

Solutions Manual: Module 2

The acidic environment

Chemistry
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Sources due to human activities:

- burning of fossil fuels
 - smelting of sulfide ores such as CuFeS_2 and ZnS .
- 4 $\text{SO}_2 \rightarrow \text{H}_2\text{SO}_3$; $\text{SO}_3 \rightarrow \text{H}_2\text{SO}_4$; $\text{NO}_2 \rightarrow \text{HNO}_3$; $\text{CO}_2 \rightarrow \text{H}_2\text{CO}_3$
- 5 Increased incidence of low pH in lakes and rivers and continued damage to metal and sandstone buildings.
- 6 The sulfur oxides in the atmosphere usually come from burning fossil fuels in power stations or smelting sulfide ores in smelting plants. Nitrogen oxide and carbon emissions usually come from motor vehicles. Therefore acid rain usually occurs in densely populated areas or industrial areas.

Review exercise 6.3

- 1 a Acidic. The solution has a pH between 4 and 6.
b The pH range is 4 to 8. This solution could be neutral, acidic or basic.
c The solution is slightly basic. The pH is between 7.5 and 8.
- 2 a Bromothymol blue: yellow; phenolphthalein: colourless; methyl orange: red
b Bromothymol blue: blue; phenolphthalein: pink; methyl orange: yellow
c Bromothymol blue: blue; phenolphthalein: colourless; methyl orange: yellow

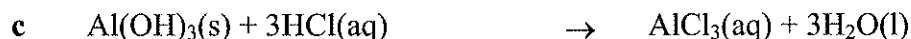
Chapter 6 Application and investigation

- 1 Not all acids are dangerous. Acids are present in foods we eat, e.g. ethanoic acid in vinegar, lactic acid in milk. Also, acids are found in our bodies, e.g. lactic acid, hydrochloric acid. The concentration of acids should be considered.
- 2 a $2\text{Al(s)} + 6\text{HCl(aq)} \rightarrow 2\text{AlCl}_3\text{(aq)} + 3\text{H}_2\text{(g)}$
b $\text{KHCO}_3\text{(s)} + \text{HNO}_3\text{(aq)} \rightarrow \text{KNO}_3\text{(aq)} + \text{CO}_2\text{(g)} + \text{H}_2\text{O(l)}$
c $\text{Fe}_2\text{O}_3\text{(s)} + 3\text{H}_2\text{SO}_4\text{(aq)} \rightarrow \text{Fe}_2(\text{SO}_4)_3\text{(aq)} + 3\text{H}_2\text{O(l)}$
d $\text{Ba(OH)}_2\text{(aq)} + 2\text{HF(aq)} \rightarrow \text{BaF}_2\text{(aq)} + 2\text{H}_2\text{O(l)}$
- 3 a $2\text{Al(s)} + 2\text{NaOH(aq)} + 6\text{H}_2\text{O(l)} \rightarrow 2\text{Na[Al(OH)}_4\text{](aq)} + 3\text{H}_2\text{(g)}$
b $\text{KOH(aq)} + \text{Fe(OH)}_3\text{(s)} \rightarrow \text{no reaction}$
c $2\text{KOH(aq)} + \text{Zn(OH)}_2\text{(s)} \rightarrow \text{K}_2[\text{Zn(OH)}_4]\text{(aq)}$
d $2\text{NaOH(aq)} + \text{SO}_3\text{(g)} \rightarrow \text{Na}_2\text{SO}_4\text{(aq)} + \text{H}_2\text{O(l)}$
- 4 a $\text{KHC}_4\text{H}_4\text{O}_6 + \text{NaHCO}_3 \rightarrow \text{KNaC}_4\text{H}_4\text{O}_6 + \text{CO}_2\text{(g)} + \text{H}_2\text{O(l)}$
b $\text{Fe}_2\text{O}_3\text{(s)} + 6\text{HCl(aq)} \rightarrow 2\text{FeCl}_3\text{(aq)} + 3\text{H}_2\text{O(l)}$

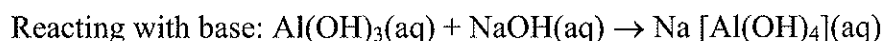
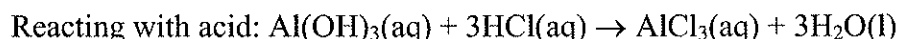
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- 5 Al(OH)_3 reacts with both acids and bases, and therefore is amphoteric.



- 6 Investigation

- 7 Investigation

- 8 A useful indicator is one whose colour change occurs over a selected pH range. Methyl orange changes colour too far outside the narrow 7.2–7.6 range for swimming pools. Litmus changes colour over this range, but the colour difference in the 7.2–7.6 range may be too subtle to detect easily. Universal indicator undergoes many colour changes and the change over the 7.2–7.6 range, from yellow-green to green may also be too subtle to detect easily. Bromothymol blue could be a useful indicator. The change for phenolphthalein is above a pH of 7.6 and so this indicator would not be useful.

- 9 Investigation

- 10 Acid rain has a pH less than 5; methyl orange when yellow means pH is greater than 4.5, and litmus when red indicates a pH of less than 7. Therefore the pH of the sample of rain water lies between 4.5 and 7, and so is unlikely to be classified as acid rain.

- 11 a Na_2O , Al_2O_3 , SiO_2 , P_4O_{10} , Cl_2O_7

- b K_2O , Ga_2O_3 , GeO_2 , As_2O_3 , Br_2O_7

- 12 $\text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{H}_2\text{CO}_3(\text{aq})$ carbonic acid
 $4\text{NO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g}) \rightarrow 4\text{HNO}_3(\text{aq})$ nitric acid
 $\text{SO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{SO}_3(\text{aq})$ sulfurous acid
 $\text{Cl}_2\text{O}_7(\text{l}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{HClO}_4$ perchloric acid

- 13 a $\text{SO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{SO}_3(\text{aq})$

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

- 14 Investigation

- 15 Investigation

- 16 Investigation

CHAPTER 7: CHEMICAL EQUILIBRIUM

Review exercise 7.1

- 1
 - a $\text{NH}_3(\text{g}) + \text{HCl}(\text{g}) \leftrightarrow \text{NH}_4\text{Cl}(\text{s})$
 - b $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \leftrightarrow 2\text{SO}_3(\text{g})$
 - c $\text{Ag}^+(\text{aq}) + \text{Fe}^{2+}(\text{aq}) \leftrightarrow \text{Ag}(\text{s}) + \text{Fe}^{3+}(\text{aq})$
 - d $2\text{NH}_3(\text{g}) \leftrightarrow \text{N}_2(\text{g}) + 3\text{H}_2(\text{g})$
- 2
 - a Ammonia molecules are reacting with hydrogen chloride molecules to form ammonium chloride at the same rate at which the ammonium chloride is decomposing to ammonia and hydrogen chloride.
 - b Sulfur dioxide reacts with oxygen to form sulfur trioxide at the same rate at which the sulfur trioxide decomposes to produce sulfur dioxide and oxygen.
 - c Silver ions are reduced to silver at the same rate at which the iron(III) is reduced to iron(II).
 - d Ammonia decomposes to nitrogen and hydrogen at the same rate at which hydrogen and nitrogen combine to form ammonia.
- 3
 - a If $0.21 \text{ mol L}^{-1} \text{H}_2$ remains, 0.79 mol L^{-1} reacted.

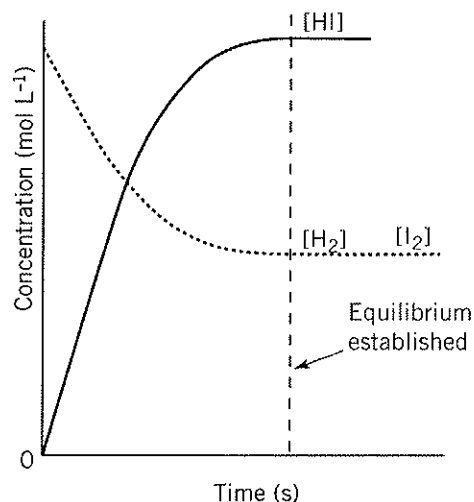
Molar ratio of $\text{H}_2 : \text{HI}$ is 1 : 2

$\therefore 0.79 \times 2 = 1.58$ moles HI formed

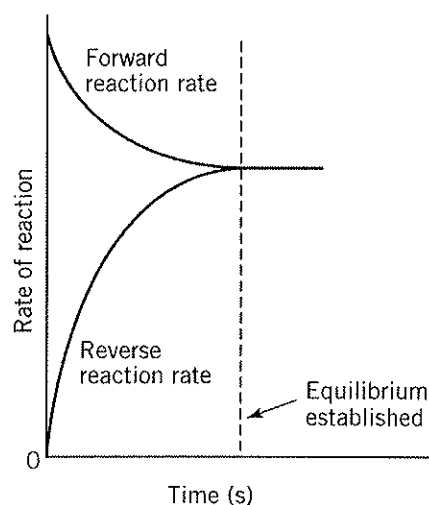
\therefore equilibrium conc $\text{HI} = 1.58 \text{ mol L}^{-1}$

b i and ii

(i) Concentration



(ii) Reaction rate



- c Forward and reverse reactions will occur at equal but opposing rates. The concentrations of reactants and products remain constant.

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- 4 In an open container, the CO_2 would escape and the reverse reaction would not occur. In a sealed container, increasing the temperature would increase the pressure until equilibrium was established.

Review exercise 7.2

- 1 a i $\uparrow [\text{NO}]$, $\uparrow [\text{H}_2\text{O}]$, $\downarrow [\text{NH}_3]$
ii Will increase rate of forward reaction until equilibrium is re-established.
b i $\downarrow [\text{NH}_3]$, $\downarrow [\text{O}_2]$, $\uparrow [\text{H}_2\text{O}]$
ii Will increase rate of forward reaction until equilibrium is re-established.
- 2 a i Concentration of H_2O will decrease, concentration of CO , H_2 will increase. No change to $[\text{C(s)}]$.
ii Will increase rate of forward reaction. This increases concentration of CO and H_2 , decreases $[\text{H}_2\text{O}]$.
b i Concentration of H_2O will increase, concentration of CO , H_2 will decrease. No change to $[\text{C(s)}]$.
ii Will increase rate of reverse reaction. $[\text{CO}] \downarrow$, $[\text{H}_2] \downarrow$ and $[\text{H}_2\text{O}] \uparrow$ until equilibrium is re-established.
- 3 a i $\uparrow [\text{CO}]$, $\uparrow [\text{O}_2]$, $\downarrow [\text{CO}_2]$
ii Will increase rate of reverse reaction.
b i $\downarrow [\text{CO}]$, $\downarrow [\text{O}_2]$, $\uparrow [\text{CO}_2]$
ii Will increase rate of forward reaction.
- 4 a The system would reach equilibrium more quickly.
b Both forward and reverse rates would increase equally, therefore no change.

Review exercise 7.3

- 1 $\text{CO}_2(\text{g}) \leftrightarrow \text{CO}_2(\text{aq})$
 $\text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{H}_2\text{CO}_3(\text{aq})$
 $\text{H}_2\text{CO}_3(\text{aq}) \leftrightarrow \text{H}^+(\text{aq}) + \text{HCO}_3^-(\text{aq})$
 $\text{HCO}_3^-(\text{aq}) \leftrightarrow \text{H}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq})$
- 2 a When the bottles are opened, the pressure in the system is decreased, causing a shift in the equilibrium to the left, where there are more moles of gas and so the change is counteracted. This results in bubbles of $\text{CO}_2(\text{g})$.
b Cooling the drink shifts the equilibrium to the right (exothermic direction), meaning that more carbon dioxide will be dissolved into the solution. When the

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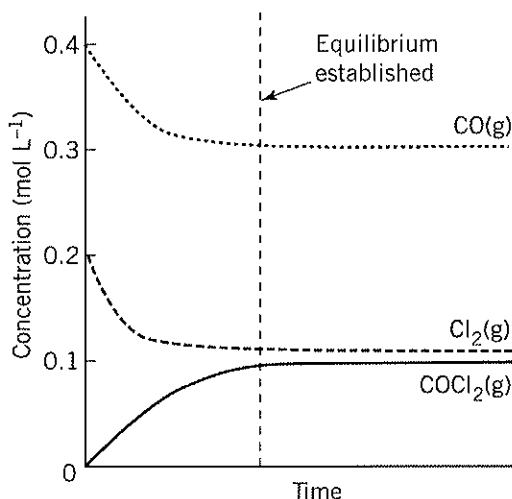
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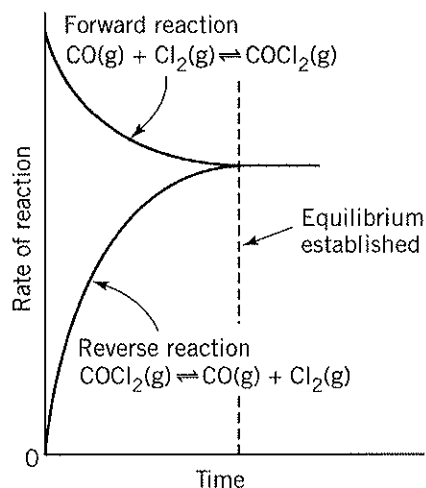
drink is served cold, the rate at which $\text{CO}_2(\text{g})$ escapes to the atmosphere is decreased.

Chapter 7 Application and investigation

1 a Changes in concentration



b Rate of reaction



- 2 No further change in the colour of the mixture would be detected.
- 3 At equilibrium, the concentration of all species remains constant, therefore there will be no change in any observable properties. The dynamic process refers to the equal but opposite reactions occurring at the molecular level.
- 4 concentration, pressure, temperature
- 5
 - a $\downarrow [\text{NO}]; \uparrow [\text{O}_2]; \uparrow [\text{NO}_2]$
 - b Concentration of all species will double.
 - c $\uparrow [\text{O}_3]; \downarrow [\text{O}_2]; \downarrow [\text{NO}_2]$

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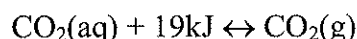
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- 6 a $\downarrow [\text{HBr}]; \downarrow [\text{O}_2]; \uparrow [\text{H}_2\text{O}]; \uparrow [\text{Br}_2]$
b $\uparrow [\text{HBr}]; \uparrow [\text{O}_2]; \downarrow [\text{H}_2\text{O}]; \downarrow [\text{Br}_2]$
- 7 a i Shift equilibrium to the right.
ii Shift equilibrium to the left.
b i Shift equilibrium to the left.
ii Shift equilibrium to the right.
- 8 a $\uparrow \text{Ca}(\text{HCO}_3)_2(\text{s}); \downarrow \text{CaO}(\text{s}); \downarrow [\text{H}_2\text{O}]; \downarrow [\text{CO}_2]$ after initial increase of CO_2
b $\downarrow \text{Ca}(\text{HCO}_3)_2(\text{s}); \uparrow \text{CaO}(\text{s}); \uparrow [\text{CO}_2]; \uparrow [\text{H}_2\text{O}]$ after initial decrease of H_2O
c $\downarrow \text{Ca}(\text{HCO}_3)_2(\text{s}); \uparrow \text{CaO}(\text{s}); \uparrow [\text{CO}_2]; \uparrow [\text{H}_2\text{O}]$
d no change
e $\uparrow \text{Ca}(\text{HCO}_3)_2(\text{s}); \downarrow \text{CaO}(\text{s}); \downarrow [\text{CO}_2]; \downarrow [\text{H}_2\text{O}]$
- 9 a i Equilibrium will shift right to counteract the change: $\downarrow [\text{NO}_2]; \uparrow [\text{SO}_3]; \uparrow [\text{NO}]$.
ii The forward reaction rate will increase.
b i There are equal numbers of gaseous molecules on each side, so pressure will increase the concentration of all species, but the system will remain at equilibrium.
ii Forward and reverse reactions increase equally.
c i Concentrations of all species will decrease, but the system will remain at equilibrium.
ii Forward and reverse reaction rates decrease equally.
d i The equilibrium will shift left in an endothermic direction: $\uparrow [\text{SO}_2], \uparrow [\text{NO}_2], \downarrow [\text{SO}_3], \downarrow [\text{NO}]$.
ii Reverse reaction is favoured.
e i No change as a catalyst does not affect the position of equilibrium.
ii Both forward and reverse reaction rates will increase.
- 10 a Pressure is decreased, so equilibrium will shift to counteract the change. Therefore $\text{CO}_2(\text{g})$ is produced and bubbles form.
b It is an exothermic reaction, so warm temperatures cause the equilibrium to shift to the left and form $\text{CO}_2(\text{g})$.
c The H^+ in the orange juice causes increased production of carbonic acid.
$$\text{HCO}_3^-(\text{aq}) + \text{H}^+(\text{aq}) \leftrightarrow \text{H}_2\text{CO}_3(\text{aq})$$

The \uparrow $[\text{H}_2\text{CO}_3]$ causes the production of more $\text{CO}_2(\text{aq})$:



Therefore the \uparrow $[\text{CO}_2(\text{aq})]$ results in the production of more $\text{CO}_2(\text{g})$ causing drinks to go flat, as follows:



11 Investigation

CHAPTER 8: THE HISTORICAL DEVELOPMENT OF IDEAS OF ACIDS AND BASES

Review exercise 8.1

- 1 a $\text{SO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{SO}_3(\text{aq})$
 b $\text{Na}_2\text{O}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{NaOH}(\text{aq})$
- 2 Hydrochloric acid, HCl; hydrobromic acid, HBr; cyanic acid, HCN
- 3 Arrhenius theory states that bases are substances which deliver hydroxide ions in water. NaCN is a substance that acts as a base but does not contain a hydroxide group.
- 4 a $\text{H}_2\text{SO}_4(\text{aq}) \rightarrow 2\text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$
 or $\text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{HSO}_4^-(\text{aq}) + \text{H}^+(\text{aq})$, then $\text{HSO}_4^-(\text{aq}) \leftrightarrow \text{SO}_4^{2-} + \text{H}^+(\text{aq})$
 b $\text{HNO}_3(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{NO}_3^-(\text{aq})$
- 5 a 1
 b 2
 c 3
 d 1
 e 1
 f 1
- 6 a 1
 b 3
 c 2
- 7 $\text{HOCCOOH}(\text{aq}) \leftrightarrow \text{HOCCOO}^-(\text{aq}) + \text{H}^+(\text{aq})$
 $\text{HOCCOO}^-(\text{aq}) \leftrightarrow ^-\text{OCCOO}^-(\text{aq}) + \text{H}^+(\text{aq})$

Review exercise 8.2

- 1 a A B–L acid is a proton donor (or has a proton ‘pulled’ from it).

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- b** A B–L base is a proton acceptor (or ‘takes’ a proton).
- 2 a** HCl , HCO_3^- , NH_4^+ , HClO_4 , HSO_4^-
- b** F^- , SO_4^{2-} , NH_3 , PO_4^{3-} , H_2O
- 3 a** An amphiprotic substance can either accept or donate a proton, and therefore it can act as both an acid and a base.
- b**
- $$\begin{array}{ccccccc} \text{HPO}_4^{2-}(\text{aq}) & + & \text{H}_2\text{O}(\text{l}) & \rightleftharpoons & \text{H}_2\text{PO}_4^-(\text{aq}) & + & \text{OH}^-(\text{aq}) \\ \text{HPO}_4^{2-}(\text{aq}) & + & \text{H}_2\text{O}(\text{l}) & \rightleftharpoons & \text{PO}_4^{3-}(\text{aq}) & + & \text{H}_3\text{O}^+(\text{aq}) \end{array}$$
- 4**
- $$\begin{array}{lcl} \text{Acid} & \text{HSO}_4^-(\text{aq}) + \text{OH}^-(\text{aq}) \rightleftharpoons \text{SO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \\ \text{Base} & \text{HSO}_4^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \rightleftharpoons \text{H}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) \end{array}$$
- 5 a** A conjugate base is the species that results when a B–L acid has lost its proton
- loses H^+ leaving ...
- $$\begin{array}{c} \text{CH}_3\text{COOH}(\text{aq}) + \text{OH}^- \rightleftharpoons \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \\ \text{acid} \qquad \qquad \qquad \text{conjugate base} \end{array}$$
- acetic acid acetate ion
- b** A conjugate acid is the species that results when a B–L base accepts a proton
- gains H^+ producing ...
- $$\begin{array}{c} \text{HSO}_4^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \rightleftharpoons \text{H}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) \\ \text{base} \qquad \qquad \qquad \text{conjugate acid} \end{array}$$
- hydrogen sulfate ion sulfuric acid
- 6 a** $\text{HCO}_3^-/\text{SO}_4^{2-}$; HF/F^-
- b** $\text{HSO}_4^-/\text{SO}_4^{2-}$; $\text{NH}_4^+/\text{NH}_3$
- c** HF/F^- ; $\text{H}_3\text{O}^+/\text{H}_2\text{O}$

Review exercise 8.3

- 1 a i** HCl
- ii** HCl
- iii** HCl
- b i** H_2SO_4
- ii** H_2SO_4
- iii** H_2SO_4
- 2 a i** NaOH
- ii** NaOH

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- iii NaOH
- b i Ba(OH)₂
ii Ba(OH)₂
iii Ba(OH)₂
- 3 a 5 mol L⁻¹ HCl
b 0.1 mol L⁻¹ NaOH
c 5 mol L⁻¹ NH₃
d 0.1 mol L⁻¹ CH₃COOH
- 4 a $\text{HBr(aq)} \rightarrow \text{H}^{\text{+}}\text{(aq)} + \text{Br}^{\text{-}}\text{(aq)}$
b $\text{H}_2\text{SO}_3\text{(aq)} \leftrightarrow \text{HSO}_3^{\text{-}}\text{(aq)} + \text{H}^{\text{+}}\text{(aq)}$
c $\text{RbOH(aq)} \rightarrow \text{Rb}^{\text{+}}\text{(aq)} + \text{OH}^{\text{-}}\text{(aq)}$
d $\text{NaF(aq)} \leftrightarrow \text{Na}^{\text{+}}\text{(aq)} + \text{F}^{\text{-}}\text{(aq)}$
- 5 a small extent
b large extent
c small extent

Review exercise 8.4

- 1 a $\text{S}^{2-}\text{(aq)} + \text{H}_2\text{O(l)} \leftrightarrow \text{HS}^{\text{-}}\text{(aq)} + \text{OH}^{\text{-}}\text{(aq)}$
b $\text{CO}_3^{2-}\text{(aq)} + \text{H}_2\text{O(l)} \leftrightarrow \text{HCO}_3^{\text{-}}\text{(aq)} + \text{OH}^{\text{-}}\text{(aq)}$
c $\text{NH}_4^{\text{+}}\text{(aq)} + \text{H}_2\text{O(l)} \leftrightarrow \text{NH}_3\text{(aq)} + \text{H}_3\text{O}^{\text{+}}\text{(aq)}$
d $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}\text{(aq)} + \text{H}_2\text{O(l)} \leftrightarrow [\text{Fe}(\text{OH})(\text{H}_2\text{O})_5]^{2+}\text{(aq)} + \text{H}_3\text{O}^{\text{+}}\text{(aq)}$
e $\text{F}^{\text{-}}\text{(aq)} + \text{H}_2\text{O(l)} \leftrightarrow \text{HF(aq)} + \text{OH}^{\text{-}}\text{(aq)}$
f $\text{HSO}_4^{\text{-}}\text{(aq)} + \text{H}_2\text{O(l)} \leftrightarrow \text{SO}_4^{2-}\text{(aq)} + \text{H}_3\text{O}^{\text{+}}\text{(aq)}$
g $\text{ClO}^{\text{-}} + \text{H}_2\text{O} \leftrightarrow \text{HClO} + \text{OH}^{\text{-}}$
h $\text{CH}_3\text{COO}^{\text{-}}\text{(aq)} + \text{H}_2\text{O(l)} \leftrightarrow \text{CH}_3\text{COOH(aq)} + \text{OH}^{\text{-}}\text{(aq)}$
- 2 Use Table 8.5.
a neutral
b acidic due to reaction of $\text{NH}_4^{\text{+}}$ ion with water
c basic due to reaction of $\text{ClO}^{\text{-}}$ ion with water
d basic due to reaction of PO_4^{3-} ion with water

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- e acidic due to reaction of Al^{3+} ion (actually will be aquated aluminium ion $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$ with water)
- f acidic due to reaction of H_2PO_4^- ion with water
- g neutral
- h basic due to reaction of CO_3^{2-} ion with water

Chapter 8 Application and investigation

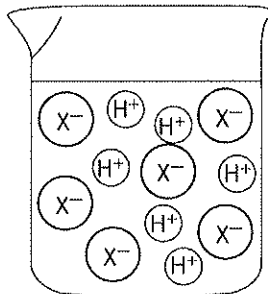
- 1 According to Arrhenius, acids are substances that release hydrogen ions in solution. $\text{HCl}(\text{aq})$ completely ionises in water to produce H^+ and Cl^- , and therefore $\text{HCl}(\text{aq})$ is an Arrhenius acid. $\text{HCl}(\text{l})$ cannot release hydrogen ions and so is not an Arrhenius acid.
- 2
 - a $\text{HCl}(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{Cl}^-(\text{aq})$
 - b $\text{Ca}(\text{OH})_2(\text{aq}) \rightarrow \text{Ca}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq})$
 - c $\text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{HSO}_4^-(\text{aq}) + \text{H}^+(\text{aq})$
 $\text{HSO}_4^-(\text{aq}) \leftrightarrow \text{SO}_4^{2-}(\text{aq}) + \text{H}^+(\text{aq})$
 - d $\text{H}_2\text{SO}_4(\text{aq}) + 2\text{NaOH}(\text{aq}) \rightarrow \text{Na}_2\text{SO}_4(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$
 - e $\text{Al}(\text{OH})_3(\text{aq}) + 3\text{HCl}(\text{aq}) \rightarrow \text{AlCl}_3(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$
- 3
 - a 4
 - b 2
 - c 2
 - d $\text{CH}_2(\text{COOH})_2(\text{aq}) + 2\text{NaOH}(\text{aq}) \rightarrow \text{CH}_2(\text{COONa})_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$
- 4
 - a $\text{HCl}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{Cl}^-(\text{aq})$
 - b $\text{CH}_3\text{COOH}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{CH}_3\text{COO}^-(\text{aq})$
 - c $\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})$
 - d $\text{H}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{HSO}_4^-(\text{aq})$
 $\text{HSO}_4^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$
 - e $\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
- 5
 - a ClO_3^- , S^{2-} , NH_3 , OH^-
 - b H_2CO_3 , H_2S , $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$, N_2H_5^+
- 6
 - a As acid: $\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{CO}_3^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
As base: $\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{H}_2\text{CO}_3(\text{aq}) + \text{OH}^-(\text{aq})$

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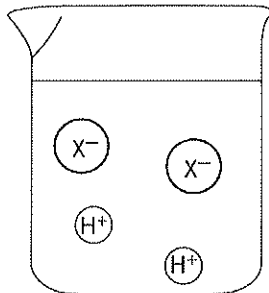
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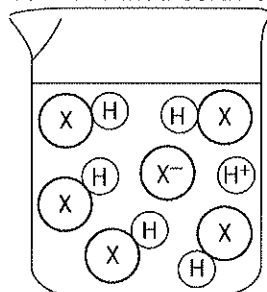
- b The extent to which the HCO_3^- ion reacts as a base with water exceeds the degree to which it reacts with water as an acid. (K value is greater for HCO_3^- as a base.) Hence more OH^- ions are produced than H_3O^+ ions.
- 7 a i $\text{H}_2\text{C}_2\text{O}_4/\text{HC}_2\text{O}_4^-$, $\text{H}_3\text{O}^+/\text{H}_2\text{O}$
ii small extent
b i $\text{H}_2\text{O}/\text{OH}^-$, HCN/CN^-
ii small extent
c i $\text{CH}_3\text{COOH}/\text{CH}_3\text{COO}^-$, $\text{HS}^-/\text{S}^{2-}$
ii large extent
d i HCl/Cl^- , HF/F^-
ii large extent
- 8 a $\text{HClO}_4(\text{l}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{ClO}_4^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
b $\text{HCOOH}(\text{l}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{HCOO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
c $\text{LiOH}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{Li}^+(\text{aq}) + \text{OH}^-(\text{aq})$
d $\text{N}_2\text{H}_4(\text{l}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{N}_2\text{H}_5^+(\text{aq}) + \text{OH}^-(\text{aq})$
- 9 a concentrated solution of a strong acid



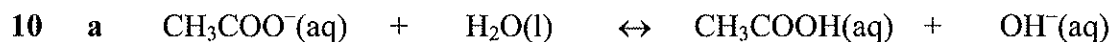
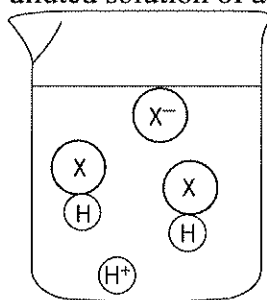
- b diluted solution of a strong acid



c concentrated solution of a weak acid

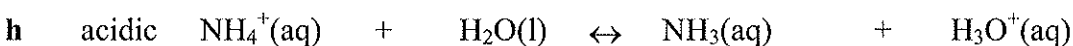
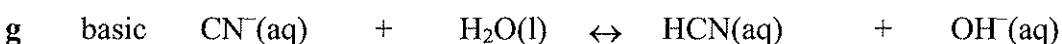
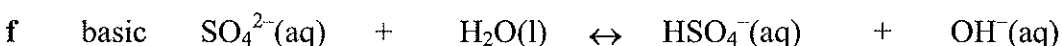
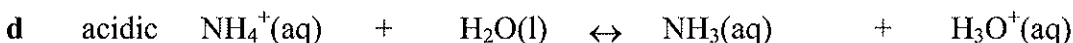
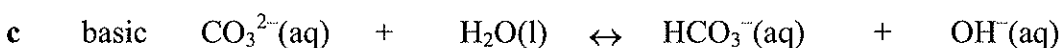
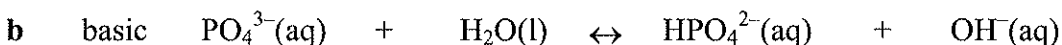


d diluted solution of a weak acid



b The hydroxide ions produced raise the pH above 7. The ethanoic acid molecule formed has only a very small degree of dissociation.

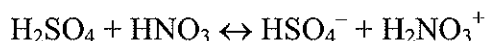
11 a neutral



12

	Acid	Base	Neutralisation
Arrhenius	produces H^+ ions in water	produces OH^- ions in water	$\text{H}^+ + \text{OH}^- \leftrightarrow \text{H}_2\text{O}$
Brønsted–Lowry	proton donor	proton acceptor	$\text{NH}_3(\text{aq}) + \text{H}_2\text{O} \leftrightarrow \text{NH}_4^+ + \text{OH}^-$ proton transfer

- 13 The reaction: $\text{HCl(g)} + \text{NH}_3\text{(g)} \rightarrow \text{NH}_4\text{Cl(s)}$ can be viewed as a Brønsted–Lowry acid–base reaction because a proton is transferred. However, the reaction is not happening in solution and there are no hydroxide ions released, so the reaction cannot be viewed as an Arrhenius acid–base reaction. When nitric acid is mixed with sulfuric acid, for the manufacture of nitroglycerine, the reaction that occurs is



This is a B–L acid–base reaction because a proton is transferred but it is not an Arrhenius acid–base reaction.

- 14 Investigation

CHAPTER 9: HYDROGEN ION CONCENTRATION AND THE pH SCALE

Review exercise 9.1

- 1 a $K_w = [\text{H}^+][\text{OH}^-]$
 $1.0 \times 10^{-14} = [\text{H}^+] \times 1.6 \times 10^{-7}$
 $[\text{H}^+] = 6.2 \times 10^{-8} \text{ mol L}^{-1}$
- b $[\text{H}^+]$ is less than $1 \times 10^{-7} \text{ mol L}^{-1}$ \therefore pool is slightly basic
- 2 a $[\text{H}^+] = 5.0 \times 10^{-3} \text{ mol L}^{-1}$
 $[\text{NO}_3^-] = 5.0 \times 10^{-3} \text{ mol L}^{-1}$
 $[\text{OH}^-] = 1 \times 10^{-14} \div 5.0 \times 10^{-3}$
 $= 2 \times 10^{-12} \text{ mol L}^{-1}$
- b $[\text{H}^+] = 1.5 \text{ mol L}^{-1}$
 $[\text{Cl}^-] = 1.5 \text{ mol L}^{-1}$
 $[\text{OH}^-] = 1 \times 10^{-14} \div 1.5$
 $= 6.7 \times 10^{-15} \text{ mol L}^{-1}$
- c $[\text{K}^+] = 0.25 \text{ mol L}^{-1}$
 $[\text{OH}^-] = 0.25 \text{ mol L}^{-1}$
 $[\text{H}^+] = 4 \times 10^{-14} \text{ mol L}^{-1}$
- d $[\text{Ba}^{2+}] = 6.0 \times 10^{-2} \text{ mol L}^{-1}$
 $[\text{OH}^-] = 0.12 \text{ mol L}^{-1}$
 $[\text{H}^+] = 8.3 \times 10^{-14} \text{ mol L}^{-1}$

- 2 a Buffered; contains approximately equal amounts of the weak acid HSO_4^- and its conjugate base SO_4^{2-} .
- b Not buffered; HNO_3 is a strong acid.
- c Buffered; contains approximately equal amounts of the weak acid HClO and its conjugate base ClO^- .
- 3 a $\text{HPO}_4^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \leftrightarrow \text{H}_2\text{PO}_4^-(\text{aq}) + \text{H}_2\text{O}(\text{l})$
When excess hydrogen ions are added, the system shifts to the right and thus decreases the H^+ concentration.
- b $\text{H}_2\text{PO}_4^-(\text{aq}) + \text{OH}^-(\text{aq}) \leftrightarrow \text{HPO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
When excess hydroxide is added, the system shifts to the right and thus decreases the OH^- concentration.
- 4 The concentration of the acid and conjugate base ions is limited. If too much H^+ or OH^- is added then the system is unable to provide sufficient acid or conjugate base particles to counteract their effect.
- 5 Lactic acid in the blood produces lactate ions and hydrogen ions. The blood's buffering system $\text{H}_2\text{CO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{HCO}_3^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$ responds by combining the extra hydrogen ions with the hydrogencarbonate ions, thus shifting the system to the left and decreasing their concentration.

Chapter 9 Application and investigation

- 1 a $[\text{H}^+] = 0.5 \text{ mol L}^{-1}$
 $[\text{OH}^-] = 1 \times 10^{-14} \div 0.5$
 $= 2 \times 10^{-14} \text{ mol L}^{-1}$
 $\text{pH} = -\log[0.5]$
 $= 0.30$
- b $[\text{OH}^-] = 3.0 \times 10^{-3} \times 2$
 $= 6.0 \times 10^{-3} \text{ mol L}^{-1}$
 $[\text{H}^+] = 1 \times 10^{-14} \div 0.006$
 $= 1.67 \times 10^{-12} \text{ mol L}^{-1}$
 $\text{pH} = -\log[1.67 \times 10^{-12}]$
 $= 11.8$
- 2 a $[\text{H}^+] = 1.0 \times 10^{-3} \text{ mol L}^{-1}$

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$$\begin{aligned}[\text{OH}^-] &= 1 \times 10^{-14} \div 0.001 \\ &= 1 \times 10^{-11} \text{ mol L}^{-1}\end{aligned}$$

$$\begin{aligned}\text{b} \quad [\text{H}^+] &= 3.9 \times 10^{-3} \text{ mol L}^{-1} \\ [\text{OH}^-] &= 2.51 \times 10^{-12} \text{ mol L}^{-1}\end{aligned}$$

$$\begin{aligned}\text{c} \quad [\text{H}^+] &= 3.2 \times 10^{-9} \text{ mol L}^{-1} \\ [\text{OH}^-] &= 3.2 \times 10^{-6} \text{ mol L}^{-1}\end{aligned}$$

$$\begin{aligned}\text{d} \quad [\text{H}^+] &= 7.9 \times 10^{-13} \text{ mol L}^{-1} \\ [\text{OH}^-] &= 1.3 \times 10^{-2} \text{ mol L}^{-1}\end{aligned}$$

$$\begin{aligned}3 \quad \text{a} \quad \text{i} \quad [\text{H}^+] &= 0.20 \text{ mol L}^{-1} \\ [\text{NO}_3^-] &= 0.20 \text{ mol L}^{-1} \\ [\text{HNO}_3] &= 0 \text{ mol L}^{-1} \\ \text{ii} \quad \text{pH} &= -\log_{10}[0.20] \\ &= 0.70\end{aligned}$$

b As HNO_2 is a weak acid, it will not dissociate completely. Therefore $[\text{H}^+]$ will be less than 0.20 mol L^{-1} and pH will be higher than 0.70.

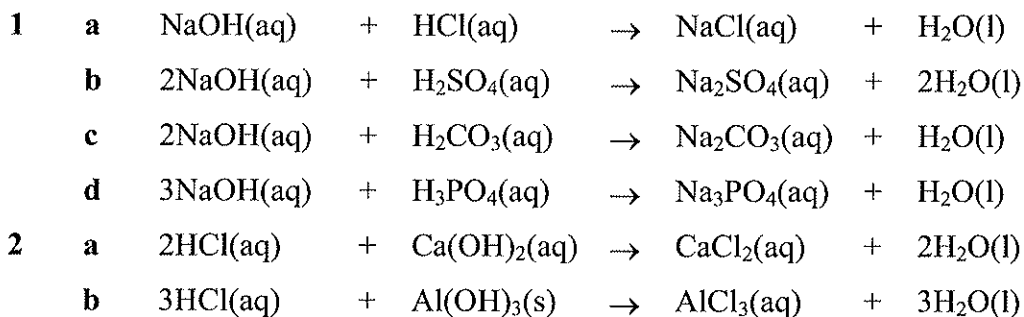
4 H_2CO_3 , H_3PO_4 , HClO_2 , H_2SO_3 , HCl

5 Investigation

6 Investigation

CHAPTER 10: VOLUMETRIC ANALYSIS AND ESTERIFICATION

Review exercise 10.1



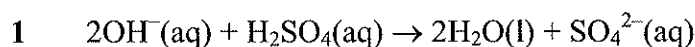
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- c $2\text{HCl(aq)} + \text{MgO(s)} \rightarrow \text{MgCl}_2\text{(aq)} + \text{H}_2\text{O(l)}$
- d $2\text{HCl(aq)} + \text{Na}_2\text{CO}_3\text{(s)} \rightarrow 2\text{NaCl(aq)} + \text{CO}_2\text{(g)} + \text{H}_2\text{O(l)}$
- 3 Neutralisation is the result of an acid–base interaction. In Brønsted–Lowry terms this refers to proton transfer from the acid to the base.
- 4 Neutralisation results in the formation of a new bond as the proton bonds to its base. Bond formation is an exothermic process, and thus neutralisation is an exothermic process.
- 5 a Add solid sodium hydrogencarbonate until the ‘fizzing’ stops. The reaction produces carbon dioxide, so when the fizzing stops, this indicates that the neutralisation is complete.
- b Rinse with copious amounts of water. A base should not be used, as the neutralisation reaction is exothermic—i.e. it releases a lot of heat.

Review exercise 10.2



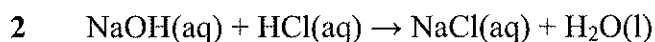
Calculate moles of OH^-

$$\begin{aligned}n(\text{OH}^-) &= cV \\&= 1.90 \times 0.02368 \\&= 0.045 \text{ moles}\end{aligned}$$

$$\begin{aligned}\therefore \text{moles of H}_2\text{SO}_4 : n(\text{H}_2\text{SO}_4) &= 0.5n(\text{OH}^-) \text{ (from equation)} \\&= 0.0225 \text{ moles}\end{aligned}$$

\therefore concentration of H_2SO_4

$$\begin{aligned}n(\text{H}_2\text{SO}_4) &= cV \\0.0225 &= c \times 0.005 \\c &= 4.50 \text{ mol L}^{-1}\end{aligned}$$



Calculated moles of HCl

$$\begin{aligned}n &= cV \\&= 0.02052 \times 0.952 \\&= 0.019535 \text{ moles} \\ \text{moles of HCl} &= \text{moles NaOH (from equation)}\end{aligned}$$

$$\begin{aligned}\therefore \text{concentration of NaOH} &= \frac{n}{V} \\ &= 0.019535 / 0.005 \\ c &= 3.91 \text{ mol L}^{-1} \text{ NaOH}\end{aligned}$$

- 3 a Pipettes are more accurately calibrated than a measuring cylinder; this accuracy is important in volumetric analysis.
- b If rinsed with water, any drops left in the pipette or burette will alter the concentration of the solution and this will affect the results. Rinsing with the solution will not have this effect.
- c Volume may change slightly once the solid is dissolved; the customary unit of concentration is mol/L, where the volume refers to litres of solution, not water.

4 a No. moles Na_2CO_3 = 0.250×0.1
 = 0.025 moles

$$\text{moles} = \frac{m}{M}$$

$$\text{so } 0.25 = \frac{m}{105.99}$$

$$m = 2.65 \text{ g of Na}_2\text{CO}_3 \text{ is dissolved in water in a 250 mL volumetric flask with solution made up to the calibrated mark}$$

b $n = cV$

$$\begin{aligned}n\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O} &= 0.5 \times 0.015 \\ &= 7.5 \times 10^{-3} \text{ moles}\end{aligned}$$

$$n = \frac{m}{M}$$

$$7.5 \times 10^{-3} = \frac{m}{126.07}$$

$$m = 0.95 \text{ g oxalic acid is dissolved in water in a 500 mL volumetric flask with the solution made up to the calibrated mark}$$

5 a $n = \frac{m}{M}$

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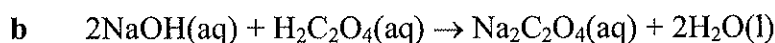
$$= \frac{0.3162}{126.07}$$

$$= 0.0025 \text{ moles}$$

$$n = cV$$

$$0.0025 = c \times 0.25$$

$$c = 0.010 \text{ mol L}^{-1} \text{ H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$$



$$n(\text{H}_2\text{C}_2\text{O}_4) = cV$$

$$n = 0.010 \times 0.02061$$

$$= 2.068 \times 10^{-4} \text{ moles H}_2\text{C}_2\text{O}_4$$

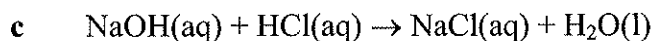
$$n(\text{OH}^-) = 2 \times n\text{H}_2\text{C}_2\text{O}_4 \text{ (from equation)}$$

$$n(\text{OH}^-) = 4.136 \times 10^{-4} \text{ mol}$$

$$n(\text{NaOH}) = cV$$

$$4.136 \times 10^{-4} = c \times 0.020$$

$$c = 0.0207 \text{ mol L}^{-1} \text{ NaOH}$$



$$n(\text{NaOH}) = cV$$

$$n = 0.0207 \times 0.020$$

$$= 4.14 \times 10^{-4} \text{ mol NaOH}$$

$$\text{volume of HCl used} = 20.26 - 1.83$$

$$= 18.43 \text{ mL}$$

$$= 0.01843 \text{ L}$$

$$n\text{HCl} = n\text{NaOH from equation}$$

$$n(\text{HCl}) = 4.14 \times 10^{-4} \text{ moles}$$

$$n\text{HCl} = cV$$

$$4.14 \times 10^{-4} = c \times 0.01843$$

$$c = 2.24 \times 10^{-2} \text{ HCl mol L}^{-1}$$

Review exercise 10.3

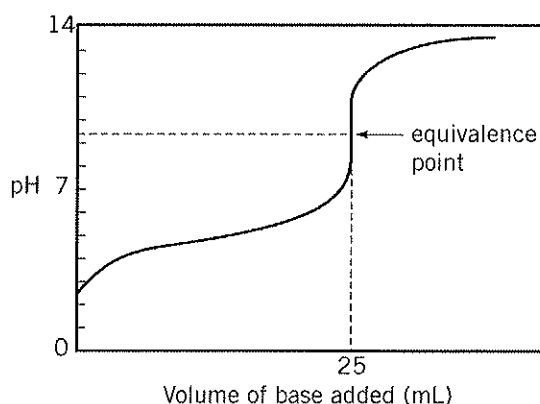


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- ii basic
 - iii phenolphthalein
 - b
 - i $\text{KNO}_3(\text{aq})$
 - ii neutral
 - iii methyl orange/phenolphthalein
 - c
 - i $\text{NaCl}(\text{aq})$
 - ii acidic
 - iii methyl orange
- 2
 - i
 - a Phenolphthalein; as a strong acid/strong base titration and endpoint will be around 7.
 - b Colourless in acid changing to pink as base added, with pale pink at equivalence point.
 - ii
 - a Methyl orange; as strong acid/weak base titration and endpoint will be less than pH 7.
 - b Yellow in base and changing to orange at equivalence point, and to red as point is passed.
 - iii
 - a Bromothymol blue; weak acid/strong base titration and endpoint will be greater than pH 7.
 - b Yellow in acid changing to blue as base added, with pale yellow at equivalence point.
- 3 This is a weak acid/strong base titration with an equivalence point above pH 7. If methyl orange was used as an indicator, a colour change would be observed at around pH 3.1–4.4 and an equivalence point assumed, so the volume of hydroxide recorded would be too low.
- 4
 - a Running this strong base into the weak acid.

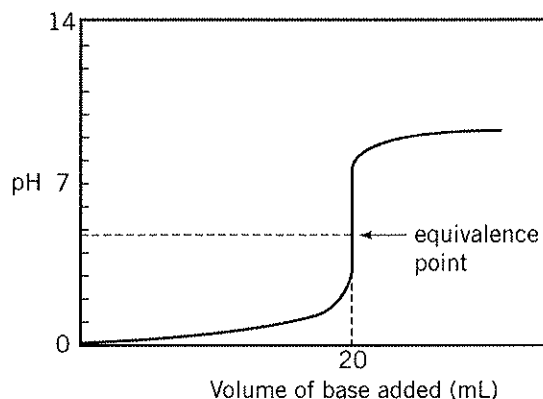


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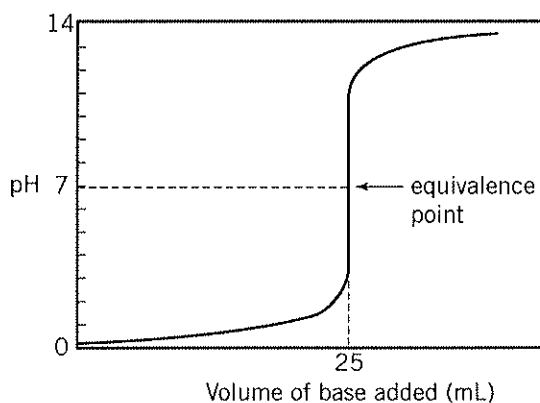
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b Running this weak base into the strong acid.



c Running this strong base into the strong acid.



Review exercise 10.4

$$\begin{aligned} \mathbf{1} \quad \mathbf{a} \quad n &= \frac{V}{22.71} = \frac{2.5}{22.71} \\ &= 0.11 \text{ mol H}_2 \end{aligned}$$

$$\begin{aligned} \mathbf{b} \quad n &= \frac{m}{M} \\ 0.11 &= \frac{m}{2.016} \\ &= 0.22 \text{ g hydrogen gas} \end{aligned}$$

$$\begin{aligned} \mathbf{2} \quad \mathbf{a} \quad n &= \frac{m}{M} = \frac{48.0}{32} \\ &= 1.5 \text{ mol} \end{aligned}$$

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$$n = \frac{V}{22.71}$$

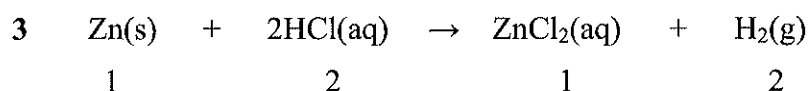
$$1.5 = \frac{V}{22.71}$$

$$V = 34.07 \text{ L at } 0^\circ\text{C and } 100 \text{ kPa}$$

b $n = \frac{V}{24.79}$

$$1.5 = \frac{V}{24.79}$$

$$V = 37.19 \text{ L at } 25^\circ\text{C and } 100 \text{ kPa}$$



a
$$n\text{H}_2 = \frac{V}{24.79}$$

$$n = \frac{2.5}{24.79}$$

$$= 0.1 \text{ moles H}_2$$

$$\text{From equation } n\text{Zn} = 0.1 (n\text{H}_2)$$

$$= 0.1 \text{ moles}$$

$$n\text{Zn} = \frac{m}{M}$$

$$0.1 = \frac{m}{65.4}$$

$$= 6.54 \text{ g Zn required}$$

b From equation $n\text{HCl} = 2 \times n\text{H}_2$

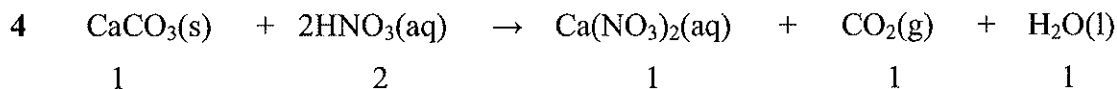
$$= 2 \times 0.1$$

$$= 0.2 \text{ moles}$$

$$n\text{HCl} = cV$$

$$0.2 = 1.5 \times V$$

$$V = 0.13 \text{ L HCl required}$$

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$$\text{a} \quad n\text{CaCO}_3 = \frac{m}{M} = \frac{10}{100.1}$$

$$n = 0.10 \text{ moles}$$

$$\text{From equation } n\text{CaCO}_3 = n\text{CO}_2$$

$$\therefore n\text{CO}_2 = 0.10 \text{ moles}$$

$$n\text{CO}_2 = \frac{V}{22.71}$$

$$0.1 = \frac{V}{22.71}$$

$$V = 2.271 \text{ L CO}_2 \text{ at } 0^\circ\text{C and } 100 \text{ kPa}$$

$$\text{b} \quad n\text{CO}_2 = \frac{V}{24.79}$$

$$0.1 = \frac{V}{24.79}$$

$$V = 2.48 \text{ L CO}_2 \text{ at } 25^\circ\text{C and } 100 \text{ kPa}$$

$$\text{c} \quad \text{From equation } n\text{HNO}_3 = 2 \times n\text{CaCO}_3$$

$$\therefore n\text{HNO}_3 = 2 \times 0.1$$

$$= 0.2 \text{ moles}$$

$$n\text{HNO}_3 = cV$$

$$0.2 = 1.00 \times V$$

$$V = 0.2 \text{ L HNO}_3 \text{ required}$$

$$\text{d} \quad \text{From equation } n\text{CaCO}_3 = n\text{Ca}(\text{NO}_3)_2$$

$$\therefore n\text{Ca}(\text{NO}_3)_2 = 0.10 \text{ moles}$$

$$n\text{Ca}(\text{NO}_3)_2 = \frac{m}{M}$$

$$0.1 = \frac{m}{164.1}$$

$$m = 16.41 \text{ g of Ca}(\text{NO}_3)_2 \text{ produced}$$

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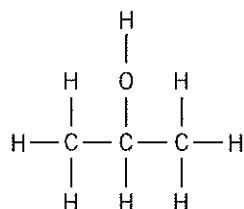
Review exercise 10.5

1 a 1-propanol

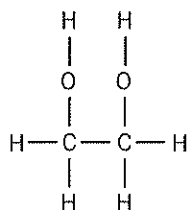
b 1-butanol

c 2-butanol

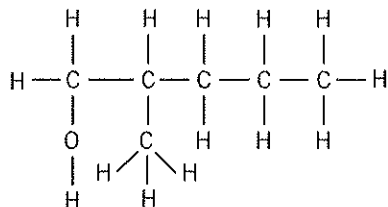
2 a



b



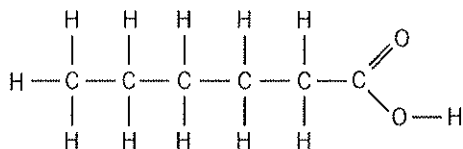
c



3 a pentanoic acid

b 5-methylhexanoic acid

4 a

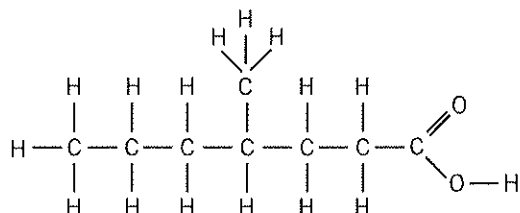


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b

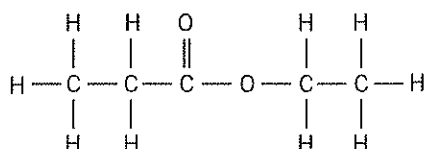


5 They form more H-bonds because they have a C=O group as well as an -OH group, making two H-bonds possible between two molecules.

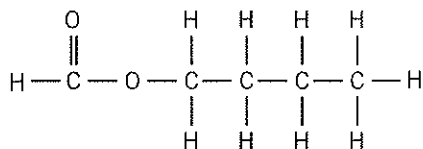
6 a methyl butanoate

b ethyl methanoate

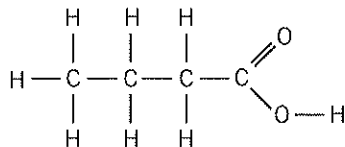
7 a



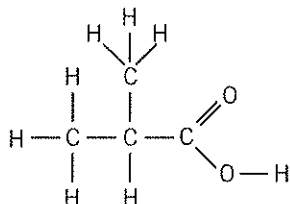
b



8 a



b

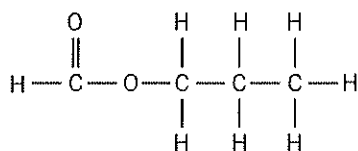


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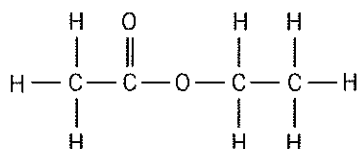
The acidic environment

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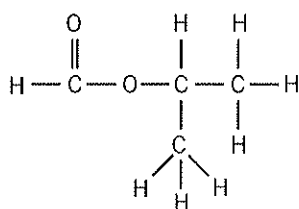
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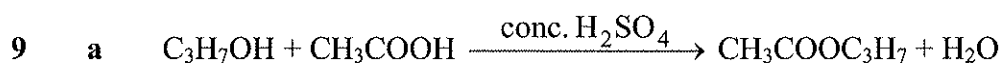
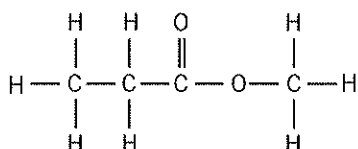
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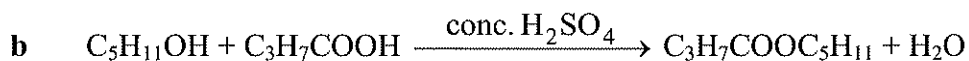
e



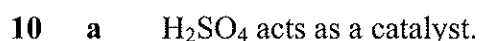
f



The ester is propyl ethanoate.



The ester is pentyl butanoate.



b Refluxing prevents volatile reactants from escaping before equilibrium is reached and allows the reaction to be carried out at temperatures lower than would normally be possible.

Chapter 10 Application and investigation



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- b** $3\text{H}_2\text{SO}_4(\text{aq}) + 2\text{Fe}(\text{OH})_3(\text{s}) \rightarrow \text{Fe}_2(\text{SO}_4)_3(\text{aq}) + 6\text{H}_2\text{O}(\text{l})$
- c** $2\text{HNO}_3(\text{aq}) + \text{CaCO}_3(\text{s}) \rightarrow \text{Ca}(\text{NO}_3)_2(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
- d** $\text{HCl}(\text{aq}) + \text{NaHCO}_3(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
- 2 a i** $\text{Na}^+(\text{aq}), \text{SO}_4^{2-}(\text{aq}), \text{OH}^-(\text{aq}), \text{H}^+(\text{aq}), \text{H}_2\text{O}(\text{l})$
- ii** $\text{H}^+(\text{aq}), \text{Na}^+(\text{aq}), \text{OH}^-(\text{aq})$ all at 2 mol L^{-1}
- b i** $\text{H}^+(\text{aq}), \text{SO}_4^{2-}(\text{aq}), \text{H}_2\text{O}(\text{l})$
- ii** $\text{H}^+(\text{aq})$
- c i** $\text{Na}^+(\text{aq}), \text{SO}_4^{2-}(\text{aq}), \text{H}_2\text{O}(\text{l})$
- ii** $\text{Na}^+(\text{aq}), \text{SO}_4^{2-}(\text{aq})$
- 3 a i** Pipette: used to place an accurate volume of solution into a conical flask.
- ii** Burette: used to deliver variable volumes into a conical flask.
- iii** Conical flasks: used to mix two solutions.
- b i** citric acid
- ii** NaOH
- iii** deionised water
- 4** Sodium hydroxide cannot be made as a primary standard and hence must be standardised by titration with an acid of accurately known concentration.
- 5 a** A good primary standard has a relatively high molecular weight to minimise weighing errors, does not react with any component of the atmosphere such as oxygen, moisture or carbon dioxide, and is available in a very pure form.
- b** Investigation
- 6 a** $n\text{NaHCO}_3 = cV = 2 \times 1$
 $= 2 \text{ moles}$
- $$n = \frac{m}{M}$$
- $$2 = \frac{m}{84.008}$$
- $$m = 168 \text{ g}$$
- b** $n\text{Na}_2\text{CO}_3 = cV$
 $n = 0.05 \times 0.5$

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$$= 0.025 \text{ moles}$$

$$n = \frac{m}{M}$$

$$0.025 = \frac{m}{105.99}$$

$$m = 2.65 \text{ g}$$

c $n\text{Ba(OH)}_2 \cdot 8\text{H}_2\text{O} = cV$

$$\begin{aligned} n &= 2 \times 10^{-3} \times 2 \\ &= 0.004 \end{aligned}$$

$$n = \frac{m}{M}$$

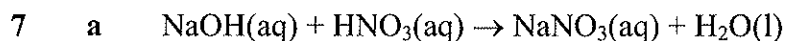
$$\begin{aligned} m &= 0.004 \times 315.444 \\ &= 1.26 \text{ g} \end{aligned}$$

d $n\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = cV$

$$\begin{aligned} n &= 0.150 \times 0.25 \\ &= 0.0375 \text{ moles} \end{aligned}$$

$$n = \frac{m}{M}$$

$$\begin{aligned} m &= 0.0375 \times 126.068 \\ &= 4.728 \text{ g} \end{aligned}$$



$$\begin{aligned} n\text{HNO}_3 &= cV \\ &= 0.0961 \times 0.02 \\ &= 1.9 \times 10^{-3} \end{aligned}$$

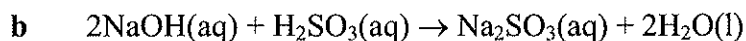
$$\begin{aligned} \text{From equation } n\text{NaOH} &= n\text{HNO}_3 \\ &= 1.9 \times 10^{-3} \end{aligned}$$

$$\begin{aligned} n\text{NaOH} &= cV \\ 1.9 \times 10^{-3} &= 0.118 \times V \\ V &= 1.62 \times 10^{-2} \text{ L} \end{aligned}$$

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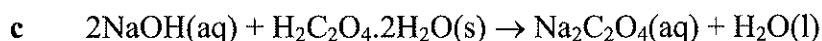
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$$\begin{aligned}n\text{H}_2\text{SO}_3 &= cV \\&= 0.0531 \times 0.02 \\&= 1.062 \times 10^{-3} \text{ moles}\end{aligned}$$

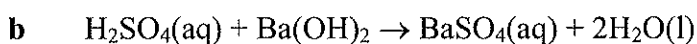
$$\begin{aligned}n\text{NaOH} &= 2 \times n\text{H}_2\text{SO}_3 \text{ from equation} \\2 \times 1.062 \times 10^{-3} &= 0.118 \times V \\V &= 18 \times 10^{-3} \text{ L}\end{aligned}$$



$$\begin{aligned}n\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O} &= \frac{m}{M} \\&= \frac{0.134}{126} \\&= 1 \times 10^{-3} \text{ moles} \\2 \times n(\text{oxalic acid}) &= n(\text{NaOH}) \\n &= cV \\2 \times 10^{-3} &= 0.118 \times V \\V &= 16.95 \times 10^{-3} \text{ L}\end{aligned}$$



$$\begin{aligned}n\text{NaOH} &= cV \\&= 0.5 \times 0.02 \\&= 0.01 \text{ moles} \\n\text{H}_2\text{SO}_4 &= 0.5n\text{NaOH} \\&= 0.005 \text{ moles H}_2\text{SO}_4 \\n &= cV \\V &= \frac{0.005}{0.202} \\&= 2.48 \times 10^{-2} \text{ L}\end{aligned}$$

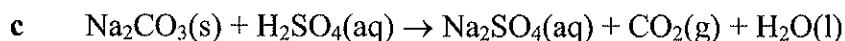


$$\begin{aligned}n\text{Ba(OH)}_2 &= 0.02 \times 0.165 \\&= 0.0033 \text{ moles}\end{aligned}$$

$$n\text{Ba(OH)}_2 = n\text{H}_2\text{SO}_4$$

$$\therefore n\text{H}_2\text{SO}_4 = 0.0033 = 0.202 \times V$$

$$V = 1.63 \times 10^{-2} \text{ L}$$

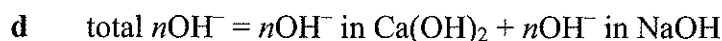


$$\begin{aligned} n\text{Na}_2\text{CO}_3 &= \frac{m}{M} \\ &= \frac{0.343}{106} \\ &= 3.24 \times 10^{-3} \text{ moles} \end{aligned}$$

$$n\text{Na}_2\text{CO}_3 = n\text{H}_2\text{SO}_4$$

$$n\text{H}_2\text{SO}_4: 3.24 \times 10^{-3} = 0.202 \times V$$

$$V = 1.60 \times 10^{-2} \text{ L}$$



$$\begin{aligned} n\text{Ca(OH)}_2 &= \frac{m}{M} \\ &= \frac{0.0746}{74.1} \\ &= 1 \times 10^{-3} \text{ moles} \end{aligned}$$

$$\begin{aligned} \text{moles OH}^- &= 1 \times 10^{-3} \times 2 \\ &= 2 \times 10^{-3} \text{ moles} \end{aligned}$$

$$\begin{aligned} n\text{NaOH} &= \frac{m}{M} \\ &= \frac{0.247}{40} \\ &= 6.2 \times 10^{-3} \text{ moles OH}^- \end{aligned}$$

$$\begin{aligned} \text{Total } n\text{OH}^- &= 2 \times 10^{-3} + 6.2 \times 10^{-3} \\ &= 8.18 \times 10^{-3} \text{ moles} \end{aligned}$$

$$\begin{aligned} n\text{H}_2\text{SO}_4 &= n\text{OH}^- \times 0.5 \\ &= 4.08 \times 10^{-3} \text{ moles} \end{aligned}$$

$$n = cV$$

$$= 4.08 \times 10^{-3} = 0.202 \times V$$

$$V\text{H}_2\text{SO}_4 = 2.02 \times 10^{-2} \text{ L}$$



$$n\text{HCl} = cV$$

$$= 0.121 \times 0.02565$$

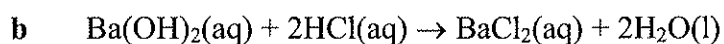
$$= 3.1 \times 10^{-3} \text{ moles}$$

$$n\text{HCl} = n\text{NaOH}$$

$$n\text{NaOH} = cV$$

$$3.1 \times 10^{-3} = c \times 0.020$$

$$c = 0.16 \text{ mol L}^{-1}$$



$$n\text{HCl} = cV$$

$$= 0.0503 \times 0.01523$$

$$= 7.66 \times 10^{-4} \text{ moles}$$

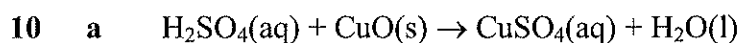
$$n\text{Ba(OH)}_2 = 0.5n\text{HCl}$$

$$= 0.5 \times 7.66 \times 10^{-4}$$

$$= 3.83 \times 10^{-4} \text{ moles}$$

$$\text{Ba(OH)}_2 = 3.83 \times 10^{-4} \div 0.02$$

$$= 1.92 \times 10^{-2} \text{ mol L}^{-1}$$



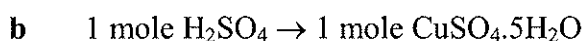
$$n\text{CuO} = \frac{m}{M} = \frac{1.05}{79.5}$$

$$= 0.013 \text{ moles}$$

$$n\text{CuO} = n\text{H}_2\text{SO}_4$$

$$n\text{H}_2\text{SO}_4 = 0.13 \text{ moles} = 2.0 \times V$$

$$V = 6.6 \times 10^{-3} \text{ L}$$



$$\therefore n\text{CuSO}_4 \cdot 5\text{H}_2\text{O} = 0.013 \text{ moles}$$

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$$n = \frac{m}{M}$$

$$0.013 = \frac{m}{249.6}$$

$$m = 3.24 \text{ g}$$

11 Investigation

- 12** A known mass of the tablets could be dissolved in 20 mL of water. This solution could be titrated against HCl of known concentration to determine the concentration of NaHCO_3 .

13

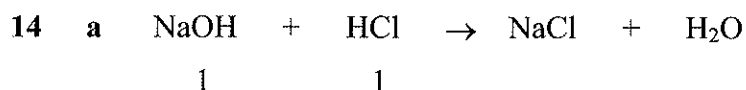
$$\begin{aligned} n\text{NaOH} &= cV \\ &= 0.119 \times 0.02053 \\ &= 2.4 \times 10^{-3} \text{ moles} \\ \therefore n \text{ vitamin C} &= 2.44 \times 10^{-3} \text{ moles} \end{aligned}$$

$$n = \frac{m}{M}$$

$$2.44 \times 10^{-3} = \frac{m}{176}$$

$$m = 0.4294 \text{ g}$$

$$\begin{aligned} \% \text{ in capsule} &= \frac{0.4294}{0.450} \times 100 \\ &= 95.4\% \end{aligned}$$



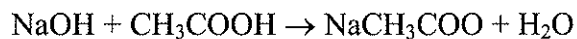
$$\begin{aligned} n\text{HCl} &= cV \\ &= 0.125 \times 0.01759 \\ &= 0.0022 \text{ moles} \end{aligned}$$

$$\begin{aligned} n\text{NaOH} &= n\text{HCl} \\ &= 0.0022 \text{ moles} \end{aligned}$$

$$\begin{aligned} c &= \frac{n}{V} = \frac{0.0022}{0.020} \\ &= 0.11 \text{ mol L}^{-1} \end{aligned}$$

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$$\begin{aligned} n_{\text{NaOH}} &= cV \\ &= 0.11 \times 0.03812 \\ &= 4.2 \times 10^{-3} \text{ moles} \end{aligned}$$

$$\begin{aligned} n_{\text{NaOH}} &= n_{\text{CH}_3\text{COOH}} \\ &= 4.2 \times 10^{-3} \end{aligned}$$

$$\begin{aligned} n_{\text{CH}_3\text{COOH}} &= 4.2 \times 10^{-3} \\ &= \frac{m}{M} \end{aligned}$$

$$4.2 \times 10^{-3} = \frac{m}{60}$$

$$m = 0.25 \text{ g in } 5.00 \text{ mL sample vinegar}$$

$$\begin{aligned} \text{b } \% \text{ mass} &= 0.25/5.00 \times 100 \\ &= 5\% \text{ ethanoic acid in vinegar} \end{aligned}$$



$$\begin{aligned} n_{\text{HCl}} &= cV \\ &= 0.110 \times 0.02462 \\ &= 2.7 \times 10^{-3} \text{ moles} \end{aligned}$$

$$\begin{aligned} \therefore n_{\text{NH}_3} &= 2.7 \times 10^{-3} \\ &= cV \end{aligned}$$

$$2.7 \times 10^{-3} = c \times 0.02$$

$$c = 0.135 \text{ mol L}^{-1} \text{ ammonia}$$

Number of moles NH_3 present in 250 mL

$$\begin{aligned} n &= cV \\ &= 0.135 \times 0.25 \\ &= 0.339 \text{ moles} \end{aligned}$$

$$n = \frac{m}{M}$$

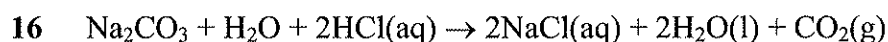
$$0.339 = \frac{m}{17}$$

$$m = 0.575 \text{ g ammonia in } 9.97 \text{ g}$$

% mass ammonia in household ammonia

$$= \frac{0.575}{9.97} \times 100$$

$$= 5.77\%$$



$$\begin{aligned} n\text{HCl} &= cV \\ &= 0.104 \times 0.02520 \\ &= 2.62 \times 10^{-3} \text{ moles} \end{aligned}$$

$$\begin{aligned} n\text{Na}_2\text{CO}_3 &= 0.5n\text{HCl} \\ n\text{Na}_2\text{CO}_3 &= 0.5 \times 2.62 \times 10^{-3} \\ &= 1.31 \times 10^{-3} \text{ moles} \end{aligned}$$

$$n\text{Na}_2\text{CO}_3 = \frac{m}{M}$$

$$1.31 \times 10^{-3} = \frac{m}{106}$$

$$m = 0.1389 \text{ g}$$

$$\begin{aligned} \text{Mass of water in washing soda} &= 0.374 - 0.1389 \\ &= 0.235 \text{ g H}_2\text{O} \end{aligned}$$

$$n\text{H}_2\text{O} = \frac{m}{M}$$

$$n = \frac{0.235}{18}$$

$$n = 0.0131 \text{ moles}$$

$$\begin{aligned} \text{Ratio of } n\text{Na}_2\text{CO}_3 : n\text{H}_2\text{O} &= 1.31 \times 10^{-3} : 1.31 \times 10^{-2} \\ &= 1 : 10 \end{aligned}$$

\therefore Number of molecules of water of crystallisation = 10

i.e. $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$

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17 The pH at the equivalence point is below 7 due to the reaction of NH_4^+ produced at the equivalence point reacting with H_2O to form H_3O^+ . Phenolphthalein changes colour above 7, and therefore it would not be appropriate.

18 a i Na^+ , CH_3COO^- , H_2O , CH_3COOH , OH^-

ii basic

iii phenolphthalein

b i KCl(aq) , H_2O

ii neutral

iii bromothymol blue

c i NH_4^+ , NO_3^- , NH_3 , H_3O^+

ii acidic

iii methyl orange

d i $\text{BaCl}_2\text{(aq)}$, H_2O

ii neutral

iii bromothymol blue

e i $\text{H}_2\text{CO}_3\text{(aq)}$, NaCl , H_3O^+ , HCO_3^-

ii acidic

iii methyl orange

19 a i $n\text{O}_2 = \frac{V}{22.71}$

$$0.500 = \frac{V}{22.71}$$

$$V = 11.36 \text{ L O}_2 \text{ at } 0^\circ\text{C and } 100 \text{ kPa}$$

ii $n\text{O}_2 = \frac{V}{24.79}$

$$0.500 = \frac{V}{24.79}$$

$$V = 12.4 \text{ L O}_2 \text{ at } 25^\circ\text{C and } 100 \text{ kPa}$$

b i $n\text{N}_2 = \frac{V}{22.71}$

$$= \frac{2}{22.71}$$

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$$= 0.09 \text{ moles N}_2 \text{ at } 0^\circ\text{C and } 100 \text{ kPa}$$

$$\text{ii } n\text{N}_2 = \frac{V}{24.79}$$

$$= \frac{10}{24.79}$$

$$= 0.40 \text{ moles N}_2 \text{ at } 25^\circ\text{C and } 100 \text{ kPa}$$

$$20 \quad \text{a} \quad \text{i} \quad n\text{Cl}_2 = \frac{V}{22.71}$$

$$= \frac{3}{22.71}$$

$$= 0.13 \text{ moles}$$

$$n\text{Cl}_2 = \frac{m}{M}$$

$$0.13 = \frac{m}{71}$$

$$m = 9.5 \text{ g Cl}_2 \text{ at } 0^\circ\text{C and } 100 \text{ kPa}$$

$$\text{ii } n\text{Cl}_2 = \frac{V}{24.79}$$

$$\frac{3}{24.79}$$

$$= 0.12 \text{ moles}$$

$$n = \frac{m}{M}$$

$$0.12 = \frac{m}{71}$$

$$m = 8.7 \text{ g Cl}_2 \text{ at } 25^\circ\text{C and } 100 \text{ kPa}$$

$$\text{b} \quad \text{i} \quad n\text{CO}_2 = \frac{m}{M}$$

$$= \frac{55}{44}$$

$$= 1.25 \text{ mol}$$

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$$n = \frac{V}{22.71}$$

$$1.25 = \frac{V}{22.71}$$

$$V = 28.39 \text{ L CO}_2 \text{ at } 0^\circ\text{C and } 100 \text{ kPa}$$

ii $n\text{CO}_2 = 1.25 \text{ mol}$

$$n = \frac{V}{24.79}$$

$$1.25 = \frac{V}{24.79}$$

$$V = 30.99 \text{ L CO}_2 \text{ at } 25^\circ\text{C and } 100 \text{ kPa}$$

21 a $n\text{FeS}_2 = \frac{m}{M}$

$$= \frac{1000}{120}$$
$$= 8.33 \text{ mol}$$

From equation, $\text{FeS}_2:\text{O}_2$ equals 1:2.75

$$\begin{aligned} n\text{O}_2 &= 2.75 \times n\text{FeS}_2 \\ &= 2.75 \times 8.33 \\ &= 22.92 \text{ mol O}_2 \end{aligned}$$

$$n\text{O}_2 = \frac{V}{22.71}$$

$$22.92 = \frac{V}{22.71}$$

$$V = 520.5 \text{ L O}_2 \text{ at } 0^\circ\text{C and } 100 \text{ kPa}$$

b i $n\text{SO}_2 = 2 \times n\text{FeS}_2$

$$= 2 \times 8.33$$
$$= 16.67 \text{ moles}$$

At 0°C and 101.3 kPa :

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$$16.67 = \frac{V}{22.71}$$

$$V = 378.6 \text{ L SO}_2 \text{ produced at } 0^\circ\text{C and } 100 \text{ kPa}$$

ii At 25°C and 101.3 kPa :

$$16.67 = \frac{V}{24.79}$$

$$V = 413.3 \text{ L SO}_2 \text{ produced at } 25^\circ\text{C and } 100 \text{ kPa}$$

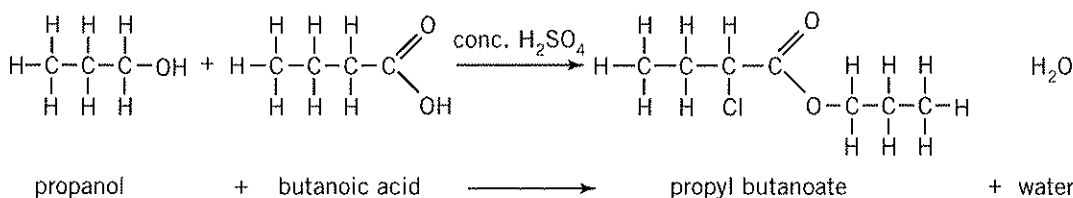
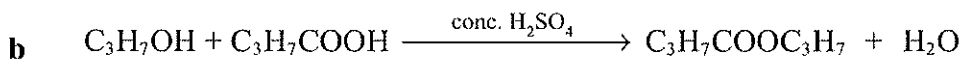
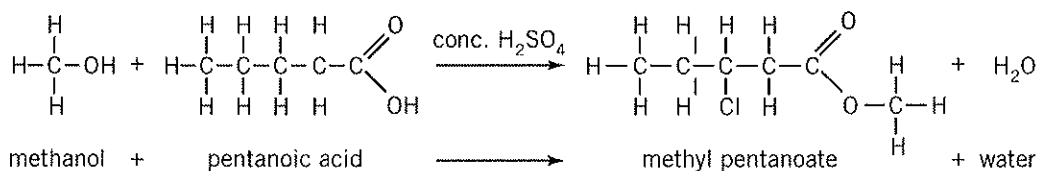
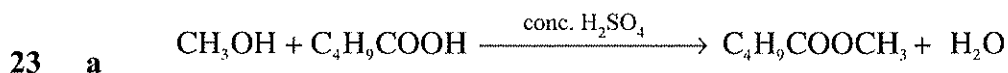
22 a $\text{CH}_3\text{CH}_2\text{CH}_3$; $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$; $\text{CH}_3\text{CH}_2\text{COOH}$

b propane -41°C

1-propanol 97°C

propanoic acid 141°C

Propane has only weak dispersion forces between molecules \therefore lowest boiling point. 1-propanol has strong H-bonds between molecules but propanoic acid has stronger intermolecular forces due to two H-bonds between acid molecules.



24 a Reflux ethanol with butanoic acid with concentrated H_2SO_4 as a catalyst as an esterification process

b Reflux pentanol with propanoic acid with concentrated H_2SO_4 as a catalyst as an esterification process

Refluxing is necessary so that none of the volatile components of the reaction are lost while this slow, low-yielding reaction proceeds.

25 Investigation

Module 2

REVIEW

1 A

2 D

3 D

4 B

5 D

6 A

7 B

8 C

9 A

10 B

11 a $\text{CH}_3\text{COOH}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{CH}_3\text{COONa}(\text{aq}) + \text{H}_2\text{O}(\text{l})$

b $n_{\text{NaOH}} = 0.095 \times 0.02$

$$= 1.9 \times 10^{-3} \text{ moles}$$

$$\text{Average} = \frac{18.9 + 18.8 + 19.0}{3}$$

$$= 18.9 \text{ mL}$$

$$n_{\text{CH}_3\text{COOH}} = 1.9 \times 10^{-3} = c \times 0.0189$$

$$c = 0.1005 \text{ mol L}^{-1} \text{ acetic acid}$$

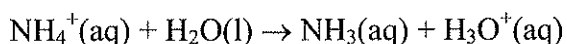
c $c_1 V_1 (\text{original}) = c_2 V_2 (\text{volumetric flask})$

$$c \times 0.02 = 0.1005 \times 0.2$$

$$c = 1.005 \text{ mol L}^{-1}$$

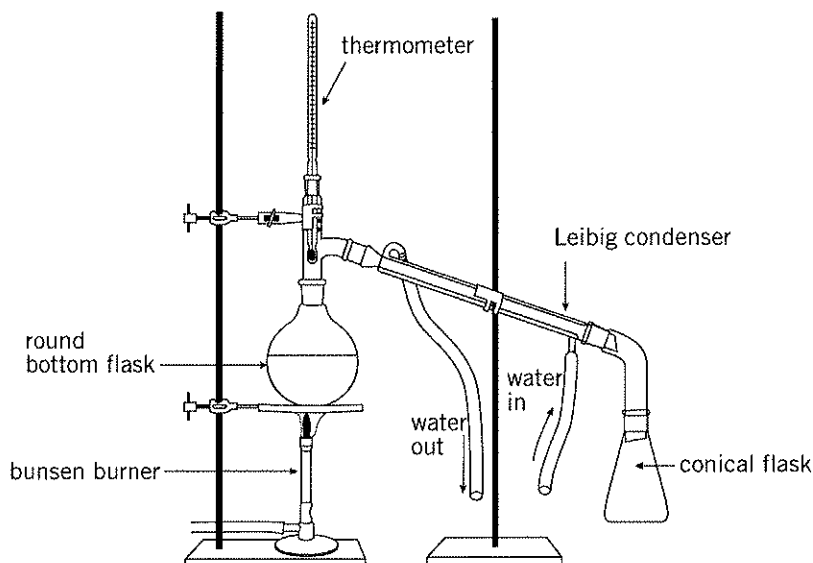
d Phenolphthalein; pH at end point will be above 7.

e Distilled water. The number of moles of vinegar added will not be affected by water in the flask.

12 $\text{NH}_3(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})$ The OH^- causes the solution to be basic.The H_3O^+ causes the solution to be acidic.

- 13** **a** HCl is a strong acid which dissociates completely and therefore has high conductivity and low pH. Acetic acid is weak and therefore only slightly dissociates, causing a higher pH and lower conductivity.
- b** The CH_3COO^- reacts with H_2O to form some OH^- ions.
- c** Greater number of ions are present in the solution in Beaker 3.
- 14** **a** Bacteria can decompose organic matter to produce H_2S , which then oxidises to SO_2 . Burning of fossil fuels and smelting of sulfide ores results in sulfur compounds which are oxidised to SO_2 .
- b** $2\text{CuFeS}_2(\text{s}) + 5\text{O}_2(\text{g}) + 2\text{SiO}_2(\text{s}) \rightarrow 2\text{Cu}(\text{l}) + 4\text{SO}_2(\text{g}) + 2\text{FeSiO}_3(\text{l})$
- c** **i** $\text{SO}_3(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{SO}_4(\text{aq})$ sulfuric acid
- ii** Lakes and waterways become acidic, killing aquatic life. Soil can become acidic, affecting plant growth. Limestone can be dissolved by the action of acid rain. These are all of concern if we want to protect our environment.
- iii** Student opinion
- 15** **a** Both molecules have an $-\text{OH}$ group but ethanoic acid contains a $\text{C}=\text{O}$ group, which increases the intermolecular forces. Even though 1-butanol has more dispersion forces than acetic acid, acetic acid has more H-bonding and so the intermolecular forces are very nearly the same in each substance.
- b** **i** $\text{CH}_3\text{COOH}(\text{aq}) + \text{C}_4\text{H}_9\text{OH}(\text{l}) \rightarrow \text{CH}_3\text{COOC}_4\text{H}_9(\text{aq}) + \text{H}_2\text{O}(\text{l})$
 Catalyst is conc. H_2SO_4 .
- ii** H_2SO_4 acts as a catalyst.
- c** Refluxing allows the reaction mixture to be boiled without losing the volatile reactants and increases the time over which this quite slow reaction can occur.
- d** Acetic acid would be more soluble than 1-butanol. Compound X would be least soluble.

e



- 16 a i Equilibrium shifts to the left and more $\text{CO}_2(\text{g})$ is produced
 \therefore the drink goes flat.
- ii More space above the liquid means that pressure is lower and $\text{CO}_2(\text{aq}) \rightarrow \text{CO}_2(\text{g})$ and the drink will be flat.
- b The soft drink could be carefully poured into a beaker and gently heated. If bubbles of CO_2 are observed forming in the solution (which they should be), this would indicate that the equilibrium is shifting to the left ($\text{CO}_2(\text{g}) \leftrightarrow \text{CO}_2(\text{aq})$). As the addition of heat favours the reverse reaction, it follows that this reaction must be endothermic. Therefore the forward reaction must be exothermic.

Alternatively:

Take an unopened bottle of soft drink. Immediately upon opening it, insert a thermometer (at the same initial temperature as the drink) and observe any change in temperature. Bubbles of CO_2 gas should be observed forming in the solution, indicating that the equilibrium is shifting to the left (as written). If a temperature decrease is recorded (which it should), this will indicate that the reverse reaction is endothermic, as heat is being absorbed from the surroundings (the drink itself). Therefore the forward reaction must be exothermic.

- 17 a An acid loses an H^+ to become its conjugate base,
 e.g. $\text{C}_6\text{H}_5\text{N}_2\text{O}_5(\text{aq}) \rightarrow \text{C}_6\text{H}_4\text{N}_2\text{O}_5^-(\text{aq})$.
- b Yellow. The CN^- would react with the H_3O^+ , causing the equilibrium to shift to the right.
- $$\text{CN}^-(\text{aq}) + \text{H}_3\text{O}^+ \rightarrow \text{H}_2\text{O}(\text{l}) + \text{HCN}(\text{aq})$$

Solutions Manual: Module 2

The acidic environment

Chemistry
Contexts 2
SECOND EDITION

- c i Yes: strong acid–strong base titration. $\text{pH} = 7$ at end point and the pH changes from 11 to 3 very rapidly.
- ii Yes: weak base–strong acid; $\text{pH} < 7$ at end point.
- iii No: weak acid–strong base; $\text{pH} > 7$ at end point.
- 18 a $[\text{H}^+] = 0.12 \text{ mol L}^{-1}$
 $\text{pH} = -\log_{10}[\text{H}^+] = -\log_{10}[0.12]$
 $\text{pH} = 0.92$
- b $\text{Mg}(\text{OH})_2(\text{aq}) + 2\text{HCl}(\text{aq}) \rightarrow \text{MgCl}_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$
The antacid reacts with excess acid to produce salt and water.
- 19 a Curve 1
- b The acetate ion reacts with water to form OH^- and CH_3COOH , raising the pH at equivalence point. There is no such reaction in the $\text{NaCl}(\text{aq})$ produced at the equivalence point where $\text{pH} = 7$.
- c Starting pH is higher for acetic acid due to less dissociation.
- 20 a $\text{CH}_3\text{COOH}(\text{aq}) \leftrightarrow \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}^+(\text{aq})$
If CH_3COO^- is added then the equilibrium will shift left, resulting in less H^+ and a higher pH.
Also $\text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{CH}_3\text{COOH}(\text{aq}) + \text{OH}^-(\text{aq})$. The presence of OH^- ions raises the pH.
- b Buffering systems result from the action of a weak acid in approximately equal concentration with its conjugate base. Acetic acid is a weak acid and the acetate ions from the sodium acetate would be close in concentration to the acetic acid. Thus the resulting solution could act as a buffering system.
- 21
$$\begin{aligned} n(\text{SO}_2) &= 2 \times n(\text{CuFeS}_2) \\ &= 2 \times \text{mass}(\text{CuFeS}_2) \div \text{molar mass}(\text{CuFeS}_2) \\ \text{Vol}(\text{SO}_2) &= 2 \times \text{mass}(\text{CuFeS}_2) \div \text{molar mass}(\text{CuFeS}_2) \times \text{molar vol}_{\text{SATP}} \\ &= 2 \times 500 \times 10^3 \div 183.54 \times 24.79 \\ &= 135066 \text{ L} \end{aligned}$$
- 22 a Decreased pressure would cause the equilibrium to shift to the left. This would result in the formation of $\text{CaCO}_3(\text{s})$ and $\text{CO}_2(\text{g})$.
- b Change in temperature. Increased temperature would cause this exothermic reaction to shift to the left to counteract the change. This would cause a decrease in $[\text{Ca}^{2+}]$.

CHAPTER 11: THE ROLE OF CHEMISTS AND CHEMICAL ANALYSIS**Review exercise 11.1**

- 1 Most products used in the home, car etc, e.g. shampoo, medications, food additives, laundry detergents
- 2 Investigation
- 3 Energy industry, mineral industry, petrochemical industry

Review exercise 11.2

- 1 Qualitative analysis identifies substances present in a sample.
Quantitative analysis determines the amount of each substance present.
- 2 Treating substances with electromagnetic radiation and measuring the amount of absorption or emission.
- 3
 - a AAS is most useful for determining concentrations of cations in samples. The sample to be tested is vaporised in a flame. A beam of light emitted by a cathode lamp of the element being investigated is shone through the vaporised sample. The element absorbs that wavelength of radiation and the remaining light is analysed to determine the intensities remaining. By comparing to known samples gathered under the same conditions, concentrations can be identified.
 - b AAS is a relatively cheap and rapid process that can detect very low concentrations (ppm and ppb) of elements, and therefore is useful in detecting trace elements.
- 4 Concentration of Pb in solution = 5.5 mg kg^{-1} (from the graph)
Mass of Pb in solution = 5.5×0.1
= 0.55 mg
Concentration of Pb in soil = $\frac{0.55}{0.002}$
= 275 ppm

Review exercise 11.3

- 1 Their electrons occupy different energy levels and will absorb then emit light of different frequencies when they fall back from higher to lower energy levels.
- 2
 - a
 - i Ba^{2+}
 - ii Add to H_2SO_4 solution; a white precipitate of $\text{BaSO}_4(\text{s})$ will form.