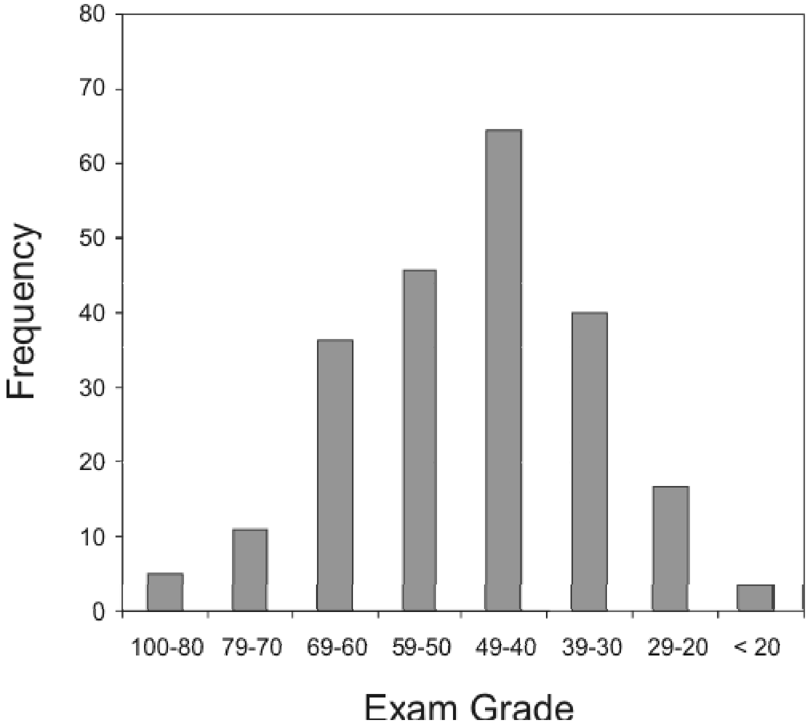
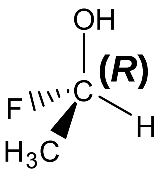
Chemistry 2301 Monday, October 22, 2007

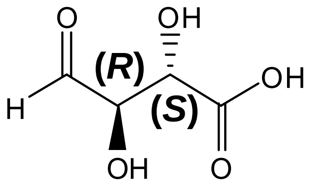
# Exam 2
## Answer Key

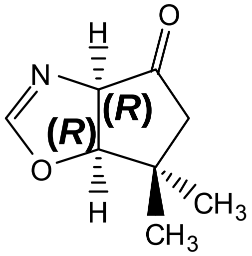
Exam 2 Mean: 49
Exam 2 Median: 47
Exam 2 St. Dev.: 14



1. (10 pts) On the structures below, label each chiral center with its appropriate Cahn-Ingold-Prelog designation [(*R*) or (*S*)].

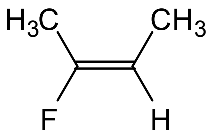


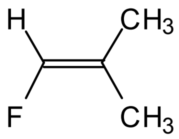


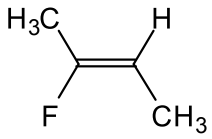


Rubric:
2 points each stereocenter labeled above. (10 points total.)
-2 points for any other center labeled as chiral.

2. (6 pts) Label the stereochemistry at each olefin below as (*E*), (*Z*), or “neither”.







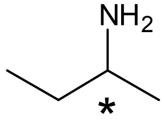
**(*E*)**

**neither**

**(*Z*)**

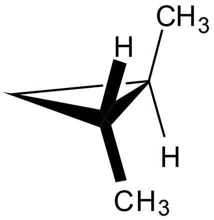
Rubric:
2 points each answer. (6 points total.)

3. (8 pts) Are the following molecules chiral or achiral? For each structure, **circle one answer.**



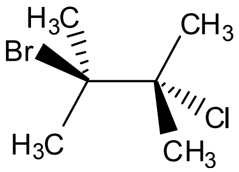
[✓ **CHIRAL**] *or* **ACHIRAL** ?

One chiral center, so this molecule is chiral. I haven't drawn stereochemistry at the stereocenter, but either amine-forward or amine-back, it's chiral.



[✓ **CHIRAL**] *or* **ACHIRAL** ?

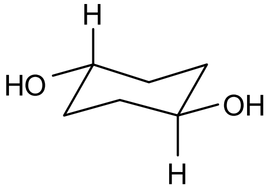
Not superimposable on its mirror image.



**CHIRAL** *or* [✓ **ACHIRAL**] ?

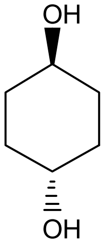
Each of the two carbons in the middle of the molecule has two methyl groups attached to it, and a carbon that has two of the same thing attached can't be chiral. This molecule has no chiral centers, (and it's not one of those crazy examples where no chiral centers still = chiral), so it's not chiral.

<u>Rubric:</u> 2 points each. (8 total.)



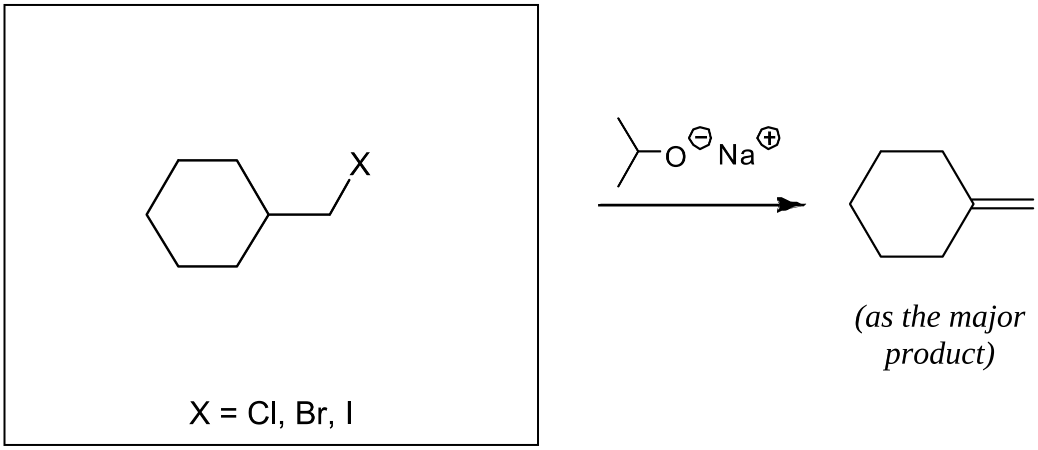
**CHIRAL** *or* [✓ **ACHIRAL**] ?

In class, we discussed how if it was possible to draw a molecule such that it has a plane of symmetry, then the molecule is achiral. You might have already seen that plane in the molecule as shown, but in case you didn't:



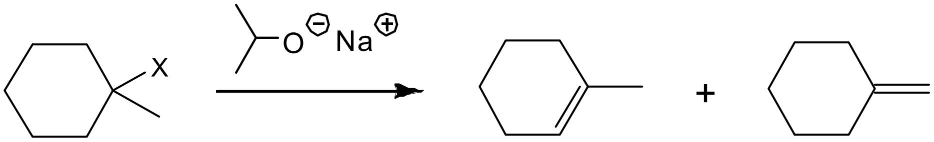
Mirror plane down the middle of the molecule, so achiral.

4. (20 pts) Draw the missing reactant or product in the empty boxes. For products, give the predominant, most favored product.



*(as the major product)*

Putting X at the primary carbon is the only way to ensure that the disubstituted olefin is the major product. If X were at the tertiary carbon, the major product would be the internal alkene:

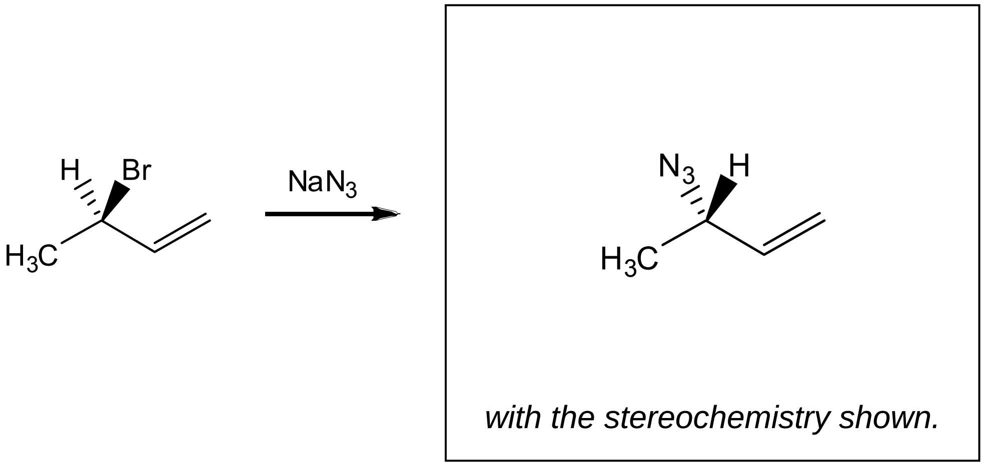


*tertiary halide* *major* *minor*

Rubric:

5 points for correct structure.

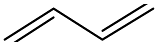
- *3 points partial for this structure, where X is a leaving group other than halide.*
- *3 points partial for tertiary halide above.*
- *-2 points for each clearly trivial structure mistake.*



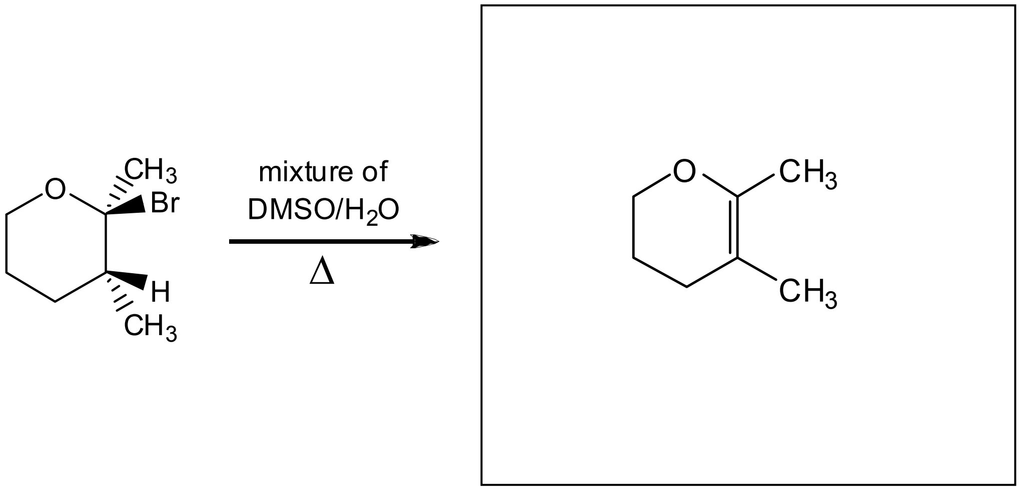
*with the stereochemistry shown.*

$N_3^-$ is a good nucleophile and a poor base, and so at a secondary, allylic halide, this reaction will proceed by $S_N2$ substitution. $S_N2$ involves inversion of stereochemistry (so the $N_3$ is in back, opposite of where the Br was in the starting material). E2 will compete, but not significantly. I also haven't given you a solvent, so you can't really asses the probability of $S_N1$ or E1, but the nucleophile is so good here that it would probably go $S_N2$ anyway.

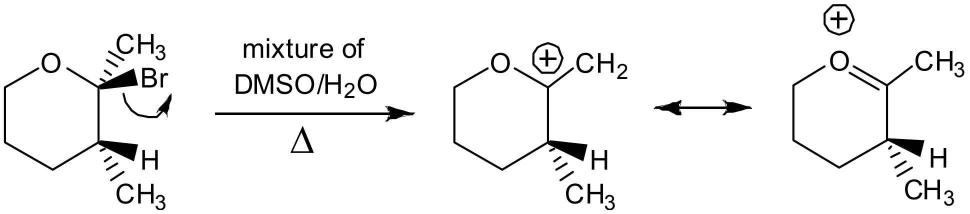
<u>Rubric:</u>
5 points for correct structure, including correct stereochemistry.
  *3 points partial for this structure, but opposite or no stereochemistry.*
  *3 points partial for elimination product.*
  *-2 points for each clearly trivial structure mistake.*



*elimination product*

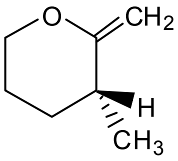


This reaction should proceed by E1, because it's in a highly ionizing solvent, with very poor bases, and with a tertiary halide. In fact, the intermediate tertiary carbocation would be stabilized by resonance in this case:

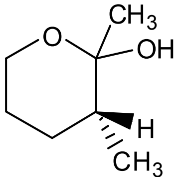


Because the reaction is E1 rather than E2, the H from the carbon in the ring next to the cation can be taken by the base, even though the H wasn't *anti*- to the Br in the starting material.

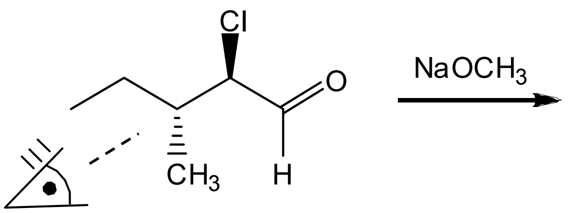
<u>Rubric:</u>
5 points for correct structure.
  *3 points partial for exocyclic alkene.*
  *3 points for –OH substitution (any stereochemistry)*
  *-2 points for each clearly trivial structure mistake.*

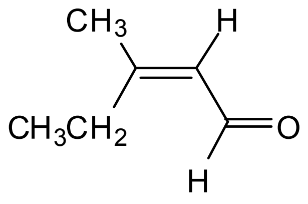


*exocyclic alkene*

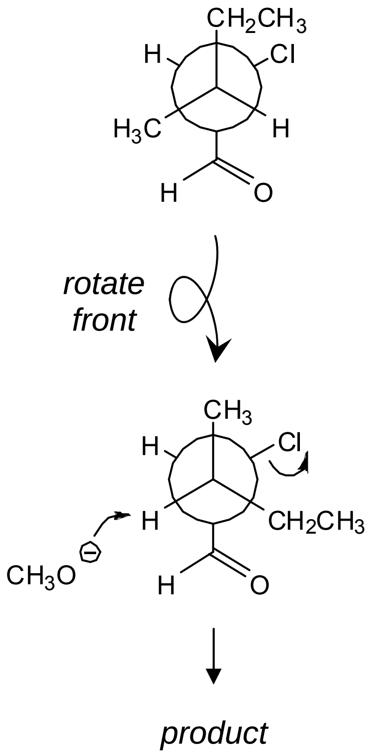


*-OH substitution*





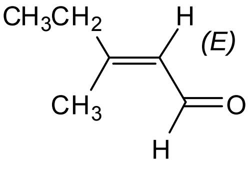
*with the alkene stereochemistry shown.*

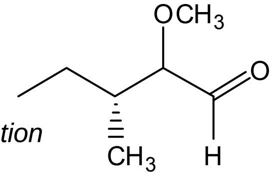


Reaction here will be E2—the base is strong, and even though reaction at secondary halides can go by $S_N2$, this one is hindered by isobutyl substitution on the carbon next door. So I'd pick E2 here.

E2 requires that the proton and leaving group be antiperiplanar, so we have to re-draw the rotamer to get it there. The result is exclusively the (*Z*) alkene above.

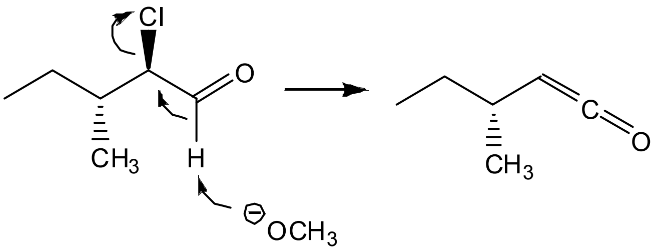
<u>Rubric:</u>
5 points for correct structure.
  *3 points partial for (E) alkene.*
  *3 points partial for $OCH_3$ substitution (any stereochem).*
  *-2 points for each clearly trivial structure mistake.*



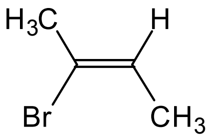


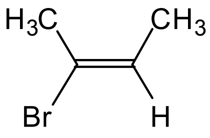
*$OCH_3$ substitution*

A number of you had the base take the proton I drew, to generate a ketene (at right). This would never happen. Elimination does not occur at $sp^2$-hybridized carbon, and the product I drew above has resonance structures, while this one doesn't. We gave this 1 point partial credit.



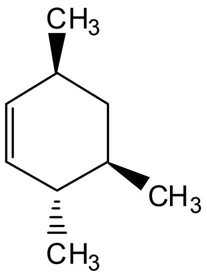
5. (9 pts) How would you describe the relationship between each of the pairs of structures below? Are they enantiomers or diastereomers, or are they just two ways of illustrating the same molecule? **Circle one answer** for each pair**.**

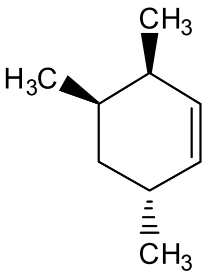




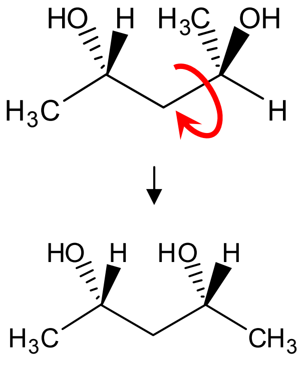
**ENANTIOMERS**
*or*
[✓ **DIASTEREOMERS**]
*or*
**SAME MOLECULE**

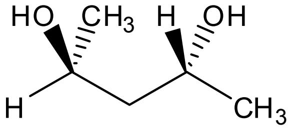
Diastereomers = stereoisomers that aren't enantiomers. That's what these are.





**ENANTIOMERS**
*or*
[✓ **DIASTEREOMERS**]
*or*
**SAME MOLECULE**





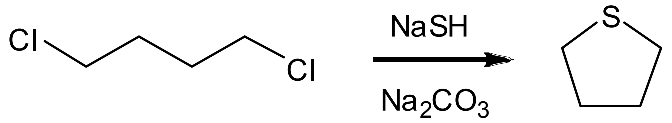
**ENANTIOMERS**
*or*
**DIASTEREOMERS**
*or*
[✓ **SAME MOLECULE**]

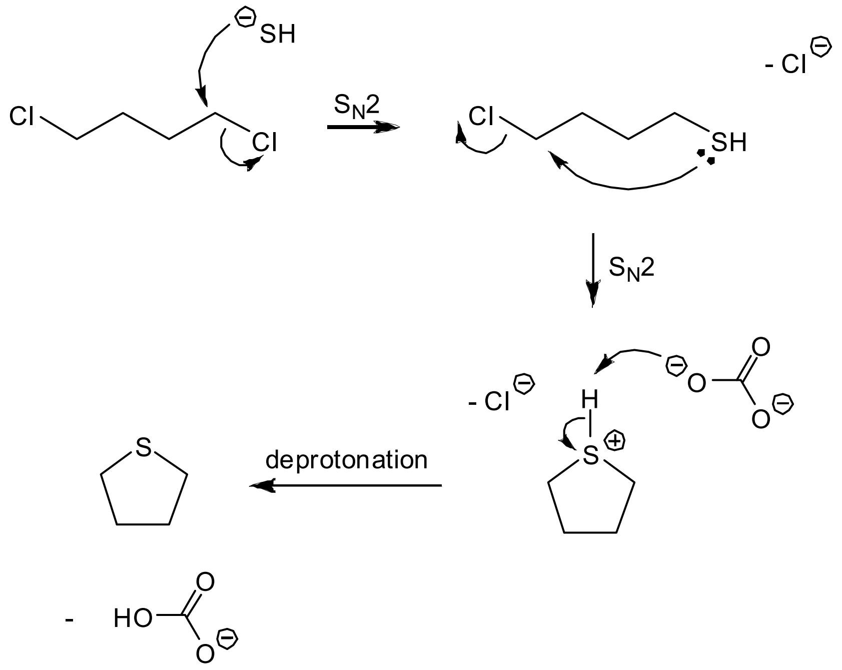
…which has a plane of symmetry, making it achiral. So, by definition, the mirror image is the same molecule. Another way of thinking about it: the molecule is (*R*,*S*) and has the same groups attached to each stereocenter, so the molecule is *meso*, achiral.

Rubric: 3 points each.

6. (27 pts) For each of the reactions shown below, draw a mechanism that explains how each product is generated from the starting material. In your answers, make sure that you:
   - Draw each step of the mechanism separately;
   - Use "electron pushing" to show where the electrons in each step go.

(a)





I've drawn an intermolecular $S_N2$, an intramolecular $S_N2$, and a deprotonation. $CO_3^{2-}$ is a reasonable base though, and it could deprotonate the thiol before it attacks too, so you could have drawn the mechanism intermolecular $S_N2$ → deprotonation → intramolecular $S_N2$ instead (full credit for that answer). (You could also use $HS^-$ as the base. $Cl^-$ isn't as strong as either, so probably not $Cl^-$.)

Rubric for part (a): *(9 points total this part)*

3 points for each of the three steps. (In either order explained above.)

*Things that have left (e.g., $Cl^-$), and spectators (e.g., $Na^+$), may be omitted.*

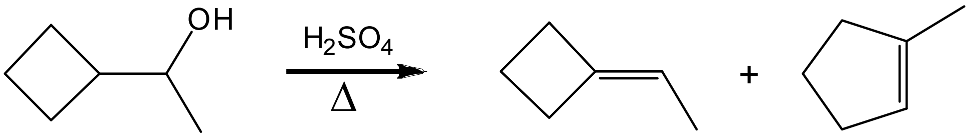
*-1 point, for each arrow in each step, for errors in drawing arrows. Arrow must start at an electron pair, and end at nucleus where electrons will newly interact. Can only lose points if you get them.*

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

*-1 point for each step combined with another.*

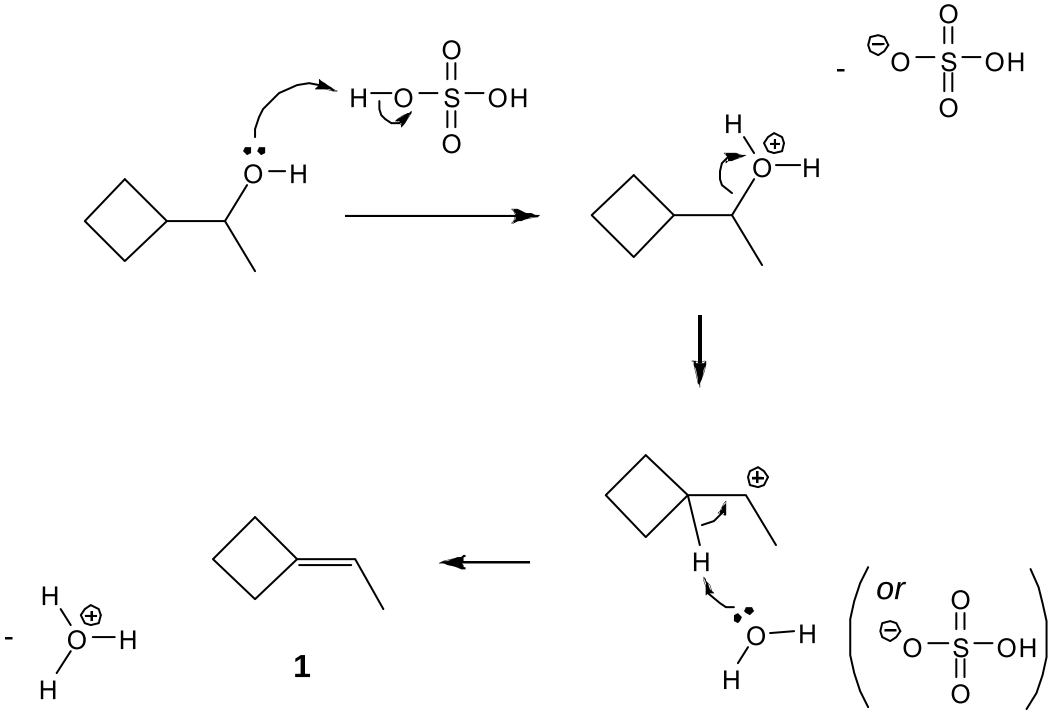
*-1 point for using an unreasonable base (e.g., $Cl^-$), or omitting base.*

(b)



**1** **2**

*mechanism for product* **1**

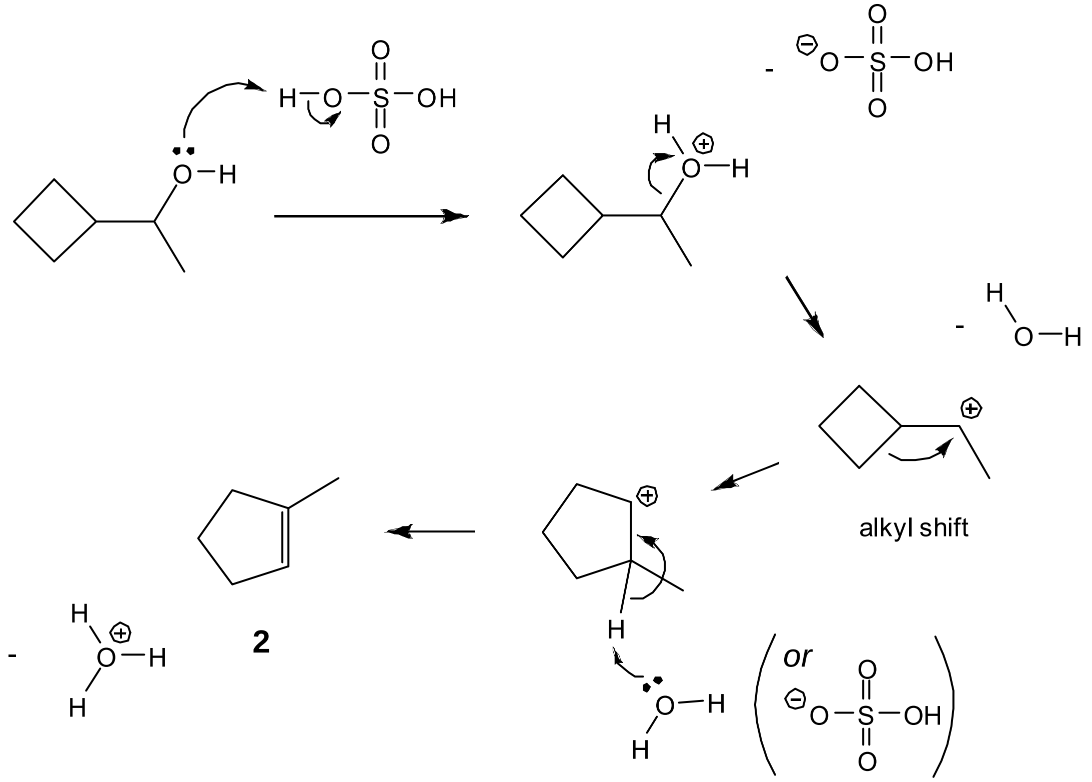


-OH <u>must</u> be protonated before leaving—it's a horrible leaving group by itself, and in a strong acid like $H_2SO_4$, $OH^-$ just wouldn't exist. Final two steps <u>must</u> be E1; available bases aren't strong enough to do E2. So these are the only steps, and the only order, allowed.

<u>Rubric for part (b), first box:</u> *(9 points total this box)*
3 points for each of the three steps.

- *Things that have left (e.g., $H_2O$) and spectators may be omitted.*
- *-1 point, for each arrow in each step, for errors in drawing arrows. Arrow must start at an electron pair, and end at nucleus 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.*
- *-1 for each step combined with another.*
- *If you had $OH^-$ leave, you get maximum 3 points total for last step.*

*mechanism for product* **2**



*(see also Wade, p.255-6.)*

Here, the first two steps are the same as the previous mechanism. The alkyl shift yields the more stable carbocation; although it's still secondary, the ring strain in the cyclobutane has been relieved by expanding to a cyclopentane. Then, deprotonation by E1 yields the more stable, more substituted alkene.

Rubric for part (b), second box: *(9 points total this box)*

3 points for starting with cyclobutyl cation.

*(You may have re-written the mechanism from the first box, as I did above, but you don't have to have done this to get credit.) No points taken off for mechanistic errors (because you presumably already lost them in the first box).*

3 points for the alkyl shift.

3 points for deprotonation.

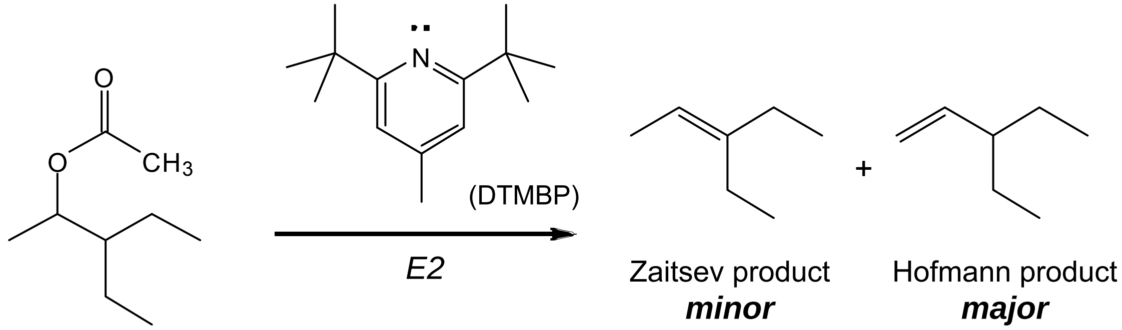
*Things that have left (e.g., $H_2O$) and spectators may be omitted.*

*-1 point, for each arrow in each step, for errors in drawing arrows. Arrow must start at an electron pair, and end at nucleus 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.*

*-1 point for each step combined with another.*

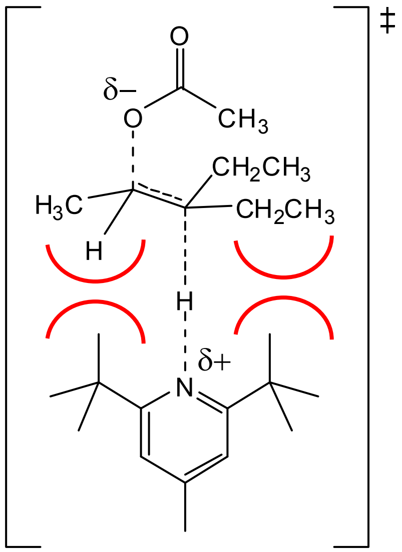
7. (20 pts) When the starting material shown below is combined with 2,6-di-tert-butyl-4-methylpyridine (DTBMP), a sterically hindered base, the resulting E2 elimination predominantly yields the *less* substituted (Hofmann) alkene product.



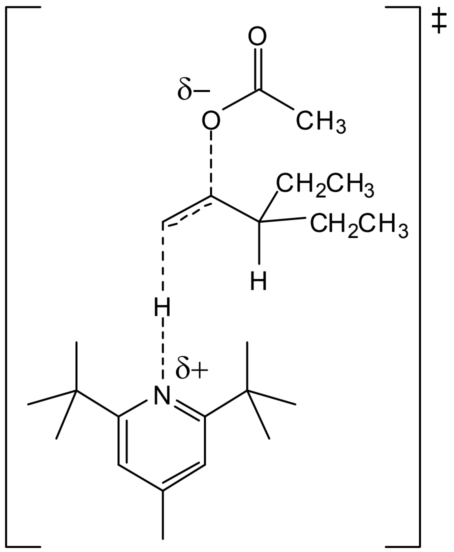
In the space below, explain this preference using a potential energy diagram that illustrates:

- Two potential energy curves, one for each product.
- In the brackets, the structure of the rate-determining transition state for each pathway.
- The relative potential energies of all starting materials, transition states, intermediates (if any), and products. Show which energies correspond to which chemical structures.
- Two overall activation energies, $E_a$[Zaitsev] and $E_a$[Hofmann], for the two pathways.

This problem describes an unusual situation, in which the less substituted, less stable product actually predominates. The only reason why this would happen is if the product-determining (and in this case, rate-determining as well) transition state for the less stable product was actually lower in energy than the TS for the more stable product. (In other words, only if Hammond's Postulate did not hold true.)

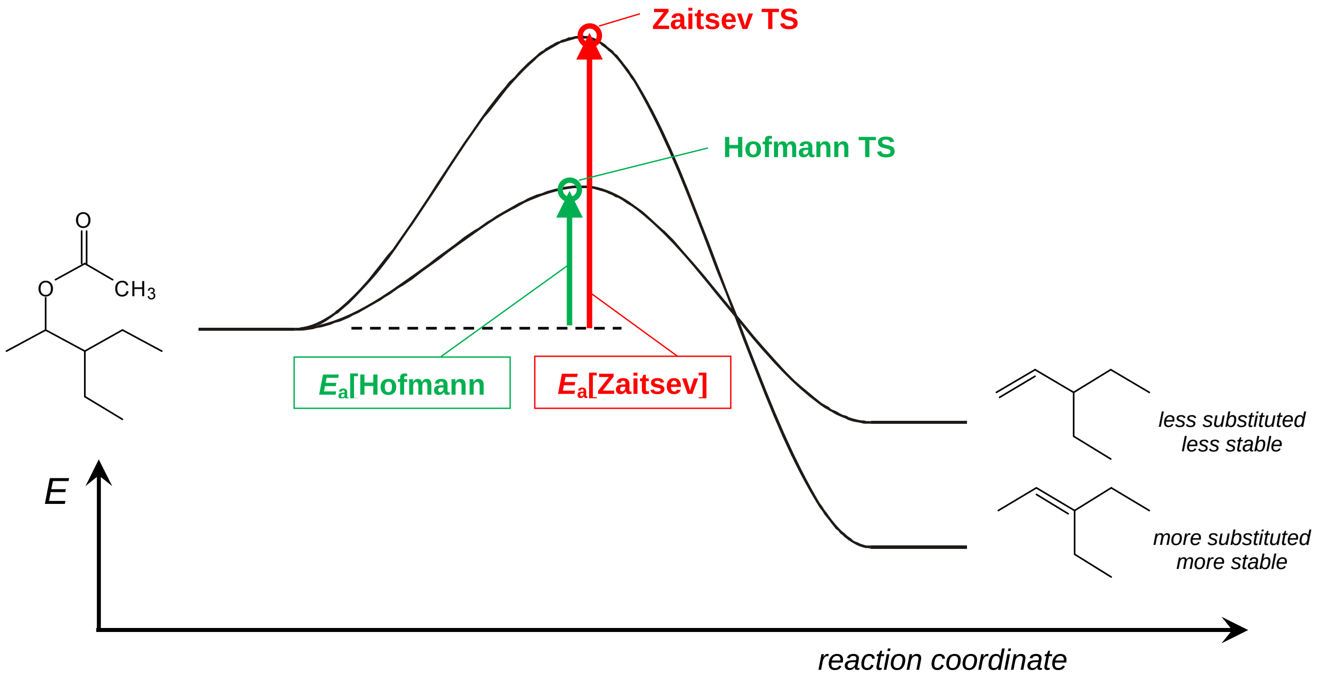


*→ Zaitsev product*



*→ Hofmann product*

In this case, the reason for this unusual situation is that the hindered base makes it such that the more substituted, more crowded proton is harder to get to (due to steric hindrance). As a result, the crowded, Zaitsev transition state is higher in energy than the less hindered, primary (Hofmann) proton. Because of this, we'd expect the potential energy diagram to look a little different from the usual situation:



Rubric:

4 points for each E2 transition state. (8 points total for TS's.)

*-1 for missing/incorrect partial charges.*

*-1 for incorrect partial bonds.*

*-1 for other trivial structural errors.*

*Can denote base as "B" if you want. Don't need to draw out. But you must include base in transition state; -2 (each) if you leave out the base. For some, this combined with other errors meant 0 points for TS structures.*

On PE diagram: (12 points total)

2 points for single-step (E2).

2 points for products in the right order.

2 points for starting material the same.

2 points for labeling with $E_a$'s (correctly connected to products, but not necessarily correct relative energies)

4 points for correct relative $E_a$'s ($E_a$[Hofmann] < $E_a$[Zaitsev])