HKU Med LKS Faculty of Medicine
School of Chinese Medicine
香港大學中醫藥學院

Enrichment Course in Biology (2022-23)

Topic 5-8: Basic Chemistry

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Class Learning Objectives

1. **Understand the basic concepts, definitions and theories**
2. **Identify the formation and properties of chemical bonds**
3. **Explain the binding and structures of organic compounds**
4. **Discuss the systematic nomenclature and type of formula**
5. **Discover the biochemical impacts of inorganic and organic compounds**
6. **Identify the functional groups and chemical families of organic compounds**

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Class Content

1. **Basic Inorganic Chemistry (Topic 5)**
2. **Basic Organic Chemistry I (Topic 6)**
3. **Basic Organic Chemistry II (Topic 7)**
4. **Basic Organic Chemistry III (Topic 8)**

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1.1 Chemical Composition for Living Organisms

Ginseng Plant

NUTRITION FACTS	
Serving Size 8.4 fl. oz (250 ml)	
Servings Per Container 1	
Amount Per Serving	
Calories 6	**Calories From Fat** 0
	% Daily Value*
Total Fat 0 g	**0%**
Saturated Fat 0 g	
Trans Fat 0 g	
Cholesterol 0 g	
Sodium 10 mg	**0%**
Potassium 5 mg	**0%**
Total Carb. 15 g	**5%**
Dietary Fiber 0 g	**0%**
Sugars 15 g	
Protein 0 g	**0%**
Magnesium 1%	**Vitamin C 0%**
Vitamin B6 100%	**Niacin (B3) 100%**
Vitamin B12 100%	**Pantothenic Acid 100%**

Inorganic compounds

Sodium (Na^+),
Potassium (K^+)
Magnesium (Mg^{2+})
Chloride (Cl^-)
Sulfate (SO_4^{2-})

Organic compounds

Fat
Cholesterol
Carbohydrates
Proteins
Vitamins

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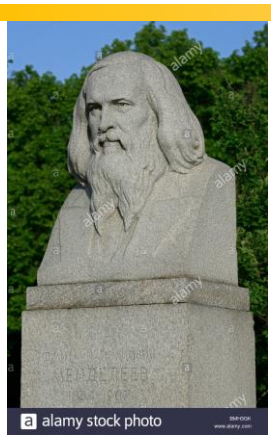
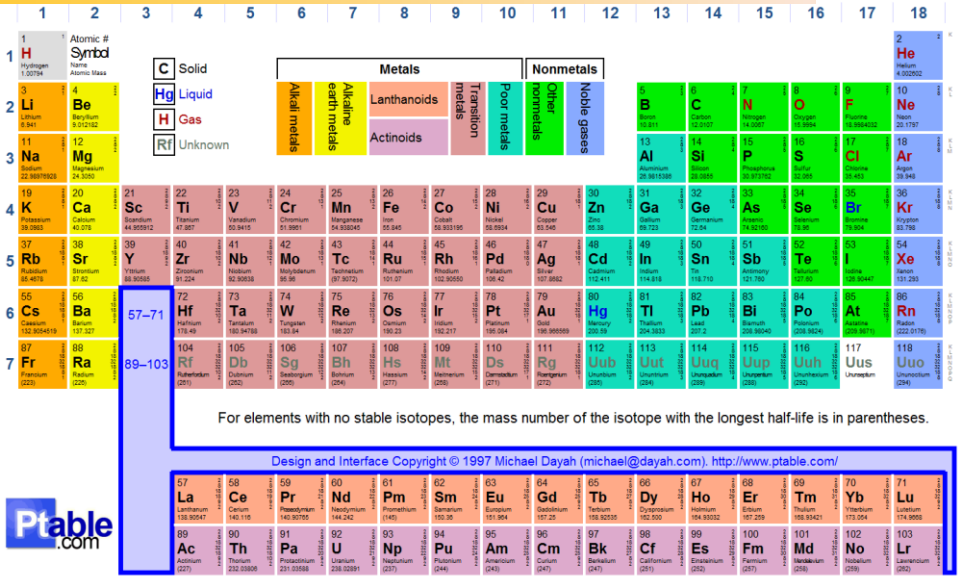
1.2 Periodic Table of Elements



Dmitri Mendeleev
(1834–1907)
Russian chemist



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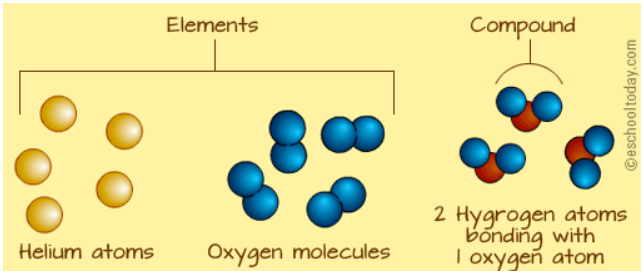
1.3 Elements and Compounds

Atom: The smallest unit of an element.

Element: Atoms chemically bonded with other atoms.

Compound: Molecules composed of two or more different kinds of elements.



All compounds are molecules but not all molecules are compounds.

Compounds contain two or more elements

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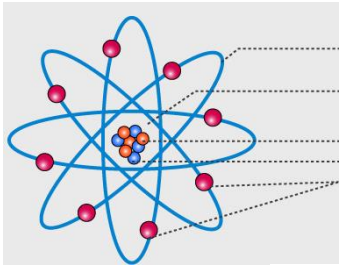
1.4 Atomic Theory

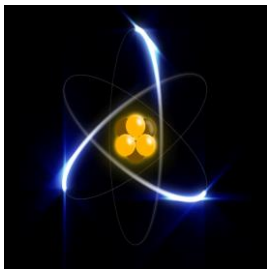


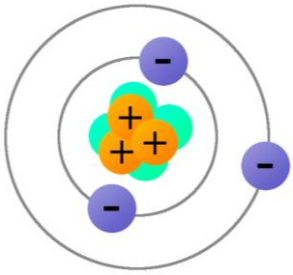
Electrons orbits: where electrons whizzes around nucleus.

Nucleus: The atom center for protons and neutrons

Proton
Neutron
Electrons

The number of protons makes each element unique whereas the number of neutrons and electrons vary, like isotopes (e.g., ^{1}H, ^{2}H, ^{3}H)





Electron → "-" negative charge

Proton → "+" positive charge

Neutron → neutral (a charge of zero)

Valence electrons: the electrons in the outmost shell

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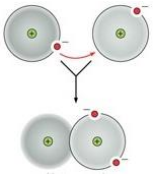
1.5 Intermolecular Interaction

Ionic bonds

atoms

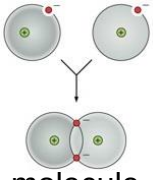


positive ion negative ion

-Transfering electrons
-Metals lose electrons, form cation
-Non-metals gain electrons, form anion
-Be hydrophilic, dissolve in water
-Form electrolytes

Covalent bonds

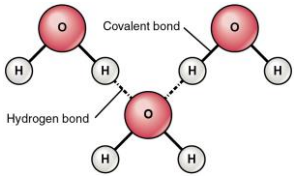
atoms



molecule

-Sharing electrons
-Non-metals to non-metals
-Do not form ions in solution
-Polar or non-polar covalent
-Stronger than ionic bonds

Hydrogen Bonds



-Electromagnetic attraction
-Hydrogen (H) shares electron
-N, O, or F offers electron pair
-Do not technically bond atoms together.

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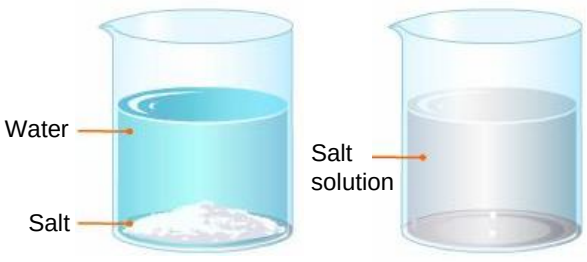
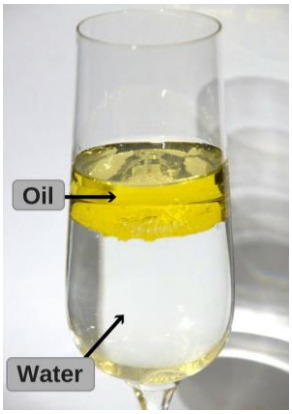
1.6 Solubility In Water

1) Compounds with ionic bonding are soluble in polar solvents,
2) Compounds with covalent bonding are insoluble in polar solvents.

B. Cooking oil

A. Table salt





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1.7 Acids and Bases

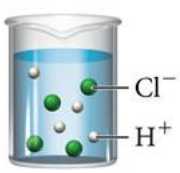
Acid: Any ionic compound that releases hydrogen ions (H^+) in solution.

e.g. hydrochloric acid (HCl), citric acid, phosphoric acid.

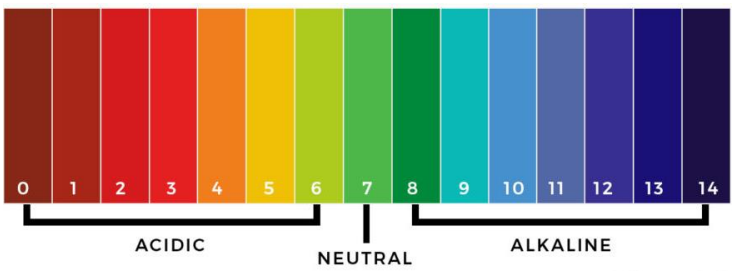
Base: Any ionic compound that releases hydroxyl ions (OH^-) in solution.

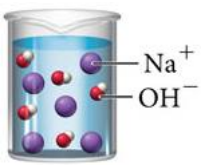
e.g. sodium hydroxide (NaOH), magnesium hydroxide, ammonia.

pH value for indicating acidity & alkalinity



HCl





NaOH

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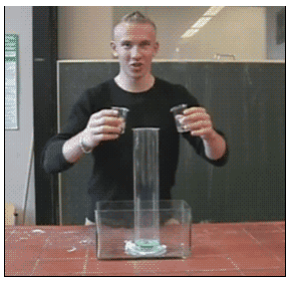
1.8 Chemical Kinetics

Chemical kinetics studies the reaction rate

Slow reaction: $CO_2 + H_2O \Rightarrow H_2CO_3$

Fast reaction: $\text{Sugar} + H_2SO_4 \Rightarrow \text{dehydration}$



Factors affecting **reaction rate**:

1) Concentration of reactants
2) Catalyst
3) Temperature
4) Surface area of reactants or catalyst

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1.9 Body Contents of Inorganic Elements

Metal and non-metal content of a human body (70 kg)

Element	Content	Element	Content
Ca	1000 g	Sn	20 mg
K	140 g	V	20 mg
Na	100 g	Cr	14 mg
Mg	25 g	Mn	12 mg
Fe	4.2 g	Mo	5 mg
Zn	2.3 g	Co	3 mg
Cu	72 mg	Ni	1 mg

Element	Content	Element	Content
O	45500 g	N	2100 g
C	12600 g	P	700 g
H	7000 g		

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1.10 Biochemical Functions of Inorganic Elements

- Assembly of structures (DNA, biomineralization), endo- and exoskeletons. Ca, Mg, Zn, Si
- Information carriers (muscle contractions, nerve function). Na, K, Ca, Mg
- Activation of enzymes. Mg, Ca
- Formation, metabolism and degradation of organic compounds. Zn, Mg
- Transfer of electrons (energy conversion). Fe II, Fe III, Fe IV
- Uptake, transport, storage and conversion of small molecules
- Symptoms of deficiency: Mg (muscle cramps), Fe (anemia), Mn (infertility)

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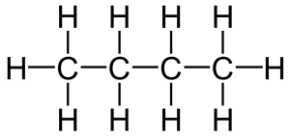
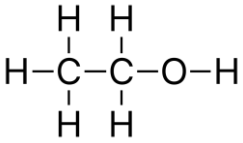
2.1 Bonding of Organic Compounds

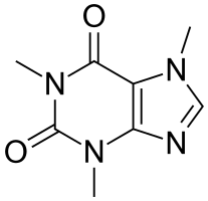
Organic chemistry studies the organic compounds with carbon (C) backbone chains. Organic compounds are biologically important for wide distribution in all living organisms. Most organic compounds contain the covalent bond between carbon (C), hydrogen (H), oxygen (O), and nitrogen (N).



Butane (C_4H_{10})



Ethanol (C_2H_6O)



Caffeine ($C_8H_{10}N_4O_2$)

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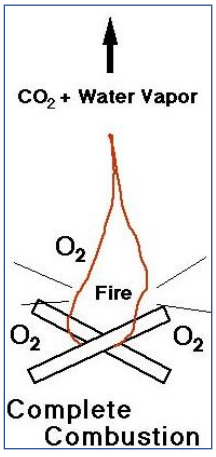
2.2 Properties of Organic Compounds

- Exist as gases, volatile liquids or low melting solids.
- Insoluble in water (polar solvents), unless some polar groups such as –OH, and –COOH are present.
- Soluble in organic, non-polar solvents.
- Complete combustion of hydrocarbons yields carbon dioxide and water.
- Organic compounds exist in groups of families (homologous series) for similar chemical properties and physical properties.



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2.3 Functional Groups of Organic Compounds

The functional groups are presented as an atom or group of atoms joined in a specific manner. The functional groups define the chemical and physical properties of the organic compounds.

-hydroxyl group (-OH): CH_3CH_2OH (ethanol)

-aldehyde group (-CHO): HCHO (formadehyde)

-carboxylic acid group (-COOH): CH_3COOH (acetic acid)

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2.4 Classes of Organic Compounds

A group or a series of organic compounds each containing a characteristic functional group form a homologous classes.

The members of a homologous classes can be represented by general molecular formula and the successive members differ from each other in molecular formula by a $–CH_2$ unit.

— Alkane series: CH_4 (methane), C_2H_6 (ethane), C_3H_8 (propane), …

— Alcohol series: CH_3OH (methanol), C_2H_5OH (ethanol), C_3H_7OH (propanol), …

General formula of the alkane and alcohol series are $\mathbf{C_nH_{2n+2}}$ and $\mathbf{C_nH_{2n+1}OH}$ respectively (n is the number of carbon atoms in the molecule).

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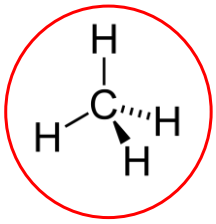
2.5 Structures of Organic Compounds

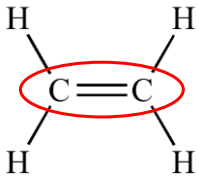
Alkane



-Single C-C bonds

-Formula: C_nH_{2n+2}

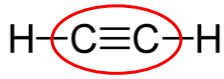
Alkene



-Contain C=C bonds

-Formula: C_nH_{2n}

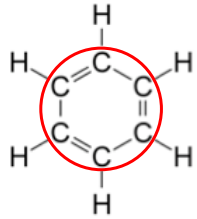
Alkyne



-Contain C≡C bonds

-Formula: C_nH_{2n-2}

Aromatic



-Contain benzene

-Formula: C_nH_{2n-2}

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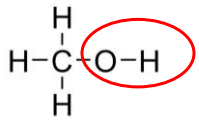
2.6 Functional Groups of Organic Compounds

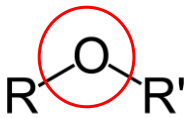
Alcohol



-hydroxy group (-OH)

-Formula: $C_nH_{2n+1}OH$

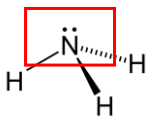
Ether



-Ether group (C-O-C)

-Formula: **R-O-R**

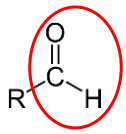
Amine



-Nitrogen group (N)

-Formula: $R^1R^2R^3N$

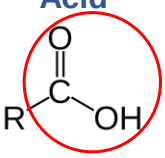
Aldehyde



-Aldehyde group

-Formula: **RCHO**

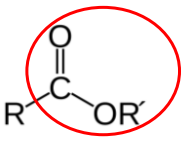
Acid



-Carboxylic group (-COOH)

-Formula: **R-COOH**

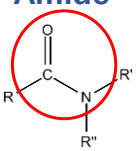
Ester



-Ester group (-COOR)

-Formula: **R-COOR**

Amide



-Amide group (-$CONR^1R^2$)

-Formula: **$R-CONR^1R^2$**

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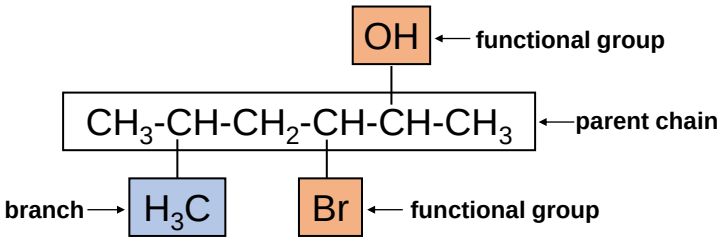
3.1 Systematic Nomenclature

- International Union of Pure and Applied Chemistry (IUPAC) developed a systematic method for naming different compounds.
- Organic compound is given a systematic name based on the parent hydrocarbon chain and the functional group(s).



- the names are correlated with the structure such that the reader or listener can deduce the structure from the name.

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3.1 Systematic Nomenclature

Example 1: Straight chain hydrocarbons

- They are homologues of alkane series.
- The names of such compounds are based on their chain structure, and end with suffix "-ane".

Name	Molecular formula	Name	Molecular Formula
Methane	CH_4	Heptane	C_7H_{16}
Ethane	C_2H_6	Octane	C_8H_{18}
Propane	C_3H_8	Nonane	C_9H_{20}
Butane	C_4H_{10}	Decane	$C_{10}H_{22}$
Pentane	C_5H_{12}	Icosane	$C_{20}H_{42}$
Hexane	C_6H_{14}	Triacontane	$C_{30}H_{62}$

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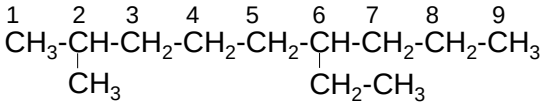
3.1 Systematic Nomenclature

Example 2: Branched chain hydrocarbons

The names of alkyl groups attached as a branch are then prefixed to the name of the parent alkane, and position of the substituents is indicated by the appropriate numbers.

If different alkyl groups are present, they are listed in alphabetical order.

e.g. The name of this compound is 6-ethyl-2-methylnonane.



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3.1 Systematic Nomenclature

Consideration of functional group(s)

In the case of polyfunctional compounds, one of the functional groups is chosen as the principal functional group and the compound is then named on that basis.

The remaining functional groups, which are subordinate functional groups, are named as substituents using the appropriate prefixes.

The choice of principal functional group is made on the basis of order of preference. The order of decreasing priority for some functional group is :

(suffix)-COOH, -SO_3H, -COOR (R=alkyl group), -COCl, -$CONH_2$, -CN, -HC=O, >C=O, -OH, -NH_2, -C≡C-, >C=C<, -C-C-. (prefix)

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3.1 Systematic Nomenclature

Class of compounds	Functional group structure	IUPAC group prefix	IUPAC group suffix	Example
Alkanes	-	-	-ane	butane, **$CH_3(CH_2)_2CH_3$**
Alkenes	>C=C<	-	-ene	but-1-ene, **CH_2=$CHCH_2CH_3$**
Alkynes	-C≡C-	-	-yne	bu-1-yne, **CH≡CCH_2CH_3**
Arenes	-	-	-	benzene, 
Halides	-X (X=F, Cl, Br, I)	halo-	-	1-bromobutane, **$CH_3(CH_2)_2CH_2Br$**
Alcohols	-OH	hydroxy-	-ol	butan-2-ol, **$CH_3CH_2CHOHCH_3$**
Aldehydes	-CHO	formyl, or oxo	-al	butanal, **$CH_3(CH_2)_2CHO$**
Ketones	>C=O	oxo-	-one	butan-2-one, **$CH_3CH_2COCH_3$**
Nitriles	-CN	cyano	nitrile	pentanenitrile **$CH_3CH_3CH_3CH_3CN$**
Ethers	-R-O-R	alkoxy-	-	ethoxyethane, **$CH_3CH_2OCH_2CH_3$**

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3.1 Systematic Nomenclature

Class of compounds	Functional group structure	IUPAC group prefix	IUPAC group suffix	Example
Carboxylic acids	-COOH	carboxy	-oic acid	butanoic acid, **$CH_3(CH_2)_2CO_2H$**
Carboxylate ions	$-COO^-$	-	-oate	sodium butanoate, **$CH_3(CH_2)_2CO_2^-Na^+$**
Esters	-COOR	alkoxycarbonyl	-oate	methyl propanoate, **$CH_3CH_2COOCH_3$**
Acyl halides	-COX (X=F, Cl, Br, I)	halocarbonyl	-oyl halide	butanoyl chloride, **$CH_3(CH_2)_2COCl$**
Amines	$-NH_2$, >NH, >N-	amino-	-amine	butan-2-amine, **$CH_3CHNH_2CH_2CH_3$**
Amides	$-CONH_2$, -CONHR, $-CONR_2$	-carbamoyl	-amide	butanamide,-2-ol, **$CH_3(CH_2)_2CONH_2$**
Nitros	$-NO_2$	nitro	-	1-nitrobutane, **$CH_3(CH_2)_3NO_2$**

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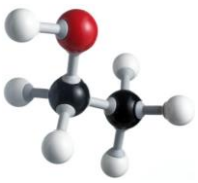
3.2 Types of formula



Ethyl alcohol

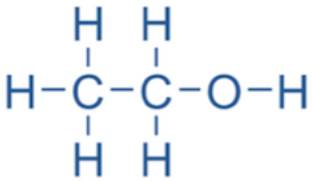
Molecular formula

C_2H_5OH

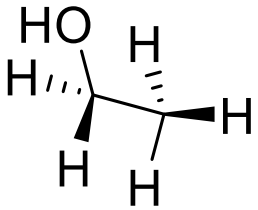
Empirical formula

C_2H_6O

Dash formula



Dash and wedge formula



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Class Content

1. Basic Inorganic Chemistry (Topic 5)
2. Basic Organic Chemistry I (Topic 6)
3. Basic Organic Chemistry II (Topic 7)
4. **Basic Organic Chemistry III (Topic 8)**

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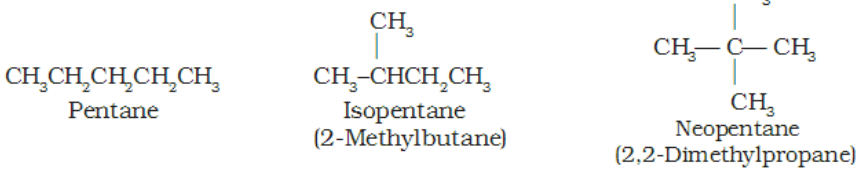
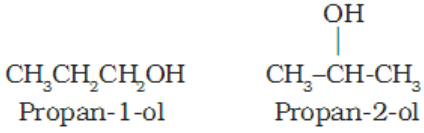
4.1 Structural Isomerism of Organic Compounds

Chain isomers: Compounds have same molecular formula but different carbon skeletons.



Position isomers: Compounds differ in the position of functional group on the carbon skeleton.



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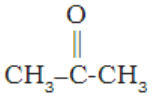
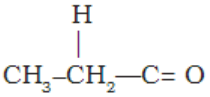
4.2 Functional Isomerism of Organic Compounds

Functional isomers: Compounds having the same molecular formula but different functional groups.

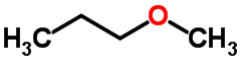


Propanone

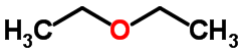


Propanal

Metamerism: Different alkyl chains are presented at either side of functional group in the molecule.

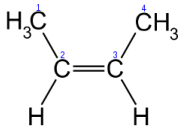


methoxypropane

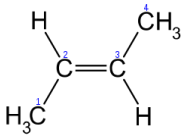


ethoxyethane

Geometric isomerism: Cis-trans isomerism or configuration isomerism in organic compounds containing C=C bonds



cis-2-butene



trans-2-butene

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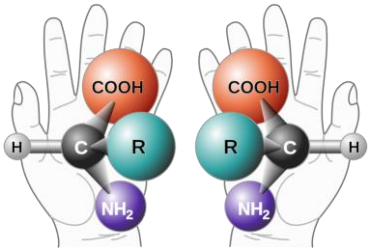
4.3 Chirality of Organic Compounds

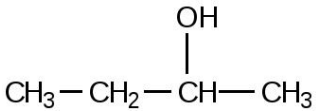
Chirality

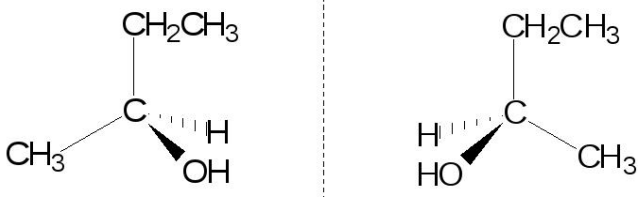


derived from the Greek χειρ (kheir), "hand," a familiar chiral object.

a geometric property of some molecules and ions. A chiral molecule/ion is non-superimposable on its mirror image.

e.g. butan-2-ol:





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Summary

1) The basics of inorganic chemistry and organic chemistry
2) The chemical bonding and biologically relevance of inorganic compounds
3) The types, formula and systematic nomenclature of organic compounds
4) The structural and functional properties of organic compounds

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