Topic 8: Acids and bases

6.5 hours

Essential idea: Many reactions involve the transfer of a proton from an acid to a base.

8.1 Theories of acids and bases

Nature of science:

Falsification of theories—HCN altering the theory that oxygen was the element which gave a compound its acidic properties allowed for other acid–base theories to develop. (2.5)

Theories being superseded—one early theory of acidity derived from the sensation of a sour taste, but this had been proven false. (1.9)

Public understanding of science—outside of the arena of chemistry, decisions are sometimes referred to as "acid test" or "litmus test". (5.5)

Understandings:

- A Brønsted–Lowry acid is a proton/H^+ donor and a Brønsted–Lowry base is a proton/H^+ acceptor.
- Amphiprotic species can act as both Brønsted–Lowry acids and bases.
- A pair of species differing by a single proton is called a conjugate acid-base pair.

Applications and skills:

- Deduction of the Brønsted–Lowry acid and base in a chemical reaction.
- Deduction of the conjugate acid or conjugate base in a chemical reaction.

Guidance:

- Lewis theory is not required here.
- The location of the proton transferred should be clearly indicated. For example, CH_3COOH/CH_3COO^- rather than $C_2H_4O_2/C_2H_3O_2^-$.
- Students should know the representation of a proton in aqueous solution as both H^+ (aq) and H_3O^+ (aq).
- The difference between the terms amphoteric and amphiprotic should be covered.

International-mindedness:

- *Acidus* means sour in Latin, while *alkali* is derived from the Arabic word for calcined ashes. *Oxygene* means acid-forming in Greek, and reflects the mistaken belief that the element oxygen was responsible for a compound's acidic properties. Acid–base theory has been developed by scientists from around the world, and its vocabulary has been influenced by their languages.

Theory of knowledge:

- Acid and base behaviour can be explained using different theories. How are the explanations in chemistry different from explanations in other subjects such as history?

Utilization:

Syllabus and cross-curricular links:
Topic 3.2—the acid/base character of oxides
Topic 8.5—non-metal oxides are responsible for acid precipitation
Option B.2—amino acids acting as amphiprotic species
Option D.4—antacids are bases which neutralize excess hydrochloric acid in the stomach

Aims:

- **Aim 9**: Each theory has its strengths and limitations. Lavoisier has been called the father of modern chemistry but he was mistaken about oxygen in this context.

Essential idea: The characterization of an acid depends on empirical evidence such as the production of gases in reactions with metals, the colour changes of indicators or the release of heat in reactions with metal oxides and hydroxides.

8.2 Properties of acids and bases	
Nature of science: Obtaining evidence for theories—observable properties of acids and bases have led to the modification of acid–base theories. (1.9)	
Understandings: • Most acids have observable characteristic chemical reactions with reactive metals, metal oxides, metal hydroxides, hydrogen carbonates and carbonates. • Salt and water are produced in exothermic neutralization reactions. **Applications and skills:** • Balancing chemical equations for the reaction of acids. • Identification of the acid and base needed to make different salts. • Candidates should have experience of acid-base titrations with different indicators. **Guidance:** • Bases which are not hydroxides, such as ammonia, soluble carbonates and hydrogen carbonates should be covered. • The colour changes of different indicators are given in the data booklet in section 22.	**Utilization:** • A number of acids and bases are used in our everyday life from rust removers to oven cleaners, from foods to toothpastes, from treatments for bee stings to treatment of wasp stings. Syllabus and cross-curricular links: Topic 1.3—acid–base titrations Topic 3.2—the acid/base character of oxides Topic 5.1—enthalpy change of neutralization reactions **Aims:** • **Aim 6**: The evidence for these properties could be based on a student's experimental experiences.

Essential idea: The pH scale is an artificial scale used to distinguish between acid, neutral and basic/alkaline solutions.

8.3 The pH scale

Nature of science:

Occam's razor—the pH scale is an attempt to scale the relative acidity over a wide range of H^+ concentrations into a very simple number. (2.7)

Understandings:

- $\mathrm{pH} = -\log[\mathrm{H}^+(\mathrm{aq})]$ and $[\mathrm{H}^+] = 10^{-\mathrm{pH}}$.
- A change of one pH unit represents a 10-fold change in the hydrogen ion concentration $[H^+]$.
- pH values distinguish between acidic, neutral and alkaline solutions.
- The ionic product constant, $Kw = [\mathrm{H}^+][\mathrm{OH}^-] = 10^{-14}$ at 298 K.

Applications and skills:

- Solving problems involving pH, $[\mathrm{H}^+]$ and $[\mathrm{OH}^-]$.
- Students should be familiar with the use of a pH meter and universal indicator.

Guidance:

- Students will not be assessed on pOH values.
- Students should be concerned only with strong acids and bases in this sub-topic.
- Knowing the temperature dependence of Kw is not required.
- Equations involving H_3O^+ instead of H^+ may be applied.

Theory of knowledge:

- Chemistry makes use of the universal language of mathematics as a means of communication. Why is it important to have just one "scientific" language?

Utilization:

Syllabus and cross-curricular links:
Mathematics SL (topic 1.2) and Mathematics HL (topic 1.2)—study of logs

Aims:

- **Aim 3**: Students should be able to use and apply the pH concept in a range of experimental and theoretical contexts.
- **Aim 6**: An acid–base titration could be monitored with an indicator or a pH probe.

Essential idea: The pH depends on the concentration of the solution. The strength of acids or bases depends on the extent to which they dissociate in aqueous solution.

8.4 Strong and weak acids and bases

Nature of science:

Improved instrumentation—the use of advanced analytical techniques has allowed the relative strength of different acids and bases to be quantified. (1.8)

Looking for trends and discrepancies—patterns and anomalies in relative strengths of acids and bases can be explained at the molecular level. (3.1)

The outcomes of experiments or models may be used as further evidence for a claim—data for a particular type of reaction supports the idea that weak acids exist in equilibrium. (1.9)

Understandings:

- Strong and weak acids and bases differ in the extent of ionization.
- Strong acids and bases of equal concentrations have higher conductivities than weak acids and bases.
- A strong acid is a good proton donor and has a weak conjugate base.
- A strong base is a good proton acceptor and has a weak conjugate acid.

Applications and skills:

- Distinction between strong and weak acids and bases in terms of the rates of their reactions with metals, metal oxides, metal hydroxides, metal hydrogen carbonates and metal carbonates and their electrical conductivities for solutions of equal concentrations.

Guidance:

- The terms ionization and dissociation can be used interchangeably.
- See section 21 in the data booklet for a list of weak acids and bases.

Theory of knowledge:

- The strength of an acid can be determined by the use of pH and conductivity probes. In what ways do technologies, which extend our senses, change or reinforce our view of the world?

Utilization:

Syllabus and cross-curricular links:
Topic 1.3—solution chemistry
Topic 7.1—weak acids and basis involve reversible reactions

Aims:

- **Aim 6**: Students should have experimental experience of working qualitatively with both strong and weak acids and bases. Examples to include: H_2SO_4 (aq), HCl (aq), HNO_3 (aq), NaOH (aq), NH_3 (aq).
- **Aim 7**: Students could use data loggers to investigate the strength of acid and bases.

Essential idea: Increased industrialization has led to greater production of nitrogen and sulfur oxides leading to acid rain, which is damaging our environment. These problems can be reduced through collaboration with national and intergovernmental organizations.

8.5 Acid deposition

Nature of science:

Risks and problems—oxides of metals and non-metals can be characterized by their acid–base properties. Acid deposition is a topic that can be discussed from different perspectives. Chemistry allows us to understand and to reduce the environmental impact of human activities. (4.8)

Understandings:

- Rain is naturally acidic because of dissolved CO^2 and has a pH of 5.6. Acid deposition has a pH below 5.0.
- Acid deposition is formed when nitrogen or sulfur oxides dissolve in water to form HNO_3, HNO_2, H_2SO_4 and H_2SO_3.
- Sources of the oxides of sulfur and nitrogen and the effects of acid deposition should be covered.

Applications and skills:

- Balancing the equations that describe the combustion of sulfur and nitrogen to their oxides and the subsequent formation of H_2SO_3, H_2SO_4, HNO_2 and HNO_3.
- Distinction between the pre-combustion and post-combustion methods of reducing sulfur oxides emissions.
- Deduction of acid deposition equations for acid deposition with reactive metals and carbonates.

International-mindedness:

- The polluter country and polluted country are often not the same. Acid deposition is a secondary pollutant that affects regions far from the primary source. Solving this problem requires international cooperation.

Theory of knowledge:

- All rain is acidic but not all rain is “acid rain”. Scientific terms have a precise definition. Does scientific vocabulary simply communicate our knowledge in a neutral way or can it have value-laden terminology?

Utilization:

Syllabus and cross-curricular links:
Topic 3.2—the acid/base character of the oxides
Option B.2—pH change and enzyme activity
Option C.2—sulfur dioxide is produced by the combustion of fossil fuels with high levels of sulfur impurities
Environmental systems and societies topic 5.8—acid deposition
Geography Option G: Urban Environments—urban stress and the sustainable city; HL—Global interactions—environmental change

Aims:

- **Aim 6**: The effects of acid rain on different construction materials could be quantitatively investigated.
- **Aim 8**: A discussion of the impact of acid rain in different countries will help raise awareness of the environmental impact of this secondary pollutant and the political implications.
- **Aim 8**: Other means of reducing oxide production—bus use, car pooling, etc. could be discussed.