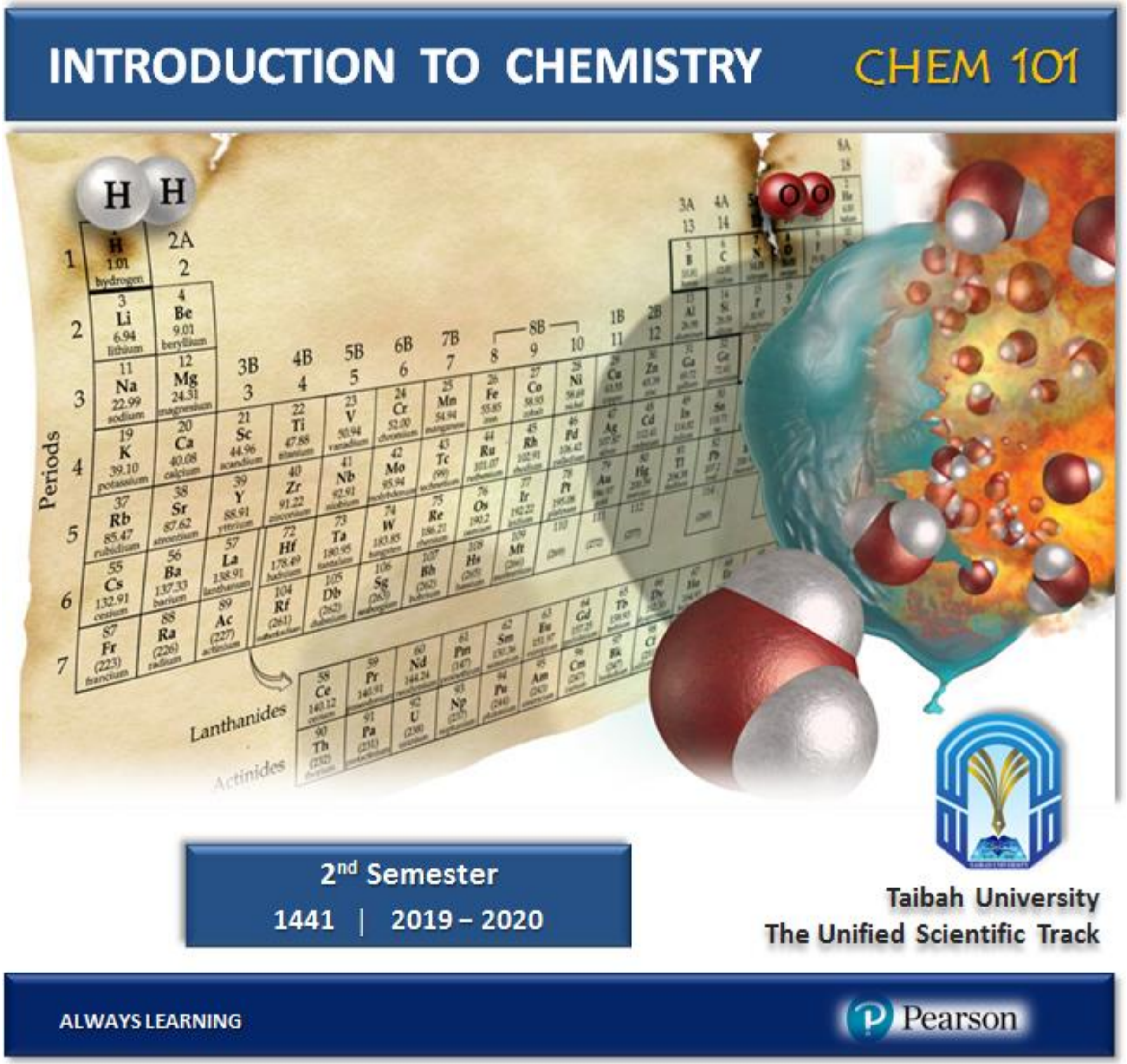


Lecture Presentation

Chapter 7

The Chemistry of Life: Organic and Biological Chemistry

Topic 19

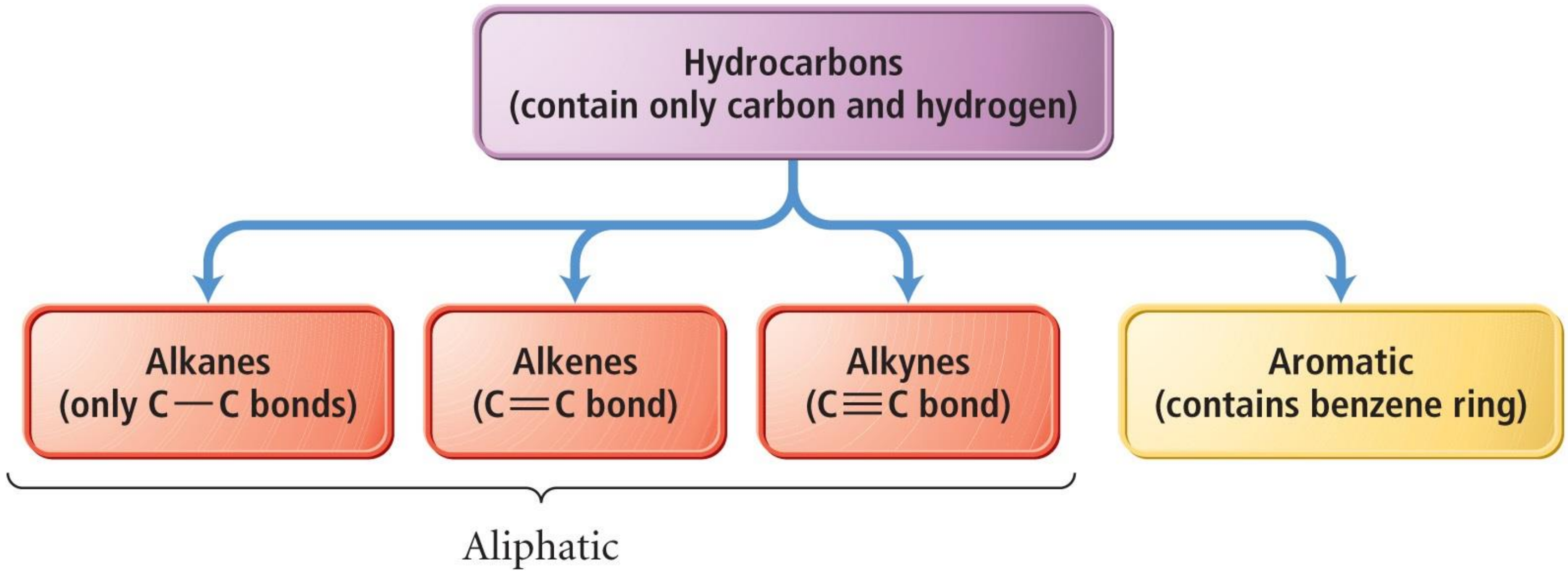
- **Introduction to Organic Chemistry**
- **Hydrocarbons**
- **Alkanes & Cycloalkanes**

Introduction To Organic Chemistry

- Organic chemistry is an old interesting branch of chemistry, but has only started in the 19th century as a science in its modern sense.
- **Organic Chemistry** is the chemistry of **carbon element**. Carbon forms strong chemical bonds to other carbon atoms and to many other elements.
- Because of its versatility in forming covalent bonds, millions of carbon compounds are known.
- The existence of a great number of different organic compounds has raised up the need to classify them into **"families".**
- Carbon always forms **four covalent bonds** (four shared pairs of electrons) that may be present as:
  - 4 single bonds
  - 2 single and 1 double bond
  - 1 single and 1 triple bond
  - 2 double bonds

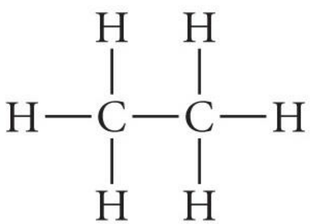
Hydrocarbons

- The family of "**Hydrocarbons**" is the simplest family of organic compounds, containing only hydrogen and carbon atoms.
- **Hydrocarbons** are **non-polar** molecules, **insoluble** in water and soluble in non-polar solvents.
- Hydrocarbons have low melting and boiling points.
- There are four basic types of hydrocarbons:
  - **Alkanes** (C–C)
  - **Alkenes** (C=C)
  - **Alkynes** (C≡C)
  - **Aromatic hydrocarbons** ()

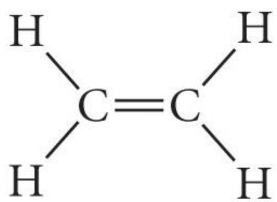


Generic Formula*	Generic Formula*	Generic Formula*	Benzene Formula
C_nH_{2n+2}	C_nH_{2n}	C_nH_{2n-2}	C_6H_6

Example

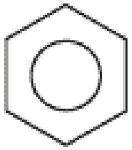


Ethane



Ethene

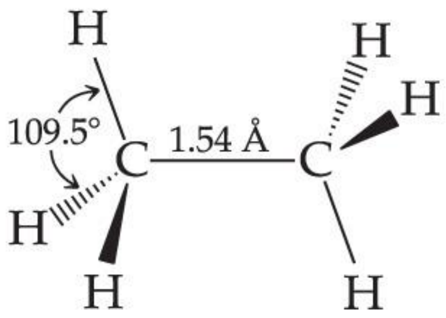
Ethyne



Benzene

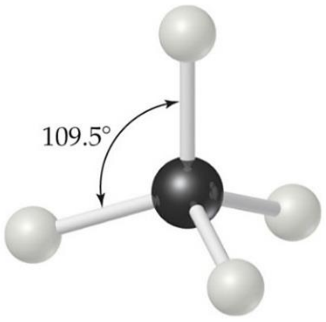
Alkanes (C—C)

Alkane Ethane CH_3CH_3

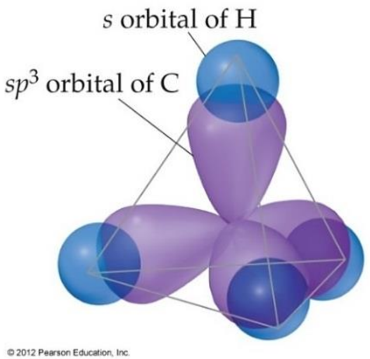


The general formula of **alkanes** is **C_nH_{2n+2}**

Alkanes are known as "**saturated hydrocarbons**" that contain only single bonds (**C–C**).



- Each carbon atom makes **4 single bonds.**

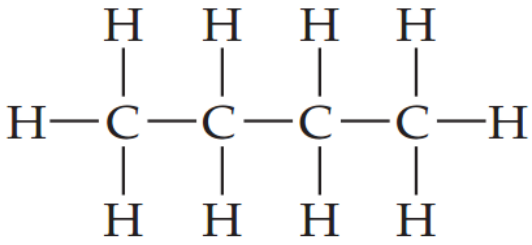


Representing Bonding Connections

There are 3 ways to represent bonding connections:

Example: bonding connections for n-butane (**C_4H_{10}**):

1. Expanded Structure:



2. Condensed Structure:

$CH_3CH_2CH_2CH_3$ or $CH_3(CH_2)_2CH_3$

3. Stick Structure (Carbon Skeleton):

Properties of Alkanes

- Boiling points of **Alkanes** increase as chain length increases:

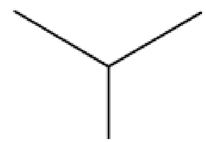
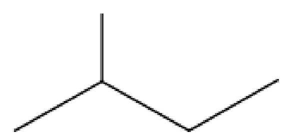
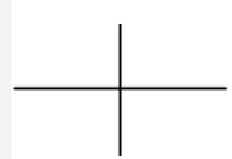
TABLE 24.2 • First Ten Members of the Straight-Chain Alkane Series

Molecular Formula	Condensed Structural Formula	Name	Boiling Point (°C)
CH_4	CH_4	Methane	−161
C_2H_6	CH_3CH_3	Ethane	−89
C_3H_8	$CH_3CH_2CH_3$	Propane	−44
C_4H_{10}	$CH_3CH_2CH_2CH_3$	Butane	−0.5
C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$	Pentane	36
C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$	Hexane	68
C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	Heptane	98
C_8H_{18}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Octane	125
C_9H_{20}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Nonane	151
$C_{10}H_{22}$	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Decane	174

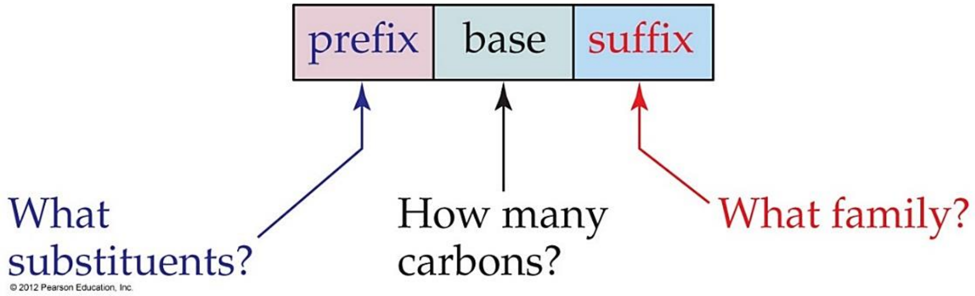
Isomers of Alkanes

- **Isomers**: compounds that have the same molecular formula but **different molecular structures** (i.e. different order of bonding).

Example 1: Isomers of C_4H_{10}

Systematic Name (Common Name)	Condensed Structural Formula	Stick Formula	Melting Point (°C)	Boiling Point (°C)
Butane (*n*-butane)	$CH_3CH_2CH_2CH_3$		−138	−0.5
2-Methylpropane (isobutane)	$CH_3-CH(CH_3)-CH_3$		−159	−12
Example 2: Isomers of C_5H_{12}				
Pentane (*n*-pentane)	$CH_3CH_2CH_2CH_2CH_3$		−130	+36
2-Methylbutane (isopentane)	$CH_3-CH(CH_3)-CH_2-CH_3$		−160	+28
2,2-Dimethylpropane (neopentane)	$CH_3-C(CH_3)_2-CH_3$		−16	+9

Nomenclature of Organic Compounds



- **The names of organic compounds contain three parts:**
  - **Prefix**: This tells what substituent groups are attached to the chain.
  - **Base**: This tells how many carbons are there in the longest continuous carbon chain.
  - **Suffix**: This tells what type of compound it is (the family)

Nomenclature of Alkanes

➢ The Base Names:

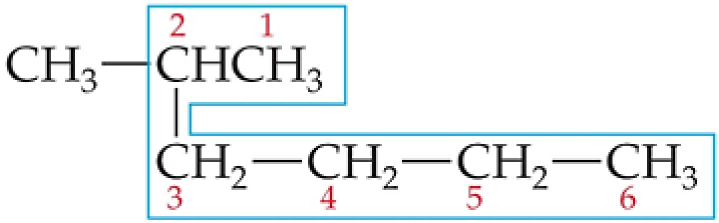
Alkane Nomenclature

Number of carbon atoms	Base Name	Alkane Formula	Name of alkane	Name of alkyl group (R)	Alkyl (R) Formula
1	meth –	CH_4	methane	methyl	$CH_3–$
2	eth –	CH_3CH_3	ethane	ethyl	$CH_3CH_2–$
3	prop –	$CH_3CH_2CH_3$	propane	propyl	$CH_3CH_2CH_2–$
4	but –	$CH_3(CH_2)_2CH_3$	butane	butyl	$CH_3(CH_2)_2CH_2–$
5	pent –	$CH_3(CH_2)_3CH_3$	pentane	pentyl	$CH_3(CH_2)_3CH_2–$
6	hex –	$CH_3(CH_2)_4CH_3$	hexane	hexyl	$CH_3(CH_2)_4CH_2–$
7	hept –	$CH_3(CH_2)_5CH_3$	heptane	heptyl	$CH_3(CH_2)_5CH_2–$
8	oct –	$CH_3(CH_2)_6CH_3$	octane	octyl	$CH_3(CH_2)_6CH_2–$
9	non –	$CH_3(CH_2)_7CH_3$	nonane	nonyl	$CH_3(CH_2)_7CH_2–$
10	dec –	$CH_3(CH_2)_8CH_3$	decane	decyl	$CH_3(CH_2)_8CH_2–$

➢ The base names and alkyl groups (R) names are **to be memorized**!

Nomenclature of Alkanes

1. Find the **longest continuous chain** of carbon atoms in the molecule and use this chain as the **base name** (see the table of base names).



2-Methyl*hexane*

2. Number the carbon atoms in the longest chain, beginning with the end **nearest to a substituent.**

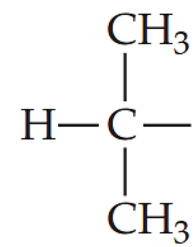
3. Name each substituent (**prefixes**)

4. Begin the name with the number or numbers of carbon atoms to which each substituent is bonded.

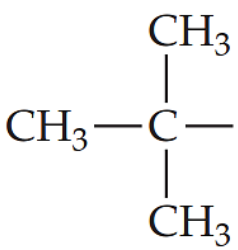
5. When two or more substituents are present, list them **alphabetically**

Names of Substituent Groups (Branches)

- **Carbon Groups (alkyl groups, R):**
  - Methyl CH_3-
  - Ethyl CH_3CH_2-
  - Propyl $CH_3CH_2CH_2-$
  - Butyl $CH_3CH_2CH_2CH_2-$



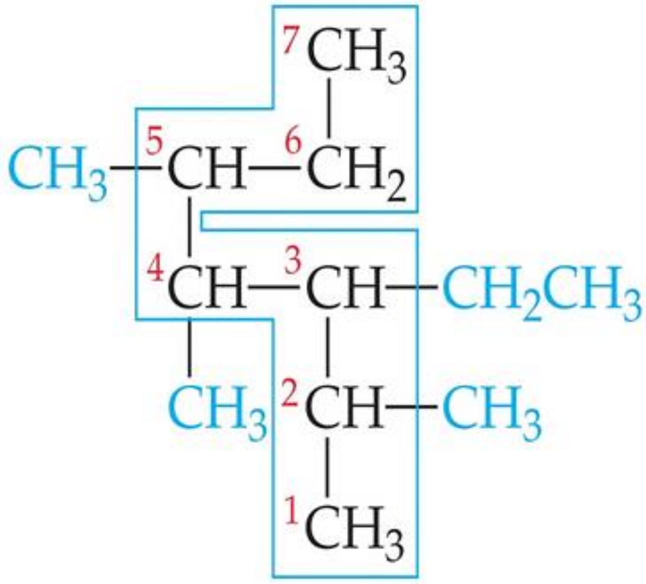
Isopropyl



tert-Butyl

- **Halogens:**
  - Fluoro **F —**
  - Chloro **Cl —**
  - Bromo **Br —**
  - Iodo **I —**

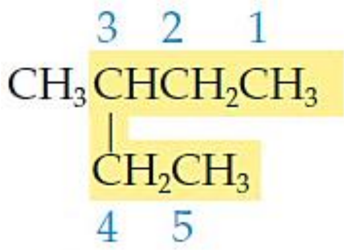
Names of Substituent Groups (Branches)



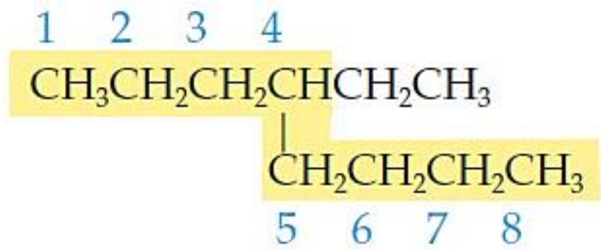
If there is more than one type of substituent in the molecule, list them **"alphabetically"**.

3-**E**thyl-2,4,5-tri**m**ethylheptane

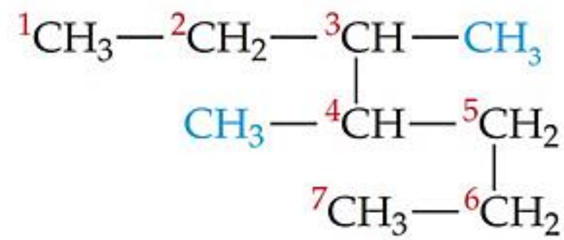
Nomenclature of Alkanes: Exercises



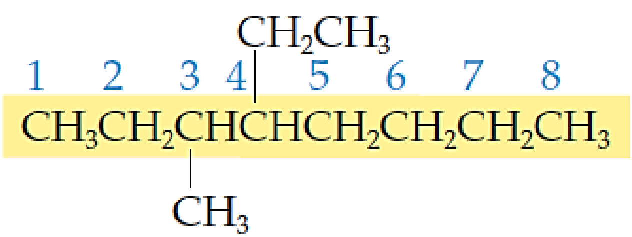
3-Methyl
3-Methylpentane



4-Ethyl
4-Ethyloctane

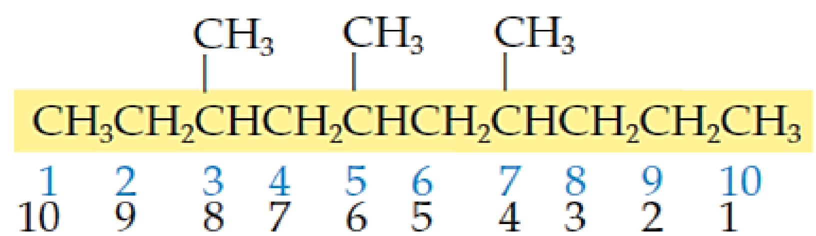


3,4-dimethylheptane



✓ 4-Ethyl-3-methylocatane

✗ *NOT* 3,3-Methyl-4-ehyloctane



✓ 3,5,7-Trimethyldecane

✗ *NOT* 4,6,8-Trimethyldecane

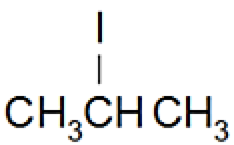
Nomenclature of Alkanes: Exercises

- **Give the systematic (IUPAC) name for each compound:**

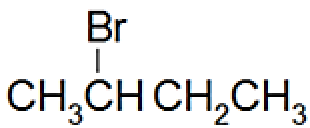
CH_3Cl
Chloromethane

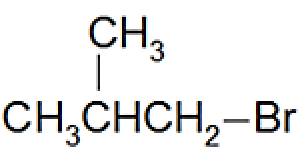
CH_3CH_2-Br
Bromoethane

$CH_3CH_2CH_2-I$
1-Iodopropane

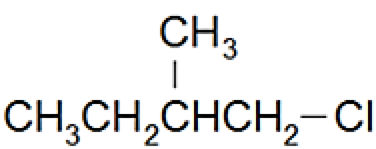

2-Iodopropane

$CH_3CH_2CH_2CH_2-Br$
1-Bromobutane


2-Bromobutane


1-Bromo-2-methylpropane

$CH_3CH_2CH_2CHCH_2CH_2-Cl$
1-chlorohexane

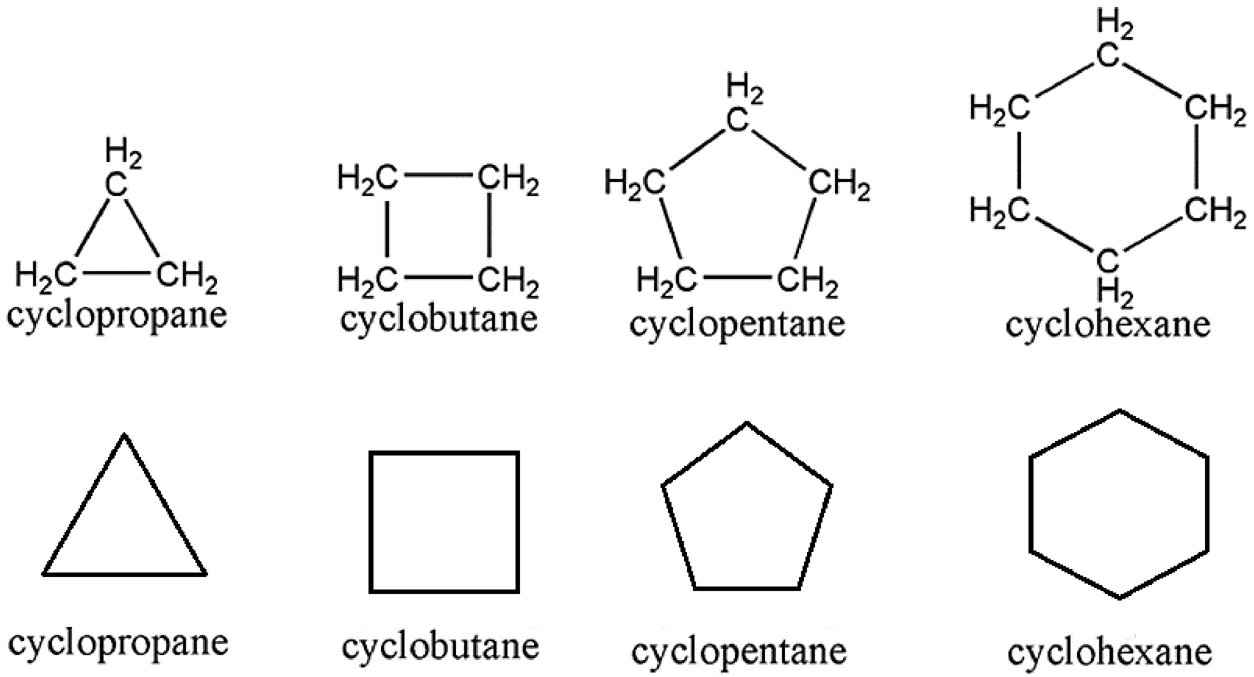

1-Chloro-2-methylbutane

Cycloalkanes

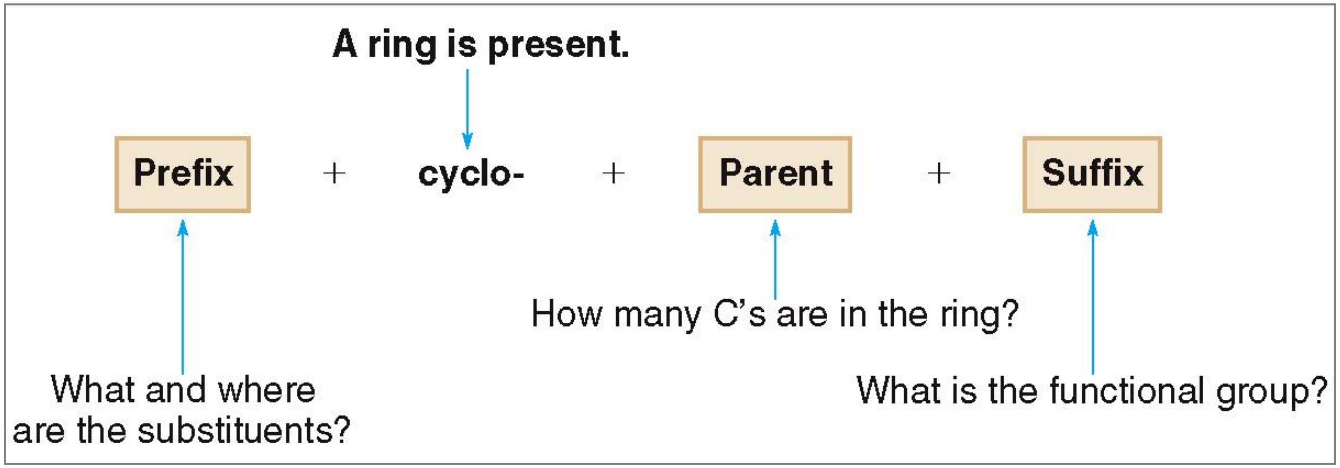
- Carbon can also form **cyclic (ringed)** structures.

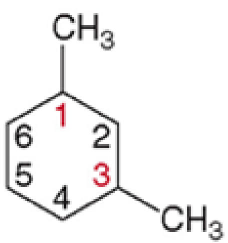
The general formula of **cycloalkanes** is C_nH_{2n}

- Six-membered rings are the most stable cyclic compounds.



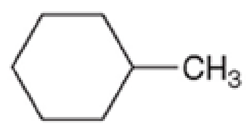
Nomenclature of Cycloalkanes



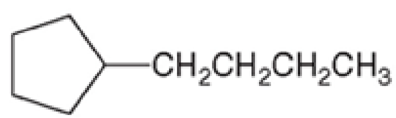


✔ **1,3-dimethylcyclohexane**

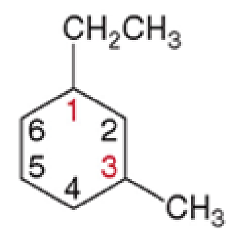
✘ (*not* 1,5-dimethylcyclohexane)



methylcyclohexane



butylcyclopentane



Earlier letter ----→ lower number

- ethyl group at **C1**
- methyl group at **C3**

✔ **1-ethyl-3-methylcyclohexane**

✘ (*not* 3-ethyl-1-methylcyclohexane)

Reactions of Alkanes

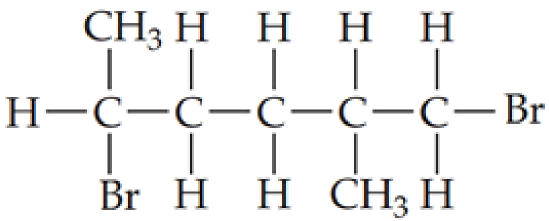
- Alkanes are mainly used as **non-polar solvents**.
- Most alkanes are relatively **unreactive** at room temperature, because they contain only C−C and C−H bonds.
- However, alkanes are not completely inert. One of their important reactions is their **combustion** in oxygen, making them important **fuels** and a source of thermal energy:

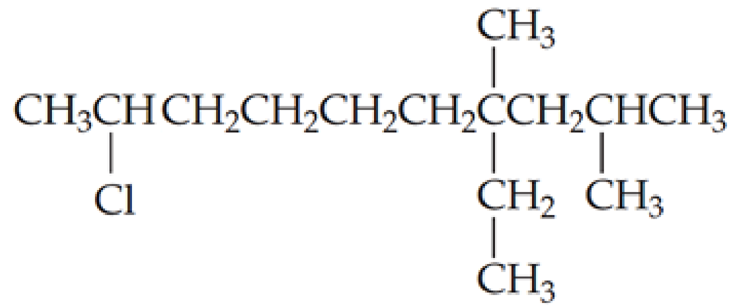
- **Example**: the combustion of ethane:

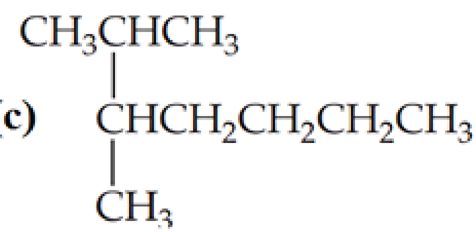
$$2\,C_2H_6(g) + 7\,O_2(g) \rightarrow 4\,CO_2(g) + 6\,H_2O(l) \quad \Delta H = -2855\ kJ$$

Assessment

1. Give the the name or structural formula, as appropriate:

(a) 

(b) 

(c) 

(d) 2-methylheptane

(e) 2,2-dimethylpentane

(f) 4-ethyl-2,3-dimethyloctane

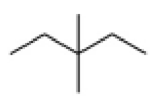
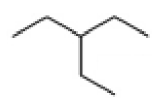
(g) 4-ethyl-1,1-dimethylcyclohexane

(h) 1,2-dimethylcyclohexane

(i) $(CH_3)_2CHCH_2CH_2C(CH_3)_3$

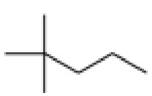
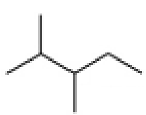
2. Which of the following pairs of compounds are isomers?

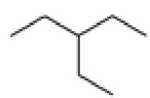
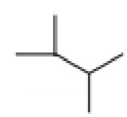
a)  and 

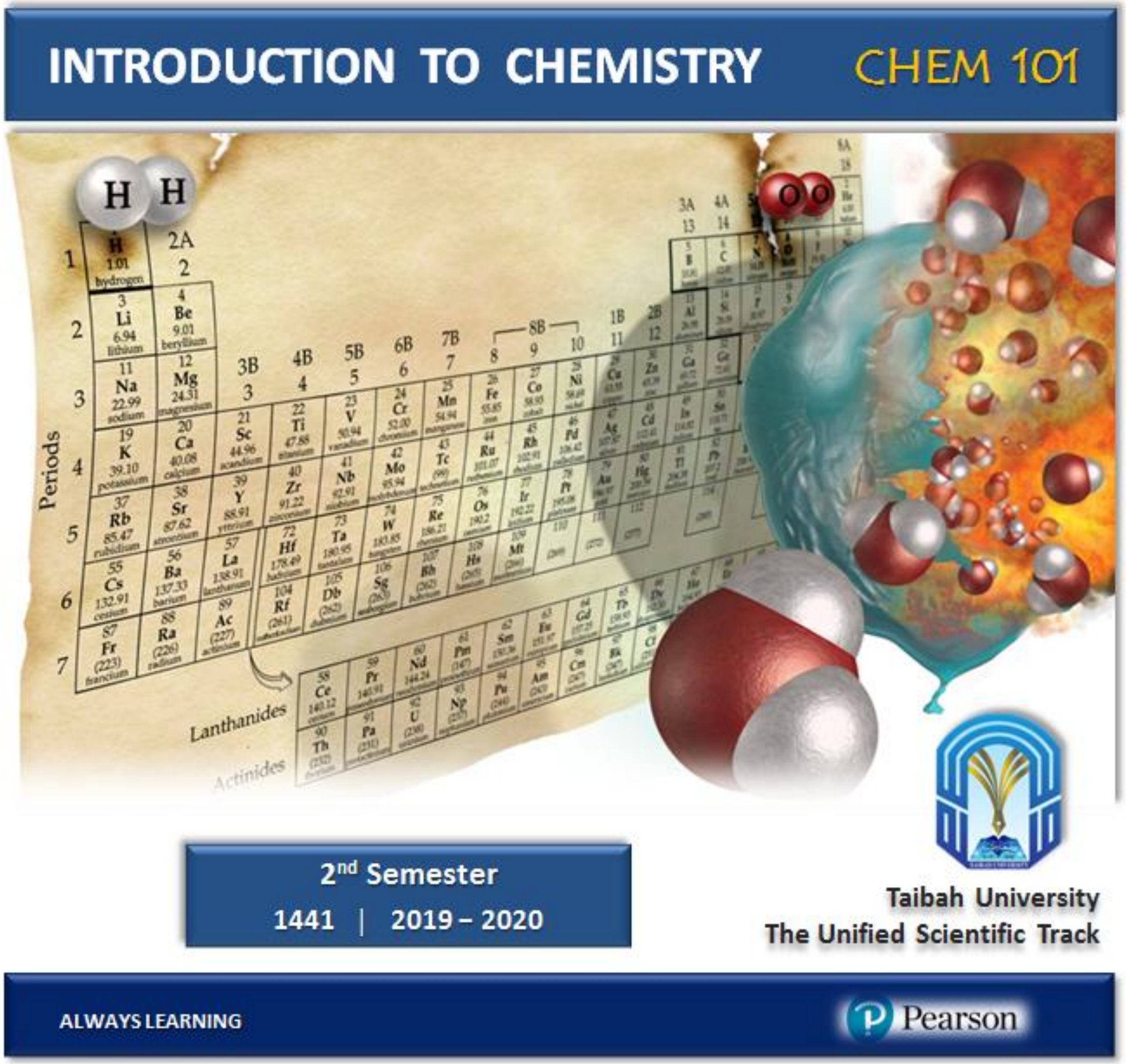
b)  and 

c) C_2H_4 and C_2H_6

d) C_3H_8 and C_4H_{10}

e)  and 

F)  and 



Lecture Presentation

Chapter 7

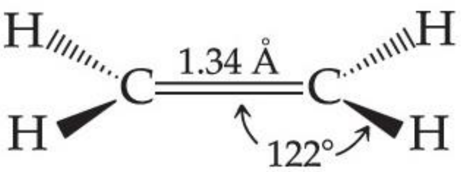
The Chemistry of Life: Organic and Biological Chemistry

Topic 20

- Alkenes
- Alkynes
- Aromatic Hydrocarbons

Alkenes (C=C)

Alkene   Ethylene $CH_2{=}CH_2$



The general formula of **alkenes** is C_nH_{2n}

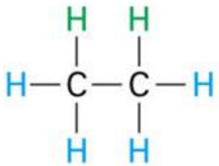
Alkenes are **unsaturated hydrocarbons** that contain at least one double bond (**C=C**).

- The simplest alkene is $CH_2{=}CH_2$, called **ethene** (IUPAC) or **ethylene** (common name).

Alkene

Ethylene: C_2H_4
(fewer hydrogens—*unsaturated*)

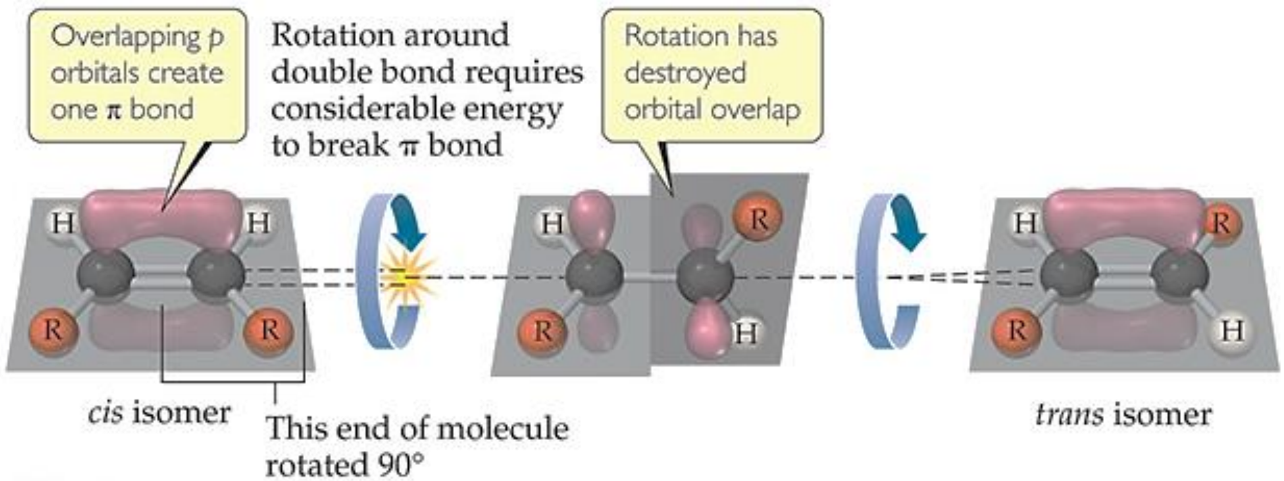
Alkane



Ethane: C_2H_6
(more hydrogens—*saturated*)

Structure of Alkenes: *cis/trans* Geometric Isomers

- Unlike alkanes, alkenes cannot rotate around the C=C bond:

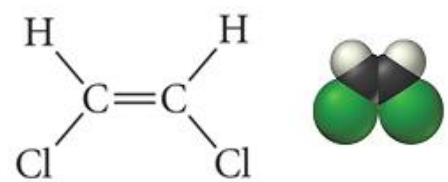


cis/trans **geometric isomerism:**

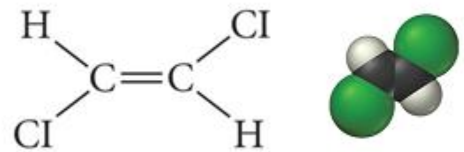
- *cis*-Alkenes: have the two prior **R** groups on the same side of the double bond plan.

- *trans*-Alkenes: have the two prior **R** groups on opposite sides of the double bond plan.

- Geometric isomers can differ significantly from each other in chemical behaviour.



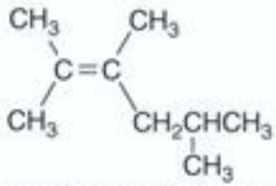
cis-1,2-Dichloroethene



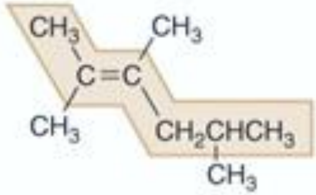
trans-1,2-Dichloroethene

Nomenclature of Alkenes

Example **Give the IUPAC name of the following alkene:**



Step [1] **Find the longest chain that contains *both* carbon atoms of the double bond.**



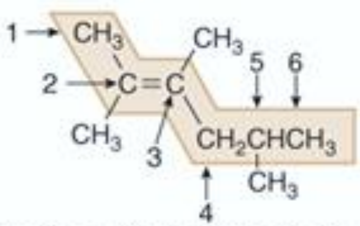
6 C's in the longest chain

hex*ane* ----→ **hex*ene***

- Change the ***-ane*** ending of the parent alkane to ***-ene.***

Step [2] **Number the carbon chain to give the double bond the lower number, and apply all other rules of nomenclature.**

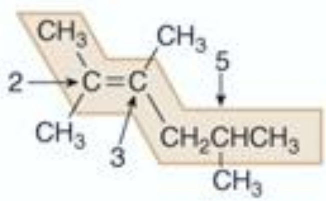
[a] **Number** the chain, and name using the ***first*** **number** assigned to the C=C.



- Number the chain to put the C=C at C2, not C4.

2-hexene

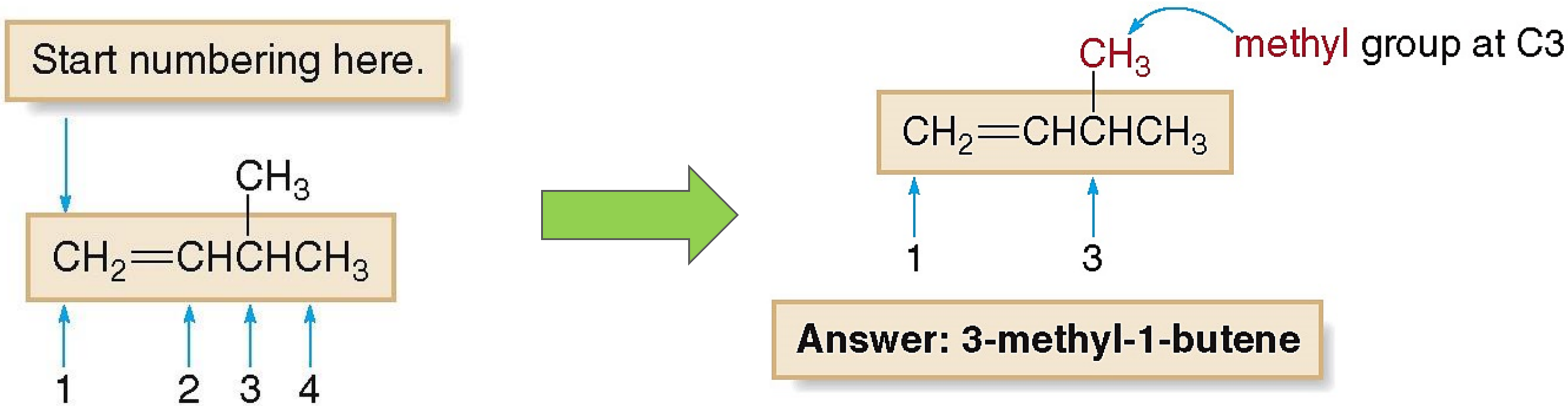
[b] **Name** and **number** the substituents.

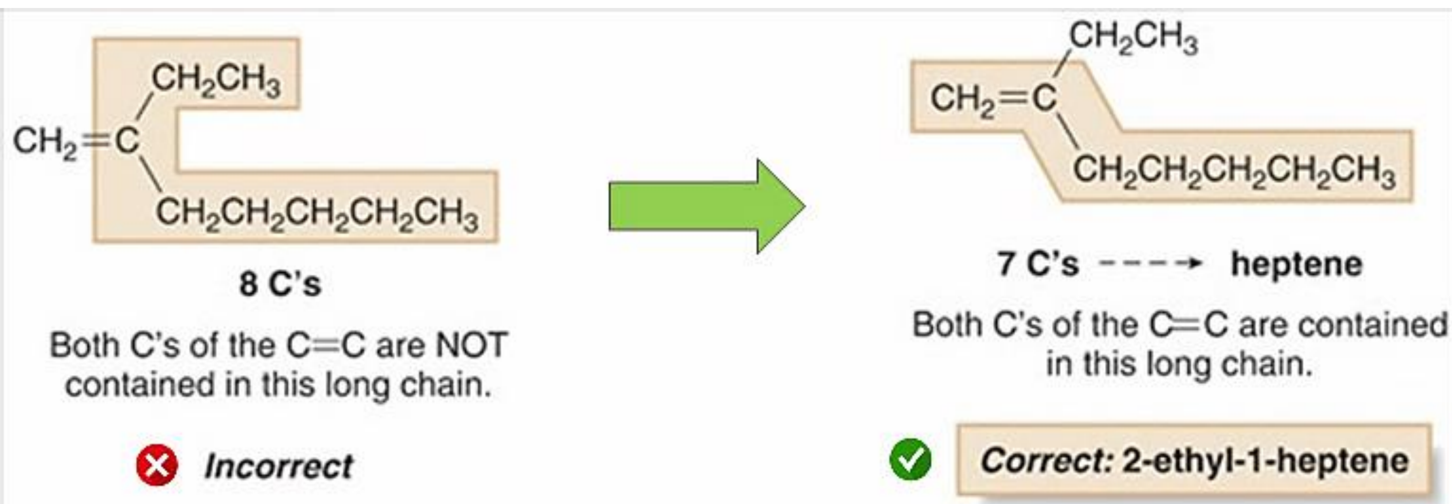


three methyl groups at C2, C3, and C5

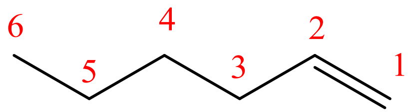
Answer: 2,3,5-trimethyl-2-hexene

Nomenclature of Alkenes



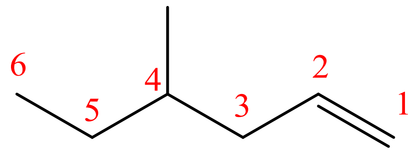


Nomenclature of Alkenes



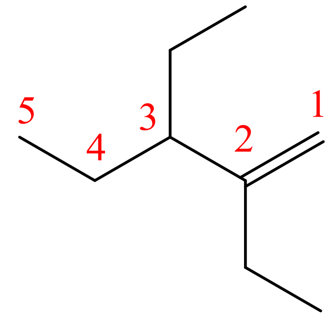
CH_3-CH_2-CH_2-CH_2-CH=CH_2

1-Hexene



CH_3 (on C-4)
CH_3-CH_2-CH-CH_2-CH=CH_2

4-methyl-1-hexene



CH_2CH_3 (on C-3)
CH_3-CH_2-CH-C=CH_2
CH_2CH_3 (on C-2)

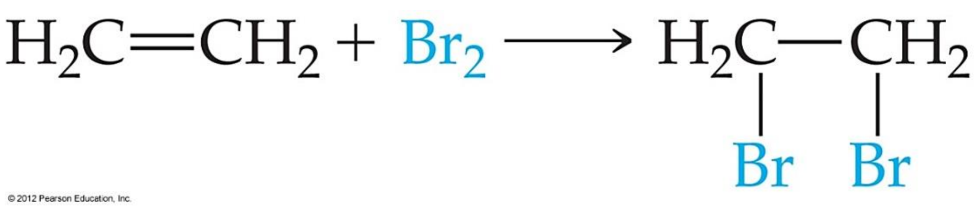
2,3-diethyl-1-pentene

Note: If an alkene contains two or more double bonds, the location of each is indicated by numerical prefix, and the ending of the name is altered to identify the number of double bonds: diene (two), triene (three):

Example: CH_2=CH–CH_2–CH=CH_2 is named: **1,4-pentadiene.**

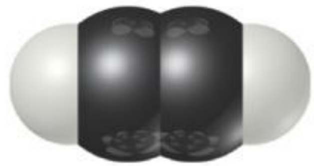
Addition Reactions of Alkenes

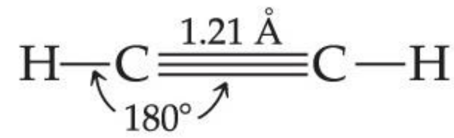
- One important reaction of alkenes is the **Addition Reaction**:
  - In which, two atoms (e.g., bromine) add across the double bond.
  - One π-bond (from C=C) and one σ-bond (from Br−Br) are replaced by two σ-bonds (2 C−Br); therefore, ΔH is negative.



Alkynes (C≡C)

Alkyne   Acetylene   CH≡CH

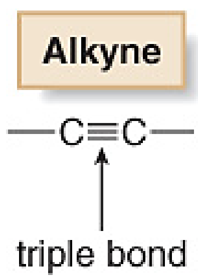




The general formula of **alkynes** is C_nH_{2n-2}

Alkynes are **unsaturated hydrocarbons** that contain at least one triple bond (**C≡C**).

- The simplest alkyne is H-C≡C-H, called **ethyne** (IUPAC) or **acetylene** (common name).



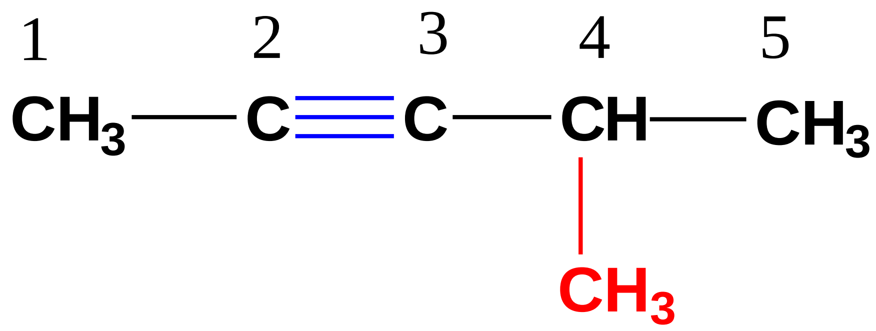
$CH_3CH_2CH_2$—C≡C—H

terminal alkyne

$CH_3CH_2CH_2$—C≡C—CH_2CH_3

internal alkyne

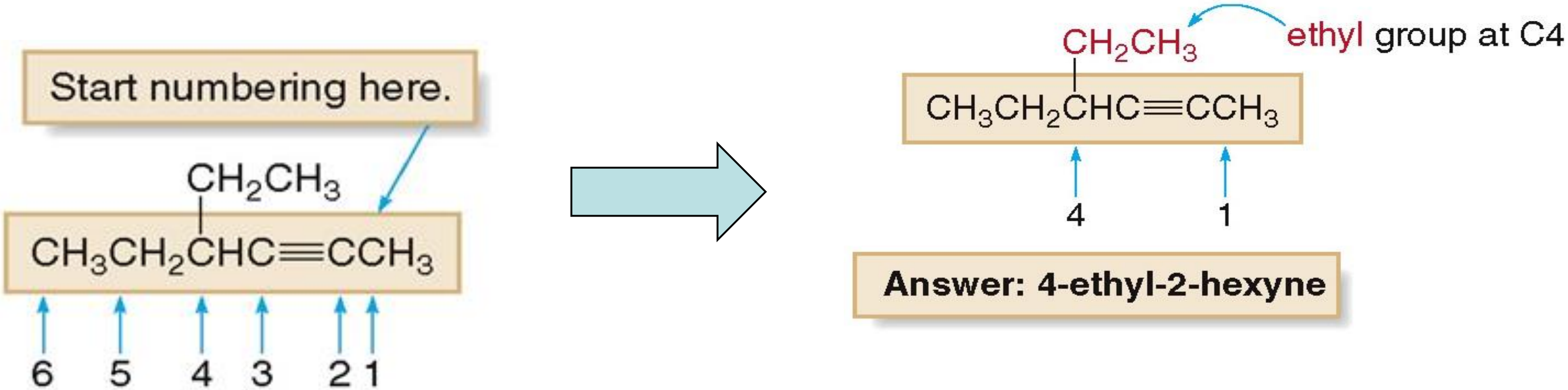
Nomenclature of Alkynes

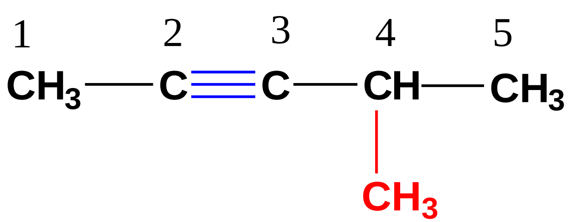


4-methyl-2-pentyne

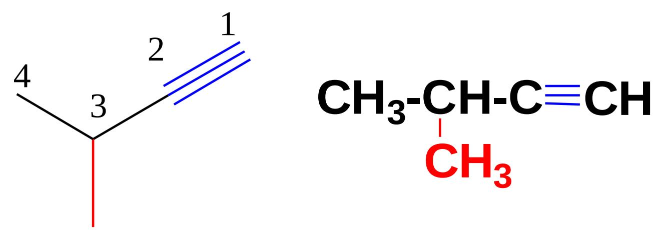
- The method for naming alkynes is **similar** to that for naming alkenes.
- However, the suffix *–yne* is used rather than *–ene*.

Nomenclature of Alkynes

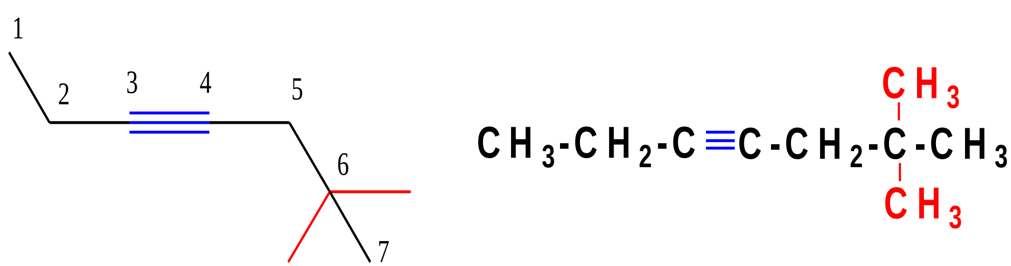




4-methyl-2-pentyne



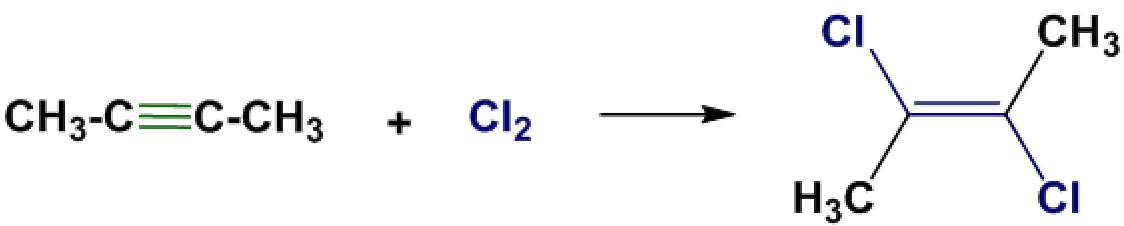
3-Methyl-1-butyne



6,6-Dimethyl-3-heptyne

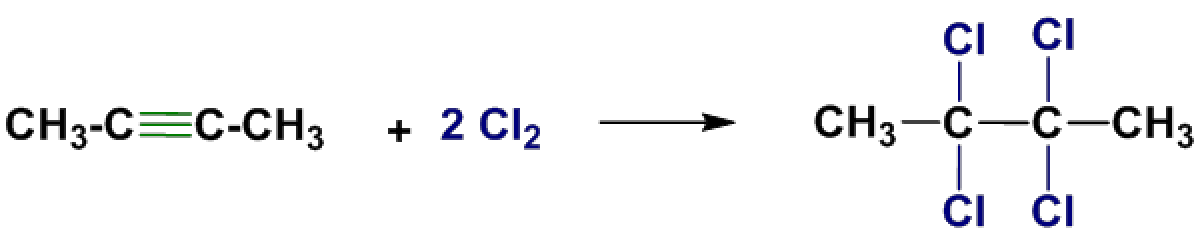
Addition Reactions of Alkynes

- Alkynes undergo many of the same reactions that alkenes do.
- As with alkenes, the drive for the addition reaction is the replacement of π-bonds by σ-bonds.



2-Butyne

trans-2,3-dichloro-2-butene

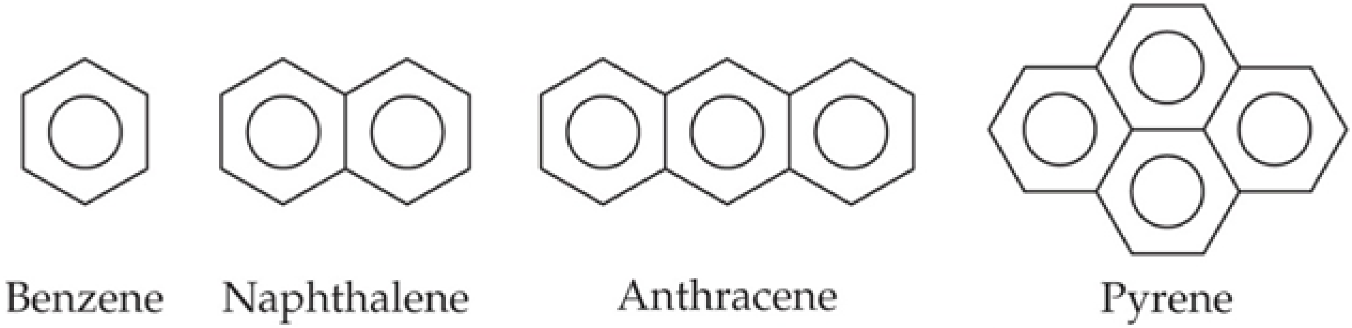


2-Butyne

2,2,3,3-Tetrachlorobutane

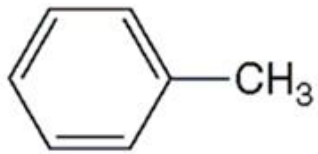
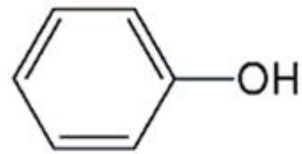
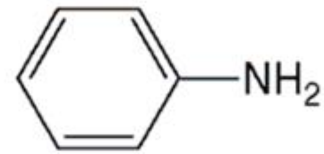
Aromatic Hydrocarbons

- **Aromatic Compound:** A hydrocarbon that contains one or more benzene-like rings.
- **Benzene** (C_6H_6) is the simplest and the most important aromatic hydrocarbon.
- It contains three alternated single/double bonds.
- Compared to alkenes, benzene is very stable and unreactive towards normal reagents.



Some Common Aromatic Hydrocarbons

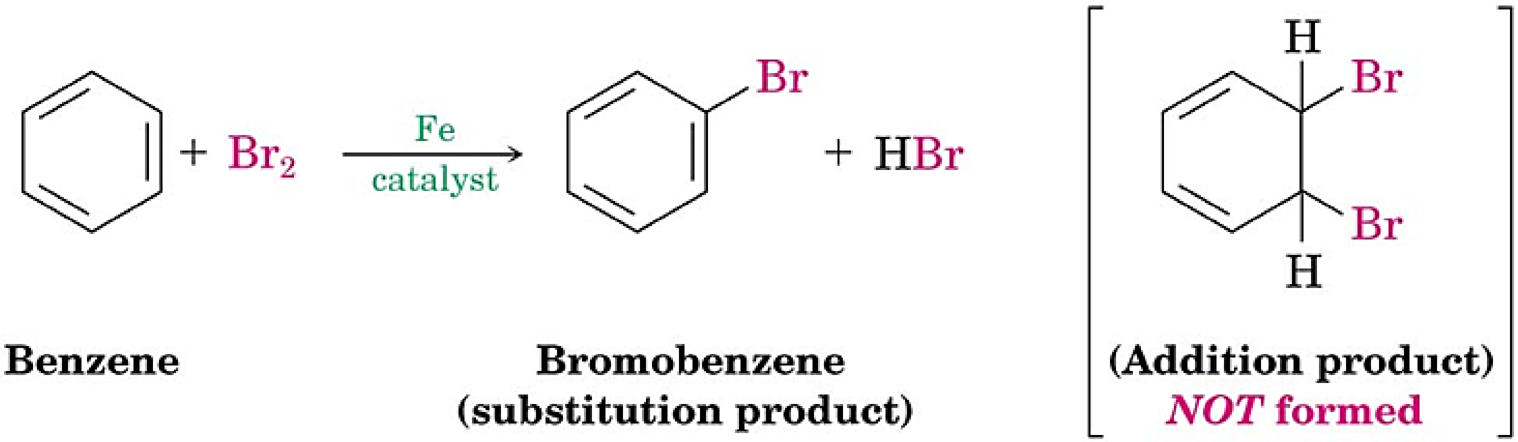
- Some important mono-substituted benzene compounds have **common names** that you must learn:

- **Structure:**			
- **Common Name:**	toluene	phenol	aniline
- **IUPAC Name:**	(methylbenzene)	(hydroxybenzene)	(aminobenzene)

*Students shall **carefully memorize** these examples

Substitution Reactions of Benzene

- It reacts differently to alkenes, yielding substitution products instead of addition ones.
- Benzene reacts slowly with Br_2, producing the bromobenzene as a substitution product.
- Addition products are NOT formed.



Benzene

Bromobenzene (substitution product)

(Addition product) *NOT* formed

1. Name or write the condensed structural formula for the following compounds:

a) *trans*-2-pentene

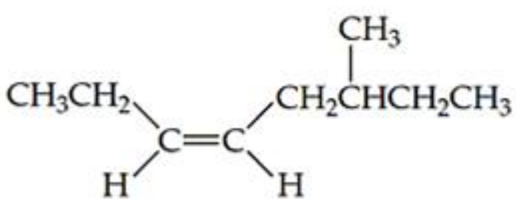
b) 2,5-dimethyl-4-octene

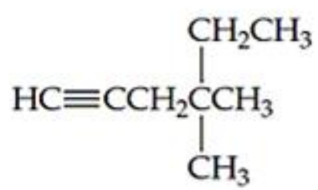
c) 1,1-dichloro-1-butene

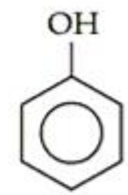
d) 1,4-dichlorobenzene

e) 2,4-dichloro-2-butene

f) 4,4-dimethyl-2-pentyne

g) 

h) 

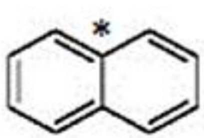
i) 

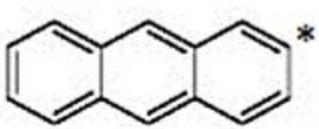
2. Identify the type of the following hydrocarbons (alkane, alkene, or alkyne)

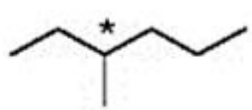
a) C_4H_8 b) C_4H_6 c) C_5H_{12} d) C_7H_{14}

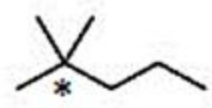
e) C_8H_{16} f) $C_{18}H_{38}$ g) C_6H_{10} h) $C_{10}H_{22}$

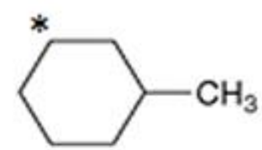
3. In the following carbon skeletons , how many hydrogen atoms shall be bonded to the carbon marked with a *?

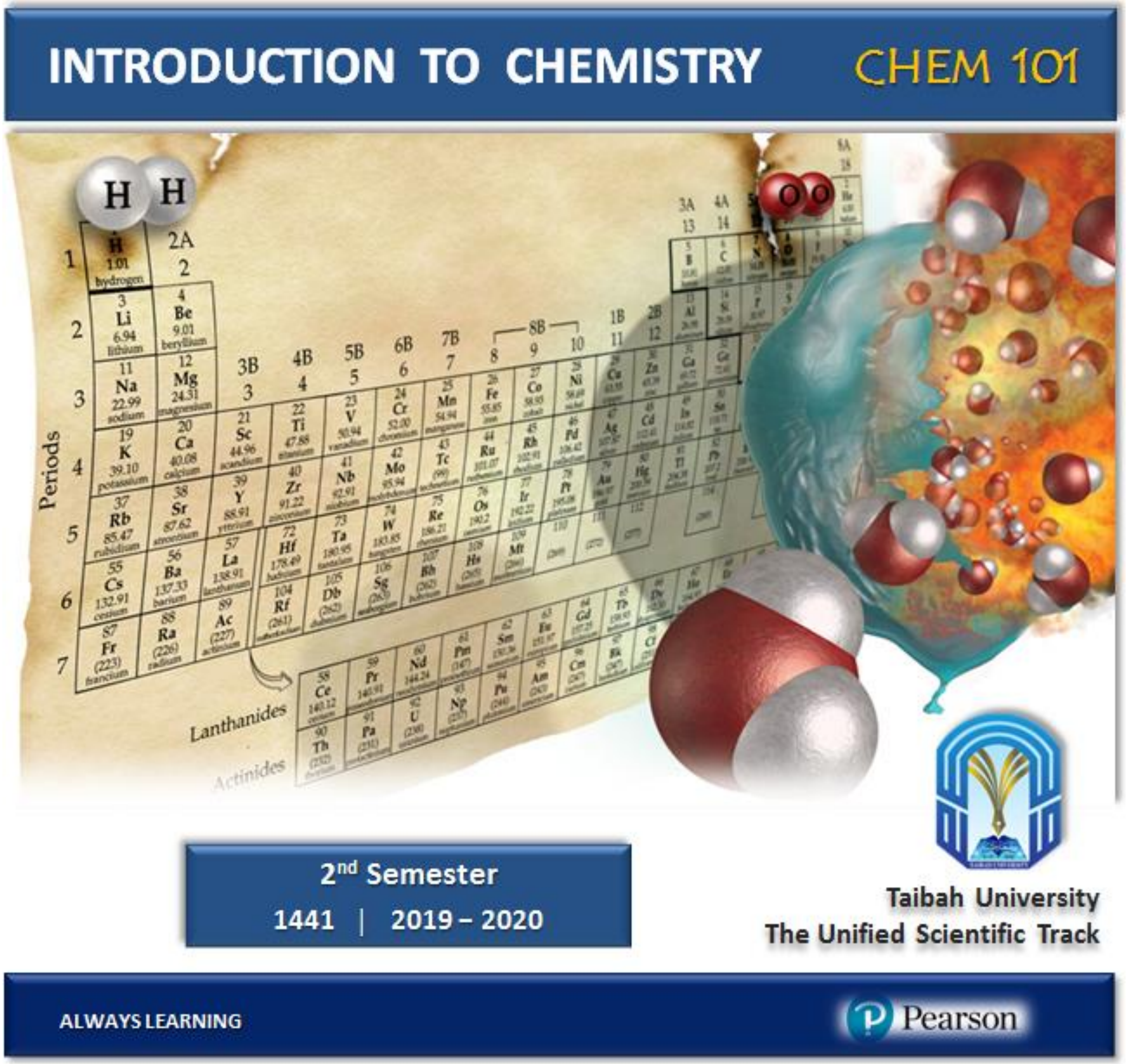












Lecture Presentation

Chapter 7

The Chemistry of Life: Organic and Biological Chemistry

Topic 21

Organic Functional Groups:

Alcohols, Ethers, Aldehydes, Ketones, Carboxylic Acids, Esters, Amines & Amides

7.3 Organic Functional Groups

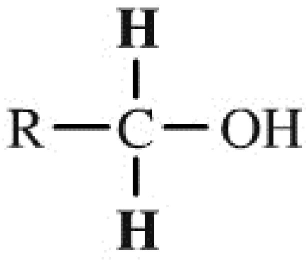
- The **Functional Group** is the active part of the organic molecule, where reactions tend to occur.

For example, the double bond **C=C** is the functional group of **alkenes** and the triple bond **C≡C** is the functional group of **alkynes**.

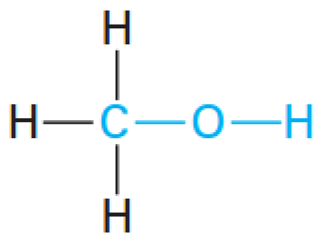
- When drawing the structure of some organic molecule, the **alkyl** parts are represented by "**R**" (**R = CH_3–, CH_3CH_2–, $CH_3CH_2CH_2$– …**) which are unreactive, giving rise to the functional groups to react.
  - ✓ When the present alkyl groups are different, they are represented as R, R', R" ….. or R^1, R^2, R^3, …..

Alcohols (R–OH)

- **Alcohols** are organic compounds, containing one or more **(–OH)** groups (called either the hydroxyl group or the alcohol group).

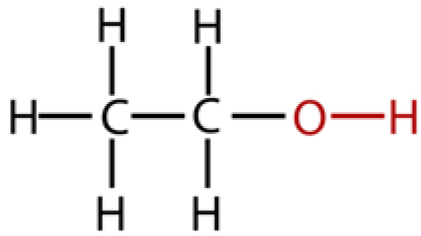


- The systematic names for alcohols ends with ***–ol.***
- The O–H bond is polar, so alcohols are more soluble in polar solvents than are hydrocarbons.



Methanol

(Methyl Alcohol)



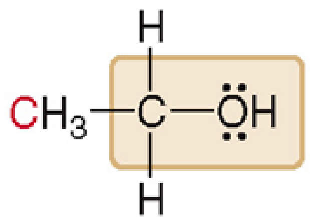
Ethanol

(Ethyl Alcohol)

Classes of Alcohols

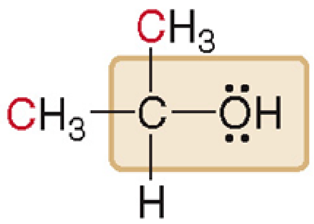
- **Alcohols** are classified according to the number of carbon atoms bonded to the **"C"** carrying the **"OH"** group:

1°



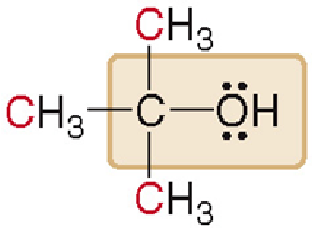
A **primary** (1°) alcohol has an OH group on a C which is bonded to another **1 C atom + 2 H atoms.**

2°



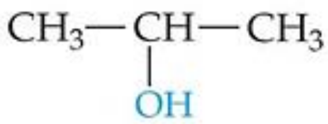
A **secondary** (2°) alcohol has an OH group on a C which is bonded to other **2 C atoms + 1 H atoms.**

3°

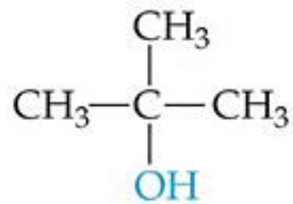


A **tertiary** (3°) alcohol has an OH group on a C which is bonded to other **3 C atoms + no H atoms.**

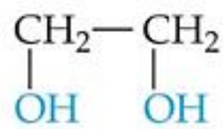
- Alcohols are named from the hydrocarbon parent; The suffix is changed to ***–ol*** and a number designates the carbon to which the hydroxyl is attached.



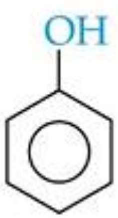
2-Propanol
Isopropyl alcohol; rubbing alcohol



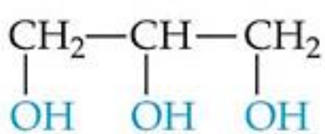
2-Methyl-2-propanol
t-Butyl alcohol



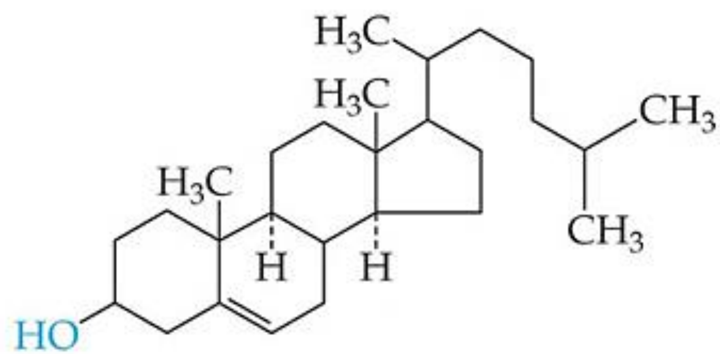
1,2-Ethanediol
Ethylene glycol



Phenol



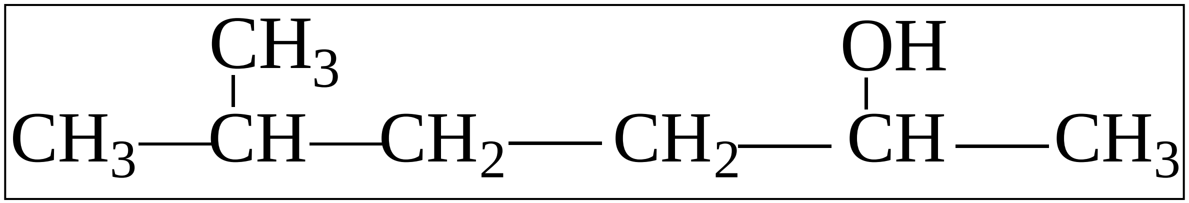
1,2,3-Propanetriol
Glycerol; glycerin



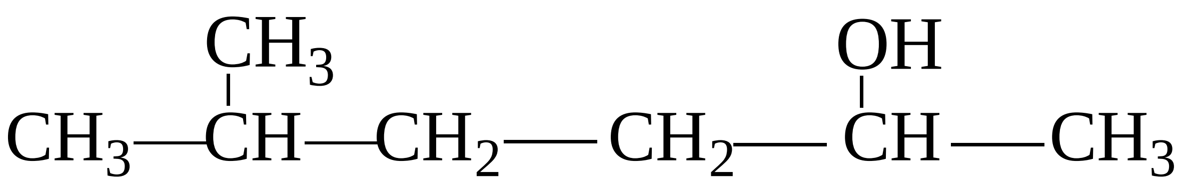
Cholesterol

Naming of Alcohols

Exercise: Give the IUPAC name for the following compound:



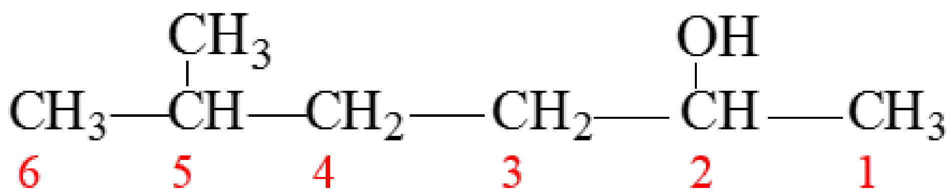
- ✓ **Step 1:** Name the longest carbon chain attached to the **—OH** group by replacing the ***"e"*** in the corresponding alk**ane** name with ***–ol***.



hexanol

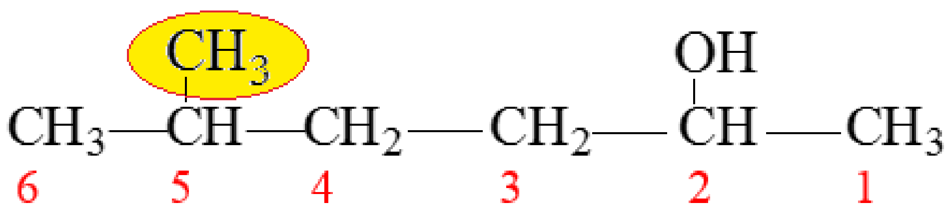
Naming of Alcohols

✓ **STEP 2:** Number the chain starting at the end nearer to the **—OH** group.



2-hexanol

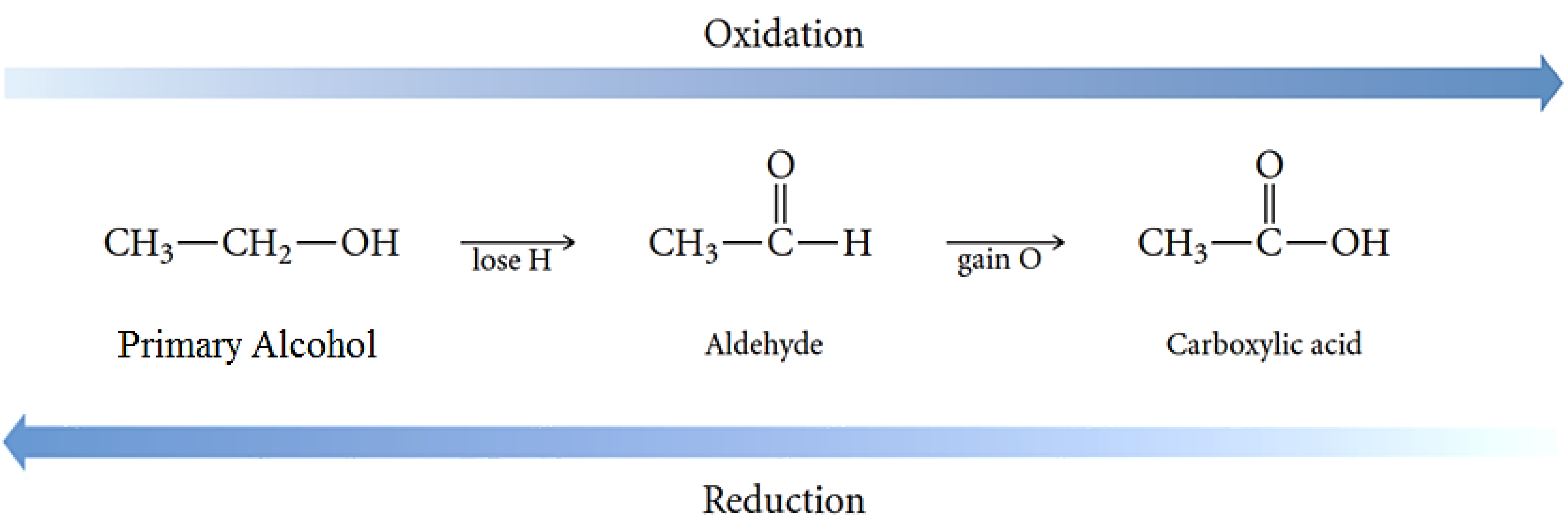
✓ **STEP 3:** Give the location and name for each substituent relative to the **—OH** group.



5-methyl-2-hexanol

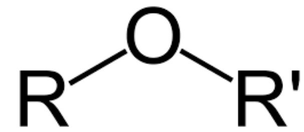
Oxidation Reactions of Alcohol

- The partial oxidation of **primary alcohols** produces the corresponding **aldehydes**, while the further oxidation produces **carboxylic acids**.
- The partial oxidation of **secondary alcohols** produce the corresponding **ketones**.
- The oxidation of a tertiary alcohol is not possible.



Ethers (R–O–R´)

Ethers: compounds in which two hydrocarbon groups **(R)** are bonded to one oxygen atom.



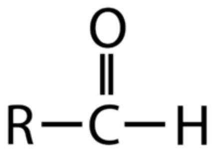
- Ethers can be formed from two molecules of alcohol by splitting out a molecule of water **(Condensation Reaction).** This reaction is catalyzed by sulfuric acid.

$$CH_3CH_2—OH + H—OCH_2CH_3 \xrightarrow{H_2SO_4} CH_3CH_2—O—CH_2CH_3 + H_2O$$

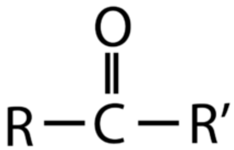
- Ethers tend to be quite **unreactive**. Therefore, they are common solvents for organic reactions.
- The systematic names of **ethers** are ended by the suffix ***–ether***

Some **Ethers** are used as medical "**anesthetics**" that inhibit pain signals to the brain during surgeries.

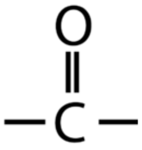
Aldehydes (R–CHO) and Ketones (R–CO–R´)



aldehyde



ketone



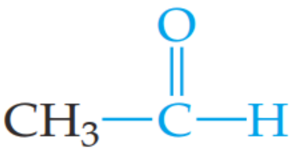
Carbonyl Group

R & R′

Alkyl Group (e.g. CH_3-)

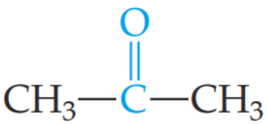
- In **Aldehydes**, at least **one "H"** is attached to the carbonyl (**C=O**) carbon atom.

Methanal
Formaldehyde

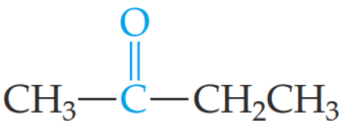


Ethanal
Acetaldehyde

- In **Ketones**, there are **two "C"** bonded to the carbonyl (**C=O**) carbon atom.



Propanone
Acetone

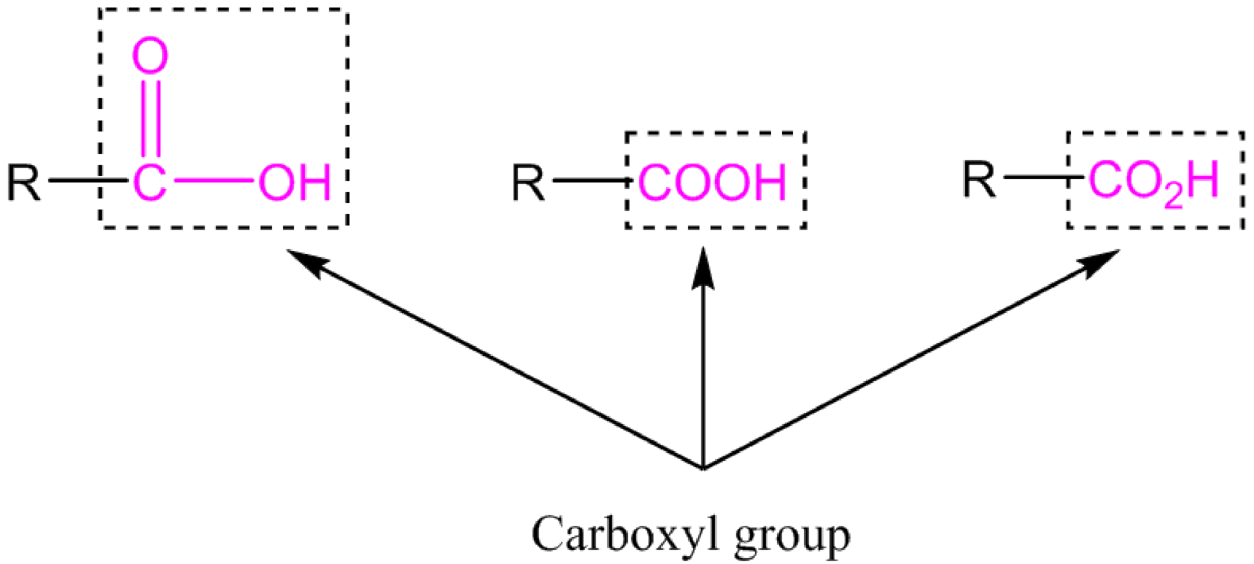


2-Butanone
Methyl ethyl ketone

- The systematic names of **aldehydes** are ended by the suffix ***–al*** and that of **ketones** are ended by the suffix ***–one.***
- They can be prepared by the controlled **oxidation of alcohols**.

Carboxylic Acids (R–COOH)

Carboxylic Acids contain the carboxyl group. Often written as (−COOH) attached to a carbon of an alkyl group (R):



Carboxylic Acids

- Carboxylic acids are week acids, they can be produced by **oxidation of alcohols**. Under appropriate conditions, the aldehyde may be isolated as the first product of oxidation, as in the sequence:

$$\underset{\text{Ethanol}}{CH_3CH_2OH} + (O) \longrightarrow \underset{\text{Acetaldehyde}}{CH_3\overset{\overset{\displaystyle O}{\|}}{C}H} + H_2O$$

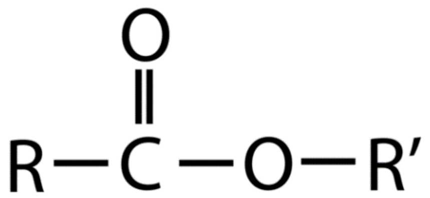
$$\underset{\text{Acetaldehyde}}{CH_3\overset{\overset{\displaystyle O}{\|}}{C}H} + (O) \longrightarrow \underset{\text{Acetic acid}}{CH_3\overset{\overset{\displaystyle O}{\|}}{C}OH}$$

where (O) represents any **oxidizing agent** that can provide oxygen atoms.

- The systematic names of **carboxylic acids** are ended by the suffix ***–oic acid.***

Esters (R–COOR´)

- **Esters** are compounds in which the H−atom of a carboxylic acid is replaced by a carbon-containing group (R’):

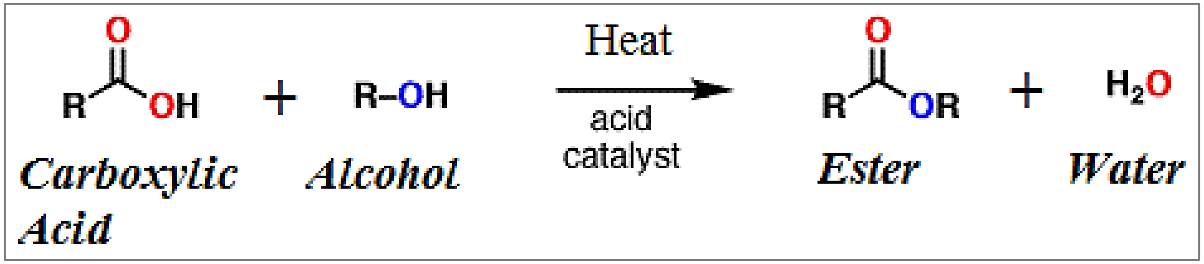


- Esters are the products of reactions between carboxylic acids and alcohols.

- Esters are responsible for the **pleasant aroma (odor or smell)** of fruits and perfumes.

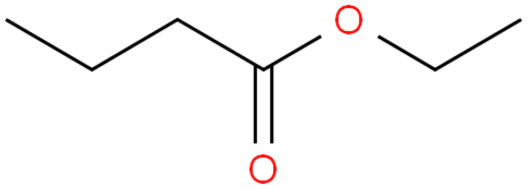
Esters

- Esters can be synthesized by **Condensation Reactions** of carboxylic acids with alcohols:



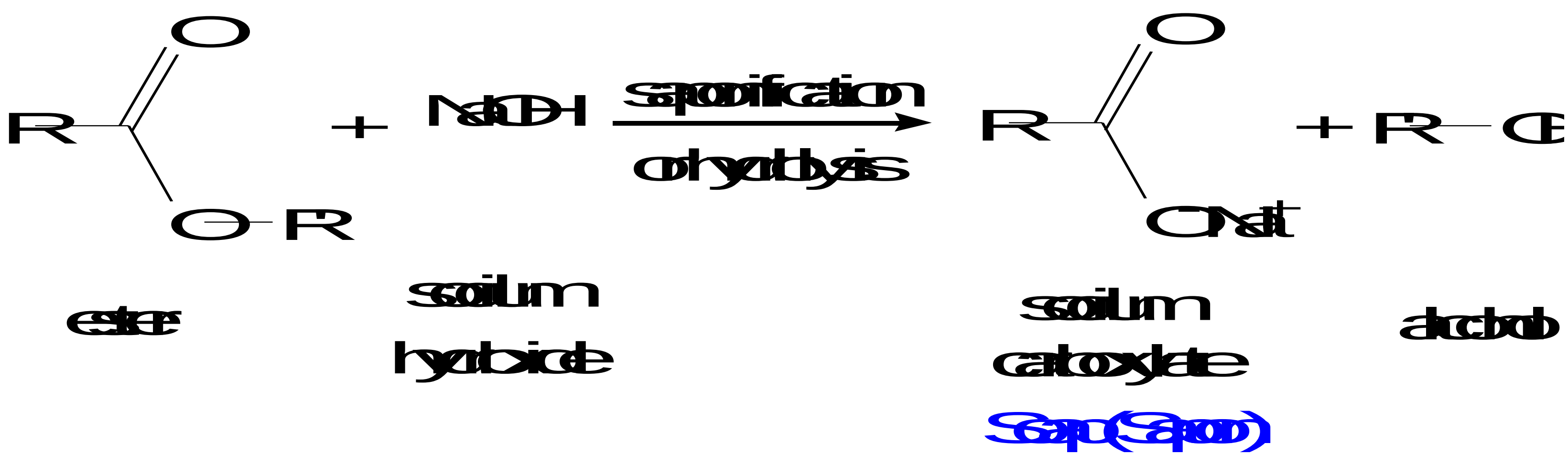
- The systematic names of **esters** are ended by the suffix ***–oate***

For example, the ester formed from ethyl alcohol, CH_3CH_2OH, and butanoic acid, $CH_3(CH_2)_2COOH$ is named as: Ethyl butan**oate**

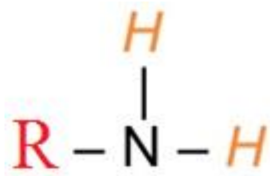


Saponification Reaction of Esters

- **Saponification:** is the hydrolysis of an ester in the presence of a base, a term that comes from the Latin word for **soap: *(sapon)***.
  - ✓ Naturally occurring **esters** include **fats** and **oils**, and in making soap an animal fat or a vegetable oil is boiled with a **strong base (NaOH or KOH)**.
  - ✓ The resultant soap consists of salts of **long-chain carboxylic acids (called fatty acids)**, which form during the saponification reaction.



Amines ($R–NH_2$) and Amides ($R–CO–NH_2$)



Amine

Amide

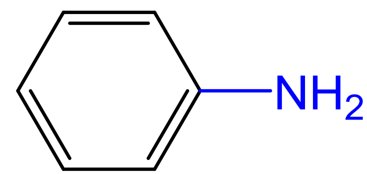
- **Amines** are compounds in which one or more hydrogen atoms of ammonia (NH_3) are replaced by alkyl groups **(R):**

$CH_3CH_2NH_2$

Ethylamine

$(CH_3)_3N$

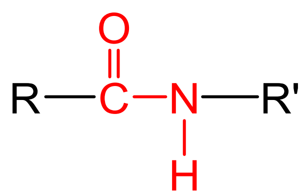
Trimethylamine

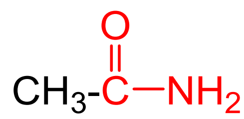


Phenylamine
Aniline

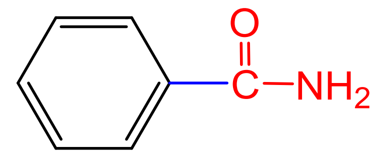
- Amines are the most common **organic bases**.
- The systematic names of **amines** are ended by the suffix **–amine**

- **Amides** are compounds which contain a carbonyl group (**C=O**) attached to "**N**" atom:



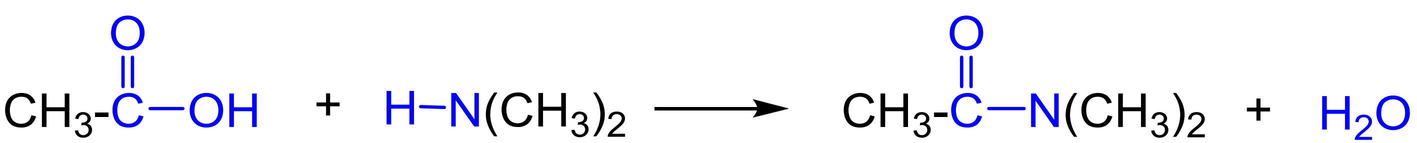


Ethylamide



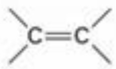
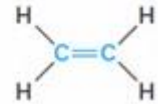
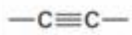
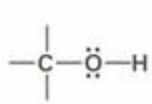
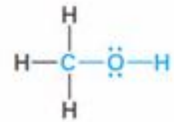
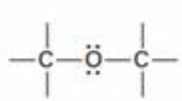
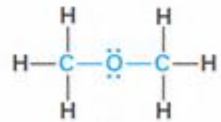
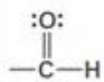
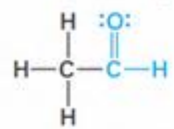
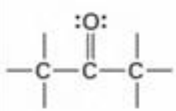
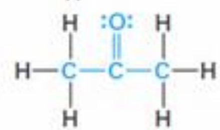
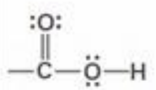
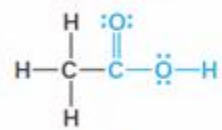
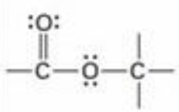
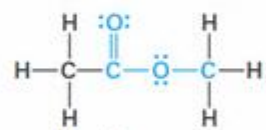
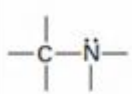
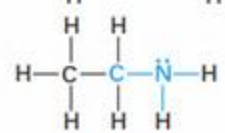
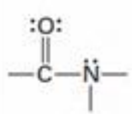
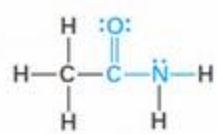
Phenylmethanamide
Benzamide

- An amines with at least one **"H"** bonded to **"N"** undergo a condensation reaction with a carboxylic acid to form amide:



- **The amide linkage (or peptide bond):** is the functional group in proteins, it links amino acids together to form "polypeptides: the building blocks of proteins".
- The systematic names of amides are ended by the suffix **–amide**

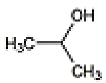
Common Functional Groups: A Summary

Functional Group	Compound Type	Suffix	Example: Structural Formula	Example: Systematic Name (common name)
	Alkene	*-ene*		Ethene (Ethylene)
	Alkyne	*-yne*		Ethyne (Acetylene)
	Alcohol	*-ol*		Methanol (Methyl alcohol)
	Ether	*ether*		Dimethyl ether
	Aldehyde	*-al*		Ethanal (Acetaldehyde)
	Ketone	*-one*		Propanone (Acetone)
	Carboxylic acid	*-oic acid*		Ethanoic acid (Acetic acid)
	Ester	*-oate*		Methyl ethanoate (Methyl acetate)
	Amine	*-amine*		Ethylamine
	Amide	*-amide*		Ethanamide (Acetamide)

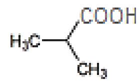
The functional groups and their suffixes are **to be memorized!**

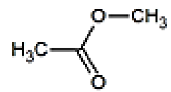
Assessment

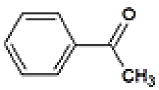
1. **Identify the type (family) of the following organic compounds**

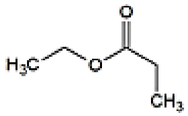
a. 

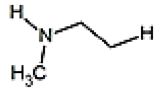
b. 

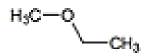
c. 

d. 

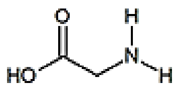
e. 

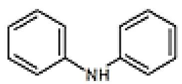
f. 

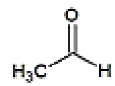
g. 

h. 

i. 

j. 

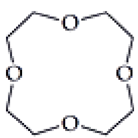
k. 

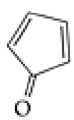
l. 

2. **Identify the functional groups in each of the following compounds:**

(a) H_3C-CH_2-OH

(c) $H_3C-\overset{H}{N}-CH_2CH=CH_2$

(b) 

(d) 

(e) $CH_3CH_2CH_2CH_2CHO$

(f) $CH_3C\equiv CCH_2COOH$

3. _____ **is formed by the reaction of a carboxylic acid with an alcohol**

A) aldehyde. B) ester. C) ether. D) ketone.

4. _______ **is the hydrolysis of an ester using a base.**

A) Saponification
B) Decarboxylation
C) Detoxification
D) Alcoholysis

5. **Oxidation of an aldehyde produces a _______.**

A) carboxylic acid.
B) alcohol.
C) ester.
D) ketone.

6. **The common functional group in aldehydes and ketones is ____.**

A) hydroxyl group.
B) phenol group.
C) ether group.
D) carbonyl group.

7. **The Product of the reaction between a carboxylic acid and an amine is ________.**

A) aldehyde. B) amide. C) ester. D) ketone.

8. _______ are used as medical anesthetics.

9. _______ are responsible for the pleasant aroma of fruits.

10. The suffix ______ is used at the end of esters names.

11. The partial oxidation of alcohols produces _________, while further oxidation produces ________.

12. ________ are the most common organic bases.