Chapter 1

Exercises

1. (a) CuCO₃ → CuO + CO₂
(b) 2Mg + O₂ → 2MgO
(c) H₂SO₄ + 2NaOH → Na₂SO₄ + 2H₂O
(d) N₂ + 3H₂ → 2NH₃
(e) CH₄ + 2O₂ → CO₂ + 2H₂O

2. (a) 2K + 2H₂O → 2KOH + H₂
(b) C₂H₅OH + 3O₂ → 2CO₂ + 3H₂O
(c) Cl₂ + 2KI → 2KCl + I₂
(d) 4Cr₂O₃ → 2Cr₂O₅ + 3O₂
(e) Fe₂O₃ + 3C → 3CO + 2Fe

3. (a) 2C₄H₁₀ + 13O₂ → 8CO₂ + 10H₂O
(b) 4NH₃ + 5O₂ → 4NO + 6H₂O
(c) 3Cu + 8HNO₃ → 3Cu(NO₃)₂ + 2NO + 4H₂O
(d) 6H₂O₂ + 2N₂H₄ → 2N₂ + 10H₂O + O₂
(e) 4C₂H₆N + 15O₂ → 8CO₂ + 14H₂O + 2N₂

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) 2KNO₃(s) → 2KNO₂(s) + O₂(g)
(b) CaCO₃(s) + H₂SO₄(aq) → CaSO₄(s) + CO₂(g) + H₂O(l)
(c) 2Li(s) + 2H₂O(l) → 2LiOH(aq) + H₂(g)
(d) Pb(NO₃)₂(aq) + 2NaCl(aq) → PbCl₂(s) + 2NaNO₃(aq)
(e) 2C₄H₁₀(g) + 9O₂(g) → 6CO₂(g) + 6H₂O(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.

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

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 \times 10^{24} \text{ C atoms}

21. 171 g (integer value because no calculator)

22. 10.0 g H\(_2\)O

23. 2.0 mol N\(_2\) > 3.0 mol NH\(_3\) > 25.0 mol H\(_2\) > 1.0 mol N\(_2\)H\(_4\)

24. (a) CH  (b) CH\(_2\)O  
   (c) C\(_{12}\)H\(_{22}\)O\(_{11}\)  (d) C\(_4\)H\(_9\) 
   (e) C\(_4\)H\(_7\)  (f) CH\(_2\)O

25. Na\(_2\)S\(_2\)O\(_3\)

26. CoSO\(_4\)\(_7\)H\(_2\)O

27. C\(_{17}\)H\(_{22}\)N

28. NH\(_3\)

29. 6.94 Li

30. CdS

31. empirical formula CH; molecular formula C\(_5\)H\(_6\)

32. empirical formula H\(_2\)PO\(_4\); molecular formula H\(_2\)P\(_2\)O\(_6\)

33. C\(_{10}\)H\(_{18}\)N\(_3\)P\(_3\)O\(_{13}\) for both empirical and molecular formulas

34. C\(_3\)H\(_8\)O

35. Let y = mass of chalk in grams.
   moles of chalk used = \(\frac{\text{mass used}}{M_1(\text{CaCO}_3)}\)
   \(= \frac{y \text{ g}}{100.09 \text{ g mol}^{-1}}\)
   This is the same as the number of moles of carbon atoms used.
   Therefore the number of carbon atoms used
   \(= \text{moles of chalk} \times (6.02 \times 10^{23} \text{ mol}^{-1})\)
   \(= \frac{6.02 \times 10^{23} y}{100.09}\)

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

37. (a) 2C\(_4\)H\(_{10}\) + 13O\(_2\) \rightarrow 8CO \(_2\) + 10H\(_2\)O  
   (b) 1.59 g

38. 4.355 kg

39. (a) CaCO\(_3\) \rightarrow \text{CaO} + \text{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\(_2\)H\(_4\)Cl\(_2\)

42. 254 g theoretical CaSO\(_4\); 77.9\%

43. 3.16 g ester

44. 107 g of C\(_6\)H\(_6\) 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\(_3\)
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.

(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, \( \frac{PV}{nRT} < 1 \)

NH\(_3\) shows greater deviation than CH\(_4\) due to stronger intermolecular attractions, especially at low temperature.

17 (a) temperature: 4
mass: 3
pressure: 3

(b) 0.0650 kg = 65.0 g
\( n = \frac{65.0}{65.02} = 1.00 \) (mol)

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
Allow whole numbers for molar masses.
18.3% C and 0.77% H without working.
Award [4] for correct final answer.

Award [3] (max) for 0.0341 dm³ or 22.7 dm³.
Award [2] (max) for 22.9 dm³.
Award [2] (max) for 0.0227 dm³.
Award [2] (max) for 0.034 dm³.

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

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

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

$\frac{1.0 \times 10^{-2}}{1.30} (100) = 0.77\% \text{ H}$

Award [3] for correct final answer of 18.3% C and 0.77% H without working.
Allow whole numbers for molar masses.

(b) $\frac{1.75}{35.45} (35.45) = 0.433 \text{ g (Cl) and}$

$\frac{0.433}{143.32} (100) = 0.0309 \text{ (Cl)}$

Award [1] for correct reactants and products.

Award [1] if the equation is correctly balanced.

Award [3] (max) for the following equations:

$2\text{HCl}(aq) + \text{CaCO}_3(s) \rightarrow \text{CaCl}_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)$

$2\text{H}^+(aq) + \text{CaCO}_3(s) \rightarrow \text{Ca}^{2+}(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)$

Ignore state symbols.

(c) $n(\text{HCl}) = 0.200 \text{ mol dm}^{-3} \times 0.02720 \text{ dm}^3 = 0.00544 \times 10^{-3} \text{ (mol)}$

(b) $n(\text{HCl}) \text{ excess is } 0.100 \text{ mol dm}^{-3} \times 0.02380 \text{ dm}^3 = 0.00238 \times 10^{-3} \text{ mol}$

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

(d) $n(\text{HCl}) \text{ reacted } = 0.00544 - 0.00238 = 0.00306 \text{ or } 3.06 \times 10^{-3} \text{ (mol)}$

Award [3] for correct final answer.

Accept answers in the range 79.8% to 81.5%.
Award [3] for correct final answer.

(g) only CaCO₃ 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%, CaCl₂ 37.1% [2]

22 (a) 0.115 mol H₂O [1]
(b) 0.0574 mol K₂CO₃ [1]
(c) K₂CO₃·2H₂O [1]
(d) Heat to constant mass – when further heating does not lead to further decrease in mass. [1]

23 (a) NH₃ is in excess [1]
(b) HCl is limiting [1]
(c) 1.64 g ammonium chloride forms [1]

24 (a) 2PbS(s) + 3O₂(g) → 2PbO(s) + 2SO₂(g) [1]
(b) 268 kg [2]
(c) All the PbO reacts/O₂ is in excess.
There are no side reactions/other products. [2]

25 (a) 2Al(s) + 3CuSO₄(aq) → Al₂(SO₄)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 CuSO₄(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 FeCl₃·6H₂O, CuSO₄·5H₂O, Co(NO₃)₂·6H₂O

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:

\[
2NaCOOH + H₂SO₄ \rightarrow 2HCOOH + Na₂SO₄
\]

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 2NaN₃(s) → 2Na(s) + 3N₂(g)

10Na(s) + 2KNO₃(s) → K₂O(s) + 5Na₂O(s) + N₂(g)

K₂O(s) + Na₂O(s) + SiO₂(s) → Na₂K₂SiO₄ (alkaline silicate glass)

6 As NaOH dissolves, the separated Na⁺ and OH⁻ ions become hydrated, i.e. they are surrounded by H₂O molecules. This involves breaking the hydrogen bonds between the H₂O molecules in pure water and allows closer packing, which reduces the volume.