

Stoichiometry

Mark scheme and worked solutions for 30 questions: 15 multiple choice, 15 structured.

1 Core Formulae [1]

Answer: C

Explanation

Calcium carbonate contains Ca^{2+} and CO_3^{2-} ions in a 1:1 ratio, so the formula is CaCO_3 (C). A wrongly doubles the calcium; B loses one oxygen from the carbonate ion; D wrongly doubles the carbonate ion and adds an unnecessary bracket.

2 Core Formulae [1]

Answer: A

Explanation

The molecular formula shows the number and type of every atom in one molecule (A). B describes the empirical formula; C describes an ionic formula (formula unit with ionic charges, not atoms in a molecule); D describes percentage composition by mass.

3 Core Formulae [1]

Answer: D

Explanation

$2\text{Mg(s)} + \text{O}_2\text{(g)} \rightarrow 2\text{MgO(s)}$ has 2 Mg and 2 O on each side, so it is balanced with correct state symbols (D). A gives the wrong formula for magnesium oxide (MgO_2); B uses atomic oxygen, O(g) , instead of the diatomic molecule $\text{O}_2\text{(g)}$; C is unbalanced (2 Mg atoms but only 1 MgO formed).

4 Supplement Formulae [1]

Answer: B

Explanation

The ratio C:H in C_4H_{10} is 4:10, which simplifies (divide by 2) to 2:5, giving C_2H_5 (B). A is the molecular formula, not simplified to the smallest ratio; C (CH_2 , ratio 1:2) does not match 4:10; D (C_2H_{10}) only halves the carbon and leaves the hydrogen unchanged, which is not a valid simplification.

5

Supplement

Formulae

[1]

Answer: A

Explanation

Charges must balance: $2 \times (+3)$ from two Al^{3+} ions cancels $3 \times (-2)$ from three SO_4^{2-} ions, giving $\text{Al}_2(\text{SO}_4)_3$ (A). B and C ignore charge balancing altogether. D swaps the subscripts incorrectly: $3 \times (+3) + 2 \times (-2) = +5$, which does not balance to zero.

6

Supplement

Formulae

[1]

Answer: C

Explanation

The ionic equation shows only the species that actually change: $\text{Ag}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \rightarrow \text{AgCl}(\text{s})$ (C). A is the full (non-ionic) equation, which still includes the spectator ions Na^+ and NO_3^- , so it is not an ionic equation. B shows silver and nitrate ions forming a precipitate, but silver nitrate is soluble and does not precipitate. D has the wrong formula and unbalanced charge (left-hand charge is +1, but the compound Ag_2Cl is not a real, correctly charge-balanced formula).

7

Core

Formulae

[4]

Mark scheme

(a)

(a)(i)

[1]

- NaOH (1)

(a)(ii)

[1]

- H_2 (1)

(b)

[2]

- correct formulae: $2\text{Na}(\text{s})$, $2\text{H}_2\text{O}(\text{l})$, $2\text{NaOH}(\text{aq})$, $\text{H}_2(\text{g})$ (1)
- correctly balanced with all four state symbols shown (1)

ALLOW $2\text{Na}(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{NaOH}(\text{aq}) + \text{H}_2(\text{g})$

Worked solution

Sodium hydroxide is made of Na^+ and OH^- in a 1:1 ratio, so its formula is NaOH . Hydrogen gas exists as diatomic molecules, H_2 . For the equation, count atoms on each side: $2\text{Na}(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{NaOH}(\text{aq}) + \text{H}_2(\text{g})$ gives 2 Na, 4 H and 2 O on the left, and 2 Na, $(2 + 2) = 4$ H and 2 O on the right, so it is balanced. State symbols show sodium as a solid, water as a liquid, sodium hydroxide dissolved in the water as aqueous, and hydrogen escaping as a gas.

Mark scheme

(a) [1]

- CH_4 (1)

(b) [1]

- $\text{C}_2\text{H}_6\text{O}$ (1)

(c) [1]

- CH_2O (1)

(d) [1]

- the number and type of different atoms in one molecule (of a compound) (1)

Worked solution

The molecular formula simply lists how many atoms of each element are in one molecule, in the order given in the table. P has 1 carbon and 4 hydrogen atoms and no oxygen, so its formula is CH_4 . Q has 2 carbon, 6 hydrogen and 1 oxygen atom, giving $\text{C}_2\text{H}_6\text{O}$. R has 1 carbon, 2 hydrogen and 1 oxygen atom, giving CH_2O . This is exactly what "molecular formula" means: the actual number and type of atoms present in one molecule, as opposed to the simplest ratio (the empirical formula).

Mark scheme

(a)

[1]

- calcium carbonate → calcium oxide + carbon dioxide (1)

(b)

[2]

- $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$ (2)
- correct formulae and balancing but missing or wrong state symbol(s) (1)

(c)

[1]

- carbon dioxide gas escapes from the open container (into the air), so only the solid calcium oxide is left behind, and this has a smaller mass than the calcium carbonate it came from (1)

ALLOW any answer that identifies that a gaseous product leaves the container, reducing the mass of solid remaining

Worked solution

Heating calcium carbonate breaks it down into calcium oxide and carbon dioxide: calcium carbonate → calcium oxide + carbon dioxide. As a symbol equation, $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$; checking atoms, there is 1 Ca, 1 C and 3 O on each side, so it is balanced. Because the container is open, the carbon dioxide gas produced is free to escape into the surrounding air. Only the solid calcium oxide remains in the container, and since some of the original mass has left as gas, the mass of solid remaining is less than the starting mass of calcium carbonate.

Mark scheme

(a) [1]

- the simplest whole-number ratio of the (different) atoms or ions in a compound (1)

(b) [1]

- C_6H_{12} (1)

(c) [1]

- CH_2 (1)

(d) [1]

- C_4H_8 (1)

Worked solution

6 carbon atoms and 12 hydrogen atoms in one molecule give the molecular formula C_6H_{12} . The empirical formula is the simplest whole-number ratio of these atoms: dividing both numbers by their highest common factor, 6, gives a ratio of 1:2, so the empirical formula is CH_2 . For the second hydrocarbon, the empirical formula CH_2 means the ratio of C:H is always 1:2. If the molecule contains 4 carbon atoms, multiply every number in the empirical formula by 4: $C(1 \times 4)H(2 \times 4) = C_4H_8$.

Mark scheme

(a) [1]

- BaSO_4 (1)

(b) [1]

- NaCl (1)

(c) [3]

- correct formulae for all species: $\text{BaCl}_2(\text{aq})$, $\text{Na}_2\text{SO}_4(\text{aq})$, $\text{BaSO}_4(\text{s})$, $2\text{NaCl}(\text{aq})$ (1)
- correctly balanced equation (1)
- all state symbols correct (1)

ALLOW $\text{BaCl}_2(\text{aq}) + \text{Na}_2\text{SO}_4(\text{aq}) \rightarrow \text{BaSO}_4(\text{s}) + 2\text{NaCl}(\text{aq})$ **Worked solution**

Ba^{2+} (charge 2+) and SO_4^{2-} (charge 2-) combine 1:1, so barium sulfate is BaSO_4 . Na^+ (charge 1+) and Cl^- (charge 1-) combine 1:1, so sodium chloride is NaCl . For the reaction, barium ions from barium chloride swap partners with sulfate ions from sodium sulfate: $\text{BaCl}_2(\text{aq}) + \text{Na}_2\text{SO}_4(\text{aq}) \rightarrow \text{BaSO}_4(\text{s}) + 2\text{NaCl}(\text{aq})$. Checking atoms: left-hand side has 1 Ba, 2 Cl, 2 Na, 1 S, 4 O; right-hand side has 1 Ba, 1 S, 4 O (in BaSO_4) plus 2 Na, 2 Cl (in 2NaCl) — balanced. The precipitate BaSO_4 is shown as a solid because it is insoluble, while the other species remain dissolved (aqueous).

12**Supplement**

Formulae

[5]

Mark scheme

(a)

[2]

- $\text{HCl(aq)} + \text{NaOH(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)}$ (2)
- correct formulae and balancing but a missing or incorrect state symbol (1)

(b)

[1]

- Na^+ and Cl^- (1)

ALLOW either order; must name both to gain the mark

(c)

[2]

- $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O(l)}$ (2)
- correct species (H^+ and OH^- forming water) but a state symbol missing or wrong (1)

Worked solution

The full equation is $\text{HCl(aq)} + \text{NaOH(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)}$; it is already balanced, with 1 of each atom type on both sides. Sodium ions, Na^+ , and chloride ions, Cl^- , appear unchanged on both sides of the equation (they start dissolved and end up dissolved, in the same form), so they are the spectator ions. Removing them from the full ionic version of the equation leaves only the ions that actually react: $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O(l)}$. This shows the essential chemistry of any strong acid–strong alkali neutralisation: hydrogen ions combine with hydroxide ions to form water.

13**Core**

Relative masses of atoms and molecules

[1]

Answer: B**Explanation**

Relative atomic mass compares the average mass of an element's isotopes to 1/12 of the mass of a carbon-12 atom (B). A confuses Ar with the actual mass of an atom in grams. C describes the mass number, not relative atomic mass. D describes the molar mass (mass of one mole), which has units of g/mol, whereas Ar has no units.

14**Core**

Relative masses of atoms and molecules

[1]

Answer: D**Explanation**

$\text{Mr}(\text{CaCO}_3) = 40 + 12 + (16 \times 3) = 40 + 12 + 48 = 100$ (D). A (68) forgets to multiply oxygen by 3, using only one oxygen atom. B (84) uses only two oxygen atoms instead of three. C (116) uses four oxygen atoms instead of three.

15**Core**

Relative masses of atoms and molecules

[5]

Mark scheme

(a) [1]

- 44 (1)

(b) [2]

- 180 (2)
- correct method $(6 \times 12) + (12 \times 1) + (6 \times 16)$ shown but arithmetic slip (1)

(c) [2]

- 80 (2)
 - correct method $(2 \times 14) + (4 \times 1) + (3 \times 16)$ shown but arithmetic slip (1)
-

Worked solution

For CO_2 : $\text{Mr} = 12 + (16 \times 2) = 12 + 32 = 44$. For glucose, $\text{C}_6\text{H}_{12}\text{O}_6$: $\text{Mr} = (6 \times 12) + (12 \times 1) + (6 \times 16) = 72 + 12 + 96 = 180$. For ammonium nitrate, NH_4NO_3 , count every atom in the formula: 2 nitrogen, 4 hydrogen, 3 oxygen. $\text{Mr} = (2 \times 14) + (4 \times 1) + (3 \times 16) = 28 + 4 + 48 = 80$.

16**Core**

Relative masses of atoms and molecules

[4]

Mark scheme

(a) [1]

- 16 g (1)

(b) [2]

- 16.0 g (2)
- correct scale factor $(9.6 \div 24 = 0.4)$ shown but final mass wrong (1)

(c) [1]

- 6.4 g (1)

ECF allow the answer consistent with the mass of oxide calculated in (b) if the method (mass of $\text{MgO} - 9.6$) is correct

Worked solution

By conservation of mass, the mass of oxygen that reacts equals the mass of magnesium oxide formed minus the mass of magnesium used: $40 - 24 = 16$ g. To scale to 9.6 g of magnesium, find the scale factor: $9.6 \div 24 = 0.4$. Multiply every mass in the original ratio by this factor: mass of $\text{MgO} = 0.4 \times 40 = 16.0$ g, and mass of oxygen = $0.4 \times 16 = 6.4$ g. As a check, $9.6 + 6.4 = 16.0$ g, which matches the mass of magnesium oxide calculated — mass is conserved.

17 Core Relative masses of atoms and molecules [4]

Mark scheme

(a) [1]

- $80 + 44 = 124$, which equals the relative formula mass of CuCO_3 , so mass is conserved (1)

(b) [2]

- 2.0 g (2)
- correct scale factor ($3.1 \div 124 = 0.025$) shown but final mass wrong (1)

(c) [1]

- 1.1 g (1)

ECF allow the answer consistent with the scale factor used in (b)

Worked solution

The equation $\text{CuCO}_3 \rightarrow \text{CuO} + \text{CO}_2$ must conserve mass, and indeed $80 + 44 = 124$, matching $M_r(\text{CuCO}_3)$. The scale factor for 3.1 g of copper carbonate compared with the 124 g used to define the relative formula masses is $3.1 \div 124 = 0.025$. Multiplying each relative formula mass by this factor gives the actual masses: mass of $\text{CuO} = 0.025 \times 80 = 2.0$ g, and mass of $\text{CO}_2 = 0.025 \times 44 = 1.1$ g. Checking: $2.0 + 1.1 = 3.1$ g, which equals the starting mass of copper carbonate, confirming the answer.

18 Core The mole and the Avogadro constant [1]

Answer: A

Explanation

Concentration can be expressed either as a mass concentration, g/dm^3 , or as a molar concentration, mol/dm^3 (A). B mixes a density-style unit (g/cm^3) with an inverted molar-mass-style unit (mol/g), neither of which is a concentration unit used for solutions here. C inverts mol/dm^3 to give dm^3/mol , which is not a concentration unit. D (g/mol) is the unit of molar mass, not concentration.

19 Supplement The mole and the Avogadro constant [1]

Answer: C

Explanation

The Avogadro constant is 6.02×10^{23} , and it gives the number of particles (atoms, ions or molecules) in one mole of a substance (C). A reverses the relationship between moles and particles. B has the correct idea but the wrong sign on the exponent, making the number extremely small rather than extremely large. D confuses the Avogadro constant with molar mass, which is measured in grams per mole, not as a pure number of particles.

20**Supplement**

The mole and the Avogadro constant

[1]

Answer: A

Explanation

Amount (mol) = mass $\div$ Ar = $11.5 \div 23 = 0.5$ mol (A). B (0.05 mol) comes from dividing by 230 instead of 23, a decimal-place slip. C (2.0 mol) inverts the calculation ($23 \div 11.5$). D (5.0 mol) is a further decimal-place slip in the other direction.

21**Supplement**

The mole and the Avogadro constant

[1]

Answer: D

Explanation

Volume = amount (mol) $\times$ molar gas volume = $0.25 \times 24 = 6$ dm³ (D). A simply restates the molar gas volume without multiplying by the amount in moles. B (96 dm³) comes from dividing 24 by 0.25 instead of multiplying. C (0.25 dm³) mistakenly restates the amount in moles as if it were already the volume.

22**Supplement**

The mole and the Avogadro constant

[1]

Answer: B

Explanation

Converting 250 cm³ to dm³ gives 0.250 dm³, so concentration = $0.25 \text{ mol} \div 0.250 \text{ dm}^3 = 1.0 \text{ mol/dm}^3$ (B). A (0.1 mol/dm³) comes from using an incorrect conversion factor of 100 instead of 1000 when converting cm³ to dm³ (250 cm³ wrongly treated as 2.5 dm³). C (4.0 mol/dm³) comes from inverting the calculation (dividing volume by amount instead of amount by volume). D (1000 mol/dm³) comes from not converting cm³ to dm³ at all and dividing the wrong way round.

23**Supplement**

The mole and the Avogadro constant

[1]

Answer: C

Explanation

Per 100 g: moles of N = $82.4 \div 14 = 5.89$, moles of H = $17.6 \div 1 = 17.6$. Dividing both by the smaller value (5.89) gives a ratio of N:H = 1:3, so the empirical formula is NH₃ (C). A (NH) and B (NH₂) do not use the correct mole ratio. D (N₃H) has the ratio the wrong way round.

24**Supplement**

The mole and the Avogadro constant

[1]

Answer: B

Explanation

Percentage yield = (actual yield $\div$ expected yield) $\times$ 100 = (9.6 $\div$ 12.0) $\times$ 100 = 80% (B). A (20%) is the percentage "lost" (100 – 80), not the percentage yield itself. C (96%) does not match either value given. D (125%) comes from inverting the fraction (12.0 $\div$ 9.6 $\times$ 100).

25**Supplement**

The mole and the Avogadro constant

[5]

Mark scheme

(a)

[1]

- 40 (1)

(b)

[2]

- 0.20 mol/dm³ (2)
- correct method (8.0 $\div$ 40) shown but arithmetic slip (1)

(c)

[2]

- 0.05 mol (2)
 - correct method (0.20 $\times$ 0.250) shown but arithmetic slip, OR correct conversion of 250 cm³ to 0.250 dm³ shown (1)
-

Worked solution

Mr(NaOH) = 23 + 16 + 1 = 40. To convert a mass concentration to a molar concentration, divide by the molar mass: concentration in mol/dm³ = concentration in g/dm³ $\div$ Mr = 8.0 $\div$ 40 = 0.20 mol/dm³. To find the amount of solute in 250 cm³, first convert the volume to dm³: 250 cm³ = 0.250 dm³. Then use amount (mol) = concentration (mol/dm³) $\times$ volume (dm³) = 0.20 $\times$ 0.250 = 0.05 mol.

Mark scheme

(a) [2]

- 0.125 mol (2)
- correct method ($3.0 \div 24$) shown but arithmetic slip (1)

(b) [2]

- 7.5×10^{22} atoms (2)

ALLOW 7.53×10^{22} or any value consistent with (a) $\times 6.02 \times 10^{23}$

- correct method (moles from (a) $\times 6.02 \times 10^{23}$) shown but arithmetic slip (1)

(c) [1]

- 14.4 g (1)

Worked solution

Amount (mol) = mass $\div$ Ar = $3.0 \div 24 = 0.125$ mol. To find the number of atoms, multiply the amount in moles by the Avogadro constant: number of atoms = $0.125 \times 6.02 \times 10^{23} = 7.525 \times 10^{22}$, which rounds to 7.5×10^{22} atoms. For part (c), rearrange the same relationship the other way: mass = amount $\times$ Ar = $0.60 \times 24 = 14.4$ g.

Mark scheme

(a) [1]

- 0.10 mol (1)

(b) [2]

- 0.24 mol (2)
- correct method ($2.0 \times (120/1000)$) shown but arithmetic slip (1)

(c) [2]

- hydrochloric acid is in excess; magnesium is the limiting reactant (1)
- supporting working: moles of HCl needed for 0.10 mol Mg = $0.10 \times 2 = 0.20$ mol; this is less than the 0.24 mol available (1)

ECF allow "magnesium in excess" only if a consistent (incorrect) comparison is shown from wrong values carried from (a) or (b)

(d) [2]

- 9.5 g (2)
- correct method (moles MgCl_2 = moles Mg used = 0.10; mass = 0.10×95) shown but arithmetic slip (1)

ECF allow an answer consistent with the limiting reactant identified in (c), even if (c) was wrong, provided the method is correct

Worked solution

Amount of Mg = mass $\div$ Ar = $2.4 \div 24 = 0.10$ mol. Amount of HCl = concentration $\times$ volume (in dm^3) = $2.0 \times (120 \div 1000) = 2.0 \times 0.120 = 0.24$ mol. The equation shows that 1 mol Mg reacts with 2 mol HCl, so 0.10 mol Mg needs $0.10 \times 2 = 0.20$ mol HCl. Only 0.20 mol HCl is needed, but 0.24 mol is available, so hydrochloric acid is in excess and magnesium is the limiting reactant. Because magnesium is used up completely, it controls how much product forms: the equation shows a 1:1 ratio between Mg and MgCl_2 , so 0.10 mol MgCl_2 forms. $\text{Mr}(\text{MgCl}_2) = 24 + (35.5 \times 2) = 24 + 71 = 95$, so mass of $\text{MgCl}_2 = 0.10 \times 95 = 9.5$ g.

Mark scheme

(a) [1]

- 0.05 mol (1)

(b) [1]

- 0.05 mol (1)

| **ECF** allow the value from (a), since the ratio of $\text{Na}_2\text{CO}_3 : \text{CO}_2$ is 1:1

(c) [2]

- 1.2 dm³ (2)

| **ALLOW** 1200 cm³

- correct method (0.05×24) shown but arithmetic slip (1)

Worked solution

$\text{Mr}(\text{Na}_2\text{CO}_3) = (2 \times 23) + 12 + (3 \times 16) = 46 + 12 + 48 = 106$. Amount of $\text{Na}_2\text{CO}_3 = \text{mass} \div \text{Mr} = 5.3 \div 106 = 0.05$ mol. The equation shows a 1:1 ratio between Na_2CO_3 and CO_2 , so the amount of CO_2 produced is also 0.05 mol. Since sulfuric acid is in excess, all of the sodium carbonate reacts, so this figure is not limited by the acid. Using the molar gas volume, volume of CO_2 at r.t.p. = amount $\times 24 = 0.05 \times 24 = 1.2 \text{ dm}^3$ (or 1200 cm³).

29**Supplement**

The mole and the Avogadro constant

[6]

Mark scheme

(a)

[1]

- 0.00225 mol (1)

(b)

[1]

- 0.00225 mol (1)

ECF allow the value from (a), since the ratio of NaOH : HCl is 1:1

(c)

[2]

- 0.09 mol/dm³ (2)

ALLOW 0.0900 mol/dm³

- correct method ($0.00225 \div 0.0250$) shown but arithmetic slip (1)

(d)

[2]

- 3.6 g/dm³ (2)

ALLOW 3.60 g/dm³

- correct method (0.09×40) shown but arithmetic slip (1)

ECF allow an answer consistent with the concentration calculated in (c)

Worked solution

Amount of HCl = concentration $\times$ volume (in dm³) = $0.100 \times (22.5 \div 1000) = 0.100 \times 0.0225 = 0.00225$ mol.

The equation shows NaOH and HCl react in a 1:1 ratio, so the amount of NaOH that reacted is also 0.00225 mol. This amount of NaOH was in 25.0 cm³ = 0.0250 dm³ of solution, so concentration = amount $\div$ volume = $0.00225 \div 0.0250 = 0.09$ mol/dm³. To convert to g/dm³, multiply by the molar mass: Mr(NaOH) = 23 + 16 + 1 = 40, so concentration = $0.09 \times 40 = 3.6$ g/dm³.

Mark scheme

(a)

[3]

- moles per 100 g: $C = 85.7 \div 12 = 7.14$; $H = 14.3 \div 1 = 14.3$ (1)
- ratio $C : H = 7.14 : 14.3$, dividing by the smaller value gives $1 : 2.00$ (1)
- empirical formula CH_2 (1)

(b)

[2]

- mass of empirical formula $CH_2 = 12 + 2 = 14$; $42 \div 14 = 3$, so molecular formula = C_3H_6 (1)
- final answer C_3H_6 (1)

Worked solution

To find the empirical formula, convert each percentage to an amount in moles using the A_r values, treating the percentages as masses in 100 g of compound: moles of $C = 85.7 \div 12 = 7.14$; moles of $H = 14.3 \div 1 = 14.3$. Dividing both by the smaller number, 7.14, gives a ratio of $C : H = 1 : 2.00$, so the empirical formula is CH_2 . The mass of this empirical formula unit is $12 + (2 \times 1) = 14$. Since the relative molecular mass of the actual compound is 42, the molecular formula must be a whole-number multiple of the empirical formula: $42 \div 14 = 3$. Multiplying every number in CH_2 by 3 gives the molecular formula, C_3H_6 .