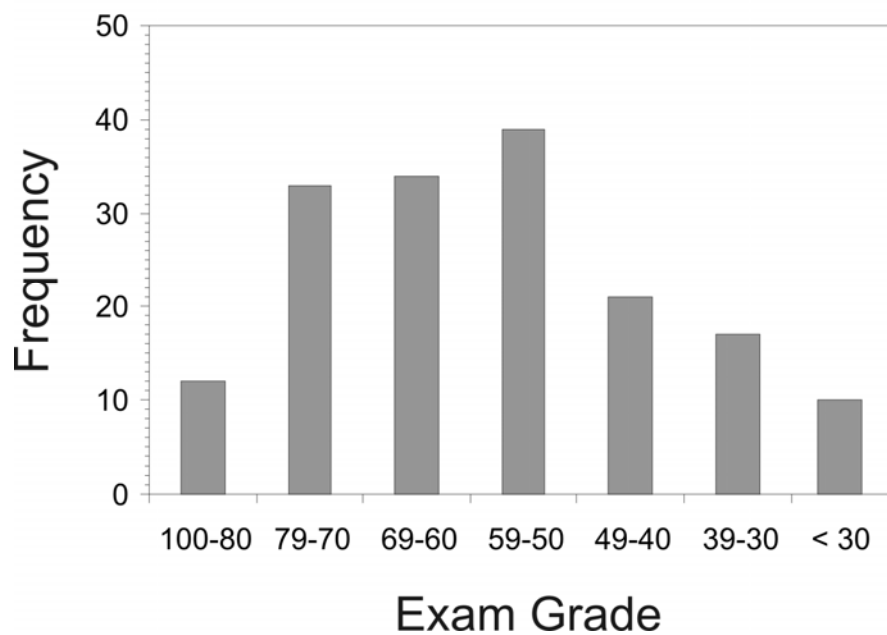
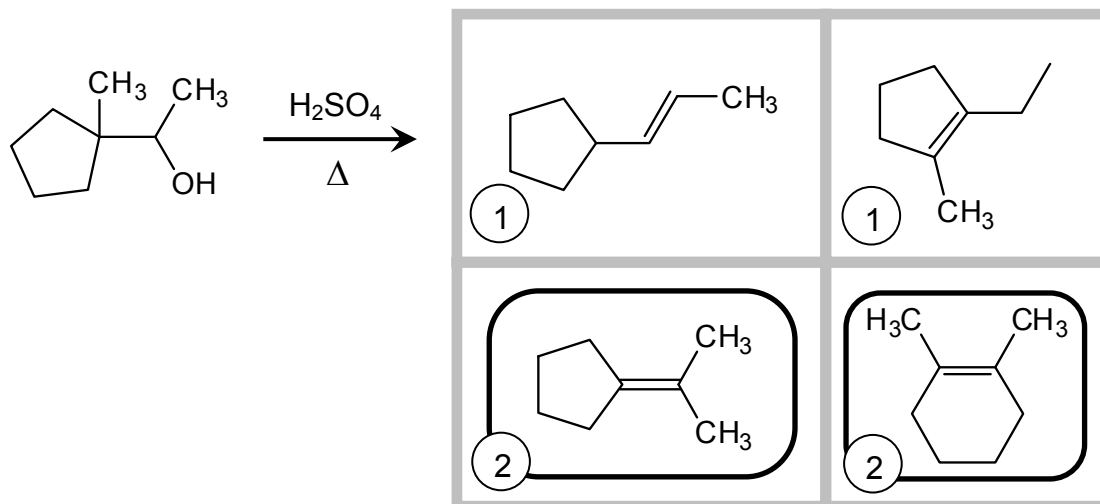


**Exam 3  
Answer Key**

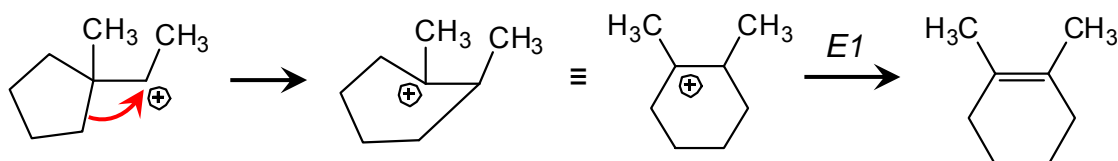
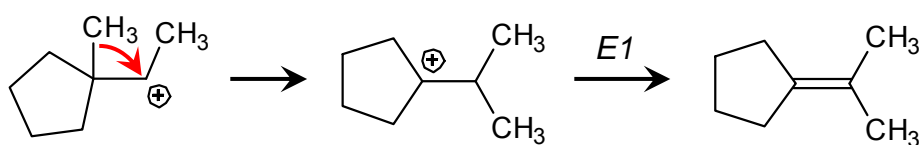
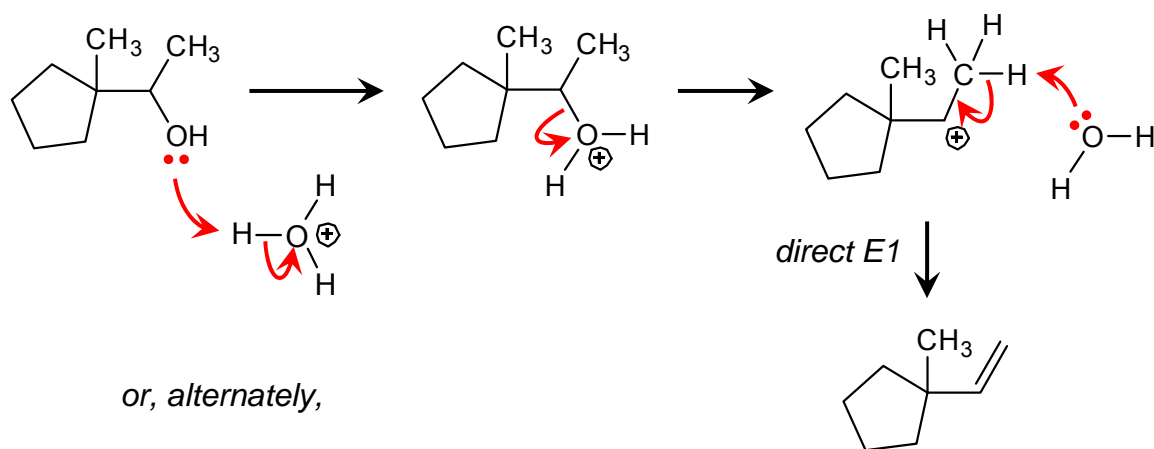
Exam 3 Mean: 59  
Exam 3 Median: 58  
Exam 3 St. Dev.: 16

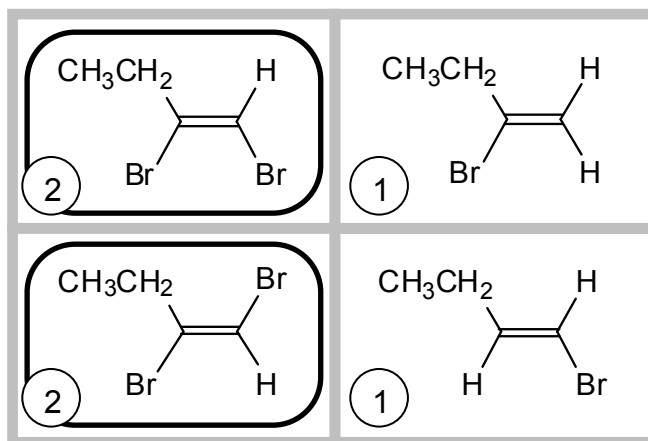
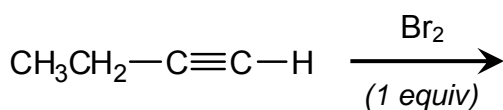


1. (14 pts) For each reaction shown below, **circle all potential products**. Keep in mind that, for each case, you might circle one, multiple, or no molecules.

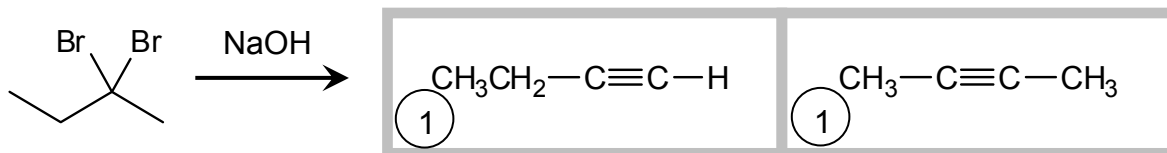


In this problem,  $\text{H}_2\text{SO}_4$ --an extremely strong acid--can protonate the alcohol group to turn it into a good leaving group (water), which leaves to form an intermediate carbocation. This carbocation can either complete E1 elimination to yield an alkene that is not among our products, or it can undergo carbocation rearrangement to give a more stable carbocation:



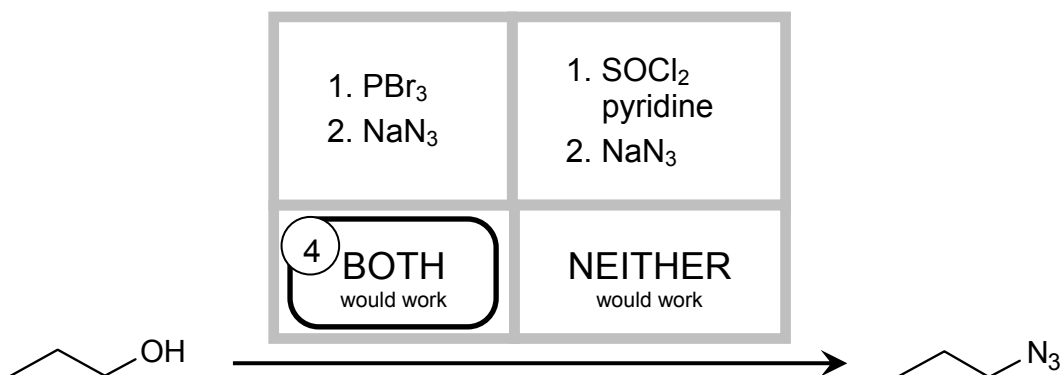


This adds one molecule of  $\text{Br}_2$  across the triple bond, one Br atom to each carbon. The intermediate vinyl cation has no stereochemical preference in the addition of the second Br atom, so we would expect both *cis*- and *trans*-isomers to form.

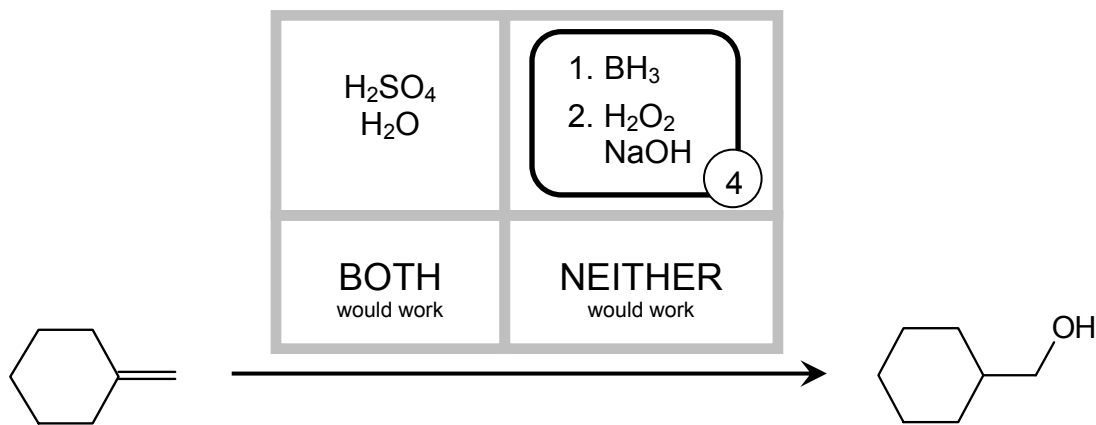


Elimination of one  $\text{HBr}$  from the starting molecule would give a monobrominated alkene. This alkene would be resistant to further elimination by any base other than  $\text{NaNH}_2$  (which can be used to make alkynes by E2 elimination of haloalkenes).

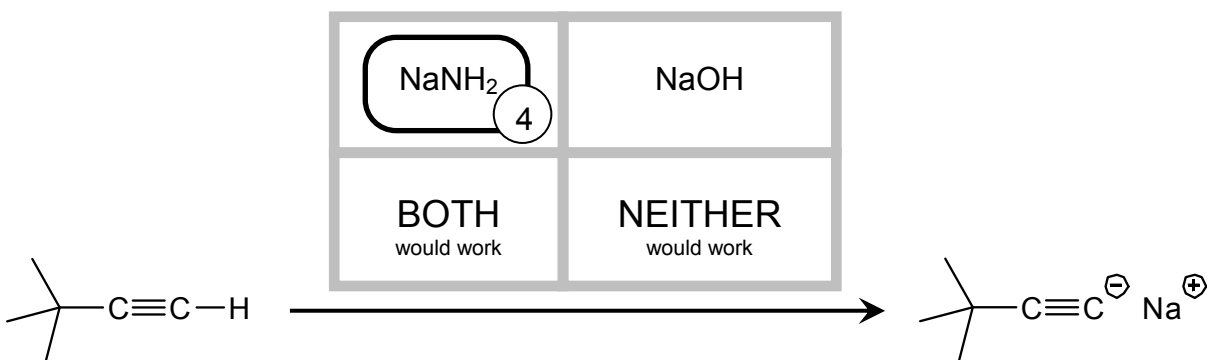
2. (12 pts) Each of the reactions below is drawn with two possible reaction conditions. If only one of the two reaction conditions would generate the given molecule as the major product, circle those conditions. If both sets of conditions would accomplish the reaction, circle "BOTH". If neither set of reaction conditions would succeed, circle "NEITHER". **Circle one answer only.**



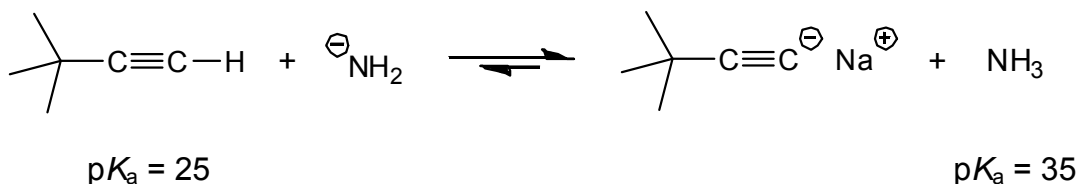
Step 1 of each of these reaction conditions converts the hydroxyl groups into a halide (the left-hand conditions to a -Br, the right-hand ones to a -Cl). Then, the second step does a substitution reaction to replace the halide leaving group with an azide group. Both sets of reaction conditions will do this.

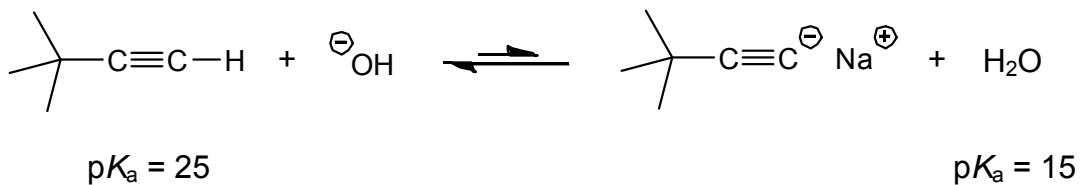


These are both methods for hydration—addition of “H-OH”—across a double bond. The first reagent set adds Markovnikov, and the second adds anti-Markovnikov. In our product, the -OH group is attached to the less substituted carbon of what used to be an alkene, which is anti-Markovnikov.



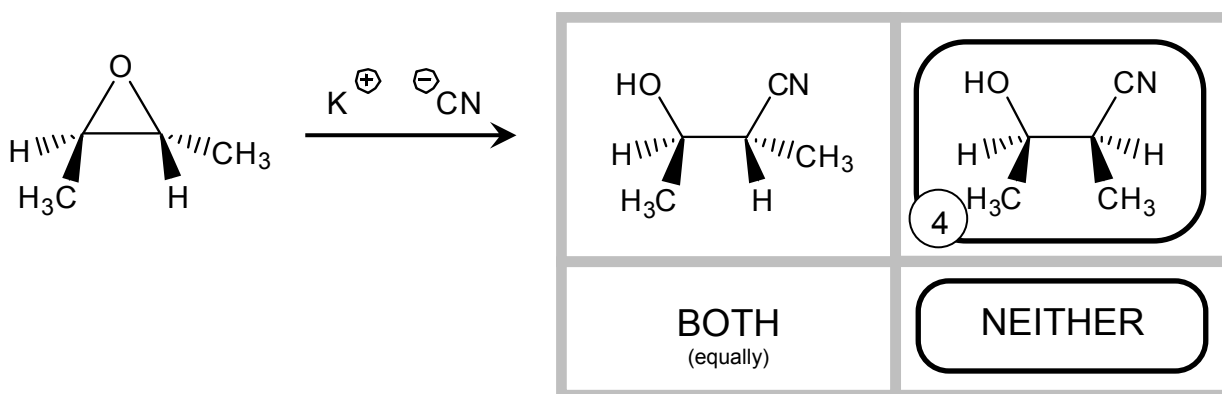
Both of these reagents are bases, but the base on the left is much stronger than the base on the right. Quantitatively speaking, we can write acid-base equilibria for each base:



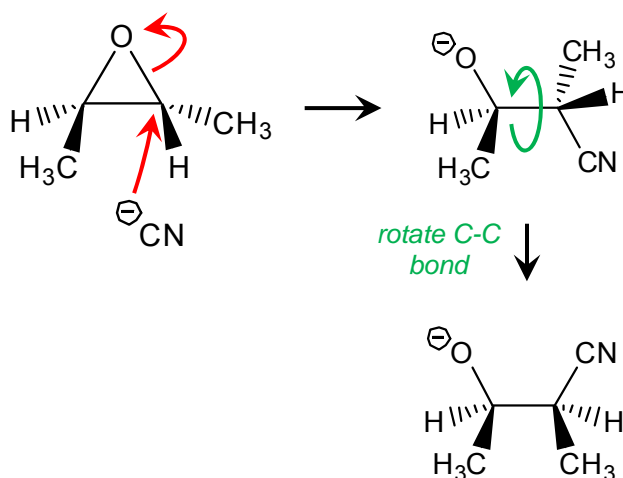


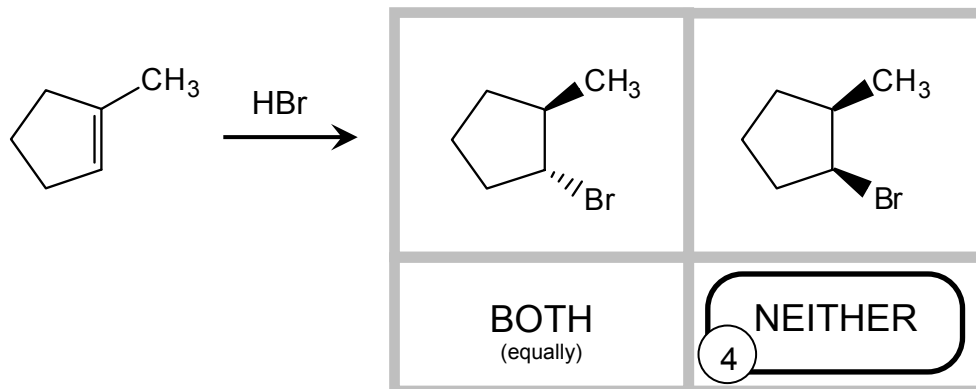
Acid-base equilibria always favor the side with the weakest (conjugate) acid. So the equilibrium with  $\text{NH}_2^-$  as the base goes forward, but the one with  $\text{OH}^-$  as the base doesn't.

3. (16 pts) Each of the reactions on the next page is drawn with two possible products. If one of the two products predominates, circle that preferred product. If the two products are produced equally, circle "BOTH". If neither product would result from the reaction, circle "NEITHER". **Circle one answer only.**

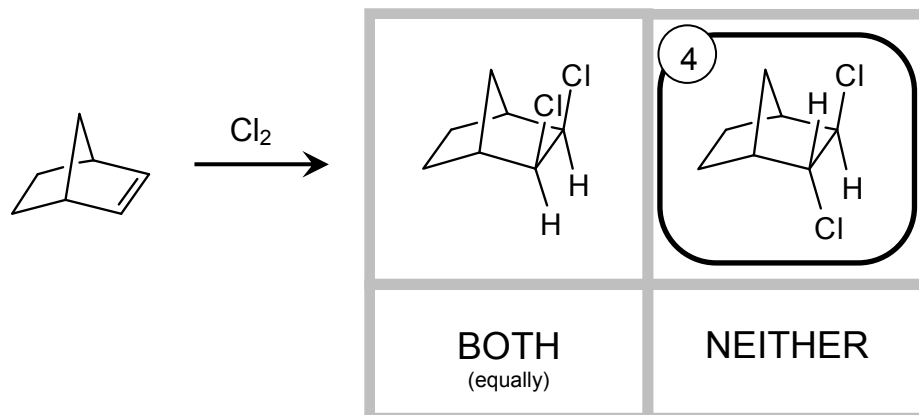


$\text{CN}^-$  attacks from behind either of the epoxide C-O bonds to generate an alkoxide that has the stereochemistry of the product on the right (or its enantiomer), but cannot generate the stereochemistry on the left. Ordinarily, this reaction would either be conducted in a solvent that could donate a proton to this alkoxide, or the reaction would be worked up with acid after it was done, but I omitted these details from the reaction conditions. So we accepted either the correct alcohol, or "NEITHER" (corresponding to the alkoxide) as correct answers.

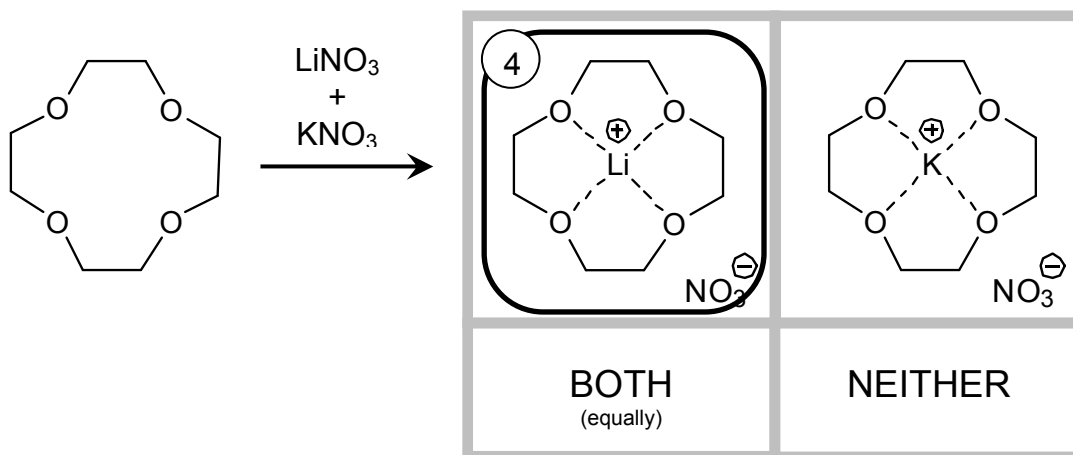




HBr adds to alkenes with Markovnikov regioselectivity—with the -Br attached to the more substituted carbon. Neither of these products is a Markovnikov product.

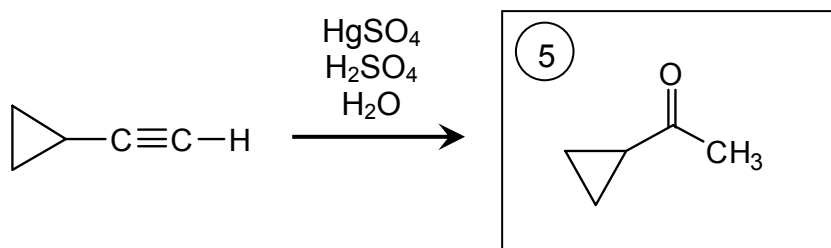


Halogenation of alkenes occurs selectively *anti*-, to yield a *trans*-dihalogenated product. We showed this in lecture for bromination; chlorination works the same way.

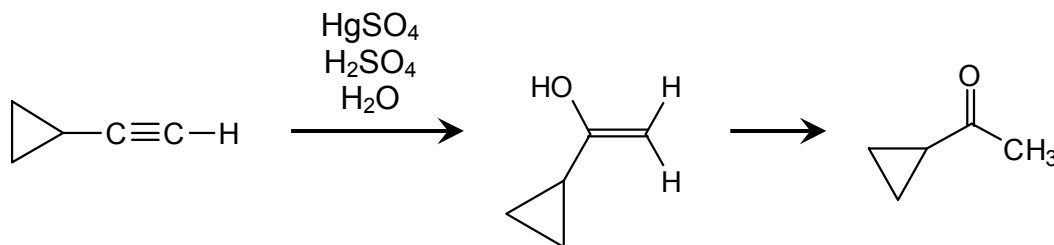


The starting material here is a crown ether—an ether with a cavity in the center that can fit cations. This one is 12-crown-4, the smallest one that coordinates anything, and it can only fit  $\text{Li}^+$ , the smallest of guests.

4. (25 pts) For each of the reactions below, **fill in the empty box corresponding to reactants or products**. For reactions that you expect to yield multiple products, give the major product. For reactions that yield multiple enantiomers, draw only one enantiomer in the box, and include the note “+ enantiomer”.



This reagent set performs Markovnikov hydration (addition of H-OH) across the triple bond. This results in an enol intermediate, which tautomerizes immediately to the ketone product.



Rubric for this part:

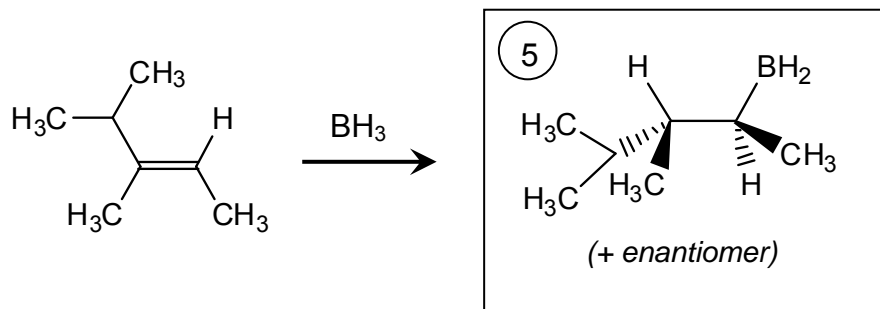
5 points for correct product.

3 points partial for wrong regiochemistry (aldehyde).

3 points partial for internal enol.

1 point partial for terminal enol.

-2 points for each trivial structural mistake.



In hydroboration of a double bond,  $\text{BH}_3$  adds across the double bond such that an  $\text{-H}$  is added to the more substituted carbon, and a  $\text{-BH}_2$  group is added to the less substituted carbon. Addition is *syn*-, meaning the groups are added to the same face of the alkene. This is typically followed by an oxidation step, in which  $\text{H}_2\text{O}_2/\text{OH}^-$  “trades” the  $\text{-BH}_2$  for an  $\text{-OH}$  group; but this step isn’t part of this problem, so the reaction stops at the boration step.

Rubric for this part:

5 points for correct product.

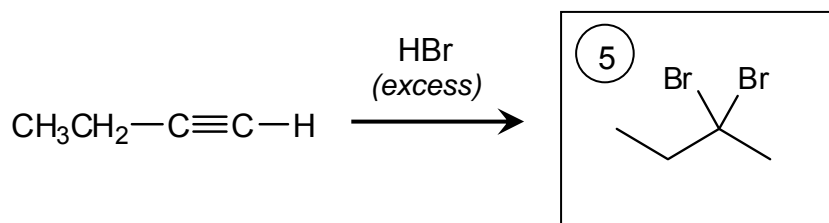
*4 points partial for correct answer, but omitting “+ enantiomer”.*

*3 points partial for incorrect or undetermined stereochemistry.*

*3 points partial for correct stereochemistry, but incorrect regiochemistry ( $\text{-BH}_2$  attached to more substituted carbon).*

*2 points partial for anti-Markovnikov alcohol (all also correct).*

*-2 points for each trivial structural mistake.*



Double Markovnikov addition.

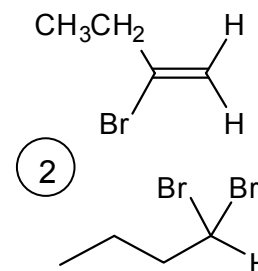
Rubric for this part:

5 points for correct product.

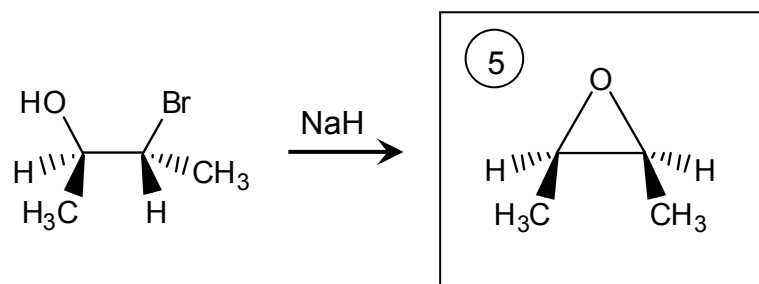
*2 points partial for Markovnikov mono-adduct of HBr.*

*2 points partial for double anti-Markovnikov adduct.*

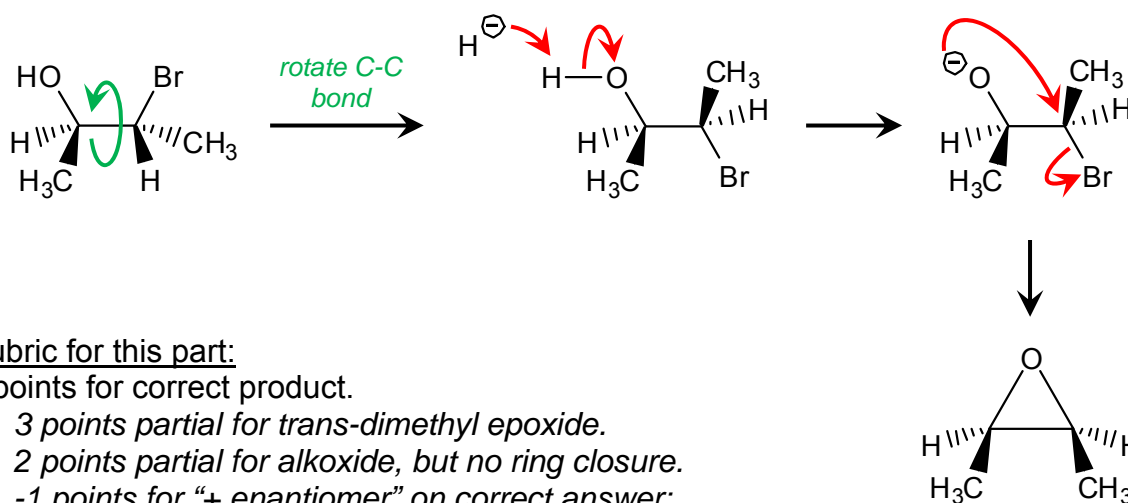
*-2 points for each trivial structural mistake.*







The halohydrin is deprotonated by sodium hydride, and the resulting alkoxide can kick out the halide to make an epoxide. But the alkoxide must come from behind the leaving group, and so the central C-C bond has to rotate before this can happen:



Rubric for this part:

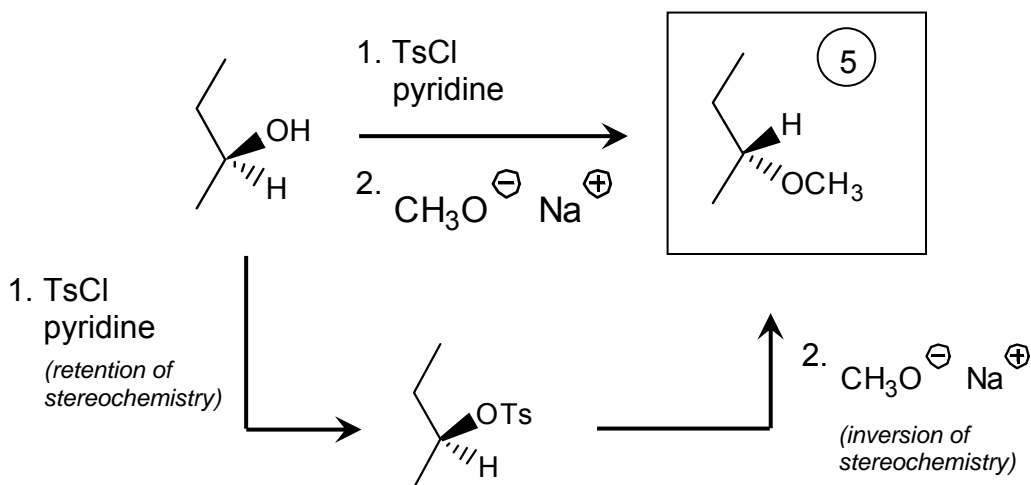
5 points for correct product.

3 points partial for *trans*-dimethyl epoxide.

2 points partial for alkoxide, but no ring closure.

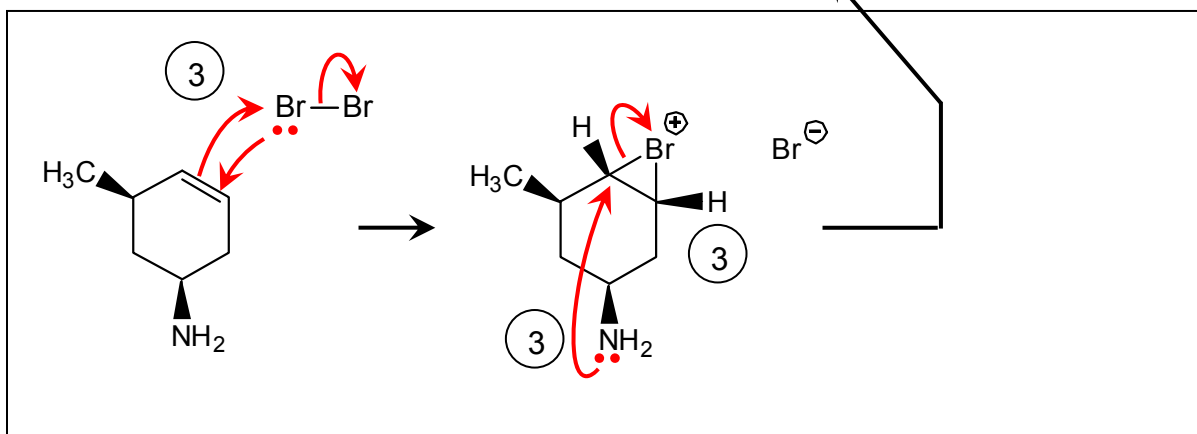
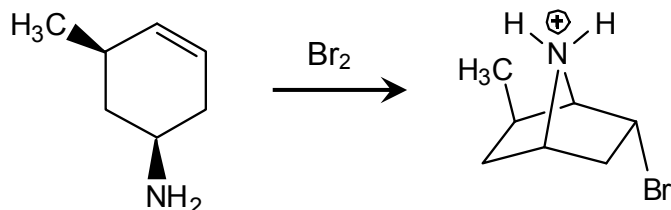
-1 points for “+ enantiomer” on correct answer;  
molecule is achiral.

-2 points for each trivial structural mistake.



5. (18 pts) For each of the reactions 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: (9 points this part)

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.

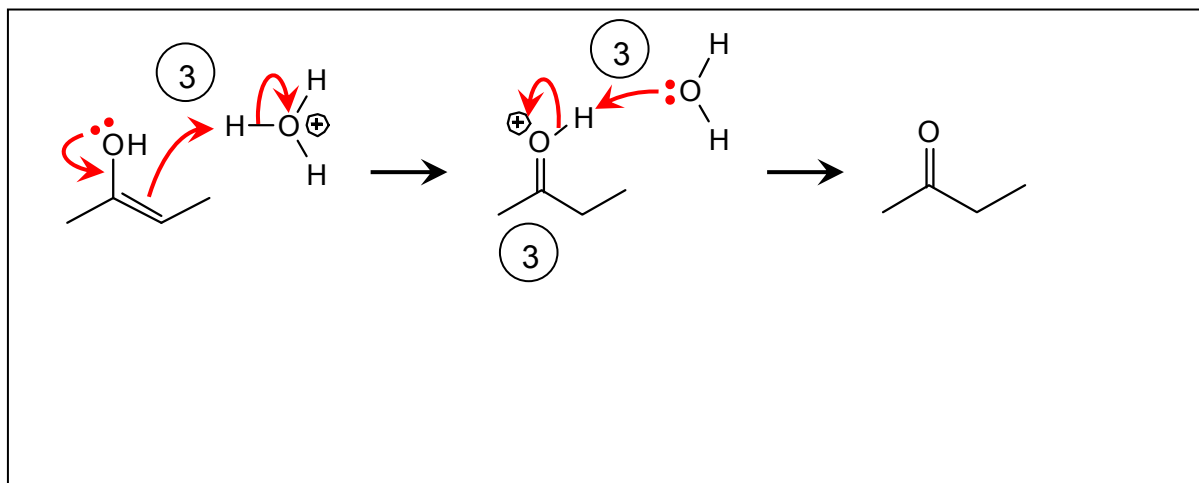
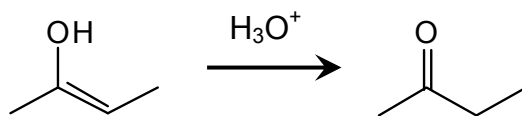
Things that have left for good (e.g.,  $\text{Br}^-$ ) and spectators may be omitted.

3 points for each set of curved arrows shown above in each step. Arrow must start at an electron pair, and end at nucleus or bond where electrons will newly interact. Grader can give partial credit for partially correct answers.

3 points for each intermediate structure. (Just one here.)

Maximum half-credit for combining separate steps.

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



Rubric: (9 points this part)

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.

3 points for each set of curved arrows shown above in each step. Arrow must start at an electron pair, and end at nucleus or bond where electrons will newly interact. Grader can give partial credit for partially correct answers.

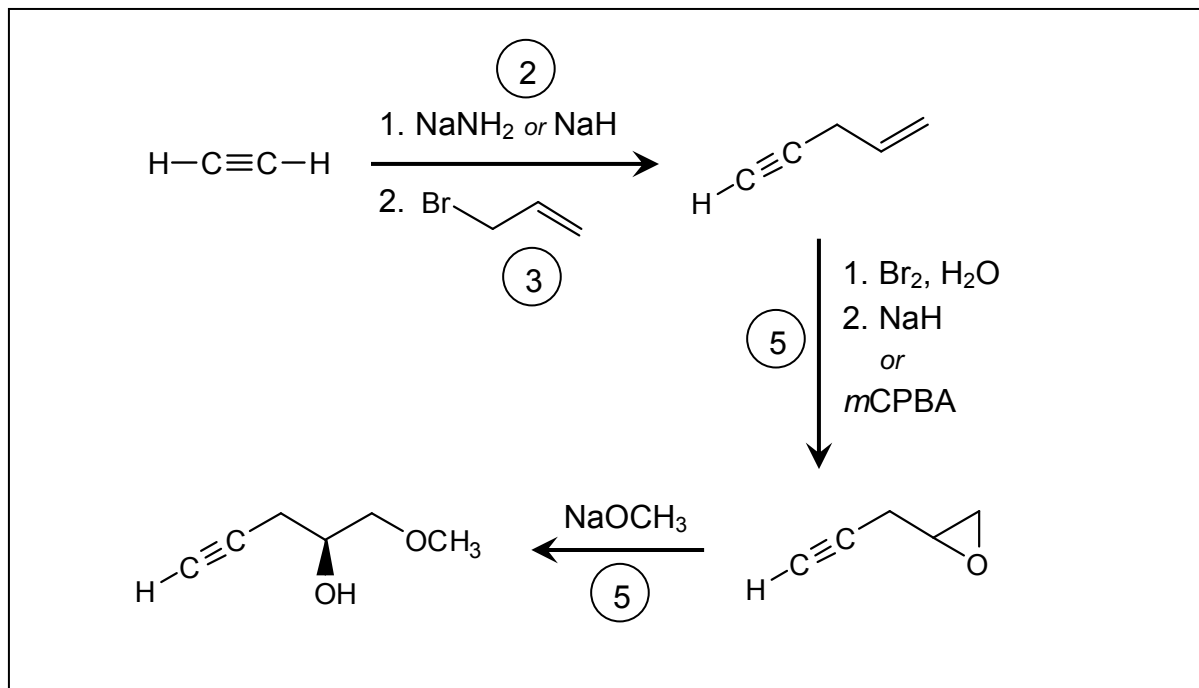
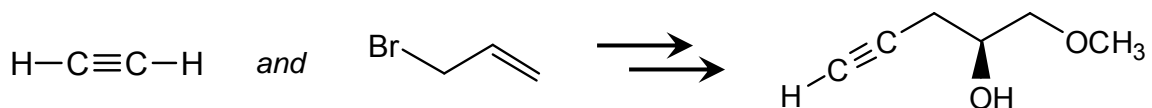
3 points for each intermediate structure. (Just one here.)

Resonance structures are fine. You could draw each of the structures above as minor resonance contributors instead of the major ones I draw and still receive full credit.

Maximum half-credit for combining separate steps.

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

6. (15 pts) For the starting materials and product shown below, **propose a multistep synthesis**. In addition to the molecules shown, you can use any reagents and reactions we've learned about in class. You might discover multiple answers to this problem; draw only your best (one) synthetic route. Feel free to draw an incomplete route—we will give you partial credit where we can.



Your answer would have required two elements:

- (1) The alkyne needs to be deprotonated to make an alkynyl anion, and combined with the other molecule as an electrophile. This needs to be done such that there are no interfering protons available to quench the alkynylide.
- (2) The alkene needs to be converted into two different functional groups. This can be done before the alkyne is added, but only if alkynyl addition is compatible with both functional groups. Once again, this needs to be done selectively, such that there are no interfering functional groups or reactivities.

Rubric: 15 points total for the two elements described above.

Each task is judged separately, and does not require that the synthesis makes sense, or that other tasks are correct.

*I've drawn deprotonation of acetylene and attack on allyl bromide on one arrow, because a chemist would carry out the reaction in one pot. However, if you wrote out each of these as individual steps, that's just fine--full credit, as long as what you've drawn makes sense.*

-1 point for each clearly minor error in structures or reagents; if error propagates, points are taken off only for initial error.

-2 points if step reagents are incorrect, but reaction could otherwise be accomplished with correct reagents.

3 points for deprotonating alkyne.

2 points for combining alkynyl anion with another molecule that doesn't have an alcohol group.

*Alcohols are more acidic than alkynes, so an alkynyl anion will take a proton before it does anything else.*

5 points for converting alkene into an epoxide.

*I can't think of a way that bromination leads to the product without competing E2 elimination on a Br by  $\text{OCH}_3^-$ , or proton exchange with a bound -OH group.*

*We gave no partial credit to using  $\text{Br}_2$ .*

5 points for incorporating  $\text{OCH}_3$  group without competing reaction.