STANDARD LEVEL

Chemistry

2nd Edition

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Supporting every learner across the IB continuum

PEARSON BACCALAUREATE

STANDARD LEVEL

ANSWERS
Chapter 1

Exercises

1 (a)  \( \text{CuCO}_3 \rightarrow \text{CuO} + \text{CO}_2 \)
(b)  \( 2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO} \)
(c)  \( \text{H}_2\text{SO}_4 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O} \)
(d)  \( \text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3 \)
(e)  \( \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \)

2 (a)  \( 2\text{K} + 2\text{H}_2\text{O} \rightarrow 2\text{KOH} + \text{H}_2 \)
(b)  \( \text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O} \)
(c)  \( \text{Cl}_2 + 2\text{KI} \rightarrow 2\text{KCl} + \text{I}_2 \)
(d)  \( 4\text{CrO}_3 \rightarrow 2\text{Cr}_2\text{O}_3 + 3\text{O}_2 \)
(e)  \( \text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 3\text{CO} + 2\text{Fe} \)

3 (a)  \( 2\text{C}_4\text{H}_{10} + 13\text{O}_2 \rightarrow 8\text{CO}_2 + 10\text{H}_2\text{O} \)
(b)  \( 4\text{NH}_3 + 5\text{O}_2 \rightarrow 4\text{NO} + 6\text{H}_2\text{O} \)
(c)  \( 3\text{Cu} + 8\text{HNO}_3 \rightarrow 3\text{Cu(NO}_3)_2 + 2\text{NO} + 4\text{H}_2\text{O} \)
(d)  \( 6\text{H}_2\text{O}_2 + 2\text{N}_2\text{H}_4 \rightarrow 2\text{N}_2 + 10\text{H}_2\text{O} + \text{O}_2 \)
(e)  \( 4\text{C}_2\text{H}_7\text{N} + 15\text{O}_2 \rightarrow 8\text{CO}_2 + 14\text{H}_2\text{O} + 2\text{N}_2 \)

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)  \( 2\text{KNO}_3(\text{s}) \rightarrow 2\text{KNO}_2(\text{s}) + \text{O}_2(\text{g}) \)
(b)  \( \text{CaCO}_3(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{CaSO}_4(\text{s}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O(l)} \)
(c)  \( 2\text{Li}(\text{s}) + 2\text{H}_2\text{O(l)} \rightarrow 2\text{LiOH(}\text{aq}) + \text{H}_2(\text{g}) \)
(d)  \( \text{Pb(NO}_3)_2(\text{aq}) + 2\text{NaCl(}\text{aq}) \rightarrow \text{PbCl}_2(\text{s}) + 2\text{NaNO}_3(\text{aq}) \)
(e)  \( 2\text{C}_2\text{H}_4(\text{g}) + 9\text{O}_2(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 6\text{H}_2\text{O(l)} \)

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

![Diagram](image)

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 × 10²⁴ C atoms
21. 171 g (integer value because no calculator)
22. 10.0 g H₂O
23. 2.0 mol N₂ > 3.0 mol NH₃ > 25.0 mol H₂ > 1.0 mol N₂H₄

24. (a) CH       (b) CH₂O
   (c) C₁₂H₂₂O₁₁  (d) C₄H₉
   (e) C₄H₇       (f) CH₂O

25. Na₂S₂O₃
26. CoSO₄·7H₂O
27. C₁₇H₂₅N
28. NH₃
29. 6.94 Li
30. CdS
31. empirical formula CH; molecular formula C₆H₆
32. empirical formula H₂PO₃; molecular formula H₄P₂O₆
33. C₁₀H₁₆N₅P₃O₁₃ for both empirical and molecular formulas
34. C₂H₄O
35. Let \( y \) = mass of chalk in grams.
   moles of chalk used = \( \frac{\text{mass used}}{M_r(\text{CaCO}_3)} \)
   = \( \frac{y \text{ g}}{100.09 \text{ g mol}^{-1}} \)
   This is the same as the number of moles of carbon atoms used.
   Therefore the number of carbon atoms used
   = moles of chalk × (6.02 × 10²³ 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) 2C₄H₁₀ + 13O₂ → 8CO₂ + 10H₂O
   (b) 1.59 g
38. 4.355 kg
39. (a) CaCO₃ → CaO + CO₂
   (b) 92.8%
   (c) CaCO₃ is the only source of CO₂; all the CaCO₃ undergoes complete decomposition; all CO₂ 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 H₂
41. 5.23 g C₂H₄Cl₂
42. 254 g theoretical CaSO₃; 77.9%
43. 3.16 g ester
44. 107 g of C₆H₁₆ needed
45. (a) 2.40 mol  (b) 0.0110 mol
   (c) 44 mol
46. (a) 35.65 dm³  (b) 5.7 dm³
47. 0.652 dm³
48. 0.138 mol Br₂ and 0.156 mol Cl₂, so more molecules of Cl₂
49. 0.113 dm³
50. 0.28 dm³
51. 90 kPa
52. 16 °C
53. 3.0 dm³
54. 2.8 dm³
55. \( M = 133 \text{ g mol}^{-1} \) so gas is Xe
56. 90.4 g mol⁻¹
57. Helium
58. 311 dm³
59. empirical formula and molecular formula = SO₃
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.

mass: 3
pressure: 3

\[ n = \frac{m}{M} = \frac{65.0}{65.02} = 1.00 \text{ (mol)} \]  

No penalty for using whole number atomic masses.

\[ n(N_2) = \frac{3}{2} \times 1.00 = 1.50 \text{ (mol)} \]

\[ T = 25.00 + 273.15 = 298.15 \text{ K or } 25.00 + 273 = 298 \text{ K} \]

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.
\[ P = 1.08 \times 1.01 \times 10^5 \text{ Pa or } 1.09 \times 1.01 \times 10^5 \text{ kPa} \]

\[ R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1} \text{ (from IB Data booklet)} \]

Use \[ PV = nRT \text{ (from IB Data booklet)} \]

\[ V = \frac{nRT}{P} = \frac{1.50 \times 8.31 \times 298.15}{1.08 \times 1.01 \times 10^5} = 0.0341 \text{ m}^3 = 34.1 \text{ dm}^3 \]

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 0.0227 dm\(^3\).

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

7

18 (a) \[ 2HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g) \]

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.

(b) \[ n(CaCO_3) = \frac{1}{2}n(HCl) = \frac{1}{2} \times 0.00306 = 0.00153 \text{ mol} \]

Award [2] for correct final answer.

Accept 0.00153 or 1.53 \(\times 10^{-3}\) mol

(c) \[ M_r(CaCO_3) = 40.08 + 12.01 + 3 \times 16.00 = 100.09 \text{ or } 100.1 \text{ g mol}^{-1} \]

Accept 100.

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

%CaCO\(_3\) = \frac{0.153}{0.188} \times 100 = 81.4\% \text{ or } 81.5\% \]

Award [3] for correct final answer.

Accept answers in the range 79.8\% to 81.5\%.

Award [3] for correct final answer.

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%, 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 → 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.
1 Examples are density (related to mass) or, for gases, rate of diffusion.

2 Tellurium has a greater proportion of heavier isotopes (with more neutrons).

3

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<th>Species</th>
<th>No. of protons</th>
<th>No. of neutrons</th>
<th>No. of electrons</th>
</tr>
</thead>
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<td>4</td>
<td>3</td>
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<td>(b) $^1\text{H}$</td>
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<td>0</td>
<td>1</td>
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<tr>
<td>(c) $^{14}\text{C}$</td>
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<td>8</td>
<td>6</td>
</tr>
<tr>
<td>(d) $^{19}\text{F}^-$</td>
<td>9</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>(e) $^{56}\text{Fe}^{3+}$</td>
<td>26</td>
<td>30</td>
<td>23</td>
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4

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<th>No. of protons</th>
<th>No. of neutrons</th>
<th>No. of electrons</th>
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<tbody>
<tr>
<td>(a) $^{40}\text{Ca}^{2+}$</td>
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<td>20</td>
<td>18</td>
</tr>
<tr>
<td>(b) $^{40}\text{Ar}$</td>
<td>18</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>(c) $^{39}\text{K}^+$</td>
<td>19</td>
<td>20</td>
<td>18</td>
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<tr>
<td>(d) $^{35}\text{Cl}^-$</td>
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<td>18</td>
<td>18</td>
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5 C

<table>
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<th>No. of protons</th>
<th>No. of neutrons</th>
<th>No. of electrons</th>
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<tr>
<td>A $^2\text{H}$</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B $^{11}\text{B}$</td>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>C $^{16}\text{O}^{2-}$</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>D $^{19}\text{F}^-$</td>
<td>9</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

6 B 7 B

8 Let $x$ atoms be $^{20}\text{Ne}$ atoms. The remaining atoms are $^{22}\text{Ne}$.

- number of $^{22}\text{Ne}$ atoms = $100 - x$
- total mass = $20 \times x + (100 - x) \times 22 = 2200 - 2x$
- average mass = $\frac{2200 - 2x}{100}$

9 From the Periodic Table we see that the relative atomic mass of neon = 20.18

\[
20.18 = \frac{2200 - 2x}{100}
\]

\[
2018 = 2200 - 2x
\]

\[
x = 91; \text{ abundance } ^{20}\text{Ne} = 91\%
\]

\[
\text{probability of } ^{35}\text{Cl} = \frac{3}{4}
\]

\[
\text{probability of } ^{37}\text{Cl} = \frac{1}{4}
\]

\[
\text{probability of } ^{35}\text{Cl} - ^{35}\text{Cl} (M = 70) = \frac{3}{4} \times \frac{3}{4} = \frac{9}{16} = 56.25\%
\]

\[
\text{probability of } ^{35}\text{Cl} - ^{37}\text{Cl}/^ {37}\text{Cl} - ^{35}\text{Cl} (M = 72) = 2 \times \frac{3}{4} \times \frac{1}{4} = \frac{6}{16} = 37.5\%
\]

\[
\text{probability of } ^{37}\text{Cl} - ^ {37}\text{Cl} (M = 74) = \frac{1}{4} \times \frac{1}{4} = \frac{1}{16} = 6.25\%
\]

10 Let the abundance of $^{25}\text{Mg}$ be $x$. Consider 100 atoms.

\[
24.31 = \frac{(78.90 \times 24) + (x \times 25) + (100 - 78.90 - x) \times 26}{100}
\]

\[
= 1893.6 + 25x + 2600 - 2051.4 - 26x
\]

\[
= 2442.2 - x
\]

\[
x = 11.20
\]

$^{26}\text{Mg}$ 11.20% and $^{25}\text{Mg}$ 9.90%

11 B 12 C 13 A 14 A

13 15 4s < 4p < 4d < 4f

16 Sub-level | 4s | 4p | 4d | 4f
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<td>No. of orbitals</td>
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<td>3</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

17 $1s^22s^22p^63s^23p^64s^2$
18 (a) V is 1s²2s²2p⁶3s²3p⁶4s¹
(b) K is 1s²2s²2p⁶3s²3p⁶4s¹
(c) Se is 1s²2s²2p⁶3s²3p⁶3d¹⁰4s²4p⁴
(d) Sr is 1s²2s²2p⁶3s²3p⁶3d¹⁰4s²4p⁶5s²

Challenge yourself

1 In 1827 Robert Brown dropped grains of pollen into water and examined them under a microscope. The pollen moved around erratically in the water. This so-called ‘Brownian motion’ was explained in 1905 by Albert Einstein. He realized that the pollen was being jostled by something even smaller: water molecules. Einstein didn’t just base this theory on his observations – he used complex mathematics to show that an atomic model could explain Brownian motion.

2 Potash, soda, magnesia and barytes are compounds of Group 1 and 2 elements. In order to obtain the Group 1 and 2 elements (which are metals) from these compounds (which are ionic compounds) it is necessary to reduce them from their ions. This was not possible using the chemical methods available at the time and these compounds were later broken down into their component elements by electrolysis.
3 The Schrödinger model:
- does not have well-defined orbits for the electrons
- does not treat the electron as a localized particle but gives a probability wave description
- predicts the relative intensities of various spectral lines.

4 (a) [Rn]7s²5f¹⁴6d⁷

(b) The first g block element would be [Rn]7s²5f¹⁴6d¹⁰7p⁶8s²8g¹

\[ Z = 86 + 2 + 14 + 10 + 6 + 2 + 1 = 121 \]

5 1s²2s²2p⁵3s²3p⁶4s²3d³4p⁶5s²4d²5p²6s²4f⁴5d¹⁰6p²⁵f¹

6 (a) There would be two types of p orbital and two types of d orbitals.
(b) Four groups in the p and d blocks.
1

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<thead>
<tr>
<th>Element</th>
<th>Period</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) helium</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>(b) chlorine</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>(c) barium</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>(d) francium</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

2 (a) Periods are rows and groups are columns.
(b) $1s^22s^22p^63s^23p^3$

The valence energy level is the third principal energy level, so the element is in period 3. It has the $3p^3$ configuration, so it is in the third group of the p block, which is Group 15.

3 Element 51 is antimony (Sb), which is in Group 15. Its valence electrons are $5s^25p^3$, and so it has five valence electrons.

4 C 5 B 6 C

7 (a) Half the distance between the nuclei of neighbouring atoms of the same element.
(b) (i) The noble gases do not form stable ions and engage in ionic bonding so the distance between neighbouring ions cannot be defined.
(ii) The atomic radii decrease from Na to Cl. This is because the number of inner, shielding, electrons is constant (10) but the nuclear charge increases from +11 to +17. As we go from Na to Cl, the increasing effective nuclear charge pulls the outer electrons closer.

8 Si$^{4+}$ has an electronic configuration of $1s^22s^22p^6$ whereas Si$^{2+}$ has an electronic configuration of $1s^22s^22p^63s^23p^6$. Si$^{4+}$ has two occupied energy levels and Si$^{2+}$ has three and so Si$^{4+}$ is larger.

9 A 10 B 11 C 12 D

13 (a) The electron in the outer electron energy level (level 4) is removed to form K$. The net attractive force increases as the electrons in the third energy level experience a greater effective nuclear charge.
(b) $P^{3-}$ has an electronic configuration of $1s^22s^22p^63s^23p^6$ whereas Si$^{4+}$ has an electronic configuration of $1s^22s^22p^6$. $P^{3-}$ has one more principal energy level than Si$^{4+}$ so its valence electrons will be further from the nucleus and it will have a larger ionic radius.
(c) The ions have the same electron configuration, $1s^22s^22p^63s^23p^6$: both have two complete shells; the extra protons in Na$^+$ attract the electrons more strongly.

14 Phosphorus exists as molecules with four atoms: $P_4$. Sulfur exists as molecules with eight atoms: $S_8$. There are stronger London dispersion forces between the larger $S_8$ molecules as there are more electrons.

15 D 16 C 17 Cl$^-$ > Cl > Cl$^+$

18 B 19 C 20 D 21 B

22 Sodium floats on the surface; it melts into a sphere; there is fizzing/effervescence/bubbles; sound is produced; solution gets hot; white smoke is produced.

$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

23 D

24 The reactivities of the alkali metals increase but those of the halogens decrease.

25 C 26 D 27 D 28 A

29 A 30 B 31 D
(a) State under standard conditions
(b) Structure and bonding

MgO (s) giant structure ionic bonding; strong attraction between oppositely charged ions

SiO2 (quartz) (s) giant structure covalent bonding; strong covalent bonds throughout structure

P4O10 (s) molecular, covalent bonding; weak intermolecular forces between molecules; P4O10 is larger molecule and so has stronger London dispersion forces and a higher melting point than SO2

SO2 (g) molecular, covalent bonding; weak intermolecular forces between molecules; SO2 is smaller molecule and so has weaker London dispersion forces and a higher melting point than P4O10

(c) Oxide | pH of solution | Equations
--- | --- | ---
MgO | alkaline | MgO(s) + H2O(l) → Mg(OH)2(aq)
SiO2 (quartz) | neutral – oxide is insoluble | SiO2(l) + H2O(l) → H4SiO4(aq)
P4O10 | acidic | P4O10(s) + 6H2O(l) → 4H3PO4(aq)
SO2 | acidic | SO2(l) + H2O(l) → H2SO3(aq)

(d) (i) Al2O3(s) + 6HCl(aq) → 2AlCl3(aq) + 3H2O(l)
(ii) Al2O3(s) + 2NaOH(aq) + 3H2O(l) → 2NaAl(OH)4(aq)

The oxides of Na and Mg are basic; the oxide of Al is amphoteric; the oxides of Si to Cl are acidic.
Ar forms no oxide.
Na2O + H2O → 2NaOH
SO3 + H2O → H2SO4

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 C 2 A 3 B 4 B
5 A 6 B 7 C

8 (a) The amount of energy required to remove one (mole of) electron(s) from (one mole of) an atom(s) in the gaseous state
(b) greater positive charge on nucleus / greater number of protons / greater core charge / greater attraction by Mg nucleus for electrons (in the same shell) / smaller atomic radius

9 Na2O(s) + H2O(l) → 2NaOH(aq)
SO3(l) + H2O(l) → H2SO4(aq)
State symbols are not needed.
Na2O is basic and SO3 is acidic

10 (a) Na: 11 p, 11/2.8.1 e− and Na+: 11 p, 10/2.8 e− OR Na+ has 2 shells/energy levels, Na has 3 / OWTTE
Na+ has greater net positive charge/same number of protons pulling smaller number of electrons
(b) Si4+: 10 e− in 2 (filled) energy levels / electron arrangement 2.8 / OWTTE
P3−: 18 e− in 3 (filled) energy levels / electron arrangement 2.8.8, thus larger / OWTTE
OR Si4+ has 2 energy levels whereas P3− has 3 / P3− has one more (filled) energy level
Si4+ has 10 e− whereas P3− has 18 e− / Si4+ has fewer electrons / P3− has more electrons

11 (a) in the solid state ions are in fixed positions / there are no moveable ions / OWTTE
Do not accept answer that refers to atoms or molecules.
(b) \(2O^{2−} \rightarrow O_2 + 4e− / O^{2−} \rightarrow \frac{1}{2}O_2 + 2e−\)  
Accept \(e\) instead of \(e^−\).

(c) (i) basic  
Allow alkaline.

(ii) \(Na_2O + H_2O \rightarrow 2NaOH / Na_2O + H_2O \rightarrow 2Na^+ + 2OH^−\)  
Do not accept \(⇌\)

**Challenge yourself**

1. Ytterbium, yttrium, terbium, erbium
2. Two liquids, 11 gases

3. Metalloids are elements that have chemical and physical properties intermediate to those of metals and non-metals, and include the elements boron, silicon, germanium, arsenic, antimony, and tellurium.

Semi-conductors are materials (elements or compounds) that have electrical conductivity between those of conductors and insulators. Some metalloids are also semi-conductors. Silicon and germanium are two examples.

4. 1s\(^2\)2s\(^2\)2p\(^6\)3s\(^2\)3p\(^6\)4s\(^2\)3d\(^{10}\)4p\(^6\)5s\(^2\)4d\(^{10}\)5p\(^6\)4f\(^{14}\)6s\(^2\) or [Xe]4f\(^{14}\)6s\(^2\)
Chapter 4

Exercises

1. lead nitrate, Pb(NO₃)₂
   barium hydroxide, Ba(OH)₂
   potassium hydrogen carbonate, KHCO₃
   magnesium carbonate, MgCO₃
   copper sulfate, CuSO₄
   calcium phosphate, Ca₃(PO₄)₂
   ammonium chloride, NH₄Cl

2. (a) KBr  (b) ZnO  (c) Na₂SO₄  (d) CuBr₂  (e) Cr₂(SO₄)₃  (f) AlH₃

3. (a) tin(II) phosphate  (b) titanium(IV) sulfate
   (c) manganese(II) hydrogen carbonate
   (d) barium sulfate
   (e) mercury sulfide

4. (a) Sn²⁺  (b) Ti⁴⁺  (c) Mn²⁺  (d) Ba²⁺  (e) Hg⁺

5. A₃B₂

6. Mg 12: electron configuration [Ne]3s²
   Br 35: electron configuration [Ar]3d¹⁰4s²4p⁵
   The magnesium atom loses its two electrons from the 3s orbital to form Mg²⁺. Two bromine atoms each gain one electron into their 4p subshell to form Br⁻. The ions attract each other by electrostatic forces and form a lattice with the empirical formula MgBr₂.

7. B  8  D

8. Test the melting point: ionic solids have high melting points.
   Test the solubility: ionic compounds usually dissolve in water but not in hexane.
   Test the conductivity: ionic compounds in aqueous solution are good conductors.

9. Test the melting point: ionic solids have high melting points.

10. D

11. C

12. (a) H—Br  (b) O═C═O  (c) Cl—F  (d) O═O  (e) H—N—H

13. (a) C 2.6  H 2.2  difference = 0.4
    C 2.6  Cl 3.2  difference = 0.6, more polar
    (b) Si 1.9  Li 1.0  difference = 0.9
    Si 1.9  Cl 3.2  difference = 1.3, more polar
    (c) N 3.0  Cl 3.2  difference = 0.2
    N 3.0  Mg 1.3  difference = 1.7, more polar

14. (a)  (b)  (c)  (d)  (e)  (f)

15. (a) 16  (b) 24  (c) 32  (d) 8  (e) 26

16. H⁺ ↔ H₂O

17. (a)  (b)  (c)  (d)  (e)
18 (a) $105^\circ$ bond angle, shape is bent  
(b) $109.5^\circ$ bond angle, shape is tetrahedral  
(c) $180^\circ$ bond angle, shape is linear  
(d) $107^\circ$ bond angle, shape is trigonal pyramidal  
(e) $120^\circ$ bond angle, triangular planar  
(f) $107^\circ$ bond angle, trigonal pyramidal  
(g) $105^\circ$ bond angle, shape is bent  

19 (a) $120^\circ$ bond angle, shape is trigonal planar  
(b) $120^\circ$ bond angle, shape is trigonal planar  
(c) $180^\circ$ bond angle, shape is linear  
(d) $120^\circ$ bond angle, shape is bent  
(e) $105^\circ$ bond angle, shape is bent  
(f) $107^\circ$ bond angle, shape is trigonal pyramidal  

20 (a) 4  
(b) 3 or 4  
(c) 2  
(d) 4  
(e) 3  

21 (a) polar  
(b) non-polar  
(c) polar  
(d) non-polar  
(e) non-polar  
(f) polar  
(g) non-polar  
(h) non-polar  

22 cis isomer has a net dipole moment  

23 $CO < CO_2 < CO_2^- < CH_3OH$  

24 The N–O bonds in the nitrate(V) ion all have a bond order of 1.33 and will be longer than two bonds in nitric(V) acid, which have a bond order of 1.5 and are shorter than the N–OH bond with a bond order of 1.  

25 Similarities: strong, high melting points, insoluble in water, non-conductors of electricity, good thermal conductors.  
Differences: diamond is stronger and more lustrous; silicon can be doped to be an electrical conductor.  

26 Graphite and graphene have delocalized electrons that are mobile and so conduct electrical charge. In diamond all electrons are held in covalent bonds and are not mobile.  

27 A metal  
B giant molecular  
C polar molecular  
D non-polar molecular  
E ionic compound  

28 A  

29 (a) London dispersion forces  
(b) H bonds, dipole–dipole, London dispersion forces  
(c) London dispersion forces  
(d) dipole–dipole, London dispersion forces  

30 (a) $C_2H_6$  
(b) $H_2S$  
(c) $Cl_2$  
(d) $HCl$  

31 B  

32 (a) malleability, thermal conductivity, thermal stability  
(b) light, strong, forms alloys  
(c) thermal conductivity, thermal stability, non-corrosive  
(d) light, strong, non-corrosive  

33 (i) anodizing: increasing the thickness of the surface oxide layer helps resist corrosion  
(ii) alloying: mixing Al with other metals such as Mg and Cu increases hardness and strength  

**Practice questions**  

For advice on how to interpret the marking below please see Chapter 1.  

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

15 (a) Award [2 max] for three of the following features:  

Bonding  
**Graphite and $C_{60}$ fullerene:** covalent bonds and van der Waals'/London/dispersion forces  
**Diamond:** covalent bonds (and van der Waals'/London/dispersion forces)  

Delocalized electrons  
**Graphite and $C_{60}$ fullerene:** delocalized electrons
**Diamond**: no delocalized electrons

**Structure**

**Diamond**: network/giant structure / macromolecular / three-dimensional structure and **Graphite**: layered structure / two-dimensional structure / planar

*C₆₀ fullerene*: consists of molecules / spheres made of atoms arranged in hexagons / pentagons

**Bond angles**

**Graphite**: 120° and **Diamond**: 109°

*C₆₀ fullerene*: bond angles between 109–120°

Allow **Graphite**: sp² and **Diamond**: sp³. Allow C₆₀ fullerene: sp² and sp³.

**Number of atoms each carbon is bonded to**

**Graphite and C₆₀ fullerene**: each C atom attached to 3 others

**Diamond**: each C atom attached to 4 atoms / tetrahedral arrangement of C (atoms) [6 max]

(b) (i) network/giant structure / macromolecular each Si bonded covalently to 4 oxygen atoms and each O atom bonded covalently to 2 Si atoms / single covalent bonds [2]

Award [1 max] for answers such as network-covalent, giant-covalent or macromolecular-covalent.

Both M1 and M2 can be scored by a suitable diagram.

(ii) **Silicon dioxide**: strong/covalent bonds in network/giant structure/macromolecule

**Carbon dioxide**: weak/van der Waals’/dispersion/London forces between molecules [2]

(c) triple (covalent) bond

one electron pair donated by oxygen to carbon atom / dative (covalent)/coordinate (covalent) bond [2]

Award [1 max] for representation of C≡O.

Award [2] if CO shown with dative covalent bond.

16 Methoxymethane is very weakly polar/weak van der Waals’/dipole–dipole forces exist between methoxymethane molecules.

Accept alternatives to van der Waals’ such as London and dispersion forces

Ethanol contains a hydrogen atom bonded directly to an electronegative oxygen atom / hydrogen bonding can occur between two ethanol molecules / intermolecular hydrogen bonding in ethanol; the forces of attraction between molecules are stronger in ethanol than in methoxymethane / hydrogen bonding stronger than van der Waals’/dipole-dipole attractions. max [3]

Award [2] max if covalent bonds breaking during boiling is mentioned in the answer.

Penalize only once if no reference given to intermolecular nature of hydrogen bonding or van der Waals’.

![Diagram](image)

17 (a) ![Diagram](image) [2]

(b) **Tetrahedral**

Bond angles 109.5° [2]

(c) **Polar**

C–F bond is more polar than C–Cl bond / F more electronegative than Cl and the bond dipoles do not cancel [2]

(d) In O₃ there is more than one possible position for the double bond.

The true structure is a resonance hybrid in which the oxygen–oxygen bonds are intermediate in length and strength between single and double bonds. [3]

(e) O₂ has double bonds and O₃ has bonds that are intermediate in strength between double and single/bond order O₂ = 2 and bond order O₃ = 1.5.

O₃ has weaker bonds than O₂.

Bonds in O₃ are broken by light of lower energy/longer wavelength than bonds in O₂. [3]
18 (a) Lewis (electron dot) structures | Shape of molecule | Bond angles
---|---|---
\( \text{PH}_3 \) | \( \cdot\text{H} : \cdot\text{P} : \cdot\text{H} \) | trigonal pyramidal | 107°
\( \text{H}_2\text{O} \) | \( \cdot\text{H} : \bigcirc : \cdot\text{H} \) | V-shaped/ bent | 105°
\( \text{C}_2\text{H}_6 \) | \( \cdot\text{H} : \cdot\text{C} : \cdot\text{C} : \cdot\text{H} \) | tetrahedral around each C atom | 109.5°
\( \text{CH}_3\text{CHO} \) | \( \cdot\text{H} : \cdot\text{C} : \cdot\text{C} : \cdot\text{H} \) | tetrahedral around one C atom and planar triangular around the other | 109.5° 120°

(b) \( \text{H}_2\text{O} \) can form hydrogen bonds with other \( \text{H}_2\text{O} \) molecules.
It is the only one of (i) to (iv) that contains an H atom directly bonded to O, N, or F. [2]

19 (a) (i) Potassium consists of a lattice of cations/K⁺ ions surrounded by a sea of delocalized electrons/mobile electrons.
The bonding is non-directional. [3]

(ii) conducts electricity delocalized electrons are mobile and can carry charge
conduces heat delocalized electrons and close-packed ions enable transfer of heat energy
malleable/ductile non-directional nature of metallic bond means that it remains intact while conformation changes with applied pressure
high melting point delocalized electrons cause metallic bonds to be strong
lustrous/shiny delocalized electrons in crystal structure reflect light

(b) (i) \( \text{F}_2 \) diatomic molecules.
Covalent bond between two F atoms.
Covalent bond is non-polar. [3]

(ii) London (dispersion) forces between the \( \text{F}_2 \) molecules.
Instantaneous dipole-induced dipole.
Weak forces between molecules. [3]

(c) \( \text{K} 1s^22s^22p^63s^23p^64s^1 \) and \( \text{F} 1s^22s^22p^5 \)
K loses its outer electron and forms \( \text{K}^+ \)/cation.
F gains electron and forms \( \text{F}^- \)/anion.
Ions are held together by electrostatic forces of attraction in a lattice structure. [4]

(d) Ions held tightly (by electrostatic forces)/non-mobile in solid state.
Ions can move (and carry charge) when molten or in solution. [2]

20 (a) \( \text{H} = \cdot\text{Si} = \cdot\text{H} \)

(i) tetrahedral

(ii) trigonal pyramidal [4]

(b) 109.5°
Four electron domains in both \( \text{SiH}_4 \) and \( \text{PH}_3 \), but lone pair in \( \text{PH}_3 \) causes greater repulsion and decreases the angles between the H atoms. [2]

21 (a) \( \text{H} : \cdot\text{N} : \cdot\text{H} \)

Trigonal pyramidal
107° [3]

(b) Polar
Polar N–H bonds do not cancel/net dipole moment. [2]

(c) \( \begin{array}{c} \text{H} \cr \cdot\text{N} : \cdot\text{H} \end{array}^+ \)
Tetrahedral
109.5° [3]

(d) Coordinate covalent bond.
Lone pair on \( \text{NH}_3 \) donates to empty orbital in \( \text{H}^+ \). [2]

(e) \( \text{NH}_3 \) and \( \text{NH}_3^+ \) both have four-electron domains, so are tetrahedrally arranged.
\( \text{NH}_3 \) has only three bonded electron domains
and one lone pair, which causes greater repulsion.

$\text{NH}_3$ bond angle is 107° and $\text{NH}_4^+$ bond angle is 109.5°. 

22 (a) It is not a Lewis (electron dot) structure. All electron pairs/lone pairs of electrons are not shown. 

(b) C1 bond angle: 109.5°  
    C2 bond angle: 120° 

(c) One carbon–oxygen bond is single and the other is double.  
The double carbon–oxygen bond is shorter and stronger than the single bond. 

(d) The true structure of the ethanoate ion is a resonance hybrid. 

\[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{C} \\
\text{H} \\
\text{O} \\
\end{array}
\]

In this structure both carbon–oxygen bonds are equal and intermediate in length and strength between single carbon–oxygen and double carbon–oxygen bonds. 

---

**Challenge yourself**

1 Aluminium oxide is less ionic than MgO due to a smaller difference in electronegativity. It has some partially covalent character, which means the comparison with more ionic oxides is not fully valid.

2 $\text{F}_2$ has lower bond enthalpy than expected from its atomic radius due to repulsion. The bond length is so short that the lone pairs in the two atoms repel each other, weakening the bond.

3 When bonded to F, e.g. in $\text{OF}_2$.

4 Run each solution out from separate burettes, and see whether the stream of liquid is deflected in the presence of a charged rod. Only the polar solution will show deflection.

Test solubility with ionic and covalent solutes. The polar solution will be a better solvent for polar/ionic solutes; the non-polar solution for covalent/non-polar solutes.

5 The high thermal conductivity of diamond is because of its strong covalent bonds. When heated the bonds becoming vibrationally excited, and as they are all connected heat energy could be readily transferred through the network from one bond to the next. Silicon is similarly a good thermal conductor – which is why computer chips need to be cooled.

6 Diamonds are kinetically stable with respect to graphite, as the conversion has a very high activation energy (see Chapter 6). So the reaction generally occurs too slowly to be observed.
Chapter 5

Exercises

1. B  2. B  3. A

4. D  5. C

6. \( q = mc\Delta T \), so \( \Delta T = \frac{q}{mc} = \frac{100}{100 \times 0.138} = 7.25 \, ^\circ C \)

\( T = 25.0 + 7.25 = 32.3 \, ^\circ C \)


10 (a) \( \Delta T = 36.50 - 25.85 = 10.65 \, ^\circ C \) (or K)

\[ q = mc\Delta T \]

\[ q = m(H_2O) \times c(H_2O) \times \Delta T(H_2O) + m(Cu) \times c(Cu) \times \Delta T(Cu) \]

\[ = (200.00 \times 4.18 \times 10.65) + (120.00 \times 0.385 \times 10.65) \]

\[ = 8900 \, J + 492 \, J \]

\[ q = 9392 \, J \]

\[ n(C_6H_{12}O_6) = \frac{1.10 \, g}{180.18 \, g \, mol^{-1}} = 6.11 \times 10^{-3} \, mol \]

In calculating the enthalpy change of combustion, \( \Delta H_c \), we have to recognize that this is an exothermic reaction and that \( \Delta H_c \) will therefore be a negative value.

\[ \Delta H_c = \frac{-9392 \, J}{6.11 \times 10^{-3} \, mol} \]

\[ = -1.54 \times 10^6 \, J \, mol^{-1} \]

\[ = -1540 \, kJ \, mol^{-1} \]

(b) \[ \Delta H = -1540 \, kJ \, mol^{-1} \]

\[ C_6H_{12}O_6(s) + 6O_2(g) \]

\[ \rightarrow 6CO_2(g) + 6H_2O(l) \]

\[ \Delta H = -1540 \, kJ \, mol^{-1} \]

11. \( q = mc\Delta T \)

\[ q = 150.00 \times 4.18 \times (31.5 - 25.0) \, K \]

\[ = 4075.5 \, J = 4100 \, J \) (to 2 s.f.) \]

\[ n(P) = \frac{0.0500 \, g}{30.97 \, g \, mol^{-1}} = 1.61 \times 10^{-3} \, mol \]

\[ \Delta H_c = \frac{-4100 \, J}{1.61 \times 10^{-3} \, mol} \]

\[ = -2525 \times 10^3 \, J \, mol^{-1} \]

\[ = -2500 \, kJ \, mol^{-1} \]

The precision of the answer is limited by the precision of measurement of the temperature difference. The value is lower than the literature value owing to heat losses and incomplete combustion.

12. \( q = mc\Delta T \)

\[ q = 1000 \times 4.18 \times (70.0 - 20.0) \, K \]

\[ = 209 \, kJ, \) for 1 mole of 1 mol dm^{-3} solution \]

\[ \Delta H = -209 \, kJ \, mol^{-1} \]

13. \( \Delta T = 32.3 - 24.5 = 7.8 \, K \)

\[ q = m(H_2O) \times c(H_2O) \times \Delta T(H_2O) \]

\[ = 100.00 \times 4.18 \times 7.8 \, K \]

\[ = 3300 \, J \]

\[ n(NaOH) = \frac{50.00 \, g}{1000 \, g} \times 0.950 = 0.0475 \, mol \]

\[ \Delta H = \frac{-3300 \, J}{0.0475 \, mol} = 69 \times 10^3 \, J \, mol^{-1} \]

\[ = -69 \, kJ \, mol^{-1} \]

Assumptions: no heat loss, \( c(\text{solution}) = c(\text{water}), m(\text{solution}) = m(H_2O), \) density(H_2O) = 1.00

14. If the mass of the solution is taken as 105.04 g (mass of water + mass of NH_2Cl dissolved), \( \Delta H = +16.5 \, kJ \, mol^{-1} \).

If the mass of the solution is instead assumed to be 100.00 g (mass of water only), \( \Delta H = +15.7 \, kJ \, mol^{-1} \).

\[ q = mc\Delta T \]

\[ = 100.00 \times 4.18 \times (21.79 - 25.55) \, K \]

\[ = -1570 \, J \) for 5.35 g
\[ q = 293.6 \text{ J per g} \]
\[ n(\text{NH}_4\text{Cl}) = 53.50 \text{ g mol}^{-1} \]
\[ \Delta H = 293.6 \text{ J g}^{-1} \times 53.50 \text{ g mol}^{-1} = 15.7 \text{ kJ mol}^{-1} \]

15 \( \Delta H \) is change in enthalpy, the heat content of a system. Enthalpy cannot be measured directly but enthalpy changes can be calculated for chemical reactions and physical processes from measured temperature changes using the equation \( q = mc \Delta T \), where \( q \) is the heat change, \( m \) is the mass of the substance(s) changing temperature, \( c \) is the specific heat capacity of the substance(s) changing temperature and \( \Delta T \) is the measured temperature change occurring in the substance(s).

16 \( \Delta H^\circ = -394 \text{ kJ} - (-283) \text{ kJ} = -111 \text{ kJ} \)
17 \( \Delta H^\circ = -180.5 \text{ kJ} + (+66.4 \text{ kJ}) = -114.1 \text{ kJ} \)
18 \( \Delta H^\circ = (2 \times (-33.2 \text{ kJ mol}^{-1})) + (+9.16 \text{ kJ mol}^{-1}) = -57.24 \text{ kJ mol}^{-1} \)

20 B 21 C 22 D 23 D

24 (a) \( 3\text{C(graphite)} + 3\text{H}_2(g) + \frac{1}{2}\text{O}_2(g) \rightarrow \text{CH}_3\text{COCH}_3(l) \)
\[ \Delta H^\circ = -248 \text{ kJ mol}^{-1} \]
(b) Under standard conditions of 298 K (25 °C) and 1.00 × 10^5 Pa. If the reaction involves solutions these have a concentration of 1.00 mol dm^{-3}.

25 +330 kJ mol^{-1}
26 −57.2 kJ mol^{-1}
27 D
28 \( 2\text{MgO(s)} + \text{C(s)} \rightarrow \text{CO}_2(g) + 2\text{Mg(s)} \)
\[ \Delta H^\circ_{\text{reaction}} = (-394) - 2(-602) = +810 \text{ kJ mol}^{-1} \]
Such a highly endothermic reaction is unlikely to be feasible.

29 B 30 A 31 C

32 \( 1 \times \text{C–C} + 6 \times \text{C–H} \)
33 B
34 \( -125 \text{ kJ mol}^{-1} \)

35 \( -486 \text{ kJ mol}^{-1} \)
36 B 37 C
38 \( \text{C}_2\text{H}_5\text{OH(l)} + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 3\text{H}_2\text{O(g)} \)
\[ \begin{array}{ccc}
\text{C} & \text{C} & \text{O} \\
\text{H} & \text{H} & \text{H} \\
\text{H} & \text{H} & \text{H} \\
\text{H} & \text{H} & \text{H} \\
\end{array} \]
\[ 2 \times \text{O=C=O(g)} + 3 \times \text{H–O–H(g)} \]

\[
\begin{array}{|c|c|c|c|}
\hline
\text{Bonds} & \Delta H / \text{kJ mol}^{-1} & \text{Bonds} & \Delta H / \text{kJ mol}^{-1} \\
\text{broken} & \text{formed} & \text{reaction} & -111 \text{ kJ mol}^{-1} \text{ mol}^{-1} \\
\hline
\text{C–C} & +346 & 4 \text{C}=\text{O} & 4 \times (-804) \\
3 \text{O}=\text{O} & 3 \times (+498) & 6 \text{H–O} & 6 \times (-463) \\
\text{O–H} & +463 & & \\
\text{C–O} & +358 & & \\
5 \text{C–H} & 5 \times (+414) & & \\
\text{Total} & +4731 & & -5994 \\
\hline
\end{array}
\]
\[ \Delta H^\circ = +4731 - 5994 \text{ kJ mol}^{-1} = -1263 \text{ kJ mol}^{-1} \]
The calculated value is less exothermic than the enthalpy of combustion in Table 13. This is because the bond enthalpy calculation assumes all species are in the gaseous state: water and ethanol are liquids.

39 (a) Step II, as bonds are formed.
(b) \( \text{O}_2 \) has a double bond. \( \text{O}_3 \) has resonance structures/delocalization with bonding intermediate between double and single bonds; the bond order is 1.5. The bonding in \( \text{O}_2 \) is stronger therefore reaction I needs more energy.

40 \( L \times E_{\text{photon}} = 498 \text{ kJ} = 498,000 \text{ J} \)
\[ E_{\text{photon}} = \frac{498,000}{6.02 \times 10^{23}} \text{ J} (= 8.272 \times 10^{-19} \text{ J}) \]
\[ \lambda = \frac{hc}{E_{\text{photon}}} \]
\[ = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8} \times 6.02 \times 10^{23}}{498,000} \]
\[ = 2.41 \times 10^{-7} \text{ m} \]
\[ = 241 \text{ nm} \]
Any radiation in the UV region with a wavelength shorter than 241 nm breaks the O=O bond in oxygen.

41 The oxygen double bond is stronger than the 1.5 bond in ozone. Thus, less energy is required
to dissociate O₃ than O₂. Longer wavelength radiation of lower energy is needed to dissociate O₃.

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 D  
2 D  
3 A  
4 C  
5 B  
6 C  
7 B  
8 B  
9 (a) amount of energy required to break bonds of reactants

\[3 \times 414 + 358 + 463 + 1.5 \times 498 \ (kJ \ mol^{-1})\]

= 2810 \ (kJ \ mol^{-1}) \text{ [1]}

amount of energy released during bond formation of products

\[4 \times 463 + 2 \times 804 \ (kJ \ mol^{-1}) = 3460 \ (kJ \ mol^{-1})\]

\[\Delta H = 2810 - 3460 = -650 \ (kJ \ mol^{-1})\]  

(b) (i) \[m(\text{methanol}) = 80.557 - 80.034 = 0.523 \ (g)\]

\[n(\text{methanol}) = \frac{0.523 \ g}{32.05 \ g \ mol^{-1}} = 0.0163 \ (mol)\]

Award [2] for correct final answer.

(ii) \[\Delta T = 26.4 - 21.5 = 4.9 \ (K)\]

\[q = (mc\Delta T) = 20.000 \times 4.18 \times 4.9 \ (J) \text{ or} \]

\[20.000 \times 4.18 \times 4.9 \times 10^{-3} \ (kJ)\]

\[= 410 \ J \ or \ 0.41 \ kJ\]

Award [3] for correct final answer.

(iii) \[\Delta H^\circ = -\frac{410 \ (J)}{0.0163 \ (mol)} \text{ or} \]

\[-\frac{0.41 \ (kJ)}{0.0163 \ (mol)} \text{ [1]}

\[= -25153 \ J \ mol^{-1} \ or \ -25 \ kJ \ mol^{-1}\]

Award [2] for correct final answer. Award [1] for (+)25 (kJ mol⁻¹).

(c) (i) bond enthalpies are average values/ differ (slightly) from one compound to another (depending on the neighbouring atoms) / methanol is liquid not gas in the reaction

(ii) not all heat produced transferred to water / heat lost to surroundings/ environment / OWTTE / incomplete combustion (of methanol) / water forms as H₂O(l) instead of H₂O(g) [Do not allow just ‘heat is lost’]  


(b) (i) \[T_{\text{final}} = 73.0 \ (°C)\]

\[\Delta T = 48.2 \ (°C)\]

Award [2] for correct final answer. Allow ECF if \(T_{\text{final}}\) or \(T_{\text{init}}\) correct.

(iii) \[10.1 \ (kJ)\]

\[Allow \ in \ the \ range \ 9.9 \ to \ 10.2 \ (kJ).\]

(c) Complete colour change shows all the copper has reacted, so \(n(\text{Zn}) = n(\text{CuSO}_4)\)

\[= \frac{1.00 \times 50.0}{1000} = 0.0500 \ (mol)\]


(d) \[-201 \ kJ \ mol^{-1}\]

\[Allow \ in \ the \ range \ -197 \ to \ -206 \ (kJ \ mol^{-1}). \]

Value must be negative to award mark.
11 (a) energy required = $\text{C}=$C + H–H
= 614 + 436 = 1050
energy released = C–C + 2(C–H)
= 346 + 2(414) = 1174 \[1\]

Allow full consideration of breaking all bonds and forming all the new bonds, which gives values of 2706 and 2830.
energy required = $\text{C}=$C + H–H + 4(C–H)/612 + 436 + 4(413)
and
energy released = C–C + 6(C–H)/347 + 6/613;
$\Delta H = (1050 – 1174) \text{ or } (2706 – 2830) = -124 \text{ kJ mol}^{-1}$ \[1\]

(b) $\Delta H = -1411 + (-286) – (-1560) = -137 \text{ kJ mol}^{-1}$ \[1\]

(c) the actual values for the specific bonds may be different to the average values / the combustion values referred to the specific compounds / OWTTE \[1\]

(d) (i) $-124 \text{ kJ mol}^{-1}$ \[1\]
(ii) average bond enthalpies do not apply to the liquid state / OWTTE; the enthalpy of vaporization/condensation of cyclohexene and cyclohexane / OWTTE \[2\]

12 bonds broken: 4 × N–H, 1 × N–N, 1 × O=O
= +2220 (kJ mol$^{-1}$) \[1\]
bonds formed: 1 × N≡N, 4 × O–H = –2797 (kJ mol$^{-1}$) \[1\]
enthalpy change = 2797 + 2220 = –577 kJ mol$^{-1}$ \[1\]

Award [3] for correct final answer.

13 reaction II (requires a shorter wavelength) \[1\]
$\text{O}_2$ has double bond/bond order 2 and $\text{O}_3$ intermediate between double and single bonds/bond order of $1\frac{1}{2}$ \[1\]

Do not accept stronger/weaker bonding without justification for the second marking point.
Chapter 6

Exercises

1 Reaction gives off a gas: change in volume could be measured. Reaction involves purple MnO$_4^-$ ions being reduced to colourless Mn$^{2+}$ ions: colorimetry could be used. Reaction involves a change in the concentration of ions (23 on the reactants side and 2 on the products side): conductivity could be used.

All these techniques enable continuous measurements to be made from which graphs could be plotted of the measured variable against time.

2 C

3 (a) (i) Measure the decrease in the mass of flask + contents.
     (ii) Measure the increase in pH of the reaction mixture.
     (iii) Measure the increase in volume of gas collected.

(b) The rate of the reaction decreases with time because the concentration of the acid decreases.

4

![Graph](image)

At 60 s, rate = $8.3 \times 10^{-4}$ mol dm$^{-3}$ s$^{-1}$
At 120 s, rate = $3.7 \times 10^{-4}$ mol dm$^{-3}$ s$^{-1}$

5 D 6 A

7 The reaction requiring the simultaneous collision of two particles is faster. The simultaneous collision of three particles is statistically less likely.

8 B 9 B 10 B

11 The ashes must contain a catalyst that speeds up the reaction between sugar and oxygen. (Deduced from the fact that all other factors that affect reaction rate can be ruled out.)

12 (a) $2\text{CO}(g) + 2\text{NO}(g) \rightarrow 2\text{CO}_2(g) + \text{N}_2(g)$

(b) CO is a toxic gas: it combines with haemoglobin in the blood and prevents it from carrying oxygen. NO is a primary air pollutant: it is oxidized in the air to form acidic oxides, leading to acid rain. It also reacts with other pollutants in the atmosphere, forming smog.

(c) The increased surface area of the catalyst in contact with exhaust gases will increase catalyst efficiency.

(d) Catalytic activity involves the catalyst interacting with the gases, and the reaction occurring on its surface. As temperature increases, the increased kinetic energy of the gases increases the frequency with which they bind to the catalyst.

(e) Catalytic converters reduce pollution from cars but do not remove it completely. As in (d), they are not effective when the engine first starts from cold, when an estimated 80% of pollution occurs. Other pollutants in car exhausts are not removed by the catalyst, e.g. ozone, sulfur oxides and particulates. Also the catalytic converter increases the output of CO$_2$, a serious pollutant because of its greenhouse gas properties.
Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1  B  2  A  3  C  4  C
5  B  6  C  7  C  8  A
9  C  10  D  11  B  12  D
13  A  14  B
15  (a) $\text{ZnCO}_3(s) + 2\text{HCl(aq)} \rightarrow \text{ZnCl}_2(aq) + \text{CO}_2(g) + \text{H}_2\text{O(l)}$ [2]
      (b) $\text{CO}_2$ is produced and escapes in an open system. [1]
      (c) The rate of reaction is greatest at the start and decreases with time.
          The concentration of acid decreases as it reacts and so collisions between reactants become less frequent.
          The rate approaches zero as the limiting reactant is used up. [3]
      (d) Draw a tangent to curve A and curve B at $t = 0$.
          Measure the gradient of each tangent.
          Curve A has higher gradient than curve B. [3]
      (e) A at a higher temperature than B.
          Catalyst used in A but not in B.
          The $\text{ZnCO}_3(s)$ in A was in smaller pieces than in B. [3]
      (f) Higher temperature increases the frequency of collisions involving particles with KE > $E_a$.
          A catalyst provides an alternate reaction route with lower $E_a$.
          Smaller particle size/greater surface area leads to higher frequency of collisions between reactants. [6]

16  (a) T2 > T1 [1]
      (b) At higher temperature a greater proportion of particles have higher values of KE.
          Curve is shifted to the right. [2]
      (c) With a catalyst a greater proportion of particles have KE > $E_a$ and can react. [4]

(d) (i) Enthalpy change, $\Delta H$, depends on the difference in energy between reactants and products.
      $\Delta H$ not affected by the rate of reaction/activation energy.
      (ii) The stoichiometric yield depends on the conversion of reactants to products/equilibrium position.
      Yield does not depend on rate of reaction. [4]

Challenge yourself

1 Collecting a gas over warm water will cause its temperature and therefore its volume to increase.
Chapter 7

Exercises

1. A
2. C
3. B

4. (a) \[ K_c = \frac{[\text{NO}_2]^2}{[\text{NO}]^2[\text{O}_2]} \]
(b) \[ K_c = \frac{[\text{NO}_2]^4[\text{H}_2\text{O}]^6}{[\text{NH}_3]^4[\text{O}_2]^7} \]
(c) \[ K_c = \frac{[\text{CH}_3\text{OH}]^2[\text{Cl}^-]}{[\text{CH}_3\text{Cl}]^2[\text{OH}^-]} \]

5. (a) \( \text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g}) \)
(b) \( \text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + 3\text{H}_2(\text{g}) \)

6. (a) \( 3\text{F}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons 2\text{ClF}_3(\text{g}) \)
\[ K_c = \frac{[\text{ClF}_3]^2}{[\text{F}_2]^3[\text{Cl}_2]} \]
(b) \( 2\text{NO}(\text{g}) \rightleftharpoons \text{N}_2(\text{g}) + \text{O}_2(\text{g}) \)
\[ K_c = \frac{[\text{N}_2][\text{O}_2]}{[\text{NO}]^2} \]
(c) \( \text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + 3\text{H}_2(\text{g}) \)
\[ K_c = \frac{[\text{CO}][\text{H}_2]^3}{[\text{CH}_4][\text{H}_2\text{O}]} \]

7. (a) Mostly reactants
(b) Mostly reactants
(c) Mostly products

8. (a) \( \frac{[\text{HOCl} ]^2}{[\text{H}_2\text{O}][\text{Cl}_2]} > K; \) not at equilibrium; reaction proceeds to the left
(b) At equilibrium
(c) \( \frac{[\text{HOCl} ]^2}{[\text{H}_2\text{O}][\text{Cl}_2]} > K; \) not at equilibrium; reaction proceeds to the left

9. (a) \( 7.73 \times 10^4 \)
(b) \( 3.60 \times 10^{-3} \)
(c) \( 6.00 \times 10^{-2} \)

10. B
11. D
12. C

13. (a) Shift to the left
(b) Shift to the right
(c) No shift in equilibrium

14. (a) Shift to the left
(b) Shift to the right
(c) This is equivalent to an increase in pressure, so shifts to the left
(d) Shift to the right
(e) Shift to the right

15. (a) Amount of CO will decrease
(b) Amount of CO will decrease
(c) Amount of CO will increase
(d) No change in CO

16. C
17. B

18. The Haber process is exothermic in the forward direction. Therefore, increasing temperature will decrease the value of \( K_c \). This represents a decrease in the reaction yield.

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1. C
2. D
3. D
4. A
5. C
6. D
7. A
8. D

9. (a) \( \langle K \rangle = \frac{[\text{SO}_3]^2}{[\text{O}_2][\text{SO}_2]^2} \) \[1\]
(b) yield (of SO\(_3\)) increases / equilibrium moves to right / more SO\(_3\) formed;
3 gaseous molecules \( \rightarrow \) 2 gaseous molecules / decrease in volume of gaseous molecules / fewer gaseous molecules on right hand side \[2\]
Do not allow ECF.
(c) yield (of SO\(_3\)) decreases;
forward reaction is exothermic / reverse / backwards reaction is endothermic / equilibrium shifts to absorb (some of) the heat \[2\]
Do not accept exothermic reaction or Le Châtelier’s principle.
Do not allow ECF.
(d) rates of both forward and reverse reactions increase equally; no effect on position of equilibrium; no effect on value of \( K_c \) \[3\]
10. (a) reactants and products in same phase/state; rate of forward reaction = rate of reverse reaction; concentrations of reactants and products remain constant / macroscopic properties remain constant [2 max]

Do not accept concentrations are equal.

(b) \( K_c = \frac{[HI]^2}{[H_2][I_2]} \) [1]

(c) no change to position of equilibrium [1]

(d) the reaction is exothermic / heat is given out / \( \Delta H \) is negative [1]

(e) no effect (on the value of the equilibrium constant) as it speeds up forward and reverse reaction / concentrations of reactants and products do not change / position of equilibrium does not change / no change in yield [2]

---

**Challenge yourself**

1. Earth receives energy from the Sun and disperses energy, largely as heat. But exchange of matter is minimal – the only exceptions to Earth being a closed system are matter received from space such as asteroids and space dust, and matter lost to space such as spacecraft.

2. The different values of \( K_c \) indicate different stabilities of the hydrogen halides. The bonding in HCl is the strongest and in HI the weakest. This is largely because of the size of the atoms. As I has a larger atomic radius than Cl, in HI the bonding pair is further from the nucleus than the bonding pair in HCl, and so experiences a weaker pull. The HI bond breaks more easily and so the dissociation reaction is favoured.

3. The concentration of a pure solid or pure liquid is a constant, effectively its density, which is independent of its amount. These constant values therefore do not form part of the equilibrium expression.

4. The value for \( K_c \) at 298 K for the reaction \( N_2(g) + O_2(g) \rightleftharpoons 2NO(g) \) is extremely low, so the equilibrium mixture lies to the left with almost no production of NO. But at higher temperatures, such as in vehicle exhaust fumes, the reaction shifts to the right and a higher concentration of NO is produced. This gas is easily oxidized in the air, producing the brown gas \( NO_2 \) which is responsible for the brownish haze: \( 2NO(g) + O_2(g) \rightarrow 2NO_2(g) \).

5. The atom economies of the Haber process and the Contact process reactions described are both 100% as there is only one product. In other words, there is no waste. But this does not mean that all reactants are converted to product, so the stoichiometric yield is less than 100%. It is the goal of these industries to maximize yield and efficiency by choosing the optimum conditions, taking equilibrium and kinetic considerations into account.
Chapter 8

Exercises

1 (a) $\text{HSO}_3^-$  
(b) $\text{CH}_3\text{NH}_3^+$  
(c) $\text{C}_2\text{H}_5\text{COOH}$  
(d) $\text{HNO}_3$  
(e) $\text{HF}$  
(f) $\text{H}_2\text{SO}_4$

2 (a) $\text{H}_2\text{PO}_4^-$  
(b) $\text{CH}_3\text{COO}^-$  
(c) $\text{HSO}_3^-$  
(d) $\text{SO}_4^{2-}$  
(e) $\text{O}^{2-}$  
(f) $\text{Br}^-$

3 (a) $\text{CH}_3\text{COOH}$ (acid)/$\text{CH}_3\text{COO}^-$ (base)  
(b) $\text{H}_3\text{O}^+$ (acid)/$\text{H}_2\text{O}$ (base)  
(c) $\text{NH}_4^+$ (acid)/$\text{NH}_3$ (base)

4 (a) $\text{HPO}_4^{2-}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{PO}_4^{3-}(aq) + \text{H}_3\text{O}^+(aq)$ (acid behaviour)  
(b) $\text{HPO}_4^{2-}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{PO}_4^-(aq) + \text{OH}^-(aq)$ (base behaviour)

5 (a) $\text{H}_2\text{SO}_4(aq) + \text{CuO}(s) \rightarrow \text{CuSO}_4(aq) + \text{H}_2\text{O}(l)$  
(b) $\text{HNO}_3(aq) + \text{NaHCO}_3(s) \rightarrow \text{NaNO}_3(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)$  
(c) $\text{H}_3\text{PO}_4(aq) + 3\text{KOH}(aq) \rightarrow \text{K}_3\text{PO}_4(aq) + 3\text{H}_2\text{O}(l)$  
(d) $6\text{CH}_3\text{COOH}(aq) + 2\text{Al}(s) \rightarrow 2\text{Al}(\text{CH}_3\text{COO})_3(aq) + 3\text{H}_2(g)$

6 B  
7 B

8 (a) nitric acid + sodium carbonate / sodium hydrogen carbonate / sodium hydroxide  
(b) hydrochloric acid + ammonia solution  
(c) copper(II) oxide + sulfuric acid  
(d) methanoic acid + potassium hydroxide

9 pH increases by 1 unit

10 pH = 4.72

11 $[\text{H}^+] = 1.0 \times 10^{-9} \text{ mol dm}^{-3}$, $[\text{OH}^-] = 1.0 \times 10^{-5} \text{ mol dm}^{-3}$

12 (a) $[\text{OH}^-] = 2.9 \times 10^{-6} \text{ mol dm}^{-3}$; basic  
(b) $[\text{H}^+] = 1.0 \times 10^{-12} \text{ mol dm}^{-3}$; basic  
(c) $[\text{H}^+] = 1.0 \times 10^{-4} \text{ mol dm}^{-3}$; acidic  
(d) $[\text{OH}^-] = 1.2 \times 10^{-10} \text{ mol dm}^{-3}$; acidic

13 pH = 2.0

14 (a) pH = 6.9  
(b) pH = 2  
(c) pH = 4.8

15 pH = 13.17

16 B  
17 A

18 (a) $\text{H}_2\text{CO}_3$  
(b) $\text{HCOOH}$

19 (a) Contains dissolved carbon dioxide which reacts with water to form carbonic acid:  
$\text{CO}_2(g) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{CO}_3(aq)$

(b) Sulfuric acid:  
$\text{S}(s) + \text{O}_2(g) \rightarrow \text{SO}_2(g)/2\text{SO}_2(g) + \text{O}_2(g) \rightarrow \text{2SO}_3(g)$  
$\text{H}_2\text{O}(l) + \text{SO}_3(g) \rightarrow \text{H}_2\text{SO}_4(aq)$

(c) Nitric acid:  
reduced by use of catalytic converters, recirculation of exhaust gases

(d) $\text{CaCO}_3(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{CaSO}_4(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)$

(e) Effects on materials, plant life and human health (see text for details).

(f) Use alternative energy source to fossil fuels or use coal with a low sulfur content.

20 (a) SO$_2$ and NO  
(b) SO$_2$ and particulates
Particulates act as catalysts in the production of secondary pollutants.

SO\textsubscript{2}(g): CaO(s) + SO\textsubscript{2}(g) \rightarrow CaSO\textsubscript{3}(g)

NO: formed from the combination of nitrogen and oxygen at the high temperature of internal combustion engines.

Dry acid deposition typically occurs close to the source of emission. Wet acid deposition is dispersed over a much larger area and distance from the emission source.

The acid is formed in the air from sulfur dioxide (SO\textsubscript{2}) and nitrogen oxide (NO) which are emitted by thermal power stations, industry and motor vehicles. A major source is the burning of fossil fuels, particularly in coal-fired power stations. Pollutants are carried by prevailing winds and converted (oxidized) into sulfuric acid (H\textsubscript{2}SO\textsubscript{4}) and nitric acid (HNO\textsubscript{3}). These are then dissolved in cloud droplets (rain, snow, mist, hail) and this precipitation may fall to the ground as dilute forms of sulfuric acid and nitric acid. The dissolved acids consist of sulfate ions, nitrate ions and hydrogen ions.

The hydroxyl free radical •OH.

It is formed by the reaction between water and either ozone or atomic oxygen:

H\textsubscript{2}O + O\textsuperscript{*} \rightarrow 2•OH

O\textsubscript{2} + O\textsuperscript{*} \rightarrow O\textsubscript{3}; O\textsubscript{3} + H\textsubscript{2}O \rightarrow 2•OH + O\textsubscript{2}

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 C 2 D 3 B 4 A
5 A 6 C 7 D 8 B
9 B 10 B 11 A 12 D

(a) Use a pH meter.
Use a suitable indicator.

(b) HCOOH(aq), KCl(aq), HNO\textsubscript{3}(aq), pH 5 7 1
Ba(OH)\textsubscript{2}(aq), NH\textsubscript{3}(aq)
pH 13 10

(c) (i) 2NaHCO\textsubscript{3}(s) + 2HCl(aq) \rightarrow Na\textsubscript{2}CO\textsubscript{3}(aq) + CO\textsubscript{2}(g) + H\textsubscript{2}O(l)

(ii) HCO\textsubscript{3}\textsuperscript{-} can act as a Bronsted–Lowry acid and base by giving and accepting protons:

as acid: HCO\textsubscript{3}\textsuperscript{-} \rightarrow H\textsuperscript{+} + CO\textsubscript{3}\textsuperscript{2-}
as base: HCO\textsubscript{3}\textsuperscript{-} + H\textsuperscript{+} \rightarrow H\textsubscript{2}CO\textsubscript{3}

(d) Acids release H\textsubscript{2}(g) when reacted with reactive metal Mg.

Mg(s) + 2H\textsubscript{2}O \rightarrow Mg\textsubscript{2}O\textsubscript{2} + H\textsubscript{2}(g)

Mg(s) + 2CH\textsubscript{3}COOH(aq) \rightarrow Mg(CH\textsubscript{3}COO\textsubscript{2})(aq) + H\textsubscript{2}(g)

(e) Conductivity can be quantified so more objective.

The method described in (c) is qualitative only.

14 (a) Acid: proton/H\textsuperscript{+} donor and Base: proton/H\textsuperscript{+} acceptor

Do not accept OH\textsuperscript{-} for base.

Weak base: (base/electrolyte) partially dissociated/ionized (in solution/water) and Strong base: (base/electrolyte assumed to be almost) completely/100% dissociated/ionized (in solution/water) / OWTTE

NH\textsubscript{3} / CH\textsubscript{3}CH\textsubscript{2}NH\textsubscript{2}

Allow either name or formula or other suitable example.

(b) sulfuric acid/H\textsubscript{2}SO\textsubscript{4}
corrodes marble / limestone buildings / statues / leaching in soils / harms/kills plants OR
nitrous acid/HNO₂

corroses marble / limestone buildings / statues / leaching in soils / harms/kills plants

OR

carbonic acid/H₂CO₃

corroses marble / limestone buildings / statues / acidification of lakes

[2] Do not allow oxides (e.g. CO₂ etc.).
Do not accept just corrodes or damages.

1 Sulfur is present in proteins in living cells (a component of two out of the twenty amino acids). Decomposition of plant material to peat and then coal conserves this sulfur. Additional sources are the depositional environment such as sea water, where sulfates are reduced by bacteria to form H₂S, which can react further to form organic sulfur structures.

2 Combustion of nitrogen involves the highly endothermic step (+942 kJ mol⁻¹) of breaking the triple N≡N bond, as well as the O=O bond (+498 kJ mol⁻¹). The exothermic step of forming the triple N≡O bond releases less energy – approximately 630 kJ mol⁻¹. Therefore enthalpy change (bonds broken minus bonds formed) is endothermic. So the stability and strength of the nitrogen triple bond creates an unusual situation where the products of combustion are less stable than the reactants.

3 HNO₂: N = +3, nitric(III) acid
HNO₃: N = +5, nitric(V) acid
H₂SO₃: S = +4, sulfuric(IV) acid
H₂SO₄: S = +6, sulfuric(VI) acid
Chapter 9

Exercises

1 (a) \( \text{NH}_4^+ = N - 3, \text{H}^+ + 1 \)  
(b) \( \text{CuCl}_2 = \text{Cu}^{+2}, \text{Cl}^{-1} \)  
(c) \( H_2O = H^+ + 1, O^{-2} \)  
(d) \( \text{SO}_2 = S^{+4}, O^{-2} \)  
(e) \( \text{Fe}_2\text{O}_3 = \text{Fe}^{+3}, O^{-2} \)  
(f) \( \text{NO}_3^{-} = \text{N}^{+5}, O^{-2} \)  
(g) \( \text{MnO}_2 = \text{Mn}^{+4}, O^{-2} \)  
(h) \( \text{PO}_4^{3-} = \text{P}^{+5}, O^{-2} \)  
(i) \( \text{K}_2\text{Cr}_2\text{O}_7 = \text{K}^{+1}, \text{Cr}^{+7}, O^{-2} \)  
(j) \( \text{MnO}_4^{-} = \text{Mn}^{+7}, O^{-2} \)  

2 (a) \[
\begin{align*}
\text{Sn}^{2+}(aq) + 2\text{Fe}^{3+}(aq) &\rightarrow \text{Sn}^{4+}(aq) + 2\text{Fe}^{2+}(aq) \\
2 + &\quad +3 \quad +4 \quad +2 \\
\text{oxidation:} \text{Sn}^{2+}(aq) &\rightarrow \text{Sn}^{4+}(aq) + 2e^- \\
\text{reduction:} 2\text{Fe}^{3+}(aq) + 2e^- &\rightarrow 2\text{Fe}^{2+}(aq)
\end{align*}
\]
(b) \[
\begin{align*}
\text{Cl}_2(aq) + 2\text{NaBr}(aq) &\rightarrow \text{Br}_2(aq) + 2\text{NaCl}(aq) \\
0 &\quad −1 \quad −1 \quad 0 \\
\text{oxidation:} 2\text{Br}^−(aq) &\rightarrow \text{Br}_2(aq) + 2e^- \\
\text{reduction:} \text{Cl}_2(aq) + 2e^- &\rightarrow 2\text{Cl}^−(aq)
\end{align*}
\]

3 (a) \[
\begin{align*}
\text{Ca}(s) + 2\text{H}^+(aq) &\rightarrow \text{Ca}^{2+}(aq) + \text{H}_2(g) \\
0 &\quad 1 \quad +2 \quad 0 \\
\text{oxidation:} \text{Ca}(s) &\rightarrow \text{Ca}^{2+}(aq) + 2e^- \\
\text{reduction:} 2\text{H}^+(aq) + 2e^- &\rightarrow \text{H}_2(g)
\end{align*}
\]
(b) \[
\begin{align*}
2\text{Fe}^{2+}(aq) + \text{Cl}_2(aq) &\rightarrow 2\text{Fe}^{3+}(aq) + 2\text{Cl}^−(aq) \\
+2 &\quad 0 \quad +3 \quad −1 \\
\text{oxidation:} 2\text{Fe}^{2+}(aq) &\rightarrow 2\text{Fe}^{3+}(aq) + 2e^- \\
\text{reduction:} \text{Cl}_2(aq) + 2e^- &\rightarrow 2\text{Cl}^−(aq)
\end{align*}
\]

4 (a) \[
\begin{align*}
\text{Zn}(s) + \text{SO}_4^{2−}(aq) + 4\text{H}^+(aq) &\rightarrow \text{Zn}^{2+}(aq) + \text{SO}_2(g) + 2\text{H}_2\text{O}(l)
\end{align*}
\]
(b) \[
\begin{align*}
2\text{I}^−(aq) + \text{HSO}_4^{−}(aq) + 3\text{H}^+(aq) &\rightarrow \text{I}_2(aq) + \text{SO}_2(g) + 2\text{H}_2\text{O}(l)
\end{align*}
\]
(c) \[
\begin{align*}
\text{NO}_3^{−}(aq) + 4\text{Zn}(s) + 10\text{H}^+(aq) &\rightarrow \text{NH}_4^{+}(aq) + 4\text{Zn}^{2+}(aq) + 3\text{H}_2\text{O}(l)
\end{align*}
\]
(d) \[
\begin{align*}
\text{I}_2(aq) + 5\text{OCl}^−(aq) + \text{H}_2\text{O}(l) &\rightarrow 2\text{IO}_3^{−}(aq) + 5\text{Cl}^−(aq) + 2\text{H}^+(aq)
\end{align*}
\]
(e) \[
\begin{align*}
2\text{MnO}_4^{−}(aq) + 5\text{H}_2\text{SO}_3(aq) &\rightarrow 2\text{Mn}^{2+}(aq) + 3\text{H}_2\text{O}(l) + 5\text{SO}_4^{2−}(aq) + 4\text{H}^+(aq)
\end{align*}
\]

5 B 6 D

7 (a) chromium(III) oxide (b) copper(I) chloride (c) nitric(V) acid (d) nitric(III) acid (e) lead(IV) oxide

8 (a) reducing agent = \( \text{H}_2(g) \); oxidizing agent = \( \text{Cl}_2(g) \) (b) reducing agent = \( \text{Al}(s) \); oxidizing agent = \( \text{Pb}^{2+}(s) \) (c) reducing agent = \( \text{I}^−(aq) \); oxidizing agent = \( \text{Cl}_2(aq) \) (d) reducing agent = \( \text{CH}_4(g) \); oxidizing agent = \( \text{O}_2(g) \)

9 (a) \( \text{CuCl}_2(aq) + \text{Ag}(s) \)  
No reaction, Cu is a more reactive metal than Ag.  
(b) \( 3\text{Fe(NO}_3)_2(aq) + 2\text{Al}(s) \rightarrow 2\text{Al(NO}_3)_3(aq) + 3\text{Fe(s)} \)  
Al is a more reactive metal than Fe, so is able to reduce Fe\(^{2+}\).
(c) \(2NaI(aq) + Br_2(aq) \rightarrow 2NaBr(aq) + I_2(aq)\)

Br is a more reactive non-metal than I, so is able to oxidize I\(^-\).

(d) \(KCl(aq) + I_2(aq)\)

No reaction, Cl is a more reactive non-metal than I.

10 (a) \(W > X > Y > Z\)
(b) (i) no reaction
(ii) no reaction

11 (a) Solution changes from purple to colourless
(b) \(C_2O_4^{2-}(aq) \rightarrow 2CO_2(g) + 2e^-\)
(c) \(MnO_4^-\) (aq) + 8H\(^+\) (aq) + 5e\(^-\) \(\rightarrow\) Mn\(^2+\) (aq) + 4H\(_2\)O (l)
(d) \(2MnO_4^-\) (aq) + 16H\(^+\) (aq) + 5C\(_2\)O\(_4\)\(^2-\) (aq) \(\rightarrow\) 2Mn\(^2+\) (aq) + 8H\(_2\)O (l) + 10CO\(_2\) (g)
(e) 6.16 \(\times\) 10\(^{-3}\)
(f) 6.16 \(\times\) 10\(^{-3}\)
(g) 24.7%

12 (a) 0.117%
(b) Solution changes from orange to green

13 (a) Zn / Zn\(^{2+}\) Fe / Fe\(^{2+}\)
   anode cathode
   Zn\((s) \rightarrow Zn^{2+}(aq) + 2e^-\)
   Fe\(^{2+}\) (aq) + 2e\(^-\) \(\rightarrow\) Fe\((s)\)
(b) Fe / Fe\(^{2+}\) Mg / Mg\(^{2+}\)
   cathode anode
   Fe\(^{2+}\) (aq) + 2e\(^-\) \(\rightarrow\) Fe\((s)\)
   Mg\((s) \rightarrow Mg^{2+}(aq) + 2e^-\)
(c) Mg / Mg\(^{2+}\) Cu / Cu\(^{2+}\)
   anode cathode
   Mg\((s) \rightarrow Mg^{2+}(aq) + 2e^-\)
   Cu\(^{2+}\) (aq) + 2e\(^-\) \(\rightarrow\) Cu\((s)\)

14 (a)  

15 The iron spatula would slowly dissolve as it is oxidized to Fe\(^{2+}\) ions. Copper metal would precipitate as Cu\(^{2+}\) ions are reduced. The blue colour of the solution would fade as Cu\(^{2+}\) ions are removed.

16 (a) At anode: 2Br\(^-\) (l) \(\rightarrow\) Br\(_2\) (l) + 2e\(^-\)
   At cathode: 2K\(^+\) (l) + 2e\(^-\) \(\rightarrow\) 2K\((l)\)
(b) At anode: 2F\(^-\) (l) \(\rightarrow\) F\(_2\) (g) + 2e\(^-\)
   At cathode: Mg\(^{2+}\) (l) + 2e\(^-\) \(\rightarrow\) Mg\((l)\)
(c) At anode: S\(^2-\) (l) \(\rightarrow\) S\((l)\) + 2e\(^-\)
   At cathode: Zn\(^{2+}\) (l) + 2e\(^-\) \(\rightarrow\) Zn\((l)\)

17 (a) 

Anode: 2Cl\(^-\) (aq) \(\rightarrow\) Cl\(_2\) (g) + 2e\(^-\)
Cathode: Mg\(^{2+}\) (aq) + 2e\(^-\) \(\rightarrow\) Mg\((s)\)
Overall: Mg\(^{2+}\) (aq) + 2Cl\(^-\) (aq) \(\rightarrow\) Mg\((s)\) + Cl\(_2\) (g)

18 D

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 B 2 C 3 A 4 A
5 A 6 C 7 A 8 D
9 A 10 D 11 C 12 D
13 C 14 A
15 (a) +2 [1]
(b) +3 [1]
(c) +2 [1]

Only penalize once if roman numerals are used or if written as 2+ or 3+.

16 (a) Electrolytic cell converts electrical energy to chemical energy and voltaic cell converts
chemical energy to electrical energy / electrolysic cell uses electricity to carry out a (redox) chemical reaction and voltaic cell uses a (redox) chemical reaction to produce electricity / electrolysic cell requires a power supply and voltaic cell does not.

Electrolysic cell involves a non-spontaneous (redox) reaction and voltaic cell involves a spontaneous (redox) reaction.

In an electrolysic cell, cathode is negative and anode is positive and vice versa for a voltaic cell / electrolysic cell, anode is positive and voltaic cell, anode is negative and voltaic cell cathode is positive.

Voltaic cell has two separate solutions and electrolysic cell has one solution / voltaic cell has salt bridge and electrolysic cell has no salt bridge.

Electrolysic cell, oxidation occurs at the positive electrode/anode and voltaic cell, oxidation occurs at the negative electrode/anode and vice versa.

17 (a) (i) Copper: 0 to +2 / increases by 2 / +2 / 2+
Allow zero/nought for 0.
Nitrogen: +5 to +4 / decreases by 1 / −1 / 1−
Penalize missing + sign or incorrect notation such as 2+ or II, once only.
(ii) nitric acid / HNO₃ / NO₃⁻ / nitrate

(b) (i) 0.100 × 0.0285
2.85 × 10⁻³ (mol)
Award 2 for correct final answer.
(ii) 2.85 × 10⁻³ (mol)
(iii) (63.55 × 2.85 × 10⁻³) = 0.181 g
Allow 63.5.
(iv) (0.181/0.456 × 100 =) 39.7%
(v) (44.2 −39.7/44.2 × 100 =) 10 / 10.2% Allow 11.3%, i.e. percentage obtained in (iv) is used to divide instead of 44.2%.

18 (a) Oxidized: S −2 → 0
Reduced: O 0 → −2
(b) Reducing agent is H₂S
Reduces SO₂(g) to S(s)/is oxidized from H₂S(g) to S(s)
(c) pH increases
SO₂ and H₂S are both acids that are used up in the reaction.
(d) Release of SO₂(g) can lead to acid rain.
SO₂(g) dissolves in water to form weakly acid solutions.

19 (a) Zn(s) → Zn²⁺(aq) + 2e⁻
(b) Oxidation of zinc occurs preferentially.
Protects the iron from oxidation.
(c) Iron rusts/corrodes/flakes off.
Colour changes, forming dark red/black patches.

20 (a) The equation is balanced for atoms/elements.
The equation is not balanced for charge.
(b) \[ 3\text{Sn}^{2+}(aq) + 2\text{H}_2\text{O}(l) + 2\text{MnO}_4^{-}(aq) \rightarrow 3\text{SnO}_2(s) + 4\text{H}^{+}(aq) + 2\text{MnO}_2(s) \]  

**Challenge yourself**

1. \( \text{H}_2\text{O}_2: H = +1, O = -1 \)
   
   Oxygen is halfway between 0 (element) and -2 (usual oxidation state in compounds), so can be oxidized (to 0) or reduced (to -2). It will more easily be reduced from -1 to -2 as it is a very electronegative element, and so acts mainly as an oxidizing agent.

2. \( \text{Cl}_2(aq) + 2\text{NaOH}(aq) \rightarrow \text{NaCl}(aq) + \text{NaClO}(aq) + \text{H}_2\text{O}(l) \)
   
   Cl changes from 0 to -1 (reduction)
   
   Cl changes from 0 to +1 (oxidation)
   
   Both changes occur simultaneously.

3. Iodine solution contains the triiodide ion, \( \text{I}_3^- \), in which the central atom has five electron domains with two bonding and three non-bonding pairs in the equatorial plane. This gives a linear ion with a low charge density, which is able to slip into the coils of the hydrophobic interior of the amylose helix.

4. Solubility of gases decreases with increasing temperature as evaporation is higher. So the discharge of hot water will lower the dissolved \( \text{O}_2 \) content.
Chapter 10

Exercises

1. (a) carboxylic acid; butanoic acid  
(b) halogenoalkane; 1,1-dichloropropane  
(c) ketone; butanone  
(d) ester; methyl ethanoate  
(e) ether; methoxyethane  
(f) ester; ethyl pentanoate

2. (a) \( \text{CH}_3\text{(CH}_2\text{)_4COOH} \)  
(b) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CHO} \)  
(c) \( \text{CH}_2\text{CH(CHO}_2\text{H}_3 \)  
(d) \( \text{CH}_2\text{BrCH(CHO}_2\text{H}_3 \) \( + \text{CH}_2\text{BrCH(CHO}_2\text{H}_2\text{CH}_2\text{H}_3 \)  
(e) \( \text{HCOOCH}_2\text{CH}_3 \)  
(f) \( \text{CH}_3\text{OCH}_2\text{CH}_2\text{CH}_3 \)  
(g) \( \text{CH}_3\text{C≡CCH}_3 \)

3.  4  D

5. 

\[ \text{Cl} \text{C} \text{Cl} \text{C} \text{H} \]  1,1,1,2,2-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \]  1,1,1,2,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,3,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,2,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{H} \text{H} \]  1,1,1,2,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,3,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,2,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,2,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,2,3-pentachloropropane

3.  4  D

5. 

\[ \text{Cl} \text{C} \text{Cl} \text{C} \text{H} \]  1,1,1,2,2-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \]  1,1,1,2,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,3,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,2,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{H} \text{H} \]  1,1,1,2,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,3,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,2,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,2,3-pentachloropropane

\[ \text{Cl} \text{C} \text{Cl} \text{Cl} \text{Cl} \]  1,1,1,2,3-pentachloropropane

7. Benzene is a cyclic molecule with a planar framework of single bonds between the six carbon atoms and six hydrogen atoms. The carbon atoms are also bonded to each other by a delocalized cloud of electrons which forms a symmetrical region of electron density above and below the plane of the ring. This is a very stable arrangement, so benzene has much lower energy than would be expected.

8. (a) Similar molar mass will mean molecules have approximately equal London (dispersion) forces and so differences in boiling point can be attributed to differences in dipole–dipole or hydrogen bonding.

(b) Solubility in hexane will increase with increasing chain length as the non-polar part of the molecule makes a larger contribution to its structure.

9. (a) \( \text{C}_5\text{H}_{12}(l) + 6\text{O}_2(g) \rightarrow 5\text{CO}(g) + 7\text{H}_2\text{O}(l) \)

(b) \( 2\text{C}_4\text{H}_{10}(g) + 13\text{O}_2(g) \rightarrow 8\text{CO}_2(g) + 10\text{H}_2\text{O}(l) \)

(c) \( \text{C}_3\text{H}_4(g) + \text{O}_2(g) \rightarrow 3\text{C}(s) + 2\text{H}_2\text{O}(l) \)

10. Bromine + ethane

\text{initiation} \quad \text{Br}_2 \quad \text{UV light} \quad \rightarrow 2\text{Br}^* \quad \text{bromine radicals}

\text{propagation} \quad \text{Br}^* + \text{C}_2\text{H}_6 \rightarrow \text{C}_2\text{H}_5^* + \text{HBr}

\text{C}_2\text{H}_5^* + \text{Br}_2 \rightarrow \text{C}_2\text{H}_5\text{Br} + \text{Br}^*

\text{C}_2\text{H}_5\text{Br} + \text{Br}^* \rightarrow \text{C}_2\text{H}_4\text{Br}^* + \text{HBr}

\text{C}_2\text{H}_4\text{Br}^* + \text{Br}_2 \rightarrow \text{C}_2\text{H}_4\text{Br}_2 + \text{Br}

\text{termination} \quad \text{Br}^* + \text{Br} \rightarrow \text{Br}_2

\text{C}_2\text{H}_5^* + \text{Br} \rightarrow \text{C}_2\text{H}_5\text{Br}

\text{C}_2\text{H}_5^* + \text{C}_2\text{H}_5^* \rightarrow \text{C}_6\text{H}_{10}

Overall, these reactions show how a mixture of products is formed.
11  (a) CH₃CH₂CH₂CH₃ butane
    (b) CH₃CH₂CH(OH)CH₃ butan-2-ol
    (c) CH₃CH₂CHBrCH₃ 2-bromobutane

12  (a) No observable change.
    (b) Burns with very smoky flame.
    (c) The bromine water changes from brown to colourless.

13  (a) C₂H₅OH(l) + 3O₂ → 2CO₂(g) + 3H₂O(l)
    2C₃H₇OH(l) + 9O₂(g) → 6CO₂(g) + 8H₂O(l)
    (b) C₂H₅COOH(aq) + C₄H₉OH(aq) →
        C₂H₅COOC₄H₉(aq) + H₂O(l)

14  (a) butanone; orange → green
    (b) methanal; orange → green
    (c) no reaction; no colour change

15  Nucleophilic substitution involves an electron-rich species (e.g. OH⁻) attacking an electron-deficient carbon atom (e.g. in chloroethane), leading to substitution of the halogen functional group by the nucleophile.

    C₂H₅Cl + OH⁻ → C₂H₅OH + Cl⁻

16  Benzene has a very stable structure as a result of its symmetrical ring of delocalized electrons. Addition reactions would involve breaking this ring and therefore decreasing its stability. Substitution reactions in which one or more hydrogen atoms of the ring are replaced by other atoms or groups preserves the aromatic ring structure and therefore its stability.

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1  C  2 A  3 A  4 A
5  B  6 A  7 A  8 A
9  C  10 B  11 C  12 A
13 B

14  A: 1-bromobutane
    B: 2-bromobutane
    C: 2-bromo-2-methylpropane
    D: 1-bromo-2-methylpropane

Penalize incorrect punctuation, e.g. commas for hyphens, only once.
Accept 2-bromomethylpropane and 1-bromomethylpropane for C and D respectively.

15  (a) Colour change from yellow / orange / rust colour / red / brown to colourless [1]
No mark for change to clear, or for decolorized with no reference to original colour.

(b) Chloroethene:

_No mark if the lone pairs are missing on Cl. Accept if lines, dots or crosses for e⁻ pairs._

Poly(chloroethene):

_n and square brackets are not required. Continuation bonds must be shown._

(c) (hydration of ethene for the manufacture of) ethanol / C₂H₄ + H₂O → C₂H₅OH; (synthesis of) CH₃COOH / ethanoic / acetic acid;
    (synthesis of) ethylene glycol / 1,2-ethanediol
    / ethane-1,2-diol; (synthesis of) drugs / pesticides; (hydrogenation of unsaturated oils in the manufacture of) margarine [2 max]
Accept other commercial applications.
Accept condensed formulas.
Award [1 max] if A and D are other way round (and nothing else correct). Award [2 max] if A and D are other way round but one substitution product B or E is correct based on initial choice of A and D. Award [3 max] if A and D are other way round but both substitution products B and E are correct based on initial choice of A and D. M2 (for B) and M5 (for E) may also be scored for substitution product if primary chloroalkane used. Penalize missing hydrogens once only.

(b) \( \text{CH}_3\text{CH}_2\text{COOH} + \text{CH}_3\text{OH} \rightleftharpoons \text{CH}_3\text{CH}_2\text{COOCH}_3 + \text{H}_2\text{O} \)

(concentrated) sulfuric acid / \( \text{H}_2\text{SO}_4 \)
Do not accept just \( \text{H}^+ \) or acid.

17 (A) (the solution changes) from orange to green [1]

(b) +6 [1]

Do not accept 6, 6+ or the use of Roman numerals unless they have already been penalized in 2(a).

(c) \( \text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O} \) [1]

(d) \( \text{CH}_3\text{CH}_2\text{OH} \rightarrow \text{CH}_3\text{CHO} + 2\text{H}^+ + 2\text{e}^- \)
\( \text{Cr}_2\text{O}_7^{2-} + 3\text{CH}_3\text{CH}_2\text{OH} + 8\text{H}^+ \rightarrow 2\text{Cr}^{3+} + 3\text{CH}_3\text{CHO} + 7\text{H}_2\text{O} \) [3]


(e) \( \text{H}^+ \) is a reactant / OWTTE [1]

(f) ethanoic acid / \( \text{CH}_3\text{COOH} \) / acid [1]

Accept acetic acid.

---

**Challenge yourself**

1 Complete combustion:
\( 2\text{C}_2\text{H}_6 + 7\text{O}_2 \rightarrow 4\text{CO}_2 + 6\text{H}_2\text{O} \)
C: \(-3 \rightarrow +4\)

Incomplete combustion:
\( 2\text{C}_2\text{H}_6 + 5\text{O}_2 \rightarrow 4\text{CO} + 6\text{H}_2\text{O} \)
C: \(-3 \rightarrow +2\)

2 Heterolytic describes breaking of the bond, producing two different products. The products are ions, and the reaction mechanism involves attraction of the electron density of the C=C double bond to the positive ion.

3 The repeating unit in polystyrene is
\(-\text{CH}(-\text{C}_6\text{H}_5)\text{CH}_2-\)
Chapter 11

Exercises

1. The smallest division is 1 so the uncertainty is ±0.5.

2. The missing diamond has a mass of between 9.87 and 9.97 g.
The found diamond has a mass between 9.9 and 10.3 g.
As the ranges overlap, it could be the missing diamond.

3. (a) $4 \times 10^{-2}$ g
   (b) $2.22 \times 10^2$ cm$^3$
   (c) $3.0 \times 10^{-2}$ g
   (d) $3 \times 10$ or $3.0 \times 10$ °C (unspecified)

4. (a) 4
   (b) unspecified
   (c) 3
   (d) 4

5. A 6 A 7 B 8 A

6. A C

7. B 10 D 11 C

8. Number of moles = concentration × volume/1000
   $= 1.00 \times 10.0/1000 = 0.0100$ mol
   % uncertainty in concentration = $(0.05/1.00) \times 100 = 5\%$
   % uncertainty in volume = $(0.1/10.0) \times 100 = 1\%$
   % uncertainty in number of moles = $5\% + 1\% = 6\%$

9. The average value = 49.0 s
   The uncertainty in the measurements is given as ±0.1 s but the results show that there is additional uncertainty, suggesting that the value could be anywhere between 48.8 and 49.2 s. So the value could be quoted as 49.0 s ± 0.2 s.

10. Note that the correct solution to this question is not one of the possible answers listed.
The temperature change expressed to the appropriate precision is 2.05 ± 0.05 K.

11. (a) $\Delta T = 43.2 - 21.2^\circ C = 22.0^\circ C$
    absolute uncertainty = (±)0.2°C
    (b) % uncertainty = $0.2/22.0 \times 100\% \approx 1\%$
    (c) $\Delta H = -4.18 \times 22.0/0.500 = -184$ kJ mol$^{-1}$
    (d) 1%
    (e) Absolute uncertainty = $1/100 \times 184 = (±) 2$ kJ mol$^{-1}$
    (f) Experimental value for $\Delta H = -184 (±) 2$ kJ mol$^{-1}$
The literature value is outside this range.
The random errors involved in reading the thermometer do not account for this difference.
There are systematic errors. The assumptions on which the calculation is based are not strictly valid. Some of the heat of reaction passes into the surroundings and the other uncertainties in the measurements cannot be ignored. It should also be noted that the standard value for $\Delta H$ refers to standard conditions of 298 K and 100 kPa.

12. B

13. The scale of the graph does not allow us to distinguish whether A or B is the best answer and both are acceptable.

14. B

15. The concentration of chromium (from graph for absorbance of 0.215) = 3.34 µg dm$^{-3}$

16. C

17. C

18. The spectrum on the left corresponds to CH$_3$CH$_2$CHO
    The spectrum on the right corresponds to CH$_3$COCH$_3$
Similarities
Both have a molecular ion corresponding to 58.

Differences
A has peaks corresponding to 29 (CH$_3$CH$_2$\(^+\)) and 28 (loss of CH$_3$CH$_2$).
B has a peak corresponding to 43 (loss of CH$_3$).

<table>
<thead>
<tr>
<th>Mass / charge</th>
<th>Fragment</th>
</tr>
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<tbody>
<tr>
<td>15</td>
<td>CH$_3^+$</td>
</tr>
<tr>
<td>29</td>
<td>C$_2$H$_5^+$</td>
</tr>
<tr>
<td>43</td>
<td>C$_3$H$_7^+$ (loss of CH$_3$)</td>
</tr>
<tr>
<td>58</td>
<td>C$<em>4$H$</em>{10}$(^+)</td>
</tr>
</tbody>
</table>

(b) CH$_3$CH$_2$CH$_2$CH$_3$

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Corresponding saturated non-cyclic molecule</th>
<th>IHD</th>
</tr>
</thead>
<tbody>
<tr>
<td>C$_6$H$_6$</td>
<td>C$<em>6$H$</em>{14}$</td>
<td>4</td>
</tr>
<tr>
<td>CH$_3$COCH$_3$</td>
<td>C$_3$H$_8$O</td>
<td>1</td>
</tr>
<tr>
<td>C$_7$H$_8$O$_2$</td>
<td>C$<em>3$H$</em>{16}$O</td>
<td>5</td>
</tr>
<tr>
<td>C$_2$H$_3$Cl</td>
<td>C$_2$H$_5$Cl</td>
<td>1</td>
</tr>
<tr>
<td>C$_3$H$_9$N</td>
<td>C$_3$H$_5$NH$_2$</td>
<td>1</td>
</tr>
<tr>
<td>C$<em>6$H$</em>{12}$O$_6$</td>
<td>C$<em>6$H$</em>{14}$O$_6$</td>
<td>1</td>
</tr>
</tbody>
</table>

31 B  32 D  33 B

34 (a) Empirical formula CH$_2$O. Molecular formula C$_4$H$_4$O$_2$\(^-\).
(b) IHD = 1
(c) CH$_3$—C—OH

35 symmetric stretch IR active  asymmetric stretch IR active  symmetric bend IR active

36 B

37 The polarity (of bond or molecule) changes as the bonds are bent or stretched.

38 Hex-1-ene shows an absorption in the range 1610–1680 cm$^{-1}$ due to the presence of the C=C bond.

39 C—H bond

40 CH$_3$OCH$_3$

41 C  42 A

43 (a) 2  (b) 1  (c) 1  (d) 2

44 The H atoms are in three different environments so there will be three peaks in the $^1$H NMR spectrum with integrated areas in the ratio 3:2:1.

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 B  2 C  3 C  4 A

5 (a) Compound:
CH$_3$—CH$_2$—CHO

Explanation: [1 max]
only this compound would give 3 peaks / OWTTE
only this compound has H atoms in 3 different chemical environments / OWTTE
only this compound has protons in ratio 3:2:1 in each environment / OWTTE
only this compound would give a peak in the 9.4–10 ppm region / OWTTE [2 max]

(b) 2.5 ppm peak
CH$_3$—CO—CH$_3$ also has hydrogen atoms on a carbon next to the >C=O group [2]

(c) (i) 1700–1750 cm$^{-1}$ (>C=O) [1]
(ii) 1610–1680 cm$^{-1}$ (>C=C<) / 3200–3600 cm$^{-1}$ (—O—H) [1]

(d) C$_3$H$_6$O\(^+\) and m/z = 58
C$_2$H$_5^+$ and m/z = 29
CHO\(^+\) and m/z = 29
CH$_3^+$ and m/z = 15 [2 max]

Penalize missing + sign once only.

6 (a) (stretches/vibrations in) HBr involve change in bond dipole / (stretches/vibrations in) Br$_2$
do not involve change in bond dipole [1]
(b) (i) I: O–H
II: C–H
III: C=O
Award [2] for C–H for I and O–H for II.

(ii) m/z 102: molecular ion peak / (CH₃)₃CCOOH⁺ / C₅H₁₀O⁺ / M⁺
m/z 57: (CH₃)₃C⁺ / (M–COOH)⁺ / C₄H₉⁺
m/z 45: COOH⁺
Penalize missing + once only.

(iii) (H of) COOH group

(iv) nine hydrogens in the same environment / (CH₃)₃C– (group)

(v) (CH₃)₃CCOOH / (CH₃)₃CCO₂H / OHC

(vi) no peak at 11.5 ppm in spectrum of isomer / different chemical shift values four peaks (instead of two) / different number of peaks;
Three of these peaks can be split in actual spectrum, so allow for this in answers if exactly four peaks is not stated.
different integration trace / different areas under the peaks / integration trace would have a 3:2:2:3 peak area ratio [2 max]
Do not award mark if incorrect peak area ratios are given for the structure drawn in (v).

7 change in bond length / bond stretching / asymmetric stretch
change in bond angle / bending (of molecule)
Allow [1 max] for only stating vibrations.
induces molecular polarity / dipole moment / OWTTE

8 (a) C₃H₉O⁺
Accept more detailed formula such as CH₂CH₂CH₂OH⁺.

(b) CH₃O⁺ / CH₂OH⁺
For (a) and (b), if charge is missing penalize once only.

(c) (A) CH₃CH₂CH₂OH
Accept more detailed formula.
(B) CH₃CH(OH)CH₃
Accept more detailed formula.
Hydrogen(s) missing, penalize once only.
Award [1] if both structures correct but the wrong way round.

9 (a) A: O–H
B: C=O
C: C–O

(b) m/z = 74: C₂H₅COOH⁺ / C₃H₆O₂⁺
m/z = 45: COOH⁺
m/z = 29: C₅H₅⁺
Penalize missing + charge once only.
Do not award mark for m/z = 29: CHO⁺.

(c) –COOH

(d) CH₃CH₂COOH / CH₃CH₂CO₂H
More detailed structural formula may be given.[1]

10 (a) absence of peak between 3200 and 3600 cm⁻¹ / above 3000 cm⁻¹ / peak for OH
presence of peak between 1700 and 1750 cm⁻¹ / peak for C=O
absence of peak between 1610 and 1680 cm⁻¹ / peak for C=C [2 max]

(b) H
   H
   H
   H
   H
   H
Accept CH₃CH₂CHO.
3:2:1
Ignore order.
ECF if structure is incorrect only if its NMR spectrum contains three peaks.

11 (a) (i) (2-)methylpropan-2-ol
the (H atoms in the three) —CH₃ groups are responsible for the peak at 1.3 ppm
the —OH hydrogen atom is responsible for the peak at 2.0 ppm
Accept explanations with suitable diagram.

(ii) (2-)methylpropan-1-ol

the first peak (at 0.9 ppm) is due to the (H atoms in the) two \(-\text{CH}_3\) groups (bonded to the second carbon atom) / \((\text{CH}_3)_2\text{CHCH}_2\text{OH}\)
the peak at 3.4 ppm is due to the (H atoms in the) \(-\text{CH}_2\text{–}\) group / \((\text{CH}_3)_2\text{CHC}_\text{H}_2\text{OH}\)

Accept explanations with suitable diagram.

(b) (i) butan-1-ol and butan-2-ol

74: \(\text{M}^+ / \text{C}_4\text{H}_{10}\text{O}^+ / \text{CH}_3\text{CH}_2\text{CH}_2\text{OH}^+\) and \(\text{CH}_3\text{CH}_2\text{CH(OH)}\text{CH}_3^+\)
59: \(\text{C}_3\text{H}_7\text{O}^+ / (\text{M} – \text{CH}_3)^+ / \text{CH}_2\text{CH}_2\text{CH}_2\text{OH}^+\) and \(\text{CH}_2\text{CH(OH)}\text{CH}_3^+ / \text{CH}_3\text{CH}_2\text{CH(OH)}\text{CH}_3^+\)
45: \(\text{C}_2\text{H}_5\text{O}^+ / (\text{M} – \text{C}_3\text{H}_7)^+ / \text{CH}_2\text{CH}_2\text{OH}^+\) and \(\text{CH(OH)}\text{CH}_3^+\)

Accept explained answers instead of formulas.

(ii) butan-1-ol

\(\text{CH}_2\text{OH}^+ / (\text{M} – \text{C}_3\text{H}_7)^+\)

Penalize missing + signs once only in parts (b)(i) and (ii).

(c) they all contain \(\text{O–H}\)
they all contain \(\text{C–H}\)
they all contain \(\text{C–O}\)

Award [1 max] for same functional groups/bonds. [2 max]

---

### Challenge yourself

1. \(Y_1^\text{ave} = Y_2^\text{ave} = 3\)
   \[
   R = \frac{(-2x(-2)) + (-1x(-1)) + 0 + (1 \times 1) + (2 \times 2)}{(-2)^2 + (-1)^2 + 0^2 + 1^2 + 2^2} = 1
   \]

2. \(Y_1^\text{ave} = Y_2^\text{ave} = 3\)
   \[
   R = \frac{(-2 \times 2) + (-1 \times 1) + 0 + (1 \times (-1)) + (2 \times (-2))}{(-2)^2 + (-1)^2 + 0^2 + 1^2 + 2^2} = -1
   \]

3. \(Y_1^\text{ave} = Y_2^\text{ave} = 3\)
   \[
   R = \frac{(-2x(-2)) + (-1x(-1)) + 0 + (1 \times 1) + (2 \times (-1))}{2^2 + 1^2 + 0^2 + 1^2 + 2^2} = \frac{4 - 2 + 1 - 2}{10} = 0.10
   \]

4. Saturated hydrocarbons have the general formula \(\text{C}_n\text{H}_{2n+2}\)
   For \(\text{C}_n\text{H}_p\):
   H atoms needed = \(2n + 2 – p\)
   \(\text{H}_2\) molecules needed = lower molar diff. (IHD) = \(\frac{1}{2}(2n + 2 – p)\)
   For \(\text{C}_n\text{H}_p\text{O}_q\):
   Oxygen forms two covalent bonds. Comparing ethane, \(\text{C}_2\text{H}_6\); \(\text{C–H}\), to ethanol, \(\text{C}_2\text{H}_5\text{OH}\); \(\text{C–O–H}\), we see that the presence of \(\text{O}\) has no impact on the IHD:
   IHD = \(\frac{1}{2}(2n + 2 – p)\)
   For \(\text{C}_n\text{H}_p\text{O}_q\text{N}_r\):
   Nitrogen forms three covalent bonds. Comparing \(\text{C–H}\) to \(\text{C–N–H}\), we see that the presence of one \(\text{N}\) increases the IHD by 1:
   IHD = \(\frac{1}{2}(2n + 2 – p + r)\)
   For \(\text{C}_n\text{H}_p\text{O}_q\text{N}_r\text{X}_s\):
   A halogen, \(\text{X}\), forms one bond, like hydrogen, so can be treated in the same way:
   IHD = \(\frac{1}{2}(2n + 2 – p + r – s)\)

5. \(E = h\nu\)
   \[
   E = 6.63 \times 10^{-34} \text{ J s} \times 3.0 \times 10^{14} \text{ s}^{-1} = 2.0 \times 10^{-19} \text{ J}
   \]
   The energy of one mole of photons = \(6.02 \times 10^{23} \text{ mol}^{-1} \times 2.0 \times 10^{-19} \text{ J}\)
   \(= 120 \text{ kJ mol}^{-1}\)

6. \(1/\lambda = 2100 \text{ cm}^{-1} = 210000 \text{ m}^{-1}\)
   \[
   \lambda = \frac{1}{210000 \text{ m}} = 4.76 \times 10^{-6} \text{ m}
   \]
   \[
   v = \frac{3.00 \times 10^8 \text{ m s}^{-1}}{4.762 \times 10^{-6} \text{ m}} = 6.30 \times 10^{13} \text{ s}^{-1}
   \]
### Chapter 12

#### Exercises

1. A

2. **Substance** | $\chi_{\text{average}}$ | $\Delta \chi$ | % ionic character | Bonding
--- | --- | --- | --- | ---
Cl$_2$O & 3.3 & 0.2 & 6 & (Polar) covalent
PbCl$_2$ & 2.5 & 1.4 & 44 & Polar covalent
Al$_2$O$_3$ & 2.5 & 1.8 & 56 & Ionic
HBr & 2.6 & 0.8 & 25 & Polar covalent
NaBr & 1.95 & 2.1 & 66 & Ionic

The % ionic character is taken from the bonding triangle (Figure 12.1).

3. **Substance** | $\chi_{\text{average}}$ | $\Delta \chi$ | % ionic character | Bonding
--- | --- | --- | --- | ---
CuO & 2.65 & 1.5 & 47 & Polar covalent

4. Metal atoms can slide across each other with the metallic bonding not breaking as the delocalized electrons can move to accommodate the changes in the lattice. The ionic and covalent bonds are directional and more rigid in ceramics. They resist changes in the atomic arrangement but will break if the applied forces are too strong.

5. Concrete can contain iron or carbon fibres. If these are connected into a network within the concrete the material will conduct electricity along the network.

6. (a) Bauxite
(b) Aluminium is more reactive than carbon.

(c) Aluminium ions are attracted towards the negative electrode where they are reduced to aluminium atoms: $\text{Al}^{3+} + 3e^- \rightarrow \text{Al}$
(d) Aluminium is more reactive than hydrogen. Hydrogen gas would be produced as the hydrogen from the water is reduced in preference to the aluminium.
(e) Aluminium oxide is only 56% ionic based on electronegativity values. The ions are not completely free in the molten compound.
(f) Oxygen is produced at the anode from the oxide ions: $2\text{O}^{2-} \rightarrow \text{O}_2 + 4e^-$  
   The oxygen reacts with the carbon to produce carbon dioxide:  
   $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$
7 At the cathode
\[ \text{Cu}^{2+} + 2e^- \rightarrow \text{Cu} \]
1 mol \( \rightarrow \) 2 mol \( \rightarrow \) 1 mol
\( n(\text{Cu})/n(e^-) = 1/2 \)
\( n(\text{Cu}) = (1/2)n(e^-) \)
0.100 F = 0.100 mol of e-
\( n(\text{Cu}) = 0.050 \text{ mol} \)
\( m(\text{Cu}) = 0.050 \text{ mol} \times 63.55 \text{ g mol}^{-1} \)
\( = 3.2 \text{ g} \)

At the anode
\[ 2\text{Cl}^- \rightarrow \text{Cl}_2 + 2e^- \]
2 mol \( \rightarrow \) 1 mol \( \rightarrow \) 2 mol
\( n(\text{Cl}_2)/n(e^-) = 1/2 \)
\( n(\text{Cl}_2) = (1/2)n(e^-) \)
0.100 F = 0.100 mol of e-
\( n(\text{Cl}_2) = 0.050 \text{ mol} \)
\( V(\text{Cl}_2) = 0.050 \text{ mol} \times 22.4 \text{ dm}^3 \text{ mol}^{-1} \)
\( = 1.1 \text{ dm}^3 \)

8 \( n(e^-) = 0.0965 \text{ A} \times 1000 \text{ s}/96.500 \text{ C mol}^{-1} = 96.5/96.500 \text{ = 0.00100 mol} \)
\( n(\text{Ti}) = 0.011975/47.9 = 0.000250 \text{ mol} \)
\( n(e^-)/n(\text{Ti}) = 4 \)
Ti is in the +4 state. Formula: \( \text{TiCl}_4 \)

9 \( \text{Fe}_2\text{O}_3(s) + \text{CH}_4(g) + \text{O}_2 \rightarrow 2\text{Fe}(l) + \text{CO}_2(g) + \text{H}_2\text{O}(l) \)
Unbalanced
Balance the elements only present in a combined state first.
Balance the C and H:
\( \text{Fe}_2\text{O}_3(s) + \text{CH}_4(g) + \text{O}_2 \rightarrow \text{Fe}(l) + \text{CO}_2(g) + 2\text{H}_2\text{O}(l) \)
Unbalanced
Balance the Fe and O:
\( \text{Fe}_2\text{O}_3(s) + \text{CH}_4(g) + \frac{1}{2}\text{O}_2 \rightarrow 2\text{Fe}(l) + \text{CO}_2(g) + 2\text{H}_2\text{O}(l) \)
Balanced

10 (a) \( \text{TiO}_2 + 2\text{C} + 2\text{Cl}_2 \rightarrow \text{TiCl}_4 + 2\text{CO} \)
(b) \( \text{TiCl}_4 + 2\text{Mg} \rightarrow \text{Ti} + 2\text{MgCl}_2 \)

11 The alloy is stronger than the pure metal.
Adding atoms of different size disrupts the regular metal lattice so that it is difficult for one layer to slide over another. Alloying can make the metal harder, stronger and more resistant to corrosion.

12 All of the electron spins are paired in diamagnetic elements.
Atoms are paramagnetic if they have unpaired electrons. So, to determine whether the elements are paramagnetic or diamagnetic, we need to consider the electron configuration for each element.

<table>
<thead>
<tr>
<th>Element</th>
<th>Electron config.</th>
<th>No. of unpaired electrons</th>
<th>Magnetic behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>[Ne]3s¹</td>
<td>1</td>
<td>para</td>
</tr>
<tr>
<td>Mg</td>
<td>[Ne]3s²</td>
<td>0</td>
<td>dia</td>
</tr>
<tr>
<td>Al</td>
<td>[Ne]3s²3p¹</td>
<td>1</td>
<td>para</td>
</tr>
<tr>
<td>Si</td>
<td>[Ne]3s²3p²</td>
<td>2</td>
<td>para</td>
</tr>
<tr>
<td>P</td>
<td>[Ne]3s²3p³</td>
<td>3</td>
<td>para</td>
</tr>
<tr>
<td>S</td>
<td>[Ne]3s²3p⁴</td>
<td>2</td>
<td>para</td>
</tr>
<tr>
<td>Cl</td>
<td>[Ne]3s²3p⁵</td>
<td>1</td>
<td>para</td>
</tr>
<tr>
<td>Ar</td>
<td>[Ne]3s²3p⁶</td>
<td>0</td>
<td>dia</td>
</tr>
</tbody>
</table>

Phosphorus has the most unpaired electrons and so is the most paramagnetic.

13

<table>
<thead>
<tr>
<th>Atom</th>
<th>K</th>
<th>Sc</th>
<th>V</th>
<th>Mn</th>
<th>Ga</th>
<th>As</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of unpaired electrons</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

K = Sc = Ga < V = As < Mn
14 (a) Positive argon ions and (free) electrons.
(b) Argon, as it is present in the plasma.
(c) ICP-MS
(d) ICP-AES, ICP-MS is less effective with non-metals as they have higher ionization energies and so form positive ions less readily.

15 (a) Different calibrations are produced for each electron transition so three transitions are analysed.
(b) It produced $3.00 \times 10^7$ counts in one minute $= 0.0500 \times 10^7 \text{ c s}^{-1} = 5.00 \times 10^{5} \text{ c s}^{-1} = 500 \text{ kc s}^{-1}$
From the graph and line II, $[\text{Hg}]$ is between 1.9 and 2.0 $\mu$g dm$^{-3}$
(c) 798 kc s$^{-1}$
(d) Series I, as it has the steepest gradient; small differences in concentration can be detected with large differences in count rate.

16 0.37% by mass

17 Transition metals are effective heterogeneous catalysts as they form weak bonds to small reactant molecules which allow them to come together with the correct orientation.
The ability of transition metals to show variable oxidation states allows them to be particularly effective homogeneous catalysts.

18 (a) Lower temperatures needed so reduced energy costs.
Catalysts act selectively, increasing the yield of the desired product. They are not used up and so can be reused over long periods of time.
(b) Sulfur impurities block the active sites of the catalyst; the impurities are adsorbed on the catalyst surface more strongly than reactant molecules.

19 (a) An activated complex is an unstable combination of reactant molecules that can go on to form products or fall apart to form reactants. A reaction intermediate is a species that is produced and consumed during a reaction but does not occur in the overall equation.
An activated complex corresponds to a maximum in the energy and a reaction intermediate corresponds to a local minimum in energy. Reaction intermediates can in theory be isolated.
(b) Heterogeneous catalysts are in a different phase from the reactants; they can be easily removed by filtration.
(c) They have a large surface area per unit mass for reactants to be adsorbed and their surface structure can be modified to improve effectiveness.
(d) Toxicity of the nanoparticles is dependent on their size, so need to regulate for type of material and size of particles.

20 (a) Liquid & Liquid crystal

<table>
<thead>
<tr>
<th>Molecular arrangement</th>
<th>Liquid</th>
<th>Liquid crystal</th>
</tr>
</thead>
<tbody>
<tr>
<td>disordered</td>
<td></td>
<td>disordered</td>
</tr>
<tr>
<td>Molecular orientation</td>
<td>disordered</td>
<td>ordered</td>
</tr>
</tbody>
</table>

(b) The phase transitions of thermotropic liquid crystals depend on temperature.
The phase transitions of lyotropic liquid crystals depend on both temperature and concentration.
(c) The molecules/ions group together to form a spherical arrangement; the hydrophilic heads are exposed to water, shielding the non-polar tails.

21 Thermotropic liquid crystal materials are pure substances that show liquid crystal behaviour over a temperature range between the solid and liquid states. Example: biphenyl nitriles.
Lyotropic liquid crystals are solutions that show the liquid crystal state at certain concentrations. Examples: soap and water, Kevlar® in solution.

22 (a) Low reactivity of C—H and C—C bonds due to high bond energy and low polarity.
(b) Increases polarity. Molecule can change orientation when an electric field is applied.

23 (a) $C_{24}H_{35}N$
The addition of a benzene ring makes the molecule more rigid and rod-shaped.

There are strong C–C covalent bonds within the chains and relatively strong intermolecular forces between the large polymer chains.

Isotactic polypropene has a regular structure with the methyl groups pointing in the same direction and so is crystalline and tough.

Isotactic polypropene

The chains in a polymer are not all the same length.

The pure form, which has strong dipole–dipole interactions between the chains, is hard and brittle. The addition of plasticizers allows the chains to slip across each other and makes the plastic more flexible.

The non-expanded form of polystyrene is a colourless, transparent, brittle plastic. The expanded form is opaque with a lower density. It is a better insulator and shock absorber.

The expanded form is produced by heating polystyrene beads with a volatile hydrocarbon such as pentane. The pentane evaporates and causes bubbles to form in the plastic.

Polystyrene can act as a good shock absorber. Its low density will reduce transport costs and make it easier to handle.

A volatile hydrocarbon is added during the polymerization process. The volatile hydrocarbon turns into a gas, forming bubbles that force the surrounding polymer to expand and take the shape of the mould.

No. of diameters = 10 × 10⁻⁶ m/1 × 10⁻⁹ m = 10⁻⁵/10⁻⁹ = 10⁴ = 10000

Strong covalent C–C bonds must be broken.

Range of tube lengths with different structures lead to a less regular structure in the solid, which reduces strength. As properties are sensitive to tube length, it is difficult to produce tubes with required properties.

Large surface area for reactants to be adsorbed; the shape and size of the tubes
make them shape-selective catalysts, only reactants of the appropriate geometry are able to interact effectively with the active sites.

(e) Quantum effects predominate and the electrons behave like waves; the length of the tube affects the behaviour of electrons; the tubes are conductors or semiconductors depending on the length.

30 (a) The size of the nanoparticles is similar to the wavelength of harmful UV radiation. UV is scattered and not absorbed.

(b) Toxicity of the nanoparticles is dependent on their size, so need to regulate for type of material and size of particles.

31 (a) Approx. 25 atoms high
   Each C atom has a diameter of $2 \times 75 \times 10^{-12} \text{ m}$ and each O atom has a diameter of $2 \times 64 \times 10^{-12} \text{ m}$
   Approximate length $= 25 \times 2 \times 70 \times 10^{-12} \text{ m}$
   $= 3.5 \times 10^{-9} \text{ m}$

(b) Scanning tunnelling microscope (STM) or atomic force microscope (AFM).

32 (a) Plastics are easily moulded; they are non-biodegradable; they have low density.

(b) | Method     | Advantages                          | Disadvantages             |
    |-------------|-------------------------------------|---------------------------|
    | landfill    | simple method to deal with large volumes | plastics are not biodegradable; limited sites |
    | incineration| reduces volume; plastics are concentrated energy source | CO$_2$ is a greenhouse gas; CO is poisonous; HCl produced from combustion of PVC causes acid rain |
    | recycling   | conserves natural resources         | plastics need to be sorted |

(c) Bacteria do not have the enzymes needed to break the C–C bonds present.

(d) Natural polymers (e.g. starch, cellulose or protein) can be added. Bacteria can break down the natural polymers and so the bag is broken down into smaller pieces.

33

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>landfill</td>
<td>efficient method to deal with large volumes</td>
<td>not popular with locals; needs to be maintained and monitored after use</td>
</tr>
<tr>
<td>incineration</td>
<td>reduces volume; energy source</td>
<td>can cause pollutants such as greenhouse gases and dioxins</td>
</tr>
</tbody>
</table>

34 Advantages: saves natural resources; saves energy; reduces pollution
Disadvantages: materials need to be sorted

35 (a) 1–5
(b) 1–4

36 Both molecules have C–H bonds so they have strong absorptions between 2850 and 3090 cm$^{-1}$.
The monomer has a C=O bond not found in the polymer so it will have a weak absorption at 1620–1680 cm$^{-1}$.

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 (a) (i) melting point of the cryolite solution is much lower than the melting point of alumina / Al$_2$O$_3$ / it lowers the melting point of the mixture / cell operates at lower temperature
   Allow lowers melting point or lowers melting point of aluminium oxide.
   Do not allow lowers melting point of aluminium.

(ii) Positive electrode:
   $2O^{2-} \rightarrow O_2 + 4e^{-}$ / $O^{2-} \rightarrow \frac{1}{2}O_2 + 2e^{-}$
   Negative electrode:
   $Al^{3+} + 3e^{-} \rightarrow Al$

2
Award [1] for correct equations but wrong electrodes.
Allow e instead of e\textsuperscript{-}.

(b) use of fossil fuels (to provide energy)
oxidation of the (graphite) positive electrode / anode

2 (a) Al is more reactive than Fe / Al is higher than Fe in the reactivity series / it is harder to reduce aluminium ores compared to iron ores / Fe\textsuperscript{3+} is a better oxidizing agent than Al\textsuperscript{3+} / OWTTE
(b) (i) Fe\textsubscript{3}O\textsubscript{4} + 4CO → 3Fe + 4CO\textsubscript{2} [1]
(ii) Fe\textsubscript{3}O\textsubscript{4} + 4H\textsubscript{2} → 3Fe + 4H\textsubscript{2}O [1]

3 (a) homogeneous mixture of metals / a metal and non-metal [1]
(b) alloying element(s) disrupts regular / repeating (metal) lattice
   difficult for one layer to slide over another / atoms smaller than the metal cations can fit into the (holes of) metal lattice disrupting bonding
   can make metal harder / stronger / more corrosion resistant / brittle [2 max]

4 Mode of action of homogeneous catalysis:
catalyst reacts in one step (of the mechanism) and is regenerated at a later step / ability to form a range of oxidation states (for transition metals) / reaction steps with catalyst have lower activation energies than for reaction without catalyst / OWTTE

Example using chemical equation:
CH\textsubscript{3}COOH(aq) + C\textsubscript{2}H\textsubscript{5}OH(aq) \rightarrow H\textsuperscript{+}(aq)
CH\textsubscript{3}COOC\textsubscript{2}H\textsubscript{5}(aq) + H\textsubscript{2}O(l) / other suitable example

Mode of action of heterogeneous catalysis:
catalyst provides the reactive surface / presence of active sites / adsorb reactant molecule(s) (on surface)

Example using chemical equation:
2SO\textsubscript{2}(g) + O\textsubscript{2}(g) \rightarrow 2SO\textsubscript{3}(g) / N\textsubscript{2}(g) + 3H\textsubscript{2}(g) \rightarrow 2NH\textsubscript{3}(g) / C\textsubscript{2}H\textsubscript{6}(g) + H\textsubscript{2}(g) \rightarrow C\textsubscript{2}H\textsubscript{6}O(g) / other suitable example

Reversible sign not required for mark.
Catalyst and states must be specified to score mark.

5 (a) biphenyl nitriles / cyanobiphenyls [1]
(b) nitrile groups make molecule polar
   intermolecular forces are strong enough to align in a common direction
   biphenyl groups make molecules more rigid / rod-shaped
   (long) alkane chain ensures that molecules cannot pack together closely (to maintain liquid-crystal state) [4]

6 (a) C–Cl bond / molecule is polar
   stronger intermolecular / van der Waals / London / dispersion forces / dipole–dipole attraction [2]
(b) addition of plasticizers
   gets between polymer chains / keeps chains further apart and reduces attraction (between the chains) [2]
(c) C
   H
   C
   H
   C
   H
   C
   H
   C
   H
   C
   H

Accept any structure with all the Cl atoms shown on the same side.
Continuation bonds at end of structure not needed.
Hydrogen atoms must be included.

7 makes the polymer low density / good thermal insulator / expanded / softer / better shock absorber / packaging / insulation

Award [1 max] if thermal insulation given for both answers.

8 (a) 1 nm to 100 nm [1]
(b) physical techniques move atoms to a specific position
   chemical techniques involve chemical reactions to position atoms (in molecules)
Accept suitable examples for chemical techniques.  

(c) reference to effect on human health (e.g. unknown, immune system may not cope, unsatisfactory toxicity regulations) reference to effect on employment (e.g. increased/decreased job opportunities, adverse effect on traditional industries) reference to effect on quality of life (e.g. medical advances, faster computers, improved performance of electronic equipment) reference to public opinion (e.g. need to improve information, encourage discussion, seek approval) reference to nanotechnology being developed in wealthier nations hence increasing the divide between different nations [2 max]

9 Advantage: reduce volume / stable odour-free residue / source of energy Disadvantage: expensive to build and operate / can form dioxins/toxic gases / requires energy / adds to greenhouse effect

10 (a) Landfill: can be used to deal with large volumes/amounts / filled ground can be re-used / low cost

Do not accept 'no air pollution'.

Incineration: reduces volume / requires minimal space / source of energy

Do not accept 'no land pollution'.

Apply list principle, i.e. award [0] when one correct and one incorrect advantage given.

(b) limited supply of oxygen (prevents the bacteria from acting)

Do not accept air.

11 (a) Positive electrode: graphite / carbon

(b) much less energy required to recycle than to produce Al from ore / OWTTE less production of CO₂/greenhouse gases (graphite used in the electrolysis is converted into CO₂) / the more that is recycled the less there will be in landfill sites / OWTTE [2]

12 (a) walls have rolled/single sheets of graphite / carbons bonded in hexagons ends have half a buckyball (fullerene) / carbons in pentagons (and hexagons) [2]

(b) covalent bonds are very strong [1]

(c) (i) large surface area Do not accept 'reactive surface'.

high selectivity related to dimensions of tube [2]

(ii) unknown health effects

Accept potentially harmful as easily ingested/inhaled.

Accept difficulty of preparing nanotubes in required amounts. [1]

13 (a) (i) CN makes molecule polar, ensures common orientation which can be changed by electric field

(ii) C₅H₁₁ prevents close packing of molecules

(iii) molecules rigid and rod-shaped

Accept chemical stability for second or third mark not both. [3]

(b) liquid crystal between two glass plates which have scratches at 90° to each other molecules form a twisted arrangement between plates due to intermolecular bonds when polarizers are aligned with scratches, light will pass through film and pixel will appear bright
applied voltage aligns polar molecules and pixel appears dark \[4\]

14 (rod-shaped) molecules aligned in the same direction
increasing temperature causes arrangement to lose its directional order / molecules to become more randomly arranged until normal liquid state occurs \[3\]

15 HDPE:
no / very few branches
chains pack closer together
stronger intermolecular forces
Allow converse argument, e.g. LDPE has more branches, so its chains are further apart and the intermolecular forces are weaker. \[4\]

16 (a) addition of plasticizers
more flexible / flexibility \[2\]
(b) polymer disadvantages
difficult to dispose of polymer properly
fills up landfill sites
litter
lack of biodegradability
use of natural resources
Award \[1\] each for any two.

PVC disadvantages
burning produces toxic gases / HCl \[3\ max\]

17 (a) \[
\begin{array}{c}
  \text{CH}_3 \\
  \text{H} \\
  \text{C}=\text{C} \\
  \text{H} \\
  \text{H}
\end{array}
\] / \[
\text{CH}_3 - \text{CH} = \text{CH}_2
\]

(b) melting point
Do not accept boiling point.
softness / hardness / flexibility / strength / rigidity / density \[2\]
(c) atactic
methyl groups arranged randomly / OWTTE \[2\]

Challenge yourself

1 (a) The molecule is rigid and rod-shaped.
(b) Thermotropic.

2 (a) The observer can see nothing. The whole area would appear dark as the polarizer and analyser are crossed.
(b) The whole area would appear light as the liquid crystal rotates the plane of polarization, so light is now transmitted by the analyser.
(c) In regions where there is no applied voltage the liquid crystal rotates the plane of polarization so light is now transmitted by the analyser. In regions where there is voltage applied the liquid crystal molecules align with the electric field and no longer rotate the plane of polarization. The observer would see a dark circle surrounded by light.

3 The halogen atoms have a larger mass and so C—X bonds vibrate at a lower frequency.
Chapter 13

Exercises

1 \[ C_{18}H_{32}O_{16} + 2H_2O \rightarrow 3C_6H_{12}O_6 \]

2 Monomers must each have two functional groups. A molecule of water is given off for each bond that forms between the monomers.

3 (a) anabolic  (b) catabolic  (c) catabolic  (d) anabolic

4 Sunlight, photosynthetic pigments to absorb light energy, water and carbon dioxide. Carbon dioxide is reduced by the hydrogen from water, forming carbohydrate. The oxidation state of carbon decreases from +4 in CO₂ to 0 in C₆H₁₂O₆. Oxygen is oxidized from −2 in H₂O to 0 in O₂.

5 Aerobic respiration yields a great deal more energy than anaerobic respiration, as in the presence of oxygen the oxidation of glucose to CO₂ and H₂O is complete. In anaerobic respiration, oxidation is incomplete, and much of the energy remains in the end products such as ethanol.

6 C

7 (a) Tyr–Val–His; Tyr–His–Val; His–Tyr–Val; His–Val–Tyr; Val–His–Tyr; Val–Tyr–His

    There are six different tripeptides possible from three amino acids: \(3 \times 2 \times 1\)

(b) There are 24 different peptides that can be synthesized from four amino acids: \(4 \times 3 \times 2 \times 1\)

8 (a) leucine  (b) threonine  (c) glutamic acid  (d) lysine

9 Fibrous proteins are usually elongated molecules with a well-defined secondary structure. They are structural materials and insoluble in water.

Globular proteins have a well-defined tertiary structure and are compact spherical molecules, soluble in water. They are functional as enzymes, carriers, hormones and receptors.

10 Hydrogen bonds in the secondary structure are between groups that are part of the peptide bonds of amino acids four residues apart in a polypeptide chain. Hydrogen bonds in the tertiary structure are between groups such as –OH in the side chains of amino acids.

11 (a) Enzymes are biological catalysts; they are made of proteins; they are very specific in their action; they are affected by changes in temperature and pH; during the reaction they form an enzyme–substrate complex in which the reaction occurs.

   (b)

   ![Graph of rate of reaction vs temperature]

   The shape shows increasing rate with increasing temperature as a result of the increase in average kinetic energy leading to more successful collisions between enzyme and substrate. This continues to a maximum point (close to 40 °C in humans), known as the optimum. At temperatures higher than this, the rate of the reaction falls dramatically as the enzyme is denatured. This means that it loses its specific tertiary structure and can no longer bind the substrate at the active site.
12 **Rate of Reaction**

- **No Inhibitor**
- **Competitive Inhibitor**

13 **Similarities:** both increase rate of reaction by providing pathway of lower $E_a$; both have no effect on $K_c$ or yield.

**Differences:** enzymes are proteins, inorganic catalysts have a varied structure; enzymes show saturation kinetics, inorganic catalysts usually do not; enzymes are regulated by inhibitors, inorganic catalysts are usually not; enzymes are sensitive to pH and temperature, inorganic catalysts usually work well at a wide range of temperature and pressure.

14 (a) Hands are likely to carry free amino acids that could be deposited on the paper and interfere with the chromatogram.

(b) Isoleucine has an isoelectric point = 6.0. Therefore, at pH < 6.0 it will be positively charged and so attracted to the cathode; at pH > 6.0 it will be negatively charged and so attracted to the anode.

(c) Glutamic acid has an isoelectric point = 3.2. Histidine has an isoelectric point = 7.6. Therefore, pH between 3.2 and 7.6 would achieve separation, e.g. pH 5.0. Glutamic acid will be negatively charged and attracted to the anode. Histidine will be positively charged and attracted to the cathode.

15 $10.16 \text{ g } I_2 = \frac{10.16}{254} \text{ moles } I_2$

$= 0.04 \text{ moles } I_2$

Therefore, 0.02 moles fat react with 0.04 moles $I_2$, so there are two double bonds in the fat.

16 B

17 Fats and oils; hydrolytic and oxidative rancidity.

18 (a) $\text{CH}_2\text{O}$

(b) Monosaccharides are water soluble as they are small molecules with many free $-\text{OH}$ groups which can form hydrogen bonds. Polysaccharides are insoluble as they are much larger molecules.

19 (a) $\text{CH}_2\text{OH}$

(b) $\text{CH}_2\text{OH}$

Lactose

$\text{C}_{12}\text{H}_{22}\text{O}_{11}$, Glycosidic bond.

20 (a) Carbon—carbon double bonds and hydroxyl groups.

(b) Water-soluble: vitamin C; fat-soluble vitamin A / vitamin D.

Vitamin C has many $-\text{OH}$ and polar groups able to form hydrogen bonds with water. Vitamins A and D are predominantly non-polar/have hydrophobic groups and so cannot form hydrogen bonds with water.

21 Fortification of certain staple foods such as rice and flour with micronutrients; supply of nutritional supplements particularly in places where certain deficiencies are known (e.g. iodine); possible changes and improvements in nutrient content through genetic modification.

22 Ionic bonds, hydrogen bonds, London dispersion forces, hydrophobic interactions.

23 Biomagnification refers to the increasing concentration of a xenobiotic substance at different levels in a food web. It is often associated with toxic effects for organisms that feed at a high trophic level, as their cells contain the highest concentrations.

24 Break down oil spills, help break down some plastics, in biological detergents that improve energy efficiency, in Green Chemistry involving less toxic chemical pathways and solvents.
Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 (a) Melting point above 25 °C: lauric, myristic, palmitic and stearic acids are solids at room temperature. [2]

(b) Melting point increases as van der Waals forces increase with size of the R group, due to an increase in number of electrons. [3]

(c) An increase in the number of the C=C double bonds adds kinks to the structure, which reduces the ability of the molecules to pack together. The intermolecular forces are weaker and the melting points decrease. [3]

2 B 3 D 4 C 5 D

6 (a) condensation
water / H$_2$O [2]

(b) $\text{H}_2\text{N} - \text{CH} - \text{CO} - \text{NH} - \text{CH} - \text{COOH}$ [2]

(c) Arg–His–Leu
Arg–Leu–His
His–Arg–Leu
His–Leu–Arg
Leu–Arg–His
Leu–His–Arg [3 max]


(d) (i) hydrogen bonding [1]

(ii) van der Waals forces / hydrophobic interactions / dispersion forces
ionic bonding / (formation of) salt bridges / electrostatic attractions
covalent bonding / (formation of) disulfide bridges [2 max]

Award [1] each for any two.
Do not accept sulfur bridges or hydrogen bonding.

7 (a) (i) C$_{12}$H$_{22}$O$_{11}$ + H$_2$O $\rightarrow$ 2C$_6$H$_{12}$O$_6$ [2]

(iii) catabolism [1]

Accept hydrolysis.

8 (a) rate of reaction increases with temperature from approximately 0 to 35°C increasing kinetic energy of enzyme and substrate increases the probability of a successful collision forming an enzyme–substrate complex catalytic action / alternative pathway of lower activation energy occurs due to binding of substrate to enzyme at 40°C tertiary structure / conformation of enzyme starts to break down / denature and less enzyme–substrate complex forms above 40°C enzyme is denatured / unable to bind to substrate [5]

(b) optimum temperature / maximum rate of reaction at temperature lower than 40°C graph rises more quickly at low temperatures [2]

9 (a) (i) linoleic acid C$_{17}$H$_{31}$COOH so has two C=C bonds
2 moles I$_2$ react with 1 mole linoleic acid
2 $\times$ 254 g react with 280 g
100 g linoleic acid reacts with $\frac{508 \times 100}{280} = 181$ g I$_2$ [3]

(ii) X has fewer C=C double bonds / is less unsaturated / more saturated [1]

(iii) X has higher melting point as molecules pack more closely unsaturation puts kinks in the hydrocarbon chains / less close packed / weaker intermolecular forces [2]

(b) Hydrolytic rancidity: fat breaks down by hydrolysis at the ester links between glycerol and fatty acids, releasing the free acids.
Favoured by high temperature and enzyme lipase. [3]

Oxidative rancidity: unsaturated fat is oxidized at the carbon—carbon double bonds forming volatile aldehydes and ketones. Favoured by light and enzymes or metal ions. [3]

(c) Lipids release more energy per unit mass on oxidation than carbohydrates, as they are more reduced. Lipids are insoluble and difficult to transport so their breakdown is more difficult and slower than carbohydrates. [3]

10 (a) substance foreign to organisms / not naturally found in the environment [2]

(b) starch absorbs water and swells, causing plastic to break into small pieces which can be broken down by bacteria [2]

(c) PVC contains the C—Cl bond for which no enzyme exists in the environment [2]

11 (specific) a particular enzyme can catalyse only one reaction

enzyme binds to/reacts with substance / E+S → ES

after reaction product leaves enzyme / EP → E+P

mention of active site [4]

OWTTE

Challenge yourself

1 The entropy of the environment increases. Energy is returned as less useful forms such as heat and other forms which quickly become randomized. Order is created at the expense of the environment, which becomes more disordered.

2 In C₆H₁₂O₆ the oxidation state of C = 0
   In CO₂ the oxidation state of C = +4

3 Threonine and isoleucine have two chiral carbon atoms.

4 Proline is a secondary amine; all other amino acids are primary amines. In peptides, proline does not have any hydrogens bonded to N, so cannot be a hydrogen bond donor, but can be a hydrogen bond acceptor. The presence of proline leads to a bend or kink in the polypeptide chain.

5 Oxidation state of carbon will be higher in a carbohydrate than in a lipid, e.g. glucose and palmitic acid.
1 (a) Solar heating, solar electricity, hydroelectricity, wind power, biomass.
(b) Fossil fuels.
(c) Tidal is due to the presence of the moon, nuclear fission due to presence of radioactive elements found in the earth.
(d) Renewable sources are generally derived from recent solar energy.

2 (a) \[
\frac{\text{useful output energy}}{\text{total input energy}} = \frac{\text{useful heat energy}}{\text{total input heat energy}} = 0.85
\]
Heat energy produced by combustion
\[
= 4.00 \times 10^7 \text{ kJ} / 0.85
= 4.71 \times 10^7 \text{ kJ}
\]
Moles of \( \text{CH}_4 \) = \( \frac{4.71 \times 10^7}{891} \) = \( 5.28 \times 10^4 \) mol
Mass = \( 5.28 \times 10^4 \) mol \( \times 16.05 \text{ g mol}^{-1} \)
= \( 8.48 \times 10^5 \) g = \( 8.48 \times 10^2 \) kg

(b) Energy produced by combustion = \( 4.00 \times 10^7 \text{ kJ} / 0.5 \)
= \( 8.00 \times 10^7 \) kJ

3 (a) & (b) Assuming ideal behaviour: \( PV = nRT \)
\[
p = \frac{m}{V} = \frac{PM}{RT}
\]
With everything in SI units, the units of density are kg m\(^{-3}\)
With the molar mass in g mol\(^{-1}\), the units of density are g m\(^{-3}\)
STP conditions: \( T = 273 \) K and \( P = 100 \) kPa

Note: energy density of a gas is not determined by the molar mass.
3 (c) Hydrogen is the best fuel. It is dangerous to store and burn.

4 (a) Empirical formula: C_{135}H_{96}O_{9}NS. (It typically also contains trace elements of silicon, sodium, calcium, aluminium, nickel, copper, zinc, arsenic, lead and mercury.)

(b) S + O_2 → SO_2 and 2SO_2 + O_2 → 2SO_3 and H_2O + SO_2 → H_2SO_3 and H_2O + SO_3 → H_2SO_4
2N + O_2 → 2NO and 2NO + O_2 → 2NO_2 and 2NO_2 + H_2O → HNO_3 + HNO_2

5 (a) \[
\begin{align*}
\text{useful output energy} &= \frac{\text{useful heat energy}}{\text{total input heat energy}} \\
&= \frac{0.38}{1.00 	imes 10^6} \\
&= 39.9 \text{ kg s}^{-1}
\end{align*}
\]

(b) They are isolated from crude oil by fractional distillation.
- The mixture of hydrocarbons is heated, causing them to vaporize.
- As the vapour travels up the fractionating column the hydrocarbons condense at different heights, resulting in their separation.
- The different compounds have different boiling points: the lowest boiling point compounds condense at the top and the highest boiling point compounds condense at the bottom.

(c) The components of gasoline have boiling points above normal temperatures. They are volatile liquids. They can be easily vaporized in the car cylinder for reaction with oxygen. Lower molar mass compounds are gases which occupy too much volume, while higher molar mass compounds do not vaporize or burn easily.

(d) Higher fractions can be cracked into smaller molecules; the larger molecules are heated with a catalyst and broken into smaller molecules. Alkenes formed in the cracking process can undergo alkylation reactions with lower molecular mass alkanes to further increase the yield of gasoline.

(e) \[
\begin{align*}
\text{Cracking:} & \quad \text{C}_{16}H_{34} \rightarrow \text{C}_6H_{12} + \text{C}_{10}H_{22} \\
\text{Alkylation:} & \quad (\text{CH}_3)_2\text{CH} + \text{CH}_3\text{CH} = \text{CHCH}_2\text{CH}_3 \\
& \rightarrow \text{CH}_3\text{CH} - \text{CHCH}_2\text{CH}_3 \\
& \quad \text{H} \quad \text{CH}_2\text{CH}(\text{CH}_3)_2
\end{align*}
\]
The general pattern is:
straight-chain alkanes < cycloalkanes < alkenes < aromatics
pentane < cyclopentane < pentene < benzene

The general pattern is that the octane number of straight-chain alkanes decreases with an increase in chain length. Alcohols have very high octane numbers.
heptane < hexane < pentane < ethanol

(a) High specific energy / energy density.
As a liquid it is convenient to handle and deliver.
Easy to vaporize, which assists combustion.
(b) It is formed by the partial decomposition of marine plants millions of years ago.
(c) Compounds are separated by fractional distillation.
Increase of petrol fraction by cracking.
Further refining: reforming, alkylation, isomerization to increase octane number.

Coal gasification
C(s) + H₂O(g) → CO(g) + H₂(g)
CO(g) + 3H₂(g) → CH₄ + H₂O

Coal liquefaction
Direct: 5C(s) + 6H₂(g) → C₅H₁₂(l)
11H₂(g) + 5CO(g) → C₅H₁₂(l) + 5H₂O(l)

Carbon-containing fuels are non-renewable.
They are needed as chemical feedstocks.
Their combustion adds carbon dioxide to the atmosphere, which contributes to global warming.

(a) CO(g) + ½O₂(g) → CO₂(g): ΔH°ₚ = −283 kJ mol⁻¹
H₂(g) + ½O₂(g) → H₂O(g): ΔH°ₚ = −286 kJ mol⁻¹
CO(g) + H₂(g) + O₂(g) → CO₂(g) + H₂O(g):
ΔH°ₚ = −283 + (−286) kJ mol⁻¹ = −569 kJ mol⁻¹
(b) CH₄(g) + 2O₂(g) → CO₂(g) + 2H₂O(g):
ΔH°ₚ = −891 kJ mol⁻¹

One mole of synthesis gas has the same volume as two moles of methane. One mole of synthesis gas produces 569 kJ and two moles of methane produce 2 × 891 kJ.

(a) Methane is the major component of natural gas. It has the formula CH₄.
CH₄(g) + 2O₂(g) → CO₂(g) + 2H₂O(g)
(b) Natural gas is the cleanest of the fossil fuels to burn as it has a high H:C ratio.
The combustion of natural gas produces minimal amounts of carbon monoxide, hydrocarbons and particulates. It does not contribute to acid rain, unlike coal and oil.
(c) Natural gas is the fossil fuel in the shortest supply and it is unevenly distributed around the world.
Oil is expected to last a little longer and coal, which is distributed more evenly around the world, longer still.
(d) Supplies of methane can be increased as a result of the cracking of larger hydrocarbons from oil or by coal gasification.

Cracking
C₄H₁₀ → CH₄ (g) + C₃H₆(g)

Coal gasification
C(s) + H₂O(g) → CO(g) + H₂(g)
CO(g) + 3H₂(g) → CH₄ + H₂O

(a) Wide availability
Relatively cheap compared to other sources
Ease of transportation
Power stations can be built close to the source
High energy density
Can be used with existing technology
Concern over nuclear
Limited productivity of other sources
Not possible to generate sufficient electrical energy without it
Many transport systems rely on fossil fuels
(b) Oil used to power internal combustion engines
It is more efficient

It produces more thermal energy per unit of mass / has a higher specific energy / energy density

It produces less CO₂ per unit of output energy

### Table 18

<table>
<thead>
<tr>
<th>Fuel</th>
<th>ΔH° / kJ mol⁻¹</th>
<th>Moles needed to produce 10 000 kJ</th>
<th>Molar mass / g mol⁻¹</th>
<th>Mass needed to produce 10 000 kJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methylbenzene</td>
<td>-3910</td>
<td>10000/3910</td>
<td>(12.01 × 7) + (8 × 1.01)</td>
<td>2.56 × 92.15</td>
</tr>
<tr>
<td>Ethanol</td>
<td>-1367</td>
<td>10000/1367</td>
<td>(12.01 × 2) + (6 × 1.01) + 16.00</td>
<td>7.31 × 46.08</td>
</tr>
</tbody>
</table>

### Table 18 (b)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Moles of CO₂ produced / mol</th>
<th>Mass of CO₂ produced / g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methylbenzene</td>
<td>7 × 2.56 = 17.92</td>
<td>17.92 × 44.01 = 789</td>
</tr>
<tr>
<td>Ethanol</td>
<td>2 × 7.31 = 14.62</td>
<td>14.62 × 44.01 = 643</td>
</tr>
</tbody>
</table>

(c) They produce less carbon dioxide / have a smaller carbon footprint.

### Table 18 (c)

<table>
<thead>
<tr>
<th>ΔE / kJ mol⁻¹</th>
<th>Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>183</td>
<td>n = 2 → n = 3</td>
</tr>
<tr>
<td>247</td>
<td>n = 2 → n = 4</td>
</tr>
<tr>
<td>276</td>
<td>n = 2 → n = 5</td>
</tr>
</tbody>
</table>

At higher energy, energy levels become closer together; the energy differences between higher energy levels and the lower level (n = 2) become closer together and the difference in wavelength decreases.

### Table 18 (b)

<table>
<thead>
<tr>
<th>λ / m</th>
<th>ΔE / kJ mol⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>656 × 10⁻⁹</td>
<td>0.00012/656 × 10⁻⁹ = 183</td>
</tr>
<tr>
<td>486 × 10⁻⁹</td>
<td>0.00012/486 × 10⁻⁹ = 247</td>
</tr>
<tr>
<td>434 × 10⁻⁹</td>
<td>0.00012/434 × 10⁻⁹ = 276</td>
</tr>
</tbody>
</table>

(b) By inspection we can see that transitions from n = 2 fall into this range.

### Table 19 (a)

1

1

### Table 19 (b)

17

### Table 19 (c)

At higher energy, energy levels become closer together; the energy differences between higher energy levels and the lower level (n = 2) become closer together and the difference in wavelength decreases.

### Table 21 (a)

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic number</th>
<th>Mass number</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>90</td>
<td>233 – 4 = 229: ²²⁹¹⁹₀Th</td>
</tr>
<tr>
<td>X</td>
<td>0</td>
<td>236 – 233 = 3: ³⁰¹³n</td>
</tr>
<tr>
<td>Y</td>
<td>93</td>
<td>239: ²³⁹¹⁹₅Np</td>
</tr>
<tr>
<td>Z</td>
<td>34</td>
<td>92: ²⁹³₃₄Se</td>
</tr>
</tbody>
</table>

(b) Process II (fission) is used to produce electricity in nuclear power plants. (Process IV is also a fission reaction and is another potential reaction.)

This process can be initiated as required by controlling the input of neutrons, whereas
the other processes are natural ones and occur randomly.

Process II is self-sustaining if the critical mass is available. It produces more neutrons than are needed initially and so a chain reaction occurs which can lead to the fission of more nuclei.

(c) The mass of the products is less than the mass of the reactants. The difference is converted to energy according to the equation \( \Delta E = \Delta mc^2 \).

22 Less than 1% of uranium is the fissionable isotope: \( {}^{235}\text{U} \).

There is less than the critical mass present. There is insufficient \( {}^{235}\text{U} \) to sustain the chain reaction.

23 (a) The mass of the products is less than the mass of the reactants. The difference is converted to energy according to the equation \( \Delta E = \Delta mc^2 \).

(b) 99.9%

24 First notice that 96.0 s = 96.0/19.2 = 5t_{1/2}

Use the information in the question to compile a table:

<table>
<thead>
<tr>
<th>Time / half-lives</th>
<th>Fraction remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>0.25</td>
</tr>
<tr>
<td>3</td>
<td>0.125</td>
</tr>
<tr>
<td>4</td>
<td>0.0625</td>
</tr>
<tr>
<td>5</td>
<td>0.03125</td>
</tr>
<tr>
<td>6</td>
<td>0.015625</td>
</tr>
<tr>
<td>7</td>
<td>0.0078125</td>
</tr>
<tr>
<td>8</td>
<td>0.00390625</td>
</tr>
<tr>
<td>9</td>
<td>0.001953125</td>
</tr>
<tr>
<td>10</td>
<td>0.000976563</td>
</tr>
</tbody>
</table>

(b) 99.9%

25 \( {}^{235}\text{U} + \frac{1}{2}n \rightarrow \ldots \rightarrow {}^{90}\text{Sr} + {}^{144}\text{Xe} + 2\frac{1}{2}n \)

26 High level: contains fission products
Low level: clothing / fuel cans / other
Stored under water
Buried underground
Encased in steel/concrete
Vitrified / made into glass

27 Use the information in the question to compile a table:

<table>
<thead>
<tr>
<th>Time / years</th>
<th>Activity / hr(^{-1}) g(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>60.0</td>
</tr>
<tr>
<td>5730</td>
<td>30.0</td>
</tr>
<tr>
<td>5730 × 2</td>
<td>15.0</td>
</tr>
<tr>
<td>5730 × 3</td>
<td>7.5</td>
</tr>
<tr>
<td>5730 × 4</td>
<td>3.75</td>
</tr>
</tbody>
</table>

The shell is approximately 5730 × 4 years = 22920 years old.

28 (a) \( \text{CH}_2=\text{CH–CH=CH}_2 \) is a conjugated system with two double bonds separated by a single bond which extends along the full length of the molecule.

(b) The double bonds disappear as the molecules undergo an addition reaction with bromine.

(c) Benzene absorbs radiation in the UV region. In nitrobenzene, conjugation between the benzene ring and the nitro group allows radiation of longer wavelength to be absorbed. This radiation occurs in the visible region of the spectrum and so the compound is coloured.

29 (a) Increased conjugation (increased n) moves the absorption band \( \lambda_{\text{max}} \) towards longer wavelength.

(b) The first members of the series are colourless as they absorb in the UV region, but the later members (\( n > 2 \)) are coloured as they absorb in the visible region.

(c) \( \text{C}_6\text{H}_5–(\text{CH}=\text{CH})_n–\text{C}_6\text{H}_5 \) absorbs in the purple region and is probably yellow.
C\textsubscript{6}H\textsubscript{5}−(CH=CH)\textsubscript{6}−C\textsubscript{6}H\textsubscript{5} absorbs in purple/blue region and is probably orange.

(d) Only $\lambda_{\text{max}}$ and not the full spectrum is given so it is not possible to give a precise answer.

30 The conjugated system includes eleven C=C bonds and so absorbs in the visible region. The molecule absorbs blue light and so appears orange.

31 (a) Fossil fuels and biomass are derived from the sun through photosynthesis. Other sources: wind and hydroelectricity.

(b) Advantage: renewable and has little environmental impact.

Disadvantages: photosynthesis is not very efficient so relatively little of the available solar energy is trapped.

32 (a) $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_12\text{O}_6 + 6\text{O}_2$

(b) Chlorophyll

(c) Conjugated system of double and single bonds

(d) Process: fermentation

Equation: $\text{C}_6\text{H}_12\text{O}_6 \rightarrow 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2$

Conditions: acidity / absence of oxygen / below 40 °C

Yeast provides enzyme

33 (a) Methane

(b) Carbon monoxide and hydrogen

(c) Particulates (soot), hydrocarbons, carbon monoxide

(d) Fossil fuels are running out. Biomass is a renewable source.

34 (a) 1%

(b) Wavelength of radiation not absorbed by chlorophyll

Some radiation is reflected or heats the surface of the earth

Plants do not cover all the earth

(c) Photosynthesis: $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_12\text{O}_6 + 6\text{O}_2$

(d) Production of biogas

Production of ethanol / fermentation

35 Biodiesel is renewable.

Biodiesel is carbon neutral. Plants use the same amount of CO\textsubscript{2} to make the oil that is released when the fuel is burned.

Biodiesel is rapidly biodegradable and completely non-toxic, meaning spillages represent far less risk than petroleum diesel spillages.

Biodiesel has a higher flash point than petroleum diesel, making it safer in the event of a crash.

Blends of 20% biodiesel with 80% petroleum diesel can be used in unmodified diesel engines. Biodiesel can be used in its pure form but engines may require certain modifications to avoid maintenance and performance problems.

Biodiesel can be made from recycled vegetable and animal oils or fats.

36 (a) Distant from localized areas of pollution; data present an accurate measure of global levels of CO\textsubscript{2}.

(b) % increase = (increase/initial value) × 100%

\[= \left[\frac{384 - 316}{316}\right] \times 100\% = 21.5\%\]

(c) Combustion of fossil fuels.

(d) The annual variation is due to CO\textsubscript{2} uptake by growing plants. The uptake is highest in the northern hemisphere springtime.

(e) Photosynthesis: $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_12\text{O}_6 + 6\text{O}_2$

CO\textsubscript{2} dissolves in water: $\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})$

(f) Decreased level of photosynthesis: less CO\textsubscript{2} taken in by plants.

(g) CO\textsubscript{2} absorbs infrared radiation, which leads to increased vibrations and bending and stretching of the bonds.

37 (a) Carbon dioxide has polar C=O bonds and the oxygen atoms have lone pairs. It can form hydrogen bonds with water molecules.

(b) Relatively strong hydrogen bonds are formed: $\Delta H$ is negative. The solubility decreases with increasing temperature, as the equilibrium shifts to the endothermic (reverse) direction as the temperature increases.
(c) Increased temperatures due to increased atmospheric carbon dioxide concentrations could result in reduced solubility of carbon dioxide. More carbon dioxide is then released, which amplifies the initial change.

(d) Increased carbon dioxide increases the rate of photosynthesis, producing more phytoplankton, which further reduce levels of carbon dioxide.

38 The removal of $\text{CO}_3^{2-}(aq)$ will cause the equilibrium $\text{HCO}_3^{-}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CO}_3^{2-}(aq)$ to shift to the right. The resulting decreased levels of $\text{HCO}_3^{-}(aq)$ will cause $\text{H}_2\text{CO}_3(aq) \rightleftharpoons \text{H}^+(aq) + \text{HCO}_3^{-}(aq)$ to shift to the right and so on until $\text{CO}_2(g) \rightleftharpoons \text{CO}_2(aq)$ shifts to the right with the absorption of $\text{CO}_2(g)$.

39 $\text{pH} = 8.2$: $[\text{H}^+] = 10^{-8.2}$

$\text{pH} = 8.1$: $[\text{H}^+] = 10^{-8.1}$

$\%$ increase $= (10^{-8.1} - 10^{-8.2})/10^{-8.2} \times 100\%$

$= (10^{0.1} - 1) \times 100\% = 26\%$

40 (a) Respiration, volcanic eruption, complete aerobic decomposition of organic matter, forest fires

(b) Methane produced from anaerobic decomposition

(c) Smoke particulates: block out sunlight

(d) High-energy short-wavelength radiation passes through the atmosphere

Lower energy / longer wavelength radiation from the earth's surface is absorbed by vibrating bonds in $\text{CO}_2$ molecules

(e) Melting of polar ice caps; thermal expansion of oceans will lead to rise in sea levels, which can cause coastal flooding; crop yields reduced; changes in flora and fauna distribution; drought; increased rainfall; desertification

41 (a) Incoming radiation from the sun is of short wavelength

Long-wavelength infrared radiation leaves earth's surface and some is absorbed by gases in the atmosphere

Results in increased vibration of bonds in molecules which then re-radiate heat back to the earth

(b) *Natural*: (evaporation from) oceans

*Artificial*: burning (any specified) fossil fuel

(c) $\text{CO}_2$ is more abundant but $\text{CH}_4$ absorbs the radiation more effectively / has a larger greenhouse factor

42 (a) coal / diesel (fuel) / wood

(b) $\text{CH}_4 + \text{O}_2 \rightarrow \text{C} + 2\text{H}_2\text{O}$

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 (a) long wavelength / infrared / IR radiation from Earth's surface

(some of this radiation) is absorbed (by gas)

Do not accept ‘trapped’ or ‘blocked’.

Do not award mark for ‘IR from sun’.

causes (increased) vibration in bonds re-radiates heat back to the Earth

Accept ‘re-transmits’

Do not accept ‘reflects/bounces’

[b] 2 max

(b) melting of polar ice caps / glaciers melting thermal expansion of oceans / rise in sea levels / coastal flooding

stated effect on agriculture (e.g. crop yields changed)

changes in flora / plant / fauna / animal / insect distribution / biodiversity

Accept specific example.

stated effect on climate (e.g. drought / increased rainfall / desertification)

Do not accept ‘climate change’ alone.

Do not allow ‘climate change’ alone.

Award [1] each for any three. [3 max]

2 high-level waste has longer half-life / low-level waste has shorter half-life
high-level waste is vitrified / made into glass / buried underground / in granite / in deep mines / under water / in steel containers / in cooling ponds / OWTTE

low-level waste is stored under water / in steel containers / in cooling ponds / filtered / discharged directly into sea / OWTTE

Accept cooling ponds/steel containers/under water/concrete containers only once. [3]

3 Catalytic cracking:
used to produce moderate length alkanes for fuels
lower temperature / lower energy consumption / more control of product [2]

4 light nuclei for fusion and heavy nuclei for fission
more massive nucleus produced in fusion as nuclei joined together and two lighter nuclei produced in fission as nuclei split apart [2]

5 6.25% remains
4 half-lives = 6400 years [2]

6 (a) energy transferred to surroundings / from system which is no longer available for use / cannot be used again [2]

(b) $^{235}_{92}$U undergoes a fission reaction due to neutron capture
reaction produces neutrons so chain reaction occurs
mass of products less than reactants

(c) the mass needed that allows fission to be sustained [1]

7 (a) wide availability
produce energy at appropriate rate
ease of transportation
current technology is based on fossil fuels
high energy density / specific energy [2 max]

(b) energy produced per unit mass / kg / stored per unit mass / kg [1]

(c) uranium / hydrogen [1]

(d) Efficiency $= 600 \times 10^6 / \text{energy}_{\text{input}}$
$\text{Energy}_{\text{input}} = 600 \times 10^6 / 0.30 \text{ J s}^{-1} = 2000 \times 10^6 \text{ J s}^{-1}$
Mass of fuel $= 2000 \times 10^6 / 60 \times 10^3 = 33.3 \times 10^3 \text{ g s}^{-1}$ [3]

8 (a) coal about 90% and petroleum about 84% and natural gas 75% [1]

(b) they have higher specific energy
liquid or gaseous state make them more convenient to use / easier to transport
produce less pollution / smaller carbon footprint [2 max]

(c) hydrogen has a very high specific energy / energy density
it is clean burning producing only $\text{H}_2\text{O}$ when it is burned [2]

9 (a) $\begin{array}{|c|c|c|c|}
\hline
\text{Formula} & M / \text{g mol}^{-1} & \Delta H_c / \text{kJ mol}^{-1} & \text{Specific energy} / \text{kJ g}^{-1} \\
\hline
\text{C}_3\text{H}_8 & 44.11 & -2219 & 2219/44.11 = 50.31 \\
\text{C}_4\text{H}_{10} & 58.14 & -2878 & 2878/58.14 = 49.50 \\
\hline
\end{array}$ [2]

(b) $\rho = PM/RT$

Formulas $\begin{array}{|c|}
\hline
\text{Formula} & \text{Specific energy} \\
\hline
\text{C}_3\text{H}_8 & (2219/44.11) \times 1.00 \times 10^5 \times 44.11/(8.13 \times 273) \\
& = 2219 \times 1.00 \times 10^5 / (8.31 \times 273) \\
& = 97000 \text{ kJ m}^{-3} \\
& = 0.978 \text{ kJ cm}^{-3} \\
\text{C}_4\text{H}_{10} & (2878/58.14) \times 1.00 \times 10^5 \times 58.14/(8.13 \times 273) \\
& = 2878 \times 1.00 \times 10^5 / (8.31 \times 273) \\
& = 127000 \text{ kJ m}^{-3} \\
& = 0.127 \text{ kJ cm}^{-3} \\
\hline
\end{array}$ [3]

10 (a) photosynthesis [1]

(b) chlorophyll
conjugated structure [2]
(c) \(6\text{CO}_2 + 24\text{H}^+ + 24\text{e}^- \rightarrow C_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} \quad [1]\)

(d) \(6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow C_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \quad [1]\)

(e) (i) fermentation
\[C_6\text{H}_{12}\text{O}_6 \rightarrow 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2 \quad [2]\]

(ii) \[\text{C}_2\text{H}_5\text{OH}(l) + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 3\text{H}_2\text{O}(l)\]
\[\Delta G = 2(-394.4) + 3(-237.1) - (-175) = -1325.1 \text{ kJ mol}^{-1}\]
thermodynamic efficiency = \(-1325.1/(-1367) = 97\% \quad [3]\)

11 (a) the octane number indicates the resistance of a motor fuel to knock / premature ignition
octane numbers are based on a scale on which 2,2,4-trimethylpentane (isooctane) is 100 (minimal knock) and heptane is 0 (maximum knock) \[2\]

(b) octane number of straight-chain alkanes decrease with an increase in chain length
straight chain alkanes < aromatics
alcohols have very high octane numbers:
hexane (24.8) < pentane (61.7) < benzene (105.8) < ethanol (108) \[4\]

12 (a) \(\text{^{235}U} \rightarrow \text{^{231}Th} + \text{^{4}He}\)
atomic number = 90 and element = Th
mass number = 231 \[2\]

(b) To answer this question you need to know that the half-life of \(\text{^{235}U}\) is 704 million years.
After one half-life the amount of \(\text{^{235}U}\) will have decayed to 50% of its original amount.
After two half-lives the amount of \(\text{^{235}U}\) will have decayed to 25% of its original amount, i.e. 75% will have decayed.

2 \times 704 \text{ million years} = 1408 \text{ million years}
It will take 1408 million years for 75% of the \(\text{^{235}U}\) to decay. \[2\]

13 (a) effects due to: increased carbon dioxide levels, global warming
non-metal / sulfur / nitrogen oxides produce acid rain
unburned hydrocarbons and carbon monoxide particulates cause global dimming \[3 \text{ max}\]

<table>
<thead>
<tr>
<th>13 (b)</th>
<th>Strategy</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased energy efficiency and conservation</td>
<td>• Use of insulation and more efficient appliances&lt;br&gt;• Reducing personal energy use by turning off lights and electronics when not in use&lt;br&gt;• Reducing distance travelled in vehicles or using more efficient modes of transport such as hybrid cars or public transport&lt;br&gt;<strong>Award [1 max] for action</strong></td>
<td></td>
</tr>
<tr>
<td>Reduced dependence on carbon-based energy resources</td>
<td>• Use alternative sources such as solar, wind, geothermal, hydropower, wave, tidal or nuclear power&lt;br&gt;• Use reduced-carbon fuels such as natural gas. The potential use of biomass depends on the processes by which it is converted to energy&lt;br&gt;<strong>Award [1 max] for action</strong></td>
<td></td>
</tr>
<tr>
<td>Capture and storage of carbon from fossil fuels or from the atmosphere</td>
<td>• Carbon dioxide can be removed from the atmosphere and stored within plants and soil supporting the plants. Alternatively, carbon dioxide can be captured either before or after fossil fuel is burned and then be stored (sequestered) within the earth&lt;br&gt;• Reduce deforestation and plant more trees&lt;br&gt;<strong>Award [1 max] for action</strong></td>
<td></td>
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</tbody>
</table>
countries with cheaper gasoline on average:
use more gasoline
have less efficient vehicles
produce more CO₂ and have higher carbon footprint [3]

octane C₈H₁₈
any other compound with C₆–C₁₀ [2]

fractional distillation
mixture of hydrocarbons is heated causing them to vaporize
different compounds have different boiling points; the lowest boiling point compounds condense higher up the column
as the size of the molecule increases the attractive van der Waals forces increase [4]
larger molecules can be cracked into smaller molecules when heated with a catalyst and broken into smaller molecules

equation for cracking: C₁₄H₃₀ → C₇H₁₄ + C₇H₁₆ [2]

Challenge yourself

1 680 kJ of heat is given out. Energy efficiency is 32%.

2 Coal and oil are fossilized decayed plants or animals that contain amino acids. The amino acid cysteine contains sulfur. Coal and oil with a higher percentage of sulfur are considered ‘dirty’ because of the sulfur dioxide pollution that they produce on combustion. Sulfur dioxide results in acid rain.

3 (a) Plotting a graph we see that the data follow an approximate straight-line relationship:

This suggests an octane number of −33.
In practise the graph is a curve rather than a straight line and octane has an octane number of −19.

(b) Assuming the same straight-line trend, for an octane number of 100, n = 3.73. So propane has an octane number above 100.

4 The isomers of octane have the essentially the same number of C–C and C–H bonds.
This suggests that they are not a key factor in a molecule’s octane number.
5 The ratio between the values is approximately 4. This corresponds to \( Z^2 = Z^2 \), where \( Z \) is the atomic number of helium. This is a general result: the energy level is proportional to the square of the atomic number.

6 \( \text{C}_{40}\text{H}_{56} \)

The position of the double bond in the hexagon on the right is different in the two isomers.

7 (a) \[ 2\text{C}_{16}\text{H}_{23}\text{O}_{11} + 19\text{H}_2\text{O} + \text{O}_2 \rightarrow x\text{H}_2 + y\text{CO} + z\text{CO}_2 \]

(b) \( C \) is oxidized
   \( O \) and \( H \) are reduced

(c) Balancing the \( H \) atoms:
   \[ 2\text{C}_{16}\text{H}_{23}\text{O}_{11} + 19\text{H}_2\text{O} + \text{O}_2 \rightarrow 42\text{H}_2 + y\text{CO} + z\text{CO}_2 \]
   \( x = 42 \)

(d) Total change of oxidation number of \( H = -84 \)

8 (e) 42\text{H}_2 + 21\text{CO} \rightarrow 21\text{CH}_3\text{OH}

2 molecules of wood produce 21 molecules of methanol
1 molecule produces 10.5 molecules

The solubility of carbon dioxide increases at lower temperatures and higher pressures. Increased levels of \( \text{CO}_2(g) \) will lead to the formation of the more soluble \( \text{Ca(HCO}_3)_2(aq) \).

\[ \text{CaCO}_3(s) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \rightarrow \text{Ca(HCO}_3)_2(aq) \]
Chapter 15

Exercises

1. intramuscular / into muscles
   intravenous / into veins
   subcutaneous / into fat

The fastest will be intravenous as the drug can be transported quickly all over the body in the bloodstream.

2. Tolerance occurs when repeated doses of a drug result in smaller physiological effects. It is potentially dangerous because increasing doses of the drug are used in response and this might get close to or exceed the toxic level.

3. (a) Lethal doses can be determined for animals; in humans the upper limit is the toxic dose.
    (b) Bioavailability, side-effects, possibility of tolerance and addiction of the drug; age, sex, diet and weight of patient.
    (c) Low therapeutic index means a low margin of safety, so small changes in dosage may produce adverse side-effects.

4. Method of administration of drug, solubility (in water and lipid) and functional group activity.

5. (a) 84.94%
    (b) melting point determination: melting point of aspirin is 138–140°C

6. Increase its solubility in water by converting to sodium salt.

7. (a) Mild analgesic blocks transmission of impulses at site of injury, not in the brain; anticoagulant acts to prevent coagulation / thickening of the blood and so reduces risk of coronary disease.
    (b) Alcohol has synergistic effect with other drugs; can cause stomach bleeding with aspirin.

8. (a) \( R-C_3H_7N_2O_4S \)
    (b) At the R group. Modification prevents the binding of the penicillinase enzyme and so maintains the action of the drug / prevents resistant bacteria rendering it inactive.
    (c) Beta-lactam ring undergoes cleavage and binds irreversibly to the transpeptidase enzyme in bacteria. This inactivates the enzyme, which interrupts the synthesis of bacterial cell walls.

9. Overuse of antibiotics in animal stocks / food chain; over-prescription; failure of patients to complete treatment regimen.

10. (a) The functional groups in common are ether linkage (–C–O–C–), tertiary amine linkage (R–N(R′) – R″), alkenyl (–C=–C–) and arene.
    (b) main effect: pain relief
        side-effect: constipation

11. Diamorphine has two ester groups in place of two –OH groups in morphine. The less polar diamorphine is more soluble in lipids and so crosses the blood–brain barrier more easily, and enters the brain where it blocks the perception of pain.

12. In favour: strongest pain killer known; the only effective analgesic against extreme pain.
    Against: addictive drug; leads to dependence and serious side-effects.

13. \( H_2 \)-receptor antagonists: block the binding of histamine, which prevents the reactions leading to stomach acid secretion.
    Proton-pump inhibitors: directly prevent the release of acid into the stomach lumen.

14. (a) \( Mg(OH)_2 + 2HCl \rightarrow MgCl_2 + 2H_2O \)
    \( Al(OH)_3 + 3HCl \rightarrow AlCl_3 + 3H_2O \)
    (b) \( Al(OH)_3 \) reacts with \( H^+ \) in a mole ratio of 1:3
    \( Mg(OH)_2 \) reacts with \( H^+ \) in a mole ratio of 1:2
    So 0.1 mol \( Al(OH)_3 \) will neutralize the greater amount.
KOH is a strong alkali so would be dangerous for body cells; it is corrosive and would upset the stomach pH.

15 (a) 5.12.  
(b) No change in pH on dilution of buffer.

Viruses lack a cellular structure and so are difficult to target. Antibiotics specifically interfere with bacterial cell walls or internal structures. Viruses replicate inside host cells and so treatment may involve killing host cells.

Subunits in hemagglutinin (H) and neuraminidase (N) can mutate and mix and match, so forming different strains. These change the specific nature of the glycoprotein–host interactions, and alter the body’s immune response. This is why it is possible to suffer from flu several times during a lifetime.

Tamiflu and Relenza do not prevent the flu virus from entering cells, but act to stop it from being released from the host cells. So if the infection is not stopped early, too many new viral particles may have already been released.

Challenges: antiretroviral costs, distribution and availability; patient compliance to regimen and multiple drug treatments; sociocultural issues. Successes: new and more effective antivirals that can be used in combination; better screening of HIV-positive; controlling infection through drugs.

Solvents cause problems of disposal. Organic solvents can be incinerated, causing release of pollutants, greenhouse gases and toxins. Solvents can contaminate ground water and soil. Some solvents can be hazardous to health of workers.

Protective shoe-covers, clothing, gloves, paper towels and contaminated implements. Interim storage in sealed containers for radioactivity to decay, before conventional disposal.

The success of antibiotics in treating disease has led to their widespread use, and in some cases over-use. Exposure of bacteria to antibiotics increases the spread of resistant strains. Antibiotic resistance renders some antibiotics ineffective, especially with multiply resistant strains, e.g. MRSA.

Patient compliance refers to the importance of patients following medical instructions, in particular to completing the course of an antibiotic treatment. This helps prevent the spread of antibiotic-resistant bacteria.

Green Chemistry principles seek to reduce toxic emissions and waste substances in the manufacture of drugs. This includes reduction in the amount of solvent used, the adoption of synthesis pathways with shorter routes, the replacement of inorganic catalysts with enzymes and the recycling of waste.

Practice questions

For advice on how to interpret the marking below please see Chapter 1.

1 C  2 B  3 D  4 B  
5 C  6 C  7 (a)  

No mark if circle includes CO or just O.  
Award [1] if it includes 7 C atoms but misses out on attached H atoms

(b) overprescription can lead to allergic reaction may wipe-out harmless/helpful/beneficial bacteria (in the alimentary canal) destroyed bacteria may be replaced by more harmful bacteria (may pass on genetic) resistance/immunity [1] each for any two.

modify R group/side chain to change penicillin effectiveness / form penicillin that
is more resistant to penicillinase enzyme [3 max]

8 (a) \[ \text{Al(OH)}_3 + 3\text{HCl} \rightarrow \text{AlCl}_3 + 3\text{H}_2\text{O} / \text{Mg(OH)}_2 + 2\text{HCl} \rightarrow \text{MgCl}_2 + 2\text{H}_2\text{O} \] [1]

Accept ionic equations.

(b) less effect and (magnesium hydroxide) \(2/0.2\) mol OH\(^{-}\) ions available as compared to (aluminium hydroxide) \(3/0.3\) mol OH\(^{-}\) ions for neutralization / neutralizes \(2\text{H}^+/0.2\) mol acid as compared to \(3\text{H}^+/0.3\) mol acid [1]

Do not accept aluminium hydroxide can neutralize more acid.

9 (a) viruses do not have cell/cellular structure
viruses do not have nucleus
viruses do not have cell wall
viruses do not have cytoplasm [2]

Accept opposite statements for bacteria.

(b) stops virus replication

Accept reproduction / multiplication.

becomes part of DNA of virus / alters virus DNA / blocks polymerase which builds DNA changes the cell membrane that inhibits the entry of virus into the cells

prevents viruses from leaving the cell (after reproducing) [2 max]

(c) HIV mutates (rapidly)

Accept AIDS mutates

HIV metabolism linked to that of host cell / HIV uses host cell / drugs harm host cell as well as HIV / difficult to target HIV without damaging host cell

HIV destroys helper cells of the immune system [2 max]

10 (a) fast delivery / OWTTE [1]

(b) diamorphine has (2) ester/acetyl/COOCH\(_3\) groups instead of hydroxyl/OH groups

diamorphine is less polar/non-polar [2]

11 if concentration is too high it will have harmful side effects / determination of the lethal dose (to 50% of the population) / OWTTE

if concentration is too low it has little or no beneficial effect / determination of the effective dose / dose which has a noticeable effect (on 50% of the population) / OWTTE

therapeutic window is the range between these doses / range over which a drug can be safely administered / ratio of \(\text{LD}_{50}/\text{ED}_{50}\)

for minor ailments a large window is desirable, for serious conditions a smaller window may be acceptable / OWTTE

(therapeutic window) depends on the drug/age/sex/weight

a small therapeutic window means that an overdose is a high risk / OWTTE [4 max]

12 (a) amine
ether
alkenyl
arene [2 max]

Allow structural representation of functional group instead of name (e.g. C=C instead of alkenyl).

(b) phenol / alcohol / hydroxyl (group) [1]

Allow OH.

(c) (di)esterification / condensation / (di)acetylation [1]

13 (a) penicillins interfere with the enzymes that bacteria need to make cell walls / interfere with formation of bacterial cell walls / OWTTE

the increased osmotic pressure causes the bacterium to die / the bacterial cells absorb too much water and burst / OWTTE [2]

(b) resistance to penicillinase enzyme / more resistance to bacteria breaking it down / effective against bacteria that are resistant (to penicillin G)

resistance to breakdown by stomach acid (so can be taken orally / OWTTE [2]

(c) amide group / –CONH– / peptide
ring is strained /

ring breaks easily so (the two fragments similar to cysteine and valine) then bond(s)
covalently to the enzyme that synthesizes the bacterium cell wall (so blocking its action) [3]

14 (a) C [1]  
(b) A / B/ A and B [1]  
(c) A [1]

15 (a) intravenous / into veins  
transported/pumped via blood (to various parts of the body) [2]  
(b) intramuscular/intermuscular/into muscles and subcutaneous/into fat [1]  
(c) inhalation/breathing it in [1]

**Challenge yourself**

1 Ethanoic anhydride is more susceptible to nucleophilic attack due to two electron-withdrawing carbonyl groups:

\[ R\overset{\delta^+}{\bigtriangledown}C\overset{\delta^-}{\bigtriangleup}O\overset{\delta^-}{\bigtriangleup}C\overset{\delta^+}{\bigtriangledown}R \]

This enables it to react more vigorously than CH₃COOH with the –OH groups in morphine.

2 Na₂CO₃ and NaHCO₃ contain the conjugate bases CO₃²⁻ and HCO₃⁻ of weak acids. They are able to hydrolyse water and release OH⁻ ions:

\[ \text{CO}_3^{2-}(aq) + H_2O(l) \rightleftharpoons \text{HCO}_3^-(aq) + OH^-(aq) \]
\[ \text{HCO}_3^-(aq) + H_2O(l) \rightleftharpoons \text{H}_2\text{CO}_3(aq) + OH^-(aq) \]

3 Neuraminidase inhibitors compete with the substrate sialic acid for binding to the enzyme neuraminidase. They have a chemical structure similar to the substrate and so bind in the same way at the active site of the enzyme.