Unit 1 · Fundamentals of Chemistry

STUDY NOTES

WHAT NEB'S GRADE 11 EXAM ASKS

- **CDC's grid (2077):** Physical Chemistry (Units 1–8 together): 28 of 75 marks
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** MCQ: how many atoms in two molecules of water (6)
- **MCQ (1 mark)**
  - what makes up most of an atom's mass
  - what isotopes share; p, e, n in $^{35}_{17}\mathrm{Cl}$
  - formula with most atoms; radical of highest valency
  - 1 amu ≈ mass of one H atom
  - tetratomic molecule; plaster of Paris for bone casts
  - same empirical and molecular formula
  - % water in $\mathrm{CuSO_4{\cdot}5H_2O}$; heaviest of several samples
- **Short (5 marks, in parts)**
  - define chemistry; four ways it helps society; central science; two roles each in farming and medicine
  - gypsum: atoms, M_r, use, % sulphate; % N in $\mathrm{NH_3}$ and $\mathrm{NH_4NO_3}$, the better fertilizer
  - formulas from ions (criss-cross table); name ions, monatomic or polyatomic, cation or anion
  - two differences: atom/molecule, atomic/molecular mass, molecular/empirical formula, atom/radical, acid/basic radical
  - why atoms can't be weighed; define 1 amu and find it in grams
  - penicillin: why a compound, atoms, M_r, % of each element; molecular and empirical formula from a structure
  - molecular formula from % composition and M_r (nicotine)

Key terms

Chemistry: study of the composition and structure of matter and the changes it undergoes; the **central science** (every other science uses it).

Matter: anything with mass that takes up space.

Element: pure substance of one kind of atom.

Compound: pure substance of two or more elements chemically combined in a **fixed proportion by mass**; broken into elements only by a chemical change.

Mixture: substances together in no fixed proportion; **homogeneous** (same throughout: air, brass, sugar in tea) or **heterogeneous** (parts seen: muddy water).

Atom: smallest particle of an element that takes part in chemical reactions and has its chemical properties.

Molecule: two or more atoms chemically combined; smallest particle of a substance that exists on its own with its properties.

Atomicity: number of atoms in one molecule.

Isotopes: atoms of one element (same protons) with different numbers of neutrons.

Relative atomic mass A_r: average mass of an element's atoms (natural isotope mixture) ÷ $\frac{1}{12}$ of the mass of a carbon-12 atom; no unit.

Relative molecular mass M_r: mass of one molecule ÷ $\frac{1}{12}$ of a carbon-12 atom = sum of the atomic masses in it.

Formula unit, **formula mass**: the smallest repeating unit of an ionic compound (NaCl) and its mass.

1 amu (u, dalton): $\frac{1}{12}$ of the mass of one carbon-12 atom.

Ion: atom or group with a charge; **cation** (+, lost electrons, **basic radical**), **anion** (−, gained electrons, **acid radical**).

Free radical: particle with an unpaired electron (Cl·, $\cdot\mathrm{CH_3}$); usually neutral.

Molecular formula: symbols and numbers of the atoms in one molecule.

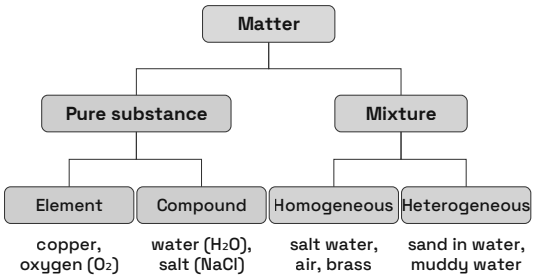
Empirical formula: simplest whole-number ratio of the atoms.

Percentage composition: mass of each element in 100 g of the compound.

Formulas

$A_r = \dfrac{12 \times \bar{m}_{\text{atom}}}{m(\text{C-12})}$	no unit **Use:** relative atomic mass
$1\ \text{amu} = m(\text{C-12})/12$	$1.993 \times 10^{-23}\ \text{g} \div 12 = 1.661 \times 10^{-24}\ \text{g}$ **Use:** atomic mass unit
$n = \dfrac{M_r}{\text{EF mass}}$	molecular formula = (EF) × n **Use:** EF = empirical formula
$\% = \dfrac{A_r \times \text{atoms}}{M_r} \times 100$	always **by mass** **Use:** percentage of an element

Matter and the branches of chemistry



Matter: a pure substance (element or compound) or a mixture (homogeneous or heterogeneous).

Branches

- inorganic: elements and compounds other than most carbon compounds
- organic: carbon compounds (first from living things)
- biochemistry: the chemistry of living things
- physical: structure and energy, by physics' methods (rates, energy, light)
- nuclear: nuclei, radioactivity, fission, fusion
- analytical: **what** a substance contains and **how much**
- environmental: pollution, waste, toxic substances
- forensic: evidence from crime scenes (Nepal: CIB, National Forensic Science Laboratory)
- applied: geochemistry, medicinal, agricultural, food, petroleum, soil, polymer

Chemistry and society

- health: medicines, vaccines, antiseptics, anesthetics, tests
- food: fertilizers, pesticides, preservation, purity tests
- homes: soap, detergent, toothpaste, cement, paint
- energy: petrol, diesel, LPG, batteries, solar silicon
- environment: water treatment, measuring pollution, greener processes

Careers

- chemical engineer
- chemical technician
- hazardous materials manager
- pharmacist
- teacher
- medical representative
- forensic chemist

Atoms and molecules

Dalton's atomic theory

1. matter is made of small, indivisible atoms
2. atoms of one element are identical; different elements' atoms differ
3. compounds: atoms in small whole-number ratios
4. a reaction only rearranges atoms; none made or destroyed

- refined since: atoms split into e, p, n; isotopes differ in mass
- a molecule has its own properties: $H_2 + O_2$ explode; water puts fires out

Atomicity

- monatomic: He, Ne, Ar
- diatomic: H_2, O_2, N_2, Cl_2, HCl, CO
- triatomic: H_2O, CO_2, O_3
- tetratomic: NH_3, P_4
- polyatomic: more than two atoms (proteins, DNA)
- NaCl is **ionic**: a lattice of Na^+ and Cl^-, formula units, **no molecules**
- **H_2** one molecule · **2H** two atoms · **$2H_2$** two molecules (4 atoms)
- $2H_2O$: $2 \times 3 =$ **6 atoms**; $3Ca(NO_3)_2$: $3 \times 6 =$ **18 O atoms**

Relative masses

- atoms 0.1–0.5 nm across; one C-12 atom 1.99×10^{-23} g: far too small for a balance → compared with **carbon-12 = 12** (since 1961)
- A_r not a whole number → the element is a **mixture of isotopes** (Ag: Ag-107 51.8%, Ag-109 48.2% → 107.87; no atom has that mass)
- Cl: 76% Cl-35, 24% Cl-37 → 35.5
- B = 10.81 → boron-11 commoner than boron-10
- proton 1.007, neutron 1.009 amu, electron 1/1836: an atom's mass is almost all in its **nucleus** (p + n); 1 amu ≈ one H atom
- $CHCl_3$: $12 + 1 + 3 \times 35.5 =$ **119.5**; NaCl: $23 + 35.5 =$ **58.5** (formula mass)
- brackets multiply: $Ca(OH)_2 = 40 + 2 \times 17 =$ **74**
- water of crystallization is **added**: $CuSO_4 \cdot 5H_2O = 159.5 + 5 \times 18 =$ **249.5** (water 90/249.5 = **36.07%**)

Values used in calculations (IUPAC, rounded): H 1, C 12, N 14, O 16, Na 23, Mg 24, Al 27, S 32, Cl 35.5, K 39, Ca 40, Fe 56, Cu 63.5, Zn 65, Ag 108

Ions and their names

- charge of a simple cation = valency: monovalent Na^+, bivalent Ca^{2+}, trivalent Al^{3+}
- metals → cations (metallic, electropositive, basic radicals); non-metals → anions (non-metallic, electronegative, acid radicals)
- variable valency: **-ous** lower, **-ic** higher (Latin root); **Stock**: Roman numeral = charge

Ion	Classical	Stock
Fe^{2+} / Fe^{3+}	ferrous / ferric	iron(II) / iron(III)
Cu^{+} / Cu^{2+}	cuprous / cupric	copper(I) / copper(II)
Hg_2^{2+} / Hg^{2+}	mercurous / mercuric	mercury(I) / mercury(II)
Mn^{2+} / Mn^{3+}	manganous / manganic	manganese(II) / (III)
Sn^{2+} / Sn^{4+}	stannous / stannic	tin(II) / tin(IV)
Pb^{2+} / Pb^{4+}	plumbous / plumbic	lead(II) / lead(IV)
Cr^{2+} / Cr^{3+}	chromous / chromic	chromium(II) / (III)
Co^{2+} / Co^{3+}	cobaltous / cobaltic	cobalt(II) / (III)
Au^{+} / Au^{3+}	aurous / auric	gold(I) / gold(III)

- mercury(I) is **Hg_2^{2+}** (mercurous chloride Hg_2Cl_2); MnO_2 is manganese(IV)
- NH_4^+: a polyatomic cation that acts like a metal ion
- monatomic anions end **-ide**: C^{4-} carbide, N^{3-} nitride, P^{3-} phosphide, O^{2-} oxide, S^{2-} sulphide, F^-, Cl^-, Br^-, I^-; also CN^- cyanide, OH^- hydroxide
- oxyanions: **-ite** fewer O, **-ate** more; **hypo-** fewest, **per-** most: ClO^- hypochlorite, ClO_2^- chlorite, ClO_3^- chlorate, ClO_4^- perchlorate
- simple ion: one atom (Cl^-, H^-, Na^+); compound ion: more than one (PO_4^{3-}, NH_4^+)

Polyatomic ions to know

- CO_3^{2-} carbonate, HCO_3^- bicarbonate
- SO_4^{2-} sulphate, HSO_4^- bisulphate, SO_3^{2-} sulphite, $S_2O_3^{2-}$ thiosulphate
- NO_3^- nitrate, NO_2^- nitrite
- PO_4^{3-} phosphate, HPO_4^{2-}, $H_2PO_4^-$
- CrO_4^{2-} chromate, $Cr_2O_7^{2-}$ dichromate
- MnO_4^- permanganate, MnO_4^{2-} manganate
- $C_2O_4^{2-}$ oxalate, SiO_4^{4-} silicate
- O_2^{2-} peroxide, O_2^- superoxide, H^- hydride
- CNO^- cyanate, SCN^- thiocyanate

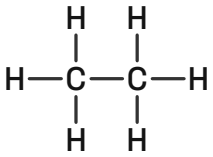
Writing a formula (criss-cross)

1. cation first, anion second
2. each one's valency becomes the other's subscript
3. cancel a common factor
4. brackets round a polyatomic ion with a subscript: $Al_2(SO_4)_3$, $Ca_3(PO_4)_2$, $Fe_2(SO_4)_3$

Common names

- baking soda $NaHCO_3$
- bleaching powder $CaOCl_2$
- borax $Na_2B_4O_7{\cdot}10H_2O$
- limestone $CaCO_3$
- Epsom salt $MgSO_4{\cdot}7H_2O$
- gypsum $CaSO_4{\cdot}2H_2O$
- plaster of Paris $CaSO_4{\cdot}\frac{1}{2}H_2O$ (bone casts)
- quicklime CaO
- slaked lime $Ca(OH)_2$
- caustic soda $NaOH$
- washing soda $Na_2CO_3{\cdot}10H_2O$
- milk of magnesia $Mg(OH)_2$
- muriatic acid HCl
- potash K_2CO_3
- saltpeter KNO_3
- gypsum heated to 120–150 °C loses ¾ of its water → **plaster of Paris**; with water it sets back into gypsum (casts)

Molecular and empirical formulas



Ethane: structural formula; molecular C_2H_6; empirical CH_3 (1 : 3).

- glucose $C_6H_{12}O_6 \rightarrow CH_2O$ (n = 6); acetic acid $C_2H_4O_2 \rightarrow CH_2O$ (n = 2): one empirical formula, two compounds
- benzene $C_6H_6 \rightarrow CH$; $H_2O_2 \rightarrow HO$; lactic acid $C_3H_6O_3$ (90) $\rightarrow CH_2O$, n = 3
- same both: H_2O, CO_2, CCl_4

Percentage composition

- CO_2: C 12/44 = 27.27%; CO 42.9% C: different proportions, different substances
- urea $CO(NH_2)_2$: N 28/60 = **46.7%**, the richest of NH_4NO_3 (35%), $(NH_4)_2SO_4$, KNO_3
- ethanol C_2H_5OH: C 24/46 = 52.17%
- round only at the end; the percentages add up to 100

Uses

- empirical formula, then molecular formula with M_r (Unit 2)
- quality control (cement, fertilizer, medicines)
- stoichiometry
- properties (CO a poison, CO_2 breathed out)

COMMON MISTAKES

✗ a molecule of NaCl
✓ NaCl is ionic: a formula unit, no molecules.

✗ all radicals are ions
✓ acid and basic radicals are ions; free radicals (Cl·) are usually neutral.

✗ mercurous ion Hg^+, HgCl
✓ Hg_2^{2+}, Hg_2Cl_2.

✗ manganic = Mn(IV)
✓ manganic is Mn^{3+}; MnO_2 is manganese(IV).

✗ chromate CrO_4^-
✓ CrO_4^{2-}.

✗ $CuSO_4{\cdot}5H_2O = 159.5 \times 5 \times 18$
✓ the water is added: 159.5 + 90 = 249.5.

✗ 1 amu = 6.67×10^{-24} g
✓ 1.661×10^{-24} g.

✗ % composition by number of atoms (water 66.7% H)
✓ by mass: water 11.1% H, 88.9% O.