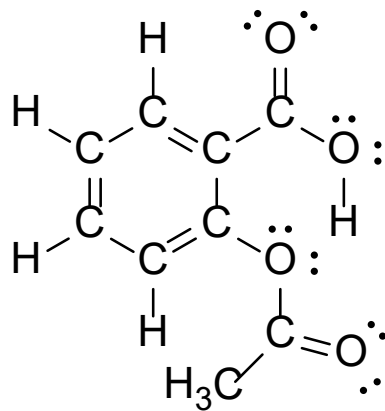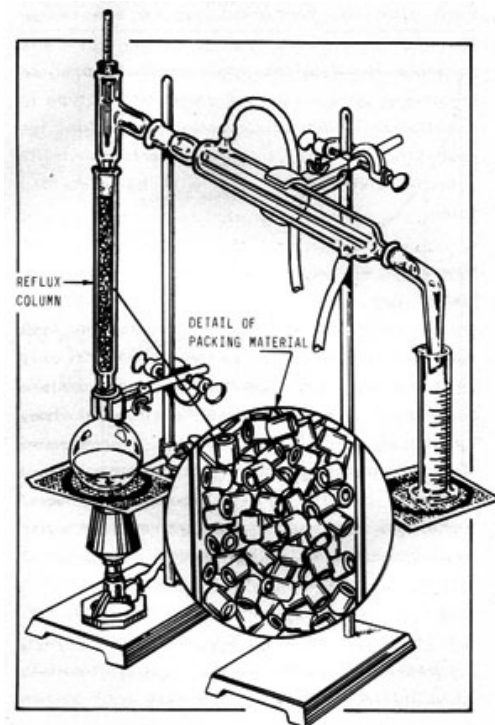aspirin

CHEMISTRY 2000

Topic #3: Organic Chemistry
Fall 2020
Dr. Susan Findlay
See Exercises in Topic 11

Reactions in Organic Chemistry

- One of the major goals of organic chemistry is synthesis of new and/or interesting organic compounds. To do this, organic chemists build up a toolkit of reactions. Note that we DON'T memorize all the reactions ever invented. That would be impossible! Instead, we recognize that the vast majority of reactions fit into one of a very short list of categories and get good at analyzing molecules to find the reactive parts and decide which category of reaction is most likely.

- Major categories for organic reactions include:
  - **Addition.** Two "halves" of a molecule are added across a π bond.
  - **Elimination.** Two "halves" of a molecule are removed, leaving behind a π bond.
  - **Substitution.** One group is replaced by another.
  - **Redox.** The average oxidation state for an element in the organic compound (usually carbon) changes.

Categories of Organic Reactions

- **Addition reactions** can be performed on almost[*] any organic molecule with a π bond. In an addition reaction, two "halves" of a molecule are added across a π bond of a different molecule.

  - e.g. addition of HCl across an alkene
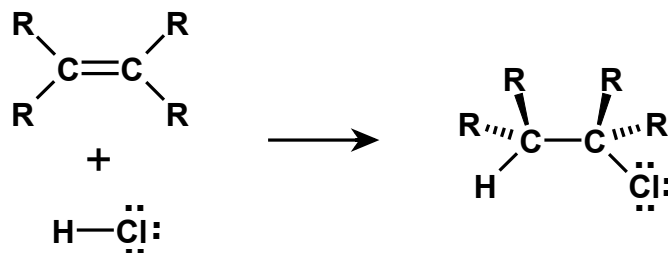
 - e.g. addition of CH$_3$Li across a ketone or aldehyde
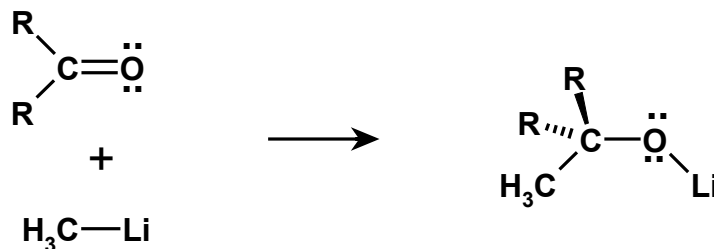
[*]The exceptions to this rule are arenes like benzene where the π electrons are very delocalized (as we saw in the MO portion of CHEM 2000). They don't tend to undergo addition reactions.

Categories of Organic Reactions

- **Elimination reactions** are the reverse of addition reactions. In an elimination reaction, two "halves" of a molecule are removed from a larger molecule, leaving behind a π bond.
  - e.g. removal of HCl from a haloalkane (giving an alkene)
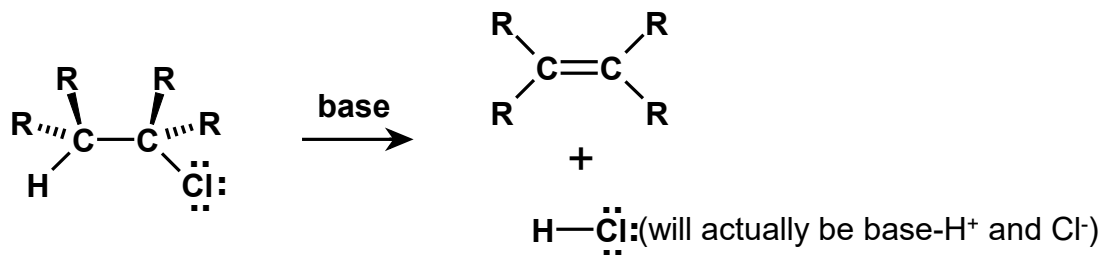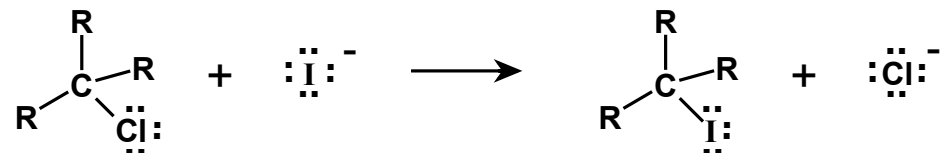

  - e.g. removal of water from a diol (giving a ketone or aldehyde)
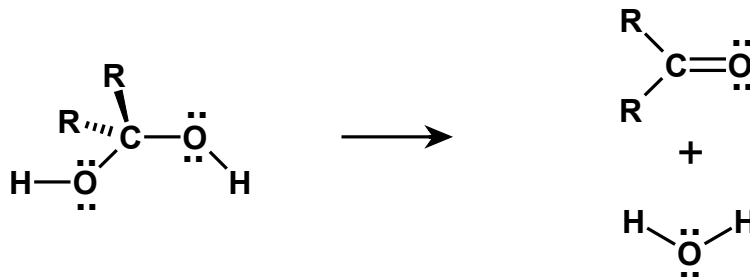
Categories of Organic Reactions

- In **substitution reactions**, one group is replaced by another group. They generally involve a tetrahedral carbon atom attached to a good **leaving group**[*] *(or something that can be turned into a good leaving group)*.

  - e.g. replacement of a chloro group by an iodo group

  - e.g. replacement of a hydroxy group by a bromo group
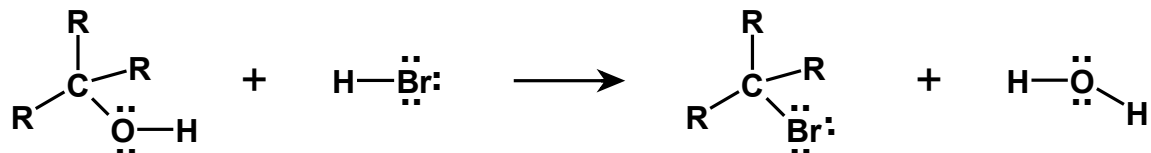
[*] A leaving group is part of an organic compound that would be a stable molecule or ion on its own if it took a pair of electrons. An example is -Cl (becomes Cl^-).

Categories of Organic Reactions

- Carbon can have any oxidation state from -4 to +4. Propose a set of nine molecules showing the nine possible oxidation states of carbon. *Hint: Some of the molecules will need to have more than one carbon atom.*

- Most redox reactions of organic molecules fit into one of the three aforementioned categories as well.

Following Electrons with "Curly Arrows"

- In most reactions, electrons flow from electron-rich atoms to electron-poor atoms, making and breaking bonds as they go. This is essentially the same as the flow of electrons from Lewis base to Lewis acid that we saw in CHEM 1000.

- In organic chemistry, the electron pair donors are called **nucleophiles** ("nucleus lovers" or "positive charge lovers").
  - Nucleophiles react with their HOMO.
  - The reactive part of a nucleophile is the **nucleophilic site**. Nucleophilic sites are usually* atoms that have either a full or partial negative charge and one or more lone pair of electrons.

*π bonding electrons can also be nucleophilic.

Following Electrons with "Curly Arrows"

- In organic chemistry, the electron pair acceptors are called **electrophiles** ("electron lovers").

  - Electrophiles react with their LUMO.

  - The reactive part of an electrophile is the **electrophilic site**. Electrophilic sites are atoms that have either a full or partial positive charge and some way to accept electrons (a π bond to break, a good leaving group, an incomplete octet, etc.).

Things That Are Essential to Remember!!!

- CURLY ARROWS **ALWAYS** SHOW MOVEMENT OF **ELECTRONS**. NEVER ATOMS OR IONS!

- Electrons flow in **ONE DIRECTION** – from electron-rich to electron-poor; from Lewis base to Lewis acid; from **NUCLEOPHILE TO ELECTROPHILE**.

- Don't push multiple arrows into the same atom. One in; one out. (Sometimes just "one in" or "one out".)

- Each arrow represents the movement of a **PAIR**[*] of electrons.

- When pushing electrons, remember that period 2 elements (including C, N and O) can **NEVER** have more than 8 electrons!!!

[*] To show movement of single electrons, chemists use half-arrows.

Following Electrons with "Curly Arrows"

- Let's look at some familiar reactions to see how we can use curly arrows to follow electron movement *(aka reaction mechanism).*
  - What happens when CH_3NH_2 is added to hydrochloric acid?

  - What happens when carbon dioxide is bubbled through an aqueous solution of sodium hydroxide?

Following Electrons with "Curly Arrows"

- Now, let's try an organic reaction or two.
  - What happens when iodide reacts with chloromethane (CH_3Cl)?

  - Use curly arrows to show the movement of electrons in the following reaction:
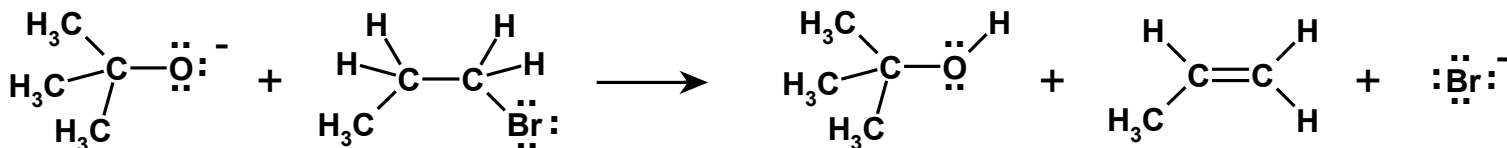
Addition Reactions of Alkenes and Alkynes (HX)

- Alkenes and alkynes are good nucleophiles because they have electron-rich π bonds *(more easily broken than σ bonds)*. As such, they react with good electrophiles like HCl, HBr and Br_2. This gives a **carbocation**, a very reactive electrophile which immediately reacts with the nucleophilic halide produced.

- Overall, we get:

Addition Reactions of Alkenes and Alkynes (HX)

- Carbocations are not particularly stable, but they can be stabilized somewhat by alkyl groups (methyl, ethyl, etc.) attached to the carbon with the positive charge:

- They can also be stabilized by **resonance**:

- A carbocation will not form unless it has some type of stabilization (either two or more alkyl groups attached or resonance). The more stabilization, the better.

Addition Reactions of Alkenes and Alkynes (HX)

- The example on page 12 involved a symmetric alkene. If the alkene was not symmetric, we would have to decide which carbon bonded to the H^+ and which carbon bonded to the Cl^-. To do this, we compare the two possible carbocations.

- Whichever carbocation is more stable will form more readily and that carbocation will then react with Cl^- to give the product:
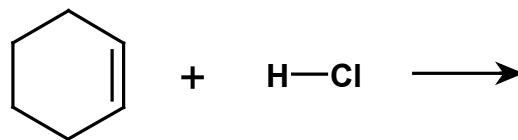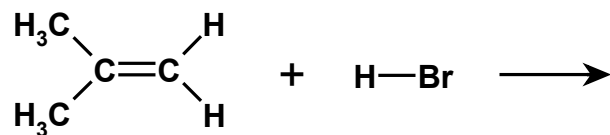
Addition Reactions of Alkenes and Alkynes (HX)

- Identifying the more stable carbocation ALWAYS works to predict the observed product.

- It's the reason for the historical **Markovnikov's rule** which was originally stated as "the hydrogen adds to the side with more hydrogens". That works for many examples – but not all!

- The <u>real</u> rule is **"make the more stable carbocation".** That one always works!
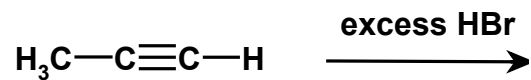
Addition Reactions of Alkenes and Alkynes (HX)

- Draw the major organic product for the following reactions:

H_3C, H_3C $C=C$ H, H +   H—Br   ⟶

   +   H—Cl   ⟶

Addition Reactions of Alkenes and Alkynes (HX)

- Draw the major organic product for the following reaction:

$$H_3C-C\equiv C-H \quad \xrightarrow{\text{excess HBr}}$$

Addition Reactions of Alkenes and Alkynes (HX)

- Draw the major organic product for the following reaction:

$$+ \quad H-Cl \quad \longrightarrow$$

Addition Reactions of Alkenes and Alkynes (HX)

- Addition of water to an alkene proceeds according to the same mechanism as addition of HCl, HBr or HI to an alkene! This means there needs to be some acid (e.g. H_2SO_4) in the flask.

- Draw the major organic product for the following reaction:
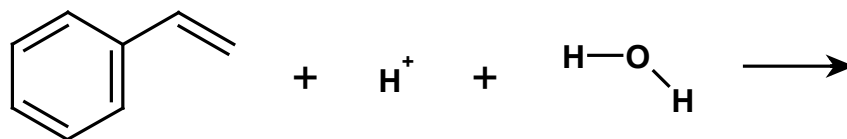
Addition Reactions of Alkenes and Alkynes (X_2)

- Addition of chlorine or bromine across a π bond works in a similar fashion (with a little extra resonance stabilization from the halogen). The π bond is nucleophilic and the halogen molecule is electrophilic.

- Wait a second… How can a halogen be electrophilic? It's nonpolar, right? Any ideas? *Hint: Think back to our discussions about intermolecular forces…*

Addition Reactions of Alkenes and Alkynes (X_2)

- Having established that, back to the reaction. The alkene donates its π electrons to the electrophilic end of the halogen, creating a cation:

- This "carbocation" gets stabilization from the halogen atom that was just attached to the molecule – so much so that the two carbon atoms and the halogen are locked in a ring and is more properly called either a "chloronium ion" or a "bromonium ion".

Addition Reactions of Alkenes and Alkynes (X$_2$)

- This cation is very reactive and quickly reacts with the halide ion also produced in the first step of the reaction. Because the halogen atom is "leaning over" to resonance stabilize the carbocation, it blocks that side of the carbocation and the halide must attack from the other side:

Addition Reactions of Alkenes and Alkynes (X$_2$)

- The product of the overall reaction has a halogen atom attached to each of the carbons that used to be double bonded:

- The halogen atoms are <u>always</u> added on **opposite sides** of the molecule:

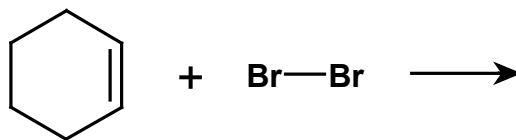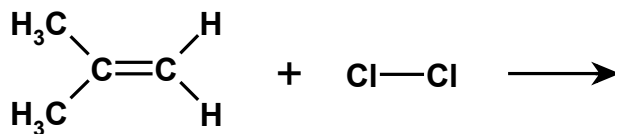# Addition Reactions of Alkenes and Alkynes (X_2)

- Addition of Br_2 to an alkene is useful for adding bromine atoms to a molecule; however, that's not the only use of this reaction. Most organic molecules are white or colourless. Br_2 is dark brown. If you add a drop of a Br_2 solution to an unknown compound, you can tell whether or not it is an alkene or alkyne.
    - What would you observe if it is an alkene/alkyne?

    - What would you observe if it isn't an alkene/alkyne?

- This is a handy way to quickly test whether a fat is saturated (no C=C bonds) or unsaturated (at least one C=C bond).
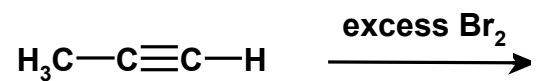
Addition Reactions of Alkenes and Alkynes (HX)

- Draw the major organic product for the following reactions:

H_3C—C=C—H (with H_3C and H substituents)   +   Cl—Cl $\longrightarrow$

(cyclohexene)   +   Br—Br $\longrightarrow$

Addition Reactions of Alkenes and Alkynes (HX)

- Draw the major organic product for the following reaction:

$$H_3C-C\equiv C-H \xrightarrow{\text{excess Br}_2}$$

Addition Reactions of Alkenes and Alkynes

- In summary, we can add a variety of small molecules across a carbon-carbon double bond. In the diagram below, X is a halogen (specifically Cl, Br or I):
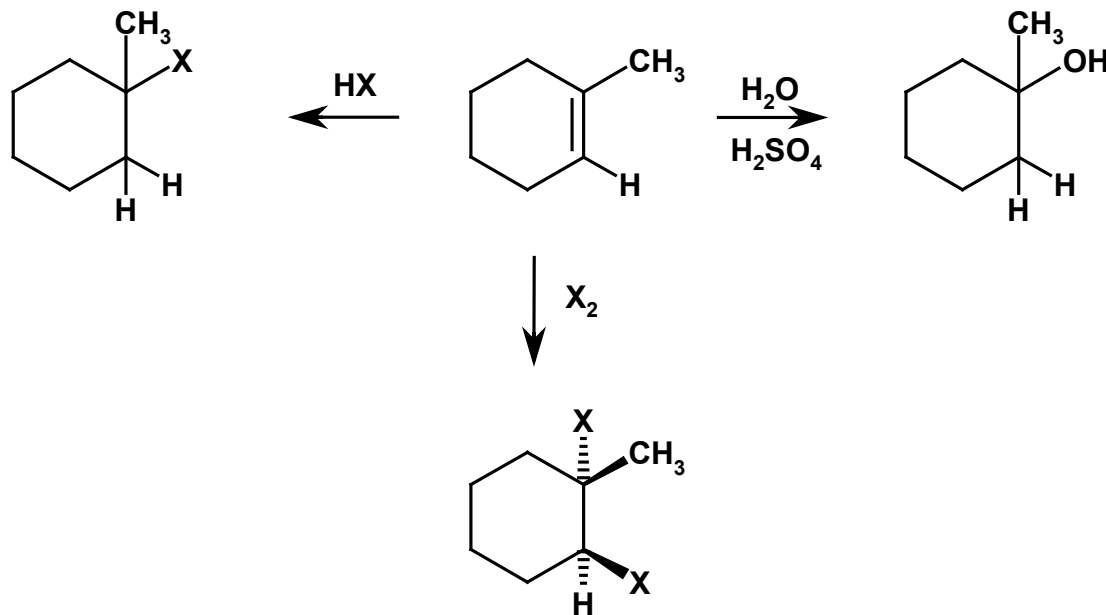
- Because we understand the mechanism behind these reactions, we can predict which isomer will be the major product *(make the more stable carbocation then attach the nucleophilic half of the small molecule there; add X₂ trans).*