Experiment 5 – Reactions of Hydrocarbons

Hydrocarbons are compounds that only contain carbon and hydrogen. Hydrocarbons can be classified further by the type of bonds they contain. If a hydrocarbon contains only single bonds, it is an **alkane**. If it contains one or more carbon-carbon double bonds, it is classified as an **alkene**. If it contains one or more triple bonds between two carbon atoms, it is an **alkyne**. If it contains a benzene ring, it is considered **aromatic**. (If it does not contain a benzene ring, it is **aliphatic**. Therefore, alkanes, alkenes, and alkynes are all aliphatic hydrocarbons.) These types of compounds react in different ways, so it is possible to distinguish between them using experimental tests.

Physical Properties

Since hydrocarbons contain only carbon and hydrogen, all hydrocarbons are nonpolar. (Carbon and hydrogen have very similar electronegativities.) This means that all hydrocarbons will be insoluble in water. When water is mixed with a nonpolar substance, there are no significant attractive forces between them. However, water molecules are very attracted to each other (since they can hydrogen bond to each other). Therefore, when a nonpolar substance is mixed with water, the water molecules tend to cluster together and exclude the nonpolar substance. If the substances were both liquids, the result would be two layers of liquid, with the more dense liquid on the bottom. Hydrocarbons are less dense than water, so they will float on top of water.

Hydrocarbons, in general, are **volatile**. This means that they have a significant vapor pressure at room temperature so they tend to evaporate easily. The rate of evaporation (for nonpolar substances) is related to the molar mass of the substance. Heavier molecules will evaporate more slowly, since they have stronger intermolecular attractive forces and therefore are more difficult to separate.

Combustion

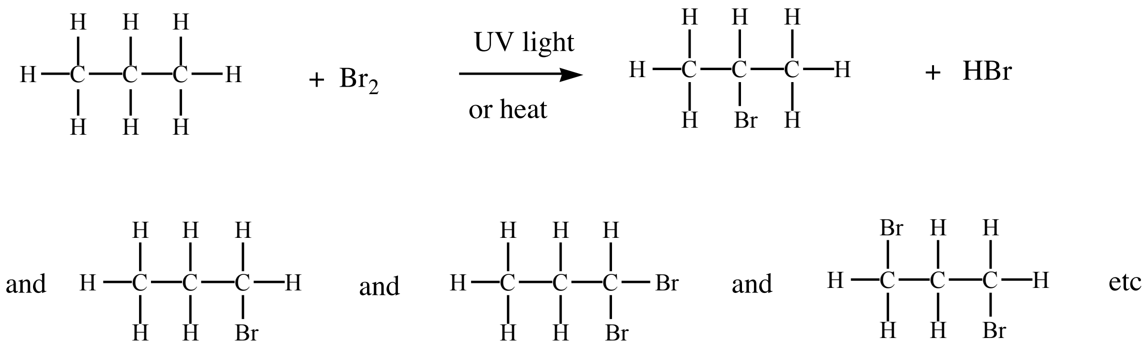
All hydrocarbons will burn in the presence of oxygen (in the air). This reaction is called **combustion**, and the products of this reaction are water and carbon dioxide gas. Here is an example of a combustion reaction:

$$C_3H_{8\,(g)} + 5\,O_{2\,(g)} \rightarrow 3\,CO_{2\,(g)} + 4\,H_2O_{(g)} + \text{heat}$$

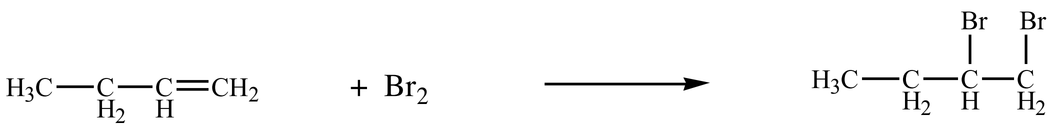
Combustion reactions also give off a great deal of heat. Because of this, many hydrocarbons are used as fuels. Some examples are methane (natural gas), propane, butane, and octane. If there is not an excess of oxygen present during the combustion, then undesirable products are also formed. Carbon monoxide (CO) is an example of an undesirable product of **incomplete combustion**. This compound is toxic.

Halogenation

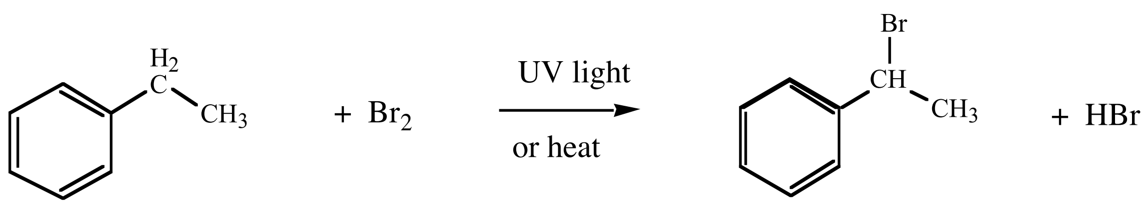
All hydrocarbons can be **halogenated** under certain conditions. Alkanes are very unreactive, but they can be brominated or chlorinated in the presence of ultraviolet (UV) light. This is a **substitution** reaction in which a hydrogen is removed from the alkane and a halogen (Br or Cl) takes its place. The halogen atom can substitute at any site on the molecule. Furthermore, the halogenated products can react further to give disubstituted or trisubstituted products (and so on). This reaction is therefore not at all selective, and mixtures of many products will result.



Alkenes and alkynes are much more reactive than alkanes. They will react readily with Br_2 or Cl_2, and ultraviolet light is not needed for the reaction. This reaction is an **addition** reaction – the halogen atoms will add at the site of the double bond only. Therefore, this reaction is selective– only one product will result.



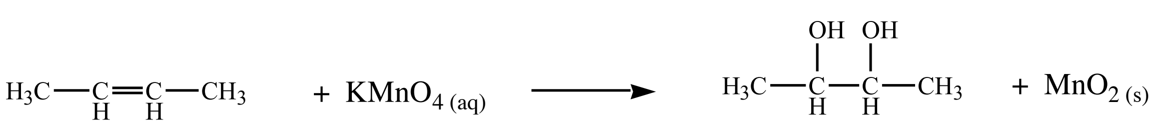
Aromatic compounds are not very reactive. They will not react with Br_2 or Cl_2 under normal conditions. If the aromatic compound has an alkyl substituent, however, the alkyl group can be halogenated in the presence of UV light. The benzene ring will not react under these conditions. (See the reaction on the next page.)



In this experiment, the bromination of several compounds will be attempted. A solution containing bromine will be added to the compounds being tested. The bromine has an orange or brown color. If this color disappears, it means that the bromine is getting used up and therefore the compound is reacting with the bromine. Thus, disappearance of the orange color corresponds to a positive reaction.

Oxidation

Another reaction that alkenes undergo is oxidation. When a purple solution of the oxidizing agent $KMnO_4$ is added to an alkene, the alkene is oxidized to a diol and the $KMnO_4$ is converted to brown MnO_2. Thus, if the purple color changes to brown in this reaction, it is a positive reaction. The diol produced has two adjacent alcohol groups.



Alkanes and aromatic compounds do not react with potassium permanganate.

Disposal

Hydrocarbons are incompatible with water and should never be poured down the sink. Water treatment plants are not equipped to remove large amounts of organic compounds from waste water. There are many household chemicals that contain water-insoluble substances: paint, motor oil, furniture polish, hair spray, spot removers, and so on. The use of these substances should be limited, and excess amounts should never be poured down a sink, toilet, or sewer drain, because they are very toxic to the environment.

Safety Precautions:

- Organic compounds are extremely flammable. Use small amounts of the compounds, and do not use Bunsen burners in the organic chemistry laboratory.
- Keep the organic solvents under the fume hood.
- Make sure to keep the bromine under the hood – the Br_2 fumes can irritate the throat and sinuses. If bromine is spilled on the skin, flood the area with water for 10 minutes.
- Avoid touching the chemicals.
- Wear your safety goggles.

Waste Disposal:

- All waste must be placed in the **organic** waste containers (which have a pink label) in one of the fume hoods.

Procedure

Part 1: Structures of Hydrocarbons

1. Using the molecular model kits, make models of ethylene, propene, *cis*-2-butene, *trans*-2-butene, and acetylene (ethyne). Use the springs in the kit to form double or triple bonds. Draw the condensed structural formula of each molecule.

Part 2: Combustion

2. In the hood, place 5 drops of hexane in a porcelain evaporating dish. Light a wooden splint with matches and carefully ignite the sample. Observe the flame and the type of smoke produced, and record your observations. Repeat the test with 5 drops of toluene and then with 5 drops of cyclohexene. Test your unknown in the same manner. Record observations for each test.

Part 3: Solubility

3. In the hood, mix about 2 mL of hexane with 1 mL of deionized (purified) water in a test tube. Shake the tube well and record your observations. Which liquid is on top and which is on the bottom?
4. In the hood, mix about 2 mL of hexane with 1 mL of toluene. Shake well and record your observations.

Part 4: Volatility

5. Obtain two evaporating dishes and place them in the hood. Measure out 3 mL of pentane with a graduated cylinder and pour it in one of the evaporating dishes. Measure out 3 mL of heptane and pour it in the other dish. Note the time. Periodically check the dishes to see when each substance has evaporated completely. Record the time needed for complete evaporation on the report sheet.

Look up the boiling points of the substances in a chemistry handbook and record them on the report sheet.

Part 5: Reaction with Bromine

Make sure to keep the bromine under the hood – the Br_2 fumes can irritate the throat and sinuses. If bromine is spilled on the skin, flood the area with water for 10 minutes.

6. You will be testing 4 different liquids: hexane, cyclohexene, toluene, and your unknown. **In the hood**, place 5 drops of each liquid to be tested in separate clean, dry test tubes. Label the tubes. Carefully add 3 drops of the bromine solution to each tube. Note whether the orange color of the bromine disappears immediately or not. The disappearance of the bromine color is a positive reaction.
7. <u>If the test is negative</u>, shine UV light on the tube for up to 2 minutes and note whether the color disappears.

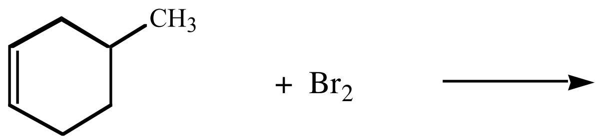
Part 6: Reaction with $KMnO_4$

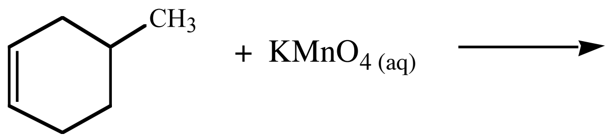
Caution: $KMnO_4$ stains the skin.

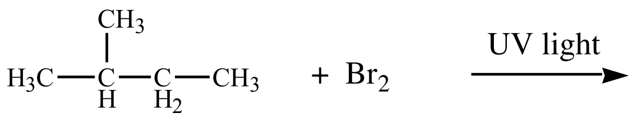
8. You will be testing 4 different liquids: hexane, cyclohexene, toluene, and your unknown. On a white spot plate, place 8 drops of alcohol-free acetone in each of 4 wells in the spot plate. Place 2 drops of the compound to be tested in each well, and mix with a stirring rod. (Wipe off the stirring rod after stirring each sample so that you don't mix the samples. If traces of different samples are accidentally mixed, you may get ambiguous results.) Add 2-3 drops of the $KMnO_4$ solution to each well and mix thoroughly with a stirring rod. Note whether the purple color of the potassium permanganate changes to brown in the first 10 seconds. Brown manganese dioxide (MnO_2) indicates a positive reaction.

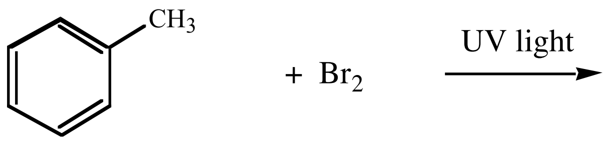
<u>Questions</u>

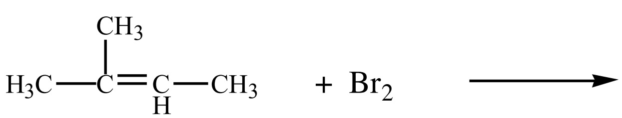
1. An unknown compound is found to burn in oxygen. When bromine is added to this unknown, the solution remains orange. What can be said about the unknown compound?
2. When a purple solution of $KMnO_4$ is added to a different unknown, a brown precipitate forms. What can be said about this unknown?
3. Discuss the differences between the bromination of an alkene and the bromination of an alkane.
4. Would 2-butene be more soluble in cyclohexane or in water? Explain.
5. Complete the following reactions and name the organic reactants and product(s). If no reaction occurs, write "NR".

a. 

b. 

c. 

d. 

e. 

7. When n-butane is reacted with bromine in the presence of UV light, many products are possible. Write the condensed structural formulas of **six** of the many possible products.

8. Complete and balance the following combustion reactions. (You will need to determine the molecular formulas of the reactants.)

   a. pentane + O_2 $\rightarrow$

   b. toluene + O_2 $\rightarrow$

   c. 2-butene + O_2 $\rightarrow$