, and S_N2 must be concerted.

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

- b. On the diagram below, draw potential energy curves for these two mechanisms. (I have already drawn the energies of starting materials and products; you need to connect them with curves. You do *not* need to draw transition-state structures.) Make sure your curves illustrate the relative energies of the rate-determining transition states for the two mechanisms.



Rubric for (b): (12 points total for this part.)

6 points for drawing S_N1 curve.

2 points for drawing as two steps.

2 point for drawing second transition state lower than first.

2 point for drawing intermediate higher in energy than starting material.

3 points for drawing S_N2 curve as one step.

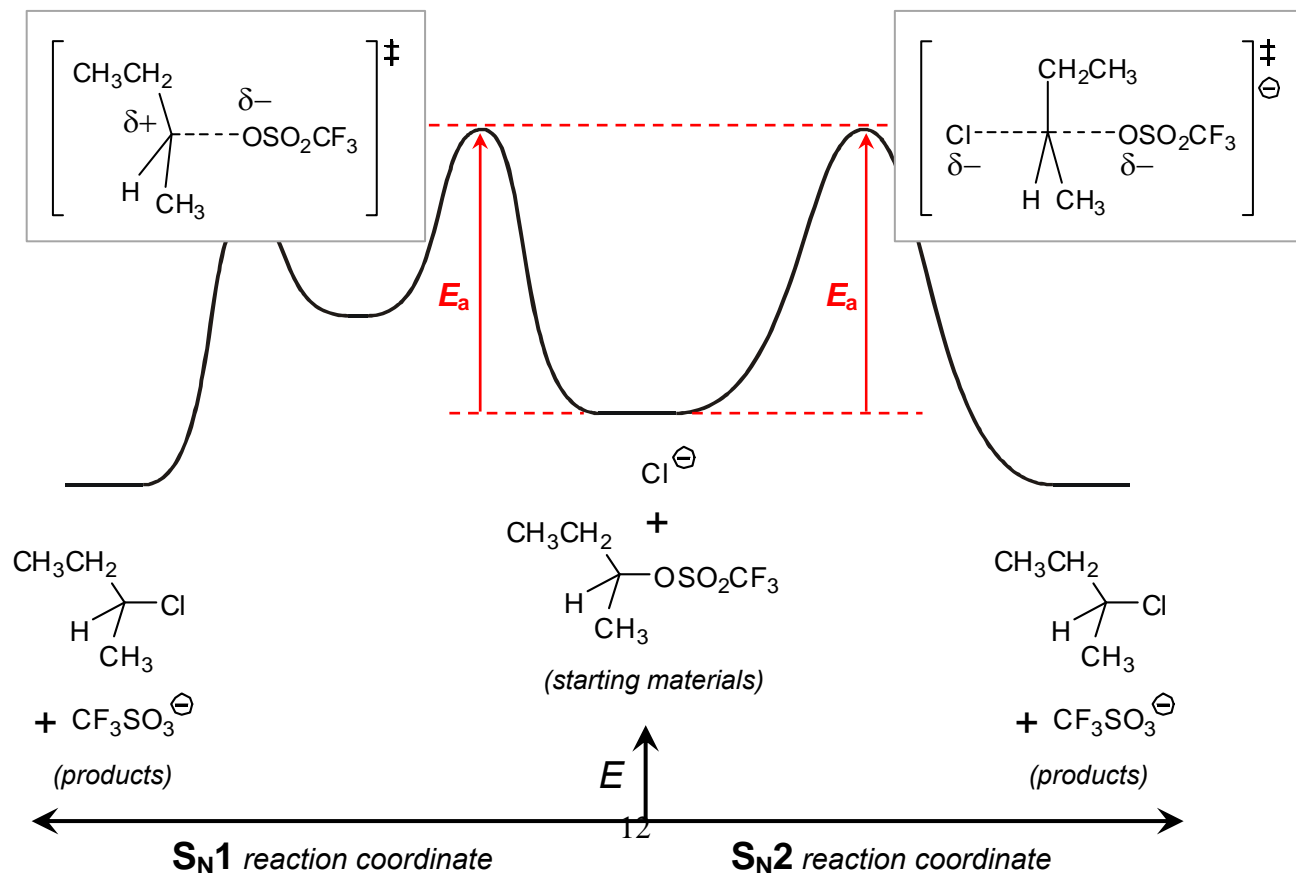
3 points for making rate-determining (highest-energy) transition states of the two reactions the same height.

21. (3 pts) Once the reaction above is complete, and all of the starting material has been converted to products, the product mixture would
- rotate polarized light counter-clockwise;
 - rotate polarized light clockwise;
 - not rotate polarized light.

The S_N1 mechanism will produce equal amounts of the (*R*) and (*S*) stereoisomers, but the S_N2 mechanism will produce only the (*R*) stereoisomer (with inversion of the original *S* stereochemistry). If the rates of S_N1 and S_N2 are equal, the combination of these two mechanisms will produce 75% (*R*), 25% (*S*). Because that mixture will rotate plane-polarized light more counterclockwise (from the *R* fraction) than clockwise (from the *S* fraction), overall the product mixture will rotate light counterclockwise.

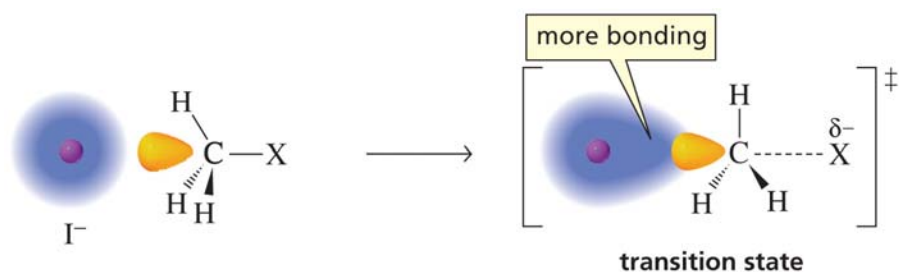
22. (3 pts) What would happen if iodide (I^-) were used as the nucleophile instead of chloride? How would the stereoselectivity of the total reaction—that is, the preference for one product enantiomer over the other—change?
- The stereoselectivity would decrease.
 - The stereoselectivity would increase.
 - The stereoselectivity wouldn't change.

To answer this, we've got to go back to the potential energy diagram and think about the rate-determining transition states.



The S_N1 transition state doesn't even involve Cl^- , so replacing Cl^- with I^- would have no effect on the energy of the transition state or on the overall activation energy for the S_N1 reaction. $E_a(S_N1)$ would be the same.

The S_N2 transition state does involve Cl^- . We said in class that I^- was the best nucleophile of the halides, because the polarizability of the electron cloud made it easier for the electrons to "reach" the electrophile center in the transition state.



This effect selectively stabilizes the S_N2 transition state, makes the activation energy for this reaction smaller, and makes the S_N2 reaction go faster.

Of the two mechanisms, S_N2 is stereospecific and S_N1 is not. The faster the S_N2 reaction goes (due to I^-), the greater a fraction of (*R*) S_N2 product there will be, and the more stereoselective the reaction will be.