Chem 232

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Representation of Reaction Mechanisms

A Simple Guide to "Arrow Pushing"

1. For a given reaction, draw out the structure of the reactants and reagents. Check that you understand what the reagents and the solvent are under the conditions of the reaction, for example, if the reaction is in a base, will one of the compounds exist as an anion?

2. Inspect the starting materials and the products and assess what has happened in the reaction. What new bonds have been formed? What bonds have been broken? Has anything been added or removed? Have any bonds moved around the molecule?

3. Identify the nucleophilic centers in all the reactant molecules and decide which is the most nucleophilic. Then identify the electrophiles present and again decide which is the most electrophilic.

4. If the combination of these two centers appears to lead to the product, draw the reactants, complete with charges, so as to position the nucleophilic and electrophilic centers within bonding distance ensuring that the angle of attack of the nucleophile is more or less consistent with the orbitals involved.

5. Draw a curly arrow from the nucleophile to the electrophile. It must start on the filled orbital or negative charge (show this clearly by just touching the bond or charge) and finish on the empty orbital (show this clearly by the position of the head). You may consider 'push' or a 'pull' mechanism at this stage.

6. Consider whether any atom that has been changed now has too many bonds; if so one of them must be broken to avoid a ridiculous structure. Select a bond to break. Draw a curly arrow from the centre of the chosen bond, the filled orbital, and terminate it in a suitable place.

7. Write out the structures of the products specified by the curly arrows. Break the bonds that are the sources of the arrows and make those that are the targets. Consider the effect on the charges on individual atoms and check that the overall charge is not changed. Once you have drawn the curly arrows, the structure of the products is already decided and there is no room for any further decisions. Just write what the curly arrows tell you. If the structure is wrong, then the curly arrows were wrong so go back and change them.

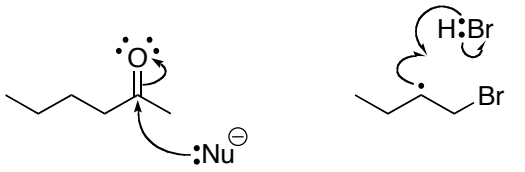
8. Repeat stages 5-7 as required to produce a stable product.

A Dozen Hints for Writing Organic Reaction Mechanisms

When writing reaction mechanisms please take note of the suggestions below. Some of the common mistakes that students make are illustrated as well as some of my personal preferences in writing mechanisms.

Hint 1

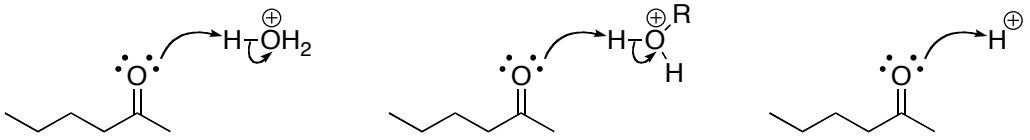
The convention for curved arrow pushing dictates that the tail of the arrow begins at the source of the electrons being pushed and the head of the arrow points to the acceptor atom. Use double-barbed arrows for ionic mechanisms (i.e. pushing two electrons at a time) and use single-barbed arrows for radical mechanisms (i.e. pushing single electrons).



Ionic nucleophilic addition Radical addition

Hint 2

Do not protonate species with "free" H^+. You should use the appropriate form of the acid as it exists in solution. Under aqueous conditions this is most often the hydronium ion (H_3O^+).



Correct *Correct* *Incorrect*

Hint 3

When protonation is required in basic (^-OH) solution you should not use H^+ or H_3O^+ as the proton source. The proton source should be the conjugate acid of the base (e.g. water in aqueous solution). There may be other possible acids present depending on the reaction conditions. Just make sure the species that you are using would actually be present under the reaction conditions.

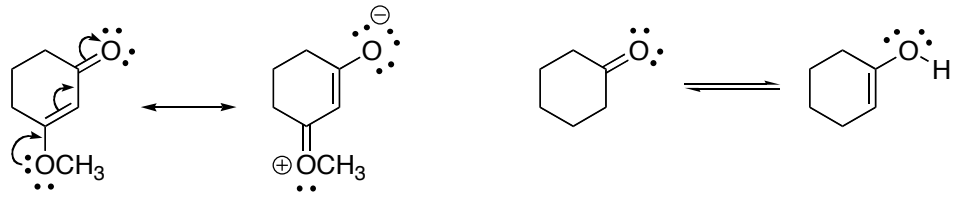
Hint 4

When deprotonation is required in acidic (H^+) solution you should not use ^-OH as the base. The base used to abstract the proton will frequently be water or a heteroatom (e.g. O, N, S) that is part of the solvent or other reagent present. There may be other possible bases present depending on the reaction conditions. Just make sure the species that you are using would actually be present under the reaction conditions.

Hint 5

Do not confuse equilibrium with resonance. Be sure to use the double-headed arrow to represent resonance structures and two separate arrows to represent equilibrium. "Mechanism arrows" are, however, used to show the electron movement necessary to **represent** two or more possible

resonance structures but this should never be taken to mean the structures have a separate existence. They do not!



Resonance
(electrons move, atoms don't)

Equilibrium
(atoms move)

Hint 6

Avoid the use of unimportant or minor resonance structures in writing mechanisms unless the structure is crucial for explaining the mechanism (this is rare). Sometimes even "important" resonance structures (such as ones where atoms do not have octets of electrons) contribute very little to the understanding of the mechanism since the mechanism can always be written using the structure where all atoms have an octet.

Unimportant Resonance

Important but Unnecessary Resonance
(Mechanisms are easily and clearly written with the left structure.)

Priority 1: No first-row elements (B, C, N, O) can have more than eight electrons in its valence shell

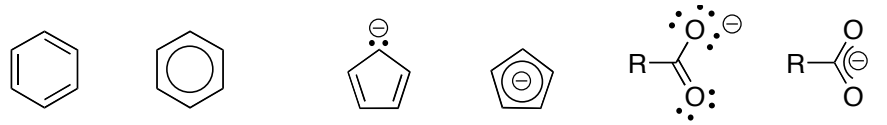
Priority 2: Resonance structures in which all atoms are surrounded by an octet of electrons are almost always lower in energy than those resonance structures in which one or more atoms are electron deficient. If there are electron deficient atoms they should be electropositive (C, B) and not electronegative (N, O)

Priority 3: Resonance structures with charge separation are typically higher in energy than those without.

Priority 4: If charge separation exists in a resonance structure, then the electronegative atoms should gain the formal negative charge and *vice versa.*

Hint 7

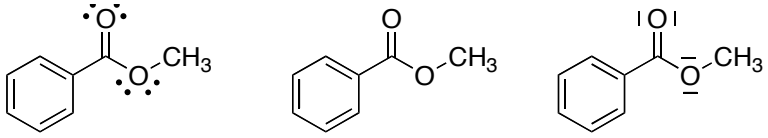
Do not use "shorthand", "inexact", or "dashed-line" structures meant to indicate several possible resonance structures at once. These are usually not useful for electron pushing.



Useful Not Useful Useful Not Useful Useful Not Useful

Hint 8

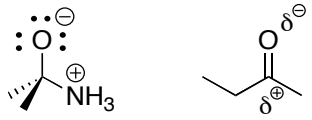
Although some texts use "lines" to represent lone pairs of electrons, this is rare in modern usage and often leads to confusion. Do not do this since the lines are easily confused with negative charges and bonds. In general, show all lone pair electrons and you will be less likely to make a mistake.



Best (When you are starting out) Good (When you are experienced) Never

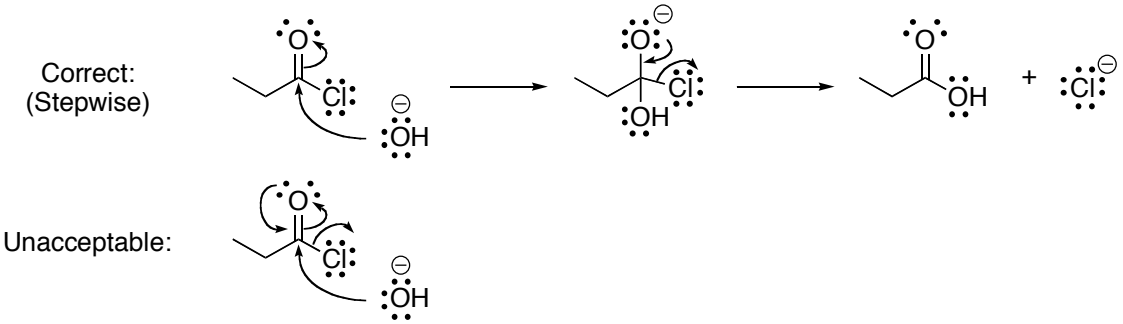
Hint 9

Keep track of formal charges and write them very close to the atom on which they reside. Never use charges in parentheses to indicate where partial charges reside as a result of other resonance structures. The δ^+ or δ^- symbol may be used to indicate partial charges in the most important resonance structure.



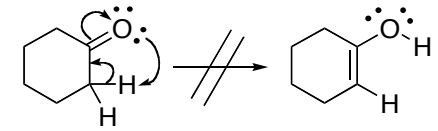
Hint 10

It is usually less confusing, and more likely correct, if you write stepwise mechanisms rather than trying to push too many electrons around in a single step. Even this can be overdone, however, and it does not mean that each step should include only a single arrow. You will develop some chemical intuition, which will help you predict whether a reaction occurs in a stepwise or concerted fashion.

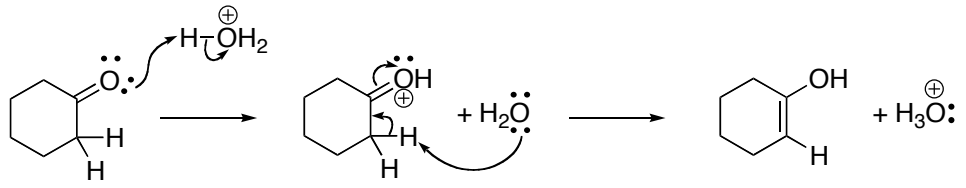


Hint 11

Consider the geometrical constraints of the compounds with which you are dealing. It may be convenient to write certain intramolecular proton transfers, for example, but you should understand that these might be geometrically impossible. This is a situation that one frequently sees "shorthanded" when discussing keto-enol tautomerism. The chemical cognoscente will understand these geometrical limitations and they may even use this method to save time in writing mechanisms. However, if you are going to pretend to belong to this group, make sure you can "walk the walk if you talk the talk."



Geometrically Impossible



\ Likely Pathway (Stepwise)

Hint 12

Always consider the pK_a of the sites involved when you are considering protonation sites or expulsion of leaving groups. The more basic site, which may be affected by resonance, will be protonated first and poor leaving groups may require protonation to convert them into better leaving groups.