Mastering Chemistry

- Book 2A
- Topic 4 Acids and Bases

Content

Continued on next page

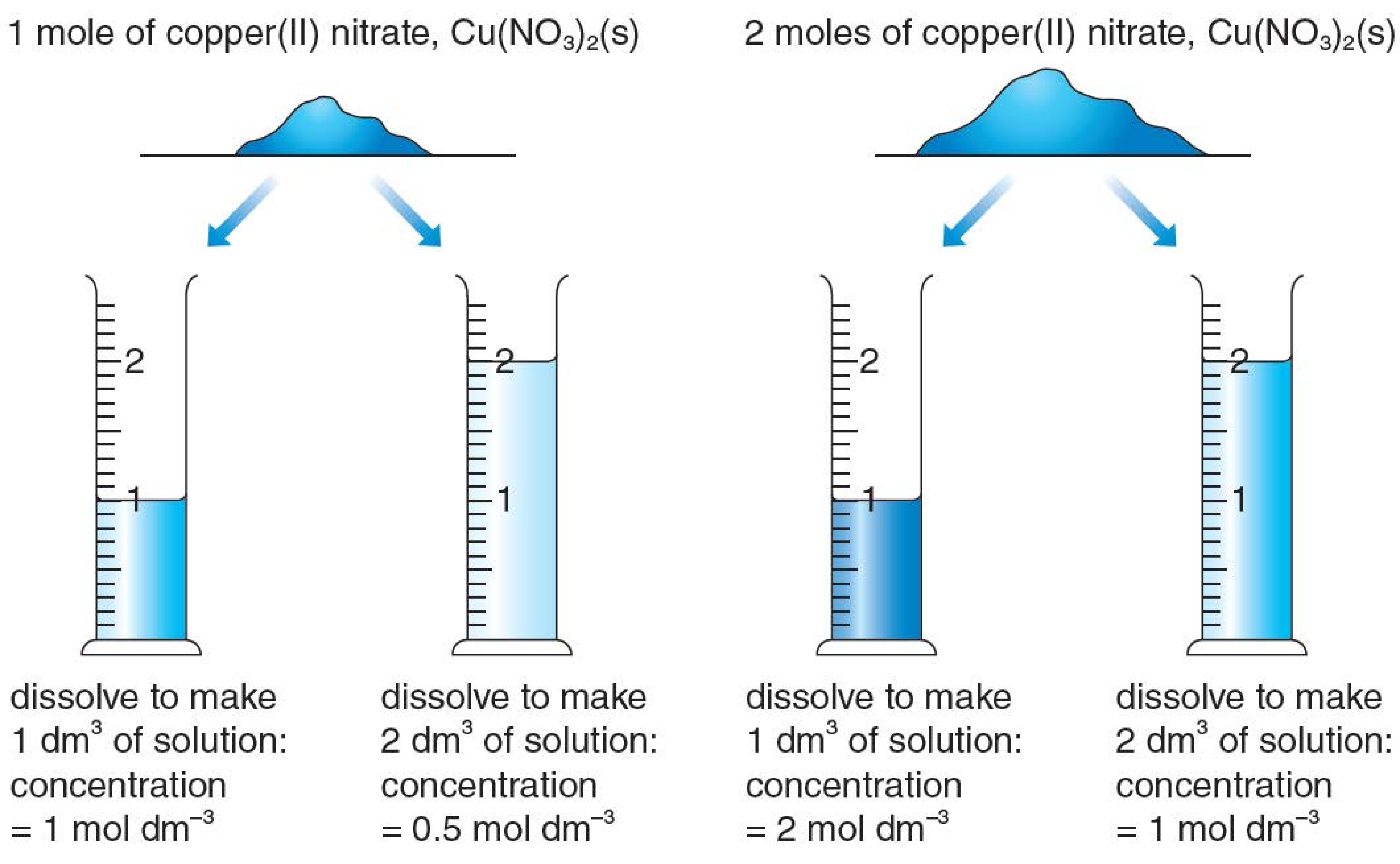
Content

- Key terms
- Summary
- Unit Exercise

15.1 Concentration of a solution (p.44)

- The concentration of a solution tells how much solute is dissolved in a certain volume of solution.
- In chemistry, the concentration of a solution is normally expressed in molarity (or molar concentration), i.e. the number of moles of solute dissolved in one cubic decimeter (dm^3) of solution.
- The units of molarity are mol dm^{-3} or M. 1 mol dm^{-3} means there is 1 mole of solute per cubic decimetre of solution; 2 mol dm^{-3} means there are 2 moles of solute per cubic decimetre of solution, and so on.

15.1 Concentration of a solution (p.44)



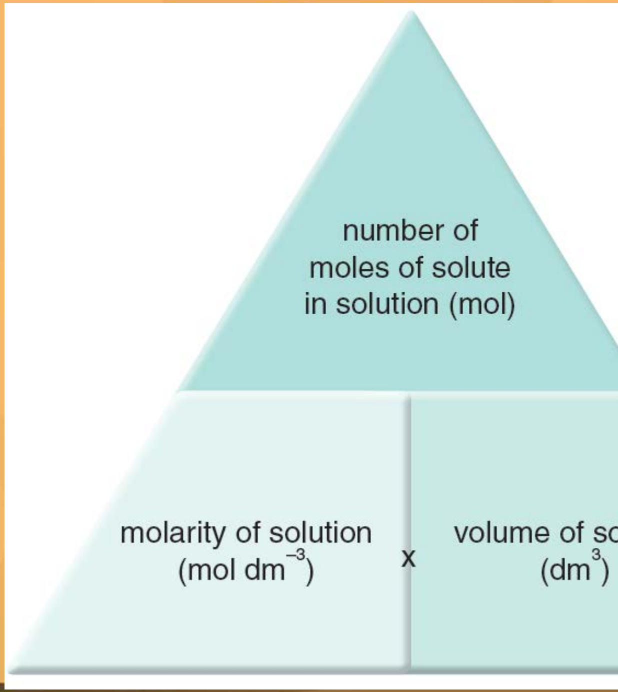
The concentration of a solution depends on the amount of the solute and the volume of the solution

15.1 Concentration of a solution (p.44)

- The molarity of a solution is given by the following expression:

$$\text{Molarity of solution} = \frac{\text{number of moles of solute (mol)}}{\text{volume of solution (dm3)}}$$

- If any one of the sections of the triangle is covered, the relationship between the other two quantities gives the covered quantity.



A triangle illustrating the relationship between molarity of solution, number of moles of solute in solution and volume of solution

15.1 Concentration of a solution (p.44)

- The number of moles of solute in a solution is given by the following expression:

Number of moles of solute in solute
= molarity x volume of solution (in dm^3)

15.1 Concentration of a solution (p.44)

Q (Example 15.1)

A car battery contains 2 350 g of sulphuric acid in 6.00 dm^3 of the battery liquid. What is the concentration of sulphuric acid (in mol dm^{-3})?
(Relative atomic masses: H = 1.0, O = 16.0, S = 32.1)

A

Molar mass of H_2SO_4 = (2 x 1.0 + 32.1 + 4 x 16.0) g mol^{-1}
= 98.1 g mol^{-1}

Number of moles of H_2SO_4 = $\frac{\text{mass}}{\text{molar mass}}$
$= \frac{2\ 350 \text{ g}}{98.1 \text{ g mol}^{-1}}$
= 24.0 mol

Concentration of H_2SO_4 = $\frac{\text{number of moles of H}_2\text{SO}_4}{\text{volume of solution}}$
$= \frac{24.0 \text{ mol}}{6.00 \text{ dm}^3}$
= 4.00 mol dm^{-3}

∴ the concentration of sulphuric acid is 4.00 mol dm^{-3}.

15.1 Concentration of a solution (p.44)

Q (Example 15.2)

What is the mass of zinc nitrate ($Zn(NO_3)_2$) required to prepare 500.0 cm^3 of 0.640 mol dm^{-3} solution?

(Relative atomic masses: N = 14.0, O = 16.0, Zn = 65.4)

A

Number of moles of $Zn(NO_3)_2$ = molarity x volume of solution (in dm^3)

$= 0.640 \text{ mol dm}^{-3} \times \frac{500.0}{1\,000} \text{ dm}^{-3}$

= 0.320 mol

Molar mass of $Zn(NO_3)_2$ = (65.4 + 2 x 14.0 + 6 x 16.0) g mol^{-1}

= 189.4 g mol^{-1}

Mass of $Zn(NO_3)_2$ required

= number of moles of $Zn(NO_3)_2$ x molar mass of $Zn(NO_3)_2$

= 0.320 mol x 189.4 g mol^{-1}

= 60.6 g

∴ 60.6 g of zinc nitrate are required.

15.1 Concentration of a solution (p.44)

Q (Example 15.3)

100.0 cm^3 of 1.20 mol dm^{-3} $FeSO_4$(aq) are mixed with 200.0 cm^3 of 0.700 mol dm^{-3} $Fe_2(SO_4)_3$(aq). What is the concentration of SO_4^{2-}(aq) ions in the resulting mixture?

A

1 mole of $FeSO_4$ contains 1 mole of SO_4^{2-} ions.

Number of moles of SO_4^{2-} ions in $FeSO_4$(aq) = 1.20 mol dm^{-3} x $\frac{100.0}{1\ 000}$ dm^3

= 0.120 mol

1 mole of $Fe_2(SO_4)_3$ contains 3 mole of SO_4^{2-} ions.

Number of moles of SO_4^{2-} ions in $Fe_2(SO_4)_3$ = 3 x 0.700 mol dm^{-3} x $\frac{200.0}{1\ 000}$ dm^3

= 0.420 mol

Total number of moles of SO_4^{2-} ions = (0.120 + 0.420) mol

= 0.540 mol

Total volume of resulting mixture = (100.0 + 200.0) cm^3

= 300.0 cm^3

Concentration of SO_4^{2-} ions in resulting mixture = $\frac{0.540 \text{ mol}}{\left(\frac{300.0}{1\ 000}\right)\text{dm}^3}$

= 1.80 mol dm^{-3}

∴ the concentration of SO_4^{2-} ions in resulting mixture is 1.80 mol dm^{-3}.

15.1 Concentration of a solution (p.44)

Practice 15.1

1 What is the concentration (in mol dm^{-3}) of a solution of sodium carbonate (Na_2CO_3) that contains 47.7 g of solute in 1.80 dm^3 of solution?
(Relative atomic masses: C = 12.0, O = 16.0, Na = 23.0)

2 A sample of potassium hydrogenphthalate ($C_8H_5O_4K$) is dissolved completely in deionised water and then diluted to 250.0 cm^3. A solution of concentration 0.0280 mol dm^{-3} is obtained. What is the mass of the sample?
(Relative atomic masses: H = 1.0, C = 12.0, O = 16.0, K = 39.1)

3 20.0 cm^3 of 1.00 mol dm^{-3} KCl(aq) are mixed with 30.0 cm^3 of 2.00 mol dm^{-3} K_2SO_4(aq). What is the concentration of K^+(aq) ions in the resulting mixture?

15.1 Concentration of a solution (p.44)

Practice 15.1 (continued)

1 Molar mass of Na_2CO_3 = (2 x 23.0 + 12.0 + 3 x 16.0) g mol^{-1}
= 106.0 g mol^{-1}

Number of moles of Na_2CO_3 = $\frac{\text{mass}}{\text{molar mass}}$

= $\frac{47.7\ g}{106.0\ g\ mol^{-1}}$

= 0.450 mol

Molarity of sodium carbonate solution = $\frac{\text{number of moles of } Na_2CO_3}{\text{volume of solution}}$

= $\frac{0.450\ mol}{1.80\ dm^3}$

= 0.250 mol dm^{-3} (M)

∴ concentration of the solution is 0.250 mol dm^{-3}.

2 Molarity of potassium hydrogenphthalate solution = $\frac{\text{number of moles of } C_8H_5O_4K}{\text{volume of solution}}$

0.0280 mol dm^{-3} = $\frac{\text{number of moles of } C_8H_5O_4K}{\frac{250.0}{1\ 000}\ dm^3}$

Number of moles of $C_8H_5O_4K$ = 0.0280 mol dm^{-3} x $\frac{250.0}{1\ 000}$ dm^3

= 0.00700 mol

Molar mass of $C_8H_5O_4K$ = (8 x 12.0 + 5 x 1.0 + 4 x 16.0 + 39.1) g mol^{-1}
= 204.1 g mol^{-1}

Mass of sample = number of moles of $C_8H_5O_4K$ x molar mass of $C_8H_5O_4K$
= 0.00700 mol x 204.1 g mol^{-1}
= 1.43 g

∴ the mass of the sample is 1.43 g.

15.1 Concentration of a solution (p.44)

Practice 15.1 (continued)

3 1 mole of KCl contains 1 mole of K^+ ions.

Number of moles of K^+ ions in KCl(aq) $= 1.00 \text{ mol dm}^{-3} \times \frac{20.0}{1\ 000} \text{ dm}^3$

$= 0.0200$ mol

1 mole of K_2SO_4 contains 2 moles of K^+ ions.

Number of moles of K^+ ions in K_2SO_4(aq) $= 2 \times 2.00 \text{ mol dm}^{-3} \times \frac{30.0}{1\ 000} \text{ dm}^3$

$= 0.120$ mol

Total number of moles of K^+ ions $= (0.0200 + 0.120)$ mol

$= 0.140$ mol

Total volume of resulting mixture $= (20.0 + 30.0) \text{ cm}^3$

$= 50.0 \text{ cm}^3$

Concentration of K^+ ions in resulting mixture $= \dfrac{0.140 \text{ mol}}{\frac{50.0}{1\ 000} \text{ dm}^3}$

$= 2.80 \text{ mol dm}^{-3}$

∴ the concentration of K^+(aq) ions in the resulting mixture is 2.80 mol dm^{-3}.

15.2 Indicators (p.48)

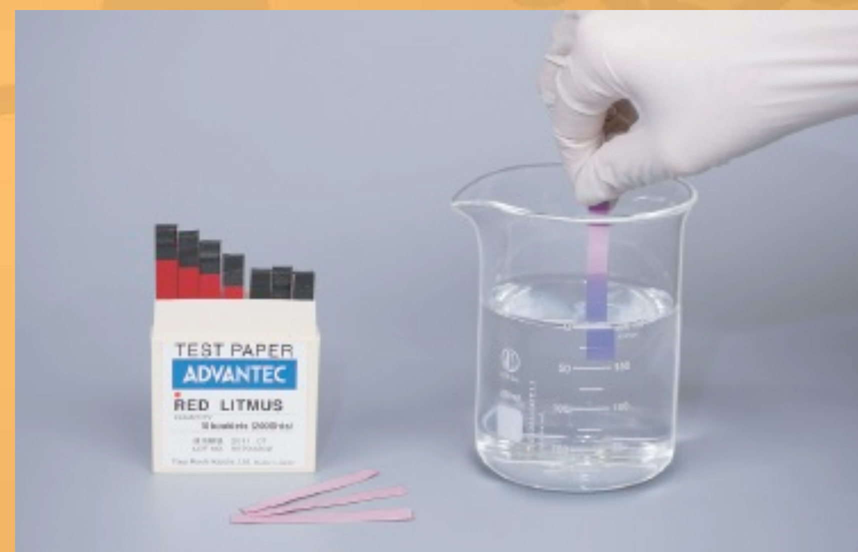
- Many **indicators (指示劑)** are dyes extracted from natural sources. Litmus solution is an example. It is purple in neutral solutions. When **litmus solution (石蕊試液)** is added to an acid, it turns red. When added to an alkali, it turns blue.

Litmus solution turns red in an acid (left) and blue in an alkali (right)

15.2 Indicators (p.48)

- **Litmus paper (石蕊試紙)** is paper that has been soaked in litmus solution. It comes in blue and red forms.
- Blue litmus paper turns red in an acid. Red litmus paper turns blue in an alkali.

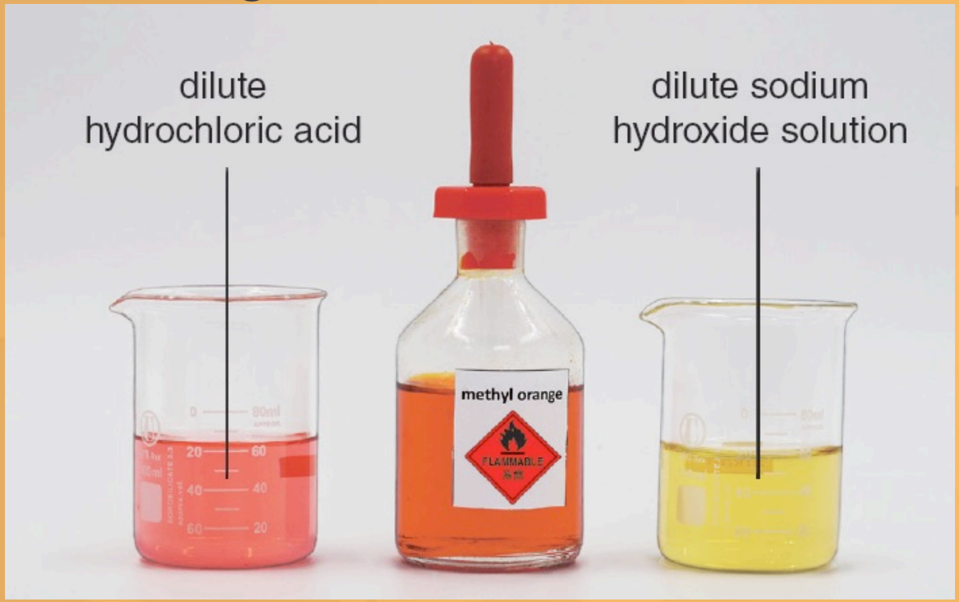
Blue litmus paper turns red in an acid

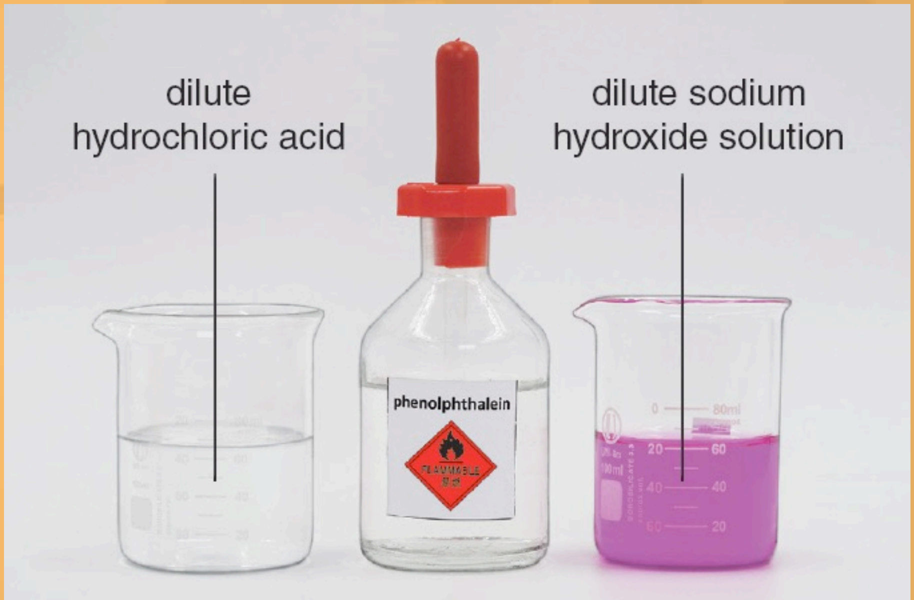


Red litmus paper turns blue in an alkali

15.2 Indicators (p.48)

- Others that have been frequently used are **methyl orange (甲基橙試液)** and **phenolphthalein (酚酞試液)**. They give colour changes different from litmus solution.





Methyl orange (left) and phenolphthalein (right) show different colours in dilute hydrochloric acid and dilute sodium hydroxide solution

15.2 Indicators (p.48)

Indicator	Colour in dilute hydrochloric acid	Colour in dilute sodium hydroxide solution
Methyl orange	red	yellow
Phenolphthalein	colourless	pink

15.3 The pH scale (p.49)

- You can say how acidic or alkaline a solution is by a scale of numbers called the **pH scale (pH標度)**.
- pH is a measure of the concentration of hydrogen ions in a solution. The concentration of hydrogen ions can be stated in mol dm^{-3}.
- In different solutions, the concentration of hydrogen ions can have a wide range of values (from about 1 mol dm^{-3} to 10^{-14} mol dm^{-3}). The use of log10 function simplifies the numbers involved.

15.3 The pH scale (p.49)

- The pH scale is defined by the expression:

$$pH = -\log_{10}[H^+(aq)]$$

- Because pH values are logarithms, they have no units.
- The concentration of hydrogen ions in a solution from its pH value can be calculated by using the expression:

$$[H^+(aq)] = 10^{-pH}$$

15.3 The pH scale (p.49)

Q (Example 15.4)

A 0.120 mol dm^{-3} nitric acid ($HNO_3(aq)$) is prepared. The acid dissociates into hydrogen ions and nitrate ions completely in water. What is its pH value?

A

$$HNO_3(aq) \longrightarrow H^+(aq) + NO_3^-(aq)$$

0.120 mol dm^{-3} → 0.120 mol dm^{-3}

According to the equation, 1 mole of HNO_3 dissociates to give 1 mole of hydrogen ions.

i.e. $[H^+(aq)] = 0.120$ mol dm^{-3}

pH of acid $= -\log_{10}(0.120)$

$= -(-0.921)$

$= 0.921$

∴ the pH value of the nitric acid is 0.921.

15.3 The pH scale (p.49)

Q (Example 15.5)

The pH of a sample of lemon juice is 2.15. What is the concentration of hydrogen ions in the lemon juice?

A

$[H^+(aq)] = 10^{-pH}$

$= 10^{-2.15}$

$= 7.08 \times 10^{-3}$ mol dm^{-3}

∴ the concentration of hydrogen ions in the lemon juice is 7.08 x 10^{-3} mol dm^{-3}.

15.3 The pH scale (p.49)

Practice 15.2

1 A bottle of hydrochloric acid is shown below. It is known that the acid dissociates into hydrogen ions and chloride ions completely.

Hydrochloric acid dissociates completely according to the following equation:

$$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$$

0.0500 mol dm^{-3} ? mol dm^{-3}

According to the equation, 1 mole of HCl dissociates to give 1 mole of hydrogen ions.

i.e. concentration of hydrogen ions = 0.0500 mol dm^{-3}

pH of acid = $-\log_{10}(0.0500) = -(-1.30) = 1.30$

What is the pH of the acid?

15.3 The pH scale (p.49)

Practice 15.2 (continued)

2 A calcium hydroxide solution has a pH of 11.9. What is the concentration of hydrogen ions in the solution?

pH of calcium hydroxide solution = 11.9

i.e. $\log_{10}[H^+(aq)] = -11.9$

$[H^+(aq)] = 10^{-11.9}$ mol dm^{-3}

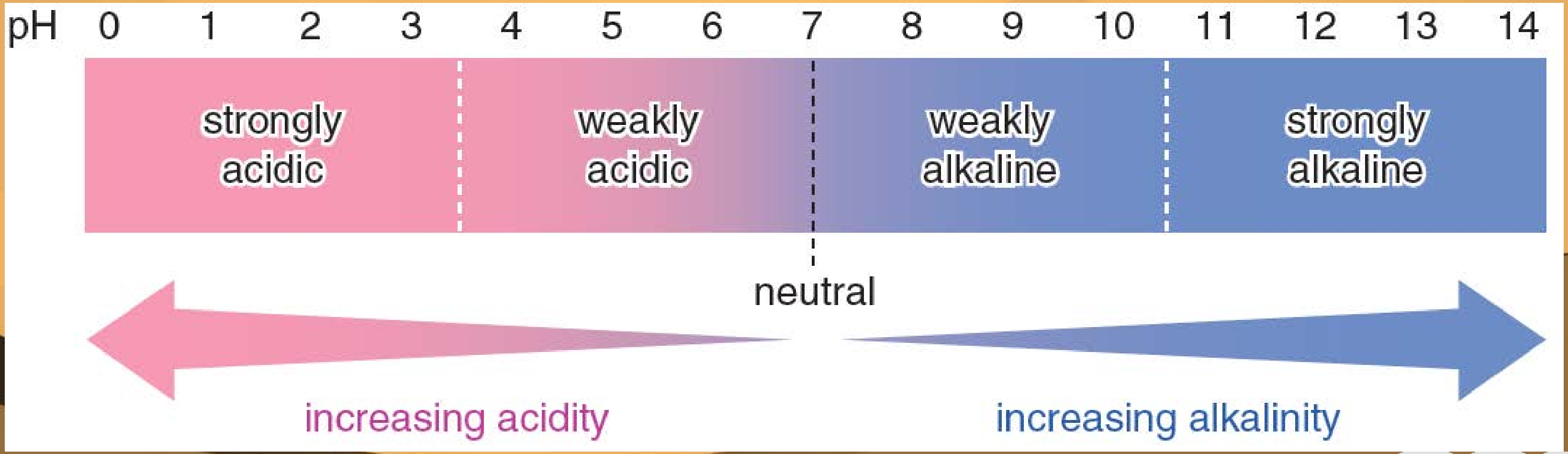
$= 1.26 \times 10^{-12}$ mol dm^{-3}

15.3 The pH scale (p.49)

- The range of a pH scale is from 0 to 14.

On this scale,
- **a solution with a pH less than 7 is acidic (酸性);**
- **a solution with a pH of exactly 7 is neutral (中性);**
- **a solution with a pH more than 7 is alkaline (鹼性).**

- The lower the pH, the more acidic the solution is. The higher the pH, the more alkaline the solution is.



15.3 The pH scale (p.49)

- A pH value of 1 means that the concentration of hydrogen ions in the solution is 0.1 mol dm^{-3}. A pH of 2 means that the concentration of hydrogen ions in the solution is 0.01 mol dm^{-3}. So as the concentration of hydrogen ions increases by a factor of 10, the pH value decreases by 1.

pH	Concentration of hydrogen ions (mol dm^{-3})	pH	Concentration of hydrogen ions (mol dm^{-3})
0	1×10^{0} = 1.0	8	1×10^{-8} = 0.000 000 01
1	1×10^{-1} = 0.1	9	1×10^{-9} = 0.000 000 001
2	1×10^{-2} = 0.01	10	1×10^{-10} = 0.000 000 000 1
3	1×10^{-3} = 0.001	11	1×10^{-11} = 0.000 000 000 01
4	1×10^{-4} = 0.000 1	12	1×10^{-12} = 0.000 000 000 001
5	1×10^{-5} = 0.000 01	13	1×10^{-13} = 0.000 000 000 000 1
6	1×10^{-6} = 0.000 001	14	1×10^{-14} = 0.000 000 000 000 01
7	1×10^{-7} = 0.000 000 1		

15.4 Measuring pH values of solutions (p.53)

Universal indicator solution

- **Universal indicator solution (通用指示劑溶液)** is a mixture of indicators that has different colours in solutions of different pH values.
- Universal indicator solution gives a bright red colour in more acidic solutions (e.g. battery acid). It gives a violet colour in more alkaline solutions.

Classifying substances as acidic, alkaline or neutral using different indicators *Ref.*

Colours of universal indicator solution in solutions of different pH values

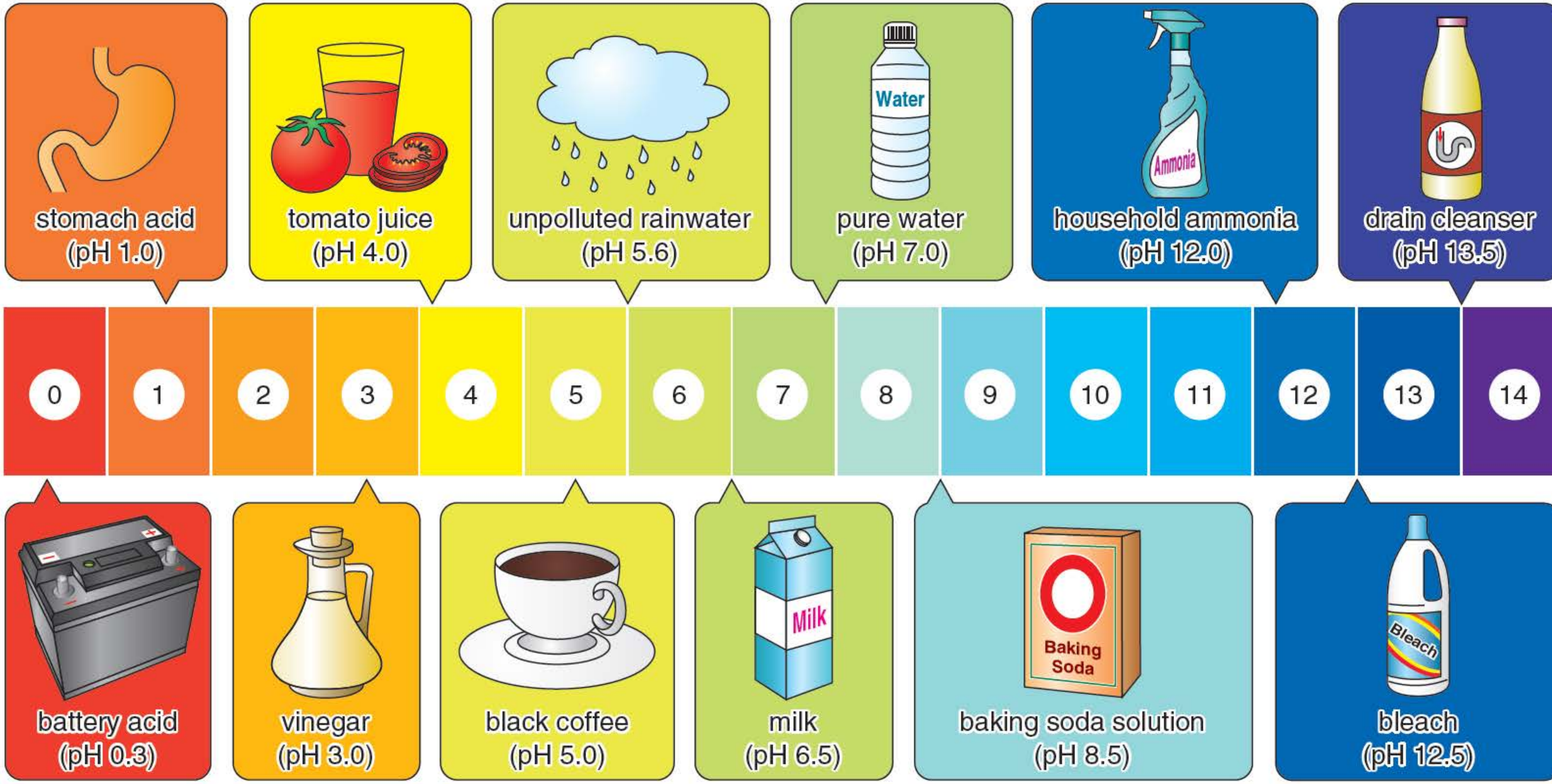
15.4 Measuring pH values of solutions (p.53)

- To measure the pH of a solution, add a few drops of universal indicator solution to the solution. Compare the colour obtained with a standard pH colour chart.
- **pH paper (pH 試紙)** can be used to measure the pH of a solution.

To measure the pH of a solution, add universal indicator solution and compare the colour obtained with a pH colour chart

Using pH paper to find the approximate pH of a solution

15.4 Measuring pH values of solutions (p.53)



pH values of some common solutions

15.4 Measuring pH values of solutions (p.53)

pH meter

- The **pH meter (pH 計)** provides a more accurate measure of pH. When the electrode is placed in a solution, the meter gives a reading of pH.

A pH meter with an electrode in an alkaline solution

15.4 Measuring pH values of solutions (p.53)

pH sensor attached to data-logger

- **A pH sensor (pH 感應器)** can be attached to a **data-logger (數據收集儀)** to measure the pH of a solution accurately. Place the pH sensor in the solution being tested. A reading of pH is shown on the system display.

15.4 Measuring pH values of solutions (p.53)

Practice 15.3

The following table shows the colours of universal indicator solution at different pH values.

Colour	red	orange	yellow	green	blue	navy blue	purple
pH range	0–2	3–4	5–6	7	8–9	10–12	13–14

a) The universal indicator solution appears yellow when added to a sample of saliva.

i) Give the pH range of the saliva. pH 5–6

ii) State what the pH range tells you about the saliva. Saliva is weakly acidic.

b) The universal indicator solution appears purple when added to an oven cleanser.

i) Give the pH range of the cleanser. pH 13–14

ii) State what the pH range tells you about the cleanser.

Oven cleanser is strongly alkaline.

15.5 Strong acids and weak acids (p.55)

Strong and weak acids
Ref.

- Not all acids are equally strong. The ethanoic acid (found in vinegar) used to make pickle vegetables is significantly less acidic than hydrochloric acid of the same concentration.
- When hydrogen chloride gas dissolves in water, almost all the hydrogen chloride molecules dissociate to give hydrogen ions and chloride ions.

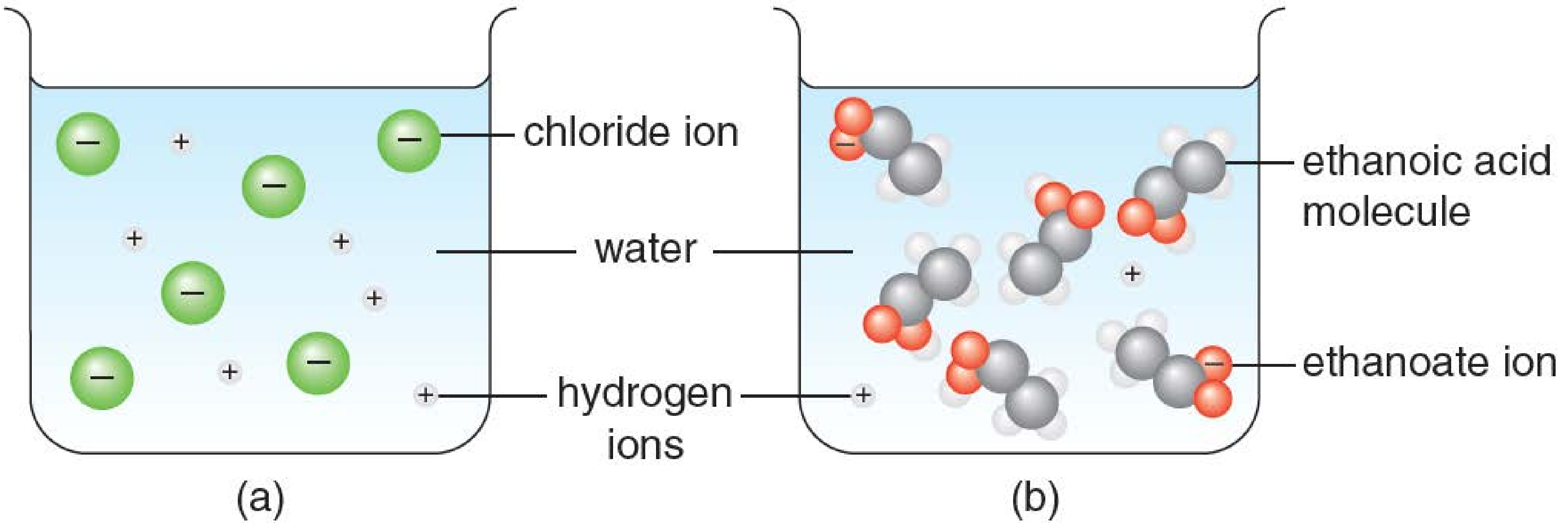
$$HCl(g) \longrightarrow H^+(aq) + Cl^-(aq)$$

- Hydrochloric acid is a **strong acid (強酸)**.

A strong acid is an acid that dissociates almost completely in water to give hydrogen ions.

15.5 Strong acids and weak acids (p.55)

- Sulphuric acid and nitric acid are also strong acids.



(a) Hydrochloric acid contains lots of hydrogen ions;
(b) ethanoic acid of the same concentration contains only a few hydrogen ions

15.5 Strong acids and weak acids (p.55)

- When pure ethanoic acid dissolves in water, only a small fraction of the molecules dissociate into hydrogen ions and ethanoate ions ($CH_3COO^-(aq)$).

$$CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$$

- Ethanoic acid is a **weak acid (弱酸)**.

A weak acid is an acid that dissociates partially in water to give hydrogen ions.

15.5 Strong acids and weak acids (p.55)

- Carbonic acid is formed when carbon dioxide dissolves in water.

$$CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$$

- It is also a weak acid. Its dissociations are described by the ionic equations below.

$$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$$
$$HCO_3^-(aq) \rightleftharpoons H^+(aq) + CO_3^{2-}(aq)$$

Acid	Main types of particle present (besides water molecules)
Ethanoic acid	$H^+(aq)$, $CH_3COO^-(aq)$, $CH_3COOH(aq)$
Carbonic acid	$H^+(aq)$, $HCO_3^-(aq)$, $CO_3^{2-}(aq)$, $CO_2(aq)$, $H_2CO_3(aq)$

Distinguishing between a strong acid and a weak acid
Ref.

15.5 Strong acids and weak acids (p.55)

Q (Example 15.6)

Consider the four solutions W, X, Y and Z listed below.

W: 0.1 mol dm^{-3} HCl(aq)

X: 0.1 mol dm^{-3} H_2SO_4(aq)

Y: 0.1 mol dm^{-3} NaOH(aq)

Z: 0.01 mol dm^{-3} NaOH(aq)

Arrange the above four solutions in increasing order of pH.

15.5 Strong acids and weak acids (p.55)

A

Both HCl(aq) and H_2SO_4(aq) are strong acids. They dissociate almost completely in water.
H_2SO_4(aq) is a dibasic acid while HCl(aq) is a monobasic acid.
Thus, 0.1 mol dm^{-3} H_2SO_4(aq) has a higher concentration of hydrogen ions than 0.1 mol dm^{-3} HCl(aq).
The pH of X (0.1 mol dm^{-3} H_2SO_4(aq)) is lower than that of W (0.1 mol dm^{-3} HCl(aq)).
0.1 mol dm^{-3} NaOH(aq) is more alkaline than 0.01 mol dm^{-3} NaOH(aq).
Thus, the pH of Y (0.1 mol dm^{-3} NaOH(aq) is higher than that of Z (0.01 mol dm^{-3} NaOH(aq).
The increasing order of pH of the above four solutions is X < W < Z < Y.

15.6 Methods for comparing the strengths of acids (p.58)

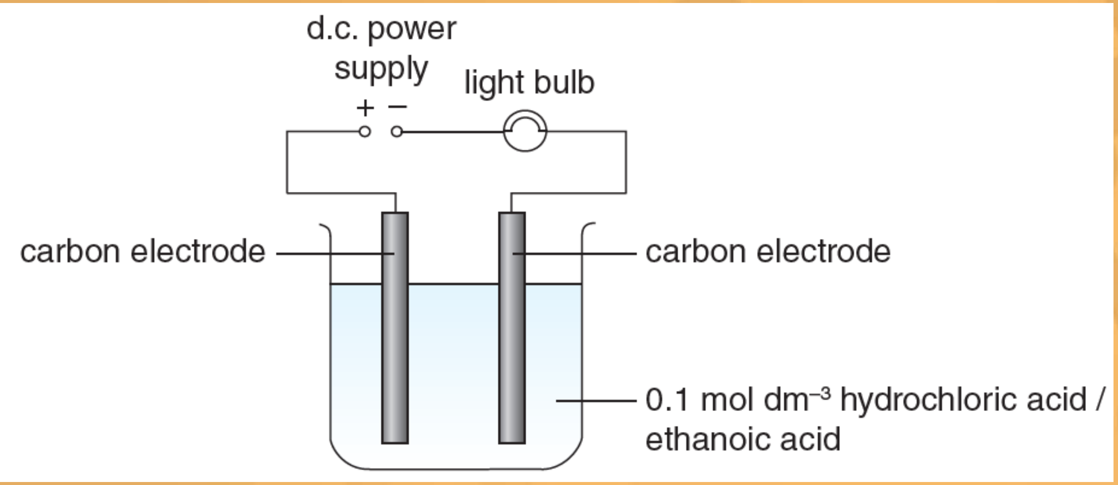
Measuring the pH value

- The pH of 0.1 mol dm^{-3} hydrochloric acid is 1 while that of 0.1 mol dm^{-3} ethanoic acid is 2.9.
- Hydrochloric acid is a strong acid while ethanoic acid is a weak acid. Hydrochloric acid dissociates more and produces a higher concentration of hydrogen ions. Thus, its pH is lower.

15.6 Methods for comparing the strengths of acids (p.58)

Electrical conductivity

- The bulb glows more brightly with hydrochloric acid than it does with ethanoic acid.



Experimental set-up for comparing the electrical conductivities of 0.1 mol dm^{-3} hydrochloric acid and 0.1 mol dm^{-3} ethanoic acid

- The electrical conductivity of a solution is proportional to the concentration of mobile ions. Hydrochloric acid dissociates more, so the concentration of mobile ions is higher. Thus, it is a better conductor of electricity.

15.6 Methods for comparing the strengths of acids (p.58)

Reaction with magnesium

- Add identical magnesium ribbons to each acid separately. More rapid bubbling occurs with hydrochloric acid.
- Hydrochloric acid has a higher concentration of hydrogen ions and thus reacts more rapidly than ethanoic acid with magnesium to form hydrogen gas.

Magnesium reacting with hydrochloric acid (left) and ethanoic acid (right)

	0.1 mol dm^{-3} HCl(aq)	0.1 mol dm^{-3} CH_3COOH(aq)
$[H^+(aq)]$	0.1 mol dm^{-3}	~0.0013 mol dm^{-3}
pH	1	2.9
Electrical conductivity	high	low
Relative rate of reaction with magnesium	high	low

15.7 Strong alkalis and weak alkalis (p.59)

A strong alkali is an alkali that dissociates almost completely in water to give hydroxide ions (OH^-(aq)).

A weak alkali is an alkali that dissociates partially in water to give a small amount of hydroxide ions (OH^-(aq)).

Strong and weak alkalis

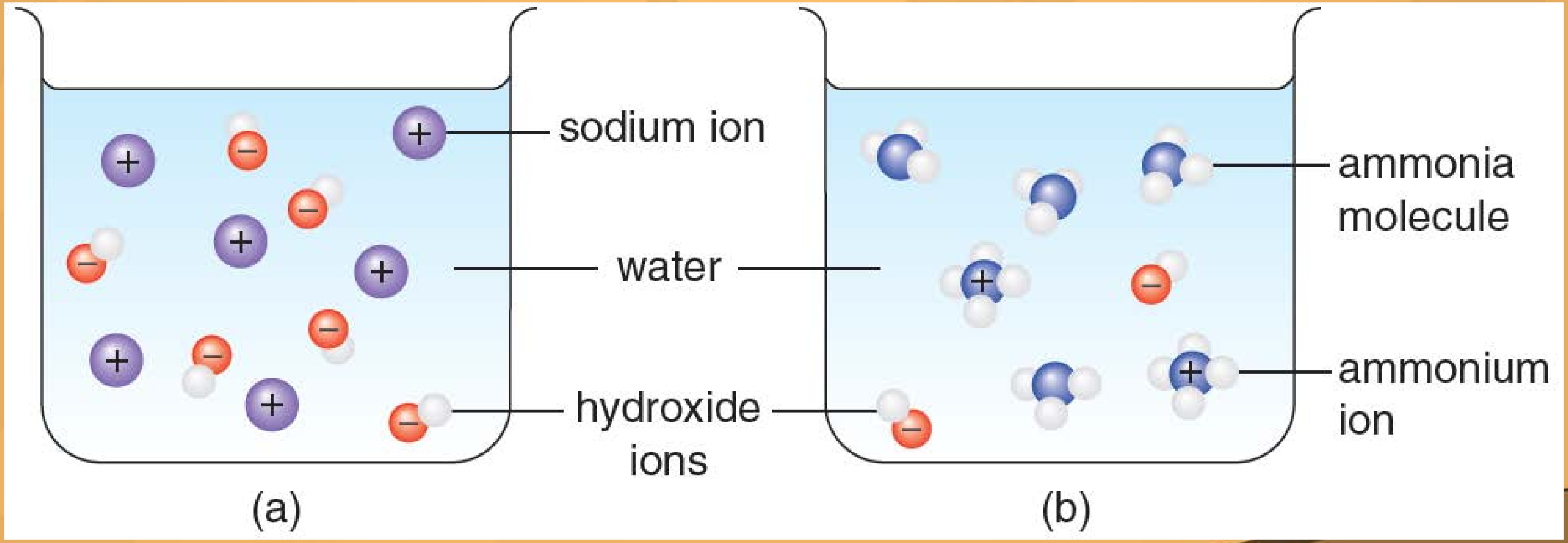
Ref.

15.7 Strong alkalis and weak alkalis (p.59)

- Sodium hydroxide is a strong alkali. It almost completely dissociates into ions in water.

$$NaOH(s) + water \longrightarrow Na^{+}(aq) + OH^{-}(aq)$$

- Potassium hydroxide and barium hydroxide are also strong alkalis.



(a) Sodium hydroxide dissociates almost completely in water;
(b) only a small fraction of ammonia molecules react with water molecules to form hydroxide ions

15.7 Strong alkalis and weak alkalis (p.59)

- Ammonia, on the other hand, is a weak alkali. When ammonia dissolves in water, only a small fraction of the molecules react with water molecules to form hydroxide ions.

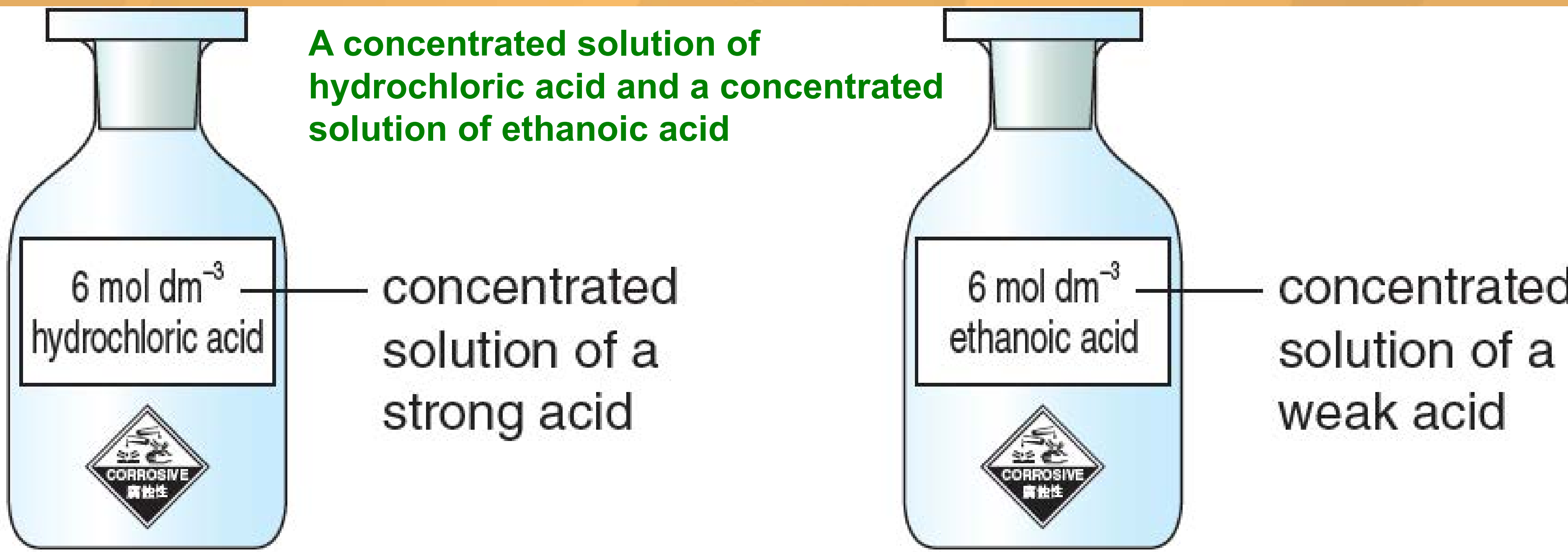
$$NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

	0.1 mol dm^{-3} NaOH(aq)	0.1 mol dm^{-3} NH_3(aq)
pH	13	11
Electrical conductivity	high	low

- Sodium hydroxide solution has a higher concentration of hydroxide ions. Thus, its pH is higher.
- Sodium hydroxide solution is a better conductor of electricity because it has a higher concentration of mobile ions.

15.8 Concentration versus strength (p.61)

- The term concentrated, as applied to an acid, means that a relatively large amount of the pure acid has been dissolved in a relatively small volume of water. Thus, a 6 mol dm^{-3} solution of hydrochloric acid is a concentrated solution of a strong acid while a 6 mol dm^{-3} solution of ethanoic acid is a concentrated solution of a weak acid.



A concentrated solution of hydrochloric acid and a concentrated solution of ethanoic acid

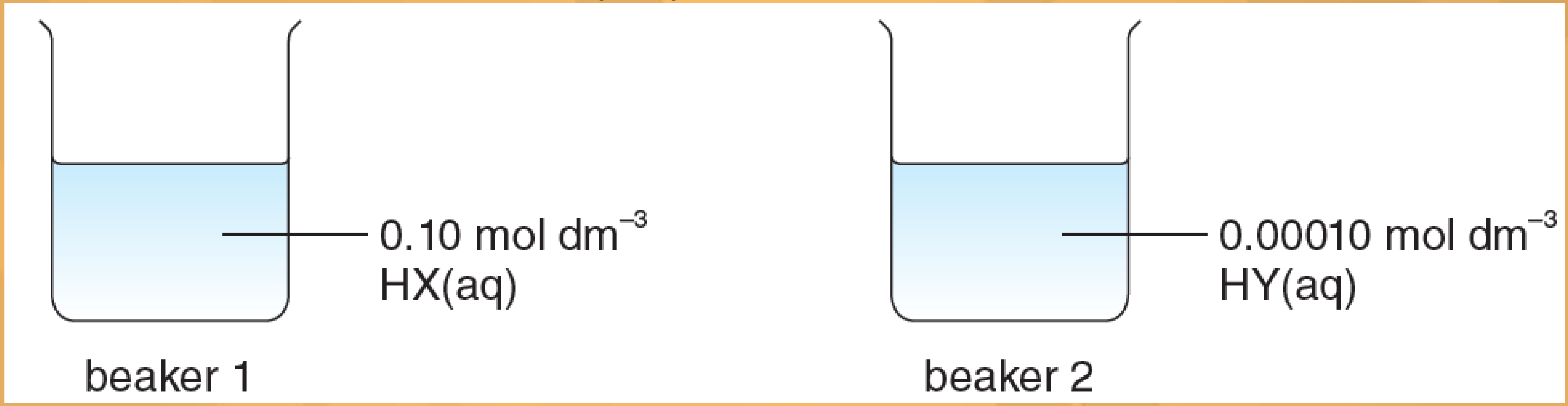
15.8 Concentration versus strength (p.61)

- The strength of an acid refers to how much it dissociates in water. No matter how concentrated a solution of ethanoic acid is, it will never become a strong acid because it always dissociates partially.
- Hydrochloric acid remains to be a strong acid even when diluted because it always dissociates completely.

15.8 Concentration versus strength (p.61)

Practice 15.4

1 HX and HY are monobasic acids. Beaker 1 contains 100 cm^3 of 0.10 mol dm^{-3} HX(aq) and beaker 2 contains 100 cm^3 of 0.00010 mol dm^{-3} HY(aq). Both solutions have a pH of 4.0.



Which of the acid, HX or HY, is stronger? Explain your answer.

2 Suggest how you can show that NaOH(aq) is a stronger alkali than NH_3(aq) through an experiment.

15.8 Concentration versus strength (p.61)

Practice 15.4 (continued)

1 pH of both acids = 4.0
i.e. $\log_{10}[H^+(aq)]$ in both acids = –4.0
$[H^+(aq)]$ in both acids
= $10^{-4.0}$
= 1.0×10^{-4} mol dm^{-3}
HY(aq) is a strong acid.
0.00010 mol dm^{-3} HY(aq) dissociates almost completely in water to give 1.0×10^{-4} mol dm^{-3} $H^+(aq)$ ions.
HX(aq) is a weak acid.
0.10 mol dm^{-3} HX(aq) contains 1.0×10^{-4} mol dm^{-3} of $H^+(aq)$ ions. Hence it can be deduced that HX(aq) dissociates partially in water.

2 Method and observation
Any one of the following:
- Measure the pH of each alkali.
  The pH of $NH_3(aq)$ is lower than that of NaOH(aq).
- Measure the electrical conductivity of each alkali.
  The electrical conductivity of $NH_3(aq)$ is lower than that of NaOH(aq).
- Measure the temperature rise when each alkali is neutralised by dilute hydrochloric acid of the same concentration.
  The temperature rise of $NH_3(aq)$ is lower than that of NaOH(aq).

Conditions for performing a fair composition
- pH — same concentration of $NH_3(aq)$ and NaOH(aq)
- Electrical conductivity — same concentration and volume of $NH_3(aq)$ and NaOH(aq)
- Temperature rise in neutralisation — same volume and concentration of $NH_3(aq)$ and NaOH(aq)

Key terms (p.62)

molarity	摩爾濃度	alkaline	鹼性
indicator	指示劑	universal indicator solution	通用指示劑溶液
litmus solution	石蕊試液	pH meter	pH 計
litmus paper	石蕊試紙	pH sensor	pH 感應器
methyl orange	甲基橙試液	data-logger	數據收集儀
phenolphthalein	酚酞試液	strong acid	強酸
pH scale	pH 標度	weak acid	弱酸
acidic	酸性	strong alkali	強鹼
neutral	中性	weak alkali	弱鹼

Summary (p.63)

1 The molarity of a solution is the number of moles of solute dissolved in 1 dm^3 of the solution.

$$\text{Molarity of solution (mol dm}^{-3}) = \frac{\text{number of moles of solute (mol)}}{\text{volume of solution (dm}^3)}$$

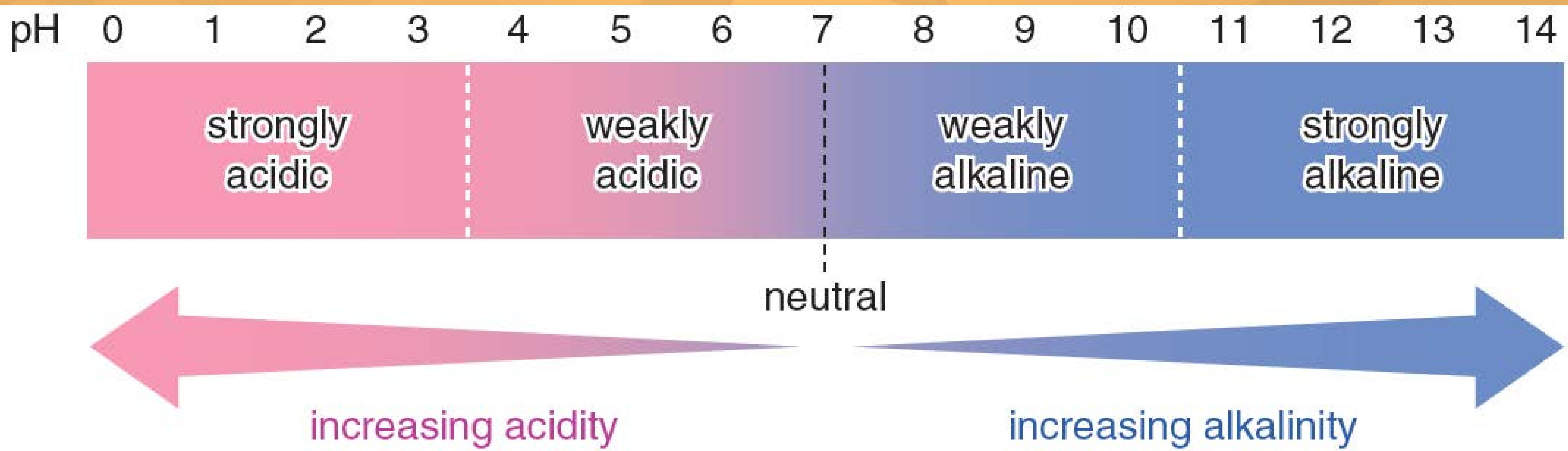
2 The table below summarises the colours of some indicators in dilute hydrochloric acid and dilute sodium hydroxide solution.

Indicator	Colour in dilute hydrochloric acid	Colour in dilute sodium hydroxide solution
Litmus solution	red	blue
Methyl orange	red	yellow
Phenolphthalein	colourless	pink

Summary (p.63)

3 The pH of a solution is $-\log_{10}$ of the molar concentration of hydrogen ions in the solution.
$pH = -\log_{10}[H^+(aq)]$

4 The pH scale is used to measure the degree of acidity or alkalinity of a solution. Its value ranges from 0 to 14.



Summary (p.63)

5 Methods used to measure the pH values of solutions include:
a) using universal indicator solution;
b) using a pH meter; and
c) using a pH sensor attached to a data-logger.

6 a) A strong acid is an acid that dissociates almost completely in water to give hydrogen ions.
A weak acid is an acid that dissociates partially in water to give hydrogen ions.
b) Compared to a weak acid of the same concentration, a strong acid has
- a lower pH;
- a higher electrical conductivity;
- a higher rate of reaction with metals.

Summary (p.63)

7 a) A strong alkali is an alkali that dissociates almost completely in water to give hydroxide ions ($OH^-(aq)$).
A weak alkali is an alkali that dissociates partially in water to give a small amount of hydroxide ions ($OH^-(aq)$).

b) Compared to a weak alkali of the same concentration, a strong alkali has
- a higher pH;
- a higher electrical conductivity.

8 The strength of an acid or alkali refers to how much it dissociates in water.
The concentration of an acid or alkali refers to the amount of acid or alkali dissolved in a unit volume of solution.

Unit Exercise (p.65)

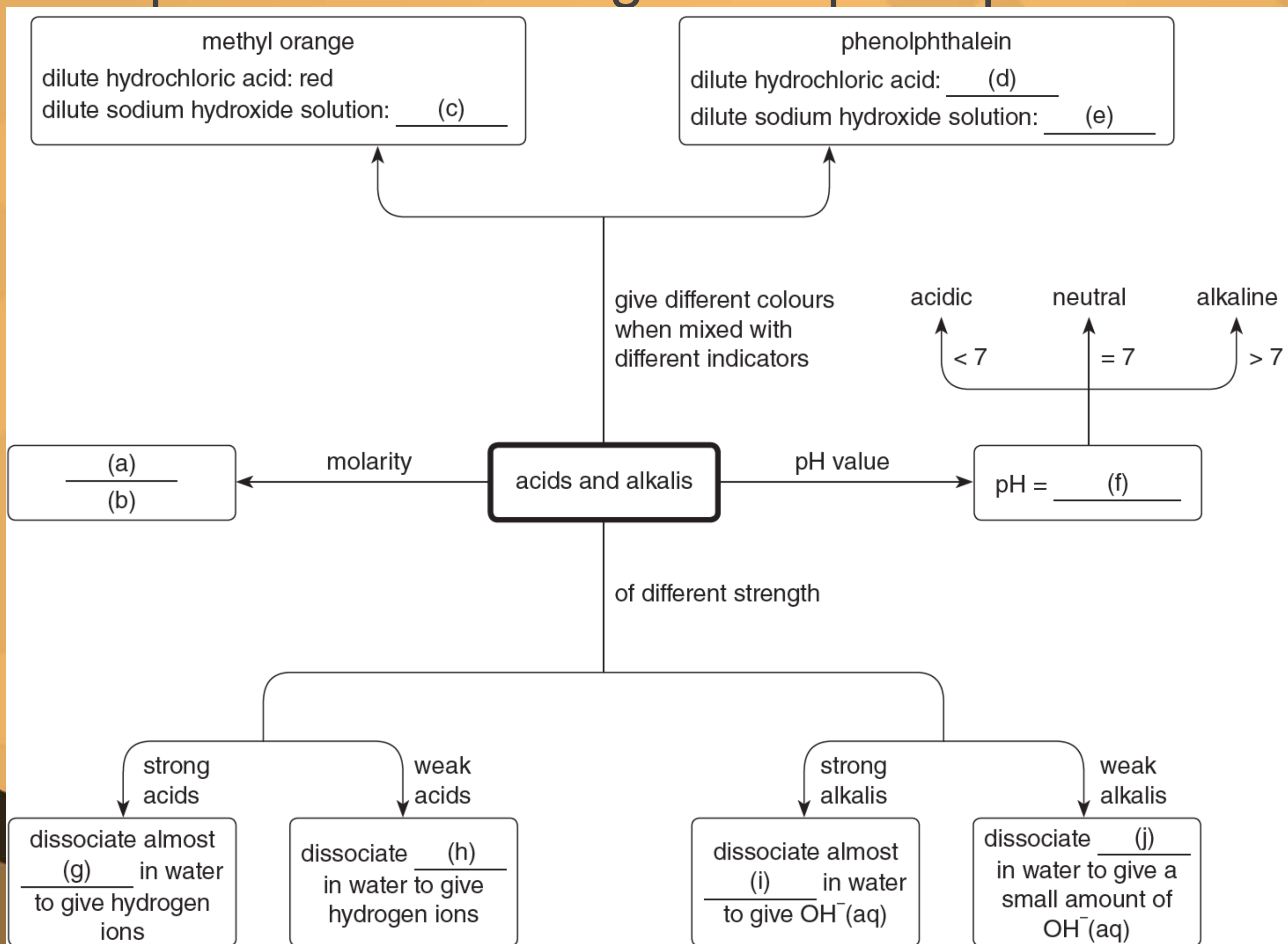
Note: Questions are rated according to ascending level of difficulty (from 1 to 5):

question targeted at level 3 and above;
question targeted at level 4 and above;
question targeted at level 5.
‘ * ’ indicates 1 mark is given for effective communication.

Unit Exercise (p.65)

PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.



a) number of moles
b) volume (in dm^3)
c) yellow
d) colourless
e) pink
f) $-\log_{10}[H^+(aq)]$
g) completely
h) partially
i) completely
j) partially

Unit Exercise (p.65)

PART II MULTIPLE CHOICE QUESTIONS

2 17.65 g of pure ethanedioic acid crystals ($(COOH)_2 \cdot 2H_2O$) are dissolved in deionised water and made up to 500.0 cm^3. What is the molarity of the solution?
(Relative atomic masses: H = 1.0, C = 12.0, O = 16.0)

A 0.280 mol dm^{-3}
B 0.430 mol dm^{-3}
C 0.560 mol dm^{-3}
D 0.883 mol dm^{-3}

Answer: A

Explanation:

Molar mass of $(COOH)_2 \cdot 2H_2O$ = (2 x 12.0 + 4 x 16.0 + 2 x 1.0 + 2 x 18.0) g mol^{-1}
= 126.0 g mol^{-1}

$$\text{Number of moles of } (COOH)_2 \cdot 2H_2O = \frac{\text{mass}}{\text{molar mass}} = \frac{17.65 \text{ g}}{126.0 \text{ g mol}^{-1}} = 0.140 \text{ mol}$$

$$\text{Molarity of solution} = \frac{\text{number of moles of } (COOH)_2 \cdot 2H_2O}{\text{volume of solution}} = \frac{0.140 \text{ mol}}{\frac{500.0}{1\,000} \text{ dm}^3} = 0.280 \text{ mol dm}^{-3}$$

Unit Exercise (p.65)

3 Methyl orange and phenolphthalein are added to dilute hydrochloric acid separately. Which of the following combinations is correct?

	Colour of methyl orange in acid	Colour of phenolphthalein in acid
A	blue	red
B	colourless	red
C	red	blue
D	red	colourless

Answer: D

Unit Exercise (p.65)

4 A sample of ethanoic acid (CH_3COOH) has a pH of 3.40. What is the concentration of hydrogen ions in this solution?

A 3.98×10^{-4} mol dm^{-3}
B 5.31×10^{-3} mol dm^{-3}
C 2.65×10^{-2} mol dm^{-3}
D 0.294 mol dm^{-3}

Answer: A

Explanation:

$\log_{10}[H^+(aq)] = -3.40$

$[H^+(aq)] = 10^{-3.40}$ mol dm^{-3}

$= 3.98 \times 10^{-4}$ mol dm^{-3}

Unit Exercise (p.65)

5 Which of the following gases, after dissolved in 1 dm^3 of water, would give a solution with the highest pH?

A 0.002 mol of NO_2
B 0.002 mol of SO_2
C 0.002 mol of NH_3
D 0.002 mol of HCl

(HKDSE, Paper 1A, 2014, 13)

Answer: C

Unit Exercise (p.65)

6 A trout fishery owner added limestone to his loch to decrease the effects of acid rain. He managed to raise the pH of the water from 5 to 7.
The concentration of $H^+(aq)$ ions

A increased by a factor of 2.
B increased by a factor of 100.
C decreased by a factor of 2.
D decreased by a factor of 100.

Answer: D

Explanation:
Concentration of $H^+(aq)$ ions in water of pH 5 = 10^{-5} mol dm^{-3}
Concentration of $H^+(aq)$ ions in water of pH 7 = 10^{-7} mol dm^{-3}
Thus, when the pH of water was raised from 5 to 7, the concentration of $H^+(aq)$ ions decreased by a factor of 100.

Unit Exercise (p.65)

7 50.0 cm^3 of 0.6 M $FeSO_4$(aq) is mixed with 150.0 cm^3 of 0.2 M $Fe_2(SO_4)_3$(aq). What is the concentration of SO_4^{2-}(aq) ions in the resulting mixture?

A 0.3 M
B 0.4 M
C 0.6 M
D 0.8 M

Answer: C

(HKDSE, Paper 1A, 2014, 6)

Unit Exercise (p.65)

8 Which of the following statements concerning hydrochloric acid is INCORRECT?

A It is a mineral acid.
B It completely ionises in water.
C It contains aqueous hydrogen ions.
D It does not contain aqueous hydroxide ions.

(HKDSE, Paper 1A, 2017, 2)

Answer: D

Unit Exercise (p.65)

9 (continued)

Explanation:

Options A, B and C — HCl(aq) is a strong monobasic acid while H_2SO_4(aq) is a strong dibasic acid. 1 mol dm^{-3} HCl(aq) contains 1 mol dm^{-3} H^+(aq) ions while 1 mol dm^{-3} H_2SO_4(aq) contains more H^+(aq) ions. Thus, the two acids have different pH values, electrical conductivities and initial rates of reaction with magnesium.

Option D — HCl(aq) and H_2SO_4(aq) react with NaOH(aq) according to the equations:

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

$$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$$

Number of moles of HCl in 20 cm^3 of 1 mol dm^{-3} HCl(aq) $= 1 \text{ mol dm}^{-3} \times \frac{20}{1\ 000} \text{ dm}^3$
$= 0.020$ mol

This acid requires 0.020 mole of NaOH for complete neutralisation.

Number of moles of H_2SO_4 in 10 cm^3 of 1 mol dm^{-3} H_2SO_4(aq) $= 1 \text{ mol dm}^{-3} \times \frac{10}{1\ 000} \text{ dm}^3$
$= 0.010$ mol

This acid requires 0.020 mole of NaOH for complete neutralisation.

Unit Exercise (p.65)

9 Which of the following statements concerning 20 cm^3 of 1 mol dm^{-3} HCl(aq) and 10 cm^3 of 1 mol dm^{-3} H_2SO_4(aq) is correct?

A They have the same pH value.
B They have the same electrical conductivity.
C They react with magnesium at the same initial rate.
D They require the same number of moles of sodium hydroxide for complete neutralisation.

Answer: D

Unit Exercise (p.65)

10 Which of the following statements about KOH(aq) are correct?

(1) There are more hydroxide ions than hydrogen ions in KOH(aq).
(2) Adding water to KOH(aq) can increase its pH.
(3) It gives a pink solution with phenolphthalein.

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Explanation:
(2) Adding water to KOH(aq) makes it less alkaline. Its pH decreases.

Answer: B

Unit Exercise (p.65)

11 Which of the following statements concerning vinegar is / are correct?

(1) The process of forming hydrogen ions in vinegar is reversible.

(2) Neutralisation occurs when sugar is added to vinegar.

(3) The pH of vinegar used in kitchen is around 1.

A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

(HKDSE, Paper 1A, 2016, 18)

Answer: A

Unit Exercise (p.65)

12 Comparing the same volume of 0.1 mol dm^{-3} NaOH(aq) and 0.1 mol dm^{-3} NH_3(aq), which of the following are correct?

0.1 mol dm^{-3} NaOH(aq)	0.1 mol dm^{-3} NH_3(aq)
(1) higher electrical conductivity	lower electrical conductivity
(2) forms a precipitate with $MgSO_4$(aq)	does not form a precipitate with $MgSO_4$(aq)
(3) larger temperature rise when completely neutralised by 1 mol dm^{-3} HCl(aq)	smaller temperature rise when completely neutralised by 1 mol dm^{-3} HCl(aq)

A (1) and (2) only

B (1) and (3) only

C (2) and (3) only

D (1), (2) and (3)

Explanation:

(2) Both NaOH(aq) and NH_3(aq) give a white precipitate with $MgSO_4$(aq).

Answer: B

(Cambridge IGCSE, Paper 1, 0620/12, Jun 201

Unit Exercise (p.65)

13 Which of the following statements about sulphuric acid is / are correct?

(1) It is a strong acid.
(2) The pH of 0.001 mol dm^{-3} sulphuric acid is 3.0.
(3) In dilute sulphuric acid, sulphuric acid exists mainly in molecular form.

A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

Explanation:
(2) $[H^+(aq)]$ in an acid with pH 3.0 = $10^{-3.0}$
= 0.0010 mol dm^{-3}

Sulphuric acid is a strong dibasic acid. The concentration of hydrogen ions in 0.001 mol dm^{-3} sulphuric acid is greater than 0.0010 mol dm^{-3}.

Thus, its pH is less than 3.0.

Answer: A

Unit Exercise (p.65)

PART III STRUCTURED QUESTIONS

14 Calculate the molarity of each solution below.

a) 37.8 g of nitric acid (HNO_3) in 400.0 cm^3 solution
(Relative atomic masses: H = 1.0, N = 14.0, O = 16.0)

b) 87.9 g of lithium sulphate (Li_2SO_4) in 2.00 dm^3 solution
(Relative atomic masses: Li = 6.9, O = 16.0, S = 32.1)

Unit Exercise (p.65)

14 (continued)

a) Molar mass of HNO_3 = (1.0 + 14.0 + 3 x 16.0) g mol^{-1} = 63.0 g mol^{-1}

Number of moles of HNO_3 = $\frac{\text{mass}}{\text{molar mass}}$

= $\frac{37.8 \text{ g}}{63.0 \text{ g mol}^{-1}}$

= 0.600 mol

Molarity of acid = $\frac{\text{number of moles of } HNO_3}{\text{volume of solution}}$

= $\frac{0.600 \text{ mol}}{\frac{400.0}{1\ 000} \text{ dm}^3}$ (1)

= 1.50 mol dm^{-3} (M) (1)

b) Molar mass of Li_2SO_4 = (2 x 6.9 + 32.1 + 4 x 16.0) g mol^{-1} = 109.9 g mol^{-1}

Number of moles of Li_2SO_4 = $\frac{\text{mass}}{\text{molar mass}}$

= $\frac{87.9 \text{ g}}{109.9 \text{ g mol}^{-1}}$

= 0.800 mol

Molarity of Li_2SO_4 solution = $\frac{\text{number of moles of } Li_2SO_4}{\text{volume of solution}}$

= $\frac{0.800 \text{ mol}}{2.00 \text{ dm}^3}$ (1)

= 0.400 mol dm^{-3} (M) (1)

Unit Exercise (p.65)

15 What is the mass of solute in each solution below?

a) 250.0 cm^3 of 0.600 mol dm^{-3} sodium carbonate (Na_2CO_3) solution
(Relative atomic masses: C = 12.0, O = 16.0, Na = 23.0)

b) 5.00 dm^3 of 0.106 mol dm^{-3} iron(III) chloride ($FeCl_3$) solution
(Relative atomic masses: Cl = 35.5, Fe = 55.8)

Unit Exercise (p.65)

15 (continued)

a) Number of moles of Na_2CO_3 = molarity of solution x volume of solution (in dm^3)

$$= 0.600 \text{ mol dm}^{-3} \times \frac{250.0}{1\ 000} \text{ dm}^3$$

$$= 0.150 \text{ mol}$$ (1)

Molar mass of Na_2CO_3 = $(2 \times 23.0 + 12.0 + 3 \times 16.0) \text{ g mol}^{-1}$

$= 106.0 \text{ g mol}^{-1}$

Mass of Na_2CO_3 = number of moles of Na_2CO_3 x molar mass of Na_2CO_3

$= 0.150 \text{ mol} \times 106.0 \text{ g mol}^{-1}$

$= 15.9 \text{ g}$ (1)

b) Number of moles of $FeCl_3$ = molarity of solution x volume of solution (in dm^3)

$= 0.106 \text{ mol dm}^{-3} \times 5.00 \text{ dm}^3$

$= 0.530 \text{ mol}$ (1)

Molar mass of $FeCl_3$ = $(55.8 + 3 \times 35.5) \text{ g mol}^{-1}$

$= 162.3 \text{ g mol}^{-1}$

Mass of $FeCl_3$ = number of moles of $FeCl_3$ x molar mass of $FeCl_3$

$= 0.530 \text{ mol} \times 162.3 \text{ g mol}^{-1}$

$= 86.0 \text{ g}$ (1)

Unit Exercise (p.65)

16 Hydrofluoric acid reacts with silicon dioxide to produce hexafluorosilicic acid (H_2SiF_6). This acid can be added to drinking water to promote good dental health. When added to water all the fluorine in the acid is available as fluoride ions.

The water in a certain city contains 7.60×10^{-6} mol dm^{-3} of fluoride ions. What mass of hexafluorosilicic acid should be added to each dm^3 of water to increase the fluoride level to 4.00×10^{-5} mol dm^{-3}?

(Relative atomic masses: H = 1.0, F = 19.0, Si = 28.1)

Unit Exercise (p.65)

16 (continued)

Increase in fluoride level = $(4.00 \times 10^{-5} - 7.60 \times 10^{-6})$ mol dm^{-3}

= 3.24×10^{-5} mol dm^{-3} (1)

1 mole of H_2SiF_6 gives 6 moles of F^- ions.

Number of moles of acid added to each dm^3 of water = $\frac{3.24 \times 10^{-5}}{6}$ mol

= 5.40×10^{-6} mol (1)

Molar mass of H_2SiF_6 = $(2 \times 1.0 + 28.1 + 6 \times 19.0)$ g mol^{-1}

= 144.1 g mol^{-1}

Mass of acid added to each dm^3 of water = number of moles of acid x molar mass of acid

= 5.40×10^{-6} mol x 144.1 g mol^{-1}

= 7.78×10^{-4} g (1)

∴ 7.78×10^{-4} g of acid should be added to each dm^3 of water.

Unit Exercise (p.65)

17 100.0 cm^3 of 0.240 mol dm^{-3} sodium chloride solution are mixed with 150.0 cm^3 of 0.200 mol dm^{-3} magnesium chloride solution.

What is the concentration of chloride ions in the resulting solution?

1 mole of NaCl contains 1 mole of Cl^- ions.

Number of moles of Cl^- ions in NaCl(aq) $= 0.240 \text{ mol dm}^{-3} \times \frac{100.0}{1\ 000} \text{ dm}^3$

$= 0.0240$ mol (1)

1 mole of $MgCl_2$ contains 2 moles of Cl^- ions.

Number of moles of Cl^- ions in $MgCl_2$(aq) $= 2 \times 0.200 \text{ mol dm}^{-3} \times \frac{150.0}{1\ 000} \text{ dm}^3$

$= 0.0600$ mol (1)

Total number of moles of Cl^- ions $= (0.0240 + 0.0600)$ mol

$= 0.0840$ mol

Total volume of resulting solution $= (100.0 + 150.0) \text{ cm}^3$

$= 250.0 \text{ cm}^3$

Concentration of Cl^- ions in resulting mixture $= \dfrac{0.0840 \text{ mol}}{\frac{250.0}{1\ 000} \text{ dm}^3}$ (1)

$= 0.336 \text{ mol dm}^{-3}$ (1)

$\therefore$ the concentration of chloride ions in the resulting solution is 0.336 mol dm^{-3}.

Unit Exercise (p.65)

18 A 0.0178 mol dm^{-3} nitric acid ($HNO_3(aq)$) is prepared. The acid dissociates into hydrogen ions and nitrate ions completely in water.
What is its pH value?

1 mole of HNO_3 dissociates to give 1 mole of hydrogen ions.
i.e. concentration of hydrogen ions = 0.0178 mol dm^{-3}
pH of acid = $-\log_{10}(0.0178)$ (1)
= $-(-1.75)$ = 1.75 (1)

Unit Exercise (p.65)

19 What is the concentration of hydrogen ions in each of the following substances?

a) Beer with a pH of 4.20

pH of beer = 4.20

i.e. $\log_{10}[H^+(aq)] = -4.20$

$[H^+(aq)] = 10^{-4.20}$ mol dm^{-3} (1)

$= 6.31 \times 10^{-5}$ mol dm^{-3} (1)

b) Sea water with a pH of 7.90

pH of sea water = 7.90

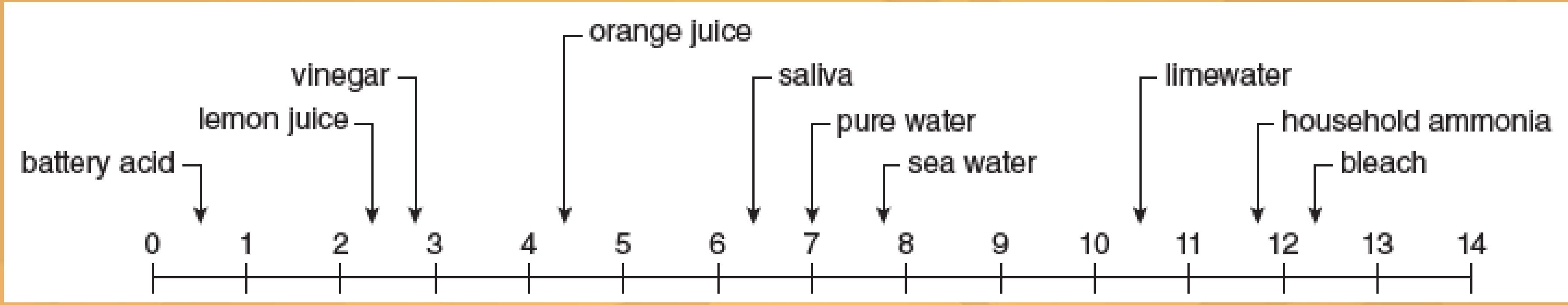
i.e. $\log_{10}[H^+(aq)] = -7.90$

$[H^+(aq)] = 10^{-7.90}$ mol dm^{-3} (1)

$= 1.26 \times 10^{-8}$ mol dm^{-3} (1)

Unit Exercise (p.65)

20 The following diagram shows the pH scale and the pH values of some common substances.



Use the information to answer the questions below.

a) Name the most acidic substance. Battery acid (1)

b) Name the acidic substance closest to being neutral. Saliva (1)

c) Name the weakest alkaline substance. Sea water (1)

d) Name the most alkaline substance. Bleach (1)

Unit Exercise (p.65)

21 The following table lists the colours of universal indicator solution at different pH values.

Colour	red	orange	yellow	green	blue	navy blue	purple
pH	0–2	3–4	5–6	7	8–9	10–12	13–14

a) Universal indicator solution turns red in 0.1 mol dm^{-3} sulphuric acid and orange in 0.1 mol dm^{-3} ethanoic acid.
State what these results tell you about the relative strength of these acids.

b) Both 0.1 mol dm^{-3} sulphuric acid and 0.1 mol dm^{-3} ethanoic acid react with sodium carbonate.
State how the reactions would differ. Explain in terms of the relative strength of these acids.

Unit Exercise (p.65)

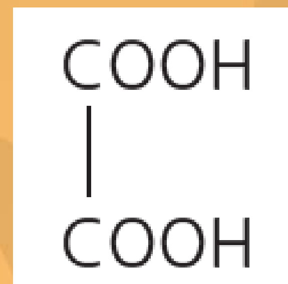
21 (continued)

a) Sulphuric acid is stronger than ethanoic acid. (1)

b) In the reaction between sodium carbonate and an acid, sodium carbonate reacts with hydrogen ions in the acid. Reaction of sodium carbonate with sulphuric acid is faster. (1) 0.1 mol dm^{-3} sulphuric acid has a higher concentration of hydrogen ions and thus reacts more rapidly than 0.1 mol dm^{-3} ethanoic acid with sodium carbonate. (1)

Unit Exercise (p.65)

22 The structure of a dibasic acid with chemical formula $H_2C_2O_4$ is shown below:



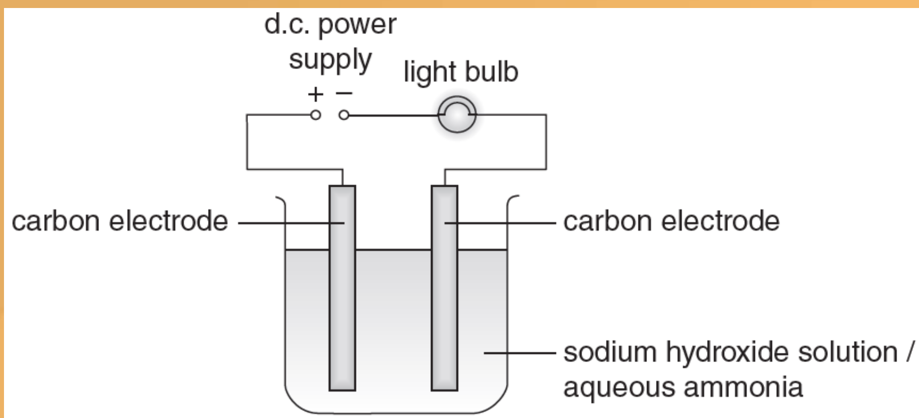
A student expected a 0.0500 mol dm^{-3} standard $H_2C_2O_4$(aq) to have a pH of 1.0. However, the pH of the solution, when measured with a calibrated pH meter, was found to be greater than 1. Explain this observation with the aid of a chemical equation.

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

(HKDSE, Paper 1B, 2013, 4(b))

Unit Exercise (p.65)

23 A student used the set-up shown below to compare the electrical conductivity of sodium hydroxide solution and aqueous ammonia of the same concentration.



The student used each alkali as an electrolyte in the set-up in turn. It was found that the light bulb glowed much more brightly with sodium hydroxide solution. Explain why. Use ideas about ions.

Sodium hydroxide is a strong alkali. It almost completely dissociates into ions in water to produce sodium ions and hydroxide ions. (1)
Ammonia is a weak alkali. When ammonia dissolves in water, only a small fraction of the molecules react with water molecules to form ammonium ions and hydroxide ions. (1)
Compared with aqueous ammonia of the same concentration, sodium hydroxide solution is a better conductor of electricity because it has a higher concentration of mobile ions. (1)

Unit Exercise (p.65)

24 Hydrogen fluoride and hydrogen chloride dissolve in water to give hydrofluoric acid and hydrochloric acid respectively.

Hydrofluoric acid is a weak acid but hydrochloric acid is a strong acid.

You are given samples of hydrofluoric acid and hydrochloric acid of the same concentration.

a) Describe and give the results of a test to show that hydrochloric acid is a stronger acid than hydrofluoric acid.

b) Explain, with the aid of a chemical equation, why hydrofluoric acid (HF(aq)) is regarded as a weak acid.

Unit Exercise (p.65)

24 (continued)

a) Any one of the following:

- Measure the pH value of each acid. (1)
  Hydrochloric acid has a lower pH than hydrofluoric acid. (1)
- Measure the electrical conductivity of each acid. (1)
  Hydrochloric acid has a higher electrical conductivity than hydrofluoric acid. (1)
- Allow each acid to react with magnesium separately. (1)
  Hydrochloric acid reacts more rapidly than hydrofluoric acid. (1)

b) $HF(aq) \rightleftharpoons H^+(aq) + F^-(aq)$ (1)

Hydrofluoric acid dissociates partially in water to give hydrogen ions. (1)