Answers

Chapter 1

Exercises

1 **(a)** $CuCO_3 \rightarrow CuO + CO_2$
(b) $2Mg + O_2 \rightarrow 2MgO$
(c) $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$
(d) $N_2 + 3H_2 \rightarrow 2NH_3$
(e) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

2 **(a)** $2K + 2H_2O \rightarrow 2KOH + H_2$
(b) $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$
(c) $Cl_2 + 2KI \rightarrow 2KCl + I_2$
(d) $4CrO_3 \rightarrow 2Cr_2O_3 + 3O_2$
(e) $Fe_2O_3 + 3C \rightarrow 3CO + 2Fe$

3 **(a)** $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$
(b) $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$
(c) $3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$
(d) $6H_2O_2 + 2N_2H_4 \rightarrow 2N_2 + 10H_2O + O_2$
(e) $4C_2H_7N + 15O_2 \rightarrow 8CO_2 + 14H_2O + 2N_2$

4 **(a)** Sand and water: heterogeneous
(b) Smoke: heterogeneous
(c) Sugar and water: homogeneous
(d) Salt and iron filings: heterogeneous
(e) Ethanol and water: homogeneous
(f) Steel: homogeneous

5 **(a)** $2KNO_3(s) \rightarrow 2KNO_2(s) + O_2(g)$
(b) $CaCO_3(s) + H_2SO_4(aq) \rightarrow CaSO_4(s) + CO_2(g) + H_2O(l)$
(c) $2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$
(d) $Pb(NO_3)_2(aq) + 2NaCl(aq) \rightarrow PbCl_2(s) + 2NaNO_3(aq)$
(e) $2C_3H_6(g) + 9O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$

6 X has diffused more quickly, so it must be a lighter gas. Its particles have greater velocity than the particles of Y at the same temperature. (Note though that they will both have the same value for average kinetic energy.)

7 From the kinetic molecular theory we would expect a solid to be more dense than its liquid, and therefore that ice would sink in water.

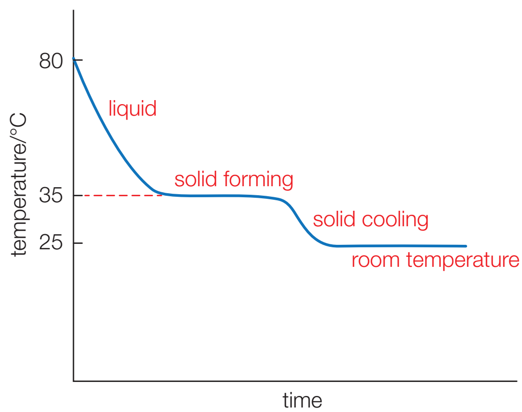
8 Bubbles will be present through the volume of the liquid. A brown gas is visible above the brown liquid. As the two states are at the same temperature, the particles have the same average kinetic energy and are moving at the same speed. The inter-particle distances in the gas are significantly larger than those in the liquid.

9 At certain conditions of low temperature and low humidity, snow changes directly to water vapour by sublimation, without going through the liquid phase.

10 Steam will condense on the skin, releasing energy as it forms liquid at the same temperature (e–d on Figure 1.4). This is additional to the energy released when both the boiling water and the condensed steam cool on the surface of the skin.

11 B

12



13 These calculations have used $L = 6.02 \times 10^{23}$
(a) 7.2×10^{22} **(b)** 3.01×10^{24}
(c) 1.2×10^{23}

14 0.53 mol H

15 0.250 mol

16 **(a)** 262.87 g mol^{-1} **(b)** 176.14 g mol^{-1}
(c) 164.10 g mol^{-1} **(d)** 248.22 g mol^{-1}

17 189.1 g

18 1.5 mol

19 0.0074 mol Cl^-

20 1.83×10^{24} C atoms

21 171 g (integer value because no calculator)

22 10.0 g H_2O

23 2.0 mol N_2 > 3.0 mol NH_3 > 25.0 mol H_2 > 1.0 mol N_2H_4

24 **(a)** CH **(b)** CH_2O
(c) $C_{12}H_{22}O_{11}$ **(d)** C_4H_9
(e) C_4H_7 **(f)** CH_2O

25 $Na_2S_2O_3$

26 $CoSO_4.7H_2O$

27 $C_{17}H_{25}N$

28 NH_3

29 6.94 Li

30 CdS

31 empirical formula CH; molecular formula C_6H_6

32 empirical formula H_2PO_3; molecular formula $H_4P_2O_6$

33 $C_{10}H_{16}N_5P_3O_{13}$ for both empirical and molecular formulas

34 C_3H_8O

35 Let y = mass of chalk in grams.

$$\text{moles of chalk used} = \frac{\text{mass used}}{M_r(CaCO_3)}$$

$$= \frac{y\text{ g}}{100.09\text{ g mol}^{-1}}$$

This is the same as the number of moles of carbon atoms used.

Therefore the number of carbon atoms used = moles of chalk × (6.02×10^{23} mol^{-1})

$$= \frac{6.02 \times 10^{23}\, y}{100.09}$$

36 **(a)** 2.50 mol **(b)** 5.63 mol
(c) 665.5 g

37 **(a)** $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$
(b) 1.59 g

38 4.355 kg

39 **(a)** $CaCO_3 \rightarrow CaO + CO_2$
(b) 92.8%
(c) $CaCO_3$ is the only source of CO_2; all the $CaCO_3$ undergoes complete decomposition; all CO_2 released is captured; heating does not cause any change in the mass of the other minerals present.

40 **(a)** 85.2 g **(b)** 1.3 g H_2

41 5.23 g $C_2H_4Cl_2$

42 254 g theoretical $CaSO_3$; 77.9%

43 3.16 g ester

44 107 g of C_6H_6 needed

45 **(a)** 2.40 mol **(b)** 0.0110 mol
(c) 44 mol

46 **(a)** 35.65 dm^3 **(b)** 5.7 dm^3

47 0.652 dm^3

48 0.138 mol Br_2 and 0.156 mol Cl_2, so more molecules of Cl_2

49 0.113 dm^3

50 0.28 dm^3

51 90 kPa

52 16 °C

53 3.0 dm^3

54 2.8 dm^3

55 M = 133 g mol^{-1} so gas is Xe

56 90.4 g mol^{-1}

57 Helium

58 311 dm^3

59 empirical formula and molecular formula = SO_3

60 At higher altitude the external pressure is less. As the air in the tyre expands on heating (due to friction with the road surface), the internal pressure increases.

61 **(a)** Particles are in constant random motion and collide with each other and with the walls of the container in perfectly elastic collisions. The kinetic energy of the particles increases with temperature. There are no inter-particle forces and the volume of the particles is negligible relative to the volume of the gas.

(b) At low temperature, the particles have lower kinetic energy, which favours the formation of inter-particle forces and reduces gas pressure. $\frac{PV}{nRT} < 1$

62 NH_3 shows greater deviation than CH_4 due to stronger intermolecular attractions, especially at low temperature.

63 B

64 2.81 g

65 4.93 g

66 0.0100 mol

67 0.400 mol dm^{-3}

68 3.1 cm^3

69 0.178 mol dm^{-3}

70 0.0220 mol dm^{-3}, 0.0802% HCl

71 0.106 mol dm^{-3} Na_2SO_4 and 0.115 mol dm^{-3} $Pb(NO_3)_2$; assume no side reactions, all $PbSO_4$ precipitates

Practice questions

The answers to the practice questions below are as given to the IB examiners. The following notes may help you to interpret these and make full use of the guidance given.

- There are no half marks awarded. Each mark is shown by the number in square brackets [1].
- Alternative possible answers are separated from each other by a slash (/).
- Any answer given in **bold** or underlined *must* be present to score the mark.
- Information in brackets ( ) is not needed to score the mark.
- Notes given in italics are to guide the examiner on what to accept/reject in their marking.
- OWTTE means ‘or words to that effect’, so alternative wording that conveys the same meaning can be equally rewarded.
- ECF means ‘error carried forward’, so examiners must award a mark for an incorrect answer from an earlier part of a question used correctly in a subsequent step.
- M1, M2 etc. represent method marks to be awarded by an examiner for answers showing the appropriate steps of the working (method) necessary for answering the question.

You may notice occasional differences between the calculations or wordings given in the answers and those in the worked solutions. This is because the answers give the final solution with the minimum of working, and the worked solutions provide the extra reasoning and working needed to understand how the answers are attained.

1	D	**2**	D	**3**	B	**4**	C
5	A	**6**	B	**7**	D	**8**	D
9	D	**10**	D	**11**	A	**12**	C
13	D	**14**	C	**15**	D	**16**	A

17 **(a)** temperature: 4

mass: 3

pressure: 3 [1]

(b) 0.0650 kg = 65.0 g

$n = \frac{65.0}{65.02} = 1.00$ (mol) [1]

No penalty for using whole number atomic masses.

(c) $n(N_2) = \frac{3}{2} \times 1.00 = 1.50$ (mol)

T = 25.00 + 273.15 = 298.15 K *or* 25.00 + 273 = 298 K

$P = 1.08 \times 1.01 \times 10^5$ Pa *or* $1.08 \times 1.01 \times 10^2$ kPa *or* 1.09×10^5 Pa *or* 1.09×10^2 kPa

$R = 8.31$ J K^{-1} mol^{-1} (from IB Data booklet)

Use $PV = nRT$ (from IB Data booklet)

$V = \frac{nRT}{P} = \frac{1.50 \times 8.31 \times 298.15}{1.08 \times 1.01 \times 10^5} =$ 0.034.1 m^3 = 34.1 dm^3 [4]

*Award **[4]** for correct final answer.*

*Award **[3]** (max) for 0.0341 dm^3 or 22.7 dm^3.*

*Award **[3]** (max) for 34.4 dm^3.*

*Award **[2]** (max) for 22.9 dm^3.*

*Award **[2]** (max) for 0.0227 dm^3.*

*Award **[2]** (max) for 0.034 dm^3.*

18 **(a)** $\left(\left(\frac{2 \times 1.01}{18.02}\right)(0.089) = \right) 1.0 \times 10^{-2}$ g H **and**

$\left(\left(\frac{12.01}{44.01}\right)(0.872) = \right) 2.38 \times 10^{-1}$ g C

$\left(\left(\frac{0.238}{1.30}\right)(100) = \right) 18.3\%$ C

$\left(\frac{1.0 \times 10^{-2}}{1.30}\right)(100) = 0.77\%$ H [3]

*Award **[3]** for correct final answer of 18.3% C and 0.77% H without working.*

Allow whole numbers for molar masses.

(b) $\left((1.75)\left(\frac{35.45}{143.32}\right) = \right) 0.433$ g (Cl) **and**

$\left(\left(\frac{0.433}{0.535}\right)(100) = \right) 80.9\%$ (Cl) [1]

Allow whole numbers for molar masses.

(c) $\left(\frac{18.3}{12.01}\right) = 1.52$ mol C **and**

$\left(\frac{0.77}{1.01}\right) = 0.76$ mol H **and**

$\left(\frac{80.9}{35.45}\right) = 2.28$ mol Cl

Allow whole numbers for atomic masses.

Empirical formula = C_2HCl_3;

*Award **[2]** for correct empirical formula without working.*

$M_r = (24.02 + 1.01 + 106.35) = 131.38$

so molecular formula is C_2HCl_3 [3]

*Award **[3]** for correct final answer without working.*

Allow whole numbers for atomic masses.

19 NH_3/ammonia in excess, by 10 dm^3 [1]

volume of N_2 produced = 25.0 dm^3 [2]

20 **(a)** $n(HCl) = 0.200$ mol $dm^{-3} \times 0.02720$ dm^3 = 0.00544 *or* 5.44×10^{-3} (mol) [1]

(b) $n(HCl)$ excess is 0.100 mol $dm^{-3} \times 0.02380$ dm^3 = 0.00238 *or* 2.38×10^{-3} mol [1]

Penalize not dividing by 1000 once only in (a) and (b).

(c) $n(HCl)$ reacted = 0.00544 – 0.00238 = 0.00306 *or* 3.06×10^{-3} (mol) [1]

(d) $2HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$ *or*

$2H^+(aq) + CaCO_3(s) \rightarrow Ca^{2+}(aq) + H_2O(l) + CO_2(g)$ [2]

*Award **[1]** for correct reactants and products.*

*Award **[1]** if the equation is correctly balanced.*

*Award **[1]** (max) for the following equations:*

$2HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + H_2CO_3(aq)$

$2H^+(aq) + CaCO(s) \rightarrow Ca^{2+}(aq) + HCO(aq)$

Ignore state symbols.

(e) $n(CaCO_3) = \frac{1}{2}n(HCl) = \frac{1}{2} \times 0.00306$

= 0.00153 *or* 1.53×10^{-3} mol [2]

*Award **[2]** for correct final answer.*

(f) $M_r(CaCO_3) = 40.08 + 12.01 + 3 \times 16.00 =$ 100.09 *or* 100.1 g mol^{-1}

Accept 100.

$m(CaCO_3) = n \times M = 0.00153$ mol $\times$ 100.09 g mol^{-1} = 0.153 g

$\%CaCO_3 = \frac{0.153}{0.188} \times 100 = 81.4\%$ *or* 81.5% [3]

Ignore state symbols.

Accept answers in the range 79.8% to 81.5%.

*Award **[3]** for correct final answer.*

(g) only $CaCO_3$ reacts with acid *or* impurities are inert *or* non-basic *or* impurities do not react with the acid *or* nothing else in the eggshell reacts with acid *or* no other carbonates. [1]

Do not accept 'all calcium carbonate reacts with acid'.

21 NaCl 62.9%, $CaCl_2$ 37.1% [2]

22 **(a)** 0.115 mol H_2O [1]

(b) 0.0574 mol K_2CO_3 [1]

(c) $K_2CO_3.2H_2O$ [1]

(d) Heat to constant mass – when further heating does not lead to further decrease in mass. [1]

23 **(a)** NH_3 is in excess [1]

(b) HCl is limiting [1]

(c) 1.64 g ammonium chloride forms [1]

24 **(a)** $2PbS(s) + 3O_2(g) \rightarrow 2PbO(s) + 2SO_2(g)$ [1]

(b) 268 kg [2]

(c) All the PbO reacts/O_2 is in excess.

There are no side reactions/other products. [2]

25 **(a)** $2Al(s) + 3CuSO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3Cu(s)$ [1]

(b) 6.920 mol Al(s) [1]

(c) 3.95 mol Cu(s) [1]

(d) The solid aluminium will seem to disappear and the pink/brown colour of copper will appear. The blue colour of the $CuSO_4(aq)$ solution will fade. [2]

Challenge yourself

1 In cold climates, temperature may approach or go below the boiling point of butane so the butane stays liquid even when it is released from the pressure it is under when stored in its canister. This makes it ineffective as a fuel.

2 $FeCl_3.6H_2O$, $CuSO_4.5H_2O$, $Co(NO_3)_2.6H_2O$

3 N = 18%, P = 22%, K = 17%

4 Many reactions with 'useless' by-products could have high stoichiometric yield under optimum conditions, but low atom economy, for example methanoic acid production:

$$2NaCOOH + H_2SO_4 \rightarrow 2HCOOH + Na_2SO_4$$

For 100% conversion with stoichiometric reactants, the yield = 100%.

$$\text{atom economy} = \frac{2 \times 46.03}{(2 \times 68.01) + 98.08} \times 100\%$$
$$= 39.33\%$$

5 $2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$

$10Na(s) + 2KNO_3(s) \rightarrow K_2O(s) + 5Na_2O(s) + N_2(g)$

$K_2O(s) + Na_2O(s) + SiO_2(s) \rightarrow Na_2K_2SiO_4$ (alkaline silicate glass)

6 As NaOH dissolves, the separated Na^+ and OH^- ions become hydrated, i.e. they are surrounded by H_2O molecules. This involves breaking the hydrogen bonds between the H_2O molecules in pure water and allows closer packing, which reduces the volume.