

Module 5 Review

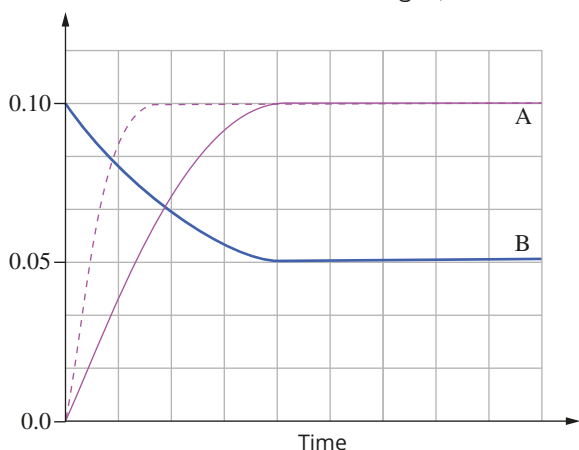
Equilibrium and acid reactions

Multiple choice

- C. The activation energy for all reactions is > 0 and the value of ΔH is > 0 for an endothermic reaction.
- D. The ΔH is the difference between the final enthalpy (products) and the initial enthalpy (reactants). The value is positive here because there is a net increase (endothermic).
- B. The activation energy is the difference between the maximum enthalpy on the curve and the initial enthalpy (on the right for the reverse reaction). It is always positive.
- D. There is no connection between the enthalpy changes in a reaction and its activation energy.
- D. An open system is open to exchange of both energy and matter to the surroundings.
- A. When an egg is boiled, the yolk and white undergo irreversible change.
- B. A lit candle is an open system so it cannot reach equilibrium. The wax in the candle is being irreversibly converted to carbon dioxide and water.
- D. For $2\text{H}_2\text{O}(\text{g}) + 2\text{Cl}_2(\text{g}) \rightleftharpoons 4\text{HCl}(\text{g}) + \text{O}_2(\text{g})$ $K_1 = 4.0 \times 10^{-4}$
 For the equation
 $4\text{HCl}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{H}_2\text{O}(\text{g}) + 2\text{Cl}_2(\text{g})$
 reversing the reaction inverts K_1 , so:
 $K_2 = \frac{1}{K_1} = \frac{1}{4.0 \times 10^{-4}} = 2.5 \times 10^3$
 For the equation $2\text{HCl}(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightleftharpoons \text{H}_2\text{O}(\text{g}) + \text{Cl}_2(\text{g})$ halving coefficients gives square root of K_2 , so:
 $K_3 = \sqrt{K_2} = \sqrt{2.5 \times 10^3} = 50$
- B. For the chemical reaction $\text{A} + 3\text{B} \rightleftharpoons 2\text{C} + 4\text{D}$, the equilibrium expression is $\frac{[\text{C}]^2[\text{D}]^4}{[\text{A}][\text{B}]^3}$
- A. Only in reactions I and II is W a reactant. An increase in the concentration of W will increase the frequency of collisions between reactant particles, resulting in an increase in the rate of the forward reaction.
- C. In the normal course of a reaction, the concentrations of the products increase and the concentrations of the reactants decrease as the reaction approaches equilibrium. In this instance the ratio:
 $\frac{\text{decrease in } [\text{A}]}{\text{increase in } [\text{B}]} = \frac{0.8}{0.4} = 2$
 So the mole ratio of A:B is 2:1 which corresponds to C.
- B. Lower temperatures give higher K_{eq} values, and hence higher yields, for exothermic reactions (negative ΔH). Higher pressures will drive an equilibrium towards the side with fewer particles, so higher pressures will increase the yield of NO_2 in this reaction.
- C. The reduction in volume will increase concentrations of all species and hence increase the net concentration of particles, causing the position of equilibrium to shift to the side with fewer particles. Hence a net reverse reaction occurs, reducing the amount of products NO and Cl_2 . However, this loss of Cl_2 does not completely offset the increase in concentration resulting from the initial volume change, so there is a net increase in the concentration of Cl_2 .
- C. The equilibrium constant gives information only about the extent of a reaction. It gives no indication about the activation energy and hence no information about the rate of a reaction. All is known about this reaction from the extremely high K_{eq} value is that when equilibrium is reached the mixture will comprise almost exclusively products.
- A. Since these equations share a common species, $\text{H}_2\text{CO}_3(\text{aq})$, changes that affect one will have a consequent effect on the other. Raising $[\text{H}_3\text{O}^+(\text{aq})]$, which will induce a shift left in the second reaction. The consequent increase in $[\text{H}_2\text{CO}_3(\text{aq})]$ will induce a shift left in the first reaction also, resulting in the loss of CO_2 from the solution. All other changes listed will induce a shift right in the first equation and lead to more dissolved CO_2 .
- D. The compound will dissociate to NH_4^+ and SO_4^{2-} ions. The formula $(\text{NH}_4)_2\text{SO}_4$ shows the charges of the two ions are different.
- B. $\text{Ba}(\text{NO}_3)_2$ will act as a source of Ba^{2+} ions and Na_2SO_4 will act as a source of SO_4^{2-} ions.
- C. All ammonium compounds are soluble in water and all compounds containing group 1 metal ions are soluble
- A. $K_{\text{sp}} = [\text{Ag}^+][\text{Br}^-] = (7.31 \times 10^{-7})(7.31 \times 10^{-7}) = 5.34 \times 10^{-13}$
- D. The formula $\text{Ca}_3(\text{PO}_4)_2$ indicates $[\text{Ca}^{2+}]$ will be to the power of 3 and will be to the power of 2 i.e. $K_{\text{sp}} = [\text{Ca}^{2+}]^3[\text{PO}_4^{3-}]^2$

Short answer

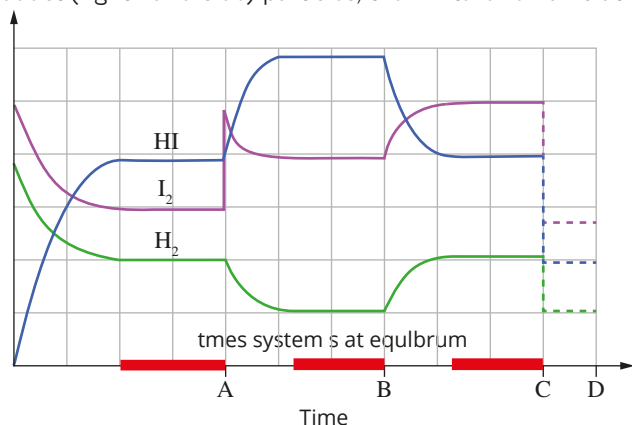
- 1 a $\text{CO}_2(\text{g}) + \text{NO}(\text{g}) \rightarrow \text{CO}(\text{g}) + \text{NO}_2(\text{g})$
 b maximum enthalpy of curve – initial enthalpy (reactants) = $350 - (-50) = 400 \text{ kJ mol}^{-1}$
 c final enthalpy (products) – initial enthalpy (reactants) = $250 - (-50) = +300 \text{ kJ mol}^{-1}$
 d The reaction is endothermic, because ΔH for the reaction is positive.
- 2 a i No. Not all of the reactants react in a reversible reaction.
 ii No. In a reversible reaction some reactant always remains.
 b i The reaction has not stopped, but the rate of the forward reaction is equal to that of the reverse reaction.
 ii Yes. The value of the equilibrium constant varies with temperature, so the amount of ammonia formed will also vary.
 c Yes. The reverse reaction can occur to form hydrogen and nitrogen gases.
- 3 a The forward and reverse reaction rates are equal up until time T .
 b The addition of reactant W increases the frequency of collisions between reactant particles so the rate of the forward reaction increases initially.
 Because the forward reaction is now faster, there will be a net forward reaction. This will consume the reactant particles (so the forward reaction will slow down) and generate product particles (so the reverse reaction will speed up). When the two rates become equal again, equilibrium will be re-established and no further change will occur.
 c i Adding Y. This accounts for the initial increase in the rate of the reverse reaction; the subsequent changes reflect the inevitable re-establishment of equilibrium.
 ii Adding a catalyst. Both rates increase equally and this is the characteristic effect of a catalyst.
 Note: Although it does not apply here, another case that would produce this change is the compression of a gas-phase reaction (volume decreased) when there are equal numbers of reactant and product species in the equation.
 iii Adding an inert gas. This does not affect the concentrations of reactants or products and so affects neither the frequency of collisions between reacting particles. Hence, it does not affect the rate of either reaction.
 d Lowering the temperature means that the particles in the mixture will be moving with less kinetic energy and hence colliding less frequently, and a smaller proportion of collisions will meet the activation energy needed to be successful. In other words, collisions will be less frequent, and a smaller proportion of collisions that occur will create products. This is true for both forward and reverse reactions.
 e Because the forward reaction is faster (because the reverse reaction has slowed to a greater extent), there will be a net forward reaction.
 f Exothermic. Lowering the temperature will always induce a shift in the exothermic direction, which in this case must be the forward reaction since that is the direction of the shift.
- 4 a A is NO_2 . B is N_2O_4 .
 From the equation: $\frac{\text{change in } [\text{N}_2\text{O}_4]}{\text{change in } [\text{NO}_2]} = \frac{1}{2}$ and from the graph: $\frac{\text{change in } [\text{B}]}{\text{change in } [\text{A}]} = \frac{0.05}{0.10} = \frac{1}{2}$
 b $K_{\text{eq}} = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]}$
 c The final concentration will be unchanged, but it will be reached in less time.



d $[\text{NO}_2] = 0.100 \text{ mol L}^{-1}$; $[\text{N}_2\text{O}_4] = 0.050 \text{ mol L}^{-1}$

$$K = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]} = \frac{(0.100)^2}{0.050} = 0.20$$

- 5
- exothermic reaction \Rightarrow decreased K_{eq}
 - shift right \Rightarrow decreased amount of I_2O_5
 - no temperature change \Rightarrow no change to K_{eq}
 - shift left \Rightarrow decreased amount of I_2
 - shift right (to side with more gas particles) \Rightarrow increased amount of CO_2
 - initial volume increased \Rightarrow decreased concentration of CO_2 (not offset by increased amount)
 - shift left \Rightarrow decreased amount of CO_2
 - catalyst does not affect equilibrium \Rightarrow no change
 - no temperature change \Rightarrow no change to K_{eq}
- 6
- Iodine (I_2) has been added, followed by a net forward reaction to re-establish equilibrium.
 - The temperature has been increased, resulting in a net reverse reaction (because the forward reaction is exothermic).
 - Equilibrium exists when the concentrations are constant (see diagram).
 - Doubling the volume will halve all concentrations. Because there are equal numbers of reactant (left-hand side) and product (right-hand side) particles, the mixture remains at equilibrium and there is no shift (see diagram).



- 7
- $\text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + 3\text{H}_2(\text{g})$
 - $\text{CO}(\text{g}) + 2\text{H}_2(\text{g}) \rightleftharpoons \text{CH}_3\text{OH}(\text{g})$
 - They are catalysts, which allows the reaction mixture to reach equilibrium more quickly.
 - The yield would be lower. Because the reaction is exothermic, increasing the temperature would lower the equilibrium constant, and shift the position of equilibrium to the left, resulting in less products when equilibrium is re-established.
 - High pressure will increase the reaction rate so products form faster. Also, because the number of product particles (1 on the right-hand side) is smaller than the number of reactant particles (3 on the left-hand side), high pressure will favour the forward reaction and increase yield.
 - Exposure to CO will drive the first reaction to the right. This lowers the concentration of free haemoglobin (Hb_4) which drives the second reaction to the left, removing $\text{Hb}_4(\text{O}_2)_4$.
 - High O_2 pressure will drive the second reaction to the right. This lowers the concentration of free haemoglobin (Hb_4) which drives the first reaction to the left, removing $\text{Hb}_4(\text{CO})_4$.
 - $\text{CH}_3\text{OH}(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{CO}(\text{g}) + 2\text{H}_2\text{O}(\text{g})$
- 8
- $K_{\text{sp}} = [\text{Li}^+][\text{Br}^-]$
 - $K_{\text{sp}} = [\text{Pb}^{2+}][\text{I}^-]^2$
 - $K_{\text{sp}} = [\text{Cu}^{2+}]^3[\text{PO}_4^{3-}]^2$
- 9
- PbCl_2
 - AgI
 - BaS
 - $\text{Ni}(\text{OH})_2$

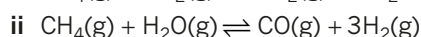
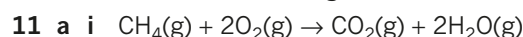
$$10 \text{ a } K_{sp} = [\text{Ba}^{2+}][\text{SO}_4^{2-}] = (1.04 \times 10^{-5})(1.04 \times 10^{-5}) = 1.08 \times 10^{-10}$$

	$\text{BaSO}_4(\text{s})$	\rightleftharpoons	$\text{Ba}^{2+}(\text{aq})$	+	$\text{SO}_4^{2-}(\text{aq})$
I			0		0
C			$+1.04 \times 10^{-5} \text{ mol L}^{-1}$		$+1.04 \times 10^{-5} \text{ mol L}^{-1}$
E			$1.04 \times 10^{-5} \text{ mol L}^{-1}$		$1.04 \times 10^{-5} \text{ mol L}^{-1}$

$$10 \text{ b } n(\text{BaSO}_4) = \frac{m}{M} = \frac{0.050}{233.4} = 2.14 \times 10^{-4} \text{ mol}$$

$$c(\text{BaSO}_4) = \frac{n}{V} = \frac{2.14 \times 10^{-4}}{0.500} = 4.3 \times 10^{-4} \text{ mol L}^{-1}$$

This concentration is greater than the molar solubility at this temperature, so a precipitate will form.



11 b i No methane will be left because the reaction is not reversible.

11 b ii Some methane will be left because the reaction is reversible.

11 c i If 2 mol of methane reacts, 2 mol of carbon dioxide will be formed.

11 c ii If 2 mol of methane reacts, less than 2 mol of carbon monoxide will be formed.

11 d i No. The amount of carbon dioxide formed is determined by the amount of methane available, not by the temperature.

11 d ii The amount of carbon monoxide will vary with the temperature as temperature affects the position of equilibrium.

$$11 \text{ e } \Delta G^\circ = \Delta H^\circ - T\Delta S^\circ = -890 - (373 \times 0.4054) = -1041 \text{ kJ mol}^{-1}$$

12 a A decrease in temperature causes:

12 a i the value of K_{eq} to increase as the forward, exothermic reaction is favoured, resulting in more products when equilibrium is re-established

12 a ii the position of equilibrium to shift to the right as the forward, exothermic reaction is favoured

12 a iii the concentration of HCl to decrease as the forward reaction is favoured

12 a iv the amount of HCl to decrease as the forward reaction is favoured.

12 b A decrease in volume is equivalent to a pressure increase, causing:

12 b i the value of K_{eq} to be unchanged as temperature has not changed

12 b ii the position of equilibrium to shift to the right as the system partially opposes an increase in pressure by moving in the forward direction as there are less product molecules than reactant molecules

12 b iii the concentration of HCl to increase due to the volume decrease

12 b iv the amount of HCl to decrease as the forward reaction is favoured.

12 c The addition of oxygen gas causes:

12 c i the value of K_{eq} to be unchanged as temperature has not changed

12 c ii the position of equilibrium to shift to the right as the system partially opposes the addition of oxygen by moving in the forward direction to remove some oxygen

12 c iii the concentration of HCl to decrease as the forward reaction is favoured

12 c iv the amount of HCl to decrease as the forward reaction was favoured.

13 a i The equation has been reversed so the value of K_{eq} is the reciprocal = $\frac{1}{12} = 0.083$

13 a ii The equation has been doubled so the value of K_{eq} is squared = $12^2 = 144$

13 a iii The equation has been reversed and halved so the value of K_{eq} is $\frac{1}{\sqrt{12}} = 0.29$

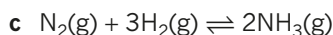
13 b $[\text{NH}_3] = 0.56 \text{ mol L}^{-1}$ and $[\text{N}_2] = 0.38 \text{ mol L}^{-1}$

$$K_{eq} = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3} = \frac{0.56^2}{0.38 \times [\text{H}_2]^3} = 12$$

$$[\text{H}_2]^3 = 0.0688$$

$$[\text{H}_2] = \sqrt[3]{0.0688} = 0.41 \text{ mol L}^{-1}$$

$$n(\text{H}_2) = c \times V = 0.41 \times 10.0 = 4.1 \text{ mol}$$



	$\text{N}_2(\text{g})$	+ $3\text{H}_2(\text{g})$	\rightleftharpoons	$2\text{NH}_3(\text{g})$
I	2.6 mol	4.4 mol		0 mol
C	$-x = -0.4$	$-3x = -1.2$		$+2x = 0.8$
E	2.2 mol	$4.4 - 3x$ $= 4.4 - 1.2$ $= 3.2 \text{ mol}$		$2x = 0.8 \text{ mol}$

$$[\text{N}_2] = \frac{n}{V} = \frac{2.2}{1.0} = 2.2 \text{ mol L}^{-1}$$

$$[\text{H}_2] = \frac{n}{V} = \frac{3.2}{1.0} = 3.2 \text{ mol L}^{-1}$$

$$[\text{NH}_3] = \frac{n}{V} = \frac{0.8}{1.0} = 0.8 \text{ mol L}^{-1}$$

$$K_{\text{eq}} = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3} = \frac{0.8^2}{2.2 \times 3.2^3} = 0.009$$

14 a i All ammonium compounds are soluble.

ii NH_4^+ and CO_3^{2-}

iii $(\text{NH}_4)_2\text{CO}_3(\text{s}) \rightarrow 2\text{NH}_4^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq})$

b The temperature of the water will decrease.

c i Ionic bonds in ammonium carbonate are broken; hydrogen bonds in water are broken.

ii Ion-dipole bonds form between ammonium or carbonate ions and water molecules.

d $(\text{NH}_4)_2\text{CO}_3(\text{aq}) + \text{Pb}(\text{NO}_3)_2(\text{aq}) \rightarrow \text{PbCO}_3(\text{s}) + 2\text{NH}_4\text{NO}_3(\text{aq})$

15 a $c(\text{PbI}_2) = \frac{n}{V} = \frac{1.3 \times 10^{-3}}{0.500} = 2.6 \times 10^{-3} \text{ mol L}^{-1}$

	$\text{PbI}_2(\text{s})$	\rightleftharpoons	$\text{Pb}^{2+}(\text{aq})$	+	$2\text{I}^-(\text{aq})$
I			0		0
C			$+2.6 \times 10^{-3} \text{ mol L}^{-1}$		$+2 \times (2.6 \times 10^{-3}) \text{ mol L}^{-1}$
E			$2.6 \times 10^{-3} \text{ mol L}^{-1}$		$5.2 \times 10^{-3} \text{ mol L}^{-1}$

$$K_{\text{sp}} = [\text{Pb}^{2+}][\text{I}^-]^2 = (2.6 \times 10^{-3})(5.2 \times 10^{-3})^2 = 7.0 \times 10^{-8}$$

b

	$\text{PbI}_2(\text{s})$	\rightleftharpoons	$\text{Pb}^{2+}(\text{aq})$	+	$2\text{I}^-(\text{aq})$
I			0		0
C			+s		+2s
E			s		2s

$$K_{\text{sp}} = [\text{Pb}^{2+}][\text{I}^-]^2 = 9.8 \times 10^{-9}$$

$$(s)(2s)^2 = 9.8 \times 10^{-9}$$

$$4s^3 = 9.8 \times 10^{-9}$$

$$s = 1.3 \times 10^{-3} \text{ mol L}^{-1}$$

c $n(\text{PbI}_2) = \frac{m}{M} = \frac{0.0756}{461.0} = 1.64 \times 10^{-4} \text{ mol}$

$$c(\text{PbI}_2) = \frac{n}{V} = \frac{1.64 \times 10^{-4}}{0.100} = 1.64 \times 10^{-3} \text{ mol L}^{-1}$$

This is greater than the molar solubility at 25°C, so a precipitate will form.

d $[\text{Pb}^{2+}]_{\text{mixture}} = \frac{c_1V_1}{V_2} = \frac{0.00170 \times 0.100}{0.200} = 8.50 \times 10^{-4} \text{ mol L}^{-1}$

$$[\text{I}^-]_{\text{mixture}} = \frac{c_1V_1}{V_2} = \frac{0.00240 \times 0.100}{0.200} = 1.20 \times 10^{-4} \text{ mol L}^{-1}$$

$$\text{ionic product} = [\text{Pb}^{2+}][\text{I}^-]^2 = (8.50 \times 10^{-4})(1.20 \times 10^{-4})^2 = 1.2 \times 10^{-11}$$

This is less than the value of K_{sp} of lead(II) iodide. A precipitate will not form.

e

	$\text{PbI}_2(\text{s})$	\rightleftharpoons	$\text{Pb}^{2+}(\text{aq})$	+	$2\text{I}^{-}(\text{aq})$
I			0		0.10
C			+s		+2s
E			s		0.10 + 2s

The contribution of iodide ions from dissolving lead(II) iodide is so small, it can be assumed that all iodide ions come from the KI solution. Hence:

$$0.10 + 2s \approx 0.10$$

$$K_{\text{sp}} = [\text{Pb}^{2+}][\text{I}^{-}]^2 = 9.8 \times 10^{-9}$$

$$(s) \times (0.10)^2 = 9.8 \times 10^{-9}$$

$$s = \frac{9.8 \times 10^{-9}}{(0.10)^2}$$

$$s = 9.8 \times 10^{-7} \text{ mol L}^{-1}$$

Note that this is lower than the molar solubility of lead(II) iodide in water calculated previously: $1.3 \times 10^{-3} \text{ mol L}^{-1}$.

f $\text{Mg}(\text{OH})_2$ can be compared to PbI_2 as they will produce the same number of ions when they dissociate in water.

Module 6 Review

Acid/base reactions

Multiple choice

- C. Ethanoic acid, hydrochloric acid and ammonium chloride are all acidic, so they have a pH of less than 7. Sodium hydroxide is a base and so has a pH greater than 7.
- A. CH_3COOH is a weak acid and so is only partially dissociated in solution, unlike HCl; 6.0 mol L^{-1} indicates a more concentrated solution than 0.01 mol L^{-1} .

B. When OH^- acts as an acid, it donates a proton and forms its conjugate base O^{2-} .
- A. To act as either a Brønsted–Lowry acid or base, a species must be able to accept and to donate an H^+ . NH_4^+ has a positive charge and so is unlikely to attract an H^+ . $\text{CO}_3^{2-}(\text{aq})$ has no H^+ to donate and CH_4 has no acidic hydrogens.

B. Polyprotic refers to an acid that can donate more than one proton.
 CH_3COOH donates only one proton to form its conjugate base CH_3COO^- .
 NH_4^+ also only donates one proton to form its conjugate base NH_3 .
 H_2SO_3 can donate one or two protons to form HSO_3^- or SO_3^{2-} respectively.
- D. Both solutions have the same concentration and volume but nitric acid is a strong acid whereas ethanoic acid is a weak acid. So statement I is not correct.
 Nitric acid is a stronger acid, so it dissociates more readily in water, releasing more $\text{H}^+(\text{aq})$. Therefore nitric acid will have a lower pH than ethanoic acid, and it will have a greater electrical conductivity. So statement II is incorrect and statement III is correct.
 Statement IV is also correct because both solutions contain the same number of moles of a monoprotic acid, which will react fully with a strong base such as NaOH.
- D. For a change of 1 unit in pH, the concentration of H^+ changes by a factor of 10. So a change of pH of 2 units means a change of H^+ concentration by a factor of 100. The pH of beaker X is higher, so the H^+ concentration will be 100 times lower.
- C. $\text{pH} = 13$ so $[\text{H}^+] = 10^{-13} \text{ mol L}^{-1}$ and $[\text{OH}^-] = 10^{-1} \text{ mol L}^{-1} = 0.10 \text{ mol L}^{-1} = [\text{NaOH}]$
 So $n(\text{NaOH}) = c \times V = 0.10 \times 0.500 = 0.050 \text{ mol}$
 And $m(\text{NaOH}) = n \times M = 0.050 \times 40.00 = 2.0 \text{ g}$
- A. An increase in the level of atmospheric carbon dioxide since the Industrial Revolution has resulted in an increased amount of dissolved carbon dioxide in the oceans. CO_2 is an acidic gas that forms carbonic acid with water.
 $\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{CO}_3(\text{aq})$ and $\text{H}_2\text{CO}_3(\text{aq}) \rightarrow \text{HCO}_3^-(\text{aq}) + \text{H}^+(\text{aq})$
 As a result, the pH of the oceans is lower.
- D. The ammonium ion (NH_4^+) can act as an acid by donating a proton to form ammonia (NH_3). A conjugate acid–base pair differs by one H^+ .
- B. $\text{H}_2\text{SO}_4(\text{aq}) + 2\text{LiOH}(\text{aq}) \rightarrow \text{Li}_2\text{SO}_4(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$
- C. 0.001 mol L^{-1} is a dilute solution and sulfuric acid is a strong acid.
- A. In a basic solution $[\text{H}_3\text{O}^+]$ is less than $10^{-7} \text{ mol L}^{-1}$. This means that the pH is over 7 and the pOH is less than 7.
- B. The volume of the solution is doubled, so the concentration is halved to 0.010 mol L^{-1} .
 $[\text{OH}^-] = 0.010 \text{ mol L}^{-1}$, therefore $\text{pOH} = -\log_{10}[\text{OH}^-] = -\log_{10}(0.010) = 2.00$
- C. Solution Z has a pH of 2 ($\text{pH} = -\log_{10}(10^{-2}) = 2$), solution W has a pH of 4, solution X has a pH of 8 ($\text{pH} = 14 - \text{pOH} = 14 - 6 = 8$), solution Y has a pH of 12 ($\text{pOH} = -\log_{10}(10^{-2}) = 2$; $\text{pH} = 14 - \text{pOH} = 14 - 2 = 12$).
- D. The expression for K_a is for methanoic acid (HCOOH), which is a weak acid, reacting with water. Dissociation is incomplete, so an equilibrium arrow is used.
- A. The OH^- ions react with CH_3COOH to form CH_3COO^- ions and water. This consumes most of the extra OH^- ions, keeping the pH almost constant.
- A. If the acid had been a strong acid and therefore completely ionised, the initial pH would have been $-\log_{10}(0.1) = 1.0$. However, the initial pH is approximately 4, an indication of only partial dissociation and hence a weak acid.
 The final pH of the mixture is close to 13 and the pH at equivalence point is higher than 7. Both these observations point to the base being strong.
- C. The indicator must change colour at a pH range within the sharply changing pH of the reaction mixture.

- 20** B. The average titre is calculated from the three concordant results. That is, the three titres that differ by no more than 0.10 mL from smallest to largest are averaged.
The average titre is $\frac{20.75+20.65+20.75}{3} = 20.72 \text{ mL}$.
- 21** C. The very small value of the equilibrium constant K_w implies a very low ratio of products to reactants so that the products will generally be in a very small minority.

Short answer

- 1 a** $n(\text{NaOH}) = \frac{m}{M} = \frac{5.00}{40.00} = 0.125 \text{ mol}$
 $[\text{NaOH}] = \frac{n}{V} = \frac{0.125}{0.400} = 0.313 \text{ mol L}^{-1}$
- b** $[\text{OH}^-] = [\text{NaOH}] = 0.313 \text{ mol L}^{-1}$
- c** $[\text{H}_3\text{O}^+] = \frac{K_w}{[\text{OH}^-]} = \frac{1.0 \times 10^{-14}}{0.313} = 3.2 \times 10^{-14} \text{ mol L}^{-1}$
- d** $\text{pH} = -\log_{10} [\text{H}_3\text{O}^+] = -\log_{10} (3.2 \times 10^{-14}) = 13.49$
- e** $\text{pOH} = 14 - \text{pH} = 14 - 13.49 = 0.51$
- 2 a** $2\text{HCl}(\text{aq}) + \text{Zn}(\text{s}) \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2(\text{g})$
- b** $2\text{HNO}_3(\text{aq}) + \text{Ca}(\text{OH})_2(\text{aq}) \rightarrow \text{Ca}(\text{NO}_3)_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$
- c** $\text{H}_2\text{SO}_4(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{Na}_2\text{SO}_4(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
- d** $\text{Mg}(\text{s}) + 2\text{HNO}_3(\text{aq}) \rightarrow \text{Mg}(\text{NO}_3)_2(\text{aq}) + \text{H}_2(\text{g})$
- 3 a** A strong acid is an acid that readily donates protons.
Alternatively, a strong acid is an acid that completely dissociates in water.
- b** Student answers will vary. Possible answers include H_2CO_3 or H_2SO_4 or H_3PO_4 .
- c i** $\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{CO}_3(\text{aq}) + \text{OH}^-(\text{aq})$
- ii** $\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{CO}_3^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
- d** H_3O^+
- 4 a i** $[\text{OH}^-] = 2 \times [\text{Ca}(\text{OH})_2] = 2 \times 0.050 = 0.10 \text{ mol L}^{-1}$
 $[\text{H}_3\text{O}^+] = \frac{1.0 \times 10^{-14}}{[\text{OH}^-]} = \frac{1.0 \times 10^{-14}}{0.10} = 1.0 \times 10^{-13} \text{ mol L}^{-1}$
 $\text{pH} = -\log_{10} [\text{H}_3\text{O}^+] = -\log_{10} (1.0 \times 10^{-13}) = 13.00$
- ii** $n(\text{HNO}_3) = c \times V = 0.125 \times 0.400 = 0.0500 \text{ mol}$
The total volume of solution after dilution is 500 mL, so the concentration of diluted HNO_3 is:
 $c(\text{HNO}_3) = \frac{n}{V} = \frac{0.0500}{0.500} = 0.100 \text{ mol L}^{-1} = [\text{H}_3\text{O}^+]$
 $\text{pH} = -\log_{10} [\text{H}_3\text{O}^+] = -\log_{10} (0.100) = 1.000$
- iii** $n(\text{HCl}) = \frac{n}{V} = \frac{2.45}{36.46} = 0.0672 \text{ mol}$
 $c(\text{HCl}) = \frac{n}{V} = \frac{0.0672}{0.065} = 1.03 \text{ mol L}^{-1} = [\text{H}_3\text{O}^+]$
 $\text{pH} = -\log_{10} [\text{H}_3\text{O}^+] = -\log_{10} (1.03) = -0.014$
- b** $[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 10^{-0.050} = 0.891 \text{ mol L}^{-1}$
 $c(\text{HNO}_3) = 0.891 \text{ mol L}^{-1}$
 $n(\text{HNO}_3) = c \times V = 0.891 \times 0.300 = 0.267 \text{ mol}$
 $m(\text{HNO}_3) = n \times M = 0.267 \times 63.02 = 16.8 \text{ g}$
- 5 a** Solution C. It has a pH above 7 and sodium hydroxide is a base. A turns blue litmus paper red, so it has to be an acid.
- b** Solution B. Because it is an acid the pH must be less than 7, so it cannot be C. A and B are acids (pH less than 7 or turns blue litmus red). B has the higher conductivity and, since they all have the same concentration, B must dissociate the more than A and so must be the stronger acid.
- c** The pH of A must be greater than 1.5 but less than 7. It is an acid because it turns blue litmus paper red, but it will have a higher pH than solution B because it has a lower conductivity.
- d i** $[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 10^{-1.5} = 0.03 \text{ mol L}^{-1}$
- ii** $[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 10^{-10.5} = 3 \times 10^{-11} \text{ mol L}^{-1}$

- 6 a** Propanoic acid is a weak acid so it is partially dissociated. The concentration of H^+ ions in a propanoic acid solution will therefore be lower than in solution of nitric acid or sulfuric acid, both strong acids, of equal concentration. As the concentration of H^+ ions is lowest, the pH of the propanoic acid solution will be highest.
- b** Sulfuric acid is diprotic. The first dissociation of H_2SO_4 is complete. In addition, there is partial dissociation of the $\text{HSO}_4^-(\text{aq})$ ion to release a second hydrogen ion. So the overall concentration of H^+ ions is higher than in a solution of the monoprotic nitric acid of the same concentration, so the pH of the solution will be lower.
- 7 a** $\text{pH} = 4$ so $[\text{H}_3\text{O}^+] = 10^{-4} \text{ mol L}^{-1}$

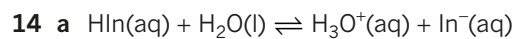
$$[\text{OH}^-] = \frac{K_w}{[\text{H}_3\text{O}^+]} = \frac{1.0 \times 10^{-14}}{10^{-4}} = 1.0 \times 10^{-10} \text{ mol L}^{-1}$$
- b** $n(\text{HCl}) = c \times V = 0.100 \times 0.0100 = 0.00100 \text{ mol} = n(\text{H}^+)$
 $n(\text{NaOH}) = c \times V = 0.100 \times 0.0120 = 0.00120 \text{ mol} = n(\text{OH}^-)$
 The OH^- ions are in excess by $0.00120 - 0.00100 = 0.00020 \text{ mol}$
 The volume of the mixture is $200 \text{ mL} = 0.200 \text{ L}$

$$[\text{OH}^-] = \frac{n}{V} = \frac{0.00020}{0.200} = 0.0010 = 1.0 \times 10^{-3} \text{ mol L}^{-1}$$

$$[\text{H}^+] = \frac{1.0 \times 10^{-14}}{[\text{OH}^-]} = \frac{1.0 \times 10^{-14}}{1.0 \times 10^{-3}} = 1.0 \times 10^{-11} \text{ mol L}^{-1}$$

 $\text{pH} = -\log_{10}[\text{H}^+] = -\log_{10}(1.0 \times 10^{-11}) = 11.00$
- 8 a** $\text{NH}_3(\text{aq}) + \text{HCl}(\text{aq}) \rightarrow \text{NH}_4\text{Cl}(\text{aq})$ or $\text{NH}_3(\text{aq}) + \text{H}^+(\text{aq}) \rightarrow \text{NH}_4^+(\text{aq})$
- b** $n(\text{HCl}) = c \times V = 0.0950 \times 0.01740 = 0.001653 \text{ mol} = n(\text{NH}_3)$ in the 20.00 mL titre
 $n(\text{NH}_3)$ in 100 mL diluted cleaner = $5 \times 0.001653 = 0.008265 \text{ mol} = n(\text{NH}_3)$ in 10.00 mL original cleaner
 $c(\text{NH}_3)$ in cleaner = $\frac{n}{V} = \frac{0.008265}{0.01000} = 0.8265 = 0.827 \text{ mol L}^{-1}$
- c** $m(\text{NH}_3)$ in 1 L cleaner = $n \times M = 0.8265 \times 17.03 = 14.07 \text{ g}$
 $m(\text{NH}_3)$ in 750 mL bottle = $14.07 \times 0.750 = 10.6 \text{ g}$
- d** The observed colour change will be from yellow at the start of the titration when the indicator is added to the ammonia solution, to orange at equivalence point and pink when excess acid is present.
- e i** The result would be the same because the amount, in mol, of ammonia in the flask is unchanged by the addition of water, so the same titre of HCl would be needed for the reaction.
- ii** It would be lower because phenolphthalein indicator would change colour before the equivalence point is reached. So the titre of HCl would be smaller than it should be. Hence, the calculated concentration of ammonia would be lower than the actual one.
- iii** Higher, because the flask would contain some drops of diluted cleaner in addition to the 20.00 mL aliquot measured out. More HCl would be needed to reach the equivalence point. Hence the calculated concentration of ammonia would be higher than the actual one.
- 9 a** $n(\text{NaOH}) = c \times V = 0.790 \times 0.0234 = 0.01849 \text{ mol}$
 Succinic acid is diprotic, so $n(\text{succinic acid})$ in the 20.00 mL sample that reacted with the NaOH is:
 $0.5 \times 0.01849 = 0.00924 \text{ mol}$
- b i** Concentration in $\text{mol L}^{-1} = \frac{n}{V} = \frac{0.00924}{0.0200} = 0.462 \text{ mol L}^{-1}$
- ii** Molar mass of succinic acid is 118.1 g mol^{-1}
 Concentration of succinic acid in $\text{g L}^{-1} = 0.462 \times 118.1 = 54.6 \text{ g L}^{-1}$
- iii** % (w/v) is equivalent to grams of solute in 100 mL of solution
 Because there are 54.6 g in 1000 mL solution:
 % (w/v) of succinic acid = 5.46% (w/v)
- c** The most likely reason would be that the solution was in fact not saturated. Another possibility is that the solution cooled during handling and so the solubility decreased.
- 10 a i** $\text{H}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{HSO}_4^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
 $\text{HSO}_4^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{SO}_4^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
- ii** HSO_4^-
- iii** $\text{H}_2\text{SO}_4 / \text{HSO}_4^-$ or $\text{HSO}_4^- / \text{SO}_4^{2-}$ or $\text{H}_3\text{O}^+ / \text{H}_2\text{O}$
- iv** H_2SO_4 (completely dissociated, so concentration = 0), HSO_4^- (product of the complete dissociation of H_2SO_4 , so concentration = 1.0 mol L^{-1}), SO_4^{2-} (product of the partial dissociation of H_2SO_4 , so concentration $< 1.0 \text{ mol L}^{-1}$).
- b i** $\text{H}_2\text{SO}_4(\text{aq}) + \text{Zn}(\text{s}) \rightarrow \text{ZnSO}_4(\text{aq}) + \text{H}_2(\text{g})$
- ii** $2\text{H}^+(\text{aq}) + \text{Zn}(\text{s}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{H}_2(\text{g})$
- iii** The pH increases as the acid is consumed.

- c i** $\text{H}_2\text{SO}_4(\text{aq}) + \text{K}_2\text{CO}_3(\text{s}) \rightarrow \text{K}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
ii $2\text{H}^+(\text{aq}) + \text{K}_2\text{CO}_3(\text{s}) \rightarrow 2\text{K}^+(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
iii The solid would disappear quickly and a gas would be evolved.
- d i** $\text{H}_2\text{SO}_4(\text{aq}) + 2\text{LiOH}(\text{aq}) \rightarrow \text{Li}_2\text{SO}_4(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$
ii $n(\text{H}_2\text{SO}_4) = 0.5 \times n(\text{LiOH}) = 0.5 \times 0.468 = 0.234 \text{ mol}$
- 11** $q = mc\Delta T = 75.0 \times 4.18 \times 12.8 = 4012.8 \text{ J} = 4.01 \text{ kJ}$
 $2\text{HCl}(\text{aq}) + \text{Ba}(\text{OH})_2(\text{aq}) \rightarrow \text{BaCl}_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$
 $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$
 $n(\text{Ba}(\text{OH})_2) = c \times V = 0.025 \times 1.50 = 0.0375 \text{ mol}$
 $n(\text{OH}^-) = 2 \times n(\text{Ba}(\text{OH})_2) = 2 \times 0.0375 = 0.0750 \text{ mol}$
 $\Delta H = \frac{q}{n} = \frac{-4.01}{0.0750} = -53.5 \text{ kJ mol}^{-1}$
- 12 a i** NH_4^+
ii NH_3
iii NH_4Cl or any other salt containing NH_4^+
- b i** The addition of a small amount of HCl to the ammonium buffer system will disturb the equilibrium. As equilibrium is re-established, the added H_3O^+ from HCl reacts with NH_3 . The position of the equilibrium shifts to the right. Because the buffer contains a relatively large amount of NH_3 , most of the added H_3O^+ is consumed and there is a small change in the concentration of H_3O^+ .
ii When a small amount of OH^- is added to the buffer system, the OH^- reacts with NH_4^+ . The excess OH^- is consumed without any large change in the concentration of OH^- , and therefore little change in the concentration of H_3O^+ .
- c** $\text{NH}_3(\text{aq}) + \text{HCl}(\text{aq}) \rightarrow \text{NH}_4^+(\text{aq}) + \text{Cl}^-(\text{aq})$
- d i**
- | NH_3 | HCl | NH_4^+ |
|---------------------------------------|---------------------------------------|-------------------------------------|
| $n(\text{start}) = 0.050 \text{ mol}$ | $n(\text{start}) = 0.050 \text{ mol}$ | $n(\text{start}) = 0 \text{ mol}$ |
| $n(\text{end}) = 0 \text{ mol}$ | $n(\text{end}) = 0 \text{ mol}$ | $n(\text{end}) = 0.050 \text{ mol}$ |
- Buffer? No, only conjugate acid present.
- ii**
- | NH_3 | HCl | NH_4^+ |
|--------------------------------------|---------------------------------------|-------------------------------------|
| $n(\text{start}) = 0.10 \text{ mol}$ | $n(\text{start}) = 0.050 \text{ mol}$ | $n(\text{start}) = 0 \text{ mol}$ |
| $n(\text{end}) = 0.050 \text{ mol}$ | $n(\text{end}) = 0 \text{ mol}$ | $n(\text{end}) = 0.050 \text{ mol}$ |
- Buffer? Yes, both weak acid and conjugate base are present.
- iii**
- | NH_3 | HCl | NH_4^+ |
|---------------------------------------|--------------------------------------|-------------------------------------|
| $n(\text{start}) = 0.050 \text{ mol}$ | $n(\text{start}) = 0.10 \text{ mol}$ | $n(\text{start}) = 0 \text{ mol}$ |
| $n(\text{end}) = 0 \text{ mol}$ | $n(\text{end}) = 0.050 \text{ mol}$ | $n(\text{end}) = 0.050 \text{ mol}$ |
- Buffer? No, only strong acid and conjugate acid present.
- 13 a i** $\text{HCl}(\text{aq}) + \text{KOH}(\text{aq}) \rightarrow \text{KCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
ii As KOH is added, H^+ ions react with OH^- to form water. H^+ ions are very conductive, so the addition of K^+ ions does not compensate for the loss of conductivity.
iii After the equivalence point, there are no further losses of ions from the solution. The conductivity will increase with the extra K^+ and OH^- ions added.
iv $n(\text{KOH}) = c \times V = 0.20 \times 0.015 = 0.0030 \text{ mol}$
 $n(\text{HCl}) = n(\text{KOH}) = 0.0030 \text{ mol}$
 $c(\text{HCl}) = \frac{n}{V} = \frac{0.0030}{0.0200} = 0.15 \text{ mol L}^{-1}$
- b** $n(\text{HCl}) = c \times V = 0.15 \times 0.0250 = 0.00375 \text{ mol}$
 $2\text{HCl}(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow 2\text{NaCl}(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
 $n(\text{Na}_2\text{CO}_3) = 0.5 \times n(\text{HCl}) = 0.5 \times 0.00375 = 0.00188 \text{ mol}$
 $V(\text{Na}_2\text{CO}_3) = \frac{n}{c} = \frac{0.00188}{0.20} = 0.0094 \text{ L} = 9.4 \text{ mL}$



b i blue

ii The system opposes the added H_3O^+ by moving in the reverse direction, forming more HIn which will be yellow.

iii The added OH^- reacts with H_3O^+ lowering the H_3O^+ concentration. The system moves in the forward direction to oppose this, forming more In^- which is blue in solution.

c i $K_a = \frac{[\text{H}_3\text{O}^+][\text{In}^-]}{[\text{HIn}]}$

ii $K_a = \frac{[\text{H}_3\text{O}^+][\text{In}^-]}{[\text{HIn}]}$

If $[\text{HIn}] = [\text{In}^-]$ then:

$$K_a = \frac{[\text{H}_3\text{O}^+] \cdot 1}{1}$$

and $K_a = [\text{H}_3\text{O}^+]$

Since $K_a = 10^{-7}$ then $[\text{H}_3\text{O}^+] = 10^{-7}$, so $\text{pH} = 7$.

Module 7 Review

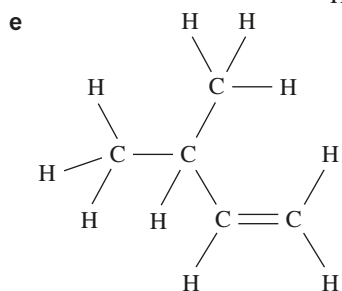
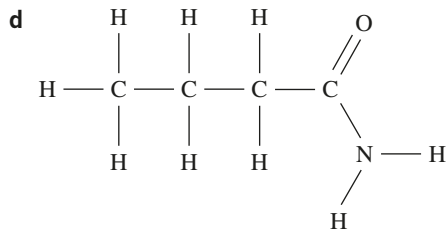
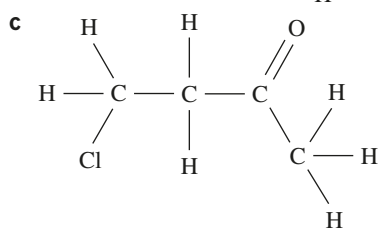
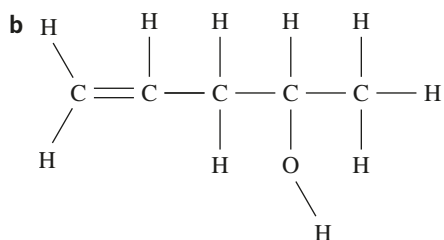
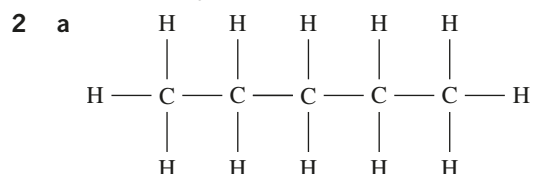
Organic chemistry

Multiple choice

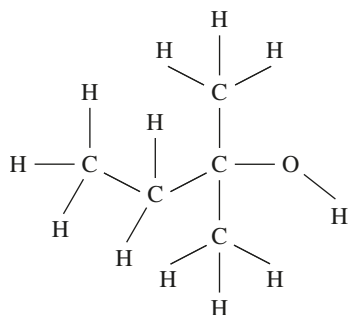
- 1 C. Ethyl propanoate and pentanoic acid have the same molecular formula, $C_5H_{10}O_2$, but different functional groups.
- 2 D. All three molecules contain 3 carbon atoms, so the name will include prop-. The $-CHO$ is an aldehyde functional group, the $C=O$ is a ketone and the $-CONH_2$ an amide.
- 3 B. The iodine atom from hydrogen iodide displaces the hydroxyl group in propan-1-ol to form 1-iodopropane. The displaced hydroxyl group combines with the free hydrogen atom to form a water molecule.
- 4 C. Ethene is the smallest alkene; there is no such thing as 'methene'. An alkene contains a carbon-carbon double bond, so the smallest alkene has to contain two carbon atoms.
- 5 B. The longest continuous chain is 5 carbons and there are no double bonds present, so the molecule is a derivative of pentane. An additional methyl (CH_3) substituent is attached at carbon 2.
- 6 D. Non-polar alkanes have only weak dispersion forces between molecules, which are weaker for smaller alkanes because the presence of functional groups such as $-Cl$ and $-OH$ introduces some additional dipole-dipole attractions between molecules. The boiling points of smaller alkanes are therefore lower than the boiling points of larger alkanes.
- 7 C. Hydroxyl groups are not significantly acidic or basic.
- 8 A. CH_2CH_2 (ethene) is unsaturated and undergoes an addition reaction with bromine, where one Br atom adds to each side of the double bond to form CH_2BrCH_2Br .
- 9 C. Reaction I involves the addition of HCl across the carbon-carbon double bond in ethene. Reaction II substitutes a hydroxyl group (OH) for a chloro group (Cl). Reaction III converts a primary alcohol to a carboxylic acid, which involves oxidation.
- 10 C. Acidified dichromate ($H^+/Cr_2O_7^{2-}$) is an oxidant typically used to convert a primary alcohol into a carboxylic acid. Heating under reflux ensures that the intermediate aldehyde, ethanal, is completely oxidised into the carboxylic acid, ethanoic acid.
- 11 D. The '-oate' component of an ester derives from the carboxylic acid used, so this ester derives from ethanoic acid. The '-yl' component derives from the alcohol used, which must be methanol.
- 12 C. IV is the only structure in which the hydroxyl group is not highest ranked, because of the carboxyl group.
- 13 C. All H atoms are in an oxidation state of +1 throughout.
- 14 A. It is an alkane with 3 carbons, so propane. There is only one way to arrange 3 carbon atoms, so there are no isomers. Therefore no number is required in the name.
- 15 C. All alkynes have names ending in -yne. All alkynes have a triple bond between two carbon atoms, so the smallest alkyne must have two carbons. A two-carbon hydrocarbon has a name with the prefix eth-.
- 16 B. The general formula for alkynes is C_nH_{2n-2} . B is an alkane.
- 17 C. There are 3 compounds: but-1-ene, but-2-ene and 2-methylpropene.
- 18 A. Alcohols contain the polar $-OH$ group, so molecules are attracted to each other by hydrogen bonds as well as by dispersion forces. Therefore, alcohols have a higher boiling point than similar-sized alkanes.
So ethanol has a higher boiling point than propane.
The strength of dispersion forces between molecules depends on the size of the molecules. The forces are weaker between ethane molecules than between propane molecules, so ethane has a lower boiling point than propane. Similarly, ethanol has a lower boiling point than propan-1-ol.
- 19 A. The double bond breaks and the monomers join together.
- 20 B. Higher density is the result of closer packing of polymer chains. Polymer chains can pack more closely if they have little or no branching. The closer the chains are packed, the more significant the dispersion forces between the chains and so the higher the softening temperature.

Short answer

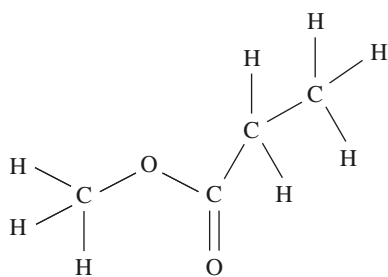
- 1 a i C_7H_{16}
 ii e.g. $CH_3CH_2CH_2CH(CH_3)CH_2CH_3$
 b i $C_4H_{10}O$
 ii e.g. $CH_3CH_2CHOHCH_3$
 c i $C_3H_6O_2$
 ii e.g. CH_3CH_2COOH
 d i $C_5H_{11}OCl$
 ii e.g. $CH_2Cl(CH_2)_4OH$
 e i C_8H_{16}
 ii e.g. $CH_3CH_2CHCHCH_2CH(CH_3)_2$
 f i $C_6H_{12}O$
 ii e.g. $CH_3CH_2CH(CH_3)CH_2CHO$
 g i C_8H_{12}
 ii e.g. $CH_3CCCH_2CH_2CHCHCH_3$
 h i $C_6H_{12}O$
 ii e.g. $CH_3CHCHCOH(CH_3)_2$
 i i $C_4H_7NO_2$
 ii e.g. $CH_3COCH_2CONH_2$



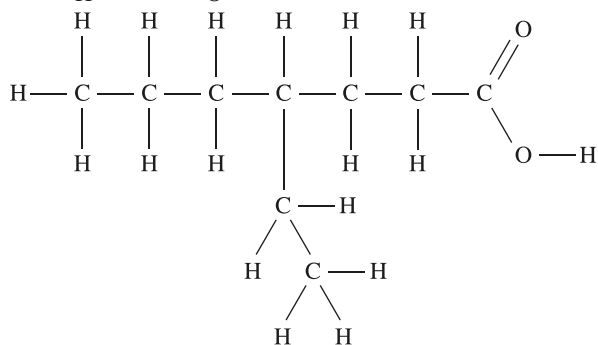
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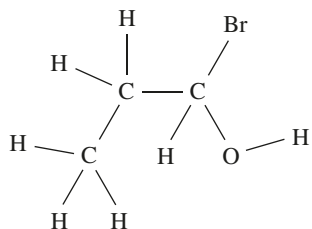
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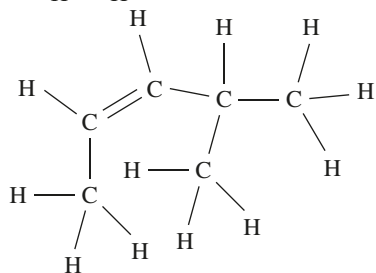
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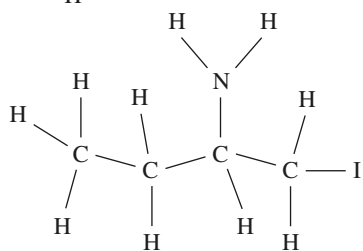
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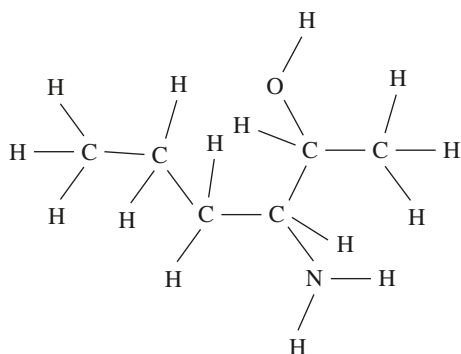
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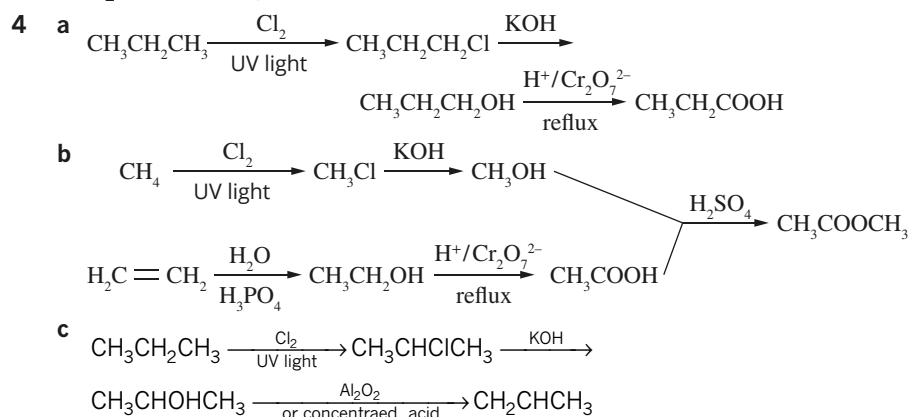
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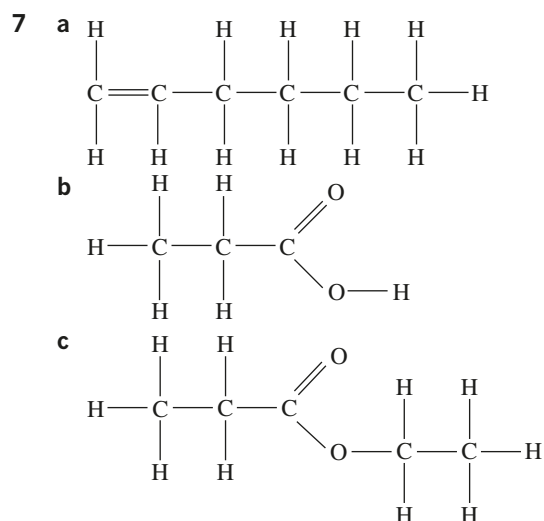


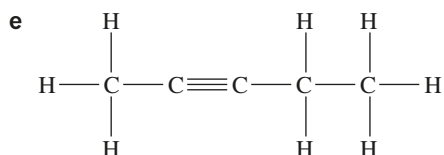
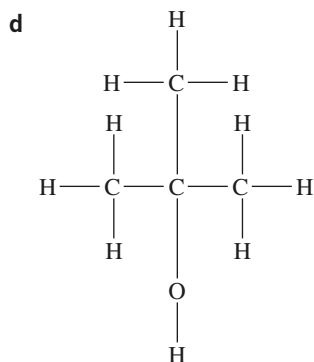
- 3 a acidified dichromate ($\text{H}^+/\text{Cr}_2\text{O}_7^{2-}$) or acidified permanganate ($\text{H}^+/\text{MnO}_4^-$), heating with distillation of product
 b heating with hydroxide ions (e.g. KOH, NaOH), or H_2O with catalyst
 c H_2O and acid catalyst (e.g. H_3PO_4 or H_2SO_4)
 d acidified dichromate ($\text{H}^+/\text{Cr}_2\text{O}_7^{2-}$) or acidified permanganate ($\text{H}^+/\text{MnO}_4^-$), heating under reflux
 e H_2 and Ni catalyst (other metals sometimes used)



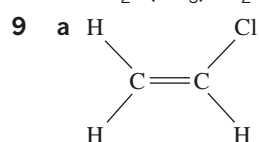
- 5 a $\text{CH}_3\text{CH}_2\text{COOH} + \text{NaHCO}_3 \rightarrow \text{NaCH}_3\text{CH}_2\text{COO} + \text{CO}_2 + \text{H}_2\text{O}$
 b $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{COOH} + 4\text{H}^+ + 4\text{e}^-$
 c $\text{CH}_3\text{CH}_2\text{COOH} + \text{CH}_3\text{CH}_2\text{OH} \rightarrow \text{CH}_3\text{CH}_2\text{COOCH}_2\text{CH}_3 + \text{H}_2\text{O}$
 d $\text{CH}_3\text{CH}_2\text{COOH} + \text{CH}_3\text{CH}_2\text{NH}_2 \rightarrow \text{CH}_3\text{CH}_2\text{COO}^- + \text{CH}_3\text{CH}_2\text{NH}_3^+$
 e $2\text{CH}_3\text{CH}_2\text{COOH} + 7\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$

- 6 a but-2-yne
 b heptane
 c 2,2,3-trimethylpentane
 d butanoic acid
 e 2-methylpropan-1-ol



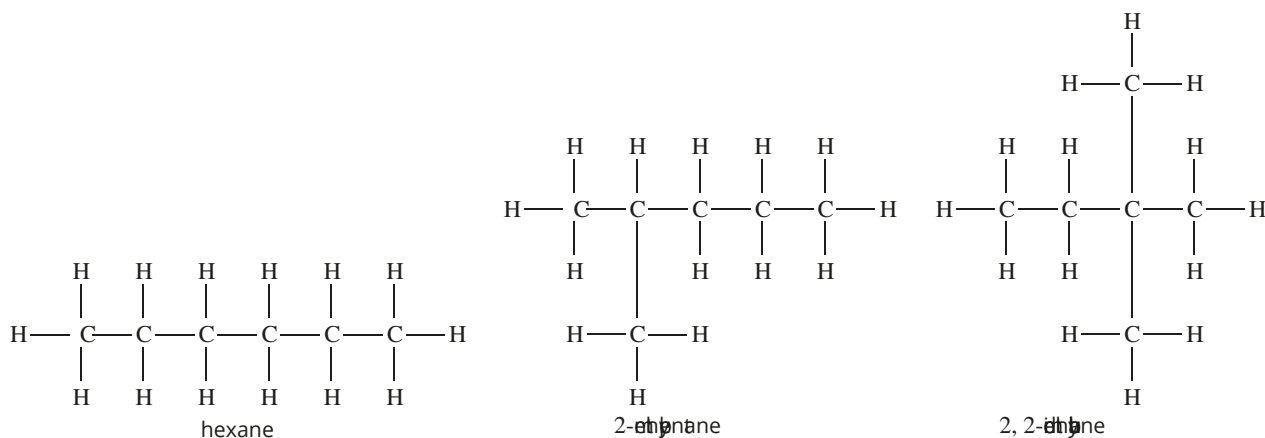


- 8 a $\text{CH}_3(\text{CH}_2)_4\text{COOH}$ or $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{COOH}$
 b $\text{CH}_3\text{C}(\text{CH}_3)_2\text{CH}_2\text{CH}(\text{C}_2\text{H}_5)\text{CH}_2\text{CH}_2\text{CH}_3$ or $(\text{CH}_3)_3\text{CCH}_2\text{CH}(\text{C}_2\text{H}_5)\text{CH}_2\text{CH}_2\text{CH}_3$
 c $\text{CH}_3\text{CHOHCH}_2\text{CH}_3$
 d HCCCH_3
 e $\text{CH}_2\text{C}(\text{CH}_3)\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3$



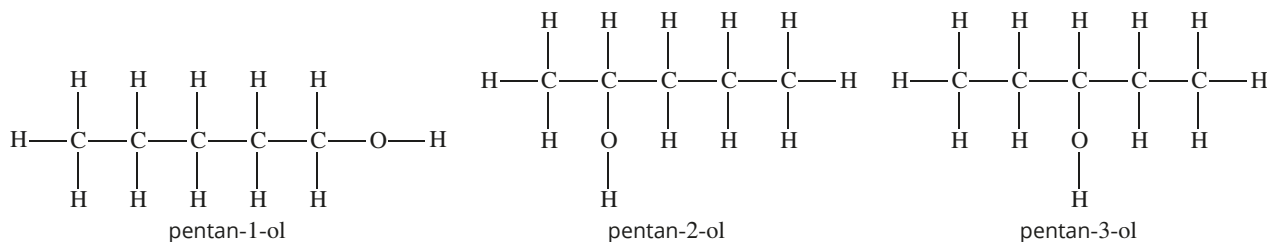
- b i The plastic will char and blacken.
 ii Thermosetting polymers have strong cross-links between polymer chains so the layers cannot slide past each other and melt.
- 10 a A monomer is a small molecule that is able to bond with other monomers to form a long-chain molecule called a polymer; e.g. ethene molecules are the monomers that join together to form the polyethene polymer.
 b A thermoplastic polymer is one that softens on heating but becomes hard again when cooled, e.g. polyethene. A thermosetting polymer is one that doesn't soften on gentle heating but if heated sufficiently will char, e.g. melamine.
 c A branched polymer is a linear polymer that has some of the atoms forming branches attached to the polymer backbone, e.g. low density polyethene. Relatively weak intermolecular forces exist between chains. A cross-linked polymer has covalent bonds linking polymer chains, resulting in a rigid polymer that does not soften on heating, e.g. melamine.
 d Crystalline regions occur when atoms in chains are arranged in a regular pattern, thus strengthening the polymer. Non-crystalline regions occur when the atoms in the chain are randomly arranged.

11 a i



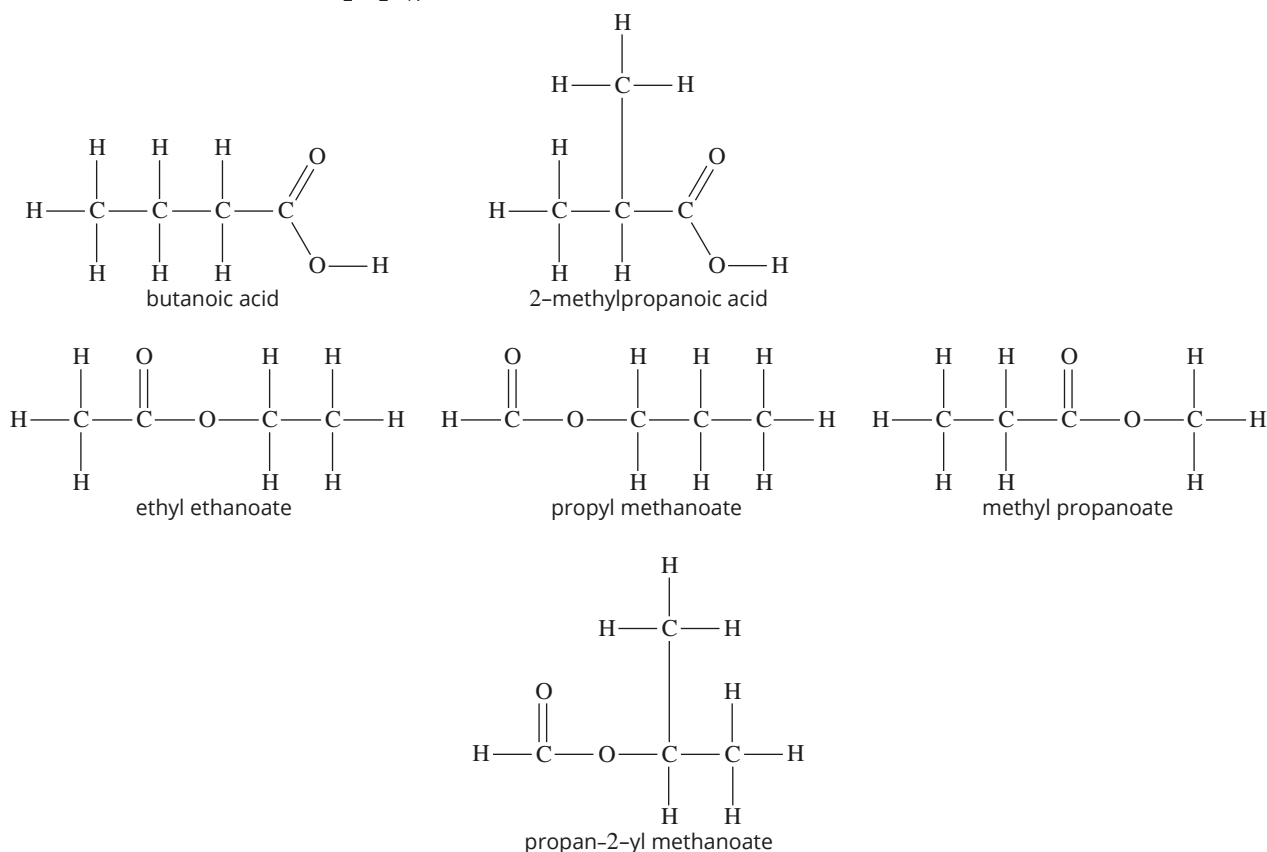
- ii Chain isomers have the same molecular formula but their structures are different due to different branching arrangements. For example, hexane is straight chained, but 2-methylpentane has a methyl branch at carbon 2.
- iii The physical properties such as boiling point will be similar. The presence of the same atoms in the molecules means the properties will be similar but the different molecule shapes will affect the strength of bonding between molecules.

b i

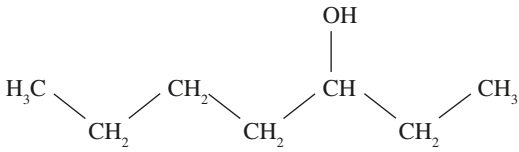
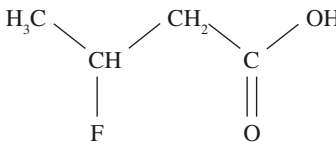
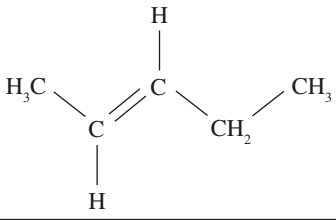
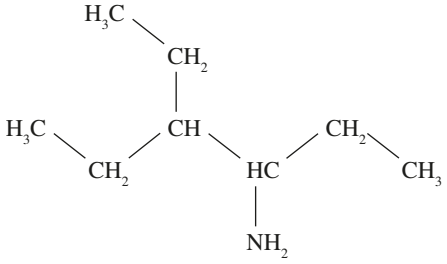
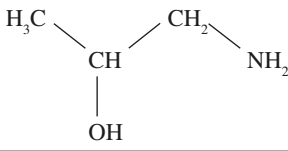
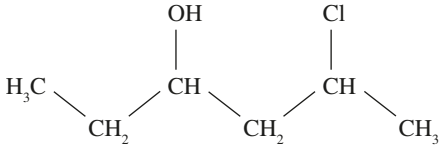
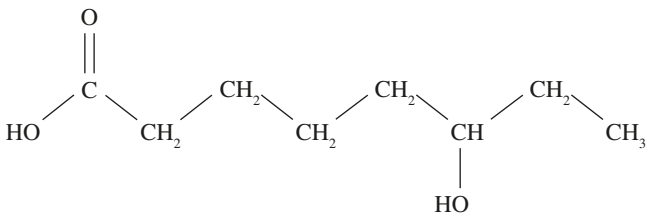
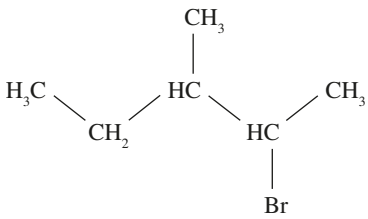
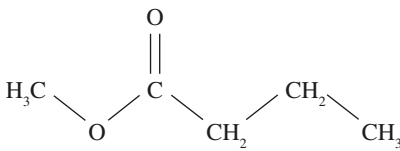


- ii Position isomers have the same molecular formula and functional groups but the functional groups are located on different parts of the chain. For example, pentan-1-ol has a hydroxyl group at carbon 1, but pentan-2-ol has the hydroxyl group at carbon 2.
- iii An example would be that a primary alcohol, such as pentan-1-ol, will form an aldehyde, then a carboxylic acid when reacting with acidified $K_2Cr_2O_7$. The secondary alcohols pentan-2-ol and pentan-3-ol will form a ketone when reacting with acidified $K_2Cr_2O_7$.

c i

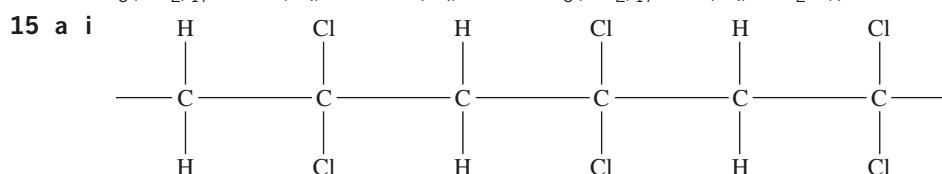


- ii Functional group isomers have the same molecular formula but contain different functional groups e.g. carboxyl and ester.

12	Molecule	Functional groups present	Correct IUPAC name
		hydroxyl	heptan-3-ol
		carboxyl, fluoro	3-fluorobutanoic acid
		alkene/alkenyl	pent-2-ene
		amino	4-ethylhexan-3-amine
		hydroxyl, amino	1-aminopropan-2-ol
		hydroxyl, chloro	5-chlorohexan-3-ol
		hydroxyl, carboxyl	6-hydroxyoctanoic acid
		bromo	2-bromo-3-methylpentane
		ester	methyl butanoate

13	Molecule	IUPAC name	Condensed structural formula	Reactants and reaction conditions that could be used to form this molecule
		butanone	$\text{CH}_3\text{CH}_2\text{COCH}_3$	butan-2-ol and acidified $\text{K}_2\text{Cr}_2\text{O}_7$
		hexanal	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CHO}$	hexan-1-ol and acidified $\text{K}_2\text{Cr}_2\text{O}_7$
		propanamide	$\text{CH}_3\text{CH}_2\text{CONH}_2$	propanoic acid and NH_3
		ethyl methanoate	$\text{CH}_3\text{CH}_2\text{OOCH}$	ethanol and methanoic acid, H_2SO_4

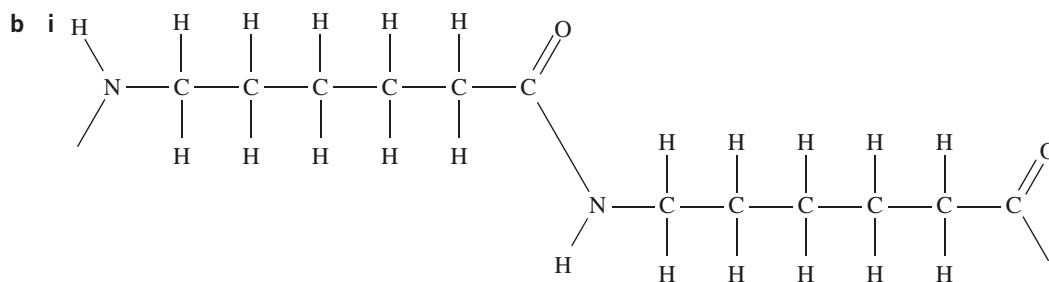
- 14 a $\text{CH}_3\text{CH}_2\text{COOH}(\text{l}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{CH}_3\text{CH}_2\text{COO}^-(\text{aq})$
 b $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2(\text{l}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_3^+(\text{aq}) + \text{OH}^-(\text{aq})$
 c $\text{CH}_3\text{CH}_2\text{COOH}(\text{l}) + \text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2(\text{l}) \rightarrow \text{CH}_3\text{CH}_2\text{CONHCH}_2\text{CH}_2\text{CH}_3(\text{l}) + \text{H}_2\text{O}(\text{l})$
 d $\text{CH}_3\text{CH}_2\text{COOH}(\text{l}) + \text{CH}_3\text{CH}_2\text{CH}_2\text{OH}(\text{l}) \rightarrow \text{CH}_3\text{CH}_2\text{COOCH}_2\text{CH}_2\text{CH}_3(\text{l}) + \text{H}_2\text{O}(\text{l})$
 e $\text{CH}_3(\text{CH}_2)_{17}\text{COOH}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaCH}_3(\text{CH}_2)_{17}\text{COO}(\text{aq}) + \text{H}_2\text{O}(\text{l})$



ii addition polymerisation

iii The linear version will be harder, more brittle and more crystalline, and will have a higher melting point, and higher density.

iv There are no crosslinks between the polymer chains, so the polymer melts readily when heated. Once molten it can be remolded into a new product.



ii condensation polymerisation

iii The presence of nitrogen and oxygen atoms in the polymer chain allows hydrogen bonds to form between chains. The forces of attraction between the molecules are relatively high, so the melting point of the polymer is also relatively high.

Module 8 Review

Applying chemical ideas

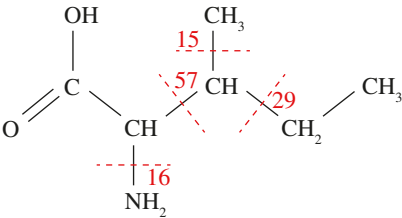
Multiple choice

- B. Reaction A would form a precipitate of BaSO_4 . Reaction C would form a precipitate of CuCO_3 . In reaction D, Cu metal would precipitate out of solution as Cu^{2+} ions were reduced to Cu metal by Zn.
- C. $n(\text{AgCl}) = \frac{m}{M} = \frac{20.37}{143.4} = 0.1421 = n(\text{Cl}^-)$
 $n(\text{Cl}^-)$ in 250 mL = $n \times M = 0.1421 \times 35.45 = 5.037$
 $c(\text{Cl}^-) = \frac{m}{V} = \frac{5.037}{0.250} = 20.1 \text{ g L}^{-1}$
- C. The absorption spectrum shows that the coloured compound does not absorb in the blue-green-yellow range of the visible spectrum. Hence these colours are reflected or transmitted.
- B. According to the absorption spectrum, this coloured compound absorbs most strongly at 460 nm. This would be the most suitable wavelength to use to determine the concentration of this compound.
- D. An absorbance of 0.3 is equivalent to 16 ppm from the graph. As the dam water had been diluted by a factor of 4, the concentration of the water in the dam is $4 \times 16 = 64$ ppm.
- B. Tea-tree oil is an organic compound produced from plants. Its extraction does not involve ionic compounds.
- C. The copper atoms in copper chloride will produce a green flame, whereas the other three compounds will produce a red flame.
- D. Blue copper(II) sulfate and sodium hydroxide will form a blue $\text{Cu}(\text{OH})_2$ precipitate. The other combinations will form white precipitates or no precipitate at all. Transition metals are more likely to form coloured compounds than group 1 or 2 metals.
- A. A precipitate with HCl indicates either lead(II) or silver ions. Ammonia can then be added to produce different coloured solutions according to the cations present.
- B. Potassium is a group 1 metal. Complexing reactions usually involve transition metals.
- D. Since the electrical conductivity changes in a linear fashion, only two readings before and after the equivalence point are required to draw the straight line segment for each phase of the titration.
- C. A series of standard solutions of known concentrations are prepared. They are tested in the instrument and a graph of absorbance against concentration is prepared.
- A. A is a tertiary alcohol. Tertiary alcohols are not oxidised by acidified $\text{K}_2\text{Cr}_2\text{O}_7$.
- C. C is an alkane with all carbon-carbon single bonds. It will not immediately react with bromine.
- B. UV-visible spectrometry is able to measure the absorbance of coloured solutions like copper solutions. The other instruments are better suited to the determination of the structures of carbon compounds.
- A. Ethanol has three different hydrogen environments. The other molecules each have two.
- B. This is an endothermic reaction so a high temperature promotes a high yield. There are more product particles than reactant particles, so low pressure will favour the forward reaction. Using an excess of steam will push the reaction in the forward direction.
- D. Addition reactions usually form one product only. Therefore all reactant atoms form part of the main product.
- D. The fingerprint region of the IR spectrum is typically unique to a particular compound. Small differences between structural isomers affect the energies of bond vibration.
- C. The base peak in a mass spectrum corresponds to the strongest signal, and therefore arises from the most commonly detected fragment. The peak corresponding to the unfragmented molecule is called the molecular ion (or parent ion) peak.

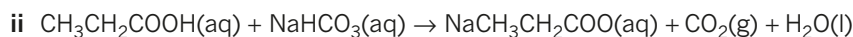
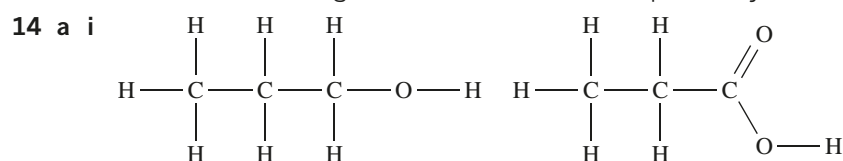
Short answer

- positive
 - The cation present is Pb^{2+} . Lead(II) and silver ions are the only ions likely to form a precipitate with chloride ions. Silver ions form a brown precipitate when ammonia is added, so the metal present in the sample must be lead.
 - $\text{Pb}^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq}) \rightarrow \text{PbCl}_2(\text{s})$
 - The anion could be nitrate or acetate. Many solutions containing lead(II) ions are insoluble, but all nitrate or acetate solutions will be soluble.

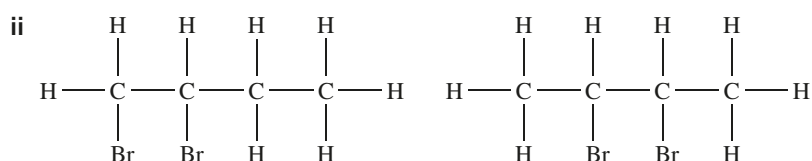
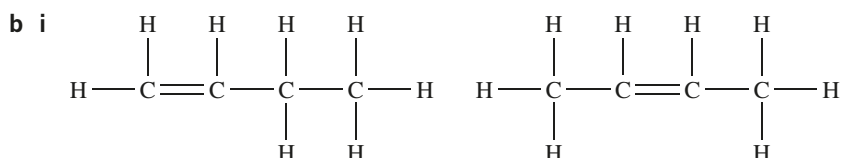
- 2 a This is a complex ion or (transition) metal complex.
 b $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$
 c $\text{Cu}^{2+}(\text{aq}) + 6\text{H}_2\text{O}(\text{l}) \rightleftharpoons [\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$
 d Cu^{2+} ions in aqueous solution have a characteristic blue colour.
 e Water is acting as a ligand.
- 3 a $\text{Pb}(\text{NO}_3)_2(\text{aq}) + 2\text{KCl}(\text{aq}) \rightarrow \text{PbCl}_2(\text{s}) + 2\text{KNO}_3(\text{aq})$
 b $\text{Pb}^{2+}(\text{aq}) + 2\text{Cl}^{-}(\text{aq}) \rightarrow \text{PbCl}_2(\text{s})$
 c i lead(II) chloride
 ii potassium ions and nitrate ions
 d i $n(\text{Pb}(\text{NO}_3)_2) = \frac{m}{M} = \frac{3.15}{331.2} = 0.00951 \text{ mol}$
 ii $n(\text{PbCl}_2)$ formed = $n(\text{Pb}(\text{NO}_3)_2)$ reacted = 0.00951 mol
 So $m(\text{PbCl}_2)$ formed = $n \times M = 0.00951 \times 278.1 = 2.64 \text{ g}$
- 4 a $n(\text{Pb}(\text{NO}_3)_2) = \frac{m}{M} = \frac{9.80}{331.2} = 0.0296 \text{ mol}$
 $c(\text{Pb}(\text{NO}_3)_2) = \frac{0.296}{0.0500} = 0.592 \text{ mol L}^{-1}$
 b New volume of solution is 80.0 mL.
 So $c(\text{Pb}(\text{NO}_3)_2) = \frac{c_1V_1}{V_2} = \frac{0.592 \times 50.0}{80.0} = 0.370 \text{ mol L}^{-1}$
 c i $\text{Pb}^{2+}(\text{aq}) + 2\text{I}^{-}(\text{aq}) \rightarrow \text{PbI}_2(\text{s})$
 ii $n(\text{Pb}^{2+}) = 0.0296 \text{ mol}$
 From the equation, this would require:
 $2 \times 0.0296 = 0.0592 \text{ mol}$ of I^{-} to react.
 $n(\text{NaI}) = c \times V = 0.650 \times 0.0500 = 0.0325 \text{ mol} = n(\text{I}^{-})$
 So there is not enough I^{-} to react with all of the Pb^{2+} .
 I^{-} is the limiting reagent and will limit the amount of product that forms.
 $n(\text{I}^{-})$ reacting = 0.0325 mol and $n(\text{PbI}_2)$ formed = $0.5 \times n(\text{I}^{-}) = 0.5 \times 0.0325 = 0.0163 \text{ mol}$
 $m(\text{PbI}_2)$ formed = $m \times M = 0.0163 \times 461.0 = 7.51 \text{ g}$
- 5 a $\text{Fe}^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_3(\text{s})$
 b $2\text{Fe}(\text{OH})_3(\text{s}) \rightarrow \text{Fe}_2\text{O}_3(\text{s}) + 3\text{H}_2\text{O}(\text{g})$
 c i $n(\text{Fe}_2\text{O}_3) = \frac{m}{M} = \frac{1.095}{159.70} = 0.006857 \text{ mol}$
 So $n(\text{Fe}^{3+}) = 2 \times n(\text{Fe}_2\text{O}_3) = 0.01371 \text{ mol}$
 and $m(\text{iron ions}) = n \times M = 0.01371 \times 55.85 = 0.7659 \text{ g}$
 ii $c(\text{iron ions}) = \frac{n}{V} = \frac{0.01371}{1.30} = 0.0105 \text{ mol L}^{-1}$
- 6 a A sample of a solution containing Ni^{2+} ions is scanned in a UV-visible spectrophotometer to determine its absorbance across a range of wavelengths. The wavelength that gives the highest absorbance is then chosen.
 b Prepare a series of standard solutions containing nickel(II) ions. Measure their absorbance at an appropriate wavelength and plot a calibration curve. Measure the absorbance of the unknown solution and determine its concentration from the calibration curve.
- 7 a From the calibration curve, an absorbance reading of 0.25 is equivalent to a concentration of mercury of 20 mg L^{-1} .
 So the 3.0 g of fish that was ground up into 100 mL water must contain $0.100 \times 20 = 2.0 \text{ mg}$
 As a % by mass of fish, this represents $\frac{2.0 \times 10^{-3}}{3.0} \times 100 = 0.067\%$
 b ppm is equivalent to mg per kg of mass.
 So 2.0 mg in 3.0 g fish is $\frac{2.0}{3.0} \times 1000 = 6.7 \times 10^2 \text{ mg}$ of mercury in 1 kg fish, i.e. $6.7 \times 10^2 \text{ ppm}$
- 8 a radiowaves (radio frequencies)
 b The changes associated with this are nuclear magnetic dipoles (or spin states) switching between low and high energy states, corresponding to alignment with the external magnetic field.
 c It is used as an internal standard for determination of chemical shifts.
 d i B. High chemical shift is characteristic of an aldehyde and the quartet results from three adjacent H atoms.
 ii D. Singlet suggests no neighbouring H atoms. Chemical shift is consistent with an adjacent C=O group.
 iii E. Quartet shows three neighbouring H atoms. Moderately high chemical shift is consistent with an adjacent O atom.

- iv C. Singlet because all H atoms in the molecule are equivalent so no splitting is observed. Chemical shift is consistent with an adjacent halogen (Cl) atom.
- v F. Triplet suggests two neighbouring H atoms, and low chemical shift is consistent with all adjacent atoms being either carbon or hydrogen.
- vi A. Doublet suggests one neighbouring H atom, and chemical shift is consistent with an adjacent C=O group.
- 9 a $C_6H_{13}NO_2$
 b 131
 c 
 i CH_3^+
 ii $C_2H_5^+$
 iii $C_4H_9^+$
 d i The base peak is the strongest signal in the mass spectrum corresponding to the most abundant fragment ion.
 ii $131 - 86 = 45$ mass units lost. This is most likely to be COOH.
- 10 a Spectrum A: about 3000 cm^{-1} is C–H, about 1700 cm^{-1} is C=O
 Spectrum B: about 3000 cm^{-1} is C–H, about 3400 cm^{-1} is O–H (alcohol)
 b Spectrum A is propanone; spectrum B is propan-2-ol.
 c Because of the symmetry of the molecule, all six hydrogens are in the same bonding environment and are 'equivalent'.
 d Again, because of the symmetry of the molecule the two terminal carbon atoms are in identical environments and hence absorb and emit the same frequency. Therefore there are only two different carbon environments.
 e Proton NMR: three peaks, as there are three different H environments ($-CH_3$, $-CHOH-$ and $-CHOH-$)
 Carbon-13 NMR: two peaks, as there are two different C environments ($-CH_3$, $-CHOH-$)
 f i 58. The small peaks at m/z are due to isotopic effects.
 ii It provides the relative molecular mass from which the molecular formula can be deduced.
 iii $[CH_3CO]^+$
- 11 a The lack of precipitate formation after the addition of HCl only indicates that Ag^+ and Pb^{2+} are not present. Fe^{3+} (as well as a number of other cations) could be present.
 b $[Fe(H_2O)_3(OH)_3]$
 c A hollow-cathode lamp containing iron would need to be used in the spectrometer. A series of standard solutions would need to be prepared and their absorbance measured to produce a calibration curve. The unknown solution could then be tested and its absorbance measured. Use the calibration curve to determine the concentration of Fe^{3+} .
 d i $Fe^{3+}(aq) + SCN^-(aq) \rightleftharpoons FeSCN^{2+}(aq)$
 ii A complementary colour to red should be used, with a wavelength around 480nm.
- 12 a $NaBr(aq) + AgNO_3(aq) \rightarrow AgBr(s) + NaNO_3(aq)$
 b As the first additions of Ag^+ ions are made, a precipitate of AgBr forms. The total number of metal ions in the solution decreases, so the electrical conductivity also decreases.
 c After the equivalence point, no further precipitate will form. All extra metal ions added will increase the total number of metal ions in the solution, increasing the conductivity.
 d $n(AgNO_3) = c \times V = 0.20 \times 0.01500 = 0.0030\text{ mol}$
 $n(NaBr) = n(AgNO_3) = 0.0030\text{ mol}$
 $c = \frac{n}{V} = \frac{0.0030}{0.02000} = 0.15\text{ mol L}^{-1}$

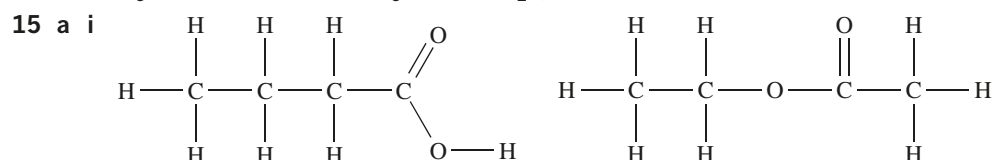
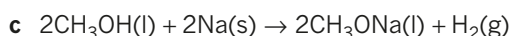
- 13 a** The deposit is 2.5% lithium, and the remaining 97.5% of other materials will generally be waste materials. It is usually not viable to transport so much waste material along with the lithium-containing ore to another site for processing.
- b** Advantage: disposal of waste affects less people. Disadvantages: transport facilities would need to be developed, as would accommodation and infrastructure.
- c** Melting ionic solids requires considerable energy. A decrease in the temperature required represents an energy and cost saving.
- d** There are unlikely to be the skilled workers required at the remote location, and it may be difficult to attract workers to this location.
- e** the world price of lithium, the price of electricity or the world demand for lithium
- f** Waste and run-off would need to be prevented from entering the Darling River. The large area where the mine is would need to be revegetated. Emissions from the plant may have to be controlled.



iii There are no other possible structures; a secondary alcohol will not form a carboxylic acid.



iii but-1-ene or but-2-ene (depending on which structure was drawn for answer to part i). Butene has two positional isomers.



ii They are functional group isomers.

b i 88

ii 29, because both substances will generate C_2H_5^+ (other answers are possible)

c Broad band around $2500\text{--}3300\text{cm}^{-1}$. This corresponds to an O–H (acid) bond that butanoic acid has but ethyl ethanoate does not.

d i butanoic acid = 4; ethyl ethanoate = 3

ii butanoic acid = triplet, sextet (not exactly symmetrical), triplet and singlet; ethyl ethanoate = triplet, quartet and singlet

iii butanoic acid = 4, ethyl ethanoate = 4