Topic 14 – Acids and Bases

Learning outcome:

(a) describe the meanings of the terms acid and alkali in terms of the ions they produce in aqueous solution and their effects on Universal Indicator
(b) describe how to test hydrogen ion concentration and hence relative acidity using Universal Indicator and the pH scale
(c) describe qualitatively the difference between strong and weak acids in terms of the extent of ionisation
(d) describe the characteristic properties of acids as in reactions with metals, bases and carbonates
(e) state the uses of sulfuric acid in the manufacture of detergents and fertilisers; and as a battery acid
(f) describe the reaction between hydrogen ions and hydroxide ions to produce water, $H^+ + OH^- \rightarrow H_2O$, as neutralisation
(g) describe the importance of controlling the pH in soils and how excess acidity can be treated using calcium hydroxide
(h) describe the characteristic properties of bases in reactions with acids and with ammonium salts

Precipitation & neutralisation reaction

Precipitation reaction	**Neutralisation reaction**
2 aqueous solutions react to form a solid product (precipitate)	Fulfil $H^+ (aq) + OH^- (aq) \rightarrow H_2O (l)$, where water is formed as a byproduct

Reactivity of some metals:

Metal	Reaction with acid
Na, K (Grp I)	too reactive → explosive
Ca. Mg, Fe, …	reactive
Cu, Ag, Au	unreactive

Acids and bases

Properties	**Acids**	**Bases**
Definition	acid: substance which ionises in water to give hydrogen ions (H+) as the only positive ions	base: metal oxide / hydroxide that react with acid to produce salt and water only alkali: substance which ionises in water to give hydroxide ions (OH^-) as the only negative ions
Physical	1. Tastes sour 2. pH < 7 • damp litmus paper: blue → red • Universal Indicator: green → red 3. dissolve in water → solution which conduct electricity (free-moving ions)	1. Tastes bitter & soapy 2. pH > 7 • damp litmus paper: blue → red • Universal Indicator: green → violet 3. dissolve in water → solution which conduct electricity (free-moving ions)
Chemical	1. acid + base → salt + water 2. acid + metal → salt + hydrogen 3. acid + carbonate / hydrogen carbonate → salt + water + carbon dioxide	1. base + acid → salt + water 2. alkali + ammonium salt → salt + ammonia gas + water 3. alkali + metal salt → insoluble metal hydroxide + soluble salt
Examples	1. Sulfuric acid (H_2SO_4) → fertiliser, detergents, battery acid 2. Hydrochloric acid (HCl) → clean impurities 3. Ethanoic acid (CH_3COOH) → vinegar 4. Phosphoric acid (H_3PO_4) → food & beverages	1. Magnesium oxide (MgO) → antacid 2. Sodium hydroxide ($NaOH$) → soap 3. Potassium hydroxide (KOH) → soap 4. Calcium hydroxide [$Ca(OH)_2$] → reduce soil acidity 5. Aqueous ammonia (NH_3) → fertiliser

11.1 Acids

Types of acids:

Monobasic acids	Dibasic acids
1 mol of acid → 1 mol of H^+ ions	1 mol of acid → 2 mol of H^+ ions
HCl (g) → H^+ (aq) + Cl^- (aq)	H_2SO_4 (g) → 2 H^+ (aq) + SO_4^{2-} (aq)

Reactions:

Reaction	Example	observation
1. acid + <u>base</u> → salt + water	H_2SO_4 (aq) + CuO (s) → CuSO4 (aq) + H_2O (*l*)	Black solid reacts and dissolves → blue solution
2. acid + <u>metal</u> → salt + hydrogen	2 HCl (aq) + Mg (s) → $MgCl_2$ (aq) + H_2 (g)	Grey metal reacts and dissolves → colourless solution + effervescence of colourless gas
3. acid + <u>carbonate / hydrogen carbonate</u> → salt + water + carbon dioxide	2 HCl (aq) + $NaCO_3$ (aq) → 2 $NaCl$ (aq) + H_2O (*l*) + CO_2 (g)	White solid reacts and dissolves → colourless solution

Ionisation of acids → produce H^+ ions

Water	Organic solvent
• Ionises into H^+ and Cl^- ions • HCl (aq) → H^+ (aq) + Cl^- (aq)	• Exist as covalent molecules • Does not ionise → produce hydrogen ions

Uses of acids:

Acids	Uses	Explanation
1. **Sulfuric acid** (H_2SO_4)	1) Fertiliser	Important starting material for production: • Ammonium sulfate • Superphosphate
	2) Detergents	• Convert hydrocarbons → organic acids • Organic acids + NaOH → detergent
	3) Battery acid (cars)	• React with lead plates + lead(IV) oxide plates • Generate electrical energy
2. **Hydrochloric acid** (HCl)	Clean impurities	rust from metals and aluminium alloys
3. **Ethanoic acid** (CH_3COOH)	vinegar	• food preservative • flavour enhancer
4. **Phosphoric acid** (H_3PO_4)	food & beverages	sour taste

11.2 Bases and Alkalis

Reactions:

Reaction	Example	Observation
1. alkali + <u>acid</u> → salt + water	NaOH (aq) + HCl (aq) → NaCl (aq) + H_2O (*l*)	No changes
2. alkali + <u>ammonium salt</u> → salt + ammonia gas + water	NaOH (aq) + NH_4Cl (aq) → NaCl (aq) + H_2O (*l*) + NH_3 (aq)	Effervescence of colourless, pungent gas
3. alkali + <u>metal salt</u> → insoluble metal hydroxide + soluble salt	2 NaOH (aq) + $FeSO_4$ (aq) → $Fe(OH)_2$ (s) + Na_2SO_4 (aq)	Dirty green precipitate formed

Uses of bases & alkalis:

Bases and alkalis	Uses
1. **Magnesium oxide** (MgO)	Antacid 1) relieve gastric pain 2) make refractory bricks
2. **Sodium hydroxide** (NaOH)	Preparation of soap
3. **Potassium hydroxide** (KOH)	
4. **Calcium hydroxide** [$Ca(OH)_2$]	Reduce acidity in soil
5. **Ammonia solution** (NH_3)	Make fertilisers

Methods to test for evolved gases:

Gas	State	Test	Observation
Hydrogen gas (**H_2**)	colourless + odourless	Place lighted splint at mouth of test tube	Lighted splint extinguished + ‘pop’ sound
Oxygen gas (**O_2**)	colourless + odourless	Insert glowing splint into test tube	Glowing splint is rekindled
Carbon dioxide (**CO_2**)	colourless + odourless	Bubble gas through limewater	White precipitate formed
Ammonia gas (**NH_3**)	colourless + pungent	Place moist red litmus paper at mouth of test tube	Moist red litmus paper turns blue

11.3 Strength and Concentration

Strength: extent / degree of ionisation of acid / alkali in water

Strong and weak acids (for same conc.)

Properties	Strong acid	Weak acid
Definition	Completely ionised (all molecules ionise)	Partially ionised (some molecules ionise)
Characteristic	• High concentration of H^+ ions • Low pH value	• Low concentration of H^+ ions • High pH value
Examples	(a) Hydrochloric acid (HCl) $\rightarrow H^+ (aq) + Cl^- (aq)$ (b) Nitric acid (HNO_3) $\rightarrow H^+ (aq) + NO_3^- (aq)$ (c) Sulfuric acid (H_2SO_4) $\rightarrow 2H^+ (aq) + SO_4^{2-} (aq)$	(a) Ethanoic acid (CH_3COOH) $\rightleftharpoons CH_3COO^- (aq) + H^+ (aq)$
Reaction	React vigorously	React slowly

pH = - lg (concentration of H^+ ions in mol/dm^3)

Strong and weak alkalis (for same conc.)

Properties	Strong alkali	Weak alkali
Definition	Completely ionised (all molecules ionise)	Partially ionised (some molecules ionise)
Characteristic	• High concentration of OH^- ions • High pH value	• Low concentration of OH^- ions • Low pH value
Examples	(a) Aqueous LiOH $\rightarrow Li^+ (aq) + OH^- (aq)$ (b) Aqueous NaOH $\rightarrow Na^+ (aq) + OH^- (aq)$ (c) Aqueous KOH $\rightarrow K^+ (aq) + OH^- (aq)$	(a) Aqueous ammonia (NH_3) $+ H_2O (aq) \rightleftharpoons NH_4^+ (aq) + OH^- (aq)$
Reaction	React vigorously	React slowly

11.4 The pH Scale

pH and Concentration of Hydrogen Ions

pH scale: indicate whether solution is acidic / neutral / alkaline
Related to concentration of H^+ and OH^-

Solution	pH value	Concentration	
		H^+	OH^-
Acid	< 7	high	low
Neutral	7	equal	equal
Alkali	> 7	low	high

Measure pH of solution:
1. **Indicator** (chemical compound) → Universal Indicator
2. **pH sensor** attached to data logger
3. **pH meter**

Universal Indicator

Universal Indicator:

Acidic	Neutral	Alkaline
red (strong acid) **orange** (weak acid)	**green**	**blue** (weak alkali) **violet** (strong alkali)

Some other indicators:

Indicator	pH range of colour change	Colour of solution	
		Acidic	Alkaline
1. **Methyl orange**	3 – 5	Red	Yellow
2. **Screened methyl orange**	3 – 5	Violet	Green
3. **Litmus**	5 – 8	Red	Blue
4. **Bromothymol blue**	6 – 8	Yellow	Blue
5. **Phenolphthalein**	8 – 10	Colourless	pink

11.5 Concentration of a Solution

Concentration in g/dm^3

Concentration

Amount of solute dissolved in unit volume of solution

Concentration in g/dm^3 = $\frac{mass\ of\ solute\ (g)}{volume\ of\ solution\ (dm^3)}$

Concentration in mol/dm^3 (molar concentration)

Molar concentration

Concentration expressed in mol/dm^3

1 mol/dm^3 = 1 mole of solute dissolved in 1 dm^3 of solution

Concentration in mol/dm^3 = $\frac{number\ of\ moles\ of\ solute\ (mol)}{volume\ of\ solution\ (dm^3)}$

Concentration in mol/dm^3 = $\frac{concentration\ (g/dm^3)}{molar\ mass\ of\ solute\ (g/mol)}$

11.6 Ionic Equations

Steps:

1. write balanced chemical equations + state symbols
2. split molecules in aqueous state → free-moving ions
3. identify **spectator ions** (aqueous state at both sides of equation)
4. cancel spectator ions
5. write final ionis equation (ensure balanced + equal electronic charge)

Examples:

Neutralisation reaction	Acid-metal reaction
dilute hydrochloric acid + sodium hydroxide → sodium chloride + water	magnesium + dilute nitric acid → magnesium nitrate + water
HCl (aq) + $NaOH$ (aq) → $NaOH$ (aq) + H_2O (*l*) H^+ (aq) + Cl^- (aq) + Na^+ (aq) + OH^- (aq) → Na^+ (aq) + OH^- (aq) + H_2O (l) H^+ (aq) + $\cancel{Cl^-\ (aq)}$ + $\cancel{Na^+\ (aq)}$ + OH^- (aq) → $\cancel{Na^+\ (aq)}$ + $\cancel{OH^-\ (aq)}$ + H2O (l)	Mg (s) + 2 HNO_3 (aq) → $Mg(NO_3)_2$ (aq) + H_2 (g) Mg (s) + 2 H^+ (aq) + 2 NO_3^- (aq) → Mg^{2+} (aq) + 2 NO_3^- (aq) + H_2 (g) Mg (s) + 2 H^+ (aq) + $\cancel{2\ NO_3^-\ (aq)}$ → Mg^{2+} (aq) + $\cancel{2\ NO_3^-\ (aq)}$ + H_2 (g)
H^+ (aq) + OH^- (aq) → H_2O (l)	Mg (s) + 2 H^+ (aq) → Mg^{2+} (aq) + H_2 (g)

Typical questions

Multiple choice questions

1 A river that is polluted by acid rain can be remedied by adding on its surface an adequate amount of:

A aqueous ammonia
B magnesium hydroxide
C chalk powder (contains $CaCO_3$)
D calcium sulfate

2 The pH of an aqueous solution of sulfuric acid is 1. What will be its pH when 1 g of sodium sulfate is added?

A 1 (sodium sulfate is neutral as it is a salt)
B 2
C 7
D 11

3 In the given reaction,

$$Ca(OH)_2\ (aq) + H_2SO_4\ (aq) \rightarrow CaSO_4\ (s) + H_2O\ (l)$$

as more aqueous calcium hydroxide is added to dilute sulfuric acid, the electrical conductivity of the uslfuric acid gets weaker over time. This is because:

A the reaction mixture becomes cooler
B the concentration of the ions increase
C the volume of the reaction mixture increases
D the concentration of ions decreases (H^+ and OH^- ions combine to form electrically neutral water molecules, so there are less ions present to conduct electricity)

4 Which of the following compounds produces a neutral solution when dissolved in water?

A iron (III) hydroxide (alkaline solution)
B potassium nitrate (salt → give a neutral solution when dissolved)
C sulfur dioxide (acidic gas)
D sodium hydroxide (alkaline solution)

Structured questions

1 The pH values of solutions can be determined by using a Universal Indicator or a pH sensor attached to a data logger.

Hydrochloric acid (HC*l*) of different concentrations have different pH values. The table below shows the pH values and colours of Universal Indicator in hydrochloric acid of different concentrations.

concentration of HC*l* / mol/dm^3	pH value measured by pH sensor attached to data logger	colour of Universal Indicator
0.1	1.0	red
0.001	3.0	orange
0.00001	5.0	yellow

(a) Using the date in the table, describe how the pH value varies with the concentration of hydrochloric acid. [1]

The pH value increases as the concentration of hydrochloric acid decreases.

(b) Bernice tried to determine the pH value of 0.1 mol/dm^3 sulfuric acid using both the pH sensor and Universal Indicator. When she measured the pH of the acid using a pH sensor, the data logger attached showed a value of 0.7.

(i) Explain why the pH value of 0.1 mol/dm^3 sulfuric acid differed from that of 0.1 mol/dm^3 hydrochloric acid. [3]

- The pH value of a solution is dependent on the concentration of hydrogen ions.
  [concept on pH and concentration of H^+ ions]
- For the same volume, 0.1 mol of hydrochloric acid will ionise completely to form 0.1 mol of hydrogen ions (monobasic acid) while 0.1 mol of sulfuric acid will ionise completely to form 0.2 mol of hydrogen ions (dibasic acid).
  [concept on acid strength]
- Since the concentration of hydrogen ions is higher in sulfuric acid than in hydrochloric acid, hence the pH value observed is smaller for sulfuric acid than hydrochloric acid.
  [explain using concept]

(ii) Bernice concluded that Universal Indicator cannot be used to differentiate between 0.1 mol/ dm^3 sulfuric acid and 0.1 mol/dm^3 hydrochloric acid. Do you agree with her? Why? [2]

Yes.

Both 0.1 mol/ dm^3 sulfuric acid and 0.1 mol/dm^3 hydrochloric acid will give a red colour with Universal Indicator.

(iii) Bernice also measured the pH of 0.00001 mol/dm3 ethanoic acid using the pH sensor. Ethanoic acid is a weak acid. Suggest a likely pH value that she would observe and explain your answer. [3]

- Hydrochloric acid is a strong acid which ionises completely in water while ethanoic acid is a weak acid that ionises partially in water.
  [concept on acid strength]
- For the same concentration of ethanoic acid and hydrochloric acid, the concentration of hydrogen ions for ethanoic acid will be lower than that of hydrochloric acid.
  [concept on acid strength and concentration of H^+ ions]
- Thus, the pH value of ethanoic acid is greater than 5 and less than 7.
  [suggest pH]

2 Given some test tubes and Universal Indicator paper, explain how you can distinguish the identity of four bottles containing dilute hydrochloric acid, magnesium carbonate solution, propanoic acid and ammonia solution.

Step 1: Add Universal Indicator paper to the solutions.

- The two acids change the colour of the Universal Indicator paper to red.
- The two alkalis change the colour of the Universal Indicator paper to blue / purple.

Step 2: Add acid to each of the two alkaline solutions. The one that gives a gas is magnesium carbonate solution. The other is ammonia solution.

Step 3: Add magnesium carbonate to the two acids. A gas (carbon dioxide) is evolved. The acid with the faster reaction is dilute hydrochloric acid. The other acid must be propanoic acid.

3 When an ammonium compound is heated in potassium hydroxide solution, a gas is produced. Suggest a suitable ammonium compound and write a balanced chemical equation for the reaction. Identify the gas and describe a test to distinguish it.

Any ammonium salt when heated with any alkali will form ammonia gas. Ammonia is commonly prepared in the laboratory by heating solid ammonium chloride together with solid sodium hydroxide.

$NH_4Cl\ (s) + NaOH\ (s) \rightarrow NaCl\ (s) + NH_3\ (g) + H_2O\ (l)$

To test for ammonia gas, hold a piece of moist red litmus paper to the gas. The colour of the litmus paper changes from red to blue.