

order to regenerate the stationary phase surface of the suppressor column.

Problems:

1. Write down the existing methods for anion analysis.
2. State the advantages of ion chromatographic technique over other existing techniques for ion analysis.
3. Write down the chemical reactions relevant to the separations of cations using suppressed ion chromatographic technique.
4. Briefly describe how the micro membrane suppressors would operate in ion exchange chromatography.
5. Provide six applications of ion exchange chromatography.

Introduction to Organic Reaction Mechanisms

Susanthi Jayasinghe

Senior Lecturer, Department of Chemistry, Faculty of Science, University of Peradeniya

Organic reactions are chemical processes that involve organic substances. The fundamental types of organic chemistry reactions include substitution reactions, elimination reactions, addition reactions, redox reactions, pericyclic reactions, and rearrangement reactions.

A reaction mechanism is a step-by-step series of simple reactions that allows for overall chemical change occurs. Every organic reaction involves both an Electrophile and a Nucleophile.

Let's find out what is a nucleophile?

A nucleophile is a substance that can donate an electron pair during a process. The word "nucleophile" means nucleus loving and denotes that it targets areas of the substrate molecule with low electron densities (positive centers). A nucleophile can be represented by a general symbol Nu. Nucleophile acts as electron source for arrows making new bonds in writing reaction mechanisms. These could be neutral molecules with unbound electron pairs or negative ions, such as carbanions and some example of nucleophiles are Cl^- , Br^- , I^- , CN^- , OH^- , RCH_2^- , NH_3 , RNH_2 , H_2O , ROH .

What is an Electrophile ?

An electrophile is a substance that can accept a pair of electrons during a reaction. The word "electrophile," which means to "electrons-loving," denotes that the substance reacts with areas of the molecule with a high density of electrons (negative centers). Electrophiles are

deficient in electrons and the general symbol E^+ can be used to denote an electrophile. Electrophile serve as **sinks** for these arrows in writing reaction mechanisms.

These could be neutral molecules with electron-poor centers or positive ions, such as carbonium ions and examples include H^+ , Cl^+ , Br^+ , I^+ , NO_2^+ , R_3C^+ , $^+\text{SO}_3\text{H}$, AlCl_3 , and BF_3 .

A molecule or portion of a molecule that acts as a source for such arrows is said to be nucleophilic, whereas a molecule or portion of a molecule that acts as a sink for such arrows is said to be electrophilic.

Success in organic chemistry classes depends on the student's ability to write an organic reaction mechanism properly. Arrow pushing is a method used by organic chemists to represent the flow or motion of electrons during chemical processes.

What Is an Arrow Pushing?

Arrow pushing demonstrates how to convert A into B while giving us a thorough understanding of how the products are made. **Arrow pushing** takes electrons from nucleophile to electrophile.

There are few important points to bear in mind when writing an organic reaction mechanism:

1: The movement of electrons is showed by using arrows.

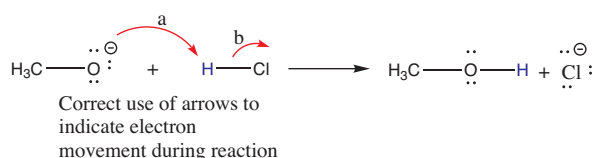
There are two different types of arrows (double sided arrowhead and single sided arrowhead) used in writing

reaction mechanisms. A regular arrow or a double-sided arrow is used to show the movement of two electrons, while a line with a single-sided arrowhead which involved in radical reactions is used to demonstrate single electron movement.

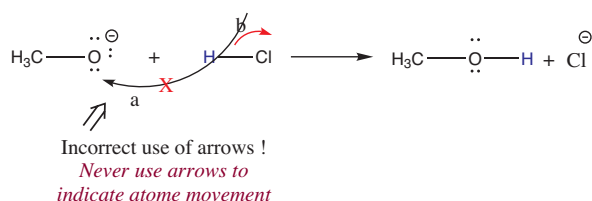


2: An arrow never be used to represent an atom's movement. The arrows indirectly depict atom movement along with bond formation and breaking.

Let's consider following reaction in which a proton is transferred from the relatively acidic H-Cl molecule to the comparatively basic methoxide anion. In this reaction nucleophile is the basic oxygen atom of the methoxide anion and electrophile is the relatively acidic proton of HCl. One arrow (labeled "a" in the diagram) is used to represent this process. It begins at a pair of unpaired electrons on the basic oxygen atom of the methoxide anion and goes to the acidic H atom of H-Cl to represent the formation of the new bond. A second arrow (arrow "b") begins at the line that represents the H-Cl bond breaking, and points to the Cl atom to indicate the formation of a lone pair. The arrows show how the relevant electrons are moving while the proton is transferred between molecules in this process.



Students frequently make the error of writing an arrow that incorrectly points from the H of the H-Cl to the O atom of the methoxide anion. This is incorrect since an arrow like that would be showing the movement of the H atom, not the movement of an electron.



We begin the arrow at the electron pair and conclude it at an electron deficient atom in order to form a bond. We have the option of creating a new single bond, double

bond, or triple bond. Always draw the arrow pointing in the direction that the electrons will move. In other words, always start the arrow at the atom with the most electrons rather than the one with the few.

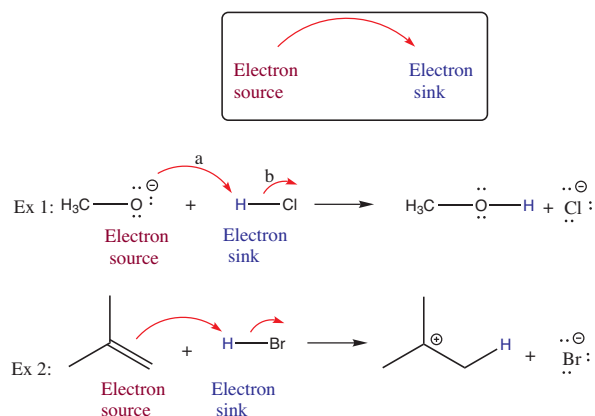
3. Arrows always start at an electron source (nucleophilic atom) and end at an electron sink (electrophilic atom).

Electron Sources and Sinks:

An **electron source** is a bond or a lone pair of electrons. It is either a π bond or a lone pair on an atom of relatively high electron density in a molecule or ion, or a bond that must break during a reaction. **Nucleophiles** act as **electron sources** for arrows making new bonds.

An **electron sink** is an atom on a molecule or ion that can accept a new bond or lone pair of electrons. **Electrophiles** serve as **sinks** for these arrows.

In the given example 1, electron source is the O atom of the methoxide anion and electron sink is the relatively electropositive proton of the HCl. Arrow start from the lone pair electrons of the O and end at the proton. In the example 2, the electron source is the π bond of the olefin and the electron sink is the proton of the HBr.



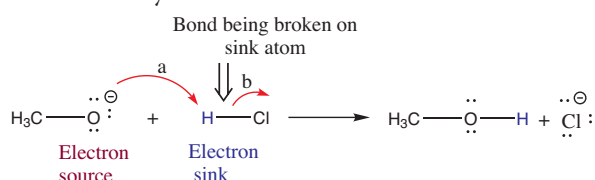
Identification of the electron source and the sink for the given step is very important. One reaction could have several steps. Each and every step, arrow will be starting from the electron source and end at the electron sink. For example, for arrows that depict the formation of new σ bonds, the electron source is often readily identified as being a lone pair on the most electron rich atom of a molecule or ion, and the electron sink is readily identified as the most electron poor atom of a molecule or ion. Thus, the prediction of electron sources and sinks could be achieved concerning the differences in electronegativity between atoms which allow you to identify partial and

formal negative and positive charges in molecules.

Making a new bond to an electrophilic atom often requires the simultaneous breaking of one of the bonds present at the electrophilic atom in order not to violate octet rule for an atom (remember that the 'octet rule' tells us that elements in the second row of the periodic table can have a maximum of eight valence electrons)

4. Breaking a bond of an electrophilic atom is required in order to avoid overfilling valence (hypervalence) on an electrophilic atom.

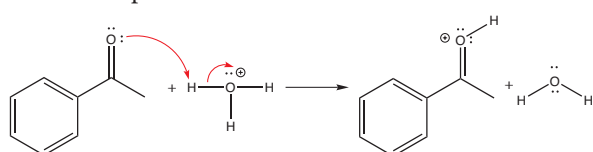
In the given example below, the bond that is being broken serves as the electron source for the arrow (arrow b), and the sink is an element that can accept the electrons as a lone pair, typically an electronegative atom like an Cl atom (halogen) or oxygen. Resonance delocalization or other stabilizing interactions are frequently used to stabilize newly formed ions.



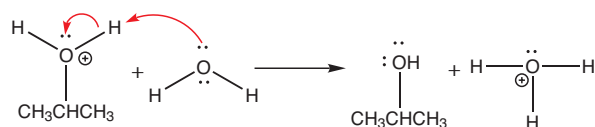
When seen in the context of the third rule, the methoxide O atom is the electron source or the (the most negatively charged atom) and the H atom of HCl is the electron sink. The H-Cl bond needs to be broken (arrow "b") in order to prevent the reaction from overfilling the valence of the H atom. By doing this, the chloride anion is formed.

Most of the organic reactions follows very similar patterns of arrows and hence it is worth to identify the common steps that present in many organic reactions. Following are some examples for such common patterns.

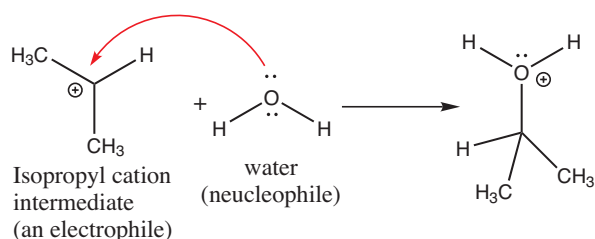
1. Add a proton - Most of organic reactions are acid or base catalyzed. If a strong acid is present and nucleophilic atom is available, we could start the mechanism with addition of proton as follows.



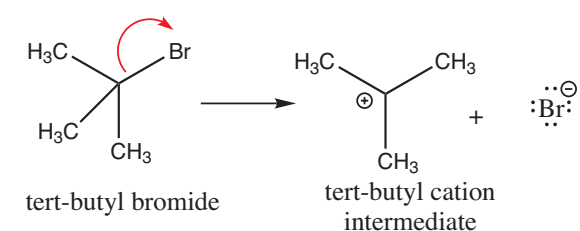
2. Take a proton away - When the molecule has a strongly acidic proton or there is a strong base is present, use this element.



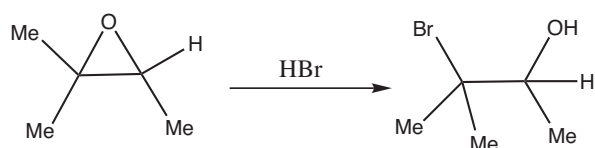
3. Make a new bond - When there is electrophile and a nucleophile is present make a new bond between a nucleophile (source for an arrow) and an electrophile (sink for an arrow).



4. Break a bond - When this is no suitable electrophile or a nucleophile or, proton transfer reaction, break a bond so that relatively stable molecules or ions are created.

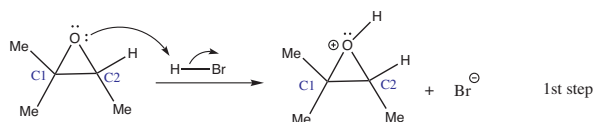


Let's write mechanism for following epoxide opening reaction.

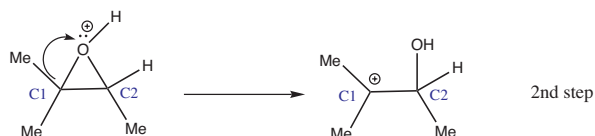


In this reaction epoxide and HBr is given as the starting materials. We need to identify what molecule will act as the nucleophile and electrophile. Here the O of the epoxide could serve as the nucleophile, while the relatively acidic proton of HBr could serve as the electrophile.

Then we could apply the common step "add a proton" for the first step of this reaction mechanism. In order to prevent the hypervalency at H, H-Br bond is broken and will provide stable bromide anion.



As you could see in the second step, C1 or C2 has to act as the electrophile and bromide will be the nucleophile. However, bromide could not attack at the sterically crowded carbon center and then common step "break a bond" could be applied in this step. Breaking of C1-O as well as C2-O bond are possible. However, the formation of the most stable tertiary carbocation at C1 will be much faster than the formation of C2 secondary carbocation and hence bond breaking at C1-O will be happened.



In the next step we have electrophilic carbocation and bromide nucleophile, which could make bond easily to provide the given product.



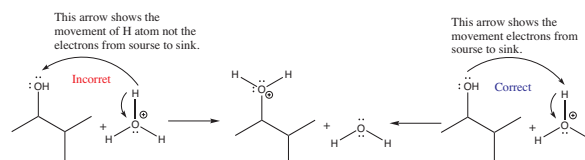
Common Mistakes in Arrow Pushing

So far, we have discussed how to write a mechanism for a given reaction. It would be beneficial to know the common mistake that students do when writing a mechanism. The mistakes given below are the ones seen most often in teaching Introductory Organic Chemistry.

Reversing the direction of one or more arrows during a chemical step is the most common mistake made by students when writing organic reaction mechanisms.

Backwards arrow pushing usually derives from a student thinking about the movement of atoms, not the movement of electrons. Hence, to avoid this mistake it is important to remember that arrows depict how electrons move, not where atoms move, within or between chemical structures. Further, one can avoid this mistake by remembering that every arrow must start at an electron source (a bond or lone pair) and terminate at an electron sink (an atom that can accept a new bond or lone pair).

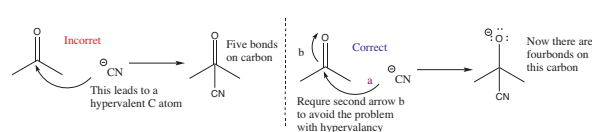
In this example, incorrect and correct mechanisms are shown.



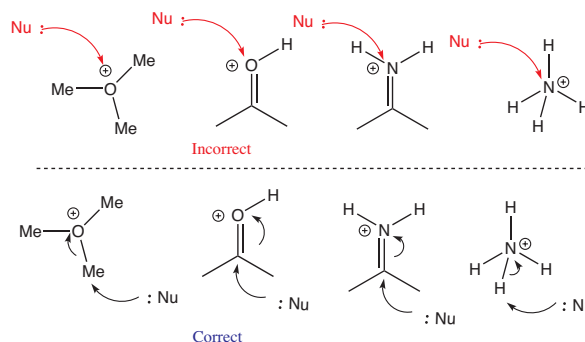
A second common mistake in writing arrow-pushing schemes is to not use enough arrows. This usually results from not keeping track of all lone pairs, bonds made, or bonds broken in a mechanism step. In other words, if you analyze exactly the new position of electrons resulting from each arrow, missing arrows will become evident.

In the following example we compare two arrow-pushing scenarios, one of which is missing an arrow.

In the incorrect scheme there is no arrow that indicates breaking of the C=O bond of the reactant and formation of oxide anion. Note that when an arrow is missing, the result is commonly too many bonds and/or lone pairs on one atom (see the next section on hypervalency) and not enough bonds or lone pairs on another. The correct mechanism arrow b is used to prevent the problem.



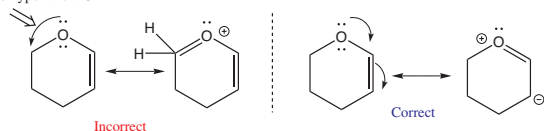
Hypervalency is another mistake which could be resulted by forgetting to count all lone pairs of electrons, or the number of hydrogens present or making more bonds than an atom could accommodate. The following examples show a negatively charged nucleophile incorrectly adding to the formal positive charge atoms. This may look correct because atoms with positive and negative charges are being directly combined, but when counting bonds and lone pairs of electrons, it is found that each atom (in this case O or N) end up with higher number of valence electrons. Hence, this is a mistake.



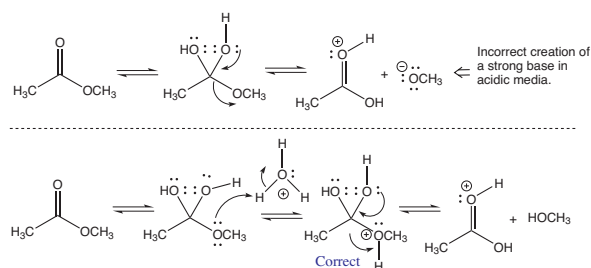
Following example shows another common way that the students mistakenly end up with a hypervalent atom

by forgetting the presence of hydrogens that are not explicitly written. In the incorrect structure the arrow drawn depicts the formation of a new bond to a carbon that already has four bonds. In the correct structure once the lone pair electrons of the oxygen moved, π bonding electrons of the olefin also moved to form anion.

This arrow is incorrect because it leads to hypervalent C

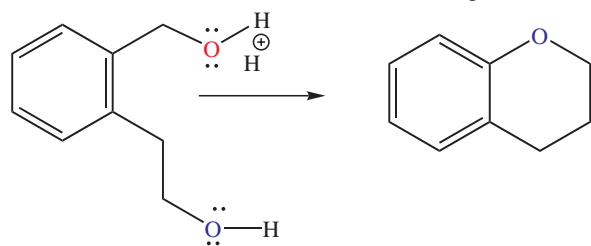


Mixed media errors are also very commonly identified mistake in writing mechanism. Acids and bases are catalysts, reactants, products, and intermediates in many organic chemistry transformations. However, we found generation of strong acids in a reaction mechanism, when a reaction has performed in strongly basic media or generation of strong base when a reaction is performed in strongly acidic media; which is an error. In strongly acidic media, all the intermediates and products will be either neutral or positively charged, while in strongly basic media, all the products and intermediates will be neutral or negatively charged.



In the above example strong base methoxide is generated in acidic media is a commonly found error in writing mechanisms and the correct way is to generation of neutral MeOH as shown in the scheme.

Let's write a mechanism for another reaction given below.

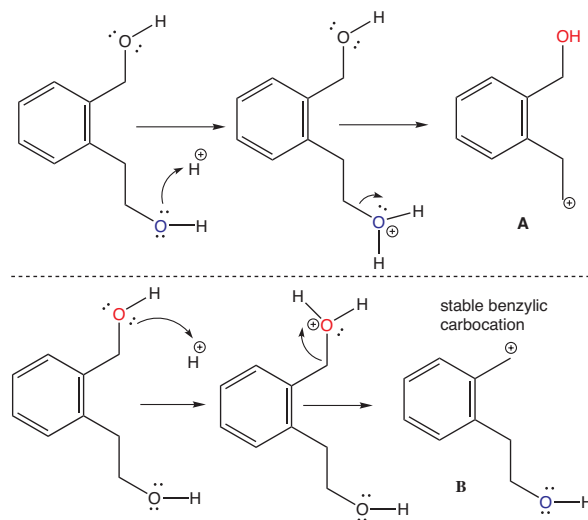


In this reaction two O atoms are available that could serve as the nucleophile and proton act as the electrophile.

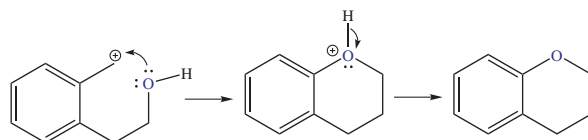
Note that only one O will be reacting as the nucleophile.

If a reactant has more than one functional group which can donate a pair of non-bonded or pi electrons, an inspection of the structures of reactant and products will usually reveal which functional group will react initially.

Here, while a pair of non-bonded electrons can be donated by either oxygen (OH), the reaction takes place preferentially at the one that leads to the more stable benzylic carbocation (B) as opposed to the less stable primary carbocation (A).



In the next step, intramolecular cyclization followed by the loss of proton provide the desired product.



Problems:

- write arrow pushing mechanisms for following reactions.

