12.0 ORGANIC CHEMISTRY

12.1 Introduction to Organic Chemistry

Learning Outcomes

1. List the elements that made up organic compounds C, H, O, N, P, S and halogens.
2. State the ability of carbon to form 4 covalent bonds with other carbons or elements.
3. Differentiate between saturated and unsaturated organic compounds.
4. Give examples of organic compounds used in medicine, engineering, biotechnology and agriculture.

WHAT IS ORGANIC CHEMISTRY?

- Organic chemistry is the chemistry of _____ _____.
- Generally, the components of organic compound are _____.
- ***Organic compounds*** are compounds obtained from living organisms (plants & animals).
- ***Inorganic compounds*** are components of non-living matter (mineral, metal, etc).

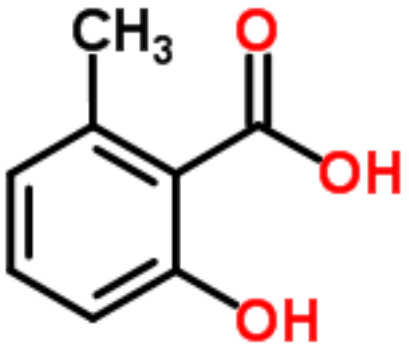
Why study **ORGANIC CHEMISTRY?**

- Organic molecules as
  - constituents of living organisms
  - information carriers
  - a food, supplementary, medicine etc.

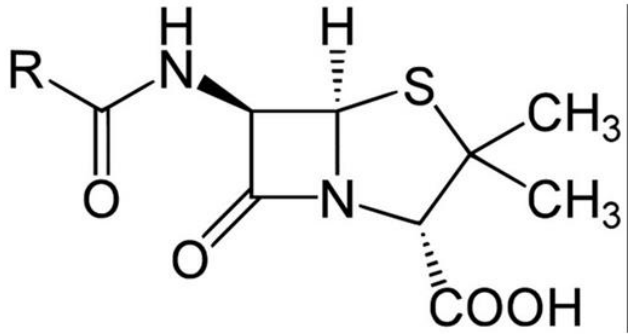
Example:

METHANE, CH_4
– a component of natural gas

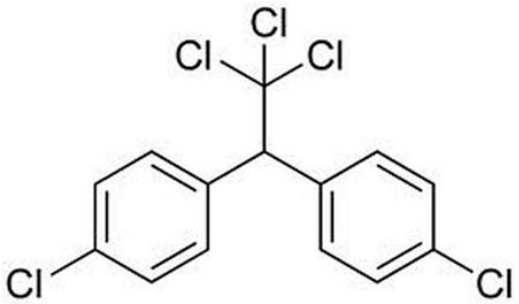
METHYL SALICYLIC ACID
– aspirin (a drug)



PENICILIN
– an antibiotic



Dichlorodipnenyltrichloroethane (DDT)
– a pesticde component



Organic Compound

- All organic compounds consist of _____.
- Properties of carbon atom:

  - has _____

  - can form _____

Types of Bonding

SINGLE BOND

DOUBLE BOND

TRIPLE BOND

Uses of Organic Compound

Medicine	Antibiotics are used to fight bacterial and fungal infections
Engineering	Gasoline-as a fuel for internal combustion engines.
Biotechnology	Genetic information like DNA
Agriculture	DDT-as insectisides to kill harmful insects.

Hydrocarbons

SATURATED

Contains **only single** bonds (-C-C-)

Examples: alkanes, cycloalkanes

UNSATURATED

Contains **at least** one carbon-carbon **double** bond (-C=C-) or carbon-carbon **triple** bond (-C ≡C-).

Example: alkenes, cycloalkenes, alkynes, cycloalkynes

12.2 Molecular and Structural Formulae

Learning Outcomes

- Define structural formula.
- Draw structural formula in the form of expanded, condensed and skeletal structures based on the molecular formula.
- Determine primary (1°), secondary (2°), tertiary (3°) and quaternary (4°) carbon.

Structural Formula

- Shows how the atoms in a molecule are bonded to each other.
- 3 types of structural formula:

Expanded Structure

- Shows every atom & type of covalent bond in the molecule.
- Not indicate the actual shapes of the molecules.

Condensed Structure

- Single bonds between carbon-hydrogen & carbon-carbon atoms are **NOT shown**.
- Double and triple bonds are **SHOWN**.
- All atoms attached to a carbon are written immediately after that carbon.

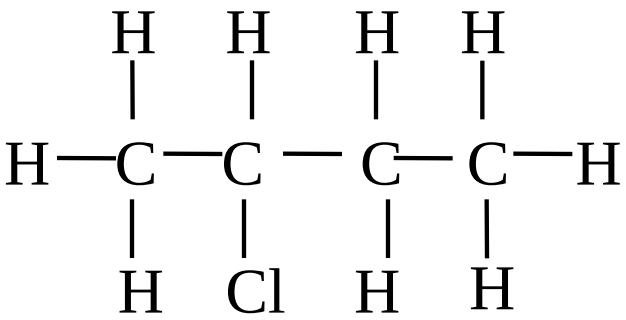
Skeletal Structure

- Shows only the carbon skeleton.
- Hydrogen atoms are not written.
- Other atoms such as O, Cl, N etc. are shown.

Structural Formula

Molecular formula: C_4H_9Cl

Expanded



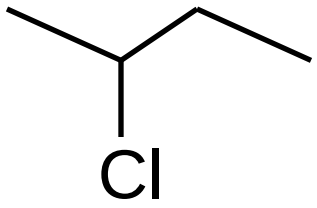
Condensed

$CH_3CHCH_2CH_3$
|
Cl

OR

$CH_3CH(Cl)CH_2CH_3$

Skeletal



Classification of Carbon Atom

A carbon atom can be classified as

- ***primary carbon (1°)*** → bonded to *1 C*
- ***secondary carbon (2°)*** → bonded to *2* C
- ***tertiary carbon (3°)*** → bonded to *3* C
- ***quarternary carbon (4°)*** → bonded to 4 C

Classification of Hydrogen Atom

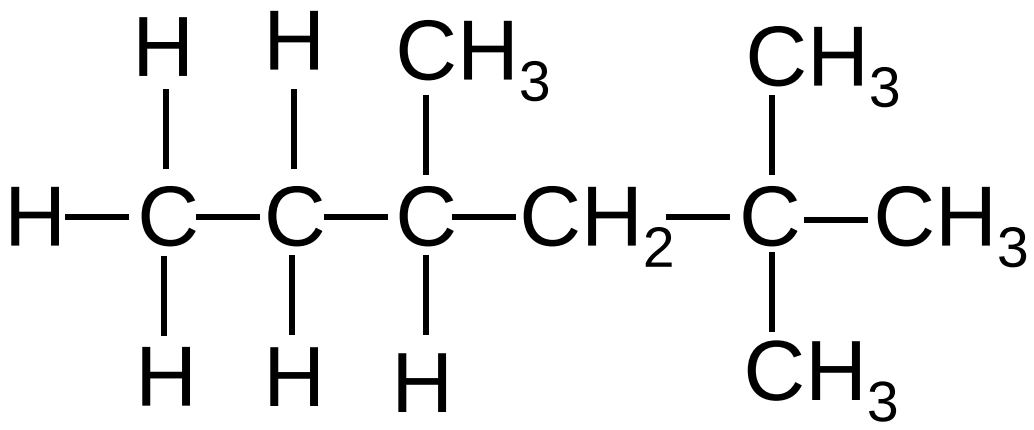
A hydrogen atom can be classified as

- ***Primary hydrogen (1°)*** → bonded to *1° C*
- ***Secondary hydrogen (2°)*** → bonded to *2°* C
- ***Tertiary hydrogen (3°)*** → bonded to *3°* C
- ***Quarternary hydrogen (4°)*** → *NIL*

Example 1:

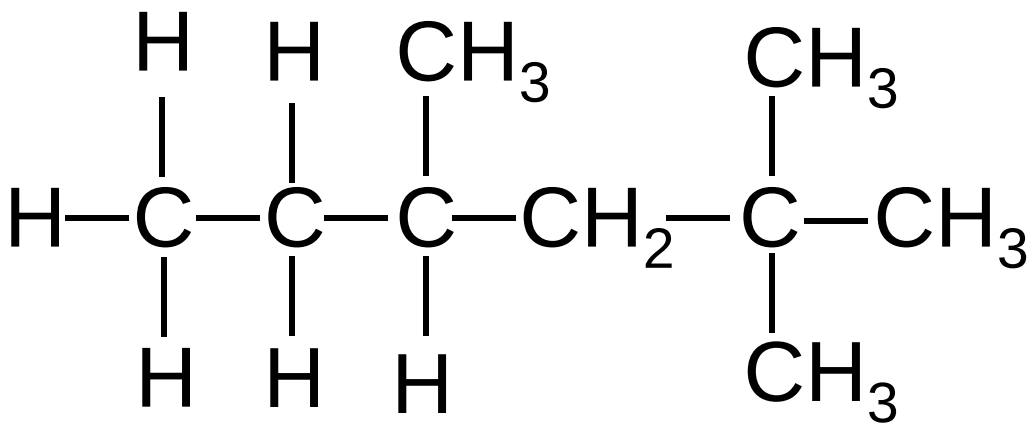
Practise 1:

Determine the number of primary carbon below.



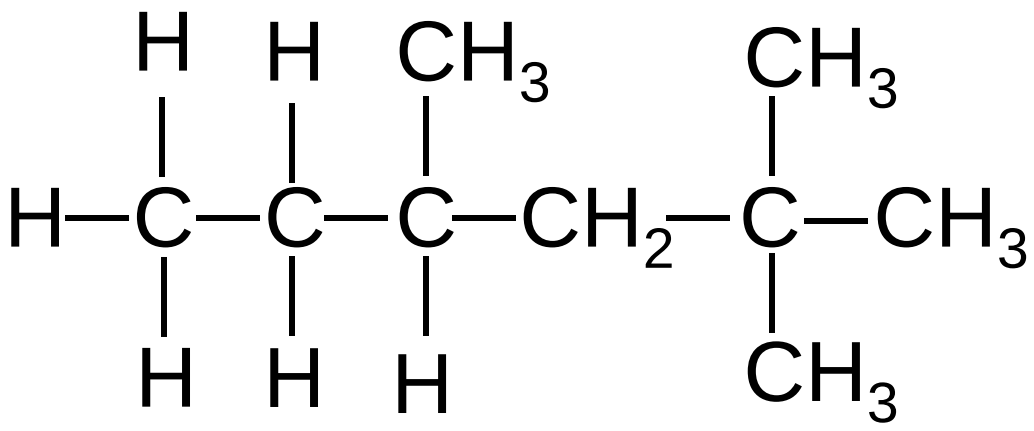
Practise 2:

Label the secondary carbon below.



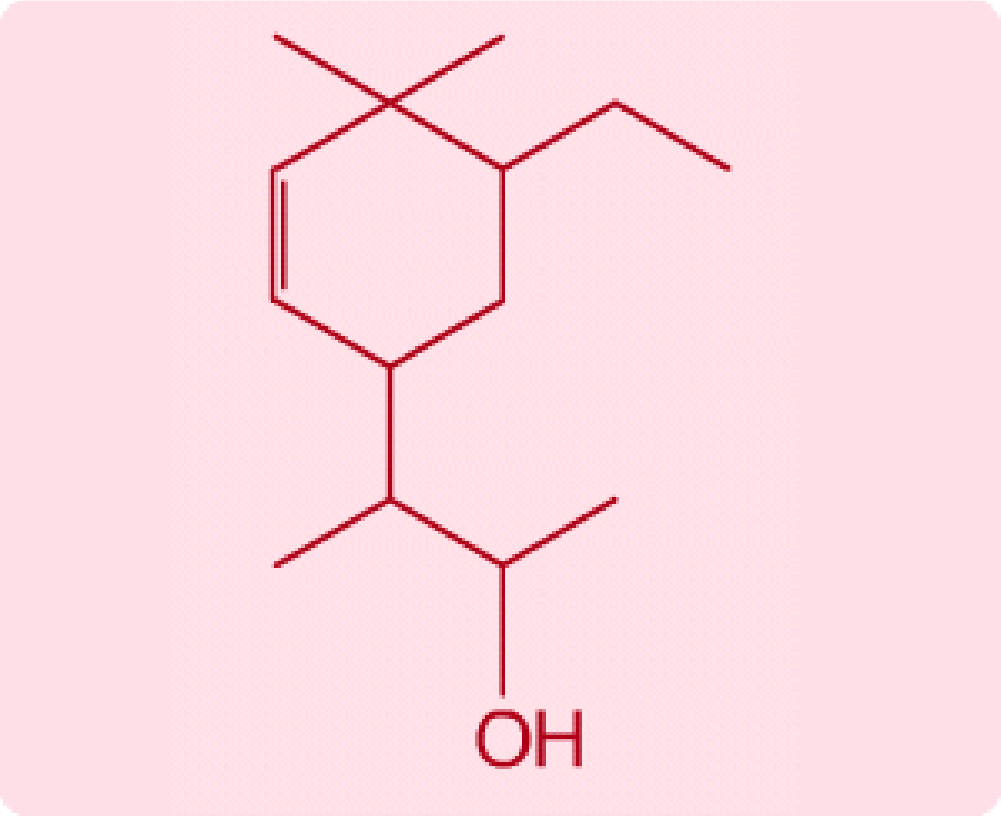
Practise 3:

Determine the number of tertiary and quarternery carbon below.



Enhancement 1:

How many
a) 2° C atoms
b) 3 C atoms
c) 4 C atoms
d) 1 H atons
are present ?



Practise 4:

Draw the;

(a) Condensed structure

(b) Expended structure

(c) Skeletal structure

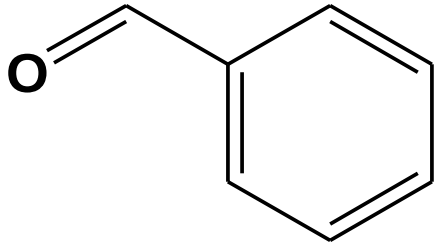
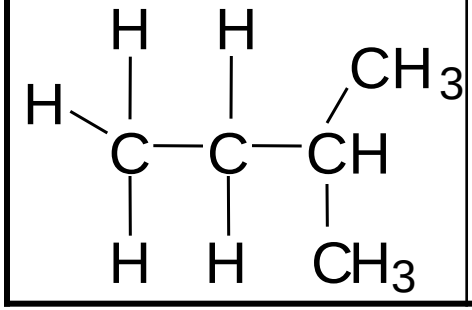
of C_5H_8

(One double bond, carbon atoms form a five-membered ring)

Answer:

Enhancement 2:

Complete the table below.

Expanded Structure	Condensed Structure	Skeletal Structure
	$CH_3(CH_2)CCl(CH_3)_2$	
		
		

12.3 Functional Group & Homologous

Learning Outcomes:

- Define functional group
- Name functional groups and classify organic compounds according to their functional groups
- Define homologous series and explain general characteristics of its members

Functional Group

is an atom or a group of atoms that determines the chemical properties of a organic compound.

Important of Functional Group

- A basic by which organic compounds are *divided* into different classes (homologous)
- A basic for *naming* organic compounds
- A particular functional group will always undergo *similar types* of chemical reactions

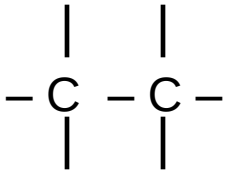
Homologous Series

- a series of compounds with similar chemical properties, which each member differs from the next member by a constant -CH_2- unit.
- Members of the same homologous series are called _____.

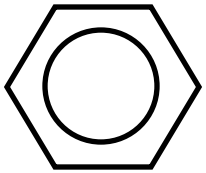
Homologous Series

- Obey a general formula:
  - Alkane: $C_nH_{2n}+_2$
  - Alkene: C_nH_{2n}
  - Alcohol : $C_nH_{2n+1}OH$
- Differ from the successive homolog by a **-CH_2 unit.**
- Show a gradual change in the **physical properties.**
- Have same **functional group.**
- Have similar **chemical properties.**
- Can be prepared by similar **general methods.**

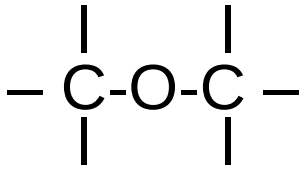
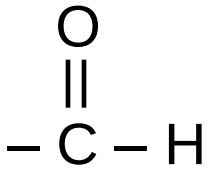
Classification of Organic Compound

Class of compound	Functional group		
	Structure	Name	Example
Alkane			
Alkene			
Alkyne			

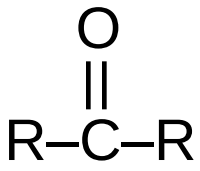
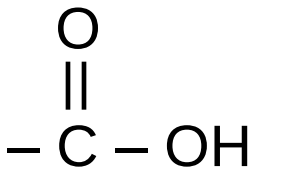
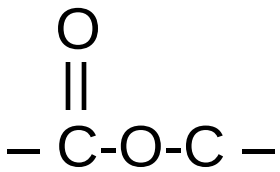
Classification of Organic Compound

Class of compound	Functional group		
	Structure	Name	Example
Aromatic			
Haloalkane	X(F,Cl,Br,I)		
Alcohol	-OH		

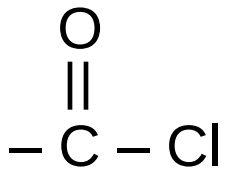
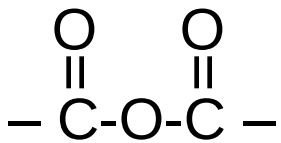
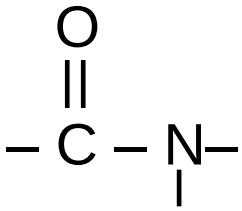
Classification of Organic Compound

Class of compound	Functional group		
	Structure	Name	Example
Phenol	-OH		
Ether			
Aldehyde			

Classification of Organic Compound

Class of compound	Functional group		
	Structure	Name	Example
Ketone			
Carboxylic acid			
Ester			

Classification of Organic Compound

Class of compound	Functional group		
	Structure	Name	Example
Acyl chloride			
Anhydride			
Amide			

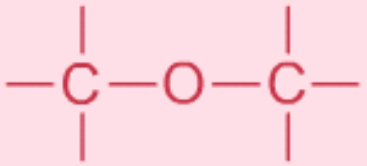
Classification of Organic Compound

Class of compound	Functional group		
	Structure	Name	Example
Amine	$-NH_2$		
Nitrile	$-C \equiv N$		

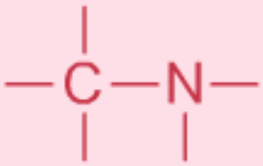
Practise 5:

Determine the functional groups of each structures.

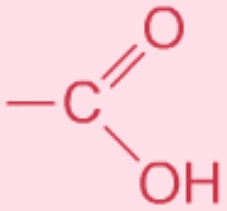
1



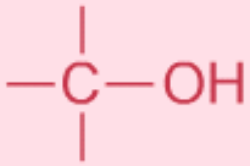
2



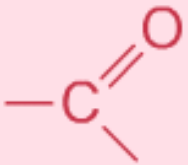
3



4

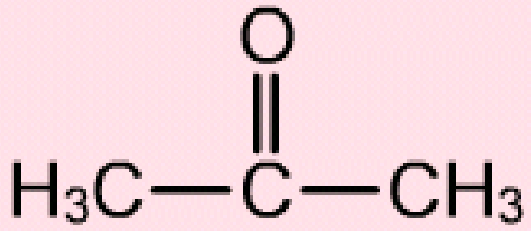


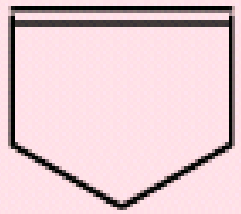
5

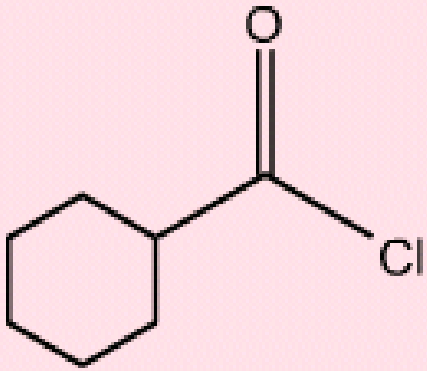


Practise 6:

Describe the functional groups in the following structures.

1. 

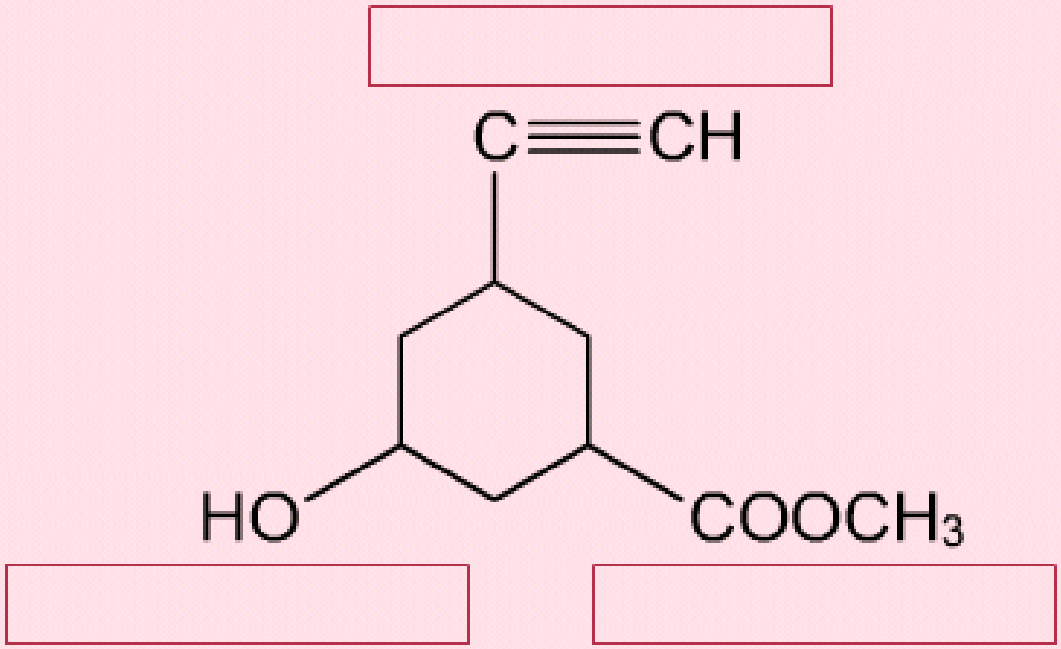
2. 

3. 

4. $CH_3CH_2CONHCH_3$

Practise 7:

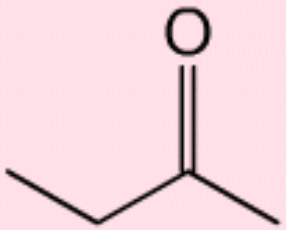
Label the functional groups in the following structures.

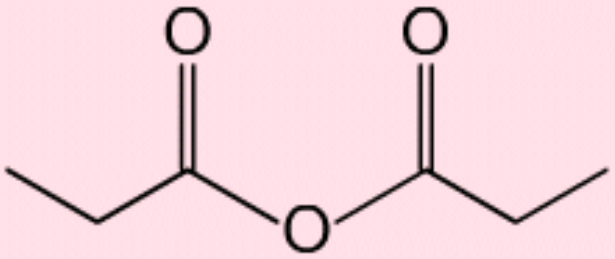


Practise 7:

Classify the following compounds into their respective families.

1. $CH_3CH_2CONHCH_3$

2. 

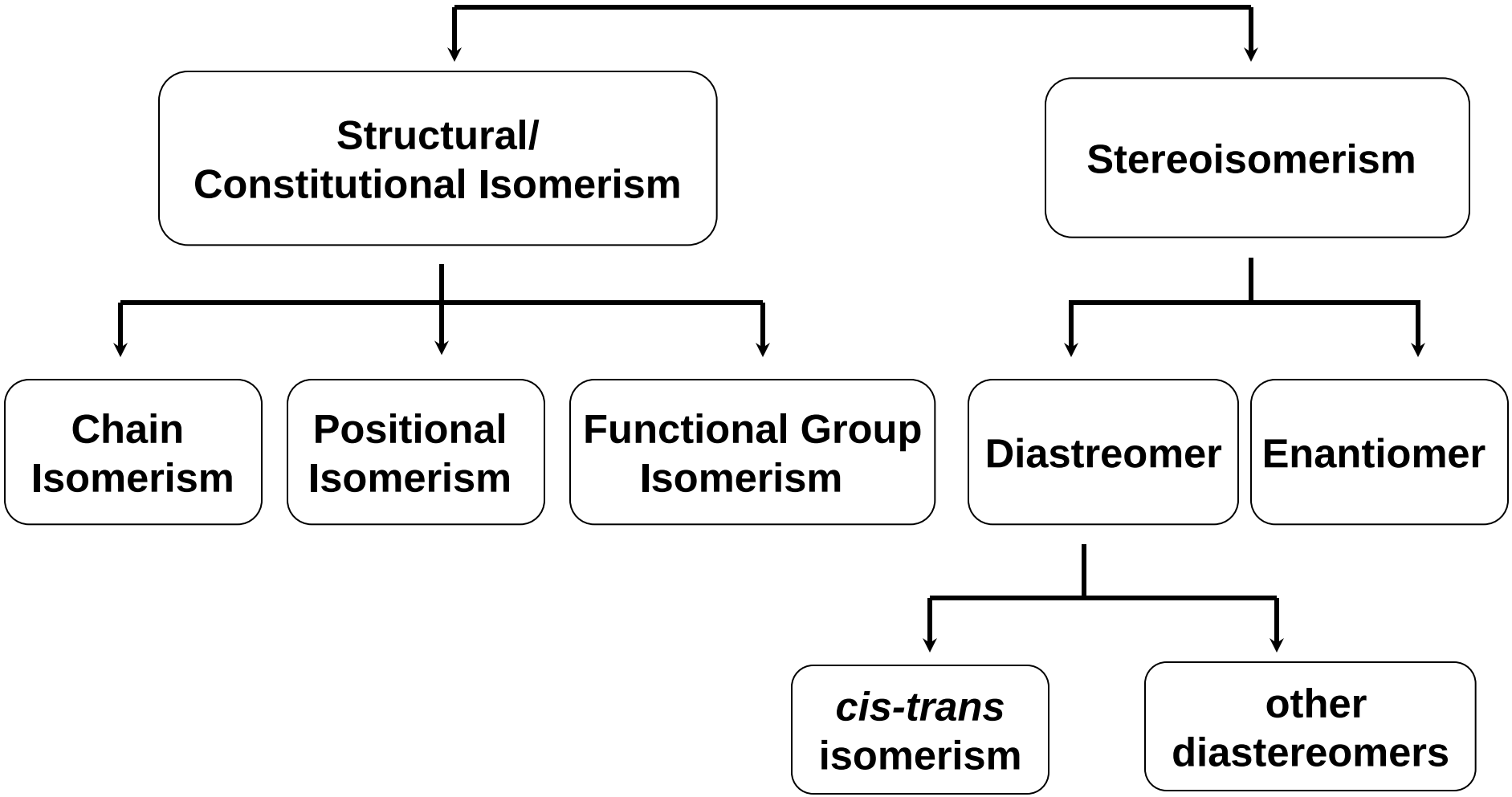
3. 

12.4 Isomerism

Learning Outcomes:

- Define isomerism.
- Explain constitutional isomerism.
  - Chain isomers
  - Positional isomers
  - Functional group isomer

Isomerism


Structural/
Constitutional Isomerism
Stereoisomerism
Chain
Isomerism
Positional
Isomerism
Functional Group
Isomerism
Diastreomer
Enantiomer
cis-trans
isomerism
other
diastereomers

Isomer

– compounds with the ***same molecular formula but different arrangements of atoms***

Isomerism

– the existence of two or more organic compounds with the ***same molecular formula but different arrangements of atoms***

A) Structural Isomerism/Constitutional Isomer

Structural isomers – molecules with same molecular formula but different structural formulae (differ in the order of attachment of atoms)

Structural isomerism – isomerism resulting from different order of attachment of atoms

i) Chain/Skeletal Isomerism

- The isomers differ in the structure of their carbon chains (differ in carbon skeleton).
  - Differ in the length of straight chains or branches
  - Possess the same functional group and belong to the same homologous series.
  - Different physical properties.
  - Similar chemical properties.

Example 2: Pentane, C_5H_{12}

ii) Position Isomerism

- Isomers with the same carbon skeleton but differ in the position of a funtional group or a substituent group.
  - Generally, similar chemical properties (same functional group).
  - Different physical properties.

Example 3: Butene, C_4H_8

Example 4: C_3H_7Cl

Example 5: C_3H_7Cl

iii) Functional Group Isomerism

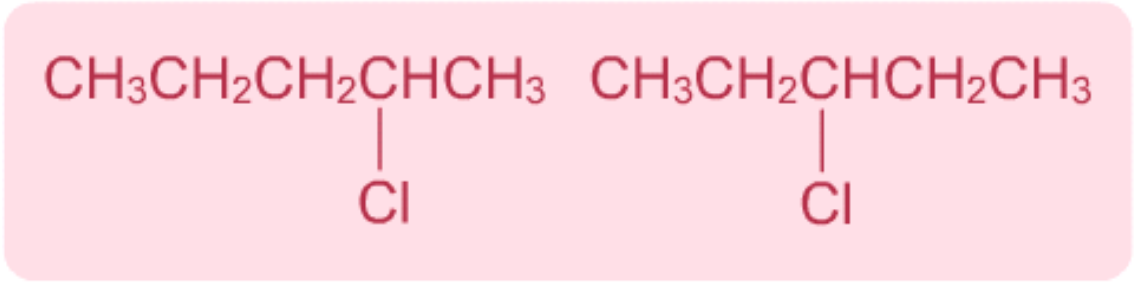
- Isomers with same molecular formula but different functional groups and belong to diff. homologous series.
  - Different physical & chemical properties.

Example 6: $C_3H_6O_2$

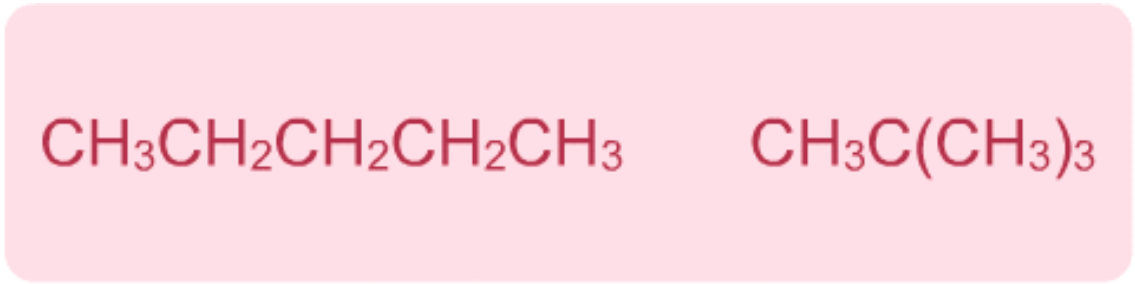
Example 7: C_3H_6O

Practise 5:

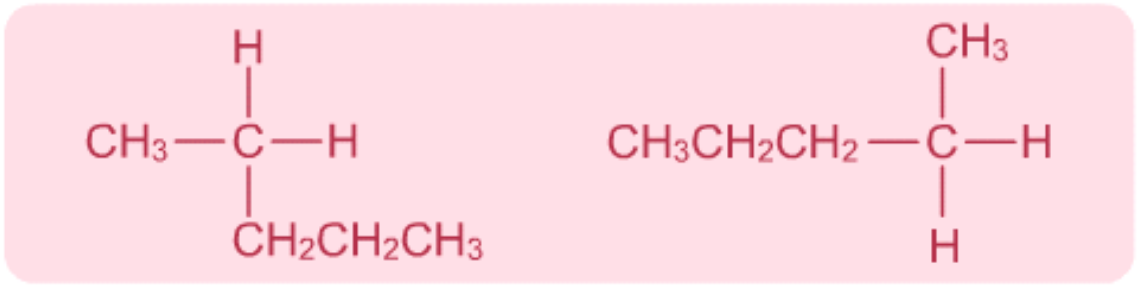
Identify the relationship between the following pairs of compounds.

1. 

_____ isomerism

2. 

_____ isomerism

3. 

_____ isomerism

Practise 6:

4. 

$CH_2{=}CHCH_3$

_____ isomerism

5. $CH_2{=}\underset{\displaystyle OH}{\underset{|}{C}}{-}CH_3$

$CH_2{=}CHCH_2OH$

_____ isomerism

QUIZ TIME !

Determine all the possible structural isomers of hexane, C_6H_{14}.

Learning Outcomes:

- Define stereoisomerism.
- Describe *cis-trans* isomerism due to restricted rotation about:
  - C=C double bond
  - C–C single bond in cyclic compounds
- Identify *cis-trans* isomerism of a given structural formula.

B) Stereoisomerism

- Same structural formula; different spatial arrangement of atoms in molecules.
- Occurs only in two classes of compound:
  - Alkenes
  - Cyclic compound

Stereoisomers

- Isomers with the same structural formula; different spatial arrangement of their atoms in molecules.

Geometrical (cis-trans) Isomerism

- The requirements for geometric isomerism:
  - Restricted rotation
    - a C=C, double bond in alkenes or
    - a C-C single bond in cyclic compounds
    - Each carbon atom of a site of restricted rotation has two different groups attached to it (different atoms or group of atoms attached to the same C=C bond or C-C in cyclic compounds).

Example 8:

Cis-Isomer – a geometrical isomer which has two similar substituents on the same side of the ring or double bond.

Trans-isomer – a geometrical isomer which two similar substituents on opposite site of the ring or double.

Example 9:

59

Example 10:

If one of the double bonded carbons have
2 identical groups,
geometric isomerism is not possible.

Practise 10:

Draw all the possible structures of cycloalkane with molecular formula C_6H_{12}. Determine which structure can perform cis –trans isomers?

12.5 Reaction of Organic Compound

Learning Outcomes:

- Explain covalent bond cleavage:
  - homolytic
  - heterolytic
- Define electrophile and nucleophile
  - Types of electrophile: Lewis acids, cation & electron deficient sites in organic compound.
  - Types of nucleophile: Lewis bases, anions & electron rich sites in organic compound.

Homolytic Cleavage

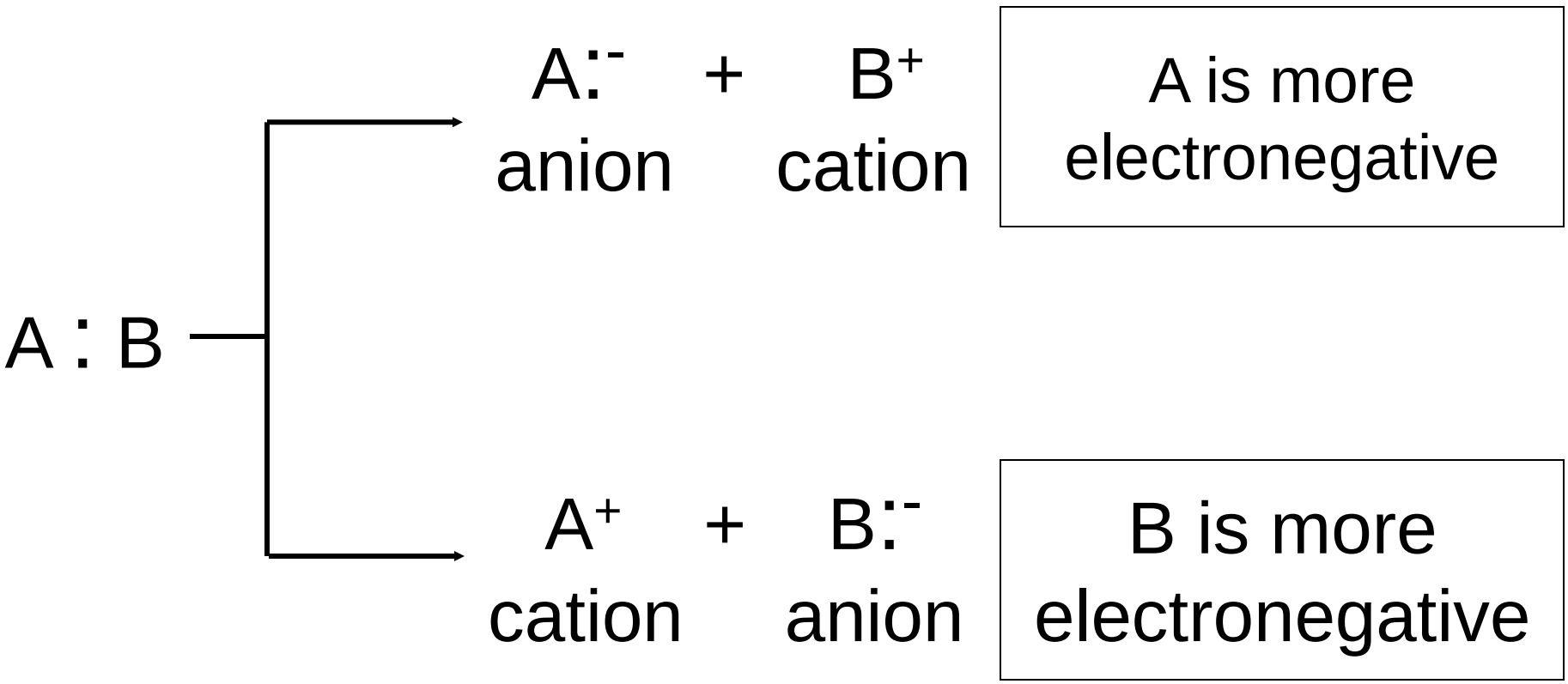
- Occurs in a non-polar bond (two atoms of similar electronegativity).
- A single bond breaks symmetrically into two equal parts, leaving each atom with one unpaired electron.
- Formed free radicals.

Example 11: Cleavage of Cl_2

Heterolytic Cleavage

- Occurs in a polar bond involving **unequal** sharing of electron pair between (two atoms of different electronegativities).
- A single bond breaks **unsymmetrically**.
- Both the bonding electrons are **transferred** to the more electronegative atom.
- Formed
  - Cation/carbocation/carbonium
  - Anion/carbanion.

Heterolytic Cleavage



Practise 11:

Choose the correct type of bond cleavage and products for the following molecules.

	Molecule	Type of bond cleavage	Product
1.	Br - Br		

	Molecule	Type of bond cleavage	Product
2.	CH_3 - Br		

Example 12:

Types of Reagents

Electrophile

- means ‘electron loving’
- an electron-deficient species and electron-pair acceptor
- attacks a part of a molecule where the electron density is high by accepting an electron pair
- can be either neutral or positively charged ions

Example 13: Electrophile

- cations such as H^+, H_3O^+, NO_2^+, Br^+ and etc
- carbocations (species with a negative charge on carbon atoms)
- lewis acids such as $AlCl_3$, $FeCl_3$, BF_3 and etc
- oxidizing agents such as Cl_2, Br_2 and etc

Types of Reagents

Nucleophile

- means ‘nucleus loving’
- an electron-rich species and electron-pair donor
- attacks a part of a molecule where the electron density is low by donating an electron pair to form a dative covalent bond
- can be either negative ions or molecules that have at least one lone pair of electrons

Example 14: Nucleophile

- anions such as OH^-, RO^-, Cl^-, CN^- and etc
- carbanions (species with a negative charge on carbon atoms)
- Lewis bases which can donate lone pair electrons such as NH_3, H_2O, H_2S and etc

Learning Outcomes:

- State 4 types of organic reaction:
  - Addition
  - Substitution
  - Elimination
  - Rearrangement

Types of Organic Reactions

There are 4 main types of organic reactions:

- Addition
  - Electrophilic Addition
  - Nucleophilic Addition
- Substitution
  - Electrophilic Substitution
  - Nucleophilic Substitution
  - Free Radical Substitution
- Elimination
- Rearrangement

Examples of electrophilic sites in organic molecules

- Molecules with low electron density around a polar bond such as:

Examples of nucleophilic sites in organic molecules

- molecules with high electron density around the carbon-carbon multiple bond such as,

Addition Reaction Reaction

A reaction in which atoms or groups ***added*** to adjacent atoms of a multiple bond.

Electrophilic Addition Reaction

- Initiated by an electrophile, accepting electron from an attacking nucleophile
- Typical reaction of unsaturated compounds such as alkenes and alkynes

Nucleophilic Additon Reaction

- Initiated by a nucleophile, which attacks an electrophilic site of a molecule.
- Typical reaction of carbonyl compounds.

Substitution Reaction

A reaction in which an atom or group in a molecule is replaced by another atom or group.

Free-radical Substitution

- Substitution which involves free radicals as intermediate species.

Electrophilic Substitution Reaction

- Typical reaction of aromatic compounds
- The aromatic nucleus has high electron density, thus it is nucleophilic and is prone to electrophilic attack.

Nucleophilic Substitution Reaction

- Typical reaction of saturated organic compounds bearing polar bond as functional group, such as haloalkane and alcohol.

Elimination Reaction

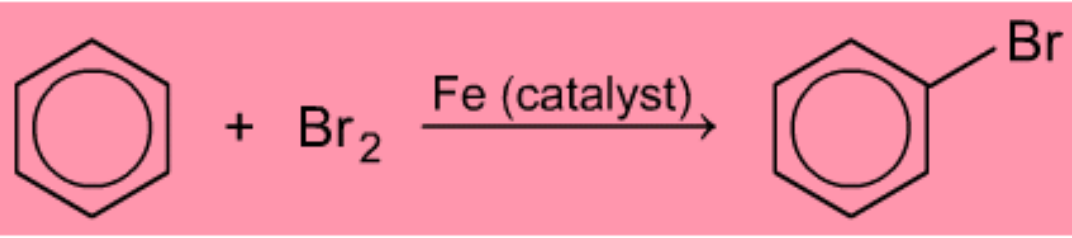
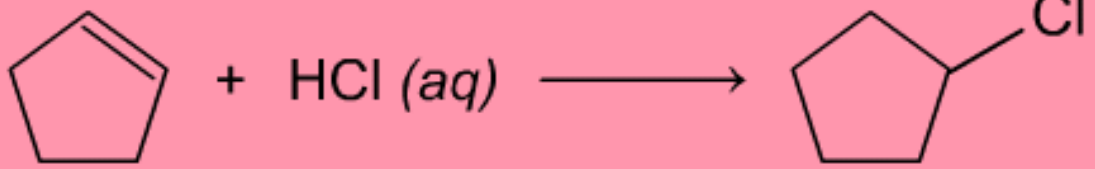
- atoms or groups are removed from adjacent carbon atoms of a molecule to form a multiple bond (double or triple bond)
- Elimination reaction results in the formation of unsaturated molecules

Rearrangement Reaction

- A reaction in which atoms or groups in a molecule *change position*
- Occurs when a single reactant reorganizes the bonds and atoms

Practise 12:

Name the types of organic reaction involved in the reaction.

reaction	name of reaction
	
	
$HC{\equiv}CH + 2H_2 \xrightarrow{Pt} H_3C-CH_3$	
$CH_3CH_3 + Br_2 \xrightarrow{uv} CH_3CH_2Br$	

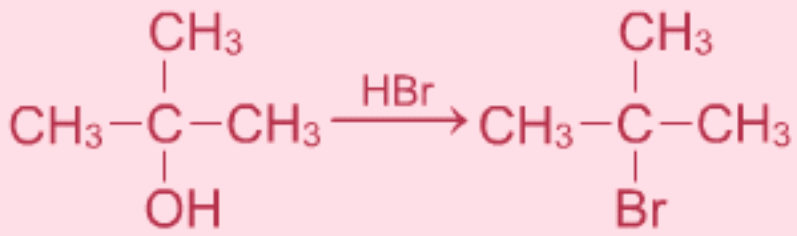
Practise 13:

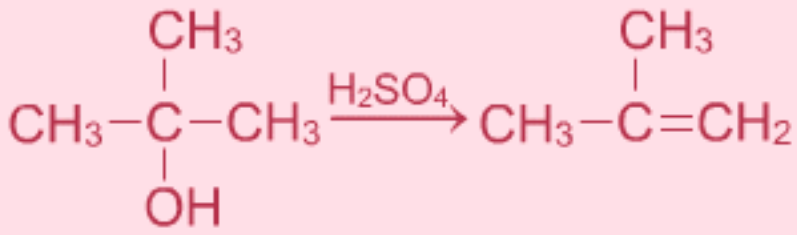
Classify the reactions according to the reaction type.

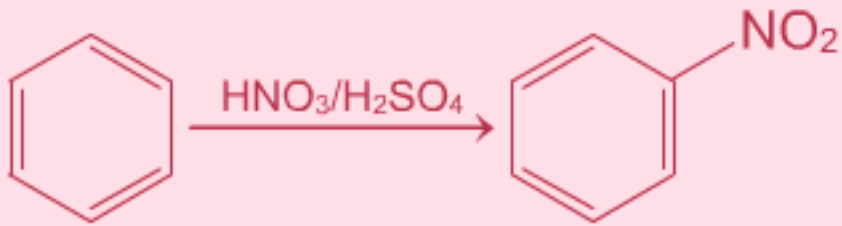
A

B

C

A 

B 

C 

Practise 14:

Name the following reaction equations.

$(CH_3)_2C{=}O + HCN \rightarrow (CH_3)_2C(OH)CN$

$CH_3CH_2CH_2Br \rightarrow CH_3CH{=}CH_2 + HBr$

$CH_3CH_2CH_2Br + NaCN \rightarrow CH_3CH_2CH_2CN + NaBr$