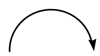
Arrow-Pushing and Solving Mechanism Problems

A. General Points:

1. It is important that you understand exactly what the various arrows represent:



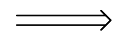
flow of two electrons

flow of one electron

reaction arrow

equilibrium arrow

resonance arrow



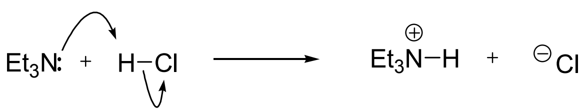
retrosynthetic arrow

2. Why curved arrows?

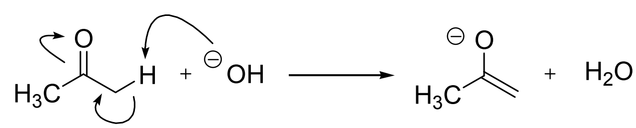
   (a) One curved arrow = two electrons = one bond (when a bond is being formed or broken) or one lone pair of electrons.

   (b) The arrow starts where the two electrons originate, and points toward the atom with which the electrons are reacting or end up on (this means that an arrow can never start at H^+).

Example 1

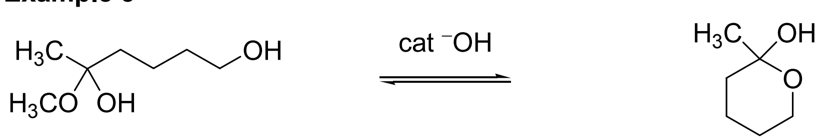


Example 2



B. Specific Tactics and Hints:

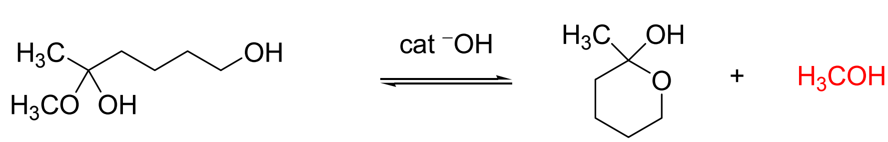
Example 3



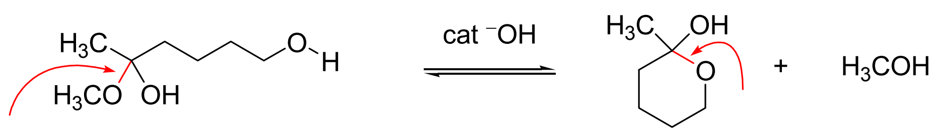
1. Draw out the starting materials, reagents, and products as clear structures, including formal charges and lone pairs.

2. Compare the starting material(s) and product(s).

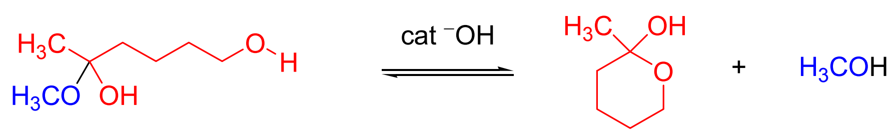
   (a) Count the atoms in the starting material(s) and product(s). Determine what is lost or gained. This helps you keep track of all the atoms in the reaction. Moreover, it may give you a hint as to what type of reaction occurs. For **Example 3**, the starting material has 7 carbons, 3 oxygens, and 16 hydrogens. The product has 6 carbons, 2 oxygens, and 12 hydrogens. This tells you that you are losing 3 carbons, 1 oxygen, and 4 hydrogens – you might recognize that this is H_3COH (methanol).



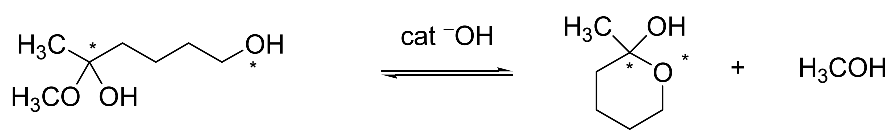
(b) Determine which bonds are formed and which are broken. Doing so gives you an idea of what reactions might occur. For **Example 3**, in order to form a cyclic structure a new C-O bond must be formed as indicated in the product. We also have identified that the starting material loses methanol, thus the C-OMe bond probably breaks.



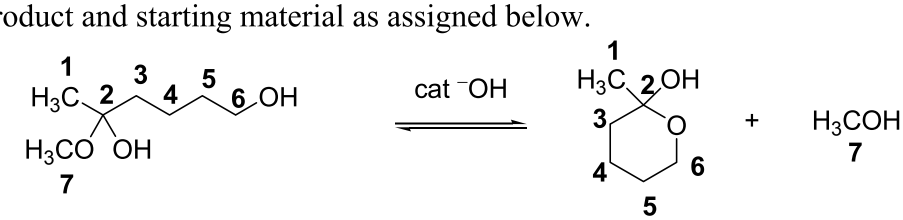
(c) Determine which pieces of the product(s) correspond to which part of the starting materials. In **Example 3**, it is most likely that the methanol comes from the OCH_3 group in the starting material as we have highlighted in blue.



(d) Determine which pieces of your starting material(s) are lost and what remains unchanged. We have already identified that we lose methanol. We can also see that the carbon indicated by an asterisk (*) forms a new bond to the alcohol (*).



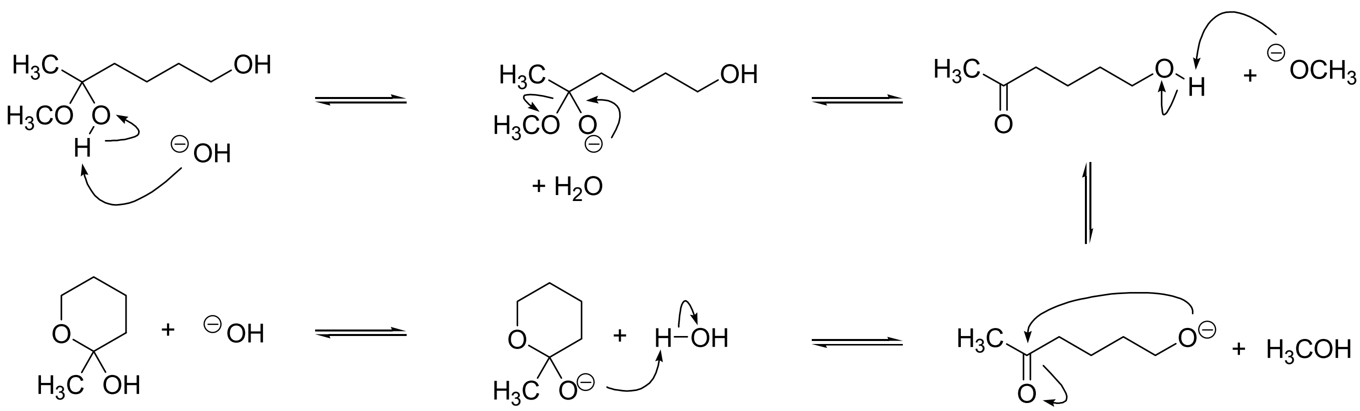
(e) Number the atoms. This exercise may help you if the starting materials and products look drastically different. First, assign each atom in the starting material a number, especially the carbon atoms. Next, try to match up one or two key atoms in the starting material with their counterparts in the product(s), and give them the same numbers. For example, there is only one methyl group in our starting material and product so we can guess that this is the same carbon #**1** in both product and starting material as assigned below.



3. Consider the reaction conditions and how the starting materials are affected by them. Ask "what do these kinds of molecules do?" For example, what are the nucleophilic and electrophilic sites of my starting materials? Or under acidic conditions, what is the most basic site of my starting material? In **Example 3**, you might recognize that the starting material is a hemiacetal. Under basic conditions, hemiacetals are in equilibrium with a carbonyl and an alcohol. Also, since the reaction is under basic conditions, it is likely that something will get deprotonated. The two alcohol protons are the most acidic protons in the starting material so these are likely candidates.

4. Start pushing arrows. In our analysis of **Example 3**, we suggested that deprotonation of one of the alcohols would be a reasonable first step under basic conditions. We also recognized that our starting material contains a hemiacetal. It therefore might make sense to begin by deprotonating the hydroxyl

group of the hemiacetal. This generates water and an alkoxide. Since we need to lose CH_3OH, we can now do that by having the lone pair on the alkoxide add to the hemiacetal carbon, breaking the C-OCH_3 bond and placing the electrons from the breaking bond on oxygen. We have produced a ketone intermediate that has the exact same number of carbons, hydrogens, and oxygens as the desired product. From here, the mechanism for product formation should be recognizable. Intramolecular (within the same molecule) hemiacetal formation leads to product as shown below.



(a) REMEMBER: write out every step of the mechanism and every intermediate.

(b) It can help to draw your starting material in a similar orientation to your product.

(c) Reevaluate your mechanism at intermediate stages to assess whether you are making productive changes (i.e. getting closer to the structure of the product).

(d) If you get stuck, analyze your intermediates in the mechanism as you did for the starting material in part 2

5. Double check your mechanism:

(a) Do not invoke strongly basic intermediates under acidic conditions. Do not invoke strongly acidic intermediates under basic conditions. For **Example 3**, you should not generate + charges on any of the intermediates.

(b) The net charge in the overall system must be conserved from starting material(s) to product(s).

(c) Check the numbering of carbon atoms in the starting material and product and determine if it is consistent with your arrow-pushing.

(d) Carbon should never have more than 8 valence electrons. In general – watch out for the octet rule (it helps to draw out all implicit hydrogens at the reaction site(s)).

Arrow Pushing Exercises

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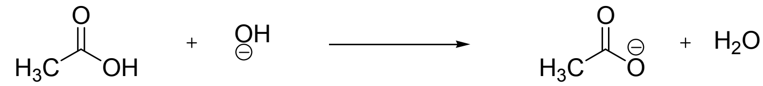

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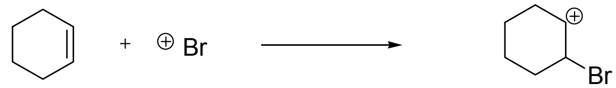

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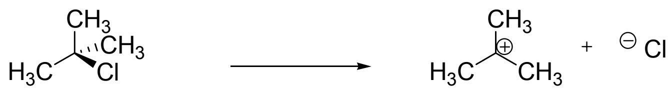

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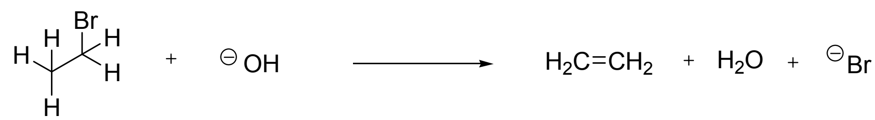

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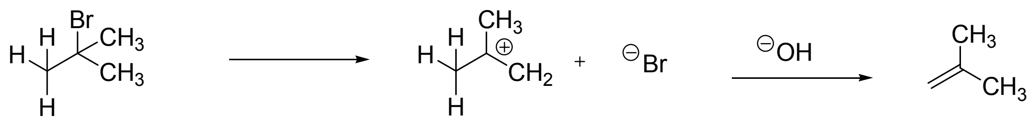

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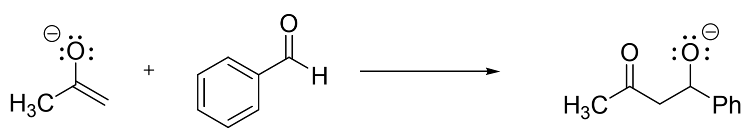

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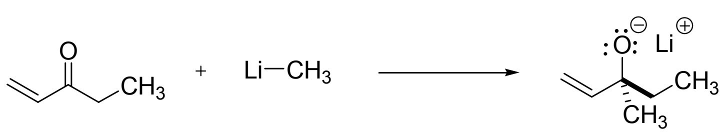

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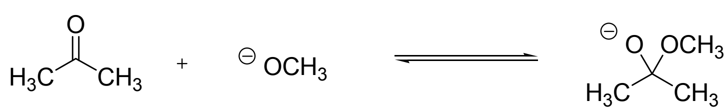

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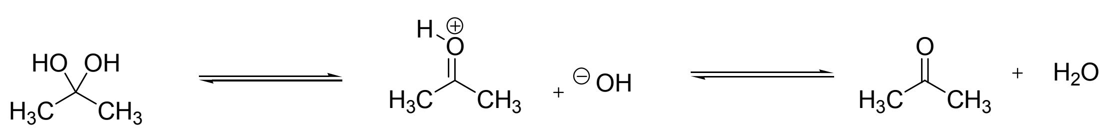

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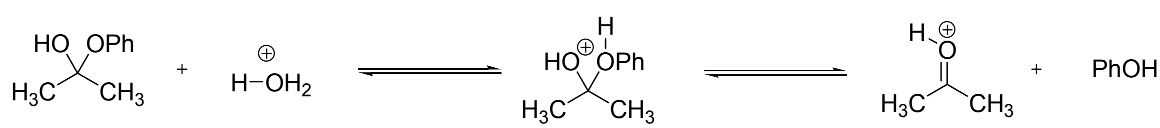

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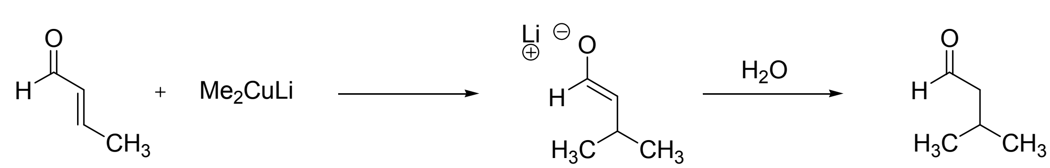

Mechanism Problems

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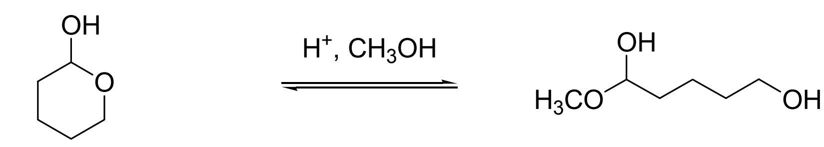

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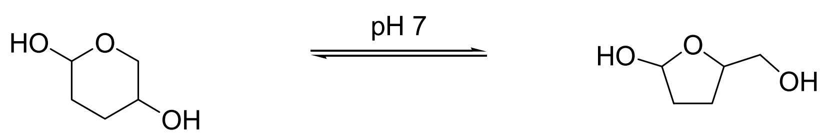

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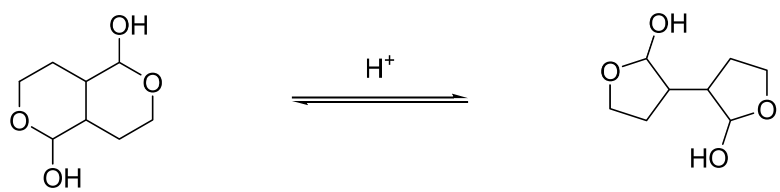

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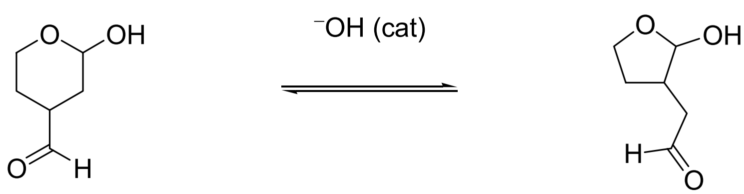

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