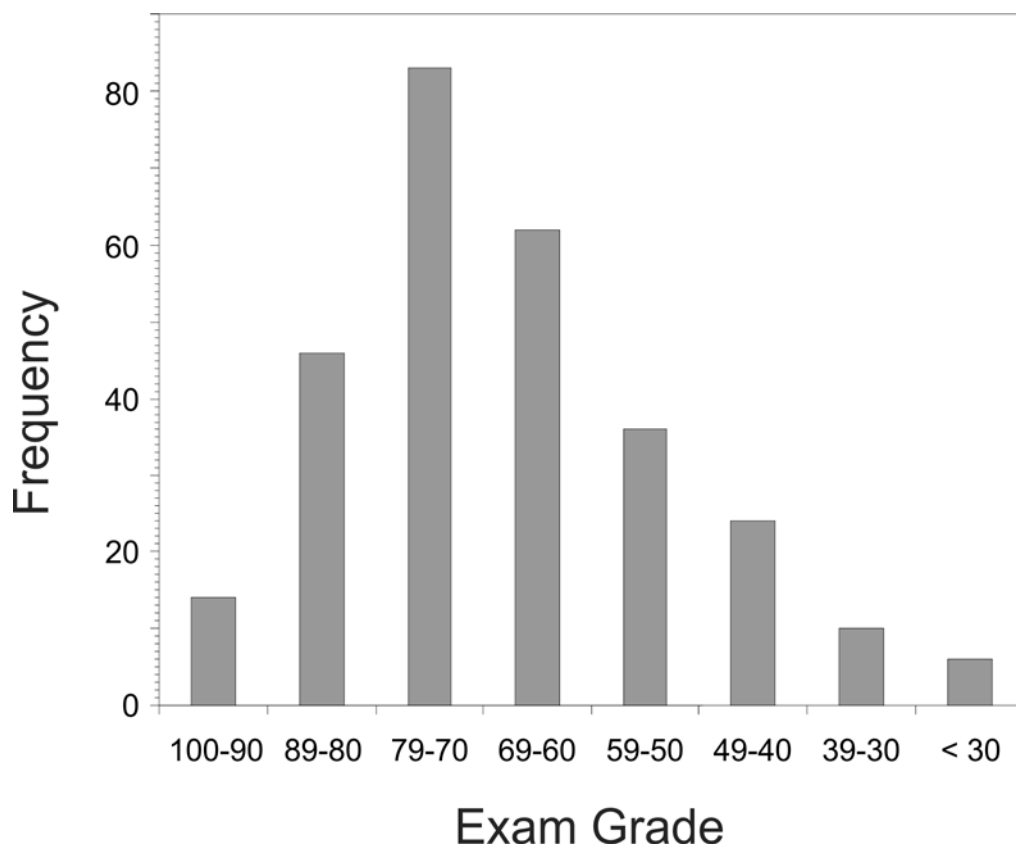
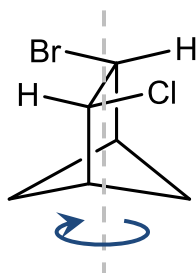
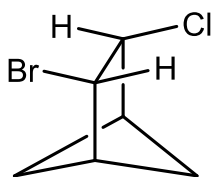


**Exam 2
Answer Key**

Exam 2 Mean: 67
Exam 2 Median: 69
Exam 2 St. Dev.: 15



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

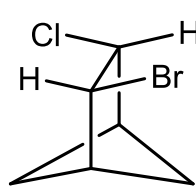
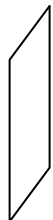
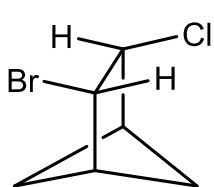
4

or

DIASTEREOMERS

or

SAME MOLECULE



rotate
180°

ENANTIOMERS

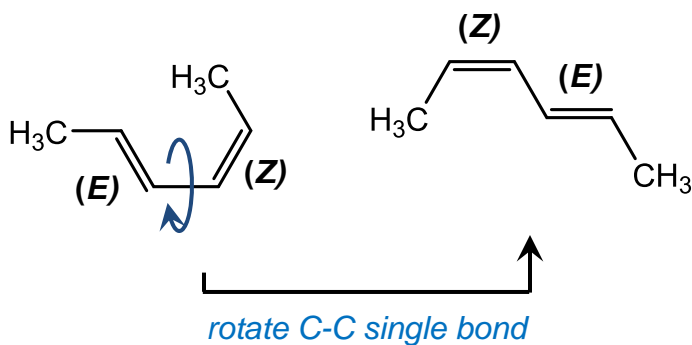
or

DIASTEREOMERS

or

SAME MOLECULE

4



ENANTIOMERS

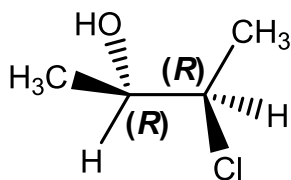
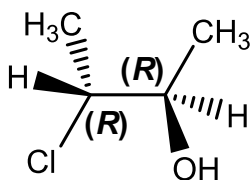
or

DIASTEREOMERS

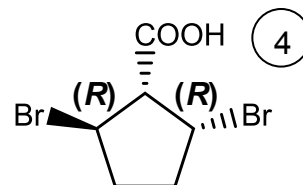
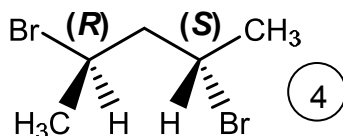
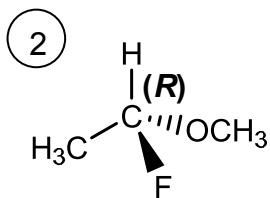
or

SAME MOLECULE

4



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.



CHIRAL (3)

or

ACHIRAL ?

CHIRAL

or

ACHIRAL (3) ?

CHIRAL (3)

or

ACHIRAL ?

Rubric:

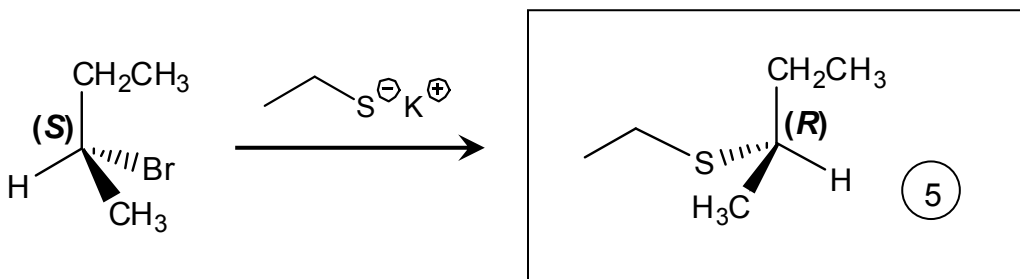
2 points for each labeled stereocenter.

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".



EtS^- is a better nucleophile than base, so this reaction will go $\text{S}_{\text{N}}2$. (Secondary halides are fine for $\text{S}_{\text{N}}2$ 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.

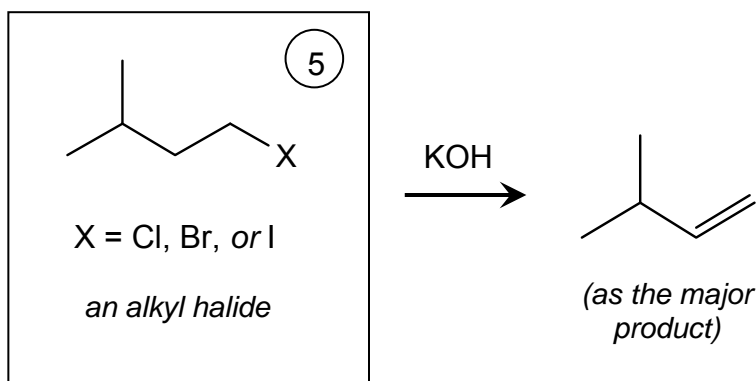
No need to put the "(R)" label on your answer. (We didn't grade it, even if you did put it in.) You can draw your correct answer in any orientation, as long as stereochemistry is correct.

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

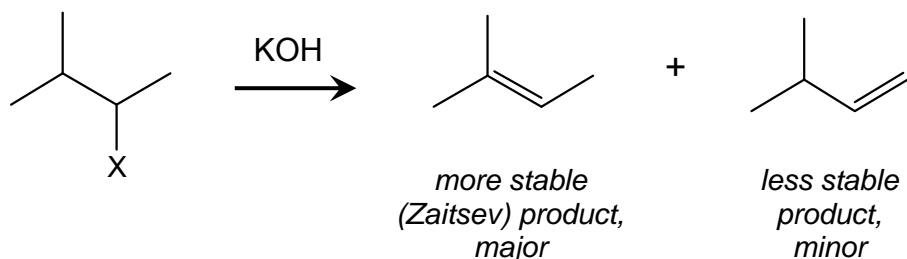
3 points partial for drawing (S) stereoisomer instead of (R), or for drawing no stereochemistry. You also got these three partial points for drawing no stereochemistry but labeling center "(R)"; instructions ask you to illustrate/draw the stereochemistry.

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.

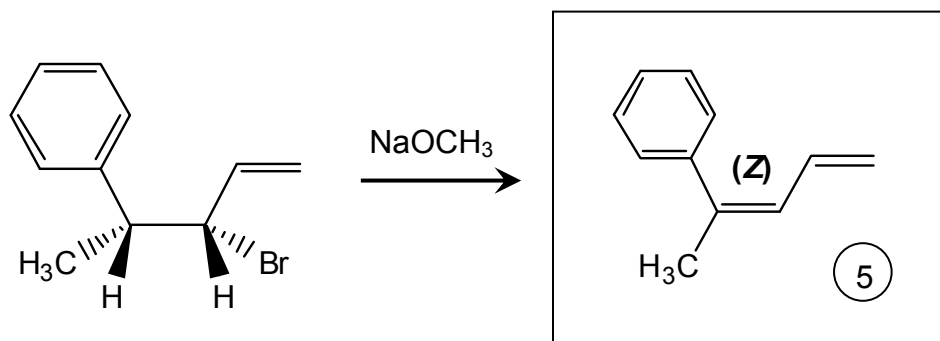
Rubric:

5 points for correct structure.

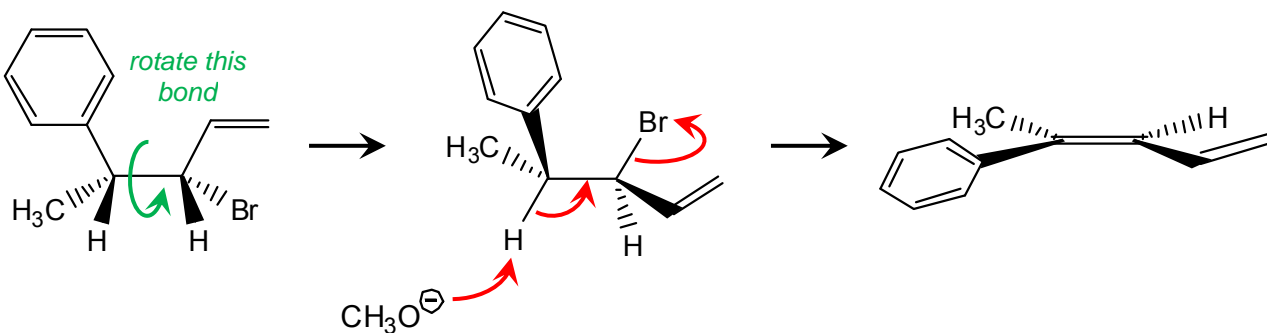
For full credit, the answer must have an "X" halide that isn't F. 3 points partial for just "X" (which could be F), or X = F.

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:



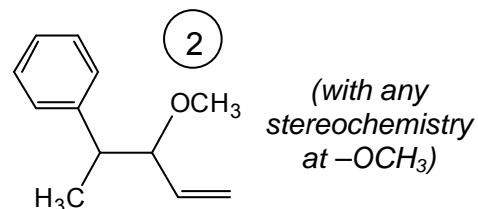
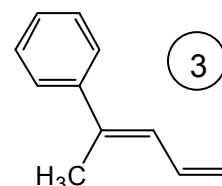
Rubric for this part:

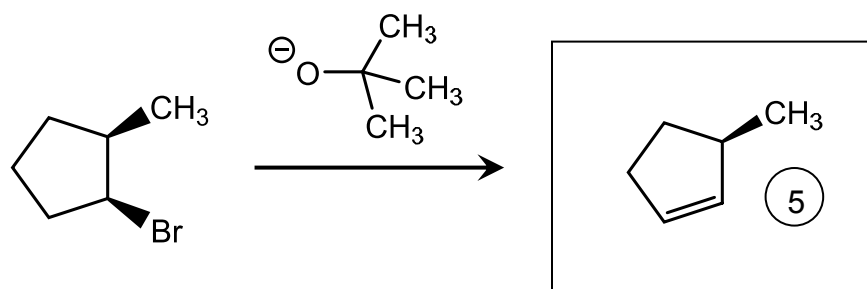
5 points for correct structure.

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.





Elimination reactions normally follow Zaitsev's rule—they generally produce the most substituted alkene. However, big bulky bases like *tert*-butoxide have trouble approaching a proton at the most substituted carbon, and so they generate the less substituted alkene product instead.

Rubric:

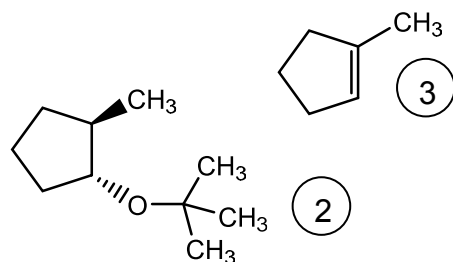
5 points for correct structure.

3 points partial for more substituted alkene.

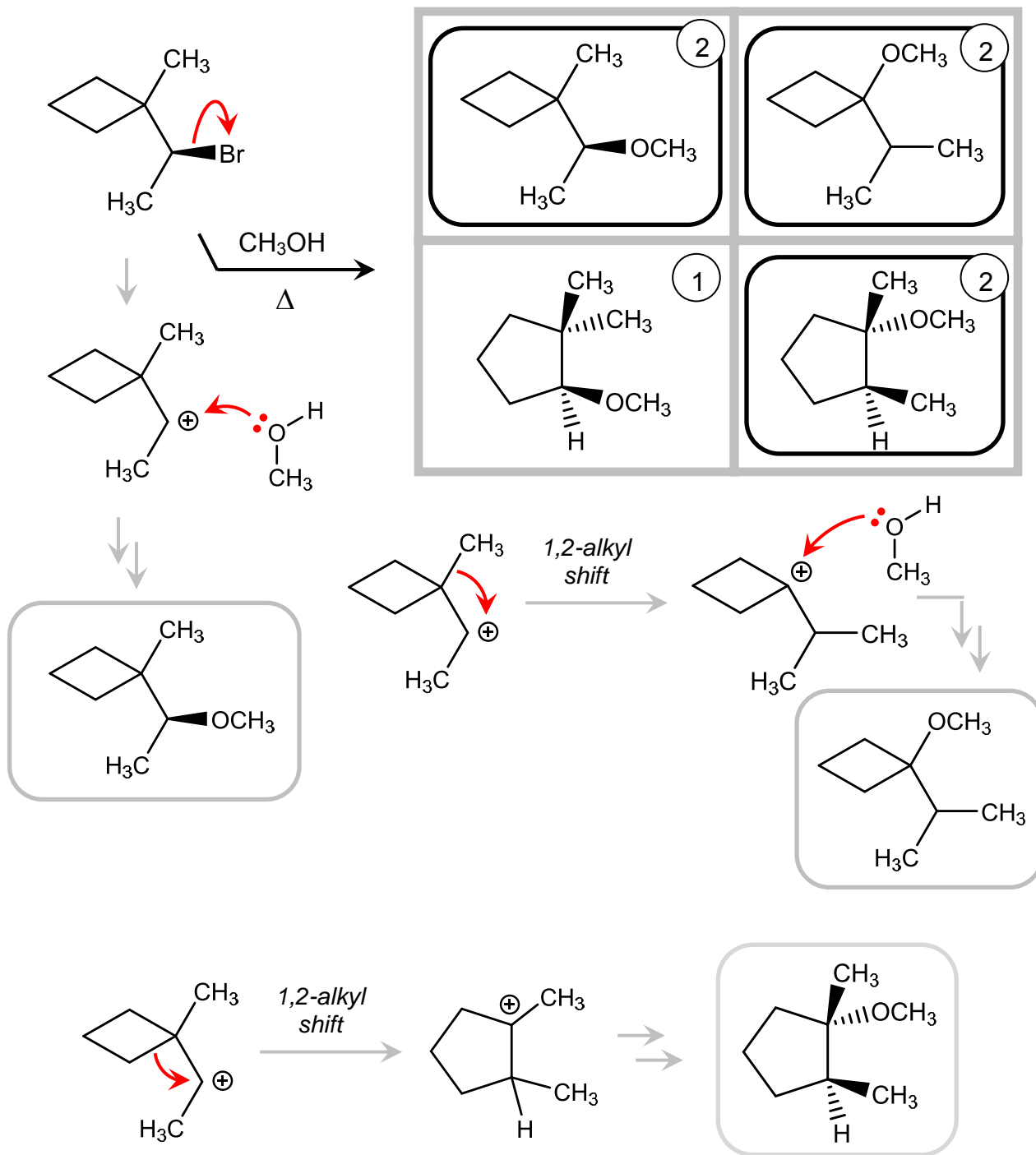
2 points partial for S_N2 product.

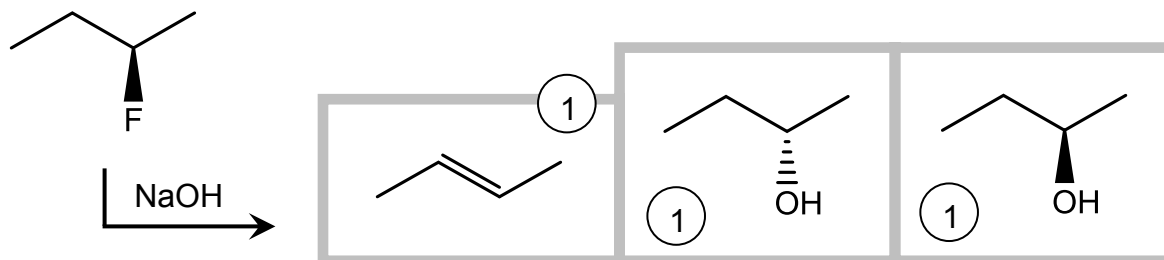
-1 point for writing "+ enantiomer"—starting material stereocenter is not affected by reaction.

-2 points for each clearly trivial structure mistake.



4. (10 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.

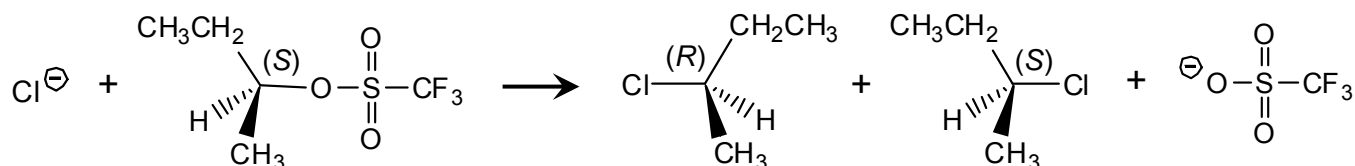




NONE CIRCLED.

Fluoride is a terrible leaving group—so terrible, as I said in lecture, that fluorinated molecules have very long lifetimes in the environment. None of these products would be observed.

5. (24 pts) The triflate group (CF_3SO_3^-) is such a good leaving group that alkyl triflates will undergo nucleophilic substitution reactions even with poor nucleophiles, such as chloride ions.



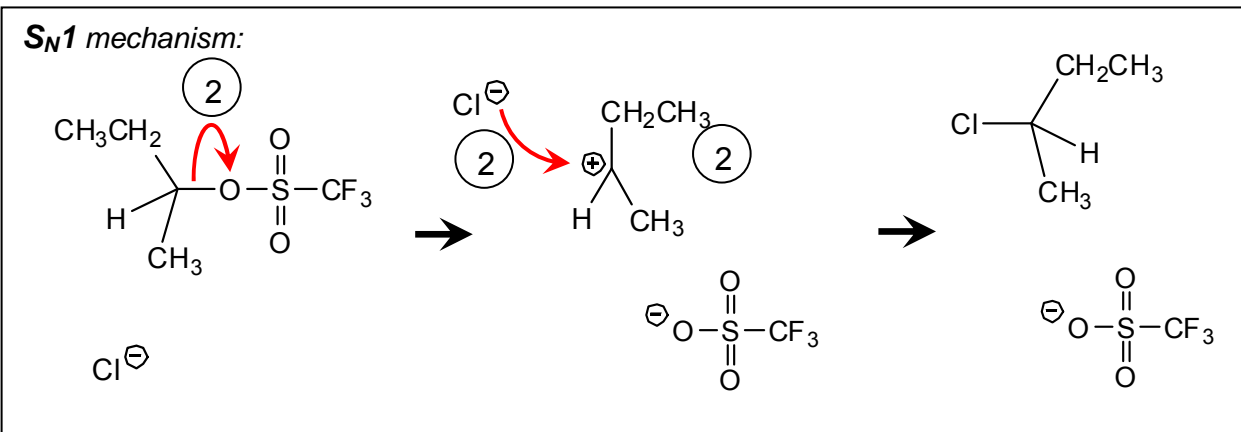
For the reaction of the triflate shown above, both $\text{S}_{\text{N}}1$ and $\text{S}_{\text{N}}2$ mechanisms occur, and some of each product enantiomer would be generated. We'll assume that the rates of $\text{S}_{\text{N}}1$ and $\text{S}_{\text{N}}2$ reactions are exactly equal.

$[\alpha] = -23^\circ$
(rotates polarized light
counterclockwise)

$[\alpha] = +23^\circ$
(rotates polarized
light **clockwise**)

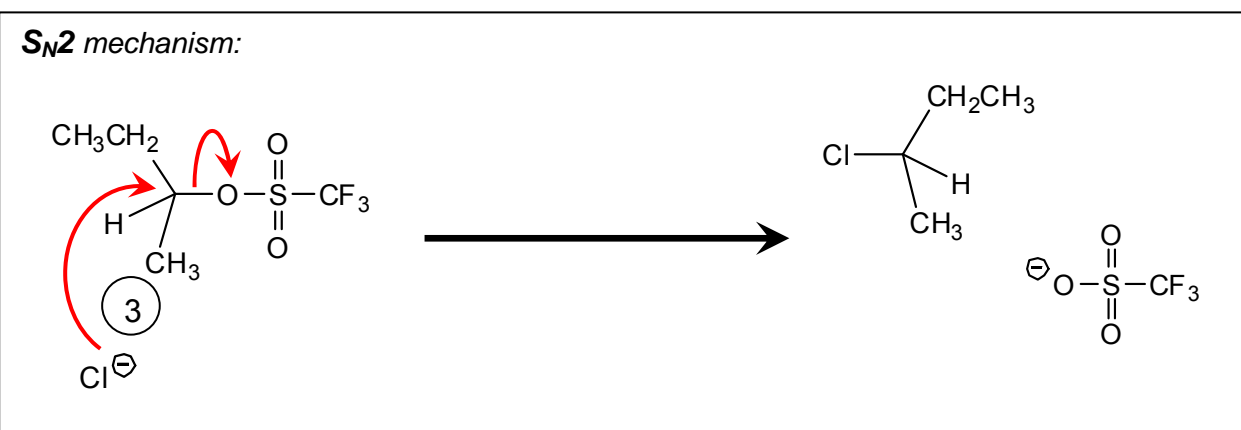
- a. In the boxes below, draw mechanisms that explain how the products above are generated from starting materials via $\text{S}_{\text{N}}1$ and $\text{S}_{\text{N}}2$ reactions. In your answer, make sure that you:
- Draw each step of the mechanism separately;
 - Use “electron pushing” to show where 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 this box:

2 points for each electron-pushing arrow step.
2 points for cation intermediate.

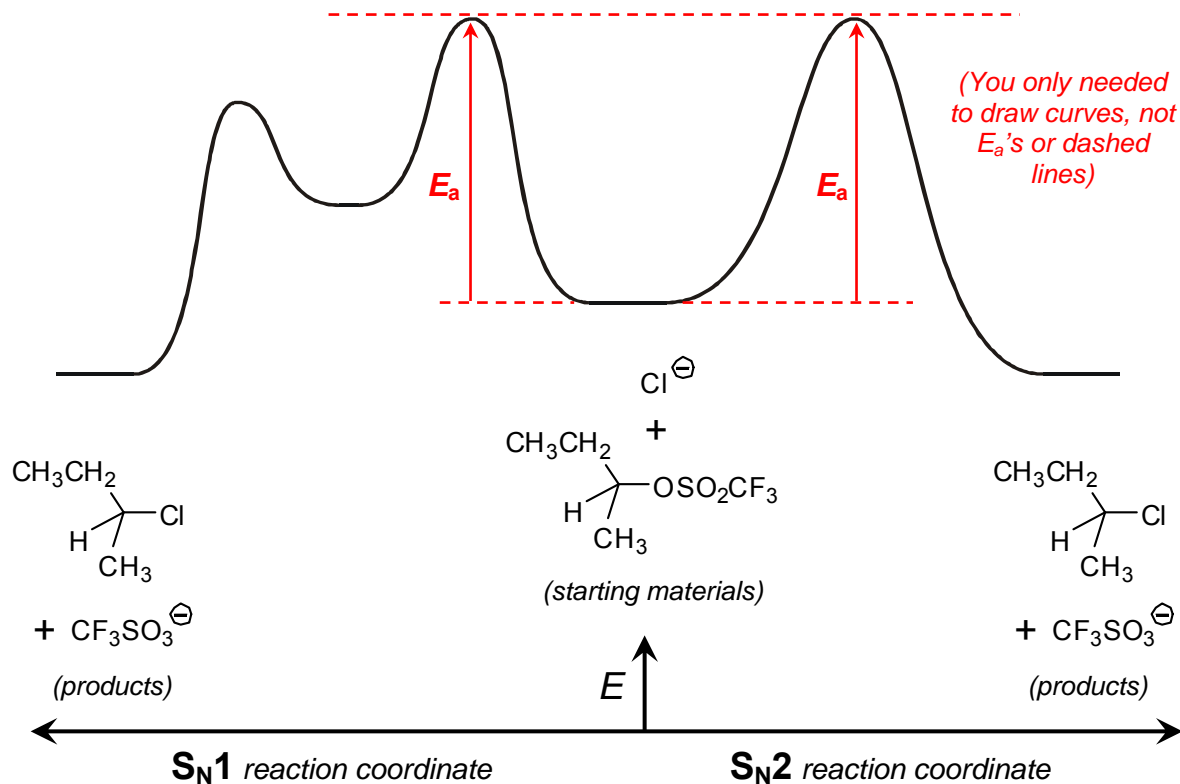


Rubric for this box:

3 points for this electron-pushing arrow step.

-2 points for error (including omission) in drawing one of the two arrows. Each arrow must start at an electron pair, and end at the nucleus or bond where electrons will newly interact.

- 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): (9 points total for this diagram.)

5 points for drawing $\text{S}_{\text{N}}1$ curve.

2 points for drawing as two steps.

2 point for drawing second transition state lower than first.

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

2 points for drawing $\text{S}_{\text{N}}2$ curve as one step.

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

- c. Once the reaction is complete, and all the starting material has been converted to products, would the product mixture rotate plane-polarized light? If so, in which direction? (Circle one answer on the next page.)

The product mixture rotates polarized light
CLOCKWISE

3
The product mixture rotates polarized light
COUNTERCLOCKWISE

The product mixture **DOES NOT ROTATE** polarized light

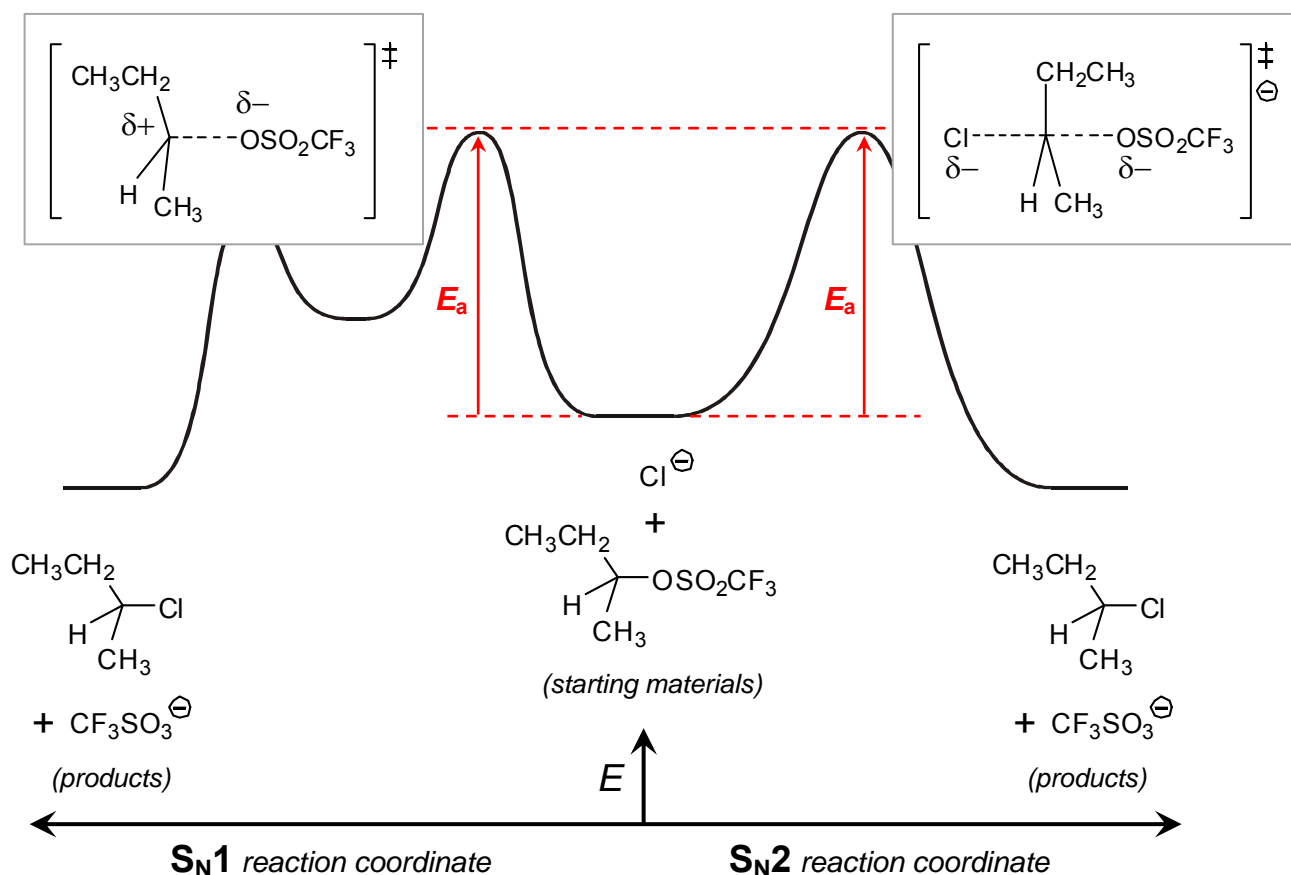
The $\text{S}_{\text{N}}1$ mechanism will produce equal amounts of the (*R*) and (*S*) stereoisomers, but the $\text{S}_{\text{N}}2$ mechanism will produce only the (*R*) stereoisomer

(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.

- d. What would happen if iodide (I^-) were used as the nucleophile instead of chloride? Would the stereoselectivity of the total reaction—that is, the preference for one product enantiomer over the other,

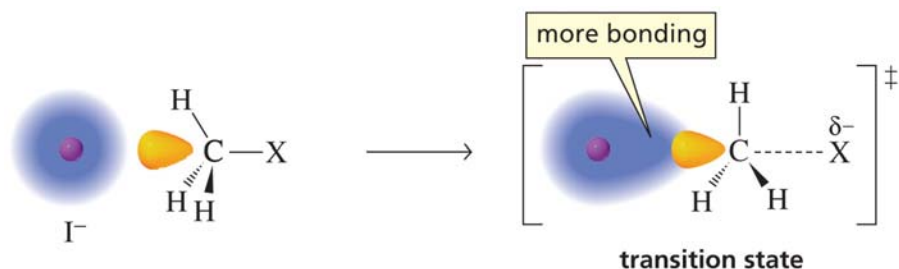
INCREASE ³, **DECREASE** , or **STAY THE SAME** ?

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.

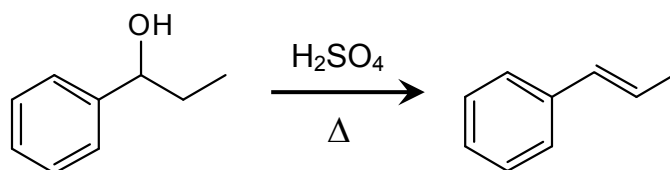


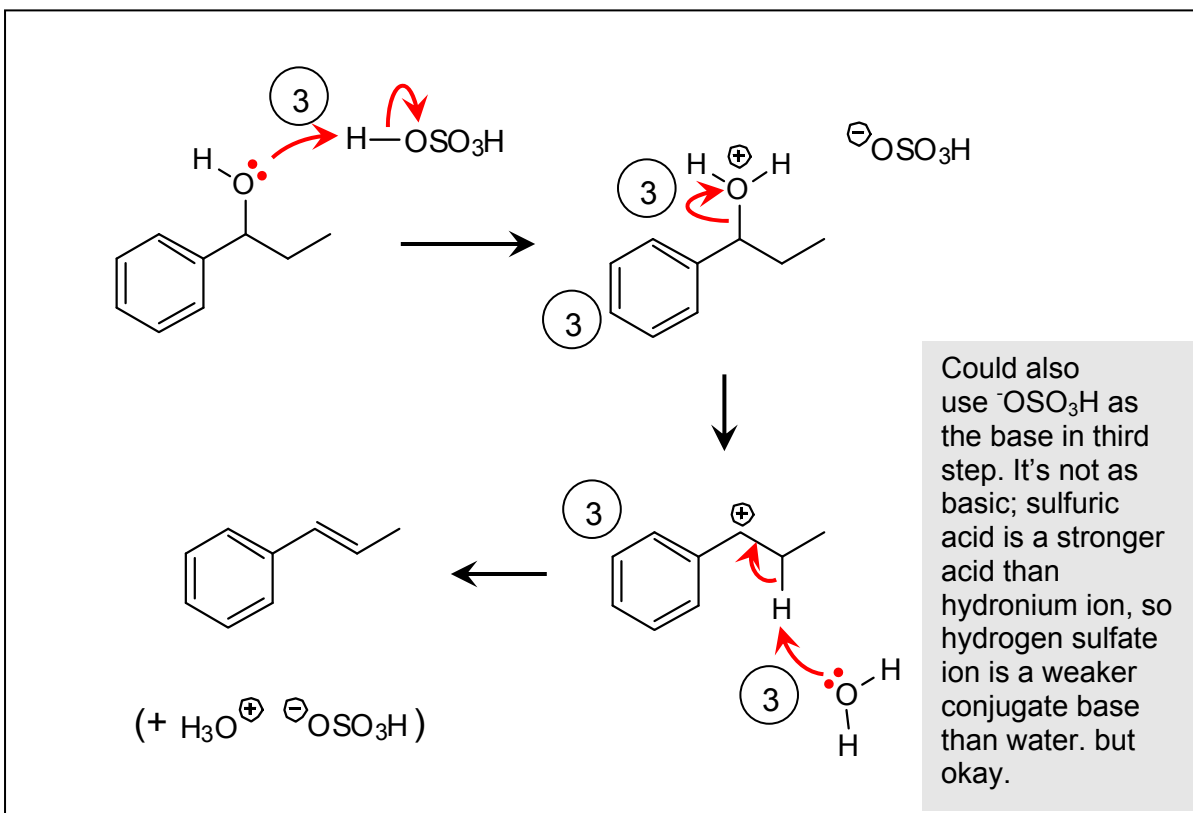
This effect selectively stabilizes the S_N2 transition state, makes the activation energy for this reaction smaller, and makes the S_N2 reaction go faster.

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.

6. (15 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:

3 points for each set of electron-pushing arrows.

3 points for each intermediate.

Overall notes:

Overall, the minimum score for each item 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.

Proton transfer must be shown explicitly, with two arrows (one to proton, one from proton-acid bond).

-2 points, for each arrow in each step, for errors (including omission) in drawing one arrow in a multi-arrow step. Arrow must start at an electron pair (either a bond or a lone pair), and end at nucleus or bond where electrons will newly interact.

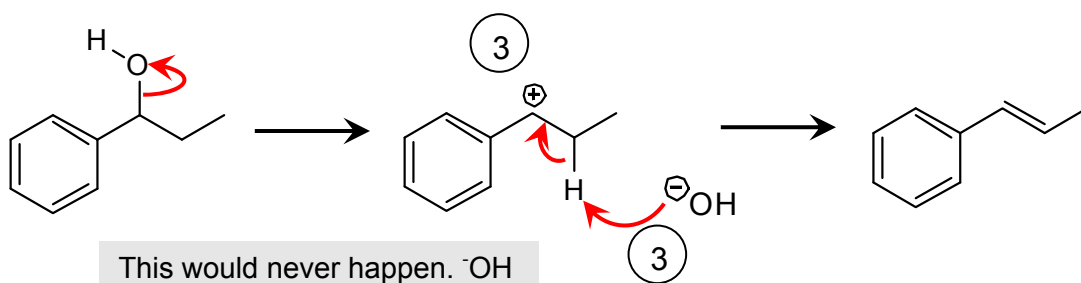
-1 points for each error in charge, valency, structure, base, etc. in an intermediate; if error propagates, points are taken off only for initial error.

Half credit for each electron-pushing step combined with another. (So, you would get 3 points total for combining two 3-point steps.)

-2 points for each use of a generic or incorrect acid/base. For example, H_2SO_4 is your only acid.

If you did not protonate -OH leaving group:

Max points you can get is 6 points.



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.