REVIEW: TOPIC 7

NAME: ________
DUE: ________

UNIT 7 – MAJOR UNDERSTANDINGS

- ☆ 3.1ff Organic compounds contain carbon atoms which bond to one another in chains, rings, and networks to form a variety of structures. Organic compounds can be named using the IUPAC system.
- ☆ 3.1gg Hydrocarbons are compounds that contain only carbon and hydrogen. Saturated hydrocarbons contain only single carbon-carbon bonds. Unsaturated hydrocarbons contain at least one multiple carbon-carbon bond.
- ☆ 3.1hh Organic acids, alcohols, esters, aldehydes, ketones, ethers, halides, amines, amides, and amino acids are categories of organic molecules that differ in their structures. Functional groups impart distinctive physical and chemical properties to organic compounds.
- ☆ 3.1ii Isomers of organic compounds have the same molecular formula but different structures and properties.

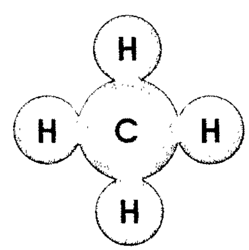
UNIT 7 – MAJOR UNDERSTANDINGS (CONTINUED)

- ☆ 5.2e In a multiple covalent bond, more than one pair of electrons are shared between two atoms. Unsaturated organic compounds contain at least one double or triple bond.
- ☆ 3.2c Types of organic reactions include: addition, substitution, polymerization, esterification, fermentation, saponification, and combustion.

INTRODUCTION

Organic chemistry is the chemistry of the compounds of carbon. Organic compounds occur extensively in nature. All living things are composed predominantly of organic compounds.

Carbon is able to form four covalent bonds not only with other kinds of atoms, but also with other carbon atoms. This makes possible a very large number of compounds. Consequently, organic compounds are much more numerous than **inorganic compounds**.



ORGANIC CHEM.

Carbon atoms bond to one another in chains, rings, and networks to form a variety of structures. The major sources of raw materials from which organic chemicals are obtained are petroleum, coal, wood, and other plant products and animal sources.

Types, varieties, uses of organic compounds – Organic (carbon) compounds exist in all life forms. Their uses range from fuels to construction material; however, most importantly, organic compounds are used in the field of medicine to diagnose and treat diseases.

A – CHARACTERISTICS OF ORGANIC COMPOUNDS

Solubility – Organic compounds are generally nonpolar and tend to dissolve in nonpolar solvents.

Those organic compounds that are somewhat polar, such as acetic acid, are soluble in water. Generally organic compounds are insoluble in water and soluble in nonaqueous solvents.

Conductivity – Organic compounds are generally nonelectrolytes. These organic acids that are electrolytes are very weak.

Melting Points – Organic compounds generally have low melting points. Since most organic compounds are essentially nonpolar, the intermolecular forces are weak. Therefore, the compounds have relatively low melting points (under 300°C).

Organic Compound Reactions – Most reactions involving organic compounds are slower than those involving inorganic compounds. Because of strong covalent bonding within the molecule, organic compounds do not readily form activated complexes (intermediates), and thus, reactions take place slowly. The activation energy required for organic reactions is generally high.

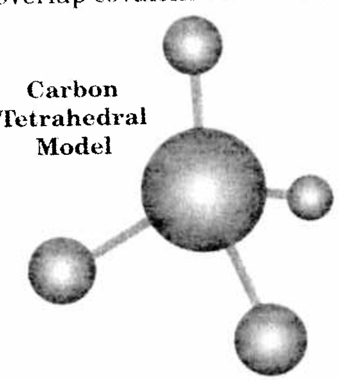
B – Bonding

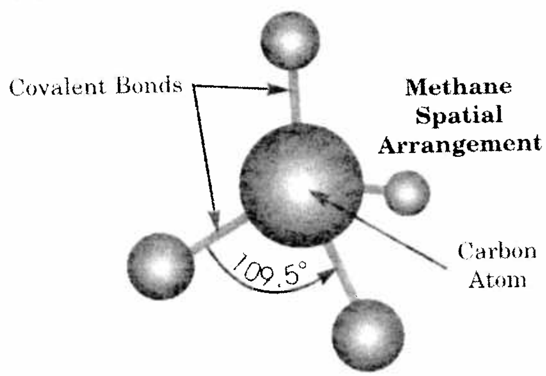
Carbon atoms bond with the following characteristics:

- the four valence electrons of the carbon allow it to form four covalent bonds;
- these four single bonds of the carbon atom are spatially directed toward the corners of a regular tetrahedron;
- the carbon atom can share electrons with other carbon atoms;
- two adjacent carbon atoms can share one to three pairs of electrons; and,
- the covalent bonding results in compounds that have molecular characteristics.

Below are two ball and stick models (Carbon Tetrahedral Model - left) showing the spatial arrangement of the tetrahedral model of the carbon atom. Spatial arrangement (Methane - right) showing bond angles and overlap covalent bonds of methane.

Carbon Tetrahedral Model

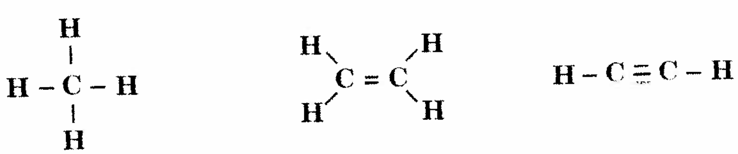




Methane Spatial Arrangement

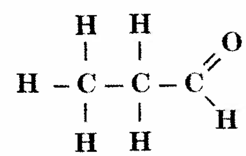
Structural Formulas

The covalent bond is usually represented by a short lien (or dash) representing one pair of shared electrons. A formula showing the bonding in this manner is known as a structural formula.

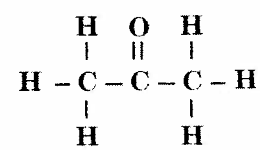


Real World Connections

Organic isomers – These are compounds that have the same molecular formula but different structures are called **isomers**. The compounds CH_3CH_2CHO (propanal – used in the manufacture of aromatic compounds) and CH_3COCH_3 (acetone – used as solvents) are isomers, both having the molecular formula C_3H_6O.



Propanal



Propanone (Acetone)

Note: you are expected to identify isomers both in molecular formulas and structural formulas. As the number of atoms in the molecule increases, the possibilities of more spatial arrangements (therefore, the number of isomers) increase.

Saturated & Unsaturated Compounds

A bond, formed between carbon atoms by the sharing of one pair of electrons, is referred to as a **single bond**. Organic compounds, where carbon atoms are bonded by the sharing of a single pair of electrons, are said to be **saturated** compounds.

Organic compounds, containing two adjacent carbon atoms bonded by the sharing of **more than one pair** of electrons, are said to be **unsaturated** compounds. A bond between carbon atoms by the sharing of two pairs of electrons is referred to as a **double bond**. A bond formed between carbon atoms by the sharing of three pairs of electrons is referred to as a **triple bond**.

C – Homologous Series of Hydrocarbons

Compounds containing only carbon and hydrogen are known as **hydrocarbons**. The study of organic chemistry is simplified by the fact that organic compounds can be classified into groups having related structures and properties. Such groups are called **homologous series**. Each member of a homologous series differs from the one before it by a common increment. The increment $\mathbf{CH_2}$ is what distinguishes one member of a series from another in each of the homologous series.

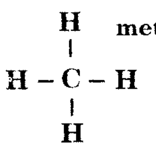
Most carbon compounds are named from, and can be considered as related to, corresponding hydrocarbons. As the members of a series increase in molecular size, the boiling points and freezing points increase due to the increased number of van der Waals forces between molecules. (Refer to *Reference Table Q – Homologous Series of Hydrocarbons*.)

Alkanes

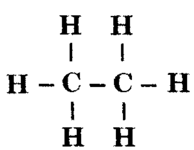
The series of saturated hydrocarbons having the general formula $\mathbf{C_nH_{2n+2}}$ is called the alkane series. This general formula allows scientists to deduce the molecular formula, once they know what **n** (number of carbon atoms) equals. Therefore, if they know that a molecule contains 16 carbon atoms, they simply substitute 16 for **n** and find the molecular formula to be $\mathbf{C_{16}H_{34}}$. The alkane series is also called the **methane series** or the **paraffin series**.

In naming organic compounds the IUPAC rules of nomenclature are followed. For the hydrocarbon series these rules are based on the number of carbon atoms in the molecule. The number of carbon atoms is indicated in the prefix of the name of each molecule, followed by the suffix, which for the **alkanes** is "**–ane**."

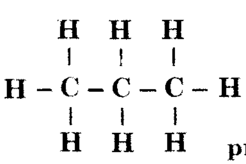
The data table (below right) and *Reference Table P* describe the naming of the first ten members of the alkane series. The alkane series shows isomerism beginning with the fourth member (butane, C_4H_{10}).



methane



ethane

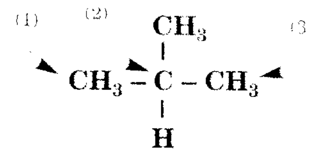


propane

Number of Carbon Atoms	Prefix	Full Name	Molecular Formula
1	meth-	methane	CH_4
2	eth-	ethane	C_2H_6
3	prop-	propane	C_3H_8
4	but-	butane	C_4H_{10}
5	pent-	pentane	C_5H_{12}
6	hex-	hexane	C_6H_{14}
7	hept-	heptane	C_7H_{16}
8	oct-	octane	C_8H_{18}
9	non-	nonane	C_9H_{20}
10	dec-	decane	$C_{10}H_{22}$

Isomers of Butane C_4H_{10}

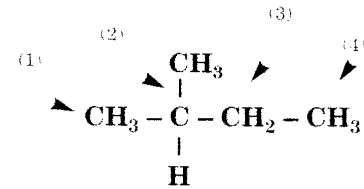
In alkanes, when adding a side chain or group, number the parent carbon chain by starting at whichever end results in the use of the lowest number.



methylpropane (2-methylpropane)

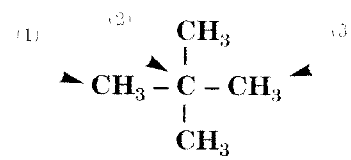
Isomers of Pentane C_5H_{12}

Numbering the carbon atoms left to right, this molecule is called 3 - methylbutane. Numbering from right to left, this molecule is called 2 - methylbutane



2-methylbutane

If the same group occurs more than once as a side chain, indicate this by the prefix di–, tri–, tetra– to show how many of these groups there are. Indicate by various numbers the positions of each group as illustrated by the second isomer of pentane: 2,2 dimethylpropane.

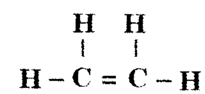


2,2-dimethylpropane

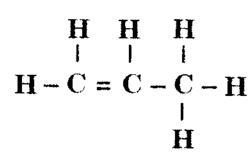
Alkenes

This series of unsaturated hydrocarbons containing one double bond and having the general formula $\mathbf{C_nH_{2n}}$ is called the alkene series. In the IUPAC system of nomenclature, the **alkenes** are named from the corresponding alkane by changing the ending "**-ane**" to "**-ene**." The alkene series is also called the ethylene series or the olefin series.

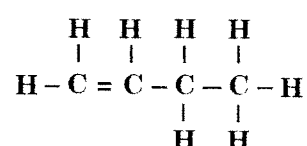
First member:	ethene — $\mathbf{C_2H_4}$
Second member:	propene — $\mathbf{C_3H_6}$
Third member:	butene — $\mathbf{C_4H_8}$
Fourth member:	pentene — $\mathbf{C_5H_{10}}$



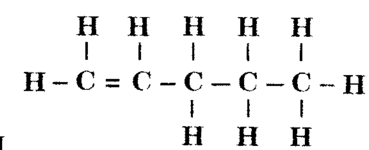
ethene



propene



1-butene

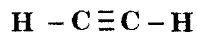


1-pentene

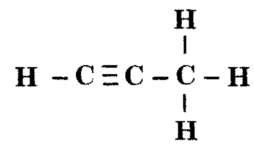
ALKYNES

The series of unsaturated hydrocarbons containing one triple bond and having the general formula C_nH_{2n-2} is called the alkyne series. In the IUPAC system of nomenclature the alkynes are named from the corresponding alkane by changing the ending "**-ane**" to "**-yne**." The common name of the first member of this series C_2H_2, is "acetylene," and the common name of the series is the **acetylene series**. **Note**: In naming alkyne compounds, the prefix is the same as the alkanes; however, the suffix is "yne" instead of "ane."

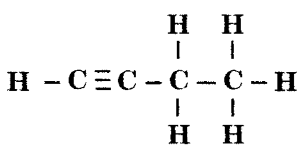
ethyne	C_2H_2
propyne	C_3H_4
butyne	C_4H_6
pentyne	C_5H_8



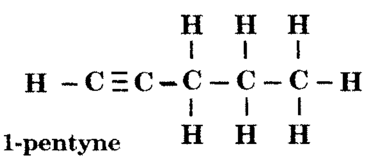
ethyne



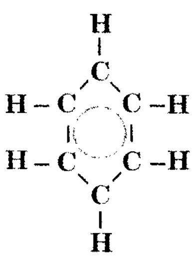
propyne



1-butyne



1-pentyne

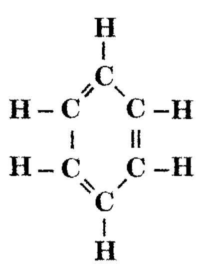


benzene

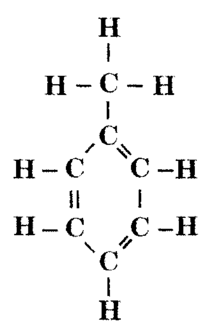
BENZENE SERIES

Cyclic hydrocarbons differ from **open chain** hydrocarbons (includes the alkane, alkene, and alkyne series), in that they are arranged in a ring structure. The most important **cyclic series** is called the **benzene series**. The benzene series is a group of aromatic hydro-carbons having the general formula C_nH_{2n-6}. Members of the **aromatic** hydrocarbons can be easily detected by their odors.

The simplest member of the benzene series is **benzene, C_6H_6**. The second member is toluene; its molecular formula is C_7H_8 (toluene is also called methylbenzene and is represented by the formula ($C_6H_5CH_3$).

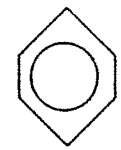


benzene

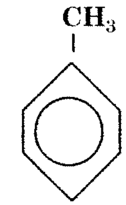


toluene (methylbenzene)

All of the carbon-carbon bonds in the benzene ring are the same, and they have structure and properties intermediate between single bonds and double bonds. Benzene is rather unreactive and in many of its reactions, it behaves like a saturated hydrocarbon rather than unsaturated hydrocarbon.



benzene

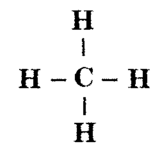


toluene (methylbenzene)

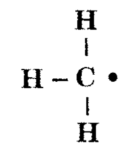
This represents a "super position," an average of single and double bonds. For simplicity, the chemist often uses either one of the structures shown (above right).

ALKYL RADICALS

When an alkane molecule loses a hydrogen atom, it has an open bond and is called an **alkyl radical**. Its formula will be the same as the alkane molecule except that it will have one less hydrogen in the formula, for example (Methyl at right):



methane CH_4

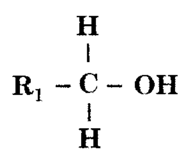


methyl radical CH_3

A **functional group** is a particular arrangement of a few atoms that gives characteristic properties to an organic molecule. Organic compounds can often be considered as being composed of one or more functional groups attached to a hydrocarbon group. The functional groups include alcohol and organic acid.

ALCOHOLS

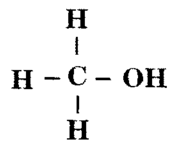
In alcohols, one or more hydrogens of a hydrocarbon have been replaced by an **-OH** group. No more than one **-OH** group can be attached to one carbon atom under ordinary conditions. The alcohols are not bases. The **-OH** group of an alcohol does not form a hydroxide ion in aqueous solution.



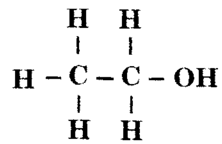
Primary alcohols. In primary alcohols, one **-OH** group is attached to the end carbon of a hydrocarbon. Since the functional group can be the end group of any hydrocarbon, the typical alcohol is frequently represented as **R-OH**, where "**R**" represents the rest of the molecule. The end group of a primary alcohol has the structure seen at the left.

The primary alcohol is frequently written as **-CH_2OH**. Primary alcohols contain the functional group **-CH_2OH**. In the IUPAC system, primary alcohols are named from the corresponding hydrocarbon by replacing the final "-e" with the ending "**-ol**."

The common names of the alcohols were formerly derived from the name of the corresponding hydrocarbon by changing the ending "-ane" to "**-yl**" and adding the name "**alcohol**." Thus, **CH_3OH**, methanol, is called methyl alcohol.



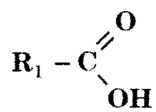
methanol
CH_3OH



ethanol
C_2H_5OH

ORGANIC ACIDS

Organic acids contain the functional group -**COOH**. Acids are represented by the general formula **R-COOH**, except for the first member. The structural formula of the acid group is shown at the right.

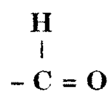


In the IUPAC system of nomenclature, organic acids are named from the corresponding hydrocarbons by replacing the final "-e" with the ending "**-oic**" and adding the name "**acid**."

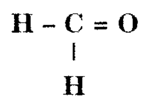
The first two members of this series, methanoic acid, **HCOOH**, and ethanoic acid, **CH_3COOH**, are more familiarly known as their common names, **formic acid** and **acetic acid**.

ALDEHYDES

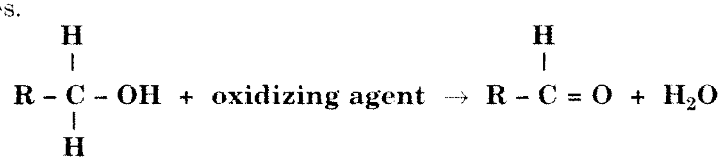
Aldehydes contain the functional group:



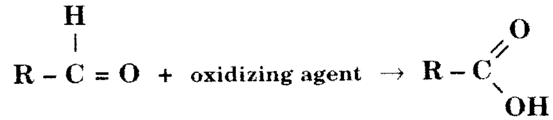
In the IUPAC system of nomenclature, aldehydes are named from the corresponding hydrocarbons by replacing the final "-e" with the ending "**al**." The first member of the aldehydes is called methanal and is commonly called **formaldehyde**. Its molecular formula is **HCHO**, and its structural formula is represented at the right.

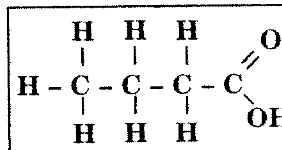


All other aldehydes are represented by the general formula **R-CHO** where "**R**" is any hydrocarbon group. Primary alcohols can be oxidized to aldehydes.



Aldehyde groups are easily oxidized to acids.



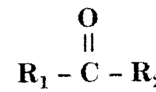


butynic acid

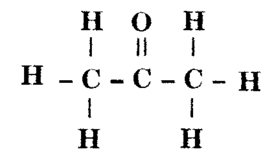
KETONES

Ketones contain the functional group.

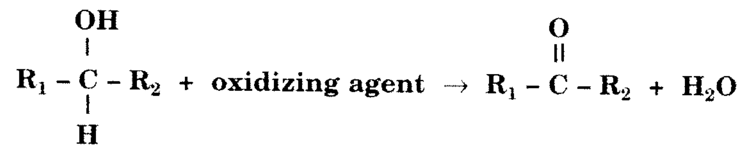
R_1 and R_2 are hydrocarbon groups.



An important ketone, widely used as a solvent, is propanone. It is generally referred to by its common name, acetone. Secondary alcohols can be oxidized to ketones.



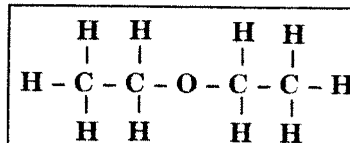
acetone (propanone)



ETHERS

The functional group of an ether is $\mathbf{R_1 - O - R_2}$

Diethyl ether, $C_2H_5OC_2H_5$, is used as an anesthetic. Primary alcohols can be dehydrated to give ethers.

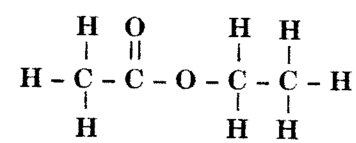


diethyl ether

$$\mathbf{R_1 - OH + R_2 - OH \rightarrow R_1 - O - R_2 + H_20}$$

ESTERS

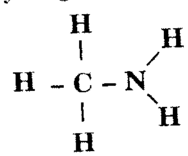
These have the following general formula where **R'** is always an alkyl group and **R** is either an alkyl group or a hydrogen atom. Oils and fats are esters of long carbon chain acids and glycerol. This is done by the hydrolysis of an ester in a basic solution. **$C_3H_7COOC_2H_5$** represents the ester ethyl butyrate which imparts the flavor and taste to pineapples. All esters have names which end with "**ate**" such as methyl salicylate and octyl acetate (see page 204).



ethyl acetate

Amines

These are derivatives of ammonia NH_3 in which the hydrogen atoms are replaced with organic radicals.



methylamine

CH_3NH_2 – primary amine called methylamine

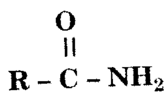
$(CH_3)_2NH$ – secondary amine called dimethylamine

$(CH_3)_3N$ – tertiary amine called trimethylamine

The above are simple amines. More complex ones are used in the manufacture of plastics, drugs, and cleansing compounds.

Amides

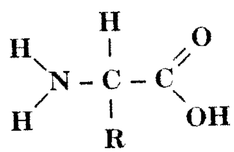
The general formula for a primary amide is:



They are a combination of ammonia and an amine or a carboxylic acid. Their names are derived by replacing the suffix **-oic** of the carboxylic acid with **-amide**. For example, CH_3CONH_2 is called ethanamide. Amides have wide usage in drug manufacture.

Amino Acids

The building blocks of proteins with a general formula containing an amino group and a carboxyl group attached to a central carbon atom.



amino acid
(general formula)

IUPAC uses what it describes as "trivial" names to these acids. The first two are glycine and alanine. Their symbols are Gly and Ala. Their formulas are NH_2CH_2COOH and $NH_2C_2H_4COOH$ respectively. They join together at their amino (NH_2) group, making a peptide linkage and eliminating a water molecule at each link as they form proteins. Found both in animal and plant tissue, they link together in large numbers to form long chain proteins.

D – Organic Reactions

Organic reactions generally take place more slowly than inorganic reactions. These reactions frequently involve only the functional groups of the reacting species, leaving the greater part of the reacting molecules relatively unchanged during the course of the reaction.

Substitution

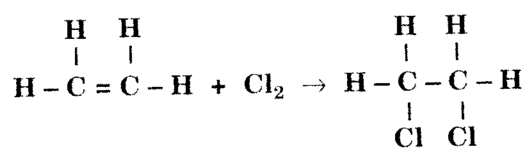
Substitution means replacement of one kind of atom or group by another kind of atom or group. For saturated hydrocarbons, reactions (except for combustion and thermal decomposition) necessarily involve replacement of one or more hydrogen atoms. The hydrogen atoms of saturated hydrocarbons can be replaced by active halogen family atoms. The general term for these reactions is **halogen substitution** (or halogenation) and the products are called **halogen derivatives**. For example:

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

Addition

Addition usually involves adding one or more atoms at a double or triple bond of a unsaturated molecule, resulting in saturation of the compound. Addition is characteristic of unsaturated compounds.

The addition of chlorine and bromine (iodine usually cannot be added) takes place at room temperature. The compounds formed are also called halogen derivatives, and the reaction is referred to as halogenation. For example:



Because addition reactions take place more easily than substitution reactions, unsaturated compounds tend to be more reactive than saturated compounds. Some addition reactions are about as fast as the reactions between ions. Alkynes are more reactive than alkenes. The addition of hydrogen to an unsaturated substance is called **hydrogenation**. This reaction usually requires the presence of a catalyst and a raised temperature.

Fermentation

In the fermentation process, enzymes produced by living organisms act as catalysts. A common fermentation product, ethanol, results from the fermentation of sugar. For example:

$$C_6H_{12}O_6 \xrightarrow{\text{zymase}} 2C_2H_5OH + 2CO_2$$

Combustion of Fuels

In order for combustion to take place, two items must be present. They are 1) two or more reactants which are unstable and, 2) energy to activate or start the reaction.

Oxygen, because of its high electronegativity, will have a tendency of drawing electrons to it. When the correct amount of activation energy is supplied, it will react with an unstable element or compound to form more stable products.

An example would be the combustion of this book. The paper in this book is made up of hydrocarbons. If a lighted match was put to a sheet of this book, the flame would supply the activation energy to cause the atmospheric oxygen to oxidize the hydrocarbons giving off energy in the form of heat and light which acts as the activation energy used to ignite the rest of the book in a chain reaction, and in the process forming new products.

Rapid combustion occurs when fuels are oxidized. An example would be a spark which would cause the combustion of acetylene gas.

$$2C_2H_2(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(l) + 2508\ kJ$$

Esterification

Esterification is the reaction of an acid with an alcohol to give an ester and water:

acid + alcohol → ester + water

$$\underset{\text{acetic acid}}{HCOOH} + \underset{\text{butanol}}{CH_3CH_2CH_2CH_2OH} \rightarrow \underset{\text{butyl acetate}}{HCOOCH_2CH_2CH_2CH_3} + \underset{\text{water}}{HOH}$$

Esterification is not an ionic reaction. It proceeds slowly and is reversible. To increase the yield of the ester, concentrated sulfuric acid is added decreasing the concentration of the water and favoring the forward reaction. Esters have certain characteristics. They are 1) covalent compounds, and 2) esters usually have pleasant odors. The aromas of many fruits, flowers, and perfumes are due to esters. (**Fats** are esters derived from glycerol and long-chain organic acids.)

Saponification

The hydrolysis of fats by bases is called **saponification**. To make soap, fat (a glycerol ester) is saponified by hot alkali (base). The products are soap (a salt of an organic fatty acid) and glycerol.

Oxidation (Combustion)

Saturated hydrocarbons react readily with oxygen under conditions of combustion. In an excess of oxygen, hydrocarbons burn completely to form carbon dioxide and water.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Burning in a limited supply of oxygen may produce carbon monoxide and carbon as well.

$$2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$$

$$CH_4 + O_2 \rightarrow C + 2H_2O$$

Polymerization

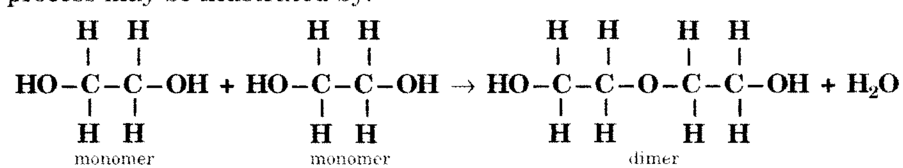
Polymerization involves the formation of a large molecule from smaller molecules called **monomers**. Synthetic rubbers, plastics such as polyethylene, and other chain molecules synthesized by humans are polymers. In nature polymerization occurs in the production of proteins, starches, and other chemicals by living organisms.

Polymers

A polymer is composed of many repeating units called monomers. Starch, cellulose, and proteins are natural polymers. Nylon and polyethylene are synthetic polymers. Polymerization is the process of joining monomers. Polymers may be formed by condensation or by additional polymerization.

Condensation Polymers

Condensation polymerization results from the bonding of monomers by a dehydration reaction. Water is the usual by-product. A condensation process may be illustrated by:



Addition Polymers

An addition polymerization results from the joining of monomers of unsaturated compounds by "opening" double or triple bonds in the carbon chain. An addition process may be illustrated as:

$$nC_2H_4 \rightarrow (\text{-}C_2H_4\text{-})_n \quad \text{or} \quad n(C_2H_{2n\text{-}2}) \rightarrow (C_2H_{2n})_n$$

UNIT 7: Organic Chemistry

KEY CONCEPTS

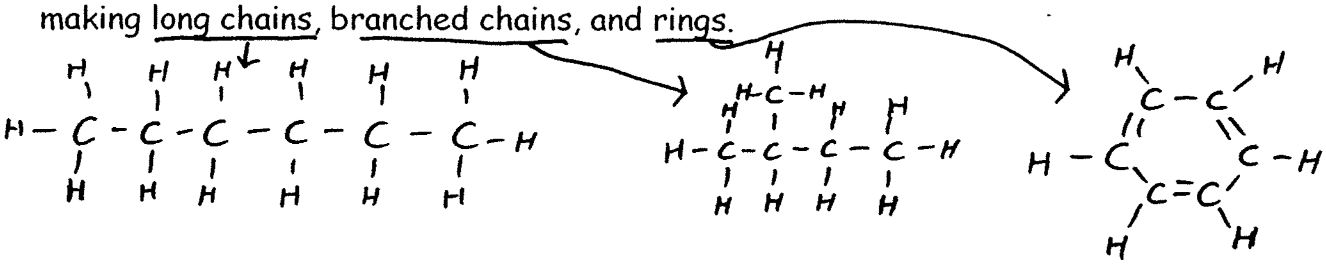
Hydrocarbon	Alkynes
Saturated	Addition reaction
Unsaturated	Substitution
Organic prefixes	Esterification
Functional groups	Fermentation
IUPAC naming	Combustion
Isomers	Polymerization
Alkanes	Saponification
Alkenes	

I. Properties of Organic Compounds

a. Covalently Bonded
b. Low to no conductivity in solution (except organic acids)
c. Low melting and boiling points
d. Soluble in nonpolar solvents (organic acids are soluble in polar solvents)
e. Slow reaction rates

II. Simple Organic Compounds

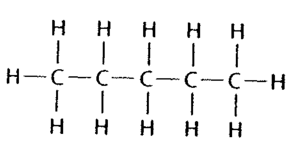
Organic compounds contain carbon atoms which can bond four times. What makes Organic compounds special is that the carbon atoms can bond to one another making long chains, branched chains, and rings.

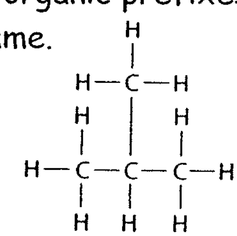


Hydrocarbons are compounds that contain only carbon and hydrogen atoms.

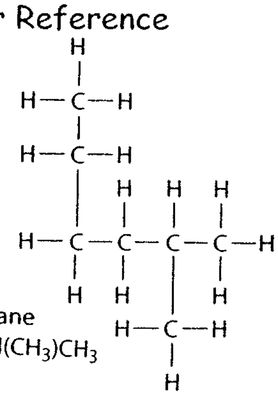
Saturated hydrocarbons contain all single carbon bonds (**alkanes**). They have the general formula C_nH_{2n+2}. Using your organic prefixes in Table P of your Reference Tables, hydrocarbons are easy to name.

Pentane
C_5H_{12}



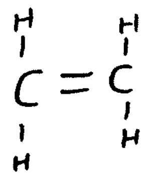


Methyl propane
$CH_3CH(CH_3)CH_3$

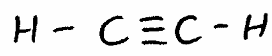


2-methyl hexane
$CH_3CH_2CH_2\text{-}CH_2\text{-}CH(CH_3)CH_3$

Unsaturated organic compounds contain at least one double or triple bond. In a double or triple covalent bond, more than one pair of electrons are shared between two atoms. If the hydrocarbon has a double bond it is and **alkene** and has the general formula of C_nH_{2n}. If the hydrocarbon has a triple bond it is and **alkyne** and has the general formula of C_nH_{2n-2}.



Ethene

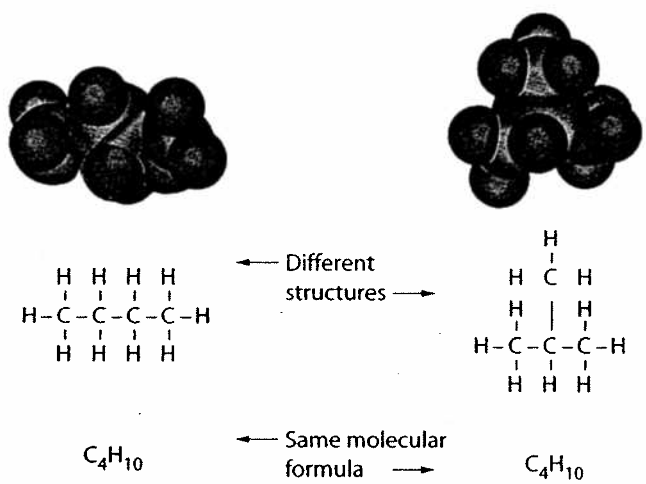


Ethyne

Use Table Q to help you determine the structural formulas for **alkanes, alkenes and alkynes.**

Organic compounds can be named by the **IUPAC naming** system - find the longest chain and use Reference Table P for the correct **organic prefixes.**

Isomers of organic compounds have the same molecular formula, but different structures and properties. There must be at least 4 carbon atoms to have an isomer of a hydrocarbon. As the number of atoms increase for a compound the number of isomers increase.



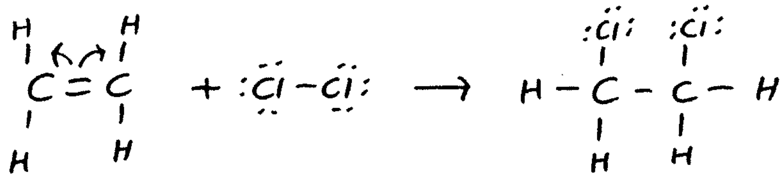
III. Functional Groups

Functional groups will give organic compounds different chemical and physical properties. There are 10 functional groups you need to know - they are listed in Table R - halides, alcohols, ethers, aldehydes, ketones, organic acids, esters, amines and amides.

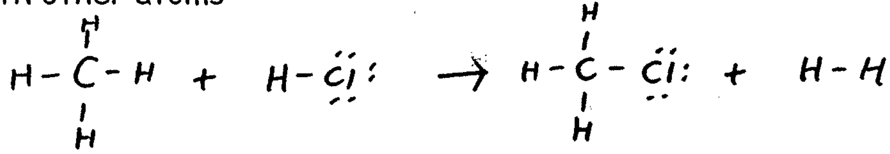
You must be able to draw the structure when given the correct IUPAC name AND be able to classify the compound based on its structural formula

IV. Organic Reactions

Addition - unsaturated compound reacts to form a saturated compound



Substitution - Saturated compound reacts by replacing one or more hydrogens with other atoms



Fermentation - Glucose reacts with an enzyme (catalyst) in yeast to produce ethanol and CO_2

$$C_6H_{12}O_6 \rightarrow C_2H_5OH$$

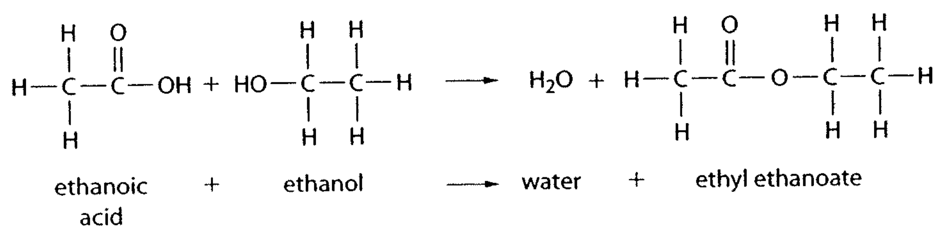
Saponification - makes soap from reacting fat & base

Fat + NaOH (base) → Glycerol + Soap

Combustion - organic compounds react with O_2 to form CO_2 and H_2O

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

Esterification - alcohol plus acid makes an ester plus water



Polymerization - monomers join together to form longer chains