

Chemistry Vocabulary

Introduction

1 Elements and elementary substances

1.1 Alkali metals

1.1.1 Elements

Atomic No.	Symbol	English Name	Latin Name	Rel. Atomic Mass
3	Li	Lithium	Lithium	6.94
11	Na	Sodium	Natrium	22.99
19	K	Potassium	Kalium	39.10
37	Rb	Rubidium	Rubidium	85.47
55	Cs	Cesium	Caesium	132.91
87	Fr	Francium	Francium	(223)

1.1.2 Elementary Substances

Element	M.P. (°C)	B.P. (°C)	Crystal Structure	Application/Source
Li	180.5	1342	BCC	Batteries, alloys
Na	97.7	883	BCC	Reducing agent, coolant
K	63.5	759	BCC	Fertilizer, gun powder
Rb	39.3	688	BCC	Photoelectric cells
Cs	28.4	671	BCC	Atomic clocks
Fr	27	677	—	Radioactive, no use

1.1.3 Preparation Methods

Sodium (Na): Electrolysis of molten NaCl: $2\text{NaCl} \xrightarrow{\text{electrolysis}} 2\text{Na} + \text{Cl}_2 \uparrow$

Potassium (K): Reduction of KCl with Na at high temperature: $\text{KCl} + \text{Na} \xrightarrow{\text{high T}} \text{K} \uparrow + \text{NaCl}$

1.2 Alkaline earth metals

1.2.1 Elements

Atomic No.	Symbol	English Name	Latin Name	Rel. Atomic Mass
4	Be	Beryllium	Beryllium	9.01
12	Mg	Magnesium	Magnesium	24.31
20	Ca	Calcium	Calcium	40.08
38	Sr	Strontium	Strontium	87.62
56	Ba	Barium	Barium	137.33
88	Ra	Radium	Radium	(226)

1.2.2 Elementary Substances

Element	M.P. (°C)	B.P. (°C)	Crystal Structure	Application/Source
Be	1287	2470	HCP	Alloys, X-ray windows
Mg	650	1090	HCP	Alloys, fireworks
Ca	842	1484	FCC	Reducing agent, cement
Sr	777	1382	FCC	Fireworks (red)
Ba	727	1897	BCC	Drilling fluids
Ra	700	1737	BCC	Radioactive, obsolete

1.2.3 Preparation Methods

Magnesium (Mg): Electrolysis of molten MgCl_2 : $\text{MgCl}_2 \xrightarrow{\text{electrolysis}} \text{Mg} + \text{Cl}_2 \uparrow$

Alternatively, reduction of MgO with coke: $\text{MgO} + \text{C} \xrightarrow{\text{high T}} \text{Mg} \uparrow + \text{CO} \uparrow$

Calcium (Ca): Electrolysis of molten CaCl_2 or reduction of CaO with Al

1.3 Transition metals

1.3.1 Elements (First Row)

Atomic No.	Symbol	English Name	Latin Name	Rel. Atomic Mass
21	Sc	Scandium	Scandium	44.96
22	Ti	Titanium	Titanium	47.87
23	V	Vanadium	Vanadium	50.94
24	Cr	Chromium	Chromium	52.00
25	Mn	Manganese	Manganese	54.94
26	Fe	Iron	Ferrum	55.85
27	Co	Cobalt	Cobaltum	58.93
28	Ni	Nickel	Niccolum	58.69
29	Cu	Copper	Cuprum	63.55
30	Zn	Zinc	Zincum	65.38

1.3.2 Important Elements (Other Rows)

Atomic No.	Symbol	English Name	Latin Name	Rel. Atomic Mass
47	Ag	Silver	Argentum	107.87
48	Cd	Cadmium	Cadmium	112.41
74	W	Tungsten	Wolframium	183.84
78	Pt	Platinum	Platinum	195.08
79	Au	Gold	Aurum	196.97
80	Hg	Mercury	Hydrargyrum	200.59

1.3.3 Elementary Substances

Element	M.P. (°C)	B.P. (°C)	Crystal Structure	Application/Source
Ti	1668	3287	HCP	Aerospace alloys, pigments
V	1910	3407	BCC	Steel alloys, catalysts
Cr	1907	2671	BCC	Stainless steel, plating
Mn	1246	2061	Cubic	Steel production
Fe	1538	2862	BCC	Construction, machinery
Co	1495	2927	HCP	Alloys, magnets
Ni	1455	2913	FCC	Alloys, catalysts, coins

Element	M.P. (°C)	B.P. (°C)	Crystal Structure	Application/Source
Cu	1085	2562	FCC	Electrical wire, plumbing
Zn	419.5	907	HCP	Galvanization, batteries
Ag	961.8	2162	FCC	Jewelry, conductors
Cd	321.1	767	HCP	Batteries, pigments
W	3422	5555	BCC	Light bulb filaments
Pt	1768	3825	FCC	Catalysts, jewelry
Au	1064	2856	FCC	Jewelry, electronics
Hg	-38.8	356.7	Rhombohedral	Thermometers, lamps

1.3.4 Preparation Methods

Iron (Fe): Reduction in blast furnace: $\text{Fe}_2\text{O}_3 + 3\text{CO} \xrightarrow{\text{high T}} 2\text{Fe} + 3\text{CO}_2$

Copper (Cu): Roasting sulfide ore then reduction: $2\text{Cu}_2\text{S} + 3\text{O}_2 \longrightarrow 2\text{Cu}_2\text{O} + 2\text{SO}_2$, then $\text{Cu}_2\text{S} + 2\text{Cu}_2\text{O} \longrightarrow 6\text{Cu} + \text{SO}_2 \uparrow$

Alternatively, leaching and electrowinning from oxide ores.

Zinc (Zn): Roasting then reduction with carbon: $2\text{ZnS} + 3\text{O}_2 \longrightarrow 2\text{ZnO} + 2\text{SO}_2$, then $\text{ZnO} + \text{C} \longrightarrow \text{Zn} + \text{CO}$

Chromium (Cr): Reduction of Cr_2O_3 with aluminum (thermite process): $\text{Cr}_2\text{O}_3 + 2\text{Al} \longrightarrow 2\text{Cr} + \text{Al}_2\text{O}_3$

1.4 Post-transition metals

1.4.1 Elements

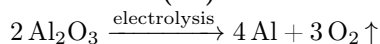
Atomic No.	Symbol	English Name	Latin Name	Rel. Atomic Mass
13	Al	Aluminum	Aluminium	26.98
31	Ga	Gallium	Gallium	69.72
49	In	Indium	Indium	114.82
50	Sn	Tin	Stannum	118.71
81	Tl	Thallium	Thallium	204.38
82	Pb	Lead	Plumbum	207.2
83	Bi	Bismuth	Bismuthum	208.98

1.4.2 Elementary Substances

Element	M.P. (°C)	B.P. (°C)	Crystal Structure	Application/Source
Al	660.3	2519	FCC	Packaging, construction
Ga	29.8	2204	Orthorhombic	Semiconductors, LEDs
In	156.6	2072	Tetragonal	LCD screens, solders
Sn	231.9	2602	Tetragonal	Solder, coatings
Tl	304	1473	HCP	Rat poison (obsolete)
Pb	327.5	1749	FCC	Batteries, radiation shield
Bi	271.4	1564	Rhombohedral	Alloys, cosmetics

1.4.3 Preparation Methods

Aluminum (Al): Hall-Héroult process (electrolysis of Al_2O_3 dissolved in molten cryolite):



Lead (Pb): Roasting galena (PbS) then reduction: $2\text{PbS} + 3\text{O}_2 \longrightarrow 2\text{PbO} + 2\text{SO}_2$, then $\text{PbO} + \text{C} \longrightarrow \text{Pb} + \text{CO}$

Tin (Sn): Reduction of cassiterite (SnO_2) with carbon: $\text{SnO}_2 + 2\text{C} \longrightarrow \text{Sn} + 2\text{CO} \uparrow$

1.5 Metalloids

1.5.1 Elements

Atomic No.	Symbol	English Name	Latin Name	Rel. Atomic Mass
5	B	Boron	Borium	10.81
14	Si	Silicon	Silicium	28.09
32	Ge	Germanium	Germanium	72.64
33	As	Arsenic	Arsenicum	74.92
51	Sb	Antimony	Stibium	121.76
52	Te	Tellurium	Tellurium	127.60
84	Po	Polonium	Polonium	(209)

1.5.2 Elementary Substances

Element	M.P. (°C)	B.P. (°C)	Crystal Structure	Application/Source
B	2075	4000	Rhombohedral	Glass, detergents
Si	1414	3265	Diamond cubic	Semiconductors, solar cells
Ge	938.3	2833	Diamond cubic	Semiconductors, optics
As	817	614 (subl.)	Rhombohedral	Alloys, pesticides
Sb	630.6	1587	Rhombohedral	Flame retardants, alloys
Te	449.5	988	Hexagonal	Alloys, solar cells
Po	254	962	Cubic	Radioactive, no common use

1.5.3 Preparation Methods

Silicon (Si): Reduction of silica (SiO_2) with carbon in electric furnace: $\text{SiO}_2 + 2\text{C} \xrightarrow{\text{high T}} \text{Si} + 2\text{CO} \uparrow$
For ultrapure silicon (semiconductors): Trichlorosilane reduction: $\text{SiHCl}_3 + \text{H}_2 \xrightarrow{\text{high T}} \text{Si} + 3\text{HCl}$

1.6 Halogen

1.6.1 Elements

Atomic No.	Symbol	English Name	Latin Name	Rel. Atomic Mass
9	F	Fluorine	Fluorum	19.00
17	Cl	Chlorine	Chlorum	35.45
35	Br	Bromine	Bromum	79.90
53	I	Iodine	Iodum	126.90
85	At	Astatine	Astatium	(210)

1.6.2 Elementary Substances

Element	M.P. (°C)	B.P. (°C)	Physical State	Application/Source
F_2	-219.6	-188.1	Pale yellow gas	Toothpaste, Teflon
Cl_2	-101.5	-34.0	Yellow-green gas	Disinfectant, PVC
Br_2	-7.2	58.8	Red-brown liquid	Flame retardants, dyes
I_2	113.7	184.3	Purple-black solid	Disinfectant, photography
At_2	302	337	Solid (radioactive)	No practical use

1.6.3 Preparation Methods

Chlorine (Cl₂): Electrolysis of brine (chlor-alkali process): $2\text{NaCl} + 2\text{H}_2\text{O} \xrightarrow{\text{electrolysis}} \text{Cl}_2 \uparrow + \text{H}_2 \uparrow + 2\text{NaOH}$

Laboratory: Oxidation of HCl: $\text{MnO}_2 + 4\text{HCl} \xrightarrow{\text{heat}} \text{MnCl}_2 + \text{Cl}_2 \uparrow + 2\text{H}_2\text{O}$

Bromine (Br₂): Oxidation of bromide in seawater: $2\text{Br}^- + \text{Cl}_2 \longrightarrow \text{Br}_2 + 2\text{Cl}^-$

Iodine (I₂): Oxidation of iodide from brine or seaweed: $2\text{I}^- + \text{Cl}_2 \longrightarrow \text{I}_2 + 2\text{Cl}^-$

Or from Chile saltpeter: $2\text{NaIO}_3 + 5\text{NaHSO}_3 \longrightarrow \text{I}_2 + 3\text{NaHSO}_4 + 2\text{Na}_2\text{SO}_4 + \text{H}_2\text{O}$

Fluorine (F₂): Electrolysis of KF in anhydrous HF: $2\text{HF} \xrightarrow{\text{electrolysis}} \text{H}_2 + \text{F}_2 \uparrow$

1.7 Noble gases

1.7.1 Elements

Atomic No.	Symbol	English Name	Latin Name	Rel. Atomic Mass
2	He	Helium	Helium	4.00
10	Ne	Neon	Neon	20.18
18	Ar	Argon	Argon	39.95
36	Kr	Krypton	Krypton	83.80
54	Xe	Xenon	Xenon	131.29
86	Rn	Radon	Radon	(222)

1.7.2 Elementary Substances

Element	M.P. (°C)	B.P. (°C)	Physical State	Application/Source
He	-272.2	-268.9	Colorless gas	Balloons, cryogenics
Ne	-248.6	-246.0	Colorless gas	Neon signs, lasers
Ar	-189.3	-185.8	Colorless gas	Welding, light bulbs
Kr	-157.4	-153.2	Colorless gas	Flash lamps, lasers
Xe	-111.8	-108.1	Colorless gas	Anesthesia, ion drives
Rn	-71	-61.7	Colorless gas	Radioactive tracer

1.7.3 Preparation

Noble gases are obtained by fractional distillation of liquid air (except He and Rn).

Helium (He): Extracted from natural gas wells.

Radon (Rn): Decay product of radium, collected from uranium/thorium ores.

1.8 Other Nonmetals

1.8.1 Elements

Atomic No.	Symbol	English Name	Latin Name	Rel. Atomic Mass
1	H	Hydrogen	Hydrogenium	1.008
6	C	Carbon	Carboneum	12.01
7	N	Nitrogen	Nitrogenium	14.01
8	O	Oxygen	Oxygenium	16.00
15	P	Phosphorus	Phosphorus	30.97
16	S	Sulfur	Sulfur	32.07
34	Se	Selenium	Selenium	78.96

1.8.2 Elementary Substances

Element	M.P. (°C)	B.P. (°C)	Form/Structure	Application/Source
H ₂	-259.2	-252.9	Colorless gas	Fuel, ammonia synthesis
C (graphite)	3825	4827 (subl.)	Hexagonal layers	Pencils, electrodes
C (diamond)	3550	—	Cubic crystal	Jewelry, cutting tools
C (fullerene)	—	—	Molecular cage	Research, electronics
N ₂	-210.0	-195.8	Colorless gas	Fertilizers, inert atm.
O ₂	-218.8	-183.0	Colorless gas	Respiration, combustion
O ₃ (ozone)	-192.5	-112.0	Blue gas	Sterilization, UV shield
P (white)	44.2	280	Molecular solid	Incendiaries, match
P (red)	590	431 (subl.)	Amorphous	Safety matches
P (black)	—	—	Layered	Research
S (rhombic)	115.2	444.6	Orthorhombic	Sulfuric acid, vulcanize
S (monoclinic)	119	444.6	Monoclinic	Allotrope of sulfur
Se (gray)	221	685	Hexagonal	Photocells, glass

1.8.3 Preparation Methods

Hydrogen (H₂):

- Steam reforming of methane: $\text{CH}_4 + \text{H}_2\text{O} \xrightleftharpoons[\text{high T}]{\text{catalyst}} \text{CO} + 3 \text{H}_2$
- Electrolysis of water: $2 \text{H}_2\text{O} \xrightarrow{\text{electrolysis}} 2 \text{H}_2 \uparrow + \text{O}_2 \uparrow$
- Laboratory: Reaction of metals with acids: $\text{Zn} + 2 \text{HCl} \longrightarrow \text{ZnCl}_2 + \text{H}_2 \uparrow$

Oxygen (O₂):

- Fractional distillation of liquid air
- Electrolysis of water: $2 \text{H}_2\text{O} \xrightarrow{\text{electrolysis}} 2 \text{H}_2 \uparrow + \text{O}_2 \uparrow$
- Laboratory: Decomposition of KMnO₄: $2 \text{KMnO}_4 \xrightarrow{\text{heat}} \text{K}_2\text{MnO}_4 + \text{MnO}_2 + \text{O}_2 \uparrow$
- Or: $2 \text{KClO}_3 \xrightarrow{\text{MnO}_2, \text{heat}} 2 \text{KCl} + 3 \text{O}_2 \uparrow$

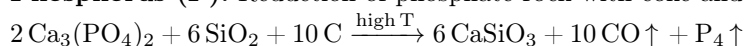
Nitrogen (N₂): Fractional distillation of liquid air

Chlorine (Cl₂): See Halogen section

Sulfur (S):

- Frasch process: Melting underground sulfur with superheated water
- Recovered from petroleum refining and natural gas processing

Phosphorus (P): Reduction of phosphate rock with coke and silica:



2 Acids and bases ions

2.1 Hydrogen halides

2.1.1 Hydrofluoric acid

HF (Hydrofluoric acid, Hydrogen fluoride)

Properties: Weak acid in aqueous solution (unlike other hydrogen halides), can dissolve glass.

Reactions:

- Etching glass: $\text{SiO}_2 + 4\text{HF} \longrightarrow \text{SiF}_4 \uparrow + 2\text{H}_2\text{O}$
- With calcium: $\text{Ca} + 2\text{HF} \longrightarrow \text{CaF}_2 + \text{H}_2 \uparrow$
- Formation of hexafluorosilicate: $\text{SiO}_2 + 6\text{HF} \longrightarrow \text{H}_2\text{SiF}_6 + 2\text{H}_2\text{O}$

2.1.2 Hydrochloric acid

HCl (Hydrochloric acid, Hydrogen chloride)

Properties: Strong acid, colorless gas, forms white fumes in moist air.

Reactions:

- Oxidation by manganese dioxide: $\text{MnO}_2 + 4\text{HCl} \xrightarrow{\text{heat}} \text{MnCl}_2 + \text{Cl}_2 \uparrow + 2\text{H}_2\text{O}$
- With ammonia: $\text{NH}_3 + \text{HCl} \longrightarrow \text{NH}_4\text{Cl}$ (white smoke)
- Dissolving metals: $\text{Fe} + 2\text{HCl} \longrightarrow \text{FeCl}_2 + \text{H}_2 \uparrow$
- With permanganate: $2\text{KMnO}_4 + 16\text{HCl} \longrightarrow 2\text{KCl} + 2\text{MnCl}_2 + 5\text{Cl}_2 \uparrow + 8\text{H}_2\text{O}$

2.1.3 Hydrobromic acid

HBr (Hydrobromic acid, Hydrogen bromide)

Properties: Strong acid, stronger reducing agent than HCl.

Reactions:

- Oxidation by sulfuric acid: $2\text{HBr} + \text{H}_2\text{SO}_4 \longrightarrow \text{Br}_2 + \text{SO}_2 + 2\text{H}_2\text{O}$
- With silver nitrate: $\text{HBr} + \text{AgNO}_3 \longrightarrow \text{AgBr} \downarrow + \text{HNO}_3$ (pale yellow precipitate)

2.1.4 Hydroiodic acid

HI (Hydroiodic acid, Hydrogen iodide)

Properties: Strong acid, strongest reducing agent among hydrogen halides.

Reactions:

- Oxidation by sulfuric acid: $8\text{HI} + \text{H}_2\text{SO}_4 \longrightarrow 4\text{I}_2 + \text{H}_2\text{S} + 4\text{H}_2\text{O}$
- Reduction of Fe(III): $2\text{Fe}^{3+} + 2\text{I}^- \longrightarrow 2\text{Fe}^{2+} + \text{I}_2$
- With chlorine: $2\text{HI} + \text{Cl}_2 \longrightarrow 2\text{HCl} + \text{I}_2$

2.2 Oxyacid

2.2.1 Nitrogen oxyacids

HNO₂ (Nitrous acid)

Structure: $\text{H} - \text{O} - \text{N} = \text{O}$

Valence: N is +3

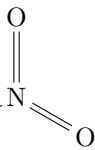
Properties: Weak acid, unstable, exists only in solution.

Reactions:

- Decomposition: $3\text{HNO}_2 \longrightarrow \text{HNO}_3 + 2\text{NO} \uparrow + \text{H}_2\text{O}$
- Oxidation of iodide: $2\text{HNO}_2 + 2\text{HI} \longrightarrow \text{I}_2 + 2\text{NO} \uparrow + 2\text{H}_2\text{O}$

- Reduction by reducing agents: $2\text{HNO}_2 + 2\text{HI} \longrightarrow 2\text{NO}\uparrow + \text{I}_2 + 2\text{H}_2\text{O}$

HNO₃ (Nitric acid)



Structure: H—O—N(=O)=O

Valence: N is +5

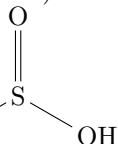
Properties: Strong acid, strong oxidizing agent.

Reactions:

- With copper: $3\text{Cu} + 8\text{HNO}_3(\text{dilute}) \longrightarrow 3\text{Cu}(\text{NO}_3)_2 + 2\text{NO}\uparrow + 4\text{H}_2\text{O}$
- Concentrated with copper: $\text{Cu} + 4\text{HNO}_3(\text{conc.}) \longrightarrow \text{Cu}(\text{NO}_3)_2 + 2\text{NO}_2\uparrow + 2\text{H}_2\text{O}$
- Nitration reaction: $\text{C}_6\text{H}_6 + \text{HNO}_3 \xrightarrow{\text{H}_2\text{SO}_4} \text{C}_6\text{H}_5\text{NO}_2 + \text{H}_2\text{O}$
- With phosphorus: $\text{P}_4 + 20\text{HNO}_3 \longrightarrow 4\text{H}_3\text{PO}_4 + 20\text{NO}_2\uparrow + 4\text{H}_2\text{O}$
- Passivation of iron: $\text{Fe} + 6\text{HNO}_3(\text{conc.}) \longrightarrow \text{Fe}^{3+}(\text{passive layer})$

2.2.2 Sulfur oxyacids

H₂SO₃ (Sulfurous acid)



Structure: HO—S(=O)—OH

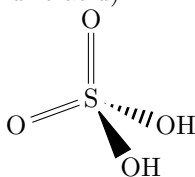
Valence: S is +4

Properties: Weak acid, exists only in solution, reducing agent.

Reactions:

- Oxidation by oxygen: $2\text{H}_2\text{SO}_3 + \text{O}_2 \longrightarrow 2\text{H}_2\text{SO}_4$
- Reduction by hydrogen sulfide: $\text{H}_2\text{SO}_3 + 2\text{H}_2\text{S} \longrightarrow 3\text{S}\downarrow + 3\text{H}_2\text{O}$
- With bromine: $\text{H}_2\text{SO}_3 + \text{Br}_2 + \text{H}_2\text{O} \longrightarrow \text{H}_2\text{SO}_4 + 2\text{HBr}$

H₂SO₄ (Sulfuric acid)



Structure: O=S(=O)(OH)OH

Valence: S is +6

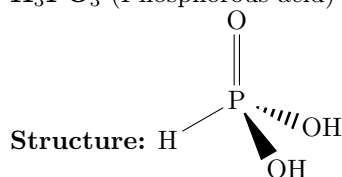
Properties: Strong acid, strong dehydrating agent, strong oxidizing agent (concentrated).

Reactions:

- With carbon (dehydration): $\text{C}_{12}\text{H}_{22}\text{O}_{11} \xrightarrow{\text{H}_2\text{SO}_4(\text{conc.})} 12\text{C} + 11\text{H}_2\text{O}$
- Hot concentrated with copper: $\text{Cu} + 2\text{H}_2\text{SO}_4(\text{conc.}) \xrightarrow{\text{heat}} \text{CuSO}_4 + \text{SO}_2\uparrow + 2\text{H}_2\text{O}$
- With NaCl (making HCl): $\text{NaCl} + \text{H}_2\text{SO}_4 \xrightarrow{\text{heat}} \text{NaHSO}_4 + \text{HCl}\uparrow$
- Esterification: $\text{CH}_3\text{COOH} + \text{C}_2\text{H}_5\text{OH} \xrightleftharpoons{\text{H}_2\text{SO}_4} \text{CH}_3\text{COOC}_2\text{H}_5 + \text{H}_2\text{O}$

2.2.3 Phosphorus oxyacids

H_3PO_3 (Phosphorous acid)



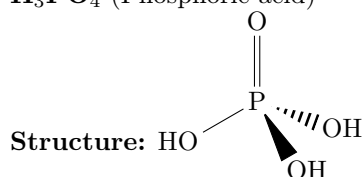
Valence: P is +3

Properties: Dibasic acid (only 2 acidic H), reducing agent.

Reactions:

- Reduction of silver nitrate: $\text{H}_3\text{PO}_3 + 2 \text{AgNO}_3 + \text{H}_2\text{O} \longrightarrow \text{H}_3\text{PO}_4 + 2 \text{Ag} \downarrow + 2 \text{HNO}_3$
- Disproportionation: $4 \text{H}_3\text{PO}_3 \xrightarrow{\text{heat}} 3 \text{H}_3\text{PO}_4 + \text{PH}_3 \uparrow$

H_3PO_4 (Phosphoric acid)



Valence: P is +5

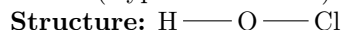
Properties: Weak tribasic acid, non-oxidizing.

Reactions:

- Dehydration to pyrophosphoric acid: $2 \text{H}_3\text{PO}_4 \xrightarrow{\text{heat}} \text{H}_4\text{P}_2\text{O}_7 + \text{H}_2\text{O}$
- With ammonia: $\text{H}_3\text{PO}_4 + \text{NH}_3 \longrightarrow \text{NH}_4\text{H}_2\text{PO}_4$
- Esterification: $\text{H}_3\text{PO}_4 + 3 \text{C}_2\text{H}_5\text{OH} \longrightarrow (\text{C}_2\text{H}_5\text{O})_3\text{PO} + 3 \text{H}_2\text{O}$

2.2.4 Chlorine oxyacids

HClO (Hypochlorous acid)



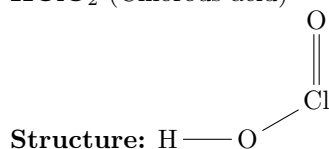
Valence: Cl is +1

Properties: Very weak acid, strong oxidizing agent, unstable.

Reactions:

- Disproportionation: $3 \text{HClO} \longrightarrow \text{HClO}_3 + 2 \text{HCl}$
- Oxidation: $\text{HClO} + \text{H}_2\text{S} \longrightarrow \text{HCl} + \text{S} \downarrow + \text{H}_2\text{O}$
- Bleaching: $\text{HClO} + [\text{dye}] \longrightarrow [\text{oxidized dye}] \text{ (colorless)}$

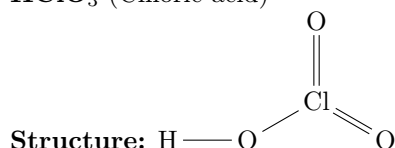
HClO_2 (Chlorous acid)



Valence: Cl is +3

Properties: Weak acid, unstable, exists only in solution.

HClO_3 (Chloric acid)



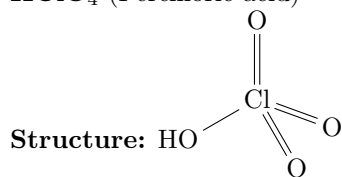
Valence: Cl is +5

Properties: Strong acid, strong oxidizing agent.

Reactions:

- Oxidation of sulfur: $3\text{S} + 6\text{HClO}_3 \longrightarrow 3\text{H}_2\text{SO}_4 + 3\text{Cl}_2 \uparrow$
- Decomposition: $8\text{HClO}_3 \longrightarrow 4\text{Cl}_2 \uparrow + 6\text{O}_2 \uparrow + 4\text{H}_2\text{O}$

HClO₄ (Perchloric acid)



Valence: Cl is +7

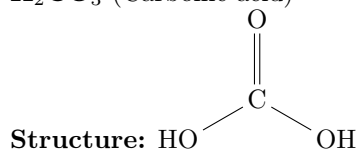
Properties: Very strong acid, strongest common acid, powerful oxidizing agent when hot/concentrated.

Reactions:

- Oxidation of organic compounds: $\text{C}_6\text{H}_{12}\text{O}_6 + 24\text{HClO}_4 \xrightarrow{\text{heat}} 6\text{CO}_2 \uparrow + 12\text{Cl}_2 \uparrow + 18\text{H}_2\text{O}$
- With metals: $\text{Mg} + 2\text{HClO}_4 \longrightarrow \text{Mg}(\text{ClO}_4)_2 + \text{H}_2 \uparrow$

2.2.5 Carbon oxyacids

H₂CO₃ (Carbonic acid)



Valence: C is +4

Properties: Weak acid, unstable, exists in equilibrium with CO₂ and H₂O.

Reactions:

- Decomposition: $\text{H}_2\text{CO}_3 \rightleftharpoons \text{CO}_2 \uparrow + \text{H}_2\text{O}$
- With ammonia: $\text{H}_2\text{CO}_3 + 2\text{NH}_3 \longrightarrow (\text{NH}_4)_2\text{CO}_3$
- Formation: $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3$

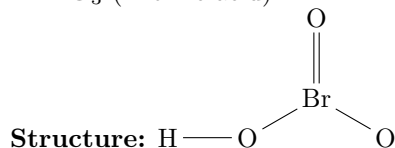
2.2.6 Bromine and iodine oxyacids

HBrO (Hypobromous acid)

Structure: $\text{H}-\text{O}-\text{Br}$

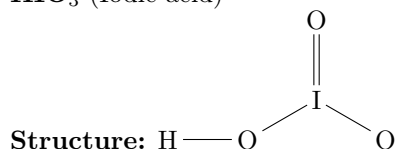
Valence: Br is +1

HBrO₃ (Bromic acid)



Valence: Br is +5

HIO₃ (Iodic acid)

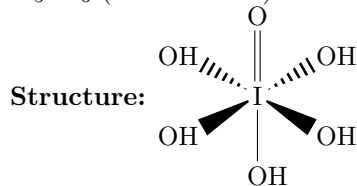


Valence: I is +5

Reactions:

- Oxidation: $5\text{HI} + \text{HIO}_3 \longrightarrow 3\text{I}_2 + 3\text{H}_2\text{O}$
- With sulfur dioxide: $\text{HIO}_3 + 3\text{H}_2\text{SO}_3 \longrightarrow \text{HI} + 3\text{H}_2\text{SO}_4$

H₅IO₆ (Periodic acid)



Valence: I is +7

Reactions:

- Oxidative cleavage of diols: Used to cleave vicinal diols (glycols) to aldehydes or ketones

2.3 Bases from metal oxides

2.3.1 Alkali metal hydroxides

NaOH (Sodium hydroxide, Caustic soda, Lye)

Valence: Na is +1

Properties: Strong base, deliquescent, corrosive.

Reactions:

- With aluminum (amphoteric): $2\text{Al} + 2\text{NaOH} + 2\text{H}_2\text{O} \longrightarrow 2\text{NaAlO}_2 + 3\text{H}_2\uparrow$
- With silicon dioxide: $\text{SiO}_2 + 2\text{NaOH} \xrightarrow{\text{heat}} \text{Na}_2\text{SiO}_3 + \text{H}_2\text{O}$
- Saponification of esters: $\text{CH}_3\text{COOC}_2\text{H}_5 + \text{NaOH} \longrightarrow \text{CH}_3\text{COONa} + \text{C}_2\text{H}_5\text{OH}$
- With chlorine (disproportionation): $\text{Cl}_2 + 2\text{NaOH} \longrightarrow \text{NaCl} + \text{NaClO} + \text{H}_2\text{O}$
- With sulfur: $3\text{S} + 6\text{NaOH} \xrightarrow{\text{heat}} 2\text{Na}_2\text{S} + \text{Na}_2\text{SO}_3 + 3\text{H}_2\text{O}$

KOH (Potassium hydroxide, Caustic potash)

Valence: K is +1

Properties: Strong base, more hygroscopic than NaOH.

Reactions:

- With CO₂: $2\text{KOH} + \text{CO}_2 \longrightarrow \text{K}_2\text{CO}_3 + \text{H}_2\text{O}$
- Excess CO₂: $\text{K}_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O} \longrightarrow 2\text{KHCO}_3$
- With haloalkanes (elimination): $\text{C}_2\text{H}_5\text{Br} + \text{KOH} \xrightarrow{\text{alcohol}} \text{C}_2\text{H}_4\uparrow + \text{KBr} + \text{H}_2\text{O}$

LiOH (Lithium hydroxide)

Valence: Li is +1

Properties: Strong base, used in CO₂ scrubbers.

Reactions:

- CO₂ absorption: $2\text{LiOH} + \text{CO}_2 \longrightarrow \text{Li}_2\text{CO}_3 + \text{H}_2\text{O}$

2.3.2 Alkaline earth metal hydroxides

Ca(OH)₂ (Calcium hydroxide, Slaked lime, Hydrated lime)

Valence: Ca is +2

Properties: Moderately strong base, sparingly soluble in water (lime water).

Reactions:

- With CO₂ (limewater test): $\text{Ca(OH)}_2 + \text{CO}_2 \longrightarrow \text{CaCO}_3\downarrow + \text{H}_2\text{O}$
- Excess CO₂: $\text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} \longrightarrow \text{Ca(HCO}_3)_2$ (soluble)
- With chlorine: $2\text{Ca(OH)}_2 + 2\text{Cl}_2 \longrightarrow \text{CaCl}_2 + \text{Ca(ClO)}_2 + 2\text{H}_2\text{O}$
- Preparation from quicklime: $\text{CaO} + \text{H}_2\text{O} \longrightarrow \text{Ca(OH)}_2$ (exothermic)

Mg(OH)₂ (Magnesium hydroxide, Milk of magnesia)

Valence: Mg is +2

Properties: Weak base, very sparingly soluble, antacid.

Reactions:

- Decomposition: $\text{Mg(OH)}_2 \xrightarrow{\text{heat}} \text{MgO} + \text{H}_2\text{O}$
- With acids (antacid action): $\text{Mg(OH)}_2 + 2\text{HCl} \longrightarrow \text{MgCl}_2 + 2\text{H}_2\text{O}$

Ba(OH)₂ (Barium hydroxide)

Valence: Ba is +2

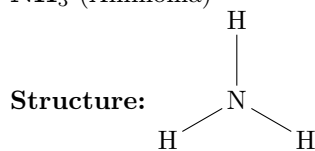
Properties: Strong base, more soluble than Ca(OH)_2 .

Reactions:

- With sulfuric acid: $\text{Ba(OH)}_2 + \text{H}_2\text{SO}_4 \longrightarrow \text{BaSO}_4 \downarrow + 2\text{H}_2\text{O}$
- With ammonium salts (endothermic): $\text{Ba(OH)}_2 \cdot 8\text{H}_2\text{O} + 2\text{NH}_4\text{Cl} \longrightarrow \text{BaCl}_2 + 2\text{NH}_3 \uparrow + 10\text{H}_2\text{O}$

2.3.3 Ammonia and related bases

NH₃ (Ammonia)



Properties: Weak base, pungent gas, very soluble in water.

Reactions:

- Complex formation with Cu^{2+} : $\text{Cu}^{2+} + 4\text{NH}_3 \longrightarrow [\text{Cu(NH}_3)_4]^{2+}$ (deep blue)
- With HCl: $\text{NH}_3 + \text{HCl} \longrightarrow \text{NH}_4\text{Cl}$ (white smoke)
- Haber process: $\text{N}_2 + 3\text{H}_2 \xrightleftharpoons[\text{high T, P}]{\text{Fe catalyst}} 2\text{NH}_3$
- Oxidation by oxygen: $4\text{NH}_3 + 5\text{O}_2 \xrightarrow{\text{Pt catalyst}} 4\text{NO} + 6\text{H}_2\text{O}$ (Ostwald process)
- With chlorine: $2\text{NH}_3 + 3\text{Cl}_2 \longrightarrow \text{N}_2 + 6\text{HCl}$
- Reduction of CuO: $3\text{CuO} + 2\text{NH}_3 \xrightarrow{\text{heat}} 3\text{Cu} + \text{N}_2 + 3\text{H}_2\text{O}$

NH₄OH (Ammonium hydroxide)

Formula: NH_4^+ and OH^- ions in aqueous solution

Valence: N is -3

Properties: Aqueous ammonia solution, weak base.

Reactions:

- Precipitation of metal hydroxides: $\text{Fe}^{3+} + 3\text{NH}_4\text{OH} \longrightarrow \text{Fe(OH)}_3 \downarrow + 3\text{NH}_4^+$
- With excess ammonia (complex formation): $\text{Zn(OH)}_2 + 4\text{NH}_3 \longrightarrow [\text{Zn(NH}_3)_4]^{2+} + 2\text{OH}^-$

2.3.4 Transition metal hydroxides

Fe(OH)₂ (Iron(II) hydroxide, Ferrous hydroxide)

Valence: Fe is +2

Properties: Weak base, white-green solid, easily oxidized.

Reactions:

- Oxidation: $4\text{Fe(OH)}_2 + \text{O}_2 + 2\text{H}_2\text{O} \longrightarrow 4\text{Fe(OH)}_3$ (turns brown)
- Decomposition: $\text{Fe(OH)}_2 \xrightarrow{\text{heat}} \text{FeO} + \text{H}_2\text{O}$

Fe(OH)₃ (Iron(III) hydroxide, Ferric hydroxide)

Valence: Fe is +3

Properties: Very weak base, brown precipitate.

Reactions:

- Decomposition: $2\text{Fe(OH)}_3 \xrightarrow{\text{heat}} \text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O}$

Al(OH)₃ (Aluminum hydroxide)

Valence: Al is +3

Properties: Amphoteric, white precipitate, antacid.

Reactions:

- With acid: $\text{Al(OH)}_3 + 3\text{HCl} \longrightarrow \text{AlCl}_3 + 3\text{H}_2\text{O}$
- With base: $\text{Al(OH)}_3 + \text{NaOH} \longrightarrow \text{NaAlO}_2 + 2\text{H}_2\text{O}$
- Decomposition: $2\text{Al(OH)}_3 \xrightarrow{\text{heat}} \text{Al}_2\text{O}_3 + 3\text{H}_2\text{O}$

Cu(OH)₂ (Copper(II) hydroxide, Cupric hydroxide)

Valence: Cu is +2

Properties: Weak base, blue precipitate.

Reactions:

- Decomposition: $\text{Cu(OH)}_2 \xrightarrow{\text{heat}} \text{CuO} + \text{H}_2\text{O}$
- With ammonia: $\text{Cu(OH)}_2 + 4\text{NH}_3 \longrightarrow [\text{Cu(NH}_3)_4]^{2+} + 2\text{OH}^-$ (deep blue solution)
- With tartaric acid (Fehling's reagent): Forms copper tartrate complex

3 Ores and alloys

3.1 Ores

English Name	Properties	Formula
Hematite	Red-brown iron ore, most important iron ore	Fe_2O_3
Magnetite	Black magnetic iron ore, high iron content	Fe_3O_4
Limonite	Yellow-brown hydrated iron oxide	$2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$
Siderite	Iron carbonate, light colored	FeCO_3
Pyrite	Brass-yellow, fool's gold, used for sulfuric acid	FeS_2
Chalcopyrite	Brass-yellow copper ore, most abundant copper ore	CuFeS_2
Chalcocite	Dark gray copper sulfide	Cu_2S
Malachite	Green basic copper carbonate	$\text{Cu}_2\text{CO}_3(\text{OH})_2$
Azurite	Blue basic copper carbonate	$\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$
Cuprite	Red copper oxide	Cu_2O
Bauxite	Reddish aluminum ore, clay-like	$\text{Al}_2\text{O}_3 \cdot n\text{H}_2\text{O}$
Cryolite	White, used as flux in aluminum production	Na_3AlF_6
Corundum	Very hard aluminum oxide, includes ruby/sapphire	Al_2O_3
Galena	Lead-gray, cubic crystals, main lead ore	PbS
Cerussite	White lead carbonate	PbCO_3
Anglesite	White lead sulfate	PbSO_4
Sphalerite blende)	(Zinc Yellow-brown to black, main zinc ore	ZnS
Smithsonite	White zinc carbonate	ZnCO_3

English Name	Properties	Formula
Zincite	Red-orange zinc oxide	ZnO
Cassiterite	Brown-black tin oxide, main tin ore	SnO ₂
Cinnabar	Bright red mercury sulfide, main mercury ore	HgS
Argentite	Dark gray silver sulfide	Ag ₂ S
Calamine	Zinc silicate ore	Zn ₄ Si ₂ O ₇ (OH) ₂ · H ₂ O
Chromite	Black chromium iron oxide, main chromium ore	FeCr ₂ O ₄
Pyrolusite	Black manganese dioxide ore	MnO ₂
Rhodochrosite	Pink manganese carbonate	MnCO ₃
Rutile	Red-brown titanium dioxide	TiO ₂
Ilmenite	Black iron titanium oxide	FeTiO ₃
Barite	White barium sulfate, heavy	BaSO ₄
Witherite	White barium carbonate	BaCO ₃
Scheelite	White tungsten calcium ore	CaWO ₄
Wolframite	Black iron manganese tungsten ore	(Fe, Mn)WO ₄
Molybdenite	Gray, soft molybdenum sulfide	MoS ₂
Carnallite	White-red potassium magnesium salt	KCl · MgCl ₂ · 6 H ₂ O
Sylvite	White-red potassium chloride	KCl
Halite (Rock salt)	Transparent-white sodium chloride	NaCl
Fluorite (Fluorspar)	Colorful calcium fluoride	CaF ₂
Limestone	White-gray calcium carbonate sedimentary rock	CaCO ₃
Dolomite	White-pink calcium magnesium carbonate	CaMg(CO ₃) ₂
Gypsum	White calcium sulfate dihydrate	CaSO ₄ · 2 H ₂ O
Anhydrite	White calcium sulfate	CaSO ₄
Apatite	Green-blue calcium phosphate	Ca ₅ (PO ₄) ₃ (F, Cl, OH)
Phosphorite	Gray-brown calcium phosphate rock	Ca ₃ (PO ₄) ₂

3.2 Alloys

English Name	Elements	Properties	Application
Steel	Fe, C (< 2%)	Strong, hard, malleable	Construction, tools
Stainless steel	Fe, Cr (10-20%), Ni	Corrosion-resistant, strong	Cutlery, medical
Cast iron	Fe, C (2-4%)	Brittle, hard, good casting	Engine blocks, pipes
Brass	Cu (55-95%), Zn	Golden, corrosion-resistant	Musical instruments, fittings
Bronze	Cu (88%), Sn (12%)	Hard, corrosion-resistant	Sculptures, bearings
Aluminum bronze	Cu, Al (5-11%)	Strong, corrosion-resistant	Marine hardware, coins
Cupronickel	Cu (75%), Ni (25%)	Silver-colored, corrosion-resistant	Coins, marine uses
German silver	Cu, Ni, Zn	Silver-white, no silver	Cutlery, jewelry base
Phosphor bronze	Cu, Sn, P	Elastic, wear-resistant	Springs, electrical
Gunmetal	Cu, Sn (10%), Zn (2%)	Corrosion-resistant, tough	Gears, bearings
Duralumin	Al (94%), Cu (4%), Mg	Light, strong, age-hardenable	Aircraft, aerospace
Magnalium	Al (70-95%), Mg	Very light, strong	Aircraft parts
Alnico	Al, Ni, Co, Fe	Strong magnetic	Permanent magnets

English Name	Elements	Properties	Application
Solder	Sn (60%), Pb (40%)	Low melting point	Electrical joints
Lead-free solder	Sn, Cu, Ag	Low melting, no lead toxicity	Electronics
Pewter	Sn (85-99%), Sb, Cu	Soft, silvery, malleable	Decorative items
Babbitt metal	Sn, Sb, Cu	Low friction, soft	Bearing surfaces
Type metal	Pb, Sn, Sb	Expands on cooling	Printing type
Wood's metal	Bi, Pb, Sn, Cd	Very low melting (70°C)	Fire sprinklers, fuses
Rose's metal	Bi, Pb, Sn	Low melting (98°C)	Fusible alloys
Nichrome	Ni (80%), Cr (20%)	High electrical resistance, heat-resistant	Heating elements
Monel metal	Ni (67%), Cu (30%)	Corrosion-resistant, strong	Marine, chemical
Invar	Fe (64%), Ni (36%)	Very low thermal expansion	Precision instruments
Permalloy	Fe (20%), Ni (80%)	High magnetic permeability	Transformers, sensors
Constantan	Cu (55%), Ni (45%)	Constant electrical resistance	Thermocouples
Manganin	Cu (86%), Mn (12%), Ni	Stable resistance vs. temperature	Precision resistors
Stellite	Co, Cr, W, C	Very hard, wear-resistant	Cutting tools
Hastelloy	Ni, Mo, Cr, Fe	Excellent corrosion resistance	Chemical equipment
Titanium alloy	Ti (90%), Al (6%), V (4%)	High strength-to-weight ratio	Aerospace, implants
Amalgam	Hg, Ag, Sn, Cu	Soft, hardens over time	Dental fillings
Elektron	Mg (90%), Al, Zn	Extremely light	Aircraft parts
Beryllium copper	Cu (98%), Be (2%)	Non-sparking, elastic	Explosion-proof tools
White gold	Au, Ni/Pd, Zn	White-silver appearance	Jewelry
Rose gold	Au (75%), Cu (22.5%), Ag	Pink-red color	Jewelry
Sterling silver	Ag (92.5%), Cu (7.5%)	Harder than pure silver	Jewelry, tableware
Britannia silver	Ag (95.8%), Cu	Softer, higher silver content	High-end silverware
Nitinol	Ni (55%), Ti (45%)	Shape memory effect	Medical devices, actuators
Zamak	Zn, Al, Mg, Cu	Good castability, moderate strength	Die castings
Babbitt	Sn, Sb, Cu (or Pb base)	Low friction, good embeddability	Bearings
Bell metal	Cu (78%), Sn (22%)	Resonant, hard	Bells, cymbals

4 Reactions

4.1 Types of reactions

4.1.1 Combination reaction (Synthesis reaction)

Definition: Two or more substances combine to form a single product.

General form: $A + B \longrightarrow AB$

Examples:

- Formation of water: $2\text{H}_2 + \text{O}_2 \longrightarrow 2\text{H}_2\text{O}$
- Formation of ammonia: $\text{N}_2 + 3\text{H}_2 \longrightarrow 2\text{NH}_3$
- Metal oxide formation: $2\text{Mg} + \text{O}_2 \longrightarrow 2\text{MgO}$
- Salt formation: $2\text{Na} + \text{Cl}_2 \longrightarrow 2\text{NaCl}$

4.1.2 Decomposition reaction

Definition: A single compound breaks down into two or more simpler substances.

General form: $AB \longrightarrow A + B$

Examples:

- Thermal decomposition of calcium carbonate: $\text{CaCO}_3 \xrightarrow{\text{heat}} \text{CaO} + \text{CO}_2 \uparrow$
- Electrolysis of water: $2 \text{H}_2\text{O} \xrightarrow{\text{electrolysis}} 2 \text{H}_2 \uparrow + \text{O}_2 \uparrow$
- Decomposition of hydrogen peroxide: $2 \text{H}_2\text{O}_2 \xrightarrow{\text{MnO}_2} 2 \text{H}_2\text{O} + \text{O}_2 \uparrow$
- Decomposition of potassium chlorate: $2 \text{KClO}_3 \xrightarrow{\text{heat}} 2 \text{KCl} + 3 \text{O}_2 \uparrow$

4.1.3 Displacement reaction (Substitution reaction)

Definition: One element replaces another element in a compound.

General form: $A + BC \longrightarrow AC + B$

Examples:

- Zinc displacing hydrogen: $\text{Zn} + 2 \text{HCl} \longrightarrow \text{ZnCl}_2 + \text{H}_2 \uparrow$
- Chlorine displacing bromine: $\text{Cl}_2 + 2 \text{NaBr} \longrightarrow 2 \text{NaCl} + \text{Br}_2$
- Magnesium displacing copper: $\text{Mg} + \text{CuSO}_4 \longrightarrow \text{MgSO}_4 + \text{Cu}$
- Iron displacing copper: $\text{Fe} + \text{CuSO}_4 \longrightarrow \text{FeSO}_4 + \text{Cu}$

4.1.4 Double displacement reaction (Metathesis reaction)

Definition: Exchange of ions between two compounds.

General form: $AB + CD \longrightarrow AD + CB$

Examples:

- Precipitation: $\text{AgNO}_3 + \text{NaCl} \longrightarrow \text{AgCl} \downarrow + \text{NaNO}_3$
- Neutralization: $\text{HCl} + \text{NaOH} \longrightarrow \text{NaCl} + \text{H}_2\text{O}$
- Formation of barium sulfate: $\text{BaCl}_2 + \text{H}_2\text{SO}_4 \longrightarrow \text{BaSO}_4 \downarrow + 2 \text{HCl}$

4.1.5 Redox reaction (Oxidation-reduction reaction)

Definition: Transfer of electrons between species, involving change in oxidation states.

Oxidation: Loss of electrons, increase in oxidation number.

Reduction: Gain of electrons, decrease in oxidation number.

Examples:

- Combustion: $\text{C} + \text{O}_2 \longrightarrow \text{CO}_2$
- Permanganate oxidation: $2 \text{KMnO}_4 + 5 \text{H}_2\text{C}_2\text{O}_4 + 3 \text{H}_2\text{SO}_4 \longrightarrow \text{K}_2\text{SO}_4 + 2 \text{MnSO}_4 + 10 \text{CO}_2 \uparrow + 8 \text{H}_2\text{O}$
- Dichromate oxidation: $\text{K}_2\text{Cr}_2\text{O}_7 + 14 \text{HCl} \longrightarrow 2 \text{KCl} + 2 \text{CrCl}_3 + 3 \text{Cl}_2 \uparrow + 7 \text{H}_2\text{O}$
- Zinc-copper cell: $\text{Zn} + \text{Cu}^{2+} \longrightarrow \text{Zn}^{2+} + \text{Cu}$

4.1.6 Acid-base reaction (Neutralization)

Definition: Reaction between an acid and a base to produce salt and water.

General form: $\text{Acid} + \text{Base} \longrightarrow \text{Salt} + \text{Water}$

Examples:

- Strong acid-strong base: $\text{HCl} + \text{NaOH} \longrightarrow \text{NaCl} + \text{H}_2\text{O}$
- Weak acid-strong base: $\text{CH}_3\text{COOH} + \text{NaOH} \longrightarrow \text{CH}_3\text{COONa} + \text{H}_2\text{O}$
- Dibasic acid: $\text{H}_2\text{SO}_4 + 2 \text{KOH} \longrightarrow \text{K}_2\text{SO}_4 + 2 \text{H}_2\text{O}$
- Carbonate with acid: $\text{Na}_2\text{CO}_3 + 2 \text{HCl} \longrightarrow 2 \text{NaCl} + \text{H}_2\text{O} + \text{CO}_2 \uparrow$

4.1.7 Precipitation reaction

Definition: Formation of an insoluble solid (precipitate) from aqueous solutions.

Examples:

- Silver chloride: $\text{Ag}^+ + \text{Cl}^- \longrightarrow \text{AgCl} \downarrow$ (white precipitate)
- Lead iodide: $\text{Pb}^{2+} + 2\text{I}^- \longrightarrow \text{PbI}_2 \downarrow$ (yellow precipitate)
- Iron(III) hydroxide: $\text{Fe}^{3+} + 3\text{OH}^- \longrightarrow \text{Fe}(\text{OH})_3 \downarrow$ (brown precipitate)
- Copper(II) hydroxide: $\text{Cu}^{2+} + 2\text{OH}^- \longrightarrow \text{Cu}(\text{OH})_2 \downarrow$ (blue precipitate)

4.2 Organic reactions

4.2.1 Halogenation reaction

Definition: Introduction of halogen atoms (F, Cl, Br, I) into organic molecules.

Free radical halogenation (alkanes):

- Chlorination of methane: $\text{CH}_4 + \text{Cl}_2 \xrightarrow{\text{UV light}} \text{CH}_3\text{Cl} + \text{HCl}$
- Further substitution: $\text{CH}_3\text{Cl} + \text{Cl}_2 \longrightarrow \text{CH}_2\text{Cl}_2 + \text{HCl}$
- Bromination of ethane: $\text{C}_2\text{H}_6 + \text{Br}_2 \xrightarrow{\text{UV light}} \text{C}_2\text{H}_5\text{Br} + \text{HBr}$

Electrophilic halogenation (aromatic):

- Bromination of benzene: $\text{C}_6\text{H}_6 + \text{Br}_2 \xrightarrow{\text{FeBr}_3} \text{C}_6\text{H}_5\text{Br} + \text{HBr}$
- Chlorination of benzene: $\text{C}_6\text{H}_6 + \text{Cl}_2 \xrightarrow{\text{AlCl}_3} \text{C}_6\text{H}_5\text{Cl} + \text{HCl}$
- Iodination of benzene: $\text{C}_6\text{H}_6 + \text{I}_2 \xrightarrow{\text{HNO}_3} \text{C}_6\text{H}_5\text{I} + \text{HI}$

Addition halogenation (alkenes):

- Bromination of ethene: $\text{C}_2\text{H}_4 + \text{Br}_2 \longrightarrow \text{C}_2\text{H}_4\text{Br}_2$
- Test for unsaturation: Decolorization of bromine water
- Chlorination of propene: $\text{C}_3\text{H}_6 + \text{Cl}_2 \longrightarrow \text{C}_3\text{H}_6\text{Cl}_2$

4.2.2 Nucleophilic substitution

Definition: Replacement of a leaving group by a nucleophile.

S_N1 mechanism (unimolecular):

- Two-step process via carbocation intermediate
- Rate depends only on substrate concentration
- Favored by tertiary halides and polar solvents
- Example: $(\text{CH}_3)_3\text{CBr} + \text{H}_2\text{O} \longrightarrow (\text{CH}_3)_3\text{COH} + \text{HBr}$

S_N2 mechanism (bimolecular):

- One-step process with backside attack
- Rate depends on both substrate and nucleophile concentration
- Favored by primary halides and aprotic solvents
- Inversion of configuration (Walden inversion)
- Example: $\text{CH}_3\text{Br} + \text{OH}^- \longrightarrow \text{CH}_3\text{OH} + \text{Br}^-$

Common nucleophiles:

- Hydroxide (OH^-): Forms alcohols
- Alkoxide (RO^-): Forms ethers
- Cyanide (CN^-): Forms nitriles
- Ammonia (NH_3): Forms amines
- Water (H_2O): Forms alcohols (weak nucleophile)

4.2.3 Nucleophilic addition

Definition: Addition of a nucleophile to a carbonyl group.

Examples:

- Cyanohydrin formation: $\text{CH}_3\text{CHO} + \text{HCN} \longrightarrow \text{CH}_3\text{CH}(\text{OH})\text{CN}$
- Grignard addition: $\text{CH}_3\text{MgBr} + \text{CH}_2\text{O} \longrightarrow \text{CH}_3\text{CH}_2\text{OH}$ (after hydrolysis)
- Bisulfite addition: $\text{RCHO} + \text{NaHSO}_3 \longrightarrow \text{RCH}(\text{OH})\text{SO}_3\text{Na}$

4.2.4 Electrophilic addition

Definition: Addition of an electrophile to a multiple bond.

Examples:

- Hydrohalogenation: $\text{C}_2\text{H}_4 + \text{HBr} \longrightarrow \text{C}_2\text{H}_5\text{Br}$
- Markovnikov's rule: H adds to carbon with more H atoms
- Hydration: $\text{C}_2\text{H}_4 + \text{H}_2\text{O} \xrightarrow{\text{H}^+} \text{C}_2\text{H}_5\text{OH}$
- Addition of sulfuric acid: $\text{C}_2\text{H}_4 + \text{H}_2\text{SO}_4 \longrightarrow \text{C}_2\text{H}_5\text{OSO}_3\text{H}$

4.2.5 Elimination reaction

Definition: Removal of atoms or groups to form multiple bonds.

Dehydrohalogenation (E1 and E2):

- E2 mechanism: $\text{C}_2\text{H}_5\text{Br} + \text{KOH} \xrightarrow{\text{alcohol, heat}} \text{C}_2\text{H}_4 \uparrow + \text{KBr} + \text{H}_2\text{O}$
- Zaitsev's rule: Major product is more substituted alkene
- E1 mechanism: Two-step via carbocation

Dehydration of alcohols:

- Ethanol dehydration: $\text{C}_2\text{H}_5\text{OH} \xrightarrow{\text{H}_2\text{SO}_4, \text{heat}} \text{C}_2\text{H}_4 \uparrow + \text{H}_2\text{O}$
- Intramolecular (forms alkene) vs intermolecular (forms ether)

4.2.6 Oxidation reactions

Oxidation of alcohols:

- Primary to aldehyde: $\text{RCH}_2\text{OH} \xrightarrow{\text{oxidation}} \text{RCHO} \xrightarrow{\text{oxidation}} \text{RCOOH}$
- Secondary to ketone: $\text{R}_2\text{CHOH} \xrightarrow{\text{oxidation}} \text{R}_2\text{CO}$
- Tertiary alcohols: Resistant to oxidation
- Oxidizing agents: $\text{K}_2\text{Cr}_2\text{O}_7/\text{H}_2\text{SO}_4$, KMnO_4 , CrO_3

Oxidation of aldehydes:

- To carboxylic acid: $\text{RCHO} \xrightarrow{\text{oxidation}} \text{RCOOH}$
- Mild oxidizing agents work (e.g., Tollens' reagent, Fehling's reagent)

4.2.7 Reduction reactions

Reduction of carbonyl compounds:

- Aldehyde to primary alcohol: $\text{RCHO} \xrightarrow{\text{reduction}} \text{RCH}_2\text{OH}$
- Ketone to secondary alcohol: $\text{R}_2\text{CO} \xrightarrow{\text{reduction}} \text{R}_2\text{CHOH}$
- Reducing agents: LiAlH_4 , NaBH_4 , H_2/Pt

Reduction of carboxylic acids:

- To primary alcohol: $\text{RCOOH} \xrightarrow{\text{LiAlH}_4} \text{RCH}_2\text{OH}$
- Requires strong reducing agent

4.2.8 Condensation reactions

Definition: Combination of molecules with elimination of small molecule (usually water).

Esterification:

- Fischer esterification: $\text{RCOOH} + \text{R}-\text{OH} \xrightleftharpoons{\text{H}^+} \text{RCOOR} + \text{H}_2\text{O}$
- Reversible reaction, equilibrium can be shifted

Aldol condensation:

- Self-condensation of aldehydes: $2 \text{CH}_3\text{CHO} \xrightarrow{\text{OH}^-} \text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{CHO}$
- Followed by dehydration: $\text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{CHO} \longrightarrow \text{CH}_3\text{CH}=\text{CHCHO} + \text{H}_2\text{O}$

4.2.9 Hydrolysis reactions

Ester hydrolysis:

- Acidic: $\text{RCOOR} + \text{H}_2\text{O} \xrightleftharpoons{\text{H}^+} \text{RCOOH} + \text{R}-\text{OH}$
- Basic (saponification): $\text{RCOOR} + \text{NaOH} \longrightarrow \text{RCOONa} + \text{R}-\text{OH}$

Amide hydrolysis:

- Acidic: $\text{RCONH}_2 + \text{H}_2\text{O} + \text{HCl} \xrightarrow{\text{heat}} \text{RCOOH} + \text{NH}_4\text{Cl}$
- Basic: $\text{RCONH}_2 + \text{NaOH} \xrightarrow{\text{heat}} \text{RCOONa} + \text{NH}_3 \uparrow$

4.3 Named reactions and tests

4.3.1 Silver mirror reaction (Tollens' test)

Purpose: Test for aldehydes; distinguishes aldehydes from ketones.

Reagent: Tollens' reagent - ammoniacal silver nitrate solution $[\text{Ag}(\text{NH}_3)_2]^+$

Principle: Aldehydes are oxidized to carboxylic acids while silver ions are reduced to metallic silver, forming a silver mirror on the test tube.

Preparation of reagent:

- $\text{AgNO}_3 + \text{NaOH} \longrightarrow \text{AgOH} \downarrow + \text{NaNO}_3$
- $\text{AgOH} + 2 \text{NH}_3 \longrightarrow [\text{Ag}(\text{NH}_3)_2]\text{OH}$ (soluble complex)

Reaction with aldehyde:

- $\text{RCHO} + 2 [\text{Ag}(\text{NH}_3)_2]^+ + 2 \text{OH}^- \longrightarrow \text{RCOO}^- + 2 \text{Ag} \downarrow + 4 \text{NH}_3 + \text{H}_2\text{O}$
- Formaldehyde: $\text{HCHO} + 4 [\text{Ag}(\text{NH}_3)_2]^+ + 4 \text{OH}^- \longrightarrow \text{CO}_3^{2-} + 4 \text{Ag} \downarrow + 8 \text{NH}_3 + 2 \text{H}_2\text{O}$
- Glucose (reducing sugar): $\text{C}_6\text{H}_{12}\text{O}_6 + 2 [\text{Ag}(\text{NH}_3)_2]^+ + 2 \text{OH}^- \longrightarrow \text{C}_6\text{H}_{12}\text{O}_7 + 2 \text{Ag} \downarrow + 4 \text{NH}_3$

Observation: Silver mirror forms on the inner surface of the test tube (positive test).

Note: Ketones do not give this reaction. Some α -hydroxy ketones may give weakly positive results.

4.3.2 Fehling's test (Benedict's test)

Purpose: Test for reducing sugars and aldehydes.

Reagent: Fehling's solution (mixture of Fehling's A and B)

- Fehling's A: Copper(II) sulfate solution CuSO_4
- Fehling's B: Alkaline sodium potassium tartrate solution (Rochelle salt)

Principle: Aldehydes reduce Cu^{2+} (blue) to Cu_2O (red-brown precipitate).

Reaction:

- $\text{RCHO} + 2\text{Cu}^{2+} + 5\text{OH}^- \xrightarrow{\text{heat}} \text{RCOO}^- + \text{Cu}_2\text{O} \downarrow + 3\text{H}_2\text{O}$
- With glucose: $\text{C}_6\text{H}_{12}\text{O}_6 + 2\text{Cu}^{2+} + 5\text{OH}^- \longrightarrow \text{C}_6\text{H}_{12}\text{O}_7 + \text{Cu}_2\text{O} \downarrow + 3\text{H}_2\text{O}$

Observation: Blue solution turns to red-brown precipitate of cuprous oxide.

Benedict's reagent: Similar test using copper citrate complex instead of tartrate.

4.3.3 Iodine clock reaction

Purpose: Demonstration of reaction kinetics and reaction mechanisms.

Principle: A sudden color change occurs after a predictable time period, demonstrating the relationship between reaction rate and concentration.

Common version (Landolt reaction):

- Reaction A (slow): $\text{H}_2\text{O}_2 + 2\text{I}^- + 2\text{H}^+ \longrightarrow \text{I}_2 + 2\text{H}_2\text{O}$
- Reaction B (fast): $\text{I}_2 + 2\text{S}_2\text{O}_3^{2-} \longrightarrow 2\text{I}^- + \text{S}_4\text{O}_6^{2-}$
- When thiosulfate is consumed, free iodine reacts with starch indicator
- $\text{I}_2 + \text{starch} \longrightarrow \text{blue complex}$

Alternative version (Dushman reaction):

- $\text{IO}_3^- + 3\text{HSO}_3^- \longrightarrow \text{I}^- + 3\text{SO}_4^{2-} + 3\text{H}^+$ (slow)
- $\text{IO}_3^- + 5\text{I}^- + 6\text{H}^+ \longrightarrow 3\text{I}_2 + 3\text{H}_2\text{O}$ (fast, when HSO_3^- depleted)

Observation: Solution remains colorless for a fixed time, then suddenly turns deep blue.

Variables affecting clock time:

- Concentration of reactants
- Temperature
- Presence of catalysts

4.3.4 Biuret test

Purpose: Test for proteins and peptide bonds; detects presence of peptide linkages.

Reagent: Biuret reagent (copper sulfate in alkaline solution)

- CuSO_4 in dilute NaOH solution

Principle: Peptide bonds form a colored complex with Cu^{2+} ions in alkaline solution.

Reaction: Copper ions coordinate with nitrogen atoms of peptide bonds, forming a violet-purple complex.

Named after: Biuret $\text{H}_2\text{N}-\text{CO}-\text{NH}-\text{CO}-\text{NH}_2$, the simplest compound that gives this test.

Observation:

- Negative (no protein): Blue color (from Cu^{2+} ions)
- Positive (protein present): Violet to purple color
- Intensity depends on number of peptide bonds

Requirements:

- At least two peptide bonds required for positive test
- Single amino acids do not give positive result
- Dipeptides give weak positive result
- Tripeptides and proteins give strong positive result

Application:

- Qualitative test for proteins
- Semi-quantitative determination of protein concentration
- Used in biochemistry and food analysis

4.3.5 Lucas test

Purpose: Distinguish between primary, secondary, and tertiary alcohols.

Reagent: Lucas reagent (anhydrous ZnCl_2 in concentrated HCl)

Principle: Alcohols react with HCl in presence of ZnCl_2 to form alkyl chlorides (insoluble, appears as cloudiness).

Reactions:

- $\text{ROH} + \text{HCl} \xrightarrow{\text{ZnCl}_2} \text{RCl} + \text{H}_2\text{O}$
- Rate: Tertiary > Secondary > Primary

Observations:

- Tertiary alcohol: Immediate cloudiness (turbidity)
- Secondary alcohol: Cloudiness within 5-10 minutes
- Primary alcohol: No reaction at room temperature

4.3.6 Diazotization reaction

Purpose: Formation of diazonium salts from primary aromatic amines.

Reagent: Sodium nitrite (NaNO_2) and dilute HCl at $0-5^\circ\text{C}$

Reaction:

- $\text{C}_6\text{H}_5\text{NH}_2 + \text{NaNO}_2 + 2\text{HCl} \xrightarrow{\text{cold}} \text{C}_6\text{H}_5\text{N}_2^+\text{Cl}^- + \text{NaCl} + 2\text{H}_2\text{O}$
- Temperature must be kept low to prevent decomposition

Applications:

- Azo dye synthesis (coupling with phenols or aromatic amines)
- Sandmeyer reaction (replacement of diazonium group)
- Gattermann reaction

4.3.7 Friedel-Crafts reactions**Friedel-Crafts alkylation:**

- $\text{C}_6\text{H}_6 + \text{RCl} \xrightarrow{\text{AlCl}_3} \text{C}_6\text{H}_5\text{R} + \text{HCl}$
- Introduces alkyl group onto aromatic ring
- Catalyst: AlCl_3 or FeCl_3
- Problem: Polyalkylation and rearrangement

Friedel-Crafts acylation:

- $\text{C}_6\text{H}_6 + \text{RCOCl} \xrightarrow{\text{AlCl}_3} \text{C}_6\text{H}_5\text{COR} + \text{HCl}$
- Introduces acyl group onto aromatic ring
- More controlled than alkylation (no polyacylation)
- Forms ketones

4.3.8 Kolbe's reaction (Kolbe-Schmitt reaction)

Purpose: Synthesis of salicylic acid from phenol.

Reaction:

- $\text{C}_6\text{H}_5\text{OH} + \text{NaOH} \longrightarrow \text{C}_6\text{H}_5\text{ONa} + \text{H}_2\text{O}$
- $\text{C}_6\text{H}_5\text{ONa} + \text{CO}_2 \xrightarrow{\text{heat, pressure}} \text{C}_6\text{H}_4(\text{OH})\text{COONa}$ (sodium salicylate)
- $\text{C}_6\text{H}_4(\text{OH})\text{COONa} + \text{HCl} \longrightarrow \text{C}_6\text{H}_4(\text{OH})\text{COOH} + \text{NaCl}$ (salicylic acid)

Conditions: High pressure (5-7 atm), 125-130°C

Application: Industrial production of aspirin (acetylsalicylic acid)

4.3.9 Cannizzaro reaction

Purpose: Disproportionation of aldehydes lacking α -hydrogen.

Principle: In strong base, one aldehyde molecule is oxidized to carboxylate, another is reduced to alcohol.

Reaction:

- $2\text{RCHO} + \text{NaOH} \xrightarrow{\text{no } \alpha\text{-H}} \text{RCOONa} + \text{RCH}_2\text{OH}$
- Example: $2\text{C}_6\text{H}_5\text{CHO} + \text{NaOH} \longrightarrow \text{C}_6\text{H}_5\text{COONa} + \text{C}_6\text{H}_5\text{CH}_2\text{OH}$
- Formaldehyde: $2\text{HCHO} + \text{NaOH} \longrightarrow \text{HCOONa} + \text{CH}_3\text{OH}$

Requirement: Aldehyde must lack α -hydrogen atoms.

4.3.10 Haloform reaction

Purpose: Test for methyl ketones; produces haloform.

Reagent: Halogen (I_2 , Br_2 , or Cl_2) in alkaline solution

Reaction:

- $\text{CH}_3\text{COR} + 3\text{I}_2 + 4\text{NaOH} \longrightarrow \text{RCOONa} + \text{CHI}_3 \downarrow + 3\text{NaI} + 3\text{H}_2\text{O}$
- Iodoform (CHI_3): Yellow precipitate with characteristic odor

Positive test:

- Methyl ketones: $\text{R}-\text{CO}-\text{CH}_3$
- Acetaldehyde: CH_3CHO
- Ethanol: $\text{CH}_3\text{CH}_2\text{OH}$ (oxidized to acetaldehyde first)

Iodoform test: Specific for compounds with CH_3CO^- or $\text{CH}_3\text{CH}(\text{OH})^-$ structure.

5 Chemical nomenclature: Prefixes and suffixes

5.1 Numerical prefixes

Prefix	Number	Example
mono-	1	Monoxide, monohydrate
di-	2	Dioxide, dichloride
tri-	3	Trichloride, trioxide
tetra-	4	Tetrachloride, tetrahedral
penta-	5	Pentoxide, pentane
hexa-	6	Hexane, hexafluoride
hepta-	7	Heptane, heptoxide
octa-	8	Octane, octahedron
nona-	9	Nonane, nonoxide
deca-	10	Decane, decahydrate
undeca-	11	Undecane
dodeca-	12	Dodecane, dodecahedron

5.2 Hydrocarbon chain prefixes

Prefix	# Carbons	Root Word	Example
meth-	1	Methane	Methanol, methyl
eth-	2	Ethane	Ethanol, ethyl
prop-	3	Propane	Propanol, propyl
but-	4	Butane	Butanol, butyl
pent-	5	Pentane	Pentanol, pentyl
hex-	6	Hexane	Hexanol, hexyl
hept-	7	Heptane	Heptanol, heptyl
oct-	8	Octane	Octanol, octyl
non-	9	Nonane	Nonanol, nonyl
dec-	10	Decane	Decanol, decyl

5.3 Structural and positional prefixes

Prefix	Meaning	Example
iso-	Branched (methyl on penultimate carbon)	Isopropanol, isobutane
neo-	New, highly branched	Neopentane
sec-	Secondary (2°, attached to 2 carbons)	sec-Butanol
tert-	Tertiary (3°, attached to 3 carbons)	tert-Butanol
cyclo-	Cyclic/ring structure	Cyclohexane, cyclopropane
ortho- (o-)	Adjacent positions on benzene (1,2)	o-Xylene, o-cresol
meta- (m-)	Separated by one carbon on benzene (1,3)	m-Xylene
para- (p-)	Opposite positions on benzene (1,4)	p-Xylene, p-cresol
cis-	Same side (geometric isomer)	cis-2-Butene
trans-	Opposite sides (geometric isomer)	trans-2-Butene

5.4 Halogen prefixes

Prefix	Halogen	Example
fluoro-	Fluorine (F)	Fluoromethane, fluorobenzene
chloro-	Chlorine (Cl)	Chloroform, chlorobenzene
bromo-	Bromine (Br)	Bromoethane, bromobenzene
iodo-	Iodine (I)	Iodoform, iodobenzene

5.5 Other common prefixes

Prefix	Meaning	Example
per-	Maximum/complete	Perchloric acid, peroxide
hypo-	Less than normal oxidation state	Hypochlorous acid
thio-	Sulfur replacing oxygen	Thiosulfate, thiol
oxy-	Oxygen in compound	Oxytocin
nitro-	$-\text{NO}_2$ group	Nitrobenzene, nitroglycerin
nitroso-	$-\text{NO}$ group	Nitrosobenzene
amino-	$-\text{NH}_2$ group	Aminobenzoic acid
hydroxy-	$-\text{OH}$ group	Hydroxybenzoic acid
oxo-	$=\text{O}$ group (ketone/aldehyde)	Oxoacid
carb-	Carbon	Carbide, carbon
cyan-	$-\text{CN}$ group	Cyanide, cyanohydrin
acet-	Related to acetic acid/acetyl	Acetate, acetone, acetyl
form-	Related to formic acid/formyl	Formate, formaldehyde
benz-	Related to benzene	Benzyl, benzoyl, benzoic
phenyl-	C_6H_5^- group	Phenylamine (aniline)
vinyl-	$\text{CH}_2=\text{CH}^-$ group	Vinyl chloride
allyl-	$\text{CH}_2=\text{CH}-\text{CH}_2^-$ group	Allyl alcohol

5.6 Functional group suffixes

Suffix	Functional Group	Example
-ane	Alkane (single bonds)	Methane, ethane, propane
-ene	Alkene (double bond)	Ethene (ethylene), propene
-yne	Alkyne (triple bond)	Ethyne (acetylene), propyne
-yl	Alkyl group (substituent)	Methyl, ethyl, propyl
-ol	Alcohol ($-\text{OH}$)	Methanol, ethanol, phenol
-al	Aldehyde ($-\text{CHO}$)	Methanal (formaldehyde), ethanal
-one	Ketone ($\text{C}=\text{O}$)	Acetone (propanone), butanone
-oic acid	Carboxylic acid ($-\text{COOH}$) and Ethanoic acid (acetic acid)	
-oate	Ester ($-\text{COO}-$)	Ethyl acetate (ethyl ethanoate)
-amide	Amide ($-\text{CONH}_2$)	Acetamide, formamide
-amine	Amine ($-\text{NH}_2$)	Methylamine, ethylamine
-nitrile	Nitrile ($-\text{CN}$)	Acetonitrile, propionitrile
-ether	Ether ($-\text{O}-$)	Diethyl ether
-thiol	Thiol ($-\text{SH}$)	Ethanethiol, methanethiol
-ate	Salt of acid	Sulfate, nitrate, acetate
-ite	Salt of -ous acid	Sulfite, nitrite
-ide	Binary compound/ion	Chloride, oxide, sulfide

5.7 Acid nomenclature patterns

Oxidation State	Acid Name	Salt Name	Example
Highest	per-...-ic acid	per-...-ate	Perchloric acid/perchlorate
High	-ic acid	-ate	Sulfuric acid/sulfate
Low	-ous acid	-ite	Sulfurous acid/sulfite
Lowest	hypo-...-ous acid	hypo-...-ite	Hypochlorous acid/hypochlorite

Examples:

- HClO_4 - Perchloric acid $\rightarrow$ Perchlorate (ClO_4^-)
- HClO_3 - Chloric acid $\rightarrow$ Chlorate (ClO_3^-)
- HClO_2 - Chlorous acid $\rightarrow$ Chlorite (ClO_2^-)
- HClO - Hypochlorous acid $\rightarrow$ Hypochlorite (ClO^-)

6 Name of organic compounds

6.1 Hydrocarbons and their Halogen derivatives

Common Name	Formula	Description/Use
Methane	CH_4	Natural gas, simplest alkane
Ethane	C_2H_6	Component of natural gas
Propane	C_3H_8	LPG fuel, refrigerant
Butane	C_4H_{10}	Lighter fuel, aerosol propellant
Isobutane	$(\text{CH}_3)_3\text{CH}$	Branched isomer of butane, refrigerant
Pentane	C_5H_{12}	Laboratory solvent
Hexane	C_6H_{14}	Extraction solvent
Octane	C_8H_{18}	Gasoline component
Paraffin	$\text{C}_n\text{H}_{2n+2}$	Wax, candles (long chain alkanes)
Ethylene	C_2H_4	Fruit ripening agent, plastic production
Propylene	C_3H_6	Polypropylene production
Acetylene	C_2H_2	Welding gas, illumination
Isoprene	C_5H_8	Natural rubber monomer
Methyl chloride	CH_3Cl	Refrigerant, methylating agent
Chloroform	CHCl_3	Solvent, formerly anesthetic
Carbon tetrachloride	CCl_4	Solvent, fire extinguisher (obsolete)
Freon-12	CCl_2F_2	Refrigerant (CFC, now banned)
Teflon monomer	$\text{CF}_2=\text{CF}_2$	Tetrafluoroethylene, non-stick coating
DDT	$(\text{ClC}_6\text{H}_4)_2\text{CHCCl}_3$	Insecticide (banned in many countries)
Vinyl chloride	$\text{CH}_2=\text{CHCl}$	PVC plastic monomer
Methylene chloride	CH_2Cl_2	Paint stripper, degreaser
Bromoform	CHBr_3	Laboratory reagent, formerly sedative
Iodoform	CHI_3	Antiseptic (yellow crystalline)
Ethyl bromide	$\text{C}_2\text{H}_5\text{Br}$	Local anesthetic, refrigerant
Methyl iodide	CH_3I	Methylating agent in synthesis

6.2 Alicyclic compounds and aromatic compounds

Common Name	Formula	Description/Use
Cyclopropane	C_3H_6	Anesthetic (cyclic alkane)
Cyclohexane	C_6H_{12}	Solvent, nylon precursor

Common Name	Formula	Description/Use
Benzene	C_6H_6	Aromatic solvent, carcinogenic
Toluene	$C_6H_5CH_3$	Solvent, paint thinner, TNT precursor
Xylene	$C_6H_4(CH_3)_2$	Solvent, histology (three isomers)
Styrene	$C_6H_5CH=CH_2$	Polystyrene monomer, plastic foam
Cumene	$C_6H_5CH(CH_3)_2$	Phenol production, isopropylbenzene
Naphthalene	$C_{10}H_8$	Mothballs, formerly used in lighting
Anthracene	$C_{14}H_{10}$	Dye production, organic semiconductor
Phenanthrene	$C_{14}H_{10}$	PAH compound, synthesis precursor
Biphenyl	$C_6H_5-C_6H_5$	Heat transfer fluid, citrus preservative
TNT	$C_6H_2(NO_2)_3CH_3$	Explosive (trinitrotoluene)
Picric acid	$C_6H_2(NO_2)_3OH$	Explosive, yellow dye
Aniline	$C_6H_5NH_2$	Dye production, rubber processing
Nitrobenzene	$C_6H_5NO_2$	Aniline precursor, shoe polish odor
Benzyl chloride	$C_6H_5CH_2Cl$	Synthesis intermediate, lachrymator
Chlorobenzene	C_6H_5Cl	Solvent, DDT production

6.3 Alcohol, phenols, ketones and aldehyde

Common Name	Formula/Structure	Description/Use
Methanol	CH_3OH	Wood alcohol, fuel, toxic
Ethanol	C_2H_5OH	Drinking alcohol, solvent, fuel
Isopropanol	$(CH_3)_2CHOH$	Rubbing alcohol, disinfectant
Butanol	C_4H_9OH	Solvent, plasticizer
Ethylene glycol	$HOCH_2CH_2OH$	Antifreeze, polyester precursor
Phenol	C_6H_5OH	Disinfectant, plastic precursor, caustic
Cresol	$CH_3C_6H_4OH$	Disinfectant, wood preservative
Resorcinol	$C_6H_4(OH)_2$	Adhesives, dyes, antiseptic
Hydroquinone	$C_6H_4(OH)_2$	Photo developer, skin lightener
Catechol	$C_6H_4(OH)_2$	Antioxidant, photo developer
Formaldehyde	$HCHO$	Preservative, disinfectant, resin
Acetaldehyde	CH_3CHO	Acetic acid precursor, flavor
Benzaldehyde	C_6H_5CHO	Almond odor, flavoring
Acetone	CH_3COCH_3	Nail polish remover, solvent
Methyl ethyl ketone	$CH_3COC_2H_5$	Paint remover, MEK solvent
Camphor	$C_{10}H_{16}O$	Medicinal, moth repellent, plasticizer
Vanillin	$C_8H_8O_3$	Vanilla flavoring from vanilla beans
Cinnamaldehyde	$C_6H_5CH=CHCHO$	Cinnamon flavor and odor
Menthol	$C_{10}H_{20}O$	Cooling sensation, mint flavor

6.4 Carboxylic acids and esters

Common Name	Formula/Structure	Description/Use
Formic acid	$HCOOH$	Ant venom, leather tanning, antibacterial
Acetic acid	CH_3COOH	Vinegar (5%), food preservative, solvent
Propionic acid	C_2H_5COOH	Food preservative, mold inhibitor
Butyric acid	C_3H_7COOH	Rancid butter odor, flavoring
Valeric acid	C_4H_9COOH	Unpleasant odor, pharmaceutical intermediate
Caproic acid	$C_5H_{11}COOH$	Goat odor, flavoring agent
Palmitic acid	$C_{15}H_{31}COOH$	Palm oil, soap making, saturated fat
Stearic acid	$C_{17}H_{35}COOH$	Candles, soap, cosmetics, saturated fat
Oleic acid	$C_{17}H_{33}COOH$	Olive oil, unsaturated fatty acid

Common Name	Formula/Structure	Description/Use
Linoleic acid	$C_{17}H_{31}COOH$	Essential fatty acid, polyunsaturated
Oxalic acid	$HOOC-COOH$	Rust remover, toxic (kidney stones)
Malonic acid	$HOOC-CH_2-COOH$	Synthesis intermediate, barbiturate precursor
Citric acid	$C_6H_8O_7$	Citrus fruits, food acidulant, chelator
Tartaric acid	$C_4H_6O_6$	Grapes, baking powder, wine making
Malic acid	$C_4H_6O_5$	Apples, sour taste in fruits
Lactic acid	$CH_3CH(OH)COOH$	Sour milk, muscle fatigue, fermentation
Benzoic acid	C_6H_5COOH	Food preservative, antifungal
Salicylic acid	$C_6H_4(OH)COOH$	Aspirin precursor, acne treatment
Phthalic acid	$C_6H_4(COOH)_2$	Plasticizer, polyester resin
Methyl formate	$HCOOCH_3$	Fumigant, solvent, tobacco flavoring
Ethyl acetate	$CH_3COOC_2H_5$	Nail polish remover, fruity odor
Butyl acetate	$CH_3COOC_4H_9$	Banana oil, lacquer solvent
Methyl salicylate	$C_6H_4(OH)COOCH_3$	Wintergreen oil, muscle pain relief
Ethyl butyrate	$C_3H_7COOC_2H_5$	Pineapple flavor, perfume
Amyl acetate	$CH_3COOC_5H_{11}$	Banana oil, pear flavor
Nitroglycerin	$C_3H_5(ONO_2)_3$	Explosive, angina medication (vasodilator)

6.5 Amines, amides and nitriles

Common Name	Formula/Structure	Description/Use
Methylamine	CH_3NH_2	Fishy odor, pharmaceutical intermediate
Ethylamine	$C_2H_5NH_2$	Solvent, dye intermediate
Dimethylamine	$(CH_3)_2NH$	Leather tanning, rocket fuel component
Trimethylamine	$(CH_3)_3N$	Fishy odor in spoiled fish
Aniline	$C_6H_5NH_2$	Dye production, rubber chemicals, toxic
Phenylethylamine	$C_6H_5CH_2CH_2NH_2$	Neurotransmitter, chocolate component
Pyridine	C_5H_5N	Solvent, denaturant, unpleasant odor
Putrescine	$H_2N(CH_2)_4NH_2$	Decaying flesh odor, diamine
Cadaverine	$H_2N(CH_2)_5NH_2$	Corpse odor, diamine
Ethanolamine	$HOCH_2CH_2NH_2$	Detergent, gas scrubbing, emulsifier
Formamide	$HCONH_2$	Solvent, softener
Acetamide	CH_3CONH_2	Plasticizer, solvent
Urea	$(NH_2)_2CO$	Fertilizer, animal feed, cosmetics
Polyacrylamide	$[-CH_2CH(CONH_2)-]_n$	Water treatment, gel electrophoresis
Paracetamol	$CH_3CONHC_6H_4OH$	Acetaminophen, pain reliever, fever reducer
Caffeine	$C_8H_{10}N_4O_2$	Coffee stimulant, central nervous system
Nicotine	$C_{10}H_{14}N_2$	Tobacco alkaloid, highly addictive, toxic
Acetonitrile	CH_3CN	HPLC solvent, extraction
Acrylonitrile	$CH_2=CHCN$	Acrylic fiber, ABS plastic monomer
Adiponitrile	$NC(CH_2)_4CN$	Nylon-66 precursor
Benzonitrile	C_6H_5CN	Solvent, chemical intermediate
Hydrogen cyanide	HCN	Extremely toxic gas, fumigant, gold extraction
Cyanamide	H_2NCN	Fertilizer, calcium cyanamide

6.6 Thiols and thioethers

Common Name	Formula/Structure	Description/Use
Methanethiol	CH_3SH	Rotten cabbage odor, natural gas odorant
Ethanethiol	C_2H_5SH	Skunk spray component, LPG odorant

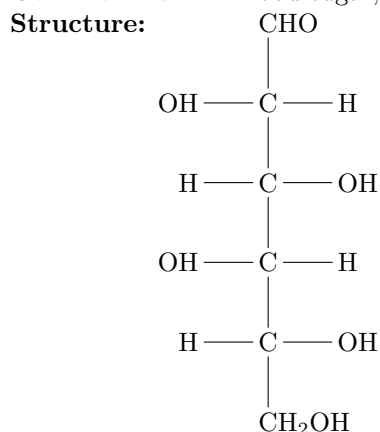
Common Name	Formula/Structure	Description/Use
Propanethiol	$\text{C}_3\text{H}_7\text{SH}$	Onion lachrymator precursor
Butanethiol	$\text{C}_4\text{H}_9\text{SH}$	Skunk secretion, extremely foul odor
Thiophenol	$\text{C}_6\text{H}_5\text{SH}$	Extremely foul odor, chemical intermediate
Glutathione	$\text{C}_{10}\text{H}_{17}\text{N}_3\text{O}_6\text{S}$	Antioxidant tripeptide, detoxification
Lipoic acid	$\text{C}_8\text{H}_{14}\text{O}_2\text{S}_2$	Antioxidant, enzyme cofactor
Mercaptoethanol	$\text{HSCH}_2\text{CH}_2\text{OH}$	Reducing agent in biochemistry
Allicin	$\text{C}_6\text{H}_{10}\text{OS}_2$	Garlic odor and flavor, antibiotic
Dimethyl sulfide	$(\text{CH}_3)_2\text{S}$	Ocean smell, cabbage odor
Diethyl sulfide	$(\text{C}_2\text{H}_5)_2\text{S}$	Garlic-like odor, solvent
Mustard gas	$(\text{ClCH}_2\text{CH}_2)_2\text{S}$	Chemical warfare agent, extremely toxic
Dimethyl sulfoxide	$(\text{CH}_3)_2\text{SO}$	DMSO, solvent, penetrates skin
Biotin	$\text{C}_{10}\text{H}_{16}\text{N}_2\text{O}_3\text{S}$	Vitamin B7, coenzyme, hair/nail health
Thioacetone	$(\text{CH}_3)_2\text{CS}$	Worst smell in history, evacuated city
Thiourea	$(\text{NH}_2)_2\text{CS}$	Photography, textile processing

6.7 Organic compounds in everyday life

6.7.1 Carbohydrates and sugars

Glucose ($\text{C}_6\text{H}_{12}\text{O}_6$)

Common name: Blood sugar, dextrose, grape sugar



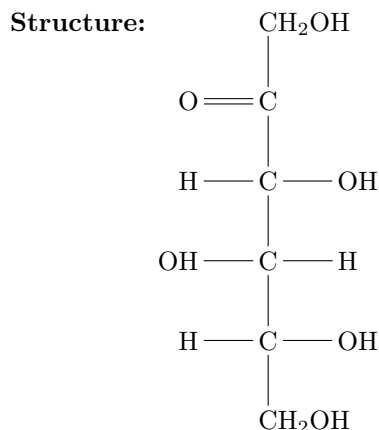
Properties:

- Most important monosaccharide in human metabolism
- Exists as cyclic form (pyranose) in solution
- Reducing sugar (positive Fehling's and Benedict's test)
- Primary energy source for cellular respiration

Occurrence: Blood, fruits, honey, cornstarch hydrolysis

Fructose ($\text{C}_6\text{H}_{12}\text{O}_6$)

Common name: Fruit sugar, levulose



Properties:

- Sweetest natural sugar
- Ketose (ketone sugar) rather than aldose
- Forms furanose ring in solution
- Reducing sugar

Occurrence: Fruits, honey, high-fructose corn syrup

Sucrose (C₁₂H₂₂O₁₁)

Common name: Table sugar, cane sugar, beet sugar

Structure: Disaccharide of glucose and fructose linked by $\alpha(1\rightarrow2)$ glycosidic bond

Properties:

- Non-reducing sugar (no free anomeric carbon)
- Highly soluble in water
- Hydrolyzes to glucose and fructose (invert sugar)
- $\text{C}_{12}\text{H}_{22}\text{O}_{11} + \text{H}_2\text{O} \xrightarrow{\text{H}^+ \text{ or invertase}} \text{C}_6\text{H}_{12}\text{O}_6 \text{ (glucose)} + \text{C}_6\text{H}_{12}\text{O}_6 \text{ (fructose)}$

Occurrence: Sugar cane, sugar beets, maple syrup

Lactose (C₁₂H₂₂O₁₁)

Common name: Milk sugar

Structure: Disaccharide of glucose and galactose linked by $\beta(1\rightarrow4)$ glycosidic bond

Properties:

- Reducing sugar (free anomeric carbon on glucose)
- Less sweet than sucrose
- Hydrolyzed by lactase enzyme
- Lactose intolerance results from lactase deficiency

Occurrence: Mammalian milk (cow milk: 4-5%, human milk: 6-7%)

Maltose (C₁₂H₂₂O₁₁)

Common name: Malt sugar

Structure: Disaccharide of two glucose units linked by $\alpha(1\rightarrow4)$ glycosidic bond

Properties:

- Reducing sugar
- Product of starch hydrolysis

- Hydrolyzed by maltase enzyme
- Important in brewing and bread making

Occurrence: Germinating grains, malt, partial starch digestion

Starch ((C₆H₁₀O₅)_n)

Common name: None (standard name)

Structure: Polymer of glucose units; mixture of amylose (linear, $\alpha(1\rightarrow4)$ links) and amylopectin (branched, $\alpha(1\rightarrow4)$ and $\alpha(1\rightarrow6)$ links)

Properties:

- Main storage polysaccharide in plants
- Forms blue-black complex with iodine (diagnostic test)
- Hydrolyzed by amylase enzymes
- Insoluble in cold water, forms colloidal suspension in hot water

Occurrence: Potatoes, rice, wheat, corn, all plant tubers and seeds

Cellulose (C₆H₁₀O₅)_n

Common name: Plant fiber

Structure: Linear polymer of glucose units linked by $\beta(1\rightarrow4)$ glycosidic bonds

Properties:

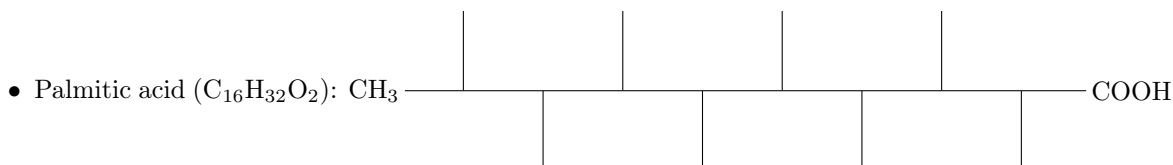
- Most abundant organic compound on Earth
- Structural polysaccharide in plant cell walls
- Not digestible by humans (lack cellulase enzyme)
- Important dietary fiber
- Strong hydrogen bonding between chains gives high tensile strength

Occurrence: Plant cell walls, cotton (95% cellulose), wood (40-50%)

6.7.2 Lipids and fats

Fatty acids (General formula: CH₃(CH₂)_nCOOH)

Common examples:



- Stearic acid (C₁₈H₃₆O₂): Saturated, 18-carbon chain
- Oleic acid (C₁₈H₃₄O₂): Monounsaturated, one C=C double bond
- Linoleic acid (C₁₈H₃₂O₂): Polyunsaturated, two C=C double bonds

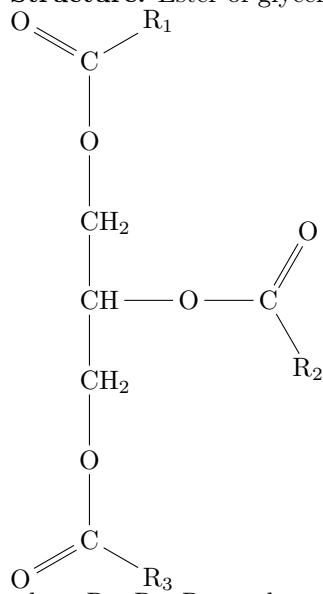
Properties:

- Saturated: All C-C single bonds, solid at room temperature
- Unsaturated: Contains C=C double bonds, liquid at room temperature
- Amphipathic: Hydrophobic tail, hydrophilic head

Triglycerides (Fats and oils)

Common name: Fat (solid), Oil (liquid)

Structure: Ester of glycerol and three fatty acid molecules



where R₁, R₂, R₃ are long-chain fatty acid residues

Properties:

- Energy storage molecules (9 kcal/g)
- Fats (saturated): Solid at room temperature (animal fats: lard, butter)
- Oils (unsaturated): Liquid at room temperature (vegetable oils: olive, corn, sunflower)
- Hydrophobic, insoluble in water
- Undergo saponification (base hydrolysis to form soap)

Saponification reaction:

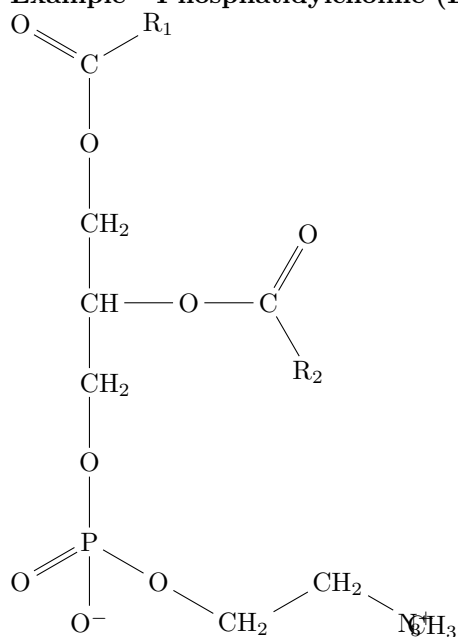
Fat + 3 NaOH $\longrightarrow$ Glycerol + 3 Soap (sodium salt of fatty acid)

Phospholipids

Common name: Cell membrane lipids

Structure: Similar to triglycerides but one fatty acid replaced by phosphate group

Example - Phosphatidylcholine (Lecithin):



Properties:

- Amphipathic molecules
- Form lipid bilayer in cell membranes
- Essential for membrane structure and function
- Emulsifying agents

Occurrence: All cell membranes, egg yolk, soybeans

6.7.3 Soaps and detergents**Soap**

Common name: Sodium or potassium salt of fatty acids

Structure (example - sodium stearate):

**Properties:**

- Amphipathic: Hydrophobic tail (C_{12} - C_{18} chain), hydrophilic head (COO^-)
- Forms micelles in water
- Lowers surface tension
- Ineffective in hard water (forms precipitate with Ca^{2+} , Mg^{2+})
- Basic in aqueous solution (pH 9-10)

Preparation: Saponification of fats with strong base (NaOH or KOH)

Mechanism of cleaning:

- Hydrophobic tails dissolve in grease/oil
- Hydrophilic heads face water
- Forms emulsion allowing oil removal

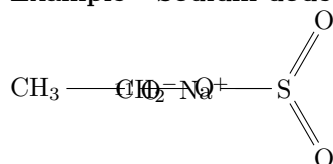
Detergents

Common name: Synthetic soaps

Types:

- Anionic: Sodium alkyl sulfates (e.g., SDS, sodium dodecyl sulfate)
- Cationic: Quaternary ammonium salts
- Non-ionic: Polyethylene glycol derivatives

Example - Sodium dodecyl sulfate (SDS):

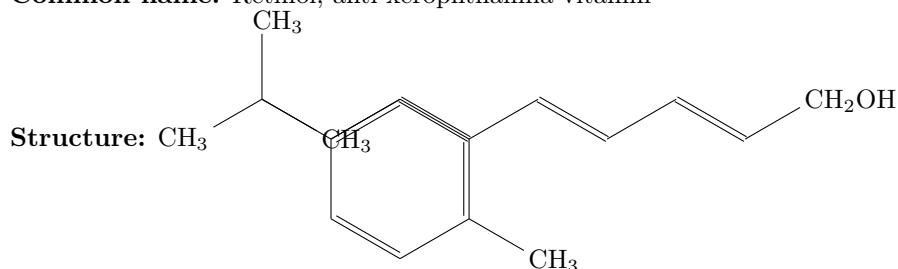
**Properties:**

- Work in hard water (do not precipitate with Ca^{2+} , Mg^{2+})
- More effective than soaps in acidic conditions
- Stronger cleaning action
- Some are non-biodegradable (environmental concern)

6.7.4 Vitamins

Vitamin A (Retinol, $C_{20}H_{30}O$)

Common name: Retinol, anti-xerophthalmia vitamin



Properties:

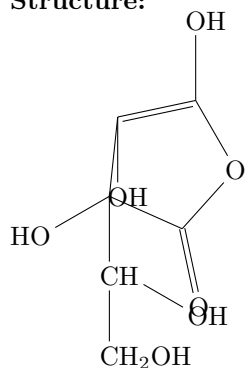
- Fat-soluble vitamin
- Important for vision (forms rhodopsin in retina)
- Essential for growth, immune function, skin health
- Deficiency: Night blindness, xerophthalmia (dry eyes)

Sources: Liver, fish oils, dairy products, carrots (as β -carotene precursor)

Vitamin C (Ascorbic acid, $C_6H_8O_6$)

Common name: Ascorbic acid, anti-scurvy vitamin

Structure:



Properties:

- Water-soluble vitamin
- Powerful antioxidant
- Essential for collagen synthesis
- Enhances iron absorption
- Easily oxidized (degraded by heat, light, air)
- Deficiency: Scurvy (bleeding gums, poor wound healing)

Sources: Citrus fruits, strawberries, peppers, broccoli, tomatoes

Vitamin D₃ (Cholecalciferol, $C_{27}H_{44}O$)

Common name: Cholecalciferol, sunshine vitamin, anti-rickets vitamin

Properties:

- Fat-soluble vitamin
- Synthesized in skin upon UV exposure
- Regulates calcium and phosphate absorption

- Essential for bone health
- Deficiency: Rickets (children), osteomalacia (adults)

Sources: Sunlight exposure, fish oils, fortified milk, egg yolk

Vitamin E (α -Tocopherol, $C_{29}H_{50}O_2$)

Common name: α -Tocopherol, anti-sterility vitamin

Structure: Chromanol ring system with long phytyl side chain

Properties:

- Fat-soluble vitamin
- Major antioxidant protecting cell membranes
- Protects polyunsaturated fatty acids from oxidation
- Important for reproduction and immune function

Sources: Vegetable oils, nuts, seeds, green leafy vegetables

Vitamin K (Phylloquinone, $C_{31}H_{46}O_2$)

Common name: Phylloquinone, anti-hemorrhagic vitamin

Properties:

- Fat-soluble vitamin
- Essential for blood clotting (activates clotting factors)
- Important for bone metabolism
- Synthesized by intestinal bacteria
- Deficiency: Prolonged bleeding, hemorrhage

Sources: Green leafy vegetables (spinach, kale), liver, bacteria synthesis

Vitamin B₁ (Thiamine, $C_{12}H_{17}N_4OS^+$)

Common name: Thiamine, anti-beriberi vitamin

Properties:

- Water-soluble vitamin
- Cofactor for enzymes in carbohydrate metabolism
- Essential for nervous system function
- Deficiency: Beriberi (nerve damage, heart failure)

Sources: Whole grains, pork, legumes, nuts

Vitamin B₂ (Riboflavin, $C_{17}H_{20}N_4O_6$)

Common name: Riboflavin

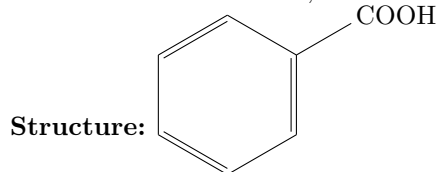
Properties:

- Water-soluble vitamin
- Component of FAD and FMN (electron carriers)
- Essential for energy metabolism
- Yellow-orange color, fluorescent in UV light
- Deficiency: Cracks at corners of mouth, skin disorders

Sources: Milk, eggs, meat, green vegetables

Vitamin B₃ (Niacin, C₆H₅NO₂)

Common name: Niacin, nicotinic acid, anti-pellagra vitamin



Properties:

- Water-soluble vitamin
- Component of NAD⁺ and NADP⁺ (electron carriers)
- Essential for energy metabolism and DNA repair
- Deficiency: Pellagra (dermatitis, diarrhea, dementia)

Sources: Meat, fish, peanuts, fortified grains

Vitamin B₆ (Pyridoxine, C₈H₁₁NO₃)

Common name: Pyridoxine

Properties:

- Water-soluble vitamin
- Cofactor for amino acid metabolism
- Important for neurotransmitter synthesis
- Deficiency: Anemia, peripheral neuropathy

Sources: Meat, fish, potatoes, chickpeas, bananas

Vitamin B₁₂ (Cobalamin, C₆₃H₈₈CoN₁₄O₁₄P)

Common name: Cobalamin, anti-pernicious anemia vitamin

Properties:

- Water-soluble vitamin
- Contains cobalt ion (only vitamin with metal)
- Essential for DNA synthesis and red blood cell formation
- Important for nervous system function
- Requires intrinsic factor for absorption
- Deficiency: Pernicious anemia, nerve damage

Sources: Animal products only (meat, fish, eggs, dairy)

6.7.5 Other everyday organic compounds

Agar

Common name: Agar-agar

Structure: Polysaccharide mixture of agarose and agarpectin extracted from red algae (mainly galactose units with 3,6-anhydro-L-galactose)

Properties:

- Forms gel at low concentrations (0.5-2%)
- Melting point: 85°C, gelling point: 32-40°C (hysteresis)

- Not digested by most bacteria
- Stable and inert
- Vegetarian alternative to gelatin

Uses:

- Microbiology: Culture medium for bacteria and fungi
- Food industry: Gelling agent, stabilizer, thickener
- Molecular biology: Gel electrophoresis
- Cooking: Desserts, jellies (especially in Asian cuisine)

Source: Red algae (seaweed): Gelidium, Gracilaria species

Gelatin

Common name: Gelatin

Structure: Protein derived from collagen hydrolysis; contains glycine, proline, hydroxyproline as major amino acids

Properties:

- Forms thermoreversible gel
- Melting point: 35-40°C (melts at body temperature)
- Amphiphilic (both hydrophobic and hydrophilic amino acids)
- Biodegradable

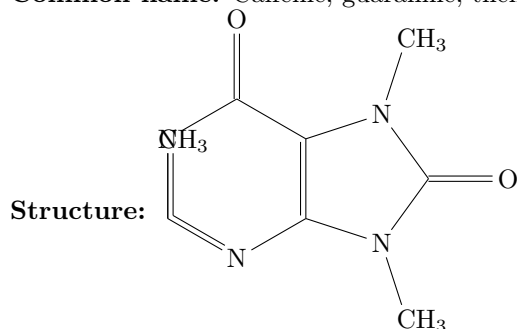
Uses:

- Food: Desserts, marshmallows, gummy candies
- Pharmaceuticals: Capsule coating, tablet binder
- Photography: Film emulsion
- Cosmetics: Face masks, creams

Source: Animal collagen (bones, skin, connective tissue)

Caffeine (C₈H₁₀N₄O₂)

Common name: Caffeine, guaranine, theine



Properties:

- Central nervous system stimulant
- Alkaloid (contains nitrogen in heterocyclic ring)
- Bitter taste
- Sublimes at 178°C without melting

- Blocks adenosine receptors (reduces drowsiness)

Effects:

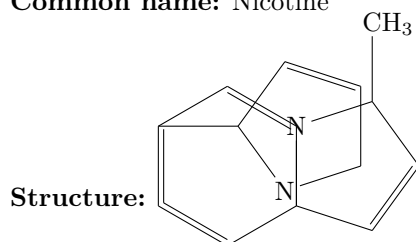
- Increases alertness and concentration
- Mild diuretic
- Can cause insomnia, jitters at high doses
- Tolerance develops with regular use

Sources: Coffee beans, tea leaves, cocoa beans, guarana, kola nuts

Content: Coffee (95 mg/cup), tea (47 mg/cup), cola (40 mg/can), chocolate (25 mg/bar)

Nicotine ($C_{10}H_{14}N_2$)

Common name: Nicotine



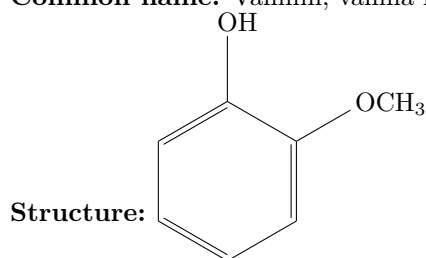
Properties:

- Highly addictive alkaloid
- Liquid at room temperature, turns brown on exposure to air
- Stimulant at low doses, depressant at high doses
- Binds to nicotinic acetylcholine receptors
- Highly toxic ($LD_{50} = 0.5-1 \text{ mg/kg}$)

Source: Tobacco plants (*Nicotiana tabacum*)

Vanillin ($C_8H_8O_3$)

Common name: Vanillin, vanilla flavor



Properties:

- Aromatic aldehyde
- Pleasant sweet vanilla odor
- White crystalline solid
- Phenolic compound (contains -OH on benzene ring)

Uses:

- Flavoring agent in food and beverages
- Fragrance in perfumes and cosmetics
- Most used flavoring compound in the world

Sources: Natural: Vanilla beans (pods of *Vanilla planifolia* orchid); Synthetic: Made from lignin or guaiacol

Menthol ($C_{10}H_{20}O$)

Common name: Menthol, peppermint camphor

Properties:

- Cyclic terpene alcohol
- Cooling sensation (activates cold-sensitive receptors)
- Minty odor and taste
- Crystalline solid at room temperature
- Local anesthetic and mild analgesic properties

Uses:

- Flavoring: Chewing gum, candy, toothpaste
- Pharmaceuticals: Cough drops, throat lozenges, topical pain relief
- Cigarettes: Menthol cigarettes
- Cosmetics: Shampoos, lip balms

Sources: Natural: Peppermint and other mint oils; Synthetic: From citronellal or thymol

Cholesterol ($C_{27}H_{46}O$)

Common name: Cholesterol

Properties:

- Steroid lipid with four fused rings (sterane core)
- Essential component of animal cell membranes
- Precursor for steroid hormones, bile acids, vitamin D
- Synthesized in liver
- Transported in blood by lipoproteins (LDL, HDL)
- High levels associated with cardiovascular disease

Sources: Synthesized by body; dietary sources include meat, eggs, dairy products

7 Macromolecule and Plastics

Macromolecules, also known as polymers, are large molecules composed of repeating structural units (monomers) connected by covalent bonds. Synthetic polymers (plastics) have become ubiquitous materials in modern life due to their versatility, durability, and low cost.

7.1 Addition polymers

Addition polymers are formed by the repeated addition of monomers containing double bonds without the loss of any atoms. The reaction is called addition polymerization or chain-growth polymerization.

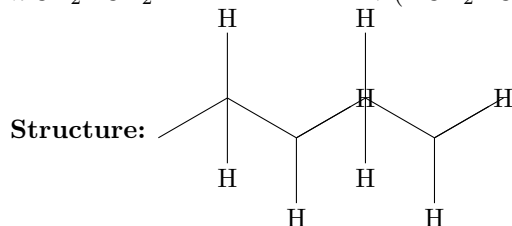
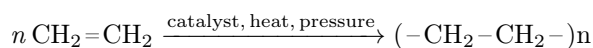
Polyethylene (PE)

Monomer: Ethylene (ethene): $CH_2=CH_2$

Chemical formula: $(C_2H_4)_n$ or $(-CH_2-CH_2-)_n$

Reaction type: Addition polymerization (free radical, Ziegler-Natta, or metallocene catalysis)

Polymerization reaction:



Types:

- LDPE (Low-density polyethylene): Branched chains, flexible, transparent
- HDPE (High-density polyethylene): Linear chains, rigid, opaque
- UHMWPE (Ultra-high molecular weight PE): Extremely long chains, very strong

Properties:

- Chemically inert, resistant to acids and bases
- Excellent electrical insulator
- Lightweight and flexible (LDPE) or rigid (HDPE)
- Water-resistant
- Recyclable (recycling code 2 for HDPE, 4 for LDPE)

Usage: Plastic bags, bottles, containers, toys, electrical insulation, pipes, packaging films

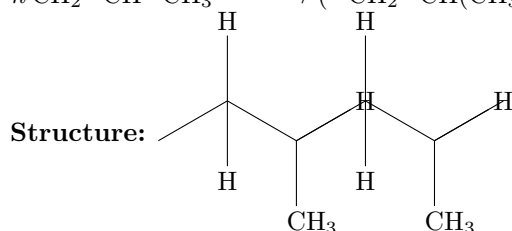
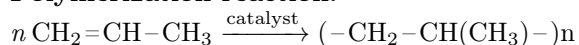
Polypropylene (PP)

Monomer: Propylene (propene): $\text{CH}_2=\text{CH}-\text{CH}_3$

Chemical formula: $(\text{C}_3\text{H}_6)_n$ or $(-\text{CH}_2-\text{CH}(\text{CH}_3)-)_n$

Reaction type: Addition polymerization (Ziegler-Natta catalysis)

Polymerization reaction:



Properties:

- Higher melting point than polyethylene (160-170°C)
- Good chemical resistance
- Strong and rigid
- Good fatigue resistance
- Lightweight
- Recyclable (recycling code 5)

Usage: Automotive parts, packaging, textiles (fibers and fabrics), food containers, bottle caps, medical equipment, living hinges

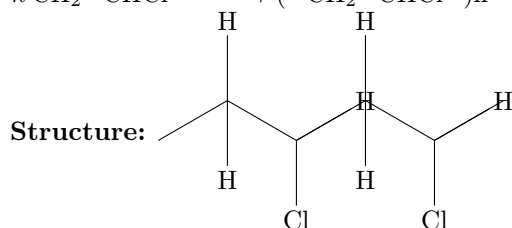
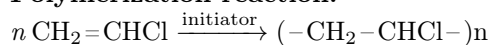
Polyvinyl chloride (PVC)

Monomer: Vinyl chloride: $\text{CH}_2=\text{CH}-\text{Cl}$

Chemical formula: $(C_2H_3Cl)_n$ or $(-CH_2-CHCl-)_n$

Reaction type: Addition polymerization (free radical polymerization)

Polymerization reaction:

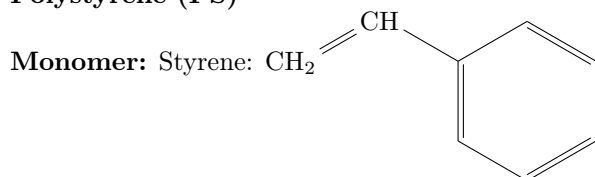


Properties:

- Rigid and hard in pure form
- Can be plasticized to become flexible
- Excellent chemical resistance
- Good electrical insulator
- Flame retardant (due to chlorine content)
- Durable and weather-resistant
- Recyclable (recycling code 3)

Usage: Water pipes, electrical cable insulation, window frames, flooring, credit cards, medical tubing, inflatable products

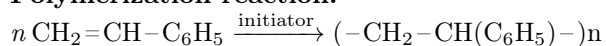
Polystyrene (PS)



Chemical formula: $(C_8H_8)_n$ or $(-CH_2-CH(C_6H_5)-)_n$

Reaction type: Addition polymerization (free radical polymerization)

Polymerization reaction:

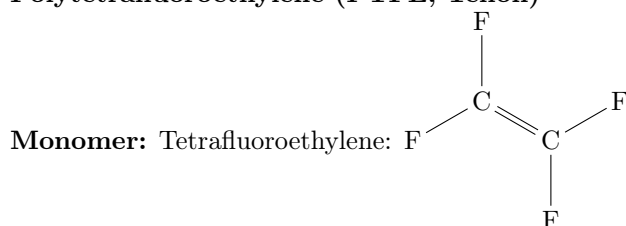


Properties:

- Transparent and rigid in pure form
- Brittle at room temperature
- Low melting point (240°C)
- Good electrical insulator
- Can be expanded into foam (EPS - expanded polystyrene)
- Recyclable (recycling code 6)

Usage: Packaging (foam peanuts, egg cartons), disposable cups and plates, insulation, CD/DVD cases, model building

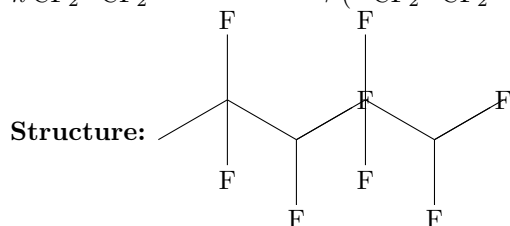
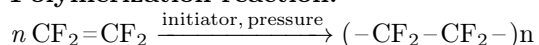
Polytetrafluoroethylene (PTFE, Teflon)



Chemical formula: $(C_2F_4)_n$ or $(-CF_2-CF_2-)_n$

Reaction type: Addition polymerization (free radical polymerization under pressure)

Polymerization reaction:

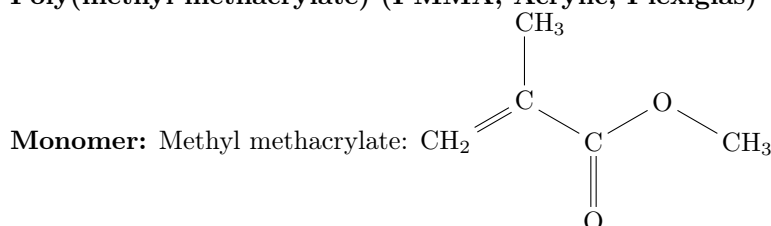


Properties:

- Extremely low coefficient of friction (non-stick)
- Chemically inert (resistant to almost all chemicals)
- High melting point (327°C)
- Excellent electrical insulator
- Hydrophobic and oleophobic
- Very stable at high temperatures

Usage: Non-stick cookware coatings, gaskets, seals, chemical-resistant tubing, electrical insulation, medical implants

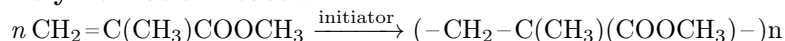
Poly(methyl methacrylate) (PMMA, Acrylic, Plexiglas)



Chemical formula: $(C_5H_8O_2)_n$ or $(-CH_2-C(CH_3)(COOCH_3)-)_n$

Reaction type: Addition polymerization (free radical polymerization)

Polymerization reaction:

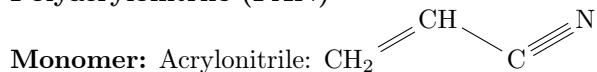


Properties:

- Optically transparent (92% light transmission)
- Scratch-resistant
- Weather-resistant
- Shatter-resistant (safer than glass)
- Good electrical insulator
- Can be easily molded and shaped when heated

Usage: Windows, aquariums, lenses, displays, signs, lighting fixtures, furniture, dental materials

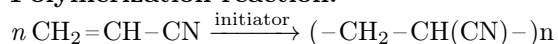
Polyacrylonitrile (PAN)



Chemical formula: $(C_3H_3N)_n$ or $(-CH_2-CH(CN)-)_n$

Reaction type: Addition polymerization (free radical polymerization)

Polymerization reaction:



Properties:

- Strong and rigid
- Good chemical resistance
- Heat-resistant
- Can be converted to carbon fiber through pyrolysis

Usage: Acrylic fibers (clothing, carpets), carbon fiber precursor, outdoor applications, barrier plastics

7.2 Condensation polymers

Condensation polymers are formed by the stepwise reaction between monomers with elimination of small molecules (usually water, HCl, or methanol). Also called step-growth polymerization.

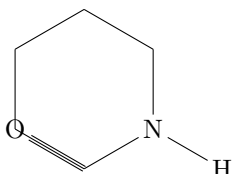
Nylon (Polyamide)

Common types: Nylon-6,6 and Nylon-6

Monomers (Nylon-6,6):

- Hexamethylenediamine: $\text{H}_2\text{N}-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{NH}_2$
- Adipic acid: $\text{HOOC}-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{COOH}$

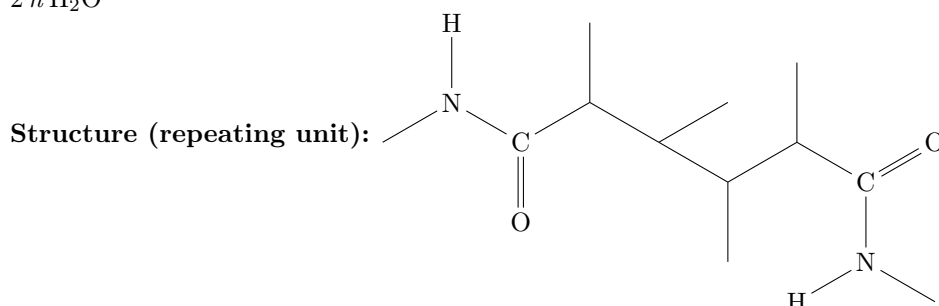
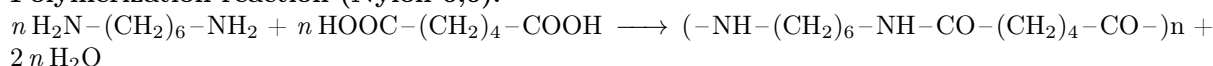
Monomer (Nylon-6): ϵ -Caprolactam:



Chemical formula: $(-\text{NH}-(\text{CH}_2)_6-\text{NH}-\text{CO}-(\text{CH}_2)_4-\text{CO}-)_n$ (Nylon-6,6) or $(-\text{NH}-(\text{CH}_2)_5-\text{CO}-)_n$ (Nylon-6)

Reaction type: Condensation polymerization (polycondensation)

Polymerization reaction (Nylon-6,6):



Properties:

- Strong and durable
- Good elasticity and abrasion resistance
- High melting point (250-260°C)
- Absorbs moisture
- Can be drawn into strong fibers

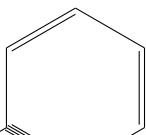
- Forms hydrogen bonds between chains

Usage: Textiles and clothing, stockings, carpets, ropes, parachutes, fishing lines, mechanical parts (gears, bearings), toothbrush bristles

Polyester (Polyethylene terephthalate, PET)

Monomers:

- Ethylene glycol: $\text{HO} - \text{CH}_2 - \text{CH}_2 - \text{OH}$

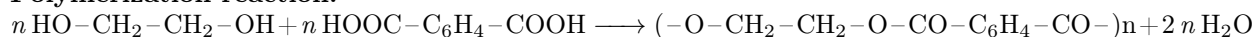


- Terephthalic acid: $\text{HOOC} - \text{C}_6\text{H}_4 - \text{COOH}$

Chemical formula: $(-\text{O}-\text{CH}_2-\text{CH}_2-\text{O}-\text{CO}-\text{C}_6\text{H}_4-\text{CO}-)_n$

Reaction type: Condensation polymerization (esterification)

Polymerization reaction:



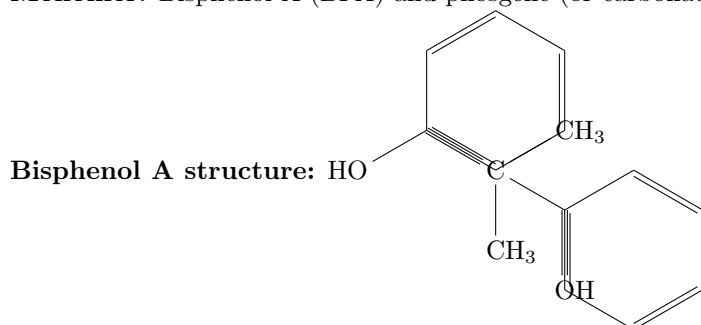
Properties:

- Strong and lightweight
- Wrinkle-resistant
- Quick-drying
- Transparent (in thin films)
- Good barrier to gases and moisture
- Recyclable (recycling code 1)

Usage: Beverage bottles, food containers, textiles (polyester fabrics), films, magnetic tape, carpets, upholstery

Polycarbonate (PC)

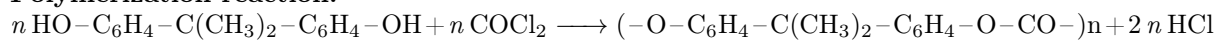
Monomer: Bisphenol A (BPA) and phosgene (or carbonate precursor)



Chemical formula: $(-\text{O}-\text{C}_6\text{H}_4-\text{C}(\text{CH}_3)_2-\text{C}_6\text{H}_4-\text{O}-\text{CO}-)_n$

Reaction type: Condensation polymerization (interfacial polymerization)

Polymerization reaction:



Properties:

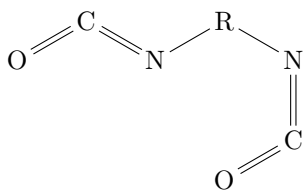
- Exceptionally high impact resistance
- Optically transparent
- Heat-resistant (working temperature up to 120°C)
- Good electrical insulator

- Lightweight
- Can be sterilized

Usage: Safety glasses, bulletproof windows, CDs/DVDs, water bottles, medical devices, automotive parts, electronics housings

Polyurethane (PU)

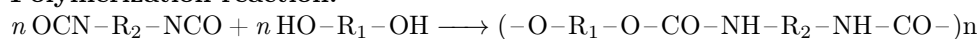
Monomers:

- Diisocyanate: 
- Polyol (diol or polyol): $\text{HO} - \text{R}' - \text{OH}$

Chemical formula: $(-\text{O}-\text{R}_1-\text{O}-\text{CO}-\text{NH}-\text{R}_2-\text{NH}-\text{CO}-)_n$

Reaction type: Condensation polymerization (addition of isocyanate and hydroxyl groups)

Polymerization reaction:



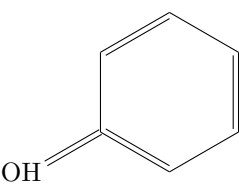
Properties:

- Highly versatile (can be rigid or flexible)
- Excellent abrasion resistance
- Good chemical resistance
- Can be foamed to various densities
- Good insulating properties

Usage: Flexible foams (cushions, mattresses), rigid foams (insulation), coatings, adhesives, elastomers (shoe soles), automotive parts

Bakelite (Phenol-formaldehyde resin)

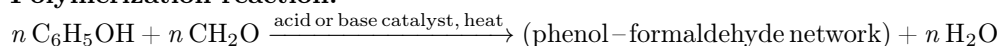
Monomers:

- Phenol: 
- Formaldehyde: $\text{H} - \text{C}(=\text{O}) - \text{H}$

Chemical formula: Complex cross-linked structure $(\text{C}_6\text{H}_6\text{O} \cdot \text{CH}_2\text{O})_n$

Reaction type: Condensation polymerization with cross-linking (thermosetting)

Polymerization reaction:



Properties:

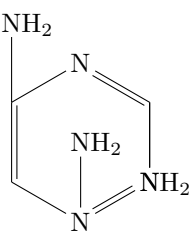
- First fully synthetic plastic (invented 1907)
- Thermosetting (cannot be remolded after curing)
- Hard and rigid
- Excellent electrical insulator

- Heat-resistant
- Chemical-resistant
- Dark color (brown or black)

Usage: Electrical insulators, switches, handles, kitchenware (vintage), automotive parts, billiard balls, jewelry

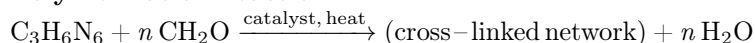
Melamine-formaldehyde resin (Melamine)

Monomers:

- Melamine: 
- Formaldehyde: CH_2O

Reaction type: Condensation polymerization with cross-linking (thermosetting)

Polymerization reaction:



Properties:

- Thermosetting plastic
- Very hard and scratch-resistant
- Heat-resistant
- Stain-resistant
- Can be colored and decorated
- Flame-retardant

Usage: Dinnerware, countertops, laminates (Formica), whiteboards, adhesives, flame retardants

7.3 Natural polymers

Cellulose

Monomer: β -D-Glucose: $\text{C}_6\text{H}_{12}\text{O}_6$

Chemical formula: $(\text{C}_6\text{H}_{10}\text{O}_5)_n$

Reaction type: Natural condensation polymerization (dehydration synthesis in plants)

Linkage: $\beta(1 \rightarrow 4)$ glycosidic bonds between glucose units

Properties:

- Linear polymer with extensive hydrogen bonding
- Crystalline structure gives high tensile strength
- Insoluble in water
- Not digestible by humans (lack of cellulase enzyme)
- Most abundant organic polymer on Earth
- Biodegradable

Usage: Paper production, textiles (cotton, linen), construction (wood), cellulose derivatives (rayon, cellophane, nitrocellulose)

Starch

Monomer: α -D-Glucose: $C_6H_{12}O_6$

Chemical formula: $(C_6H_{10}O_5)_n$

Reaction type: Natural condensation polymerization (biosynthesis in plants)

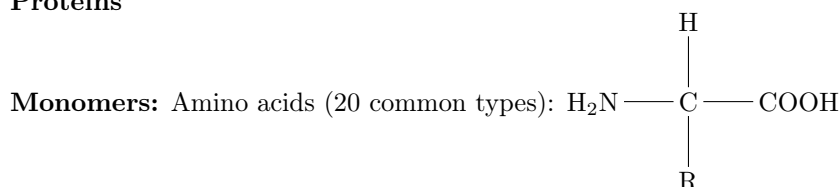
Structure: Mixture of amylose (linear, $\alpha(1\rightarrow4)$ links) and amylopectin (branched, $\alpha(1\rightarrow4)$ and $\alpha(1\rightarrow6)$ links)

Properties:

- Energy storage polysaccharide in plants
- Digestible by humans (amylase enzymes)
- Forms helical structures
- Swells in water, forms paste when heated
- Biodegradable

Usage: Food (major carbohydrate source), thickening agent, adhesive, biodegradable plastics, textile sizing

Proteins

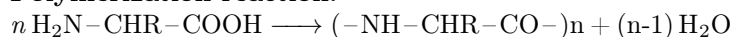


where R represents different side chains (e.g., H for glycine, CH_3 for alanine, etc.)

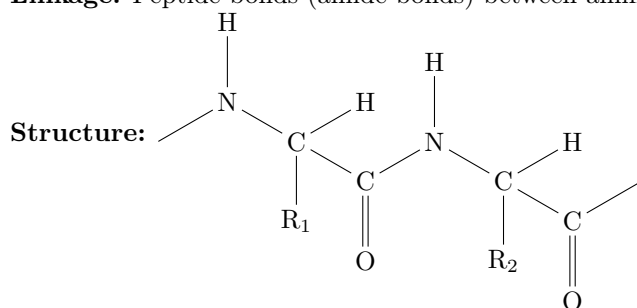
Chemical formula: Varies, general form $(C_xH_yN_zO_wS_v)_n$

Reaction type: Condensation polymerization (peptide bond formation)

Polymerization reaction:



Linkage: Peptide bonds (amide bonds) between amino acids

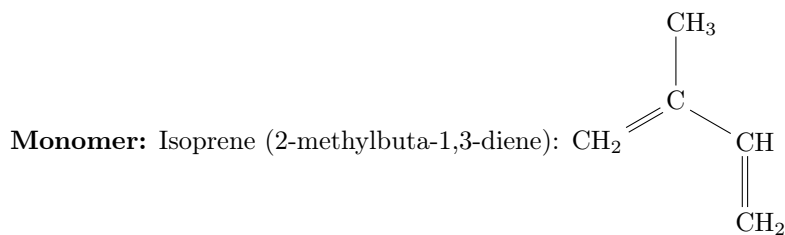


Properties:

- Four levels of structure: primary (sequence), secondary (α -helix, β -sheet), tertiary (3D folding), quaternary (multiple chains)
- Amphoteric (can act as acid or base)
- Denatured by heat, pH changes, or chemicals
- Biodegradable

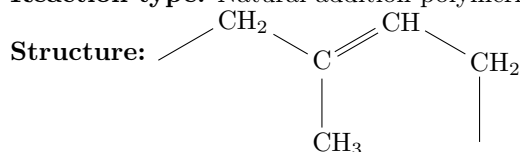
Usage: Structural proteins (collagen, keratin), enzymes (biological catalysts), hormones (insulin), transport proteins (hemoglobin), food (meat, dairy, legumes)

Natural Rubber (Polyisoprene)



Chemical formula: $(\text{C}_5\text{H}_8)_n$ in cis configuration

Reaction type: Natural addition polymerization (biosynthesis in rubber trees)



Properties:

- Elastic and flexible
- Cis configuration gives coiled structure
- Can be vulcanized (cross-linked with sulfur) for increased strength
- Good electrical insulator
- Waterproof
- Biodegradable (though slowly)

Vulcanization: Cross-linking with sulfur to improve properties

Rubber + S $\xrightarrow{\text{heat}}$ Cross-linked rubber (stronger, less sticky)

Usage: Tires, gloves, hoses, seals, footwear, elastic bands, medical devices

Source: Latex from rubber trees (*Hevea brasiliensis*)

DNA (Deoxyribonucleic acid)

Monomers: Nucleotides (phosphate + deoxyribose sugar + nitrogenous base)

Bases: Adenine (A), Guanine (G), Cytosine (C), Thymine (T)

Reaction type: Natural condensation polymerization (phosphodiester bond formation)

Linkage: Phosphodiester bonds between 3' and 5' carbons of sugar

Properties:

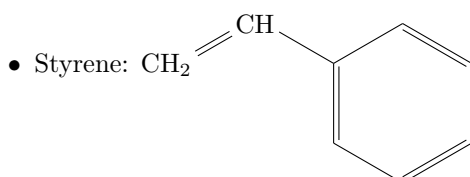
- Double helix structure (two antiparallel strands)
- Base pairing: A-T (2 hydrogen bonds), G-C (3 hydrogen bonds)
- Stores genetic information
- Can be replicated
- Relatively stable polymer

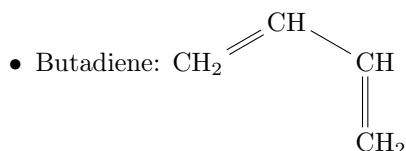
Usage: Genetic information storage, heredity, biotechnology (genetic engineering, forensics, medicine)

7.4 Synthetic rubber and elastomers

Styrene-butadiene rubber (SBR)

Monomers:





Chemical formula: Copolymer with typical ratio 1:3 (styrene:butadiene)

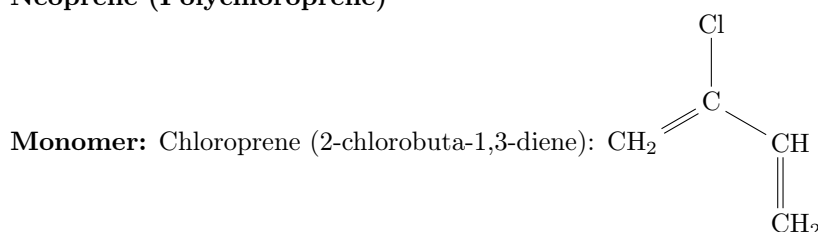
Reaction type: Addition copolymerization (emulsion polymerization)

Properties:

- Good abrasion resistance
- Good aging stability
- Better than natural rubber for some applications
- Less elastic than natural rubber

Usage: Automobile tires (most common use), shoe soles, adhesives, carpet backing

Neoprene (Polychloroprene)



Chemical formula: $(\text{C}_4\text{H}_5\text{Cl})_n$

Reaction type: Addition polymerization (free radical polymerization)

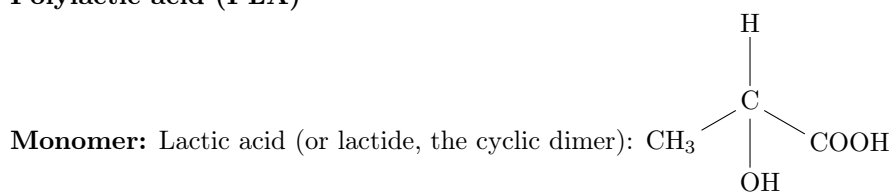
Properties:

- Resistant to oil, heat, and weathering
- Flame-resistant
- More durable than natural rubber
- Good chemical resistance

Usage: Wetsuits, laptop sleeves, electrical insulation, automotive belts and hoses, gaskets

7.5 Biodegradable and bioplastics

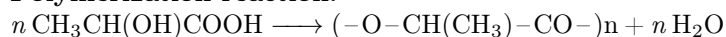
Polylactic acid (PLA)



Chemical formula: $(\text{C}_3\text{H}_4\text{O}_2)_n$ or $(-\text{O}-\text{CH}(\text{CH}_3)-\text{CO}-)_n$

Reaction type: Condensation polymerization (ring-opening polymerization of lactide)

Polymerization reaction:



Properties:

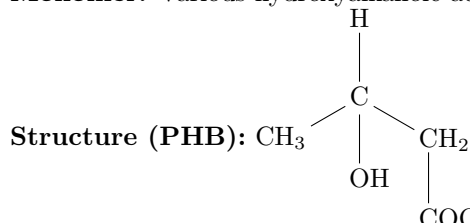
- Biodegradable and compostable
- Derived from renewable resources (corn starch, sugarcane)
- Transparent and glossy
- Low melting point (150-160°C)

- Similar properties to PET
- Recyclable

Usage: Biodegradable packaging, disposable tableware, 3D printing filament, medical implants (sutures, screws), bottles

Polyhydroxyalkanoates (PHA)

Monomer: Various hydroxyalkanoic acids, most common: 3-hydroxybutyric acid



Chemical formula: $(-\text{O}-\text{CH}(\text{CH}_3)-\text{CH}_2-\text{CO}-)_n$ for PHB

Reaction type: Natural biosynthesis by bacteria (condensation polymerization)

Properties:

- Fully biodegradable (even in marine environments)
- Produced by bacterial fermentation
- Thermoplastic
- Biocompatible
- Similar properties to polypropylene

Usage: Biodegradable packaging, agricultural films, medical applications (sutures, tissue engineering), food containers