Chemistry 243 Mini-Review

I have put this document together as a quick review of the reactions that we have covered in organic chemistry. It is not a comprehensive list and is not meant to replace your textbook or class notes.

Acid/Base Reactions

Most organic chemistry can be considered to be an acid and base reaction. There are two classes of acids and bases; Brønsted and Lewis

Brønsted Acids and Bases.

Anything that has a proton on it is a Brønsted acid. Anything that can accept a proton is a Brønsted base. Of course, some acids are soooo weak that we don't think of those protons as being acidic, we think of the deprotonated form of that weak acid being a strong base.

Here we see a strong acid donating a proton onto an amine. The products are a very weak base and a weak acid. This reaction has an equilibrium constant of about 10^{16}. At equilibrium it would be unlikely that you could detect any of the reactants. So this reaction is written with a one-way arrow as it goes to completion.

Reaction 1
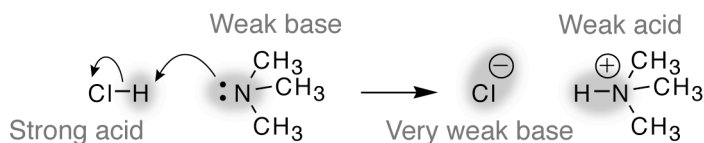
Here we see a weak acid donating a proton to a weak base. The product is a strong acid and a weak base. The equilibrium constant for this reaction is about 10^{-6}. At equilibrium there will be a small but detectable amount of product present. Since both reactants and products exist at detectable concentration after equilibrium is reached, we write this reaction with equilibrium arrows.
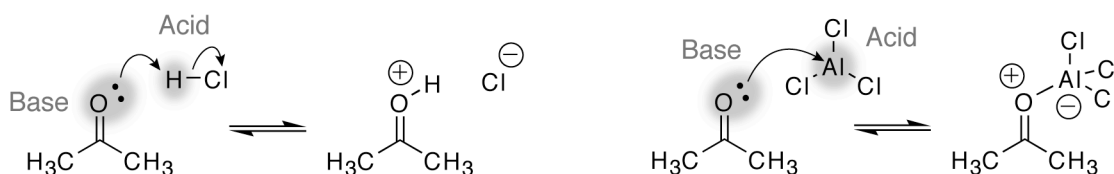
Reaction 2
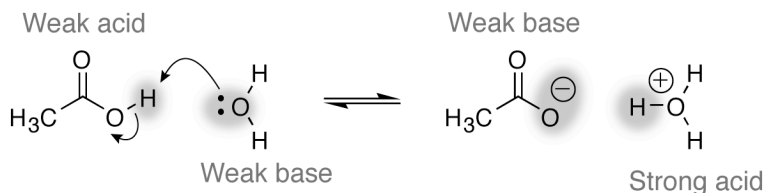
All reactions can be written with equilibrium arrows. We use the one-way arrows when we know that the reaction goes almost entirely to completion or when we are choosing to consider only the forward reaction at the time.

Lewis Acids and Bases

Anything that can accept a pair of electrons is a Lewis acid. Anything that can donate a pair of electrons is a Lewis base.

Observe that from the Lewis point of view, a Brønsted acid is a Lewis acid because a proton accepts a pair of electrons when it is transferred to a base. A Brønsted base is a Lewis base because a base donates a pair of electrons to a proton. All Brønsted acids and bases fit the Lewis definition. The Lewis definition is more general and can be used in acid/base reactions where protons are not involved.

Below we see a carbonyl group interacting with a proton and a metal atom in acid/base reactions. Both reactions fit the Lewis definition but only one fits the Brønsted definition.
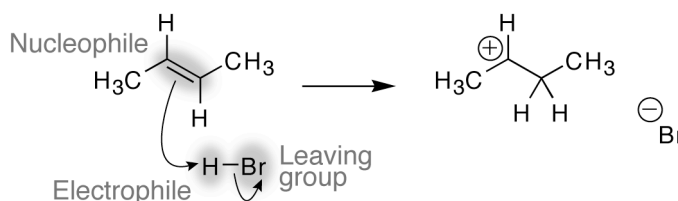
Nucleophiles and Electrophiles.

Addition of an electrophile to an alkene

A double bond is a weak nucleophile and will react with a strong electrophile, like the proton of a strong acid.

Reaction 3

In the example above, the electron pair of the π-system donates into the proton. Protons (hydrogen atoms) can only have one bond so the electron pair of the H–Br bond moves to the bromine. Bromine is fairly stable with a negative charge (it is an electronegative atom after all) and so is an excellent leaving group.
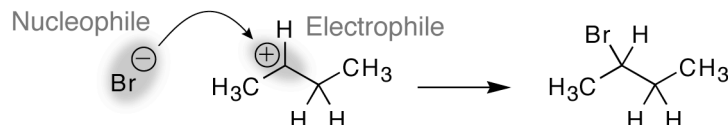
The above reaction could also be described as a Lewis or Brønsted acid/base reaction.

Nucleophilic attack on an electrophile.

The above reaction is an example of a nucleophile attacking the electrophile. As a matter of fact, most reactions in this course are: 1) a nucleophile adding to an electrophile or 2) a leaving group (nucleophile in reverse) leaving an atom (electrophile in reverse). So it's mostly all the same reaction in forward or reverse. Over and over again.

So here is a nucleophilic attack on an electrophile.

Reaction 4

The above reaction could also be described as a Lewis acid/base reaction.

Note that the above two examples of a nucleophile adding to an electrophile result in the complete mechanism for addition across a double bond.

Your Done

Congratulations! You have completed the course. Well, 90% of it anyways.

That's right, you have now seen every single reaction in this course. This organic chemistry course focused almost entirely on reactions whose every step consists of a Lewis acid/base reaction (or the reverse). All nucleophiles are Lewis bases, all electrophiles are Lewis acids.

Putting It All Together

So, using only reactions where a pair of electrons (in a lone pair or a π-system) moves into an atom that can accept them (an atom with a leaving group, an atom with less than a full valence shell, etc…), we can examine some major types reactions.

Electrophilic addition to double bonds

This is an addition to a double bond where the first step is addition of an electrophile.

A double bond donates the electrons of the π-system to an electrophile. The electrophile adds at one of the two carbon atoms and the other becomes a strong electrophile with a deficient valence shell. Subsequently, a nucleophile attacks this strong electrophile and the addition is complete. In summary: We have added a strong electrophile to the weakly nucleophilic double bond to give the addition product, which is a strong electrophile. Then just about any nucleophile, weak or strong, can add to this strong electrophile.

See the above reactions 3 and 4 for the two steps of addition of HBr to an alkene.

Electrophilic substitution of benzene

This is a substitution of benzene where the first step is addition of an electrophile.

The first step is identical to reaction 3: an electron pair from the π-system attacks an electrophile to give an addition product that is a strong electrophile. The proton of HBr is not a strong enough electrophile because benzene is a very weak nucleophile. It is weak because moving an electron pair out of the π-system breaks the aromatic electronic arrangement. An example of an electrophile that is strong enough is the nitronium ion.

Reaction 5
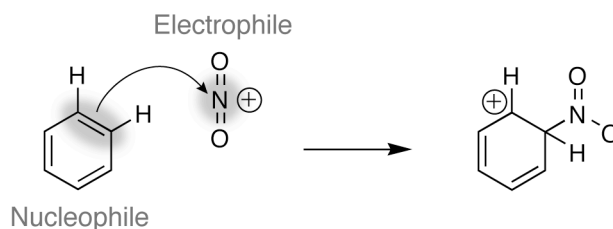
The above reaction could also be described as a Lewis acid/base reaction.

The second step is the elimination of a proton to reestablish the aromatic system. This elimination occurs much faster than any external nucleophile can add to the electrophile. This step is identical to reaction 3 in reverse. Here we see nucleophilic attack of the sulfuric acid lone pair on the proton with the benzene ring being the leaving group.
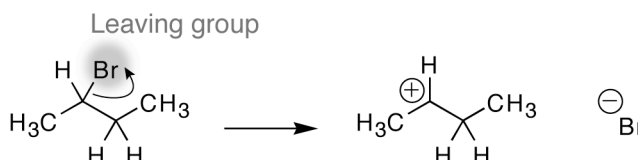
Reaction 6
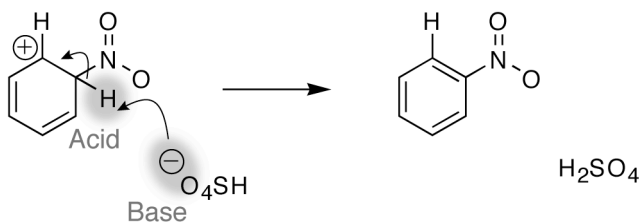
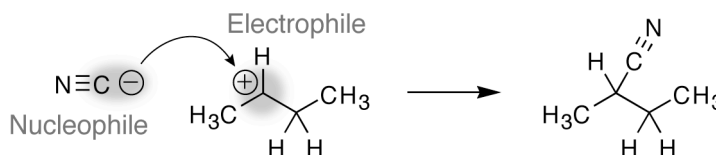The above reaction could also be described as a Lewis or Brønsted acid/base reaction.

Unimolecular nucleophilic substition (S_N1)

This is a reaction where a leaving group is replaced by a nucleophile and the first step is the unimolecular elimination of the leaving group. This is identical to reaction 4 (in reverse). For this reaction to happen we must have a good leaving group and the resulting carbocation cannot be too high in energy.

Reaction 7

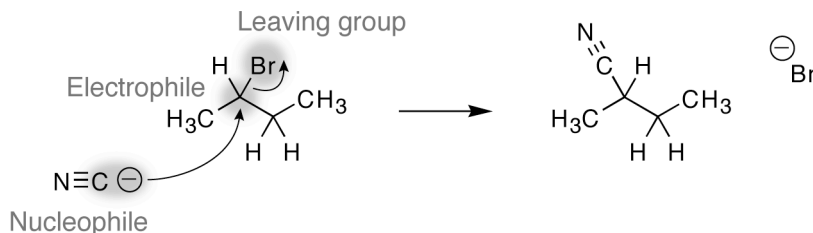The above reaction could also be described as a Lewis acid/base reaction.

The second step is addition of the nucleophile to the strong electrophile. Just about any nucleophile can add to a strong nucleophile. In this example we will have a cyanide ion as the nucleophile.

Reaction 8

The above reaction could also be described as a Lewis acid/base reaction.

Bimolecular nucleophilic substitution (S_N2)

This is a reaction where a leaving group is replaced by a nucleophile and the reaction occurs in one step with the nucleophile displacing the leaving group directly. This is identical to reaction 3 (where a nuclephile attacks the proton and displaces the bromide leaving group).
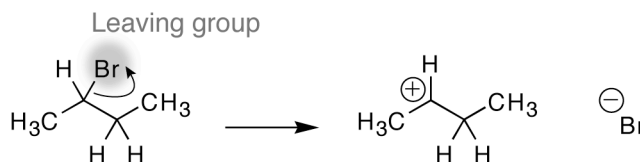
Reaction 9

The above reaction could also be described as a Lewis acid/base reaction.
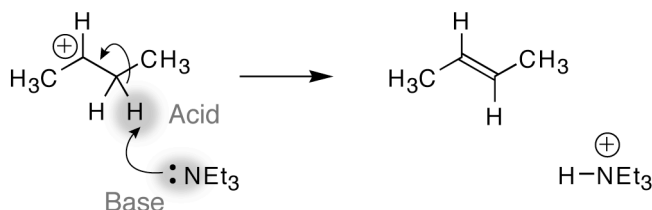
Unimolecular elimination (E1)

If the leaving group is a good leaving group and the carbocation is low enough in energy, this mechanism may be the fastest way to eliminate a group and create a double bond. The first step is identical to reactions 4 and 7.

Reaction 10

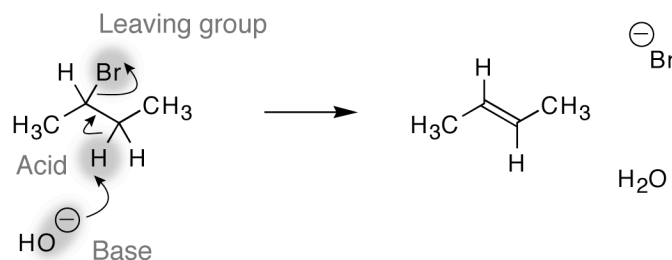The above reaction could also be described as a Lewis acid/base reaction.

The second step is identical to reaction 1 and 6

Reaction 11

The above reaction could also be described as a Lewis or Brønsted acid/base reaction.

Bimolecular elimination (E2)

If the E1 mechanism passes through an intermediate with too high an internal energy or if the leaving group is not good enough to depart on its own, we can have a one step reaction. Here a base removes a proton and the electrons in the C–H bond move towards the leaving group and push it out. In some ways you could look at the electrons of the C–H bond as the nucleophile that pushes out the leaving group.
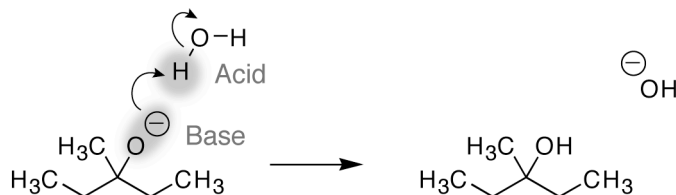
Reaction 12

Addition to a carbonyl group

Here a nucleophile attacks the electrophilic carbon of the C=O double bond. The electrons in the π-system move towards the electronegative oxygen. This is a one step reaction. The second step is an acid/base reaction where the alkoxide product is protonated to give an alcohol.

Reaction 13
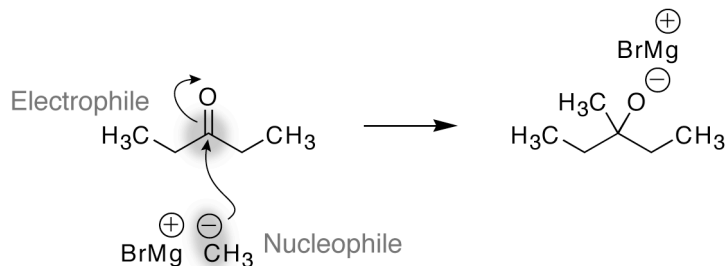
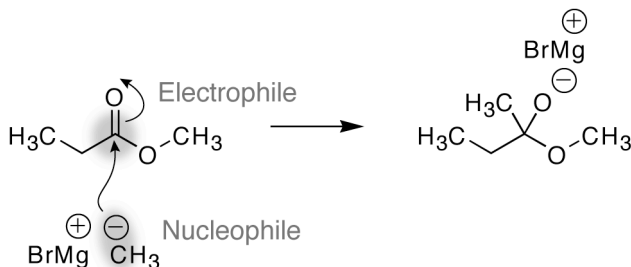The above reaction could also be described as a Lewis acid/base reaction.

Reaction 14

The above reaction could also be described as a Lewis or Brønsted acid/base reaction.

Substitution at a carbonyl group

The first step is identical to reaction 13.

Reaction 15

The above reaction could also be described as a Lewis acid/base reaction.

In the second step, the alkoxide ion acts as a nucleophile and pushes out the leaving group as a π-system is established. This type of elimination, driven by electron movement within the molecule, can push out even poor leaving groups. The methoxide anion is a poor leaving group but can be ejected by an intramolecular nucleophile.

Reaction 16
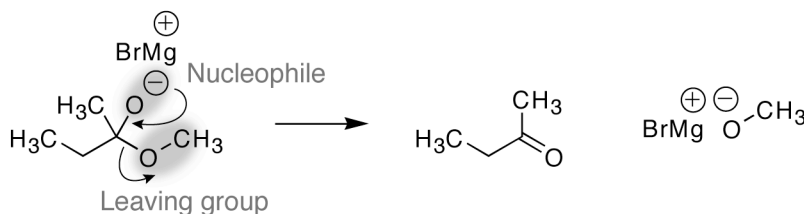
The above reaction could also be described as a Lewis acid/base reaction.

More Complex Reactions

Now that we have seen that every single reaction that we know is an example of reaction 1,3,4, 15 or 16 we can start mixing and matching these reaction steps to understand slightly more complicated reactions.

Aldol condensation

Can we understand how this product is obtained using just the 5 reactions that we know?
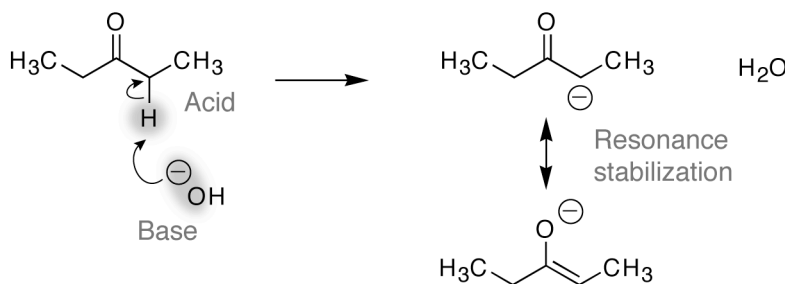
Reaction 17
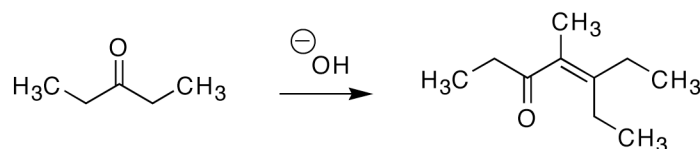
This reaction can be understood as a series of steps where each step is already known to us.

In the first step we make a nucleophilic carbanion using a base. Hydroxide ion is a strong enough base to have a very small amount of the carbanion present at equilibrium. This small amount of nucleophile is all we need. This is identical to reaction 1.
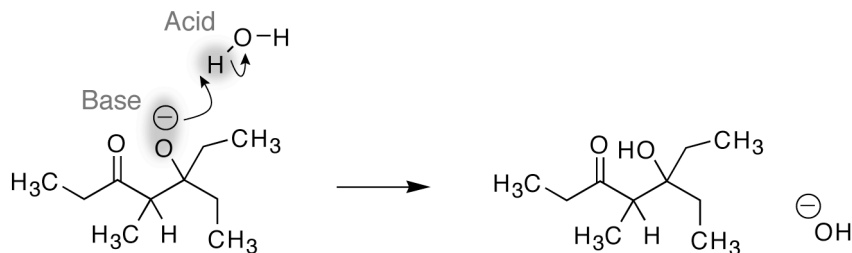
Reaction 18

In the second step this nucleophile adds to a carbonyl group of another pentanone molecule. This is identical to reaction 15
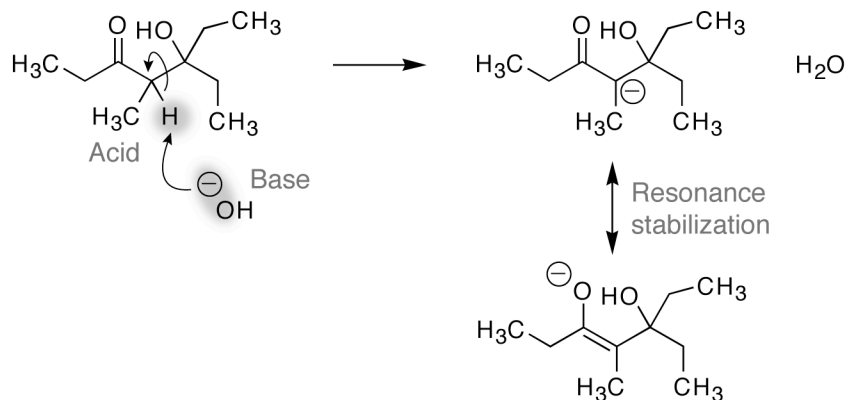
Reaction 19
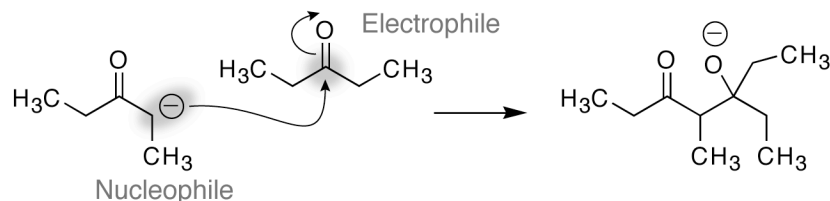
Now to make the required double bond we must eliminate a hydroxide group. A series of acid/base reactions can bring us to the required structure for elimination.
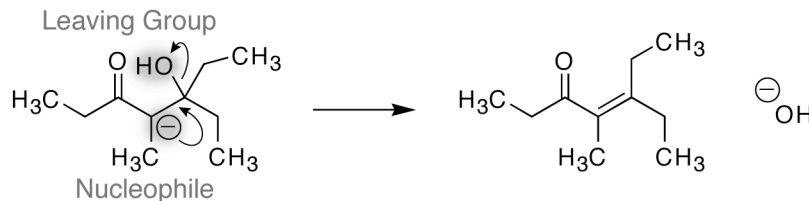
Reaction 20

Reaction 21

Reactions 20 and 21 accomplish the conversion of the alkoxide to its tautomer, the enolate anion. The lone pair on the enolate can push out the hydroxide leaving group (a poor leaving group) the same way as in reaction 16.

Reaction 22

Observe that hydroxide is a reactant in the first reaction and a product of the last. Hydroxide is therefore a catalyst for the Aldol condensation.