LOGIC BLOOM · CHEMISTRY · APPLICATIONS SET

Advanced Stoichiometry & Concentration

Mole Concept applications · JEE **Main** and **Advanced**

Twenty-four applied problems on the topics that decide the Physical Chemistry paper. Back titration, double titration, oleum, volume strength, eudiometry and the concentration interconversions, each solved with the reasoning written out.

24 Questions · Main + Advanced · Multiple-Correct & NAT · Full Solutions · Answer Key

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0 How to Use This Set

- **Section A** is concentration terms: 8 single-correct and 2 numerical.
- **Section B** is applied stoichiometry: 8 single-correct, 2 multiple-correct and 4 numerical.
- Take **molar volume at STP as 22.4 L** and use the atomic masses given in each question.
- Every number here was computed and checked before printing, including a sanity check that no purity came out above 100%.

THINK IT THROUGH

THE FOUR IDEAS THAT CARRY THIS WHOLE TOPIC

- **Mole ratio, not mass ratio.** Every stoichiometry error traces back to comparing masses.
- **Oxygen by difference.** In combustion analysis you never measure oxygen directly.
- **Indirect measurement.** Back titration and double titration both find a quantity by measuring what is left over, not what reacted.
- **Volume or mass?** Any concentration term defined with a volume drifts with temperature. Terms built from masses do not.

TRAP ALERT

THREE SANITY CHECKS THAT CATCH MOST MISTAKES

- A purity or a yield above **100%** means a coefficient was dropped.
- A diluted solution can never be **stronger** than the stock it came from.
- An average molar mass must lie **between** the molar masses of the components.
- Run these before you move on. They cost five seconds and save four marks.

SECTION A

Concentration Terms

Molarity, molality, mole fraction, normality, ppm · Q1 to Q10

1 A solution is 98% H_2SO_4 by mass and its density is 1.84 g/mL. Its molarity is:

(A) 18.4 M
(B) 9.2 M
(C) 1.84 M
(D) 36.8 M

2 A 1.00 molar aqueous solution has density 1.04 g/mL. The solute has molar mass 60 g/mol. The molality is:

(A) 1.00 m
(B) 0.96 m
(C) 1.02 m
(D) 1.04 m

3 The molarity of pure water at 25 °C, taking its density as 1.00 g/mL, is:

(A) 1.00 M
(B) 55.6 M
(C) 18.0 M
(D) 100 M

4 200 mL of 0.50 M NaCl is mixed with 300 mL of 0.20 M NaCl. The molarity of the final solution is:

(A) 0.35 M
(B) 0.25 M
(C) 0.70 M
(D) 0.32 M

5 A 0.50 molal aqueous solution has a solute mole fraction of about:

(A) 0.50
(B) 0.0089
(C) 0.033
(D) 0.0050

6 The normality of a 0.10 M H_2SO_4 solution used in complete neutralisation is:

(A) 0.05 N
(B) 0.10 N
(C) 0.40 N
(D) 0.20 N

7 Which concentration term is **independent of temperature**?

(A) Molarity
(B) Normality
(C) Molality
(D) Formality

8 A sample of water contains 0.001 M $MgSO_4$. Its hardness expressed in ppm of $CaCO_3$ is:

(A) 100 ppm
(B) 10 ppm
(C) 1 ppm
(D) 120 ppm

Numerical Answer Type

9 Calculate the mass of glucose (molar mass 180 g/mol) needed to prepare 250 mL of a 0.20 M aqueous solution. Give the answer in gram.

NUMERICAL ANSWER · Round off to TWO decimal places.

10 36.0 g of water is mixed with 46.0 g of ethanol (molar mass 46 g/mol). Find the mole fraction of ethanol.

NUMERICAL ANSWER · Round off to TWO decimal places.

SECTION B

Applied Stoichiometry

Limiting reagent, purity, combustion, titrations, oleum, eudiometry · Q11 to Q24

11 5.60 g of iron is heated with 4.00 g of sulfur to form FeS. Which is correct? (Fe = 56, S = 32)

(A) Sulfur is limiting; 11.0 g FeS forms
(B) Iron is limiting; 0.80 g FeS forms
(C) Both are fully consumed; 9.60 g FeS forms
(D) Iron is limiting; 8.80 g FeS forms

12 10.0 g of limestone that is 80% $CaCO_3$ by mass is heated. The reaction gives 85% of the theoretical yield of CO_2. The volume of CO_2 at STP is:

(A) 2.24 L
(B) 1.52 L
(C) 1.79 L
(D) 1.90 L

13 0.240 g of an organic compound on complete combustion gives 0.352 g CO_2 and 0.144 g H_2O. Its molar mass is 60 g/mol. Its molecular formula is:

(A) CH_2O
(B) C_3H_8O
(C) C_2H_6O
(D) $C_2H_4O_2$

14 2.00 g of impure $CaCO_3$ is dissolved in 50.0 mL of 1.00 M HCl. The unreacted acid needs 20.0 mL of 1.00 M NaOH to neutralise. The purity of the sample is:

(A) 50%
(B) 85%
(C) 75%
(D) 60%

15 A 25.0 mL mixture of NaOH and Na_2CO_3 is titrated with 0.100 M HCl. The phenolphthalein end point comes at 15.0 mL, and methyl orange needs a further 5.0 mL. The mass of Na_2CO_3 present is:

(A) 0.053 g
(B) 0.106 g
(C) 0.159 g
(D) 0.021 g

16 A sample of H_2O_2 is labelled '20 volume'. Its molarity is:

(A) 2.00 M
(B) 1.79 M
(C) 0.89 M
(D) 20.0 M

17 Oleum is labelled 109%. The percentage of free SO_3 in it is about:

(A) 9%
(B) 40%
(C) 36.7%
(D) 18%

18 10 mL of a gaseous hydrocarbon is burnt in excess oxygen. 40 mL of CO_2 forms, and cooling the products to room temperature causes a contraction of 50 mL due to water. The hydrocarbon is:

(A) C_4H_8

(B) C_4H_{10}

(C) C_2H_6

(D) C_5H_{10}

Multiple Correct Answer Type

19 A gaseous mixture contains CH_4 and C_2H_6. Which statements are correct? **One or more** options may be right.

(A) If mixed 40:60 by moles, the average molar mass is 24.4
(B) If mixed 40:60 by mass, the average molar mass is 22.2
(C) Mixing by mass and by moles in the same ratio gives the same average molar mass
(D) The average molar mass always lies between 16 and 30

ONE OR MORE OPTIONS MAY BE CORRECT

20 For a 1.0 M aqueous solution of a solute, which statements are correct? **One or more** options may be right.

(A) Its molarity falls if the solution is warmed
(B) Its molality falls if the solution is warmed
(C) Its molality can be found from the molarity only if the density is known
(D) Its mole fraction is unaffected by temperature

ONE OR MORE OPTIONS MAY BE CORRECT

Numerical Answer Type

21 100.0 g of $KClO_3$ is heated until it decomposes completely to KCl and O_2. Find the volume of O_2 released at STP, in litre. (K = 39, Cl = 35.5, O = 16)

NUMERICAL ANSWER · Round off to TWO decimal places.

22 A 9.20 g mixture of $CaCO_3$ and $MgCO_3$ is heated strongly until decomposition is complete. It gives 2.24 L of CO_2 at STP. Find the mass percentage of $CaCO_3$ in the mixture. (Ca = 40, Mg = 24, C = 12, O = 16)

NUMERICAL ANSWER · Round off to ONE decimal place.

23 What volume, in millilitre, of 18.0 M concentrated H_2SO_4 is needed to prepare 500 mL of 0.500 M solution?

NUMERICAL ANSWER · Round off to TWO decimal places.

24 A '20 volume' sample of H_2O_2 is diluted so that 100 mL of it becomes 500 mL. Find the volume strength of the diluted solution.

NUMERICAL ANSWER · Round off to the nearest integer.

1 Answer Key

Mark your paper first, then read every solution, including the ones you got right.

1	2	3	4	5	6	7	8	9	10
A	C	B	D	B	D	C	A	9.00	0.33
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
D	B	D	C	A	A	C	B	A, B, D	A, C, D
21	**22**	**23**	**24**						
27.43	54.3	13.89	4						

2 Solutions: Concentration Terms

Each solution names the idea, shows the working, then names the exact mistake behind each wrong option.

1 Answer A — Medium · Concentration interconversion

CORE PRINCIPLE Take exactly 1 litre. Find its mass from the density, then the mass of solute from the percentage.

MATH 1 L weighs 1840 g. Solute = 98% of that = 1803 g. Moles = 1803/98 = 18.4. So M = **18.4 M**. The shortcut is $M = 1000d\times w/(100\times M_w)$.

TRAP Using 98 g of acid per 100 g of solution but forgetting to scale to 1 litre gives 1.0 M. The density is what converts volume to mass, so it can never be left out.

2 Answer C — Hard · Molarity to molality

CORE PRINCIPLE Molarity is per litre of **solution**. Molality is per kilogram of **solvent**. So you must subtract the solute mass.

MATH 1 L of solution = 1040 g. It holds 1 mol = 60 g of solute. So solvent = 980 g = 0.980 kg. Molality = 1.00/0.980 = **1.02 m**.

TRAP (A) assumes the two are equal, which is only true for very dilute solutions. Molality is always **larger** than molarity when the solute is denser than the solvent, and density is the only bridge between them.

3 Answer B — Medium · Concentration terms

CORE PRINCIPLE Treat water as both the solvent and the solute. One litre of water is 1000 g.

MATH Moles in 1 L = 1000/18 = 55.6. So the molarity is **55.6 M**.

TRAP Answering 18 M inverts the calculation. This value is worth memorising, because it is the reason the solvent concentration is treated as effectively constant in dilute-solution equilibria.

4 Answer D — Easy · Mixing solutions

CORE PRINCIPLE Moles add. Volumes add. Divide the total moles by the total volume.

MATH Moles = (0.200)(0.50) + (0.300)(0.20) = 0.100 + 0.060 = 0.160. Volume = 0.500 L. M = 0.160/0.500 = **0.32 M**.

TRAP (A) is the simple average of 0.50 and 0.20, which ignores that the volumes are unequal. Averaging concentrations is only valid when equal volumes are mixed.

5 Answer B — Hard · Molality to mole fraction

CORE PRINCIPLE Molality fixes the solvent at exactly 1 kg. Convert that to moles of solvent, then form the fraction.

MATH 1 kg of water = 1000/18 = 55.6 mol. x_{solute} = 0.50/(0.50 + 55.6) = **0.0089**.

TRAP (B) treats molality as if it were already a fraction. Note how small the mole fraction is: even a 0.5 molal solution is overwhelmingly solvent by particle count.

6 Answer D

Easy · Normality and n-factor

CORE PRINCIPLE Normality = Molarity × n-factor. For an acid the n-factor is the number of replaceable H^+ ions.

MATH H_2SO_4 gives 2 H^+, so n = 2 and N = 0.10 × 2 = **0.20 N**.

TRAP (A) divides instead of multiplying. Normality is never smaller than molarity, because the n-factor is at least 1.

7 Answer C

Medium · Temperature dependence

CORE PRINCIPLE Any term defined using a **volume** changes with temperature, because the volume expands on heating.

MATH Molality is moles per kilogram of solvent. Both are masses, and mass does not change with temperature. So **molality** is temperature independent, as are mole fraction and mass percentage.

TRAP Molarity, normality and formality all use litres of solution, so all three drift as the temperature changes. This is exactly why molality is used in colligative property work.

8 Answer A

Hard · Hardness of water

CORE PRINCIPLE Hardness is always reported as the **equivalent mass of $CaCO_3$**, whatever salt is actually present.

MATH 0.001 mol per litre × 100 g/mol ($CaCO_3$) = 0.1 g/L = 100 mg/L = **100 ppm**.

TRAP (D) uses the molar mass of $MgSO_4$ (120). The whole convention is that you convert to $CaCO_3$, so the molar mass of the salt actually present never enters the final number.

9 Answer 9.00

Easy · Molarity

CORE PRINCIPLE Moles = molarity × volume in litres. Then convert moles to mass.

MATH n = 0.20 × 0.250 = 0.050 mol. Mass = 0.050 × 180 = **9.00 g**.

TRAP Using 250 instead of 0.250 gives 9000 g. Always convert millilitres to litres before multiplying by molarity.

10 Answer 0.33

Medium · Mole fraction

CORE PRINCIPLE Convert both masses to moles first. Mole fraction compares particle counts, never masses.

MATH n(water) = 36/18 = 2.00. n(ethanol) = 46/46 = 1.00. x(ethanol) = 1.00/3.00 = **0.33**.

TRAP Comparing the masses directly gives 46/82 = 0.56. Mole fraction is about numbers of molecules, and water molecules are much lighter, so there are twice as many of them here.

3 Solutions: Applied Stoichiometry

11 Answer D — Medium · Limiting reagent

CORE PRINCIPLE Convert both masses to moles, then compare against the 1:1 ratio in the equation.

MATH n(Fe) = 5.60/56 = 0.100. n(S) = 4.00/32 = 0.125. Fe is smaller, so **Fe is limiting**. FeS formed = 0.100 × 88 = **8.80 g**, with 0.80 g of sulfur left over.

TRAP Comparing the raw masses suggests iron is in excess because 5.60 > 4.00. Limiting reagent is decided by **moles against the stoichiometric ratio**, never by mass.

12 Answer B — Hard · Purity and yield

CORE PRINCIPLE Apply purity first to get the reacting mass, then stoichiometry, then the yield factor at the end.

MATH Pure $CaCO_3$ = 8.00 g = 0.0800 mol. Theoretical CO_2 = 0.0800 mol. Actual = 0.0800 × 0.85 = 0.0680 mol. Volume = 0.0680 × 22.4 = **1.52 L**.

TRAP (A) ignores both corrections. (B) applies only the purity. The two factors multiply, so 0.80 × 0.85 = 0.68 of the ideal. Applying only one of them is the most common single error in this topic.

13 Answer D — Hard · Combustion analysis

CORE PRINCIPLE Get carbon from the CO_2 and hydrogen from the H_2O. Find oxygen **by difference**, never by measurement.

MATH C = 0.352 × 12/44 = 0.096 g. H = 0.144 × 2/18 = 0.016 g. O = 0.240 − 0.096 − 0.016 = 0.128 g. Mole ratio = 0.008 : 0.016 : 0.008 = 1 : 2 : 1, so the empirical formula is CH_2O (30). 60/30 = 2, giving $\mathbf{C_2H_4O_2}$.

TRAP (A) stops at the empirical formula. Oxygen must come from the mass difference, because the oxygen in the products comes partly from the burning air, not only from the compound.

14 Answer C — Hard · Back titration

CORE PRINCIPLE You cannot titrate a solid directly. So use excess acid, then find how much acid **survived**, and subtract.

MATH Total HCl = 0.0500 mol. Excess = 0.0200 mol. Reacted with $CaCO_3$ = 0.0300 mol. Since $CaCO_3$ + 2HCl, n($CaCO_3$) = 0.0150 mol = 1.50 g. Purity = 1.50/2.00 = **75%**.

TRAP Forgetting the 1:2 ratio gives 0.0300 mol = 3.00 g, which exceeds the sample mass and should be an instant warning. Any purity above 100% means a stoichiometric coefficient was dropped.

15 Answer A — Hard · Double titration

CORE PRINCIPLE Phenolphthalein catches all the NaOH plus **half** the carbonate. Methyl orange then catches the second half of the carbonate alone. So the second volume measures carbonate directly.

MATH V_2 = 5.0 mL corresponds to half the carbonate, and by symmetry the other half also took 5.0 mL. n(Na_2CO_3) = (5.0)(0.100)/1000 = 5.0×10^{-4} mol. Mass = 5.0×10^{-4} × 106 = **0.053 g**.

TRAP (A) uses the full 10 mL of carbonate titration and doubles the answer. The classic trap is forgetting that V_1 already contains half the carbonate, so NaOH = ($V_1 - V_2$), not V_1.

16 Answer A

Hard · Volume strength

CORE PRINCIPLE '20 volume' means 1 litre of the solution releases 20 litres of O_2 at STP on full decomposition.

MATH $2H_2O_2$ gives O_2, so 20 L of O_2 needs 2(20/22.4) = 1.786 mol of H_2O_2 per litre. So M = 20/11.2 = **1.79 M**.

TRAP (D) reads the label as a concentration. The useful shortcuts are M = volume strength/11.2 and strength in g/L = volume strength × 34/11.2, which gives 60.7 g/L here.

17 Answer C

Hard · Oleum labelling

CORE PRINCIPLE The label means that 109 g of oleum yields 109 g of H_2SO_4 when enough water is added. So the extra 9 g is the **water absorbed**.

MATH 9 g of water = 0.50 mol, which reacts with 0.50 mol of free SO_3 = 40 g. So free SO_3 = 40/109 = **36.7%**.

TRAP (A) reads the excess 9 as the percentage of SO_3 directly. The 9 g is the mass of **water**, and each mole of water consumes a whole mole of the much heavier SO_3.

18 Answer B

Hard · Eudiometry

CORE PRINCIPLE For gases at the same temperature and pressure, **volume ratios equal mole ratios**. So read the subscripts straight off the volumes.

MATH CO_2 is 40 mL from 10 mL, so x = 4. Water vapour is 50 mL from 10 mL, so y/2 = 5, giving y = 10. The hydrocarbon is $\mathbf{C_4H_{10}}$.

TRAP (A) forgets that the water volume gives y/2, not y, because each molecule of C_xH_y makes y/2 molecules of water. Halving the hydrogen count is the standard eudiometry slip.

19 Answer A, B, D

Hard · Average molar mass

CORE PRINCIPLE Average molar mass is total mass divided by total moles. So the answer depends on whether the given ratio is a ratio of **moles** or of **masses**.

MATH By moles: M = 0.4(16) + 0.6(30) = **24.4**. By mass, take 40 g and 60 g: n = 40/16 + 60/30 = 2.5 + 2.0 = 4.5 mol for 100 g, so M = 100/4.5 = **22.2**. Any mixture must lie between the two pure values.

TRAP (C) is the trap, and the two numbers above disprove it. A mass ratio favours the **lighter** component in particle count, so it always pulls the average molar mass down.

20 Answer A, C, D

Hard · Temperature and concentration

CORE PRINCIPLE Ask one question of each term: does its definition contain a **volume**? If yes, it changes with temperature. If it contains only masses or mole counts, it does not.

MATH Molarity is per litre of solution, and warming expands the solution, so the molarity **falls**. Molality and mole fraction use only masses and mole counts, so both are **unchanged**. Converting between molarity and molality needs the mass of a known volume, which is the density.

TRAP (B) is the trap. Warming does not evaporate or create solvent, so the kilogram of solvent in the molality definition is untouched. Only volume-based terms drift.

21 Answer 27.43 — Medium · Stoichiometry, POAC

CORE PRINCIPLE Balance the equation, or simply conserve oxygen atoms. Each $KClO_3$ carries three O atoms, and each O_2 takes two.

MATH $M(KClO_3) = 122.5$, so $n = 0.8163$ mol. $2KClO_3$ gives $3O_2$, so $n(O_2) = 1.5(0.8163) = 1.2245$ mol. $V = 1.2245 \times 22.4 =$ **27.43 L**.

TRAP Using a 1:1 ratio gives 18.29 L. Conserving atoms rather than trusting a remembered coefficient is the safer route, and it is what POAC formalises.

22 Answer 54.3 — Hard · Mixture analysis

CORE PRINCIPLE Two unknowns need two equations. Use the **total mass** and the **total moles of CO_2**, since each carbonate gives exactly one CO_2.

MATH Let x and y be the moles. $x + y = 2.24/22.4 = 0.100$, and $100x + 84y = 9.20$. Solving gives $x = y = 0.0500$. Mass of $CaCO_3 = 5.00$ g, so the percentage is $5.00/9.20 =$ **54.3%**.

TRAP Setting up only one equation makes the problem unsolvable, which is the signal that a second relation is needed. Note the answer is asked as a **mass** percentage, not a mole percentage, which is 50%.

23 Answer 13.89 — Medium · Dilution

CORE PRINCIPLE Dilution does not change the number of moles of solute. So $M_1V_1 = M_2V_2$.

MATH $18.0 \times V = 0.500 \times 500$, so $V = 250/18.0 =$ **13.89 mL**.

TRAP Inverting the ratio gives 18000 mL, which is more than the final volume and is impossible. The concentrated stock is always the smaller volume.

24 Answer 4 — Hard · Volume strength and dilution

CORE PRINCIPLE Volume strength is directly proportional to concentration. So dilution scales it in exactly the same ratio as it scales molarity.

MATH The dilution factor is $500/100 = 5$. So the volume strength becomes $20/5 =$ **4**. As a check, M falls from 1.79 to 0.357, and $0.357 \times 11.2 = 4$.

TRAP Multiplying by the dilution factor gives 100 volume, which would mean dilution made it stronger. Always sanity check the direction: adding water can only weaken a solution.

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