Chemistry 2000 Slide Set 18: Reactions of organic compounds

Marc R. Roussel

March 13, 2020

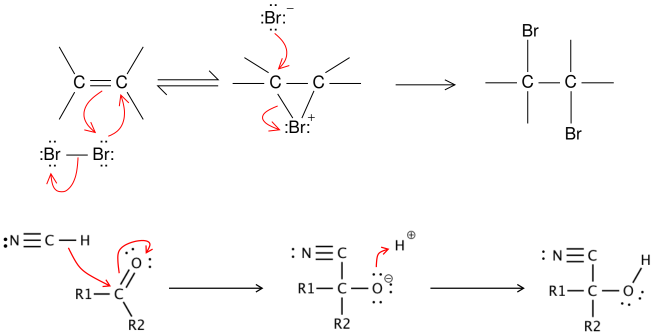
Reactions of organic compounds

- Organic chemists carry a lot of reactions in their heads.
- Like most knowledge, it's easier to remember if it's organized.
- Organic chemists organize their knowledge of reaction chemistry by grouping reactions into types and by recognizing common patterns of reactivity.
- Patterns of reactivity are in turn often associated with particular functional groups.

Some important types of organic reactions

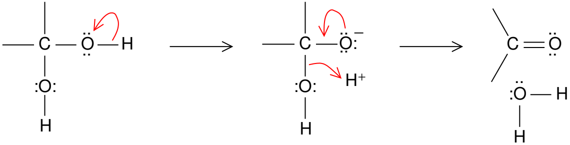
Addition: Double or triple (π) bonds are "opened up" to form new single bonds.

Examples:



Elimination: Loss of two substituents across a bond, resulting in a new π bond.

Example:



Substitution: The name is self-descriptive. . .

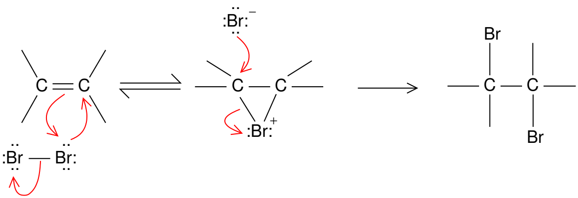
Examples:

$$\mathrm{CH_3I + Cl^- \rightarrow CH_3Cl + I^-}$$

$$\mathrm{CH_3Cl + OH^- \rightarrow CH_3OH + Cl^-}$$

Redox reactions: Many organic reactions are in fact redox reactions, including several of the example reactions we have already seen.

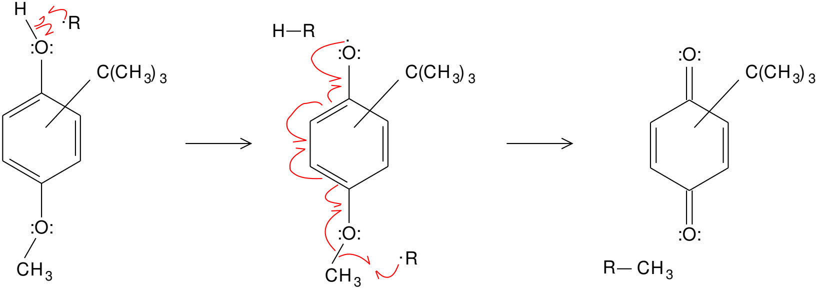
Example: In the bromination of an alkene,



the oxidation state of the carbon atoms increases by 1, i.e. carbon is oxidized.

Example: BHA as an antioxidant

BHA (don't ask for the systematic name) is a food additive that protects food from oxidation by scavenging free radicals:

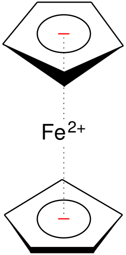


The oxidation state of the carbons bonded to O increases from 1 to 2, i.e. these carbon atoms are oxidized.

Electrophiles and nucleophiles

Electrophiles	are Lewis acids, i.e. species that tend to gain pairs of electrons in reactions. Electrophiles are themselves electron deficient, i.e. they could hold more negative charge.
Nucleophiles	are Lewis bases, i.e. species that tend to donate electron pairs to another atom in a reaction. Nucleophiles are electron rich, i.e. they carry excess negative charge. In some cases, π electrons can be considered nucleophilic.

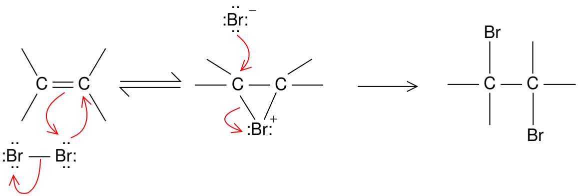
Example: In ferrocene $[Fe(C_5H_5)_2]$, Fe^{2+} is an electrophile, and the π electrons of each $C_5H_5^-$ act as nucleophiles.



Electron flow in organic reactions

As a rule, electrons flow from electron rich (nucleophilic) atoms to electron poor (electrophilic) atoms or groups of atoms.

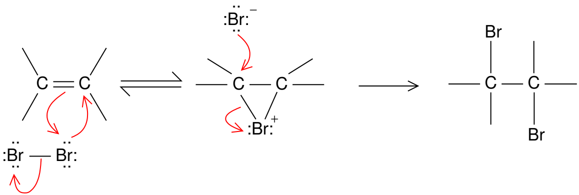
Example: bromination of an alkene

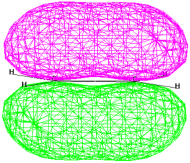


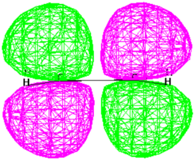
Example: bromination of an alkene

Step 1

- In the first step, the bromine atoms are in oxidation state 0 and act as electrophiles. The double bond is the nucleophile.



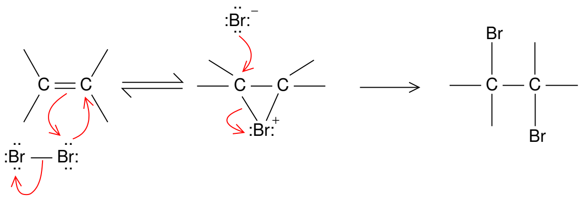

HOMO

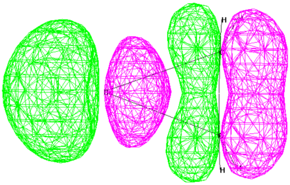

LUMO

Example: bromination of an alkene

Step 2

- In the second step, the bromide ion is a nucleophile and the *bromonium ion* is an electrophile.





Bromonium ion LUMO

Electron pushing

- We use a curved arrow () to represent the movement of two electrons, or a curved harpoon () to represent the movement of a single electron.
- Curved arrows should never be used for any other purpose. In particular, don't use them to show motion of atoms.
- Electrons typically flow from a nucleophile to an electrophile.
- Don't push more than two electrons at at time into an atom. Most of the time, one pair of electrons moves in or out of an atom at a time.
- Period 2 elements can never exceed an octet.

Electron pushing exercises

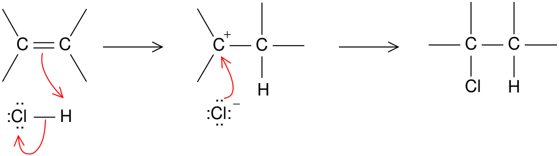
Identify electrophiles and nucleophiles, and push the electrons to form the products.

1. $CH_3NH_2 + H^+$

2. $CO_2 + OH^-$

Carbocations

- Consider the electrophilic addition reaction

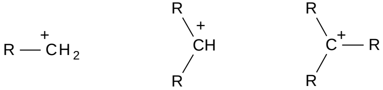


- This reaction makes a carbocation as an intermediate step.
- As a rule, carbocations are extremely powerful electrophiles.
- Some questions we might have:
  - What factors allow carbocations to form?
  - In unsymmetric cases, which of two carbocations will form?

Stabilization of carbocations by hyperconjugation

- Empirically, we observe that carbocations with alkyl substituents are more stable than those without.

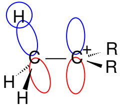
Type: Primary Secondary Tertiary



Less stable More stable

Stabilization of carbocations by hyperconjugation

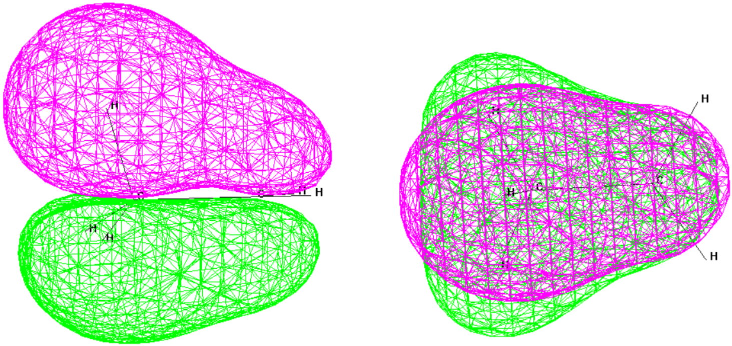
- Why?
  The C-H σ bonds on a methyl group adjacent to the C^+ can combine with the “free” p orbital on C^+ to form a bonding MO:



  This bonding arrangement is called hyperconjugation.
- The C-C bond therefore has partial double-bond character, which spreads the positive charge over a larger portion of the molecule, thus stabilizing it.
- More alkyl substituents
  = more opportunities for this kind of stabilization
  = more stable carbocation

Hyperconjugated MOs

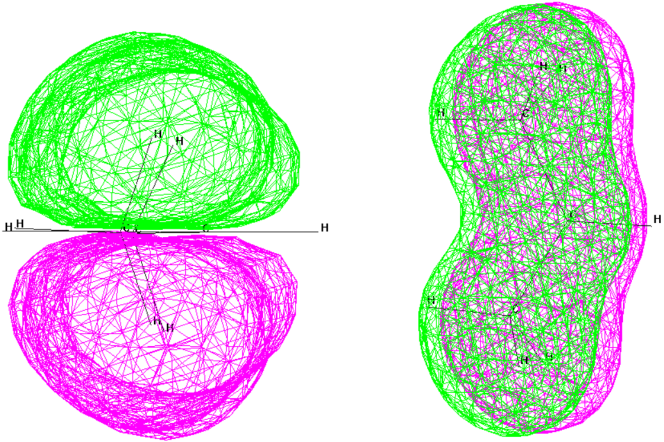
Primary carbocations



Note: These are two views of the same orbital.

Hyperconjugated MOs

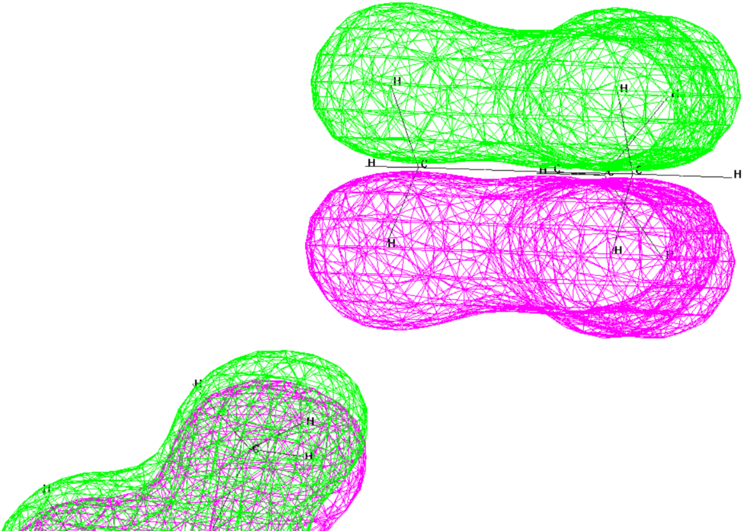
Secondary carbocations



Note: These are two views of the same orbital.

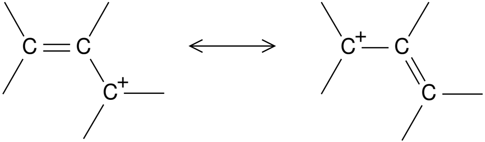
Hyperconjugated MOs

Tertiary carbocations

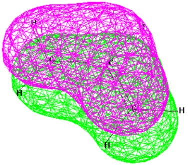


Resonance stabilization of carbocations

- Resonance can also stabilize a carbocation.
- This is the case for instance for "allylic" cations, which are particularly stable:



- Again, the charge is delocalized over a large area.
- Note that the resonance picture corresponds to the existence of a π MO that joins these three carbon atoms:



Carbocation stability

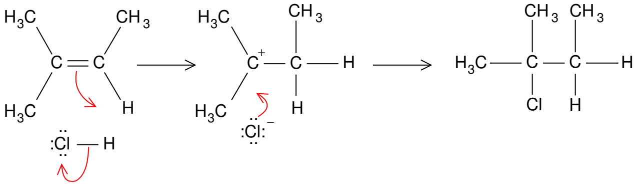
As a rule, resonance-stabilized carbocations are more stable than carbocations that are only stabilized by hyperconjugation.

Markovnikov's rule

- There is still the question of where the two atoms in HCl (e.g.) will add across an unsymmetric double bond.

Markovnikov's rule: In addition reactions, the more stable of the two possible carbocations is formed as an intermediate.

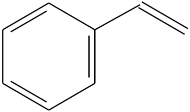
Example: In the addition of HCl to 2-methyl-2-butene, H^+ adds to the less-substituted carbon, making a tertiary carbocation:



The alternative would be to add to carbon 2, but this would make a less stable secondary carbocation. (Draw it out!)

Exercises

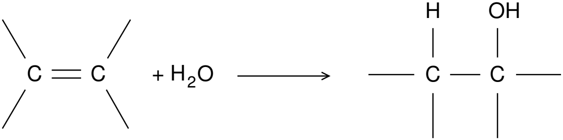
1. What product would you predict if excess HBr reacts with propyne ($HC \equiv C - CH_3$)?
2. What product would you predict in the reaction of HCl with the following molecule?



Note: The benzene ring is inert under most reaction conditions.

Acid-catalyzed addition of water to an alkene

- We could imagine adding water across a double bond to make an alcohol, in much the same way as HCl or HBr adds across a double bond:



Problem: Water isn't a strong enough acid to make the carbocation intermediate.

Solution: Do the reaction in acid!
The acid acts as a catalyst, i.e. it is needed to get the reaction to occur, but it is regenerated.

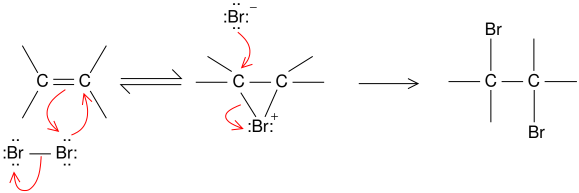
Example: Acid-catalyzed reaction of propene with water.

Addition of a halogen to an alkene

- In the addition reactions studied above, the alkene is a nucleophile.
- Addition of a halogen to an alkene is also an electrophilic addition.
  Note: This is a classic test for double and triple bonds.
- How can a halogen be an electrophile?
  Hint: Think about the intermolecular force that acts when a halogen is close to a double bond.

Addition of a halogen to an alkene

- With the exception of fluorine, halogen atoms are large.
- Halogen atoms can therefore "bridge" the two carbon atoms, forming a triangular intermediate:



- Note that the bromonium ion blocks the side of the molecule on which it forms, so the bromide ion has to attack from the opposite side in the second step.