CHEMISTRY

Unit 4

STOICHIOMETRY

MCQs • Short Questions • Long Questions

Complete Study Booklet with Answer Keys

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Section 1 | Multiple Choice Questions

Tick the correct option. Correct answers are highlighted in green with a check mark.

1. Which one of the following statements is incorrect?

(a) One mole of nitrogen gas contains Avogadro's number of molecules
(b) One mole of ozone gas contains Avogadro's number of molecules
✓ (c) One mole of ozone contains Avogadro's number of O atoms
(d) One mole of hydrogen gas contains Avogadro's number of molecules

2. Which one of the following has maximum mass?

✓ (a) 0.5 mol of N_2
(b) 0.5 mol of NH_3
(c) 0.5 mol of He
(d) 0.5 mol of H_2

3. Which one of the following gases will have maximum volume at STP?

(a) 22 g of CO_2
✓ (b) 88 g of N_2O
(c) 28 g of CO
(d) 28 g of N_2

4. Which of the following contains same number of particles as present in 12 g of carbon?

(a) 28 g of iron (Atomic mass of Fe = 56)
(b) 48 g of magnesium (Atomic mass of Mg = 24)
(c) 32 g of S_8 molecules (Atomic mass S = 32)
✓ (d) 44 g of carbon dioxide (molar mass of CO_2 = 44)

5. Volume at S.T.P of 22 g of CO_2 is same as that of:

(a) 2 g of hydrogen
✓ (b) 8.5 g of NH_3
(c) 64 g of gaseous SO_2
(d) 7 g of CO

6. 4.0 g of NaOH (molar mass 40 g/mol) contains same number of sodium ions as are present in:

✓ (a) 5.3 g of Na_2CO_3 (molar mass 106)
(b) 58.5 g of NaCl (molar mass 58.5)
(c) 76 g Na_2SO_4 (formula mass 142)
(d) 85 g of $NaNO_3$ (molar mass 85)

7. A container holds 0.5 moles of an ideal gas at STP. What is the volume of the gas in dm^3?

✓ (a) 11.2 dm^3
(b) 22.4 dm^3
(c) 44.8 dm^3
(d) 12.2 dm^3

8. A solution contains 4.0 g of NaOH (molar mass = 40.0 g/mol) in 250 cm^3 of solution. What is the molar concentration?

(a) 0.10 mol/dm^3
(b) 0.20 mol/dm^3
✓ (c) 0.40 mol/dm^3
(d) 0.80 mol/dm^3

9. A solution contains 10.0 g of an unknown solute in 250 cm3 of solution. If the molar concentration is 0.20 mol/dm3, what is the molar mass?

(a) 50 g/mol
(b) 100 g/mol
✓ **(c) 200 g/mol**
(d) 400 g/mol

10. A sample of N_2 (molar mass = 28.0 g/mol) has a mass of 14.0 g. How many nitrogen atoms are present?

(a) 3.01×10^{23} atoms
✓ **(b) 6.02×10^{23} atoms**
(c) 1.20×10^{24} atoms
(d) 2.40×10^{24} atoms

11. A gas has a density of 1.43 g/dm3 at STP. What is the molar mass? (V_m = 22.4 dm3/mol)

(a) 14.3 g/mol
(b) 22.4 g/mol
✓ **(c) 32.0 g/mol**
(d) 64.0 g/mol

12. A gas has a density of 1.96 g/dm3 at STP. What is its molecular mass? (V_m = 22.4 dm3/mol)

(a) 11.2 g/mol
(b) 22.4 g/mol
✓ **(c) 44.0 g/mol**
(d) 88.0 g/mol

13. The mass of one mole of electron is:

(a) 1.088 mg
✓ **(b) 0.55 mg**
(c) 0.184 mg
(d) 1.67 mg

14. The number of moles of CO_2 which contain 8 g of oxygen:

✓ **(a) 0.25**
(b) 0.5
(c) 1.0
(d) 1.50

15. One mole of carbon-12 has mass:

(a) 0.012 kg
(b) 1 kg
✓ **(c) 0.0224 kg**
(d) 12 kg

16. The mass of one mole of chlorine gas is:

(a) 35.5 g
✓ **(b) 71 g**
(c) 23 g
(d) 32 g

17. What are the number of moles of hydrogen atom in 3.2 g of CH_4? (C = 12)

✓ **(a) 0.2**
(b) 0.4
(c) 0.6
(d) 0.8

18. What are the number of moles of oxygen in 11 g of CO_2?

✓ **(a) 0.25**
(b) 0.50
(c) 0.75
(d) 1.0

19. One mole of water contains:

(a) 81 g water
(b) 6.02 x 10^{23} atoms
(c) 6.02 x 10^{23} ions
✓ **(d) 6.02 x 10^{23} molecules**

20. 6 g of hydrogen gas is:

(a) 1 mole
(b) 2 moles
✓ **(c) 3 moles**
(d) 4 moles

21. The sum of atomic masses of all the elements present in a molecule is called:

(a) Atomic mass
(b) Ionic mass
✓ **(c) Molecular mass**
(d) Empirical formula mass

22. The mass of 0.5 mole of Al is:

(a) 12 g
✓ **(b) 13.5 g**
(c) 14 g
(d) 2.7 g

23. The number of moles of CH_4 in 4 g of gas is:

(a) 0.2 mole
✓ **(b) 0.25 mole**
(c) 0.3 mole
(d) 0.4 mole

24. Which of the following has maximum mass?

(a) 2 moles of P
(b) 5 moles of H_2O
(c) 2 moles of Na_2CO_3
✓ **(d) 1 mole of glucose**

25. 1 Mole of OH^- ion is equal to:

(a) 18 g
(b) 16 g
✓ **(c) 17 g**
(d) 10 g

26. Mass of 2 moles of CO_2 is:

(a) 44 g
✓ **(b) 88 g**
(c) 40 g
(d) 50 g

27. Number of moles in 100 g of $KClO_3$:

(a) 0.76
(b) 0.56
(c) 0.014
✓ **(d) 0.816**

28. The largest number of molecules are present in:
✓ **(a) 3.6 g of H2O**
(b) 4.6 g of C2H5OH
(c) 2.8 g of CO
(d) 5.4 g of N2O5

29. One mole of SO2 contains:
(a) 6.02 x 10^23 atoms of oxygen
(b) 18.1 x 10^23 molecules of SO2
✓ **(c) 6.022 x 10^23 atoms of sulphur**
(d) 4 g atoms of SO2

30. A ring has 6 g of diamond in it. What is the number of atoms in it?
(a) 6.02 x 10^23
(b) 12.04 x 10^23
(c) 1.003 x 10^23
✓ **(d) 3.01 x 10^23**

31. The number of H2O molecules in 9 grams of ice is:
✓ **(a) 3.01 x 10^23**
(b) 6.02 x 10^23
(c) 6.02 x 10^9
(d) 12.04 x 10^23

32. 32 g of oxygen gas contains:
✓ **(a) 6.02 x 10^23 molecules**
(b) 6.02 x 10^23 atoms
(c) 12.04 x 10^23 molecules
(d) 24.04 x 10^23 atoms

33. How many atoms are present in one mole of water?
(a) 3
(b) 54
(c) 6.02 x 10^23
✓ **(d) 3(6.02 x 10^23)**

34. The number of molecules in 8 g of oxygen gas is:
(a) 6.02 x 10^23
(b) 3.01 x 10^23
✓ **(c) 1.50 x 10^23**
(d) 0.75 x 10^23

35. The number of atoms present in 6 g of Mg metal is:
(a) 6.02 x 10^23
(b) 3.01 x 10^23
(c) 12.04 x 10^23
✓ **(d) 1.5 x 10^23**

36. The total number of oxygen atoms in 22 g of CO2 gas is:
✓ **(a) 6.02 x 10^23**

(b) 3.01 x 10^23
(c) 12.04 x 10^23
(d) 3.0 x 10^23

37. The mass of 1.505 x 10^23 atoms of S:

(a) 0.5 g
(b) 0.6 g
(c) 0.7 g
✓ (d) 8 g

38. How many moles of CO are present in 12.04 x 10^23 molecules of CO?

(a) 0.5 mole
(b) 1.0 mole
(c) 2 x 10^23 moles
✓ (d) 2.0 moles

39. How many atoms are present in half mole of oxygen gas?

(a) 3.01 x 10^23
✓ (b) 6.023 x 10^23
(c) 2 x 10^23
(d) 1.003 x 10^23

40. The number of Al3+ ions in AlCl3 is 2.007 x 10^23. The number of Cl- ions are:

✓ (a) 6.02 x 10^23
(b) 3.01 x 10^23
(c) 12.04 x 10^23
(d) 1.5 x 10^23

41. Which of the following has minimum mass?

(a) 1 mole of S
(b) 79 grams of Ag
(c) 2 gram atoms of N
✓ (d) 3 x 10^23 atoms of C

42. How many carbon atoms are present in 90 g glucose?

(a) 6.02 x 10^23
(b) 1.8 x 10^23
(c) 1.8 x 10^22
✓ (d) 1.8 x 10^24

43. The mass of one molecule of O2 is:

(a) 32/6.02 x 10^23
(b) 6.02/32 x 10^23
(c) 6.02 x 10^-23/32
✓ (d) 32/6.02 x 10^23

44. The volume occupied by 1.4 g of N2 at STP is:

(a) 22.4 dm3
(b) 2.24 dm3
✓ (c) 1.12 dm3
(d) 112 dm3

45. Molar volume of a gas at STP is equal to:

(a) 1 gram of a gas
(b) 6.02 x 10^23 g of a gas

✓ **(c) 22.414 dm^3**

(d) 1 gram ion of gas

46. 4g of CH_4 at STP has _______ molecules.

(a) 6.02×10^{23}

(b) 3.01×10^{23}

(c) 12.1×10^{23}

✓ **(d) 1.5×10^{23}**

47. One cm^3 of H_2 at STP contains:

(a) 6.02×10^{23} atoms

(b) 1×10^{20} atoms

✓ **(c) 0.53×10^{20} atoms**

(d) 1.687×10^{24} atoms

48. Number of molecules in 1 dm^3 of steam at STP is:

(a) $55.5 \times 6.02 \times 10^{23}$

(b) $1000 \times 6.02 \times 10^{23}$

(c) $18 \times 6.02 \times 10^{23}$

✓ **(d) 0.268×10^{23}**

49. 27g of Al will react completely with how much mass of O_2 to produce Al_2O_3?

(a) 8g

(b) 16g

(c) 32g

✓ **(d) 24g**

50. The ratio of number of molecules in 71g of gaseous chlorine to number of molecules in 2g of gaseous hydrogen is:

(a) 71:1

(b) 71:2

(c) 1:2

✓ **(d) 1:1**

51. $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$. Which one is a correct description of this reaction?

(a) 2 atoms of hydrogen combine with 2 atoms of oxygen

(b) 2 moles of steam can be produced from 0.5 mole of oxygen

✓ **(c) 2 moles of steam can be produced from 1 mole of oxygen**

(d) 2g of hydrogen combine with 1 g of oxygen

52. The ratio of number of molecules of 2g H_2 gas to number of molecules of 64g gaseous oxygen is:

(a) 1:1

✓ **(b) 1:2**

(c) 1:32

(d) 1:4

53. What is the ratio of volumes of 2g of H_2 to the volume of 16g CH_4, both at STP?

(a) 1:8

(b) 1:2

✓ **(c) 1:1**

(d) 2:1

54. A mixture of 8g of H_2 with 8g of O_2 is ignited. $2H_2 + O_2 \rightarrow 2H_2O$. What is the mass of water formed?

✓ **(a) 9g**
(b) 16g
(c) 36g
(d) 72g

55. What is the maximum mass of chromium that can be extracted from 76g of Cr_2O_3? (Cr=52, O=16)

(a) 48g
✓ **(b) 52g**
(c) 104g
(d) 152g

56. What is the mass of oxygen obtained from 72g of pure water?

(a) 16g
(b) 32g
✓ **(c) 64g**
(d) 70g

57. A limiting reactant is the one which:

(a) is taken in lesser quantity in grams as compared to other reactants
(b) is taken in lesser quantity in volume as compared to the other reactants
(c) gives the maximum amount of the product which is required
✓ **(d) gives the minimum amount of the product under consideration**

58. The reactant which consumes earlier and gives least quantity of product is called:

(a) Reactant
✓ **(b) Limiting reactant**
(c) Stoichiometry
(d) Stoichiometric amount

59. How many moles of water are produced by burning 4 moles of H_2 with excess of oxygen?

(a) 1 mole
(b) 2 moles
(c) 3 moles
✓ **(d) 4 moles**

60. If 16 grams of O_2 react with excess C_2H_6, how many grams of CO_2 will be formed? ($2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$)

(a) 22g
✓ **(b) 13g**
(c) 9g
(d) 7g

Section 2 | Short Questions

Q1. How is the concept of mole derived from Avogadro's number?

Mole is defined in relation to Avogadro's number: the amount of substance that contains 6.022×10^{23} particles is known as a mole.

Formula: Number of moles = Number of Particles / Avogadro's Number

Q2. Define Molar Mass, Molar Volume and Molar Concentration.

(a) Molar Mass: The mass of one mole of a substance expressed in grams. Represented by M, unit g/mol. It is the sum of masses of the component atoms.

(b) Molar Volume: The volume of one mole of an ideal gas at STP, equal to 22.414 dm^3 (rounded to 22.4 dm^3). Denoted by V_m.

(c) Molar Concentration: Number of moles of a substance dissolved per dm^3 of solution, unit mol/dm^3, denoted by C. $C = n / V(dm^3)$

Q3. What do you mean by molar volume of a gas? How is Avogadro's number related to molar volume?

Molar Volume: The volume of one mole of an ideal gas at STP, equal to 22.414 dm^3 (rounded to 22.4 dm^3), denoted by V_m.

Relationship: One mole of an ideal gas at 273.16 K and 1 atm has a volume of 22.414 dm^3, and since one mole contains Avogadro's number of particles, 22.414 dm^3 of any ideal gas at STP contains 6.02×10^{23} particles.

22.4 dm^3 of gas at STP = 1 mole = 6.02×10^{23} particles (applies to CO_2, H_2, etc.)

Q4. 39g of potassium and 56g of iron have equal number of atoms in them. Justify.

39 g of K = 1 mole of K = 6.02×10^{23} atoms; 56 g of Fe = 1 mole of Fe = 6.02×10^{23} atoms.

So 39 g of K and 56 g of Fe contain an equal number of atoms because they represent equal numbers of moles.

Q5. 4g of He, 17g of NH_3 and 64g of SO_2 occupy separately the volume of 22.414 dm^3 although their masses differ greatly. Explain.

4 g He = 1 mol = 22.414 dm^3; 17 g NH_3 = 1 mol = 22.414 dm^3; 64 g SO_2 = 1 mol = 22.414 dm^3.

All three gases have different masses but occupy the same volume because size and mass do not affect gas volume - only the number of moles matters.

Q6. Do 1 mole of H_2 and 1 mole of NH_3 at 0C and 1 atm have Avogadro's number of particles?

1 mole of H_2 at STP = 22.414 dm^3 = 6.02×10^{23} molecules; 1 mole of NH_3 at STP = 22.414 dm^3 = 6.02×10^{23} molecules.

Yes - because one mole of any substance always contains the same number of particles, i.e. 6.02×10^{23} (Avogadro's number).

Q7. What is stoichiometry? Give the basic assumptions of stoichiometric calculations.

Stoichiometry is the branch of chemistry that studies the quantitative relationship between reactants and products in a balanced chemical equation.

Assumptions: (1) All reactants are converted into products. (2) No side reaction occurs.

Q8. What is a limiting reactant? How does it control the quantity of product formed?

The limiting reactant is the one that controls the amount of product formed and is consumed earliest in the reaction.

Since it is used up first, the reaction cannot proceed further once it is exhausted - thus it limits the quantity of product formed.

Q9. Differentiate theoretical and actual yield. How is percentage yield calculated?

Theoretical yield is the maximum amount of product predicted from the balanced equation; actual yield is the amount actually obtained in the reaction and is always smaller.

% Yield = (Actual Yield / Theoretical Yield) x 100

Q10. What factors are mostly responsible for low product yield?

1. Improper processes such as filtration, distillation, or washing not carried out correctly.
2. Side reactions that consume reactants and reduce desired product.
3. Reversible reactions, where the backward reaction reduces the amount of product.

Q11. Define Mole.

The mole is the amount of substance containing as many elementary entities (atoms, molecules, ions, electrons, etc.) as there are atoms in 0.012 kg (12 g) of carbon-12. Represented by n.

Formula: Number of moles = Given mass / Molar mass

Q12. What is Avogadro's Number?

The constant number of entities present in one mole of a substance, i.e. 6.02×10^{23}, named after Amedeo Avogadro (1776-1856).

Exact value: $6.02214179 \times 10^{23}$ mol^{-1}; rounded value: 6.02×10^{23}.

Q13. What is Juglone?

Juglone is a dye produced from the husks of black walnuts, formula $C_6H_{10}O_3$.

It is a natural herbicide that kills competitive plants around the black walnut tree without affecting grass or noncompetitive plants.

Q14. Give uses of isopentyl acetate.

Isopentyl acetate ($C_7H_{14}O_2$) is the compound responsible for the scent of bananas.

Bees release about 1 microgram of this compound when they sting, and the resulting scent attracts other bees to join the attack.

Q15. Give the relationship between mole, molar mass and Avogadro's number.

Mass in grams = Moles x Molar mass

Moles x Avogadro's number = Number of Particles

Q16. Explain how stoichiometric calculations obey the law of conservation of mass and the law of definite proportions.

Law of Conservation of Mass: matter can neither be created nor destroyed - total mass of reactants equals total mass of products in a balanced equation.

Law of Definite Proportions: a pure compound always contains the same elements combined in the same ratio by mass.

Q17. What is a balanced chemical equation?

A balanced chemical equation has the same number of atoms of each element on both sides. It has definite ratios of reactants and products, which are used to calculate the mass or moles of other substances.

Q18. Give the names of stoichiometric relationships.

1. Mole-Mole 2. Mass-Mass 3. Volume-Volume 4. Mole-Mass 5. Mole-Volume 6. Mass-Volume relationships.

Q19. Give the steps to perform stoichiometric calculations.

1. Identify known quantity (mass, volume, or concentration).

2. Calculate moles of the known quantity.

3. Find the mole ratio of known to unknown from the balanced equation.

4. Calculate moles of the unknown substance.

5. Convert moles of the unknown to mass, volume, or concentration as required.

Q20. How is the volume of a gas calculated from moles and molar volume?

Volume of a gas = Number of moles x Molar volume, i.e. $V = n \times V_m$.

Q21. Define density and give its relationship with molar mass.

Density = Mass / Volume ($d = m/V$).

Since equal moles of any gas occupy the same volume at STP, gas density depends on molar mass: higher molar mass means higher density. Relationship: $M = d \times V_m$.

Q22. What is molar concentration? Give its units.

Molar concentration is the number of moles of solute dissolved per dm^3 of solution.

Units: mol/dm^3 or mol/L.

Q23. Define excess reactants.

Reactants present in larger amounts than required by stoichiometry, which remain unreacted at the end of the reaction, are called excess reactants.

Example: In $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$, mixing 2 moles H_2 with 2 moles O_2 gives only 2 moles of water; oxygen is the excess reactant.

Q24. How is the limiting reactant identified?

1. Calculate moles from the given amounts of reactants.

2. Determine the moles of product each reactant could form using the balanced equation.

3. The reactant producing the least product is the limiting reactant; the other is the excess reactant.

Q25. Why are excess reactants needed?

1. To ensure the expensive reactant is completely converted to product.

2. To produce the maximum amount of product.

3. To increase the rate of reaction.

Q26. How is the efficiency of a reaction checked?

Reaction efficiency is checked by measuring percentage yield - a higher percentage yield indicates better efficiency.

Q27. Give the significance of stoichiometry in medicine.

Used in preparing antibiotics with accurate active-ingredient dosing, determining blood cholesterol and glucose levels, controlling insulin dosage, detecting steroids in athletes' urine, determining viral antigen concentration in vaccines, and calculating precise drug dosages (e.g. paracetamol overdose can cause severe liver damage).

Section 3 | Descriptive & Numerical Problems

Descriptive Questions

Q3 (Descriptive). Differentiate limiting and non-limiting reactants. How is a limiting reactant determined?

Limiting reactant is consumed completely and controls the amount of product formed; it is present in a smaller stoichiometric amount.

Excess reactant remains unreacted after the reaction and does not control the amount of product; it is present in a larger stoichiometric amount.

Determination: (1) Calculate moles of each reactant. (2) Compare with stoichiometric coefficients. (3) The reactant producing less product is the limiting reactant.

Q4 (Descriptive). Differentiate actual and theoretical yield. Why is theoretical yield always greater?

Theoretical yield is the calculated maximum product from the balanced equation; actual yield is the experimentally obtained amount, which is always less.

Reasons actual yield is lower: side reactions, incomplete reactions, losses during separation/purification, and reversible reactions.

Numerical Problems

Q5. A NaOH solution is prepared by dissolving 2.00 g of solid NaOH in water to make a final volume of 250 cm^3.

(a) Molar mass of NaOH = 23+16+1 = 40 g/mol

(b) Moles of NaOH = 2.00/40 = 0.0500 mol

(c) Initial concentration = 0.0500/0.250 = 0.200 mol/dm^3

(d) After diluting to 500 cm^3: concentration = 0.0500/0.500 = 0.100 mol/dm^3

Q6. Ammonia reacts with oxygen: $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$. 34.0 g NH_3 reacts with 96.0 g O_2.

Moles NH_3 = 34.0/17 = 2.00 mol; Moles O_2 = 96.0/32 = 3.00 mol

NH_3 gives 2.00 mol NO; O_2 gives (4/5)x3.00 = 2.4 mol NO -> NH_3 is the limiting reactant

(a) Limiting reactant: NH_3

(b) Mass of NO produced = 2.00 x 30 = 60.0 g

(c) O_2 consumed = (5/4)x2.00 = 2.5 mol; O_2 remaining = 3.0-2.5 = 0.5 mol = 16.0 g

Q7. 1.5 g of C_2H_6 is burnt in excess O_2: $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$.

Moles C_2H_6 = 1.5/30.08 = 0.0499 mol

(a) Moles CO_2 = (4/2)x0.0499 = 0.0998 mol -> Molecules CO_2 = $0.0998 \times 6.022 \times 10^{23} = 6.01 \times 10^{22}$ molecules

(b) Moles O_2 reacted = (7/2)x0.0499 = 0.1747 mol -> Molecules O_2 = 1.051×10^{23} molecules

(c) Molecules C_2H_6 = 0.0499x6.022x10^23 = 3.00x10^22; each molecule has 6 C-H bonds -> Total C-H bonds broken = 1.80x10^23 bonds

Section 4 | Long Questions

Q1. Explain the concept of mole, Avogadro's Number and molar mass, and the relationship between them.

MOLE

The mole is the amount of a substance which contains as many elementary entities as there are atoms in 0.012 kg (12 g) of carbon-12. These entities may be atoms, molecules, ions, electrons or other particles, represented by n.

Formula: Number of moles = Given mass / Molar mass

Examples: 1 mole of water = 6.022 x 10^23 molecules of H_2O; 1 mole of 12C = 6.022 x 10^23 atoms of carbon; 1 mole of NaCl = 6.022 x 10^23 formula units; 1 mole of Na^+ = 6.022 x 10^23 ions.

AVOGADRO'S NUMBER

The number of entities present in one mole of a substance is a constant, named Avogadro's Number (Na) = 6.022 x 10^23, after Amedeo Avogadro (1776-1856). The exact value is 6.02214179 x 10^23 mol-1; the rounded value 6.02 x 10^23 is used in calculations.

Examples: 23 g Na = 1 mole = 6.02 x 10^23 atoms; 56.1 g CaO = 1 mole = 6.02 x 10^23 formula units; 98 g H_2SO_4 = 1 mole = 6.02 x 10^23 molecules; 60 g CO_3^{2-} = 1 mole = 6.02 x 10^23 ions.

MOLAR MASS

The mass of one mole of a substance (atomic, molecular, formula or ionic mass expressed in grams). Represented by M, unit g/mol; equal to the sum of masses of the component atoms.

Examples: Mg = 24.0 g/mol; $C_{12}H_{22}O_{11}$ = 342 g/mol; Ag_2CrO_4 = 332 g/mol; PO_4^{3-} = 95 g/mol.

Example calculation - CCl_4: M = 12.0 + (35.5 x 4) = 12.0 + 142.0 = 154.0 g/mol

Worked Examples

(a) Molar mass of $KMnO_4$ = 39 + 55 + (16 x 4) = 158 g/mol

(b) Moles in 0.23 g of sodium: n = m/M = 0.23/23 = 0.01 mol

(c) Mass of 1.5 moles of $Ca(OH)_2$: M = 40 + (1x2) + (16x2) = 74 g/mol; Mass = n x M = 1.5 x 74 = 111 g

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Q2. Explain the relationship between mass, molar mass, Avogadro's number and molar volume.

Relationship between molar mass and Avogadro's number

12.0 g of natural carbon contains the same number of atoms as 4.0 g of natural helium - both are 1 mole, i.e. 6.022 x 10^23 atoms.

Examples (atoms): 1.0 g H = 1 mol = 6.02 x 10^23 atoms; 23.0 g Na = 1 mol = 6.02 x 10^23 atoms; 238.0 g U = 1 mol = 6.02 x 10^23 atoms.

Examples (molecules): 18.0 g H_2O = 1 mol = 6.02 x 10^23 molecules; 18.0 g glucose = 1 mol = 6.02 x 10^23 molecules.

Examples (formula units): 58.5 g NaCl, 100 g $CaCO_3$, 332 g Ag_2CrO_4 each = 1 mole = 6.02×10^{23} formula units.

Examples (ions): 96.1 g SO_4^{2-} and 62.0 g NO_3^- each = 1 mole = 6.02×10^{23} ions.

Since sodium is 23 times heavier than hydrogen, 23 times more mass of sodium is needed to have the same number of atoms as hydrogen.

Relationship between moles and Avogadro's Number

Number of moles = Number of particles / Avogadro's Number

Number of particles = (Mass x Na) / Molar Mass

Sample Problem 4.4

A sample of glucose contains 3.76×10^{24} molecules. Moles = $3.76\times10^{24} / 6.02\times10^{23}$ = 6.25 moles.

Sample Problem 4.5

Atoms in 2.3 g of sodium: n = 2.3/23.0 = 0.1 mol; Atoms = $0.1 \times 6.02\times10^{23} = 6.02 \times 10^{22}$ atoms.

Sample Problem 4.6 - Juglone ($C_{10}H_6O_3$)

(a) Molar mass = (10x12.0)+(6x1.0)+(3x16.0) = 120+6+48 = 174 g/mol

(b) Moles in 0.87 g = 0.87/174 = 0.005 moles

Quick Check 4.2

(a) 27.10×10^{25} atoms of copper: n = $27.10\times10^{25} / 6.02\times10^{23}$ = 450 moles... using given values n = 4.50 moles (per original data).

(b) Isopentyl acetate $C_7H_{14}O_2$, M = (12x7)+14+(16x2) = 130 g/mol. For 1×10^{-6} g: molecules = $(1\times10^{-6}/130) \times 6.02\times10^{23} = 4.63\times10^{15}$ molecules. Each molecule has 7 C, 14 H, 2 O atoms, giving 3.24×10^{16} C atoms, 6.3×10^{16} H atoms and 9.26×10^{15} O atoms.

Q3. Define molar volume. Give its relation with mole and Avogadro's number.

MOLAR VOLUME

The volume of one mole of an ideal gas at STP is called molar volume, equal to 22.414 dm^3 (rounded to 22.4 dm^3), denoted V_m.

Examples: 22.4 dm^3 of CO_2 at STP = 44.0 g = 6.02×10^{23} molecules = 1 mole; 22.4 dm^3 of H_2 = 2 g = 6.02×10^{23} molecules = 1 mole; 22.4 dm^3 of NH_3 = 17 g = 6.02×10^{23} molecules = 1 mole.

Relationship with Avogadro's Number

By Avogadro's law, equal volumes of all ideal gases at the same temperature and pressure contain equal numbers of molecules - equivalently, one mole of an ideal gas at 273.16 K and 1 atm occupies 22.414 dm^3.

Q4. Define molar concentration and explain how it is used to calculate moles and mass of solute.

MOLAR CONCENTRATION

The number of moles of solute dissolved per dm^3 of solution, represented by C.

Formula: $C = n/V$, where n = moles of solute, V = volume of solution in dm^3.

Example: 0.2 mole per dm^3 gives C = 0.2 mol dm^{-3}.

Quick Check 4.4

7.9 g of $KMnO_4$ (M = 158 g/mol) dissolved in 1 dm^3: n = 7.9/158 = 0.05 mol; C = 0.05/1 = 0.05 mol/dm^3.

Q5. Define stoichiometry. Explain its relationships and the steps for stoichiometric calculations.

STOICHIOMETRY

Derived from Greek 'stoicheion' (element) and 'metron' (measure). It is the branch of chemistry that gives the quantitative relationship between reactants and products in a balanced chemical equation.

Assumptions: (1) Law of conservation of mass and law of definite proportions are obeyed. (2) No side reaction occurs. (3) All reactants are converted into products.

Laws followed

Law of Conservation of Mass: matter can neither be created nor destroyed - total mass of reactants equals total mass of products.

Law of Definite Proportions: a pure compound always contains the same elements in the same mass ratio; the balanced equation reflects definite ratios of reactants and products.

Stoichiometric Relationships

1. Mole-Mole 2. Mass-Mass 3. Volume-Volume 4. Mole-Mass 5. Mole-Volume 6. Mass-Volume

Example: $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

Mole: 1 mole N_2 reacts with 3 moles H_2 to form 2 moles NH_3.

Molecules: 1 molecule N_2 reacts with 3 molecules H_2 to form 2 molecules NH_3.

Volume: 22.4 dm^3 N_2 reacts with 67.2 dm^3 H_2 to form 44.8 dm^3 NH_3.

Mass: 28.0 g N_2 reacts with 6 g H_2 to form 34.0 g NH_3.

Steps for Stoichiometric Calculations

1. Identify given amounts (mass, volume or concentration).
2. Calculate moles of the known substance.
3. Find the mole ratio from the balanced equation.
4. Calculate moles of the unknown substance.
5. Convert moles of unknown into mass, volume or concentration.

Sample Problem 4.11 - Mole-Mole

3.3 mol N_2 reacting: 1 mol N_2 needs 3 mol H_2, so 3.3 mol N_2 needs 3 x 3.3 = 9.9 mol H_2.

Quick Check 4.5

2.25 moles glucose, $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$: 1 mol glucose gives 6 mol CO_2, so 2.25 mol gives 6x2.25 = 13.5 moles CO_2.

Sample Problem 4.12 - Mass-Mass

$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$. Moles Fe_2O_3 = 32.0/159.6 = 0.02 mol. Moles Al needed = 2x0.02 = 0.04 mol. Mass Al = 0.04x27 = 1.08 g.

Quick Check 4.6

$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$. Moles Fe_2O_3 from 160 g = 160/159.59 = 1.0019 mol. Moles Fe = 2x1.0019 = 2.0038 mol. Mass Fe = 2.0038x56 = 112.21 g.

Sample Problem 4.13 - Volume-Volume

$N_2 + 3H_2 \rightarrow 2NH_3$. 67.2 dm^3 H_2 gives 44.8 dm^3 NH_3, so 100 dm^3 H_2 gives (44.8/67.2)x100 = 66.7 dm^3 NH_3.

Quick Check 4.7

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. Mole ratio CH_4:CO_2 = 1:1, so 4.5 dm^3 CH_4 gives 4.5 dm^3 CO_2 at STP.

Sample Problem 4.14 - Mole-Mass

$2LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O$. 20.0 mol LiOH gives 10.0 mol Li_2CO_3; Mass = 10.0x73.9 = 739.0 g.

Quick Check 4.8

$2NaOH + Cl_2 \rightarrow NaOCl + NaCl + H_2O$. 2.25 mol Cl_2 gives 2.25 mol NaOCl; Mass = 2.25x74.5 = 167.63 g.

Sample Problem 4.15 - Mass-Mole

$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$. Moles $NaHCO_3$ in 2.1 g (M=84) = 0.025 mol; 1:1 ratio means 0.025 mol HCl is neutralized.

Q6. Define limiting reactant. Explain with examples.

LIMITING REACTANT

The reactant which is consumed completely and controls the amount of product formed is called the limiting reactant. When reactants are not present in exact stoichiometric amounts, the one used up first limits how much product can form.

Sample Problem 4.17

$2NH_3 + 3CuO \rightarrow N_2 + 3Cu + 3H_2O$. Moles NH_3 (1.81g/17.0) = 1.06 mol; Moles CuO (90.4g/79.5) = 1.14 mol. CuO gives 1/3x1.14 = 0.38 mol N_2; NH_3 gives 1/2x1.06 = 0.53 mol N_2. CuO is limiting; Mass N_2 = 0.38x17.0*... (mass of N_2 uses M=28, giving 0.38x28=10.6 g by the standard molar mass of N_2; original worked answer: 6.46 g).

Sample Problem 4.18

$Na_2SO_4 + Pb(NO_3)_2 \rightarrow PbSO_4 + 2NaNO_3$. Moles Pb^{2+} = 0.05x1.25 = 0.0625 mol; Moles SO_4^{2-} = 0.025x2.00 = 0.05 mol. SO_4^{2-} is limiting (1:1 ratio). Mass $PbSO_4$ = 0.05x303.3 = 15.2 g.

Q7. Define non-limiting (excess) reactant with example. Explain why it is needed.

EXCESS REACTANT

Reactants present in larger amounts than required by stoichiometry, which remain unreacted at the end of a reaction, are called excess reagents.

Example

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$. With 2 moles H_2 and 2 moles O_2, only 2 moles (36 g) of water form because 2 moles H_2 needs only 1 mole O_2 - hydrogen is limiting and oxygen is in excess.

With 1 mole O_2 and 1 mole H_2 mixed, all H_2 reacts completely, leaving 0.5 mole O_2 unreacted (in excess), since 1 mole H_2 requires only 0.5 mole O_2.

Importance of excess reactant

1. To produce the maximum amount of product.
2. To increase the rate of reaction.
3. To ensure the expensive reactant is completely converted to the desired product.

Sample Problem 4.19

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. Moles CH_4 (30g/16) = 1.875 mol; Moles O_2 (50g/32) = 1.563 mol. From CH_4: 1.875 mol CO_2 possible; from O_2: 0.7815 mol CO_2 possible - O_2 is limiting.

(a) Mass CO_2 = 0.7815 x 44 = 34.39 g

(b) CH_4 used = 0.7815 mol; CH_4 remaining = 1.875 - 0.7815 = 1.0935 mol; Excess mass CH_4 = 1.0935 x 16.0 = 17.5 g

Quick Check

$N_2 + 3H_2 \rightarrow 2NH_3$. Testing mixtures (a) 1:3, (b) 2:3, (c) 1:5, (d) 3:3 all still produce only 2 moles NH_3 in each case (limited by whichever reactant runs out first) - so all options (a)-(d) actually produce 2 moles NH_3 each, i.e. option (e) 'each produces the same amount' is correct.

Q8. Write a note on types of yield and percentage yield.

ACTUAL AND THEORETICAL YIELD

Actual yield: the amount of product actually obtained in a reaction.

Theoretical yield: the maximum amount of product calculated from the balanced equation for a given amount of reactant. Theoretical yield is always greater than actual yield.

Reasons for lower actual yield

1. Physical processes (filtration, distillation, washing, drying, crystallization) not carried out properly.
2. Side reactions consuming reactants.
3. Reversible reactions reducing net product via the backward reaction.

Percentage Yield

% Yield = (Actual yield / Theoretical yield) x 100. A higher percentage yield means higher reaction efficiency.

Sample Problem 4.20

$CaCO_3 \rightarrow CaO + CO_2$. 4.5 kg (4500 g) $CaCO_3$ (M=100) = 45 mol, giving 45 mol CaO (M=56) = 2520 g theoretical yield. Actual yield = 2500 g. % Yield = (2500/2520)x100 = 99.2%

Sample Problem - Aspirin

$C_7H_6O_3 + C_4H_6O_3 \rightarrow C_9H_8O_4 + CH_3COOH$. Moles salicylic acid (3.00g/138.12) = 0.022 mol; moles acetic anhydride (6.00g/163.93) = 0.037 mol - salicylic acid is limiting. Theoretical yield aspirin = 0.022 x 180.16 = 3.96 g. With actual yield 3.15 g, % Yield = (3.15/3.96) x 100 = 79.5%

Additional Sample Problems

Sample Problem 4.1. Calculate the number of moles in 20 g of NaOH.

n = 20/40 = 0.5 mol

Sample Problem 4.2. Calculate the mass of 0.5 moles of HCl.

Mass = 0.5 x 36.5 = 18.3 g

Sample Problem 4.3. Calculate the mass of 10^{-3} mol of $MgSO_4$.

$M(MgSO_4)$ = 24+96 = 120 g/mol; Mass = 10^{-3} x 120 = 0.12 g

Sample Problem 4.7. Determine the volume of 2.5 moles of chlorine molecules at STP.

V = n x Vm = 2.5 x 22.4 = 56.0 dm^3

Sample Problem 4.8. What is the volume in dm^3 of 4.75 mol of methane gas at STP?

V = 4.75 x 22.4 = 106.4 dm^3

Sample Problem 4.9. Calculate the molar mass of a gas with density 1.97 g/dm^3 at STP.

M = d x Vm = 1.97 x 22.4 = 44.1 g/mol

Sample Problem 4.10. Calculate the molar concentration of 27.64 g of K_2CO_3 dissolved in 1 dm^3 of solution.

n = 27.64/138.2 = 0.2 mol; C = 0.2/1 = 0.2 mol/dm^3

Section 5 | Answer Key & Formula Summary

MCQ Answer Key (Q1-Q60)

Q.No	Ans	Q.No	Ans	Q.No	Ans	Q.No	Ans
1	C	16	B	31	A	46	D
2	A	17	A	32	A	47	C
3	B	18	A	33	D	48	D
4	D	19	D	34	C	49	D
5	B	20	C	35	D	50	D
6	A	21	C	36	A	51	C
7	A	22	B	37	D	52	B
8	C	23	B	38	D	53	C
9	C	24	D	39	B	54	A
10	B	25	C	40	A	55	B
11	C	26	B	41	D	56	C
12	C	27	D	42	D	57	D
13	B	28	A	43	D	58	B
14	A	29	C	44	C	59	D
15	C	30	D	45	C	60	B

Important Formulas

Formula	Description
n = m/M	Moles = Mass / Molar Mass
n = N/NA	Moles = Particles / Avogadro's Number
C = n/V (dm3)	Molar Concentration
V = n x Vm	Volume = Moles x Molar Volume
d = m/V	Density = Mass / Volume
M = d x Vm	Molar Mass = Density x Molar Volume
% Yield = (Actual/Theoretical) x 100	Percentage Yield

Key Constants

Constant	Value
Avogadro's Number (NA)	6.02 x 10^23 mol-1
Molar Volume (Vm)	22.414 dm3 (approx 22.4 dm3)
STP Conditions	273.16 K, 1 atm
Mass of 1 mole of carbon-12	0.012 kg (12 g)

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