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STGT PURE SCIENCE

CHEMISTRY

UNIT-WISE COMPLETE STUDY MATERIAL

Theory • Derivations • Diagrams • Solved Examples • PYQs (2016–2026) with Solutions • Trend Analysis • Practice Sets • Revision Capsule

UNIT 1

ATOMS AND MOLECULES

Valency • Formula • Chemical Equation • Chemical Reaction • Mole Concept

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CSIR NET 2020 (AIR 145) • GATE Physics 2021 (AIR 52)
CSIR NET JRF 2022 (AIR 162) • CSIR NET JRF 2023 (AIR 93)
STPGT Physics 2025 (Rank 2)

Mapped to the official TRBT Syllabus (2016) for Physical Science • Built from an analysis of 294 PYQs across 2016, 2017, 2018, 2019, 2022 and 2026

First Edition • June 2026 • For Tripura STGT (Classes IX–X) Aspirants

UNIT 1 ATOMS AND MOLECULES

SYLLABUS

Dalton's atomic theory, law of conservation of mass, law of constant proportion, Avogadro-hypothesis, concept of molecule from Avogadro hypothesis, atomic and molecular masses, Avogadro number, molar volume, mole concept, symbol of elements/ions, valency, formula, chemical equation and chemical reaction, definition of empirical and molecular formula, relation between empirical and molecular formula. Chemical equation—significance and limitation of chemical equation, balancing of chemical equation. Type of chemical reactions: Elementary problems related to chemical equation and chemical reactions.

PYQ RADAR

29 questions from this unit in six published STGT papers (2016: 7, 2017: 6, 2018: 4, 2019: 4, 2022: 4, 2026: 4) — about **10% of the Chemistry section**. Expect **4–5 questions**, dominated by the *mole concept*, *vapour density*, *molar volume at NTP* and *limiting-reagent stoichiometry*. Almost every numerical here is a 30-second, single-formula problem — this is one of the highest scoring-rate units of the paper.

1. INTRODUCTION

Definition. Chemistry begins with one question: *what is matter made of?* The answer — that all matter is built from extremely small particles called **atoms**, which combine into **molecules** — is the foundation on which the whole of this unit (and of chemistry itself) stands.

Historical background. Around 600 B.C. the Indian philosopher **Maharshi Kanada** proposed that matter is divisible only up to a smallest unit, the *paramanu*. Around 400 B.C. the Greek thinker **Democritus** called such ultimate particles *atomos* ("indivisible"). These were philosophical ideas, not science — they were not based on measurement. Quantitative chemistry began only at the end of the 18th century, when **Antoine Lavoisier** introduced the systematic use of the *chemical balance*. The mass data so generated crystallised into the **laws of chemical combination**, and in 1808 **John Dalton** explained those laws with the first scientific atomic theory.

Significance. This unit supplies the universal toolkit of chemistry: the mole concept, chemical formulae and balanced equations. Every later unit — solutions, electrolysis, acids and bases, organic chemistry — silently assumes it.

Applications. Industrial stoichiometry (how much lime from a tonne of limestone), medicine dosing, pollution accounting (mass of CO_2 per kg of fuel), and balanced-equation bookkeeping in every laboratory.

2. LAWS OF CHEMICAL COMBINATION

Chemical combination is governed by five experimental mass/volume laws. The first two are named explicitly in your syllabus; the remaining three complete the logical story and have appeared as distractors in MCQs.

2.1 LAW OF CONSERVATION OF MASS

Statement (Lavoisier, 1789). *Mass is neither created nor destroyed in a chemical reaction.* The total mass of the products equals the total mass of the reactants; matter only changes its form.

$$\sum m_{\text{reactants}} = \sum m_{\text{products}}$$

Experimental basis (Landolt's experiment). Hans Landolt (1893–1908) sealed solutions of silver nitrate and sodium chloride in the two limbs of an H-shaped tube and weighed it. On tilting, the reaction

$$AgNO_3 + NaCl \longrightarrow AgCl\downarrow + NaNO_3$$

produced a white precipitate, yet the sealed tube showed **no detectable change in mass** (to better than 1 part in 10^7).

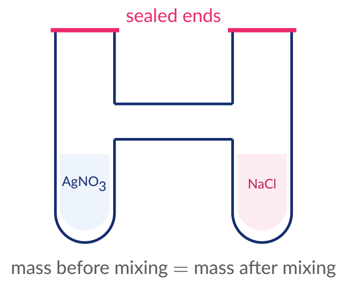

Fig. 1: *Landolt's H-tube experiment verifying conservation of mass.*

EXAMPLE 1 **EASY**

5.3 g of sodium carbonate reacts completely with 6.0 g of ethanoic acid, producing 2.2 g of CO_2, 0.9 g of water and sodium ethanoate. What mass of sodium ethanoate is formed?

Solution: By conservation of mass,

$$5.3 + 6.0 = 2.2 + 0.9 + m \;\Rightarrow\; m = 11.3 - 3.1 = 8.2\,\text{g}.$$

Mass of sodium ethanoate $= 8.2$ g. (Unit check: all quantities in grams ✓)

Limitation (advanced). In nuclear reactions mass is *not* separately conserved — it converts to energy via Einstein's relation $E = \Delta m\, c^2$. Even in ordinary chemical reactions a tiny mass change ($\sim 10^{-10}$ of the total, from bond-energy release) occurs, far below what any balance can detect. For all chemistry-exam purposes the law holds exactly.

2.2 LAW OF CONSTANT (DEFINITE) PROPORTION

Statement (Proust, 1799). *A given chemical compound always contains the same elements combined in the same fixed ratio by mass, irrespective of its source or method of preparation.*

Water from rain, a river or a laboratory always has H : O $= 1 : 8$ by mass; carbon dioxide from burning coal, respiration or heating limestone always has C : O $= 3 : 8$; ammonia always has N : H $= 14 : 3$.

EXAMPLE 2 MODERATE

3.0 g of carbon burns in 8.0 g of oxygen to give 11.0 g of CO_2. What mass of CO_2 forms when 3.0 g of carbon burns in 50.0 g of oxygen? Which law governs your answer?

Solution: Carbon and oxygen always combine in the fixed ratio $3 : 8$ in CO_2. Hence 3.0 g C can use only 8.0 g of O_2, giving 11.0 g of CO_2; the remaining 42.0 g of oxygen stays unreacted. This is the **law of constant proportion** (with oxygen in excess).

Limitations (exam favourites).

- **Non-stoichiometric (berthollide) compounds** such as wüstite $Fe_{0.95}O$ violate fixed composition. STGT 2026
- **Isotopic substitution**: H_2O and D_2O have different mass ratios although chemically the "same" compound.

2.3 LAW OF MULTIPLE PROPORTIONS

Statement (Dalton, 1803). *If two elements form more than one compound, the masses of one element that combine with a fixed mass of the other are in a simple whole-number ratio.*

In CO and CO_2, the oxygen masses combining with 12 g of carbon are 16 g and 32 g — ratio $1 : 2$. In H_2O and H_2O_2, oxygen per 2 g hydrogen is 16 g and 32 g — again $1 : 2$.

2.4 LAW OF RECIPROCAL PROPORTIONS

Statement (Richter, 1792). *The masses of elements A and B that separately combine with a fixed mass of a third element C are either the same as, or a simple multiple of, the ratio in which A and B combine with each other.* In H_2S, 32 g S combine with 2 g H; in H_2O, 16 g O combine with 2 g H, so S : O $= 2 : 1$ via hydrogen. In SO_2 the direct ratio is $32 : 32 = 1 : 1$ — a simple multiple ($\times 2$) of $2 : 1$. ✓

2.5 GAY-LUSSAC'S LAW OF COMBINING VOLUMES

Statement (1808). *When gases react, the volumes of the reacting gases and gaseous products, measured at the same temperature and pressure, bear simple whole-number ratios.*

$$\underbrace{H_2}_{1\text{ vol}} + \underbrace{Cl_2}_{1\text{ vol}} \longrightarrow \underbrace{2HCl}_{2\text{ vol}}, \qquad \underbrace{2H_2}_{2} + \underbrace{O_2}_{1} \longrightarrow \underbrace{2H_2O}_{2}$$

This volume law could not be explained by Dalton's atoms — it needed Avogadro's molecules (Sec. 5).

Table: *The five laws of chemical combination at a glance*

LAW	SCIENTIST	KEY STATEMENT
Conservation of mass	Lavoisier (1789)	Total mass unchanged in a chemical reaction
Constant proportion	Proust (1799)	Fixed mass ratio of elements in a compound
Multiple proportions	Dalton (1803)	Different compounds of same elements: simple mass ratios
Reciprocal proportions	Richter (1792)	Ratios via a third element are simply related
Combining volumes	Gay-Lussac (1808)	Reacting gas volumes in simple whole-number ratios

QUICK NOTES

Memory trick: "*Lavoisier Conserves, Proust Fixes, Dalton Multiplies, Richter Reciprocates, Gay-Lussac Gasifies.*" The first four are *mass* laws; only Gay-Lussac's is a *volume* law.

3. DALTON'S ATOMIC THEORY

Background. In *A New System of Chemical Philosophy* (1808), John Dalton converted the Greek "atom" into a quantitative scientific theory designed to explain the mass laws above.

3.1 POSTULATES

1. All matter is made of extremely small, **indivisible** particles called **atoms**; atoms can be neither created nor destroyed.
2. Atoms of a given element are **identical** in mass and properties.
3. Atoms of **different elements differ** in mass and properties.
4. Atoms combine in **small whole-number ratios** to form "compound atoms" (molecules).
5. In chemical reactions atoms are only **rearranged** — never created, destroyed or changed into atoms of another element.
6. In a given compound, the relative number and kinds of atoms are **constant**.

3.2 MERITS

- Postulate 5 directly *explains the law of conservation of mass* (rearrangement cannot alter total mass).
- Postulates 2, 4 and 6 *explain constant proportion*; postulate 4 *explains multiple proportions*.
- First theory to distinguish **elements** (one kind of atom) from **compounds** (atoms of different elements united).

3.3 LIMITATIONS

- Atom is **divisible**: electrons, protons and neutrons were discovered later (Unit 2); nuclear reactions even transmute elements.
- **Isotopes** (^{35}Cl, ^{37}Cl) — atoms of one element with different masses — contradict postulate 2.
- **Isobars** (^{40}Ar, ^{40}Ca) — atoms of different elements with the same mass number — contradict postulate 3.
- Could **not explain Gay-Lussac's law of volumes**: $H_2 + Cl_2 \longrightarrow 2HCl$ would force the "hydrogen atom" to split in half.
- Ratios are not always small whole numbers in large

molecules (e.g. sugar $C_{12}H_{22}O_{11}$); allotropy (diamond/graphite) was unexplained.

EXAM POINT

"Law of constant proportion does not hold for ..." (STGT 2026): the genuine exceptions are **non-stoichiometric (berthollide) compounds** and **isotopic variants** — *not* exothermic or endothermic compounds. Energy character has nothing to do with composition laws.

4. ATOMS, MOLECULES AND MATTER

4.1 ATOM

The **atom** is the smallest particle of an element that retains its chemical identity and takes part in a chemical reaction; it may or may not exist independently (He does; H normally pairs into H_2). Atomic radii are of the order of 10^{-10} m (1 Å); 10^6 hydrogen atoms side by side span only 0.1 mm.

4.2 MOLECULE

A **molecule** is the smallest particle of an element *or compound* capable of free, independent existence, formed by chemically bonding two or more atoms. Molecules of elements contain one kind of atom (O_2, P_4); molecules of compounds contain different kinds (H_2O, NH_3).

4.3 ATOMICITY

Definition. The number of atoms present in one molecule of an *element* is its **atomicity**.

Table: *Atomicity of common elements*

ATOMICITY	EXAMPLES	CLASS
1 (monoatomic)	He, Ne, Ar, Kr, Xe; metal vapours (Na, Fe)	noble gases, metals
2 (diatomic)	H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2	elemental gases
3 (triatomic)	O_3 (ozone)	allotrope of O
4 (tetratomic)	P_4 (white phosphorus)	solid non-metal
8 (polyatomic)	S_8 (rhombic sulphur)	solid non-metal

QUICK NOTES

Diatomic-element mnemonic: "*Have No Fear Of Ice Cold Beer*" = H_2, N_2, F_2, O_2, I_2, Cl_2, Br_2.

4.4 CLASSIFICATION OF MATTER

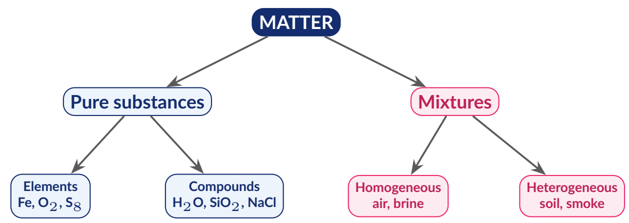

Fig. 2: *Chemical classification of matter.*

EXAM POINT

STGT 2026 asked: *Which is not an element?* **Silica** (SiO_2) is a *compound*; diamond is elemental carbon; tungsten (W) is an element. Learn the disguised compounds: silica, sand, quartz (SiO_2), alumina (Al_2O_3), brass/bronze/steel (mixtures/alloys).

5. AVOGADRO'S HYPOTHESIS

The crisis. Berzelius tried to bridge Dalton and Gay-Lussac with "equal volumes contain equal numbers of *atoms*". Apply it to hydrogen–chlorine:

$$\mathrm{H} + \mathrm{Cl} \longrightarrow \mathrm{HCl} \quad \text{(Berzelius)}$$

1 volume of H atoms + 1 volume of Cl atoms should give only 1 volume of HCl — but experiment gives **2 volumes**. Saving the data would require splitting the "indivisible" atom. Contradiction.

Statement (Avogadro, 1811). *Equal volumes of all gases, at the same temperature and pressure, contain equal numbers of* ***molecules****.*

Resolution. Let elementary gases be diatomic molecules:

$$\mathrm{H_2} + \mathrm{Cl_2} \longrightarrow 2\mathrm{HCl}$$

Each H_2 and Cl_2 molecule splits into two atoms which recombine into two HCl molecules — so 1 vol + 1 vol $\longrightarrow$ 2 vol, exactly as observed, with no atom ever divided.

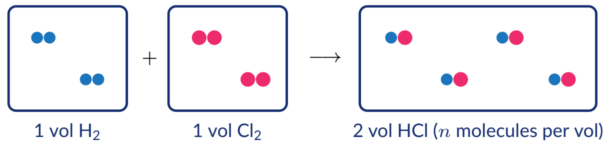

Fig. 3: *Avogadro's molecules explain Gay-Lussac's 1:1:2 volume ratio.*

5.1 CONCEPT OF MOLECULE FROM THE HYPOTHESIS

Avogadro's hypothesis forced chemistry to distinguish the **atom** (smallest unit in reactions) from the **molecule** (smallest free-existing unit), and proved that common elemental gases are **diatomic** (H_2, O_2, N_2, Cl_2). Cannizzaro (1858) used it to fix the first consistent table of atomic masses.

5.2 APPLICATIONS OF AVOGADRO'S HYPOTHESIS

1. **Molar volume:** equal numbers occupy equal volumes $\Rightarrow$ one mole of *any* gas occupies 22.4 L at STP/NTP.
2. **Relation between molecular mass and vapour density** (derived in Sec. 7.5): $M = 2 \times$ V.D.
3. **Deducing molecular formulae of gases** from reacting volumes (as in Fig. 3).
4. Gas density at the same T, P is proportional to molecular mass: $\rho \propto M$.

6. ATOMIC AND MOLECULAR MASSES

6.1 ATOMIC MASS UNIT (AMU / U)

Atoms are far too light to weigh in grams (an H atom is $\sim 1.67 \times 10^{-24}$ g), so a *relative* scale is used.

Definition. One **atomic mass unit** is one-twelfth of the mass of one atom of carbon-12:

$$1\,\mathrm{u} = \frac{1}{12}\, m(^{12}\mathrm{C}) = \frac{1}{N_\mathrm{A}}\,\mathrm{g} = 1.66 \times 10^{-24}\,\mathrm{g}$$

Historical background. Dalton first took hydrogen ($= 1$) as the standard; chemists later used oxygen ($= 16$). Because natural oxygen is an isotope mixture (^{16}O, ^{17}O, ^{18}O), physicists and chemists disagreed, and in **1961 IUPAC adopted carbon-12** — a single, abundant, solid isotope ideal for mass spectrometry.

Atomic mass. The (relative) atomic mass of an element states how many times one atom is heavier than $\frac{1}{12}$ of a ^{12}C atom. Being a ratio it is **dimensionless**, but it is conventionally quoted in u.

Why fractional? Natural chlorine is 75% ^{35}Cl $+$ 25% ^{37}Cl:

$$\bar{A} = \frac{75 \times 35 + 25 \times 37}{100} = 35.5\,\text{u}.$$

Average atomic masses are isotope-abundance weighted means — hence rarely whole numbers.

Gram atomic mass. The atomic mass expressed in grams (1 gram-atom). It contains N_A atoms. E.g. gram atomic mass of O $= 16\,$g.

Table: *Atomic masses to memorise (u, rounded as used in STGT)*

ELEMENT — ATOMIC MASS							
H	1	C	12	N	14	O	16
Na	23	Mg	24	Al	27	P	31
S	32	Cl	35.5	K	39	Ca	40
Mn	55	Fe	56	Cu	63.5	Zn	65
Br	80	Ag	108	I	127	Ba	137
Au	197	Hg	200.5	Pb	207	U	238

6.2 MOLECULAR MASS AND FORMULA MASS

Molecular mass = sum of atomic masses of all atoms in one molecule; it states how many times one molecule is heavier than $\frac{1}{12}$ of a ^{12}C atom. **Gram molecular mass** (molar mass M) is the same number in grams, containing N_A molecules.

For ionic solids like NaCl no discrete molecule exists; the analogous quantity is the **formula unit mass** (NaCl $= 23 + 35.5 = 58.5\,$u).

EXAMPLE 3 **EASY**

Compute the molecular/formula masses of (i) H_2SO_4, (ii) $Ca_3(PO_4)_2$, (iii) $CuSO_4{\cdot}5H_2O$.

Solution: (i) $2(1) + 32 + 4(16) = 98\,$u.
(ii) $3(40) + 2[31 + 4(16)] = 120 + 190 = 310\,$u.
(iii) $63.5 + 32 + 4(16) + 5(18) = 159.5 + 90 = 249.5\,$u.

7. THE MOLE CONCEPT

7.1 DEFINITION

The **mole** (symbol mol) is the SI unit of *amount of substance*. One mole contains exactly as many elementary entities (atoms, molecules, ions, electrons …) as there are atoms in $12\,$g of ^{12}C. That number is the **Avogadro constant**:

$$N_\text{A} = 6.022 \times 10^{23}\ \text{mol}^{-1} \quad (\text{exactly } 6.02214076 \times 10^{23} \text{ since the 2019 SI redefinition})$$

Why this number? Because $1\,\text{u} = 1/N_\text{A}\,$g, the atomic mass in u and the molar mass in g/mol are *numerically equal*: one O atom $= 16\,$u $\Leftrightarrow$ one mole of O atoms $= 16\,$g. The mole is the bridge between the atomic scale and the laboratory balance.

Physical feel. 6.022×10^{23} tea cups of water would drain all the oceans many times over; counting one entity per second would take 1.9×10^{16} years.

7.2 THE FOUR MOLE RELATIONS

$$n = \frac{m}{M} = \frac{N}{N_\text{A}} = \frac{V_\text{STP}}{22.4\,\text{L}} \quad \text{(gas volume in mL: divide by 22 400)}$$

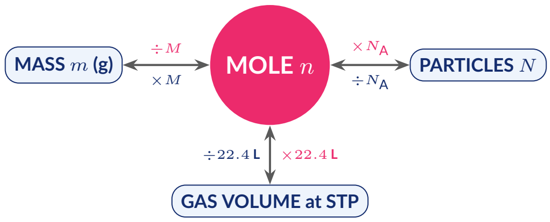

Fig. 4: *The mole map — convert anything to moles first.*

EXAMPLE 4 **EASY**

How many moles and how many atoms are in $4.6\,$g of sodium?

Solution: $n = m/M = 4.6/23 = 0.2\,$mol. Atoms $= nN_\text{A} = 0.2 \times 6.022 \times 10^{23} = 1.204 \times 10^{23}$.

EXAMPLE 5 **MODERATE**

Find the total number of atoms in $0.25\,$mol of ammonia.

Solution: Molecules $= 0.25 \times 6.022 \times 10^{23} = 1.506 \times 10^{23}$. Each NH_3 has 4 atoms, so atoms $= 4 \times 1.506 \times 10^{23} = 6.022 \times 10^{23}$ — curiously, exactly N_A atoms.

EXAMPLE 6 **ADVANCED**

What is the mass of one mole of electrons? ($m_e = 9.11 \times 10^{-28}\,$g) **STGT 2026**

Solution: $m = N_\text{A} m_e = 6.022 \times 10^{23} \times 9.11 \times 10^{-28}\,\text{g} = 5.49 \times 10^{-4}\,\text{g} \approx$ **0.55** mg. The mole counts *any* entity — even electrons.

7.3 MOLAR VOLUME

By Avogadro's hypothesis equal numbers of gas molecules fill equal volumes, so **one mole of any ideal gas at STP** (0°C $= 273\,$K, 1 atm) occupies

$$V_m = 22.4\,\text{L} = 22\,400\,\text{mL} \quad \text{(modern 1-bar STP: 22.7 L; **STGT always uses 22.4 L**)}$$

In STGT papers *NTP and STP are used interchangeably* for $273\,$K, 1 atm. At room temperature (25°C) the molar volume is about $24.5\,$L — not asked, but know the distinction.

EXAMPLE 7 **EASY**

Volume of $8.8\,$g of CO_2 at NTP?

Solution: $n = 8.8/44 = 0.2\,$mol; $V = 0.2 \times 22.4 = 4.48\,$L.

7.4 GAS DENSITY AT NTP

Since one mole (M grams) fills $22.4\,$L,

$$\rho_\text{NTP} = \frac{M\ (\text{g/mol})}{22\,400\ (\text{mL/mol})}\ \text{g/mL} \quad \Longleftrightarrow \quad M = \rho_\text{NTP} \times 22\,400$$

E.g. CO_2: $\rho = 44/22400 = 0.00196\,$g/mL $= 1.96\,$g/L.

7.5 VAPOUR DENSITY AND THE RELATION M = 2 × V.D.

Definition. Vapour density (V.D.) of a gas is the ratio of the mass of a volume V of the gas to the mass of an equal volume of hydrogen, both at the same T and P. It is **dimensionless**.

Derivation (from Avogadro's hypothesis). Equal volumes hold equal numbers n of molecules:

$$\text{V.D.} = \frac{\text{mass of } V \text{ of gas}}{\text{mass of } V \text{ of } H_2} = \frac{n\,M_{\text{gas}}}{n\,M_{H_2}} = \frac{M_{\text{gas}}}{2}$$

$$\boxed{M_{\text{gas}} = 2 \times \text{V.D.}}$$

Each step uses only Avogadro's hypothesis and $M(H_2) = 2$; no gas law is needed — which is why the result is exam-proof. **Five of the 29 PYQs of this unit use this single line.**

EXAMPLE 8 MODERATE

11.2 L of a gas at STP weighs 22 g. Find its vapour density.

Solution: Moles $= 11.2/22.4 = 0.5$; $M = 22/0.5 = 44$ g/mol; V.D. $= M/2 =$ **22**.

EXAMPLE 9 ADVANCED

A mixture contains 80% N_2 and 20% O_2 *by volume*. Find its mean vapour density. STGT 2019

Solution: For gases, volume fraction = mole fraction. $\bar{M} = 0.8(28) + 0.2(32) = 22.4 + 6.4 = 28.8$; V.D. $= 28.8/2 =$ **14.4**.

COMMON MISTAKES

(i) V.D. has *no units* — never write g/L. **(ii)** $M = 2\times$V.D. works only because hydrogen is *diatomic*. **(iii)** Absolute density ($\rho = M/22.4$ g/L) and vapour density ($M/2$) are different quantities — STGT options are built to trap the confusion.

8. PERCENTAGE COMPOSITION & FORMULAE

8.1 PERCENTAGE COMPOSITION

$$\%\,X = \frac{(\text{no. of atoms of } X) \times (\text{atomic mass of } X)}{\text{molecular mass}} \times 100$$

EXAMPLE 10 EASY

Find the percentage of oxygen in NaOH. STGT 2022

Solution: $M = 23 + 16 + 1 = 40$. % O $= \frac{16}{40} \times 100 =$ **40%**.

EXAMPLE 11 MODERATE

Find the mass percentage of each element in urea, $CO(NH_2)_2$.

Solution: $M = 12 + 16 + 2(14) + 4(1) = 60$. %C $= \frac{12}{60} \times 100 = 20\%$; %O $= \frac{16}{60} \times 100 = 26.67\%$; %N $= \frac{28}{60} \times 100 = 46.67\%$; %H $= \frac{4}{60} \times 100 = 6.66\%$. (Sum $= 100\%$ ✓)

8.2 EMPIRICAL AND MOLECULAR FORMULA

Empirical formula (EF): the simplest whole-number ratio of atoms in a compound.
Molecular formula (MF): the actual number of atoms of each element in one molecule.

$$\text{MF} = (\text{EF})_n, \qquad n = \frac{\text{molecular mass}}{\text{empirical formula mass}}$$

Table: *Empirical vs molecular formula — classic pairs*

COMPOUND	MF	EF	N
Hydrogen peroxide	H_2O_2	HO	2
Benzene	C_6H_6	CH	6
Glucose	$C_6H_{12}O_6$	CH_2O	6
Acetic acid	$C_2H_4O_2$	CH_2O	2
Water	H_2O	H_2O	1

Note that different compounds (glucose, acetic acid, formaldehyde HCHO) can share one empirical formula — EF does *not* identify a substance.

8.3 STEPS TO DETERMINE THE FORMULAE

% mass of each element → ÷ atomic mass ⇒ moles → ÷ smallest; make whole → EF, then $n = \frac{M}{\text{EF mass}}$

Fig. 5: *From analysis data to molecular formula.*

EXAMPLE 12 MODERATE

A compound has C 40.0%, H 6.67%, O 53.33% and molecular mass 180. Find EF and MF.

Solution: Relative moles: C $= 40/12 = 3.33$; H $= 6.67/1 = 6.67$; O $= 53.33/16 = 3.33$. Divide by 3.33: $1 : 2 : 1 \Rightarrow$ EF $= CH_2O$ (mass 30). $n = 180/30 = 6 \Rightarrow$ MF $= C_6H_{12}O_6$ (glucose). STGT 2016

EXAMPLE 13 ADVANCED

0.0833 mol of a carbohydrate of empirical formula CH_2O contains 1 g of hydrogen. Find its molecular formula.

Solution: Moles of H atoms $= 1/1 = 1$ mol. H atoms per molecule $= 1/0.0833 = 12$. MF $= (CH_2O)_n$ has $2n$ H $\Rightarrow 2n = 12,\ n = 6 \Rightarrow$ $C_6H_{12}O_6$, molar mass 180 g/mol.

9. SYMBOLS, IONS, VALENCY AND FORMULA WRITING

9.1 SYMBOLS OF ELEMENTS

Berzelius introduced one- or two-letter symbols from element names (first letter capital, second small). Some come from **Latin/German names** — a favourite one-mark question:

Table: *Symbols derived from classical names*

ELEMENT	SYM.	FROM	ELEMENT	SYM.	FROM
Sodium	Na	Natrium	Copper	Cu	Cuprum
Potassium	K	Kalium	Silver	Ag	Argentum
Iron	Fe	Ferrum	Gold	Au	Aurum
Tin	Sn	Stannum	Lead	Pb	Plumbum
Mercury	Hg	Hydrargyrum	Antimony	Sb	Stibium
Tungsten	W	Wolfram	–	–	–

What a symbol tells you (quantitative meaning). "O" means one atom of oxygen, 16 u of oxygen, and (as gram-atom) 16 g i.e. one mole of O atoms.

9.2 IONS AND RADICALS

An **ion** is an atom or group of atoms carrying a net charge: **cations** (+, e.g. Na^+, NH_4^+) form by electron loss; **anions** (−, e.g. Cl^-, SO_4^{2-}) by electron gain. A charged *group* of atoms that behaves as a single unit in reactions (NH_4^+, OH^-, NO_3^-) is a **polyatomic ion** or **radical**.

9.3 VALENCY

Definition. Valency is the **combining capacity** of an element — classically, the number of hydrogen atoms (or twice the oxygen atoms) one atom of the element combines with.

Electronic theory of valency. If the valence shell holds x electrons, then STGT 2022

$$\text{valency} = x \ \ (\text{if } x \le 4, \text{ by losing/sharing}) \qquad \text{valency} = 8 - x \ \ (\text{if } x > 4, \text{ by gaining})$$

Na (x=1) ⇒ 1; Ca (x=2) ⇒ 2; C (x=4) ⇒ 4; N (x=5) ⇒ 3; O (x=6) ⇒ 2; Cl (x=7) ⇒ 1; Ne (x=8) ⇒ 0.

Table: *Valency table of common ions (learn cold — formula writing depends on it)*

VAL.	CATIONS	ANIONS / RADICALS
1	H^+, Na^+, K^+, Ag^+, NH_4^+, Cu^+(ous), Hg^+(ous)	F^-, Cl^-, Br^-, I^-, OH^-, NO_3^-, NO_2^-, HCO_3^-, HSO_4^-, CN^-, CH_3COO^-, ClO_3^-, MnO_4^-
2	Mg^{2+}, Ca^{2+}, Ba^{2+}, Zn^{2+}, Ni^{2+}, Fe^{2+}(ous), Cu^{2+}(ic), Sn^{2+}(ous), Pb^{2+}(ous), Hg^{2+}(ic)	O^{2-}, S^{2-}, SO_4^{2-}, SO_3^{2-}, CO_3^{2-}, CrO_4^{2-}, $Cr_2O_7^{2-}$
3	Al^{3+}, Fe^{3+}(ic), Cr^{3+}	N^{3-}, P^{3-}, PO_4^{3-}

Variable valency. Many metals show two valencies; the suffix **-ous** marks the lower, **-ic** the higher: ferrous Fe^{2+}/ferric Fe^{3+}; cuprous Cu^+/cupric Cu^{2+}; stannous Sn^{2+}/stannic Sn^{4+}; plumbous Pb^{2+}/plumbic Pb^{4+}; mercurous Hg^+/mercuric Hg^{2+}.

9.4 WRITING FORMULAE: THE CRISS-CROSS METHOD

Write the symbols with their valencies; *exchange* the valencies as subscripts; reduce to the simplest ratio; bracket polyatomic ions before multiplying.

Fig. 6: *Criss-cross method. Always bracket radicals:* $Ca_3(PO_4)_2$, $(NH_4)_2SO_4$.

EXAMPLE 14 EASY

Write formulae of: ammonium sulphate, ferric oxide, magnesium nitride, mercurous chloride.

Solution: $NH_4^+ + SO_4^{2-}$ ⇒ $(NH_4)_2SO_4$; $Fe^{3+} + O^{2-}$ ⇒ Fe_2O_3; $Mg^{2+} + N^{3-}$ ⇒ Mg_3N_2; $Hg^+ + Cl^-$ ⇒ HgCl (written Hg_2Cl_2 as the real dimer).

QUICK NOTES

A **chemical formula** carries quantitative meaning: H_2O = 1 molecule of water = 2 H atoms + 1 O atom = $18\,$u; as gram-formula, $18\,$g = 1 mol = 6.022×10^{23} molecules.

10. CHEMICAL EQUATIONS

Definition. A **chemical equation** is the symbolic shorthand of a chemical reaction: reactant formulae on the left, product formulae on the right, joined by an arrow, with coefficients ensuring atom conservation.

10.1 SIGNIFICANCE OF A BALANCED EQUATION

For $2H_2 + O_2 \longrightarrow 2H_2O$:

Table: *Information packed in one balanced equation*

SCALE	$2H_2$	O_2	$2H_2O$
Molecules	2	1	2
Moles	2 mol	1 mol	2 mol
Mass	4 g	32 g	36 g
Gas volumes (STP)	44.8 L	22.4 L	44.8 L (steam)

Mass check: $4 + 32 = 36$ ✓ — a balanced equation *is* the law of conservation of mass in symbols.

10.2 LIMITATIONS OF A CHEMICAL EQUATION

An ordinary equation does **not** reveal:

- the **rate** of the reaction (fast/slow) or its **mechanism**;
- the **conditions** (T, P, catalyst) unless written over the arrow;
- the **physical states** and **concentrations** unless (s), (l), (g), (aq) are added;
- the **heat change** unless written as a thermochemical equation;
- whether the reaction is **reversible**, goes to **completion**, or has **side reactions**;
- any precipitate (↓) or gas (↑) evolution unless marked.

These gaps are repaired by "making the equation informative" (Sec. 10.4).

10.3 BALANCING OF CHEMICAL EQUATIONS

Why balance? Atoms are conserved (Dalton, postulate 5); an unbalanced equation is chemically illegal. *Never balance by changing a subscript* — that changes the substance itself.

(a) Hit-and-trial method — worked. Balance $Fe + H_2O \longrightarrow Fe_3O_4 + H_2$.

1. Start with the most complex formula, Fe_3O_4: put 3 before Fe and 4 before H_2O:
   $3Fe + 4H_2O \longrightarrow Fe_3O_4 + H_2$.
2. Hydrogen: left $4 \times 2 = 8$, so write $4H_2$:
   $3Fe + 4H_2O \longrightarrow Fe_3O_4 + 4H_2$.
3. Audit: Fe 3/3, O 4/4, H 8/8 ✓.

(b) Algebraic method — worked. Balance $a\,C_3H_8 + b\,O_2 \longrightarrow c\,CO_2 + d\,H_2O$. C: $3a = c$; H: $8a = 2d \Rightarrow d = 4a$; O: $2b = 2c + d = 6a + 4a \Rightarrow b = 5a$. With $a = 1$: $C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$ ✓. Use this method when hit-and-trial loops endlessly.

10.4 MAKING EQUATIONS INFORMATIVE

$$CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)\uparrow$$

$$N_2(g) + 3H_2(g) \underset{}{\overset{\text{Fe, }450^\circ\text{C, }200\text{ atm}}{\rightleftharpoons}} 2NH_3(g) + \text{heat}$$

$$AgNO_3(aq) + NaCl(aq) \longrightarrow AgCl(s)\downarrow + NaNO_3(aq)$$

Symbols: (s) solid, (l) liquid, (g) gas, (aq) aqueous; Δ heat; $h\nu$ light; catalyst over the arrow; $\uparrow$ gas evolved; $\downarrow$ precipitate; $\rightleftharpoons$ reversible.

11. TYPES OF CHEMICAL REACTIONS

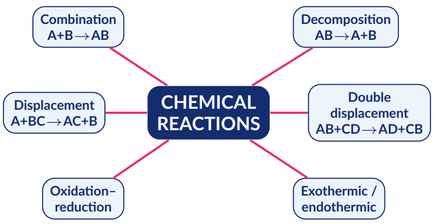

Fig. 7: *Concept map of reaction types. One reaction may belong to several classes.*

11.1 COMBINATION (SYNTHESIS)

Two or more substances unite into one product.

$$2Mg + O_2 \longrightarrow 2MgO \quad \text{(dazzling white flame)}$$

$$CaO + H_2O \longrightarrow Ca(OH)_2 + \text{heat (slaking of lime)}$$

$$H_2 + Cl_2 \xrightarrow{h\nu} 2HCl$$

11.2 DECOMPOSITION

One compound breaks into simpler substances. Energy must be supplied — by heat, electricity or light:

- **Thermal:** $CaCO_3 \xrightarrow{\Delta} CaO + CO_2\uparrow$; $2FeSO_4 \xrightarrow{\Delta} Fe_2O_3 + SO_2\uparrow + SO_3\uparrow$ (green → brown);

  $$2Pb(NO_3)_2 \xrightarrow{\Delta} 2PbO + 4NO_2\uparrow + O_2\uparrow$$

  the **reddish-brown gas** NO_2 is a confirmed STGT answer. STGT 2018
- **Electrolytic:** $2H_2O \xrightarrow{\text{electricity}} 2H_2\uparrow + O_2\uparrow$ ($V_{H_2} : V_{O_2} = 2:1$).
- **Photochemical:** $2AgCl \xrightarrow{h\nu} 2Ag + Cl_2$ (white turns grey); 2AgBr likewise — basis of photographic film.

11.3 DISPLACEMENT

A more reactive element evicts a less reactive one from its compound:

$$Zn + CuSO_4 \longrightarrow ZnSO_4 + Cu \quad \text{(blue colour fades)}$$

$$Fe + CuSO_4 \longrightarrow FeSO_4 + Cu$$

$$Cu + 2AgNO_3 \longrightarrow Cu(NO_3)_2 + 2Ag$$

Activity series (decreasing): K > Na > Ca > Mg > Al > Zn > Fe > Sn > Pb > **H** > Cu > Hg > Ag > Au. Metals above H displace hydrogen from dilute acids.

11.4 DOUBLE DISPLACEMENT (METATHESIS)

Ions exchange partners; driven by formation of a precipitate, gas or water:

$$BaCl_2 + Na_2SO_4 \longrightarrow BaSO_4\downarrow\text{(white)} + 2NaCl$$

$$NaOH + HCl \longrightarrow NaCl + H_2O \quad \text{(neutralisation)}$$

11.5 OXIDATION–REDUCTION (PREVIEW)

Classically: gain of O / loss of H is **oxidation**; loss of O / gain of H is **reduction**. In $CuO + H_2 \xrightarrow{?} Cu + H_2O$, CuO is reduced while H_2 is oxidised — both always occur together (full theory in Unit 7).

11.6 ENERGY CLASSIFICATION

Exothermic (heat released): $C + O_2 \longrightarrow CO_2 + 393.5\,\text{kJ}$; all combustions; respiration; CaO + water. **Endothermic** (heat absorbed): $N_2 + O_2 \longrightarrow 2NO - 180.5\,\text{kJ}$ (i.e. $\Delta H > 0$); $CaCO_3 \xrightarrow{\Delta} CaO + CO_2$; photosynthesis $6CO_2 + 6H_2O \xrightarrow{h\nu} C_6H_{12}O_6 + 6O_2$.

11.7 REVERSIBLE, IRREVERSIBLE AND CATALYTIC

$N_2 + 3H_2 \rightleftharpoons 2NH_3$ (Haber process; Fe catalyst) is reversible; precipitation of AgCl is practically irreversible. A **catalyst** alters the rate without being consumed: $2KClO_3 \xrightarrow{MnO_2,\,\Delta} 2KCl + 3O_2\uparrow$ (lab oxygen, Unit 6).

Hydrolysis worth memorising: STGT 2019

$$Mg_3N_2 + 6H_2O \longrightarrow 3Mg(OH)_2 + 2NH_3\uparrow$$

one mole of magnesium nitride liberates exactly **two moles of ammonia**.

12. STOICHIOMETRY — CHEMICAL ARITHMETIC

Definition. Stoichiometry (Greek *stoicheion* = element, *metron* = measure) is the calculation of masses, moles and volumes of species linked by a balanced equation. The coefficients are the **mole ratios**.

12.1 UNIVERSAL STRATEGY

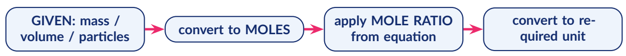

Fig. 8: *All stoichiometry is three steps wide.*

EXAMPLE 15 EASY

(Mass–mass) What mass of carbon must burn to give 33 g of CO_2? STGT 2018

Solution: $C + O_2 \longrightarrow CO_2$: 12 g C → 44 g CO_2. $m_C = \frac{12}{44} \times 33 = 9$ g.

EXAMPLE 16 EASY

(Mass–mass) Mass of oxygen needed to burn 27 g of aluminium completely? STGT 2016

Solution: $4Al + 3O_2 \longrightarrow 2Al_2O_3$. $n_{Al} = 27/27 = 1$ mol; $n_{O_2} = \frac{3}{4} \times 1 = 0.75$ mol; $m = 0.75 \times 32 = \mathbf{24}$ g.

EXAMPLE 17 MODERATE

(Mass–volume) Volume of CO_2 at NTP from the complete decomposition of 2 kg of $CaCO_3$? STGT 2016

Solution: $n = 2000/100 = 20$ mol; equation gives 1:1; $V = 20 \times 22.4 = \mathbf{448}$ L.

EXAMPLE 18 MODERATE

(Volume–volume) 50 mL of CO is exploded with 25 mL of O_2. Find the volume of CO_2 formed (all at the same T, P).

Solution: $2CO + O_2 \longrightarrow 2CO_2$: ratios $2:1:2$. 50 mL CO needs exactly 25 mL $O_2 \rightarrow$ **50** mL CO_2 (Gay-Lussac + Avogadro).

12.2 LIMITING REAGENT

Definition. When reactants are not supplied in the exact stoichiometric ratio, the one that is **consumed first** — the **limiting reagent (LR)** — fixes the maximum product; the other reactant is *in excess*.

Detection (quick method). Divide the available moles of each reactant by its coefficient; **the smallest quotient marks the LR**. Compute all products from the LR only.

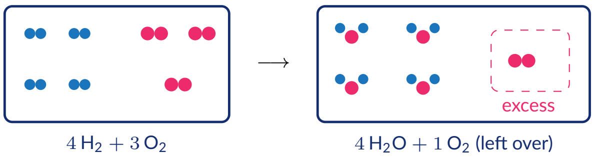

Fig. 9: $2H_2 + O_2 \longrightarrow 2H_2O$ *with 4 mol* H_2 *and 3 mol* O_2*: quotients* $4/2 = 2$ *and* $3/1 = 3$*, so* H_2 *is limiting; only 4 mol water forms.*

EXAMPLE 19 MODERATE

5 moles of A react with 6 moles of B by $2A + 4B \longrightarrow 3C + 4D$. How many moles of C form? STGT 2016

Solution: Quotients: A: $5/2 = 2.5$; B: $6/4 = 1.5 \Rightarrow$ **B is limiting**. $n_C = \frac{3}{4} \times 6 =$ **4.5** mol.

EXAMPLE 20 MODERATE

8 g of H_2 and 64 g of O_2 are exploded in a sealed vessel. How much water forms? STGT 2017

Solution: $n_{H_2} = 8/2 = 4$; $n_{O_2} = 64/32 = 2$. Quotients: $4/2 = 2$ and $2/1 = 2$ — the mixture is *exactly* stoichiometric. Water $= 4$ mol $= 72$ g. Mass audit: $8 + 64 = 72$ g ✓.

EXAMPLE 21 ADVANCED

(Purity) A limestone sample is 90% pure $CaCO_3$. What mass of quicklime is obtained by fully decomposing 1 tonne (10^6 g) of the sample, and what volume does the released CO_2 occupy at NTP?

Solution: Pure $CaCO_3 = 0.9 \times 10^6$ g, so $n = \dfrac{0.9 \times 10^6}{100} = 9000$ mol. The equation $CaCO_3 \longrightarrow CaO + CO_2$ is $1:1:1$. CaO: $9000 \times 56 = 5.04 \times 10^5$ g $=$ **504** kg. CO_2: $9000 \times 22.4 = 2.016 \times 10^5$ L $\approx$ **2.02×10^5** L.

EXAMPLE 22 ADVANCED

(Back-calculation) 4.4 g of CO_2 is released when a metal carbonate MCO_3 of mass 10 g reacts with excess dilute HCl. Find the molar mass of the metal M.

Solution: $n_{CO_2} = 4.4/44 = 0.1$ mol $= n_{MCO_3}$. So $M_{MCO_3} = 10/0.1 = 100$ g/mol $\Rightarrow M = 100 - 60 =$ **40** g/mol (calcium).

13. EXAM CAPSULE — FACTS, TRAPS, HABITS

EXAM POINT

Single-line facts that have already earned marks:

- Maximum atoms/molecules questions: compare *moles*, never grams. (2016, 2018)
- 1 amu $= 1.66 \times 10^{-24}$ g. (2017)
- V.D. of a gas $= M/2$; for a mixture use the mole-fraction average of M. (2017–2022)
- ρ_{NTP} (g/mL) $= M/22400$. (2019, 2022)
- Brown gas from heated lead nitrate $= NO_2$. (2018)
- Mg_3N_2+ water $\rightarrow$ 2 mol NH_3 per mol nitride. (2019)
- Valency $= x$ or $8 - x$. (2022)
- Mass of 1 mol electrons ≈ 0.55 mg. (2026)
- Berthollides ($Fe_{0.95}O$) break the law of constant proportion. (2026)
- Silica = compound; diamond, tungsten = elements. (2026)

COMMON MISTAKES

- Dividing by atomic *number* instead of atomic *mass* (the 2016 paper deliberately printed Al (13) to bait this).
- Using 22.4 L for liquids/solids or at non-STP conditions.
- Forgetting to halve: V.D. $= M/2$, not M.
- Computing product from the *excess* reagent instead of the LR.
- Changing subscripts while balancing equations.
- Writing $Ca(PO_4)_2$ or $CaPO_4$ — bracket and criss-cross properly: $Ca_3(PO_4)_2$.
- Confusing empirical with molecular formula — always finish with $n = M/$EF mass.

All **29 Chemistry MCQs** from this unit asked in STGT 2016, 2017, 2018, 2019, 2022 and 2026, grouped by sub-topic, each with year, difficulty and a teaching solution.

Table: *Year-wise distribution of Unit-1 questions*

2016	2017	2018	2019	2022	2026	TOTAL
7	6	4	4	4	4	**29**

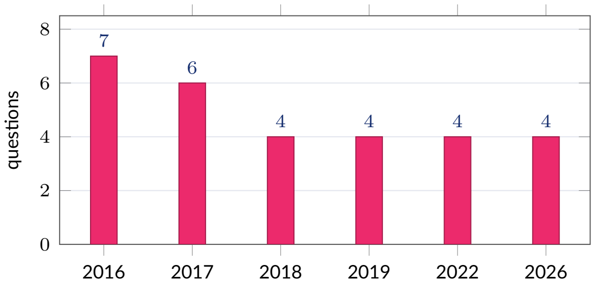

Fig. 10: *The unit has stabilised at 4 questions per paper since 2018.*

Table: *Sub-topic frequency across the six papers*

SUB-TOPIC	QS	REPEAT CHANCE
Stoichiometry & limiting reagent	8	VERY HIGH
Molar volume, gas density, V.D.	7	VERY HIGH
Mole concept & Avogadro number	6	VERY HIGH
% composition, EF & MF	3	HIGH
Conceptual (valency, laws, types)	4	HIGH
Atomic mass unit	1	MODERATE

A. MOLE CONCEPT AND AVOGADRO NUMBER

Q1. STGT 2016 EASY

Which has the maximum number of atoms?

(A) 24 g of C (12) (B) 56 g of Fe (56)
(C) 27 g of Al (27) (D) 108 g of Ag (108)

Answer: (A). Atoms $= \frac{m}{A}N_A$. C: $24/12 = 2$ mol; Fe: $56/56 = 1$; Al: $27/27 = 1$; Ag: $108/108 = 1$. Carbon wins with $2N_A$ atoms. *Trap:* 13 is aluminium's atomic *number* — divide by 27, never 13.

Q2. STGT 2017 EASY

The number of water molecules in 18 mg of water in terms of Avogadro's number N is

(A) $10^{-1}N$ (B) $10\,N$
(C) $10^{-21}N$ (D) $10^{-3}N$

Answer: (D). 18 mg $= 0.018$ g; $n = 0.018/18 = 10^{-3}$ mol; molecules $= 10^{-3}N$. (Re-asked verbatim in 2022 — learn it cold.)

Q3. STGT 2018 EASY

Which of the following contains the maximum number of molecules?

(A) 1 g H_2 (B) 2 g N_2
(C) 4 g O_2 (D) 8 g CO_2

Answer: (A). Moles: H_2: 0.5; N_2: $2/28 = 0.071$; O_2: $4/32 = 0.125$; CO_2: $8/44 = 0.182$. Most moles = most molecules: hydrogen.

Q4. STGT 2019 EASY

The number of atoms in 0.1 mole of a triatomic gas is

(A) 1.806×10^{22} (B) 6.023×10^{23}
(C) 1.806×10^{23} (D) 6.023×10^{22}

Answer: (C). Molecules $= 0.1N_A = 6.023 \times 10^{22}$; atoms $= 3\times$ that $= 1.806 \times 10^{23}$. *Trap:* option (D) is the molecule count.

Q5. STGT 2022 EASY

The number of molecules in 18 mg of water in terms of Avogadro's number N is

(A) $10N$ (B) $10^{-3}N$
(C) $10^{-2}N$ (D) $10^{-5}N$

Answer: (B). Identical to the 2017 question: $0.018/18 = 10^{-3}$ mol $\Rightarrow 10^{-3}N$ molecules. A literal repeat across years — the strongest possible signal of what TRBT recycles.

Q6. STGT 2026 MODERATE

Mass of 1 (one) mole of electron is

(A) 0.20 mg (B) 0.02 mg
(C) 0.55 mg (D) None of the above

Answer: (C). $m = N_A m_e = 6.022 \times 10^{23} \times 9.11 \times 10^{-28}$ g $= 5.49 \times 10^{-4}$ g ≈ 0.55 mg.

B. MOLAR VOLUME, GAS DENSITY AND VAPOUR DENSITY

Q7. STGT 2016 EASY

The volume occupied by 2.5 mole O_2 at NTP will be

(A) 56 L (B) 5.6 L
(C) 0.056 L (D) 56.27 L

Answer: (A). $V = n \times 22.4 = 2.5 \times 22.4 = 56$ L.

Q8. STGT 2016 EASY

The volume of CO_2 gas obtained from 2 kg $CaCO_3$ at NTP is

(A) 448 L (B) 44.8 L
(C) 22.4 L (D) 4.48 L

Answer: (A). $CaCO_3 \xrightarrow{\Delta} CaO + CO_2$; $n = 2000/100 = 20\,\text{mol}$; $V = 20 \times 22.4 = 448\,\text{L}$.

Q9. STGT 2017 MODERATE

The volume of 60 g of a gas at STP is 5.6 L. Its vapour density is

(A) 30 (B) 120
(C) 60 (D) 240

Answer: (B). $M = \dfrac{60 \times 22.4}{5.6} = 240\,\text{g/mol}$; V.D. $= M/2 = 120$.

Q10. STGT 2018 MODERATE

The volume of 20 g of a gas at STP is 5.6 L. Its vapour density is

(A) 10 (B) 40
(C) 20 (D) 80

Answer: (B). $M = \dfrac{20 \times 22.4}{5.6} = 80$; V.D. $= 40$. The 2017 question re-skinned with new numbers — same two lines of work.

Q11. STGT 2019 MODERATE

The density of a gas at NTP is 0.002848 g mL^{-1}. The gas is

(A) N_2 (B) CO_2
(C) CH_4 (D) SO_2

Answer: (D). $M = \rho \times 22400 = 0.002848 \times 22400 = 63.8 \approx 64\,\text{g/mol} \Rightarrow SO_2$. *Note:* a widely circulated key prints (B), but CO_2 would require $\rho = 44/22400 = 0.00196\,\text{g/mL}$; the arithmetic unambiguously selects SO_2.

Q12. STGT 2019 MODERATE

Volumes of N_2 and O_2 in a gas mixture are 80% and 20% respectively. The average vapour density of the mixture is

(A) 14.4 (B) 15
(C) 30 (D) None of the above

Answer: (A). Volume % = mole % for gases: $\bar{M} = 0.8(28) + 0.2(32) = 28.8$; V.D. $= 28.8/2 = 14.4$.

Q13. STGT 2022 MODERATE

If the density of a gas at NTP is 0.001936 g/mL, then the molecular weight of the gas is

(A) 44 (B) 22
(C) 32 (D) 64

Answer: (A). $M = 0.001936 \times 22400 = 43.4 \approx 44$ (carbon dioxide). The 2019 density question recycled in reverse — they give ρ, you return M.

C. STOICHIOMETRY AND LIMITING REAGENT

Q14. STGT 2016 MODERATE

5 moles of A react with 6 moles of B according to the equation $2A + 4B \longrightarrow 3C + 4D$. How many moles of C are formed?

(A) 9 moles (B) 11 moles
(C) 4.5 moles (D) 6 moles

Answer: (C). Quotients: A: $5/2 = 2.5$; B: $6/4 = 1.5 \Rightarrow$ B limiting. $n_C = \frac{3}{4} \times 6 = 4.5\,\text{mol}$.

Q15. STGT 2016 MODERATE

[Bengali-version repeat of the above on the same paper.] 5 mole A reacts with 6 mole B as $2A + 4B \longrightarrow 3C + 4D$; moles of C formed?

(A) 9 mole (B) 11 mole
(C) 4.5 mole (D) 6 mole

Answer: (C). Same working: B is limiting, 4.5 mol of C. TRBT printed the bilingual twin as a separate item — effectively a free repeat mark.

Q16. STGT 2016 EASY

The amount of oxygen necessary to react completely with 27 g of Al is

(A) 8 g (B) 16 g
(C) 24 g (D) 32 g

Answer: (C). $4Al + 3O_2 \longrightarrow 2Al_2O_3$; 1 mol Al needs $\frac{3}{4}$ mol O_2 $= 0.75 \times 32 = 24\,\text{g}$.

Q17. STGT 2017 EASY

If 1.5 moles of oxygen combine with Al to form Al_2O_3, the mass of Al (at. mass 27) used is

(A) 54 g (B) 40.5 g
(C) 27 g (D) 2.7 g

Answer: (A). $n_{Al} = \frac{4}{3} \times 1.5 = 2\,\text{mol} \Rightarrow 54\,\text{g}$. The 2016 aluminium question inverted — same equation, opposite direction.

Q18. STGT 2017 MODERATE

8 g of H_2 and 64 g of O_2 are filled in a steel vessel and exploded. The amount of water produced is

(A) 3 mol (B) 1 mol
(C) 2 mol (D) 4 mol

Answer: (D). $n_{H_2} = 4$, $n_{O_2} = 2$; the $2:1$ requirement is met exactly, so all of it reacts: 4 mol H_2O ($= 72\,\text{g} = 8 + 64$, conservation check ✓).

Q19. STGT 2017 EASY

The amount of CO_2 released from the reaction of 10 g $CaCO_3$ with excess dilute HCl is

(A) 0.4 g (B) 4.4 g
(C) 44 g (D) 88 g

Answer: (B). $CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$; $n = 10/100 = 0.1\,\text{mol} \Rightarrow 0.1 \times 44 = 4.4\,\text{g}$.

Q20. STGT 2018 EASY

How many grams of carbon must be burnt to produce 33 g of CO_2?

(A) 9 g (B) 12 g
(C) 6 g (D) 16.5 g

Answer: (A). $12\,\text{g C} \to 44\,\text{g CO}_2$; $m = \frac{12}{44} \times 33 = 9\,\text{g}$.

Q21. STGT 2019 EASY

One mole of magnesium nitride on reaction with excess of water gives

(A) 2 moles of ammonia (B) 1 mole of nitric acid
(C) 2 moles of nitric acid (D) 1 mole of ammonia

Answer: (A). $Mg_3N_2 + 6H_2O \longrightarrow 3Mg(OH)_2 + 2NH_3$. A nitride ion ($N^{3-}$) hydrolyses to ammonia, never nitric acid; the $1:2$ ratio gives two moles.

D. ATOMIC MASS UNIT

Q22. STGT 2017 EASY

The value of 1 amu in gram is

(A) 1.66×10^{-24} (B) 16.6×10^{-24}
(C) 166×10^{-24} (D) 0.166×10^{-24}

Answer: (A). $1\,\text{amu} = \frac{1}{N_A}\,\text{g} = \frac{1}{6.022 \times 10^{23}} = 1.66 \times 10^{-24}\,\text{g}$.

E. PERCENTAGE COMPOSITION AND FORMULAE

Q23. STGT 2016 EASY

The empirical formula and molecular mass of a compound are CH_2O and 180 g respectively. The molecular formula is

(A) $C_9H_8O_9$ (B) CH_2O
(C) $C_6H_{12}O_6$ (D) $C_2H_4O_2$

Answer: (C). EF mass $= 30$; $n = 180/30 = 6$; MF $= (CH_2O)_6 = C_6H_{12}O_6$ (glucose).

Q24. STGT 2022 EASY

The amount of oxygen present in NaOH in percent is

(A) 16 (B) 32
(C) 40 (D) None of the above

Answer: (C). $M = 40$; %O $= \frac{16}{40} \times 100 = 40\%$. *Trap:* option (A) is oxygen's atomic mass, not its percentage.

Q25. STGT 2026 DIFFICULT

A carbohydrate having empirical formula CH_2O has 1 g hydrogen in its 0.0833 mole. Then the molecular formula of the carbohydrate is

(A) $C_5H_{10}O_5$ (B) $C_3H_4O_3$
(C) $C_{12}H_{22}O_{11}$ (D) None of the above

Answer: (A) as per the released key — but read the analysis. H atoms per molecule $= \frac{1\,\text{mol H}}{0.0833\,\text{mol}} = 12 \Rightarrow 2n = 12,\ n = 6 \Rightarrow C_6H_{12}O_6$, which is *absent* from the options. The intended answer per the circulated key is the pentose $C_5H_{10}O_5$ (the only listed carbohydrate of type $(CH_2O)_n$); options (B) and (C) are not $(CH_2O)_n$ at all. In a defective question, eliminate structurally impossible options first.

F. CONCEPTUAL: VALENCY, LAWS AND REACTIONS

Q26. STGT 2018 EASY

Lead nitrate when heated strongly evolves a brown coloured gas. The gas is

(A) N_2 (B) N_2O
(C) NO_2 (D) NO

Answer: (C). $2Pb(NO_3)_2 \xrightarrow{\Delta} 2PbO + 4NO_2 \uparrow + O_2 \uparrow$; nitrogen dioxide is the reddish-brown gas.

Q27. STGT 2022 EASY

If the valence shell of an element contains x electrons, then the valency of the element is

(A) x (B) $x - 8$
(C) $8 - x$ (D) x and $8 - x$

Answer: (D). Metals ($x \le 4$) lose electrons: valency x. Nonmetals ($x > 4$) gain: valency $8 - x$. Both rules together describe "the valency of an element" in general.

Q28. STGT 2026 DIFFICULT

Law of constant proportion does not hold good for

(A) exothermic compounds (B) stoichiometric compounds
(C) endothermic compounds (D) None of the above

Answer: (D). The genuine exceptions are *non-stoichiometric* (berthollide) compounds like $Fe_{0.95}O$ and isotopic variants — none of which is listed. Heat character (exo/endo) is irrelevant to composition.

Q29. STGT 2026 EASY

Which of the following is not an element?

(A) Diamond (B) Silica
(C) Tungsten (D) None of the above

Answer: (B). Silica $= SiO_2$, a compound. Diamond is carbon; tungsten (W) is a metal.

TREND ANALYSIS AND EXAM STRATEGY

EXAM PATTERN CONTEXT

The STGT Physical/Pure Science paper is a **150-mark MCQ test** spanning Physics, Chemistry and Mathematics; Chemistry contributes roughly 50 questions, of which this unit reliably supplies **4–5**. Every question is single-correct, four-option. (Always confirm the marking scheme in the current TRBT notification.)

WHAT THE SIX PAPERS REVEAL

- **Numericals outnumber theory 3:1** in this unit — 22 of 29 questions are calculations, almost all single-formula.
- **Literal repeats occur**: the 18-mg-water question appeared verbatim in 2017 and 2022; the 5A+6B limiting-reagent item ran twice in 2016 alone (bilingual twin); the gas-at-5.6-L vapour-density template ran in 2017 and 2018 with changed numbers.
- **The 22.4-litre lever**: 13 of 29 questions are solved by $n = m/M$ plus $V = 22.4\,n$ or $M = 2\times$V.D. — master two lines, win 45% of the unit.
- **2026 turned conceptual**: three of four questions (electron-mole, berthollides, silica) tested concepts rather than arithmetic — prepare definitions and exceptions, not just formulas.
- Difficulty mix across six years: $\approx 62\%$ easy, 31% moderate, 7% difficult.

MOST IMPORTANT AREAS (IN ORDER)

1. Mole $\leftrightarrow$ mass $\leftrightarrow$ particles $\leftrightarrow$ volume conversions.
2. V.D. $= M/2$ and $\rho_{\text{NTP}} = M/22400$.
3. Limiting reagent by the quotient method.
4. Mass–mass stoichiometry on $CaCO_3$, Al/O_2, C/CO_2.
5. EF $\to$ MF via $n = M/$EF mass.
6. One-liner facts: amu, NO_2 colour, Mg_3N_2 hydrolysis, valency rule, berthollides.

LAST-MINUTE REVISION POINTS

- $N_A = 6.022 \times 10^{23}$; 1 amu $= 1.66 \times 10^{-24}$ g; $V_m = 22.4$ L; 1 mol e$^-$ $= 0.55$ mg.
- Max-atoms trick: convert to moles; watch atomic-number decoys.
- Mixture V.D.: mole-fraction-weighted $\bar{M}$, then halve.
- Quotient rule: n_i/ν_i smallest $\Rightarrow$ limiting reagent.
- $CaCO_3$ family: $100\,\text{g} \to 56\,\text{g}$ CaO $+\ 44\,\text{g}$ CO_2 (22.4 L at NTP).

EXAM POINT

Probability outlook for the next paper (from 2016–2026 frequencies): one mole-counting question ($p \approx 0.9$), one V.D./density question ($p \approx 0.85$), one stoichiometry/LR question ($p \approx 0.9$), one conceptual one-liner ($p \approx 0.7$). Expect at least two recycled templates from the solved set above.

PREDICTED HIGH-PROBABILITY QUESTIONS

QP1. STGT TARGET | MOLE MAP

The volume occupied by 3.2 g of SO_2 at NTP is

(A) 1.12 L (B) 2.24 L
(C) 11.2 L (D) 22.4 L

Answer: (A). $n = 3.2/64 = 0.05$; $V = 0.05 \times 22.4 = 1.12$ L.

QP2. STGT TARGET | V.D.

11 g of a gas occupies 5.6 L at STP. Its vapour density is

(A) 11 (B) 22
(C) 44 (D) 88

Answer: (B). $M = 11 \times 22.4/5.6 = 44$; V.D. $= 22$. (The 2017/2018 template with fresh numbers.)

QP3. STGT TARGET | MOLES

Which contains the maximum number of molecules?

(A) 4 g H_2 (B) 32 g O_2
(C) 44 g CO_2 (D) 28 g CO

Answer: (A). Moles: 2, 1, 1, 1 — hydrogen again. The "max particles" stem appeared in 2016 and 2018; expect it re-skinned.

QP4. STGT TARGET | PERCENT

The percentage of oxygen in Na_2CO_3 is

(A) 45.3% (B) 16%
(C) 48% (D) 30.2%

Answer: (A). $M = 106$; %O $= \frac{48}{106} \times 100 = 45.3\%$.

QP5. STGT TARGET | MOLE OF p

The mass of one mole of protons is approximately

(A) 1 g (B) 1 mg
(C) 0.55 mg (D) 9.1 g

Answer: (A). $6.022 \times 10^{23} \times 1.67 \times 10^{-24}$ g ≈ 1.0 g. (The 2026 electron question with a proton swap.)

QP6. STGT TARGET | EF–MF

A hydrocarbon has empirical formula CH and vapour density 39. Its molecular formula is

(A) C_2H_2 (B) C_6H_6
(C) C_4H_4 (D) C_8H_8

Answer: (B). $M = 2 \times 39 = 78$; EF mass $= 13$; $n = 78/13 = 6 \Rightarrow C_6H_6$ (benzene).

QP7. STGT TARGET LIMITING

3 mol of N_2 and 6 mol of H_2 react by $N_2 + 3H_2 \longrightarrow 2NH_3$. Moles of ammonia formed:

(A) 6 (B) 4
(C) 2 (D) 12

Answer: (B). Quotients: $3/1 = 3$; $6/3 = 2 \Rightarrow H_2$ limiting; $n_{NH_3} = \frac{2}{3} \times 6 = 4$ mol.

QP8. STGT TARGET REACTION

On strong heating, copper(II) nitrate evolves a reddish-brown gas, which is

(A) O_2 (B) N_2O
(C) NO_2 (D) NH_3

Answer: (C). Heavy-metal nitrates release NO_2 (brown) + O_2 on heating — the 2018 lead-nitrate fact generalised.

QP9. STGT TARGET CONCEPT

$Fe_{0.95}O$ is an example of a compound that violates the law of

(A) conservation of mass (B) constant proportion
(C) multiple proportions (D) combining volumes

Answer: (B). Berthollide = non-stoichiometric = composition not fixed $\Rightarrow$ the law of constant (definite) proportion fails.

QP10. STGT TARGET HYDROLYSIS

Two moles of Mg_3N_2 react with excess water. Moles of NH_3 liberated:

(A) 2 (B) 3
(C) 4 (D) 6

Answer: (C). $Mg_3N_2 + 6H_2O \longrightarrow 3Mg(OH)_2 + 2NH_3$: each mole gives 2, so $2 \to 4$ mol.

PRACTICE QUESTIONS — LEVEL 1 (FOUNDATION)

1. The SI unit of amount of substance is
(A) kilogram (B) mole
(C) candela (D) litre

2. The number of molecules in one mole of CO_2 is
(A) 3.011×10^{23} (B) 6.022×10^{23}
(C) 1.20×10^{24} (D) 22.4×10^{23}

3. The molecular mass of H_2SO_4 is
(A) 49 u (B) 96 u
(C) 98 u (D) 100 u

4. The volume occupied by 0.5 mol of O_2 at NTP is
(A) 22.4 L (B) 11.2 L
(C) 5.6 L (D) 44.8 L

5. The mass of 0.25 mol of $CaCO_3$ (M = 100) is
(A) 400 g (B) 40 g
(C) 25 g (D) 2.5 g

6. The symbol of tungsten is
(A) Tu (B) Tg
(C) W (D) Wo

7. The correct formula of aluminium sulphate is
(A) $AlSO_4$ (B) $Al_2(SO_4)_3$
(C) $Al_3(SO_4)_2$ (D) $Al(SO_4)_3$

8. Which sample contains more molecules: 1 g of H_2 or 1 g of O_2?
(A) 1 g H_2 (B) 1 g O_2
(C) equal (D) cannot be compared

9. The vapour density of methane (CH_4) is
(A) 16 (B) 8
(C) 4 (D) 32

10. "Total mass remains constant during a chemical change" is the law of
(A) constant proportion (B) multiple proportions
(C) conservation of mass (D) combining volumes

11. Which of the following is a diatomic molecule?
(A) O_3 (B) P_4
(C) S_8 (D) N_2

12. The number of moles in 90 g of water is
(A) 2 (B) 5
(C) 10 (D) 18

13. The formula of ferric oxide is
(A) FeO (B) Fe_2O_3
(C) Fe_3O_4 (D) FeO_2

14. $CaCO_3 \xrightarrow{\Delta} CaO + CO_2$ is an example of a
(A) combination reaction (B) displacement reaction
(C) decomposition reaction (D) double displacement reaction

15. The atomicity of white phosphorus is
(A) 1 (B) 2
(C) 4 (D) 8

PRACTICE QUESTIONS — LEVEL 2 (STGT STANDARD)

1. The number of atoms in 4.8 g of magnesium (M = 24) is
(A) 1.204×10^{23} (B) 6.022×10^{23}
(C) 2.4×10^{22} (D) 4.8×10^{23}

2. The volume of 1.7 g of ammonia at NTP is
(A) 22.4 L (B) 2.24 L
(C) 1.12 L (D) 11.2 L

3. The vapour density of a gas is 22. The gas could be
(A) CO (B) N_2O
(C) SO_2 (D) NO_2

4. The percentage of nitrogen in $(NH_4)_2SO_4$ (M = 132) is about
(A) 10.6% (B) 21.2%
(C) 28% (D) 42.4%

5. A hydrocarbon has empirical formula CH_2 and vapour density 28. Its molecular formula is
(A) C_2H_4 (B) C_3H_6
(C) C_4H_8 (D) C_5H_{10}

6. 12 g of magnesium reacts with excess dilute HCl. The volume of hydrogen evolved at NTP is
(A) 22.4 L (B) 11.2 L
(C) 5.6 L (D) 2.24 L

7. The mass of a single water molecule is closest to
(A) 3×10^{-23} g (B) 3×10^{-21} g
(C) 1.8×10^{-22} g (D) 6×10^{-24} g

8. 4 mol of Al reacts with 4 mol of O_2 ($4Al + 3O_2 \longrightarrow 2Al_2O_3$). The moles of Al_2O_3 formed are
(A) 1 (B) 2
(C) 3 (D) 4

9. Equal masses of CH_4 and O_2 are mixed. The ratio of the numbers of their molecules is
(A) 1 : 1 (B) 1 : 2
(C) 2 : 1 (D) 16 : 32

10. 5.6 L of a gas at NTP weighs 8 g. The gas is
(A) CH_4 (B) N_2
(C) O_2 (D) CO_2

11. The number of sodium ions in 0.5 mol of Na_2SO_4 is
(A) 3.011×10^{23} (B) 6.022×10^{23}
(C) 1.204×10^{24} (D) 1.5×10^{23}

12. The volume of O_2 at NTP obtained by decomposing 49 g of $KClO_3$ (M = 122.5) is
(A) 6.72 L (B) 13.44 L
(C) 22.4 L (D) 4.48 L

13. The percentage of water of crystallisation in $CuSO_4 \cdot 5H_2O$ (M = 249.5) is about

(A) 18% (B) 25%
(C) 36% (D) 45%

14. One gram each of Li (7), Na (23), Au (197) and Cl_2 (71) is taken. The maximum number of atoms is present in

(A) Li (B) Na
(C) Au (D) Cl_2

15. The mass of $CaCl_2$ (M = 111) needed to obtain 0.2 mol of chloride ions in solution is

(A) 22.2 g (B) 11.1 g
(C) 5.55 g (D) 44.4 g

PRACTICE QUESTIONS — LEVEL 3 (ADVANCED / COMPETITIVE EDGE)

1. Equal *masses* of CH_4 (16) and O_2 (32) are mixed in a vessel. The mean molar mass of the mixture is

(A) 24.0 g/mol (B) 21.3 g/mol
(C) 26.7 g/mol (D) 18.5 g/mol

2. A hydrated salt $Na_2CO_3 \cdot xH_2O$ contains about 62.9% water of crystallisation by mass. The value of x is

(A) 5 (B) 7
(C) 10 (D) 12

3. 10 g of impure chalk liberates 2.016 L of CO_2 at NTP on complete reaction with acid. The percentage purity of $CaCO_3$ is

(A) 75% (B) 80%
(C) 90% (D) 95%

4. 0.1 mol of a hydrocarbon on complete combustion gives 0.3 mol CO_2 and 0.4 mol H_2O. The hydrocarbon is

(A) C_3H_6 (B) C_3H_8
(C) C_4H_8 (D) C_2H_6

5. Counting at one billion (10^9) entities per second, the time needed to count one mole is nearest to

(A) 19 years (B) 1.9 thousand years
(C) 19 million years (D) 19 billion years

6. The mass of aluminium present in 34.2 g of $Al_2(SO_4)_3$ (M = 342) is

(A) 2.7 g (B) 5.4 g
(C) 8.1 g (D) 10.8 g

7. 1 L of methane is burnt with the exact volume of oxygen needed, all volumes at the same T and P. The volumes of O_2 used and CO_2 formed are

(A) 2 L and 1 L (B) 1 L and 1 L
(C) 2 L and 2 L (D) 3 L and 2 L

8. 10 g of $CaCO_3$ is treated with 10 g of HCl ($CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$). The mass of CO_2 produced is

(A) 4.4 g (B) 6.0 g
(C) 8.8 g (D) 2.2 g

9. In a preparation, the theoretical yield of a product is 5.4 g but only 4.86 g is isolated. The percentage yield is

(A) 85% (B) 88%
(C) 90% (D) 95%

10. An oxide of nitrogen has vapour density 23. The oxide is

(A) NO (B) N_2O
(C) NO_2 (D) N_2O_5

ASSERTION–REASON QUESTIONS

Code: (A) Both A and R are true and R is the correct explanation of A. (B) Both A and R are true but R is *not* the correct explanation of A. (C) A is true but R is false. (D) A is false but R is true.

AR1. A: One mole of O_2 and one mole of O_3 contain the same number of molecules.
R: Equal amounts (in moles) of all substances contain equal numbers of elementary entities.

AR2. A: The vapour density of CO_2 is 22.
R: Vapour density equals half the molecular mass of a gas.

AR3. A: The law of conservation of mass holds exactly in nuclear reactions.
R: In nuclear reactions a measurable amount of mass is converted into energy according to $E = \Delta mc^2$.

AR4. A: 1 g of H_2 contains more molecules than 16 g of O_2.
R: The number of moles of a substance equals its mass divided by its molar mass.

AR5. A: CH_2O can be the empirical formula of both glucose and acetic acid.
R: Different compounds may share the same simplest whole-number atomic ratio.

AR6. A: 4 g of hydrogen reacts exactly with 32 g of oxygen to form water.
R: Mass is conserved in every chemical reaction.

AR7. A: The gas evolved on strongly heating lead nitrate is reddish-brown.
R: Thermal decomposition of lead nitrate produces nitrogen dioxide.

AR8. A: The valency of nitrogen in ammonia is 3.
R: Nitrogen has five valence electrons and its valency is $8-5=3$.

HOTS — HIGHER ORDER THINKING

H1. Two identical flasks at the same temperature and pressure contain H_2 and CO_2 respectively. The ratio of the mass of CO_2 to the mass of H_2 is

(A) 1 : 1 (B) 22 : 1

(C) 44 : 1 (D) 11 : 1

H2. If the Avogadro constant were redefined as 10^{24} mol^{-1}, the mass of one mole of ^{16}O atoms would become about

(A) 16 g (B) 9.6 g

(C) 26.6 g (D) 32 g

H3. A coal sample contains 3.2% sulphur by mass. The mass of SO_2 released on completely burning 1 kg of this coal is

(A) 32 g (B) 64 g

(C) 128 g (D) 16 g

H4. One drop of water has a volume of about 0.05 mL (density 1 g/mL). The number of molecules in one drop is nearest to

(A) 1.7×10^{21} (B) 3.0×10^{22}

(C) 6.0×10^{23} (D) 1.7×10^{19}

H5. Natural boron is 19.9% ^{10}B and 80.1% ^{11}B. Its average atomic mass is closest to

(A) 10.2 u (B) 10.5 u

(C) 10.8 u (D) 11.0 u

H6. A vessel holds a mixture of equal masses of N_2 (28) and CO (28). The vapour density of the mixture is

(A) 28 (B) 21

(C) 14 (D) cannot be found without volumes

ANSWER KEYS AND HINTS

Table: *Level 1*

1	2	3	4	5	6	7	8
B	B	C	B	C	C	B	A
9	**10**	**11**	**12**	**13**	**14**	**15**	
B	C	D	B	B	C	C	

Table: *Level 2*

1	2	3	4	5	6	7	8
A	B	B	B	C	B	A	B
9	**10**	**11**	**12**	**13**	**14**	**15**	
C	C	B	B	C	A	B	

Table: *Level 3*

1	2	3	4	5	6	7	8	9	10
B	C	C	B	C	B	A	A	C	C

Table: *Assertion–Reason and HOTS*

AR1	AR2	AR3	AR4	AR5	AR6	AR7	AR8
A	A	D	D	A	B	A	A
H1	**H2**	**H3**	**H4**	**H5**	**H6**		
B	C	B	A	C	C		

HINTS TO SELECTED PROBLEMS

- **L2-8:** Quotients $4/4 = 1$ (Al) vs $4/3 = 1.33$ (O_2); Al limiting; $Al_2O_3 = \frac{2}{4} \times 4 = 2$ mol.
- **L2-14:** Moles of atoms: Li $1/7$, Na $1/23$, Au $1/197$, Cl_2 $\frac{1}{71} \times 2 = 1/35.5$ — lithium wins.
- **L3-1:** Equal masses ⇒ harmonic mean: $\bar{M} = \dfrac{2}{\frac{1}{16} + \frac{1}{32}} = \dfrac{2 \times 32}{3} = 21.3$ g/mol.
- **L3-2:** $\dfrac{18x}{106 + 18x} = 0.629 \Rightarrow x \approx 10$ (washing soda).
- **L3-3:** $n_{CO_2} = 2.016/22.4 = 0.09$ mol ⇒ 9 g pure $CaCO_3$ in 10 g.
- **L3-4:** C $= 0.3/0.1 = 3$; H $= 2(0.4)/0.1 = 8 \Rightarrow C_3H_8$.
- **L3-5:** $6.022 \times 10^{23}/10^{9} = 6.022 \times 10^{14}$ s $\approx 1.9 \times 10^{7}$ years.
- **L3-8:** Quotients: $CaCO_3$ $0.1/1 = 0.1$; HCl $0.274/2 = 0.137 \Rightarrow$ $CaCO_3$ limiting $\Rightarrow 0.1 \times 44 = 4.4$ g.
- **H2:** The mass of one O atom is fixed ($16 \times 1.66 \times 10^{-24}$ g); multiplying by the new 10^{24} gives ≈ 26.6 g.
- **H4:** $\dfrac{0.05}{18} \times 6.022 \times 10^{23} = 1.67 \times 10^{21}$.
- **H6:** Both components have $M = 28$, so $\bar{M} = 28$ and V.D. $= 14$ — composition irrelevant.

QUICK REVISION — ONE-PAGE SUMMARY

LAWS OF CHEMICAL COMBINATION

- **Conservation of mass** (Lavoisier): $\sum m_R = \sum m_P$; verified by Landolt's sealed H-tube; fails only for nuclear changes ($E = \Delta mc^2$).
- **Constant proportion** (Proust): fixed mass ratio; exceptions — berthollides ($Fe_{0.95}O$), isotopic variants.
- **Multiple proportions** (Dalton): CO vs $CO_2 \Rightarrow$ O ratio $1:2$.
- **Reciprocal proportions** (Richter); **combining volumes** (Gay-Lussac, gases only).

DALTON VS REALITY

Postulates: indivisible atoms, identical within an element, simple ratios, rearrangement only. Broken by: subatomic particles, isotopes/isobars, Gay-Lussac's volumes (fixed by Avogadro's *molecules*).

MOLE ESSENTIALS

- $n = \frac{m}{M} = \frac{N}{N_A} = \frac{V_{STP}}{22.4\,L}$; $N_A = 6.022 \times 10^{23}$ mol^{-1}.
- $1\,u = 1.66 \times 10^{-24}$ g; atomic mass scale: $\frac{1}{12}$ of ^{12}C (IUPAC 1961).
- V.D. $= M/2$ (from Avogadro); $\rho_{NTP} = M/22400$ g/mL.
- Mixture: $\bar{M} = \sum x_i M_i$ (mole/volume fractions); equal masses $\Rightarrow$ harmonic mean.
- 1 mol $e^- = 0.55$ mg; 1 mol $p^+ \approx 1$ g.

FORMULAE AND VALENCY

- Valency $= x$ ($x \le 4$) or $8 - x$ ($x > 4$); -ous = lower, -ic = higher.
- Criss-cross with bracketed radicals: $Ca_3(PO_4)_2$, $(NH_4)_2SO_4$, Fe_2O_3.
- $\%X = \frac{n_X A_X}{M} \times 100$; MF = $(EF)_n$, $n = \frac{M}{\text{EF mass}}$.

EQUATIONS AND REACTIONS

- Balanced equation = conservation of mass; balance by coefficients (hit-and-trial / algebraic), never subscripts.
- Significance: mole, mass and volume ratios. Limitations: no rate, conditions, states, heat, reversibility unless added.
- Types: combination, decomposition (Δ / electric / light), displacement (activity series), double displacement (ppt., neutralisation), redox, exo/endo, reversible, catalytic.
- Must-know: $2Pb(NO_3)_2 \xrightarrow{\Delta} 2PbO + 4NO_2 + O_2$ (brown gas); $Mg_3N_2 + 6H_2O \longrightarrow 3Mg(OH)_2 + 2NH_3$; $CaCO_3 \xrightarrow{\Delta} CaO + CO_2$.
- Limiting reagent: smallest n_i/ν_i; compute everything from it.

FORMULA SHEET

$n = \frac{m}{M}$	moles from mass	$N = n\,N_A$	particles from moles
$V = 22.4\,n$ L at STP/NTP	gas volume	$M = \frac{m \times 22400}{V(\text{mL})}$	molar mass from gas data
$M = 2 \times$ V.D.	vapour density link	$\rho_{NTP} = \frac{M}{22400}$ g/mL	absolute gas density
$\bar{M} = x_1M_1 + x_2M_2$	gas mixtures (mole fr.)	$1\,u = \frac{1}{N_A}\,g = 1.66 \times 10^{-24}$ g	atomic mass unit
$\%X = \frac{n_X A_X}{M} \times 100$	percent composition	$n_{(EF \to MF)} = \frac{M}{\text{EF mass}}$	molecular formula
$\bar{A} = \sum(\text{abundance} \times \text{isotopic mass})$	avg. atomic mass	LR: smallest $\frac{n_i}{\nu_i}$	limiting reagent
$\%\,\text{yield} = \frac{\text{actual}}{\text{theoretical}} \times 100$	efficiency	$\%\,\text{purity} = \frac{\text{pure mass}}{\text{sample mass}} \times 100$	impure samples

QUICK NOTES

Memory tricks.

- Diatomic elements: "*Have No Fear Of Ice Cold Beer*" (H, N, F, O, I, Cl, Br).
- Laws: "*Lavoisier Conserves, Proust Fixes, Dalton Multiplies, Richter Reciprocates, Gay-Lussac Gasifies.*"
- Activity series in reactivity blocks: **K Na Ca Mg Al** (very reactive) > **Zn Fe Sn Pb** (moderate) > **H** > **Cu Hg Ag Au** (noble) — metals left of H displace hydrogen from dilute acids.
- Mole day: 6.02, 10/23 — 6:02 am, 23 October.
- Latin symbols: *Natrium*, *Kalium*, *Ferrum*, *Cuprum*, *Ag* (argentum), *Au* (aurum), *Pb* (plumbum), *Sn* (stannum), *Hg* (hydrargyrum), *W* (wolfram).

Table: *Frequently confused pairs — settle them now*

PAIR	DISTINCTION
Atomic mass vs mass number	Weighted isotopic average (fractional) vs $p+n$ count of one isotope (whole number)
Atom vs molecule	Reaction unit vs smallest free-existing unit
Atomicity vs valency	Atoms per elemental molecule vs combining capacity
Mole of atoms vs mole of molecules	1 mol O_2 $=2$ mol O atoms — read the question's entity
V.D. vs gas density	Dimensionless $M/2$ vs $M/22.4$ g/L at NTP
STP/NTP (exam) vs room temp.	22.4 L/mol at 273 K, 1 atm vs ~ 24.5 L/mol at 298 K
Empirical vs molecular formula	Simplest ratio vs actual count; same EF $\neq$ same compound
1 u vs 1 g	1.66×10^{-24} g vs N_A u
Coefficient vs subscript	Balancing may change coefficients only — subscripts define the substance

EXAM POINT

Final 60-second drill before the exam: $N_A = 6.022\times10^{23}$ • 22.4 L • 1 u $= 1.66\times10^{-24}$ g • V.D. $= M/2$ • e^--mole $= 0.55$ mg • NO_2 brown • $Mg_3N_2 \to 2NH_3$ • valency x / $8-x$ • $Fe_{0.95}O$ breaks Proust • silica is a compound • LR $=$ smallest n/ν • $CaCO_3$: $100 \to 56 + 44$.

END OF UNIT 1 — ATOMS AND MOLECULES

Next in this series: Unit 2 — Structure of Atom • Quarks Physics Institute • STGT Pure Science