19 Proton transfer reactions

Teaching plan

Sub-chapter	Approximate number of learning hours	Learning content	Resources
19.1 Acids, bases and salts 19.2 Reactions of acids 19.3 Brønsted–Lowry acids and bases	2	Explain what a Brønsted–Lowry acid / base is and distinguish them in reactions. Understand that a proton can be represented by either $H^+(aq)$ or $H_3O^+(aq)$ in an aqueous solution. Understand what a conjugate acid–base pair is and know how to work out the conjugate acid or base in a reaction. Recognise that some species can act as both Brønsted–Lowry acids and bases and write equations to show their reactions. Write balanced chemical equations between acids and bases.	**Coursebook** Sections 19.1–19.3 Test your understanding Question 4 **Workbook** Exercises 19.1–19.3 **Teacher's resource** PowerPoint 19, slides 2–3 End of Chapter 19 test Questions 1–3
19.4 pH 19.5 Strong and weak acids and bases 19.6 The dissociation of water 19.7 Calculating pH values	3	Interconvert $[H^+]$ and pH. Describe how pH can be measured using universal indicator or a pH meter. Know how to calculate the ionic product constant K_w. Use the relative concentrations of H^+ and OH^- to determine whether a solution is acidic, neutral or basic. Explain why K_w of water increases as temperature increases. Explain the difference between strong and weak acids / bases and know examples of strong acids and bases.	**Coursebook** Sections 19.4–19.7 Test your understanding Questions 10–13 and 25 **Workbook** Exercises 19.4–19.7 **Teacher's resource** PowerPoint 19, slides 4–10 End of Chapter 19 test Questions 4, 6–9

Sub-chapter	Approximate number of learning hours	Learning content	Resources
19.8 Acid–base titrations	2	Sketch and interpret the general shapes and feature of pH curves for strong acid–strong base titrations.	**Coursebook** Section 19.8 **Workbook** Exercise 19.8 **Teacher's resource** PowerPoint 19 Slide 11
19.9 pOH 19.10 Ionisation constants for acids and bases 19.11 The base ionisation constant, K_b 19.12 The strength of an acid and its conjugate base	2–3	Interconvert $[OH^-]$, pOH, $[H^+]$ and pH values. Explain the strengths of weak acids and bases from their K_a, K_b, pK_a and pK_b values. Know how to interconvert K_w, K_a and K_b, and solve problems involving these values.	**Coursebook** Sections 19.9–19.10 Test your understanding Questions 35, 37, 38, 44, 45, 50 and 51 **Workbook** Exercises 19.9–19.10 **Teacher's resource** PowerPoint 19, slides 12–15 End of Chapter 19 test Questions 5 and 10
19.13 The pH of salt solutions 19.14 More pH curves	4–5	Predict and explain the pH of a salt solution. Interpret and sketch the pH curves of different combinations of acids and bases. Explain how indicators work using equilibria. Know how the pH range of an indicator is related to its pK_a value. Know that universal indicator is a mixture of many indicators and can show a wide range of colours over different pH values. Identify suitable indicators for a specific titration and distinguish between the terms *end point* and *equivalence point*.	**Coursebook** Section 19.11 Test your understanding Questions 58, 60-62, 68 **Workbook** Exercise 19.11 **Teacher's resource** PowerPoint 19, slides 16–19 Worksheet 19.1 End of Chapter 19 test Questions 11–13, 15

Sub-chapter	Approximate number of learning hours	Learning content	Resources
19.15 Buffer solutions	2–3	Explain how buffer solutions are made and how they function. Calculate the pH of a buffer solution.	**Coursebook** Section 19.12 Test your understanding Questions 70–71, 74–75 and 79 **Workbook** Exercise 19.12 **Teacher's resource** PowerPoint 19, slide 20 Worksheet 19.2 End of Chapter 19 test Question 14

BACKGROUND KNOWLEDGE

- State the Arrhenius definitions of acids and alkalis (acids produce H^+ and alkalis produce OH^- in aqueous solutions).
- Know that alkalis are soluble bases.
- Recall the general reactions of acids and predict their products (metal + acid, base / alkali + acid, carbonate / hydrogencarbonate + acid).
- Construct balanced chemical equations and ionic equations for the reactions of acids.
- Describe the use of litmus, phenolphthalein and methyl orange to distinguish between acidic and alkaline solutions.
- Understand how the pH scale can be used to classify solutions as acidic, neutral and basic.
- Describe the use of universal indicator to measure the approximate pH value of an aqueous solution.
- Describe how to carry out an acid–alkali titration.

Syllabus overview

- Neutralisations between acids and bases are probably one of the first reactions that students become aware of and can relate to real-life situations. From the treatment of heartburn using antiacids to making a toy volcano with baking soda and vinegar, the reactions of acids and bases are easy to observe.
- Acid–base theory is expanded in this chapter from the Arrhenius definitions to Brønsted–Lowry theory, which generalises the definitions of acids and bases beyond aqueous solutions. Students are introduced to the concept of strong and weak acids / bases and how to distinguish between them. pH can be calculated from $[H^+]$, and it is important to realise that neutral solutions do not always have a pH of 7. The ion product constant of water, K_w, is used to calculate the concentrations of H^+ and OH^- in aqueous solutions, and it is the relative concentrations of H^+ and OH^- that determine whether a solution is acidic, neutral or basic.

- Conjugate acids and bases can be identified, and a strong acid produces a weak conjugate base and vice versa. Students should become familiar at Higher Level with the mathematical manipulation to interconvert K_a, K_b, K_w, pK_a, pK_b, pH and pOH values.
- Through titration, students can link pH curves to salt hydrolysis and understand how to extract information from these curves. This includes concentrations of acids and bases, $[H^+]$ and $[OH^-]$, pK_a of a weak acid and pK_b of a weak base, and pH of the salt solution formed during the reaction. Indicators change colour, depending on the pH of the solution, and different indicators should be selected depending on the acid and base combinations in titrations.
- Students probably know that blood in our body can buffer changes in pH. Here, they can apply knowledge of equilibria (Chapter 18) to explain how buffers work. Buffers of different pH can be made by varying the relative acid and salt or base and salt concentrations, and students should be familiar with the calculations of buffer pH values from these concentrations.

19.1 Acids, bases and salts; 19.2 Reactions of acids and 19.3 Brønsted–Lowry acids and bases

LEARNING PLAN

Learning objectives	Success criteria
Understand that acids react with bases in neutralisation reactions	Students should be able to identify acids and bases and explain that acids react with bases in neutralisation reactions.
Understand the Brønsted–Lowry definition of acids and bases	Students should be able to explain the Brønsted–Lowry definition of acids and bases.

Common misconceptions

Misconceptions	How to identify	How to overcome
Students confuse alkalis and bases	Give students a list of basic substances (metal oxides, metal hydroxides, ammonia, amines, metal carbonates and hydrogencarbonates) and ask them to identify alkalis	Bases are proton acceptors. Alkalis are a sub-group of bases that can form OH^- ions in aqueous solution. All alkalis are bases, but the reverse is not true.
Students struggle to understand conjugate acid–base pairs	Ask students if CO_3^{2-} is a conjugate base for H_2CO_3	Emphasise that a conjugate acid–base pair differs by just one proton. The conjugate base of H_2CO_3 is HCO_3^-, not CO_3^{2-}.

Starter ideas

1 Classify the following substances as acidic, neutral or basic (15 minutes)

Resources: A list of substances to categorise, for example, HCl, apple juice, coffee, NaOH, table salt solution, distilled water, baking soda, ammonia, antiacid tablets, lemon juice and vinegar.

Description and purpose: Test students' general knowledge on acids and bases, relating to real-life examples.

What to do next: If students are not sure about any of the substances, their pH values can be found online, or universal indicator paper / a pH probe can be used to measure the pH values of some of the solutions.

2 Construct word equations for acid–base reactions (10 minutes)

Resources: A mini-whiteboard and a pen.

Description and purpose: Ask students to write word equations for the following reactions: copper oxide / copper carbonate / copper hydroxide with sulfuric acid. This is to assess their prior knowledge on acids, bases and general reactions of acids.

What to do next: If students are confident with predicting the products of the reactions of acids, they can move on to writing balanced chemical equations or those using organic acids. Otherwise, continue with Main teaching ideas 1 to recap knowledge on the reactions of acids.

Main teaching ideas

1 Reactions of acids (50 minutes)

Resources: Mg, Zn and Cu metals, dilute HCl, CuO, dilute H_2SO_4, $CaCO_3$ marble chips and $NaHCO_3$ solution.

Description and purpose: Revise reactions of acids using a demonstration or practical for metals with acids, bases with acids and metal carbonates / hydrogencarbonates with acids. The gases produced can also be tested to give a reminder on qualitative tests for gases. Students should note down observations and write balanced chemical questions.

Differentiation ideas:

Support: Give a list of general reactions of acids on the board and practice naming and writing salt formulas formed from different acids. Relate to Chapter 6 on the formulas of polyatomic ions.

Stretch and challenge: Write ionic equations for these reactions. Ask students to explain how they arrive at an ionic equation.

2 Brønsted–Lowry theory and conjugate acid–base pairs (20 minutes)

Resources: Test your understanding Question 4 from the Coursebook.

Description and purpose: The teacher introduces the definition of Brønsted–Lowry acids and bases and the relationship between conjugate acids and bases. For example, use $CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$ to identify the two pairs of conjugate acid–base pairs. Students can continue to attempt the Test your understanding question.

Differentiation ideas:

Support: The teacher can assess students' answers and give verbal support.

Stretch and challenge: Students can explain to a class the meaning of *amphiprotic* and how it differs from amphoteric.

Plenary ideas

1 Complete and balance the following equations and name the salts formed in each reaction (15 minutes)

Resources: A list of equations on the reactions of acids, for example:

1. $CuO + HNO_3 \rightarrow$
2. $Mg + CH_3COOH \rightarrow$
3. $NH_3 + HCl \rightarrow$
4. $Ba(OH)_2 + HNO_3 \rightarrow$
5. $CaCO_3 + H_2SO_4 \rightarrow$
6. $NaHCO_3 + HCOOH \rightarrow$
7. $Cu + HCl \rightarrow$

Description and purpose: Students need to apply their knowledge of the general reactions of acids and charges of ions to complete these questions. For more able students, they can specify state symbols and write out ionic equations.

2 Multiple choice questions on conjugate acid–base pairs (5 minutes)

Resources: End of Chapter 19 test Question 2.

Description and purpose: A quick assessment of the students' understanding of the definition of conjugate acid–base pairs and students can correct the wrong options.

19.4 pH; 19.5 Strong and weak acids and bases; 19.6 The dissociation of water and 19.7 Calculating pH values

LEARNING PLAN

Learning objectives	Success criteria
Understand what pH is and calculate pH and $[H^+(aq)]$	Students can explain what pH is and interconvert pH and $[H^+(aq)]$.
Understand that water dissociates and relate $[H^+(aq)]$ and $[OH^-(aq)]$ to acidity and basicity	Students can describe the dissociation of water and use the relative concentrations of H^+ and OH^- to determine whether a solution is acidic, neutral or basic.
Distinguish between strong and weak acids and bases	Students can explain the definitions of strong and weak acids and bases and give examples of each.

Common misconceptions

Misconceptions	How to identify	How to overcome
Students think that neutral solutions always have pH = 7.	Students can calculate the pH of water at 50 °C using its K_w value (5.476×10^{-14}) and determine whether it is acidic, basic or neutral.	Water dissociates more at higher temperatures, as the process is endothermic. The pH of water falls below 7 when the temperature is above 25 °C. However, since $[H^+] = [OH^-]$ in water, water is always neutral. The relative concentrations of $[H^+]$ and $[OH^-]$ determine the neutrality of the solution, rather than pH values.
Students confuse strong acids and concentrated acids.	Ask students which acid is stronger, 0.1 mol dm^{-3} HCl or 1 mol dm^{-3} CH_3COOH, and why.	A strong acid is not the same as a concentrated acid. Strong acids are acids that dissociate completely in aqueous solutions, independent of their concentrations. Concentration means the number of particles per unit volume, and this is a concept that can be applied to many substances not just acids and bases.

Starter ideas

1 Log and power of 10 calculation practice (15 minutes)

Resources: Quick algebra calculations, for example:

1 $\log 10 =$, $\log 1000 =$, $\log 0.1 =$, $\log 0.001 =$, $\log 1 =$, $\log (10 \times 10^2) =$, $\log (10^{-2}) =$, $\log (10^{-1} \times 10^2) =$
2 $\log x = 1$, $x =$
3 $\log y = -2$, $y =$

Description and purpose: Assess students' knowledge of log calculations.

What to do next: Some students might be unfamiliar with the interconversion between log and power of 10. Introduce log calculations and practice with more examples.

2 Use of pH values (5 minutes)

Resources: A mini-whiteboard, pens and a list of pH values of solutions at 25 °C.

Description and purpose: The teacher provides a list of solutions with their pH values at 25 °C. Students need to identify whether they are acidic, neutral or basic. This provides a reminder of the use of pH values.

What to do next: Students should be familiar with the previous idea of using pH to determine acidity / basicity of solutions. More able students can continue to research the origin of the pH concept.

Main teaching ideas

1 Definition of pH (40 minutes)

Resources: Test your understanding Questions 10–13 from the Coursebook.

Description and purpose: Introduce the definition of pH and how to interconvert pH and $[H^+]$. Emphasise that pH depends on hydrogen ion concentration, which is not always equivalent to acid concentration.

Differentiation ideas:

Support: Start with Questions 10 and 11. Students can follow the formulas of pH = −log[H^+] or [H^+] = 10^{-pH}, and the teacher can provide support by showing how to use calculators to perform these calculations.

Stretch and challenge: Students do Questions 12 and 13 without calculators.

2 Strong and weak acids and bases (30 minutes)

Resources: 1 mol dm^{-3} HCl and 1 mol dm^{-3} CH_3COOH solutions (unlabelled); universal indicator paper or pH meters with data loggers; powerpacks, wires, crocodile clips, ammeters, and graphite electrodes to test the conductivity of the acid solutions.

Description and purpose: The teacher goes through the definitions of strong and weak acids and bases. Ask students to suggest and test ways of distinguishing between strong and weak acids. Write equations for the dissociation of various acids and bases.

Differentiation ideas:

Support: Students can work in groups to discuss and carry out experiments to test which of the two acids is the stronger one.

Stretch and challenge: Ask students to explain to the class which of the following pair of acids, HNO_3 and HCOOH, has a stronger conjugate base using equations.

3 Determine whether a solution is acidic, neutral or alkaline using K_w calculations (30 minutes)

Resources: IB Chemistry data booklet and a table for calculations of [H^+], [OH^-] and pH at 25 °C; for example:

[H^+(aq)] / mol dm^{-3}	[OH^-(aq)] / mol dm^{-3}	pH	Acidic, neutral or alkaline?
1.00×10^{-10}			
	1.00×10^{-8}		
		3.00	
1.32			
	5.03×10^{-3}		
		2.18	

Description and purpose: Introduce the dissociation of water; the ion product constant of water, K_w; and how it is calculated from the concentrations of H^+ and OH^-.

Differentiation ideas:

Support: The teacher can show steps in the calculations on the board and go through a few examples.

Stretch and challenge: Students complete the work independently. They can then look into how K_w changes with temperature and calculate the pH of water at 80 °C (Test your understanding Question 25 from the Coursebook).

Plenary ideas

1 Calculate the pH of the following solutions (15 minutes)

Resources: Calculate the pH of 1) a 0.035 mol dm^{-3} solution of HNO_3 and 2) a 0.820 mol dm^{-3} $Ba(OH)_2$.

Description and purpose: These questions require students to first identify the substances as strong acid / base and then work out [H^+] either directly from the acid concentration or by using K_w and the base concentration. They also need to be confident with performing log calculations on a calculator.

2 Q&A on the order of pH of solutions (15 minutes)

Resources: Arrange the following solutions (all of 0.100 mol dm^{-3} concentration) in order of pH: HCl, NaOH, HCOOH, $Ba(OH)_2$, H_2SO_4 and CH_3NH_2.

Description and purpose: Students need to apply their knowledge of strong and weak acids / bases and understand that pH depends on $[H^+]$.

19.8 Acid–base titrations

LEARNING PLAN	
Learning objectives	**Success criteria**
Understand the shape of a pH curve for a strong acid–strong base titration	Students should be able to sketch and interpret a pH curve for a strong acid–strong base titration.

Starter ideas

1 A titration calculation (20 minutes)

Resources: Calculate the pH of the reaction mixture when 1) 10 cm^3 of 0.100 mol dm^{-3} NaOH are added to 25.0 cm^3 0.100 mol dm^{-3} HCl and 2) 30 cm^3 of 0.100 mol dm^{-3} NaOH are added to 25.0 cm^3 0.100 mol dm^{-3} HCl.

Description and purpose: Students revise their knowledge of solution calculations (Chapter 4).

What to do next: Students should be able to predict that for 1) pH $<$ 7 and 2) pH $>$ 7 and check their answers to see if they make sense. The teacher can go through the moles calculations with excess reactants step by step on the board to support.

Main teaching ideas

1 Practical on acid–base titration (60 minutes)

Resources: For each group of students, 0.100 mol dm^{-3} NaOH and 0.100 mol dm^{-3} HCl solutions, a 50 cm^3 burette, a 25 cm^3 pipette with a filler, a pH meter with data logger, graph paper, pen and paper. Or an Online version of the experiment.

Description and purpose: Students perform a strong acid–strong base titration, adding NaOH from a burette to 25 cm^3 of HCl in a conical flask. Record the pH values for every 0.5 cm^3 addition of NaOH, plot a graph of pH against volumes of NaOH added and compare the experimental pH values with the theoretical calculations done in Starter activity 1. Alternatively, search for 'RSC titration screen experiment' for an online version of the experiment.

› **Differentiation ideas:**

Support: Students can be assigned to mixed-ability groups. The teacher can support by giving a step-by-step method of the titration and setting up the data logger. Students can model their curves using Figure **19.10** in the Coursebook.

Stretch and challenge: Ask students to explain 1) why pH = 7 when equal moles of acids and bases are mixed (equivalence point) and 2) the information that can be extracted from the *y* intercept of the pH curve and the final pH the curve approaches.

Plenary ideas

1 Sketching a pH curve for a strong acid–strong base titration (15 minutes)

Resources: A mini-whiteboard and pens to sketch a pH curve for adding 0.5 mol dm^{-3} HNO_3 to 25 cm^3 of 0.5 mol dm^{-3} $Ba(OH)_2$ and mark on the curve the initial pH, the final pH the curve tends to, the volume of HNO_3 required to reach the equivalence point and the pH at the equivalence point.

Description and purpose: This exercise requires students to plot and explain a pH curve for a strong acid being added to a strong alkali.

19.9 pOH; 19.10 Ionisation constants for acids and bases; 19.11 The base ionisation constant, K_b and 19.12 The strength of an acid and its conjugate base

LEARNING PLAN

Learning objectives	Success criteria
Understand what pOH is and use it in calculations	Students can explain what pOH is and interconvert pOH, [OH$^-$] and [H$^+$].
Understand the connection between the values of K_a, K_b, pK_a and pK_b and the strengths of acids and bases	Students should be able to interconvert the values of K_a, pK_a, K_b and pK_b and use these values to identify the relative strengths of acids and bases.
Solve problems using K_a, K_b, pK_a and pK_b	Students can solve questions involving K_a, K_b, pK_a and pK_b values.
Understand the connection between K_a and K_b for a conjugate acid–base pair	Students can interconvert K_a and K_b for conjugate acid–base pairs using their relationships with K_w.

Starter ideas

1 pH calculations (10 minutes)

Resources: Pens, paper and a calculator.

Description and purpose: Calculate the pH of a 0.200 mol dm^{-3} LiOH solution at 25 °C. This question helps students to recap their knowledge on how [H$^+$] and [OH$^-$] are related to K_w in aqueous solutions and how to work out pH from [H$^+$].

What to do next: If students are not confident with manipulating the concentrations of hydrogen and hydroxide ions and working out pH values, then go back to sub-chapters 19.4–19.7 to consolidate the knowledge first before moving onto Higher Level contents.

Main teaching ideas

1 pOH calculations (40 minutes)

Resources: Test your understanding Questions 35, 37 and 38:

1. easy: Question 35, simply interconverting pOH and [OH$^-$]
2. medium: Question 37, calculating both [OH$^-$] and [H$^+$] from pOH
3. hard: Question 38, calculating pOH and pH from the concentrations of solutions.

Description and purpose: The teacher can start the activity by introducing an example of a pOH calculation and drawing an analogy to pH calculations covered at Standard Level.

› **Differentiation ideas:**

Support: Give students the choice to start from different levels and the teacher can provide support accordingly.

Stretch and challenge: Students complete the hard questions on their own and self-assess their answers. Students prove that pH + pOH = 14 for an aqueous solution at 25 °C.

2 K_a and pH of weak acids (40 minutes)

Resources: Test your understanding Questions 44 and 45, IB Chemistry data booklet.

Description and purpose: Introduce the activity by giving the expression of K_a and showing one or two calculations of pH of a weak acid, with and without the assumption that $[HA]_{initial} = [HA]_{equilibrium}$. Emphasise that the weaker the acid is, the more valid the assumption is.

› **Differentiation ideas:**

Support: The teacher can give a step-by-step method for the calculation of pH of weak acids. For example, writing out the expression of K_a → finding the value of K_a → multiplying K_a by the initial concentration of the acid → taking the square root of the value to find $[H^+]$ → calculating pH from $[H^+]$.

Stretch and challenge: Students can complete the questions on their own and self-assess their answers. Afterwards, they can use the pK_a values of the organic acids in the IB Chemistry data booklet to compare the acidity of carboxylic acids and research why adding carbons to an alkyl chain makes the acids weaker.

3 K_b and pOH of weak bases (40 minutes)

Resources: Test your understanding Questions 50 and 51.

Description and purpose: Introduce by giving the expression of K_b and showing two calculations of pOH and pH of a weak base, with the assumption that $[B]_{initial} = [B]_{equilibrium}$. Emphasise that the weaker the base is, the more valid the assumption is.

› **Differentiation ideas:**

Support: The teacher can give a step-by-step method for the calculation of pH / pOH of a weak base. For example, writing out the expression of K_b → finding the value of K_b → multiplying K_b by the initial concentration of the base → taking the square root of the value to find $[OH^-]$ → calculating pOH from $[OH^-]$ then pH from pOH, or calculating $[H^+]$ from $[OH^-]$ then pH from $[H^+]$.

Stretch and challenge: Students can complete the questions on their own and self-assess their answers. They can explain their solutions to others in the class. In addition, students can work out the relationships between K_a, K_b and K_w for a conjugate acid–base pair.

Plenary ideas

1 pK_a and pK_b calculations (15 minutes)

Resources: Complete the following table:

Acid	K_a / mol dm^{-3}	pK_a	Conjugate base	pK_b
C_6H_5COOH		4.20		
	1.35×10^{-5}		$CH_3CH_2COO^-$	
			CN^-	4.69
			CH_3NH_2	3.34

Description and purpose: Students need to recall and apply their knowledge of K_a, K_b, pK_a and pK_b. They can self-assess their answers. They can then arrange the conjugate acids in order of acidity and the conjugate bases in order of basicity.

19.13 The pH of salt solutions and 19.14 More pH curves

LEARNING PLAN

Learning objectives	Success criteria
Predict the pH of a salt solution	Students can predict the pH of a salt solution from the strengths of the acid and base from which it forms.
Sketch and explain pH curves	Students can sketch and interpret pH curves of all four combinations of strong and weak acids and bases.
Understand how acid–base indicators work and predict a suitable indicator for a titration	Students can explain how indicators change colour and how to choose an appropriate indicator for different types of titration.

Common misconceptions

Misconceptions	How to identify	How to overcome
Students think that a neutralisation reaction always results in the formation of a neutral salt	Ask students to predict the pH when 25 cm^3 of 1 mol dm^{-3} NaOH react with 25 cm^3 of 1 mol dm^{-3} CH_3COOH	A pH meter with a data logger can be used to show that, after the neutralisation reaction, the solution of CH_3COONa has pH > 7. Equations of salt hydrolysis can be written to show that there is more OH^- than H^+ in this salt solution.
Students think that a titration with an indicator can be used to distinguish between a strong acid and a weak acid of the same concentration	Question students on ways to distinguish between a strong acid and a weak acid. Often students answer with titration	Titration can be used to identify a strong acid and a weak acid if the pH of the reaction mixture is continuously monitored using a pH meter. Using an indicator will not work, as the volumes of the alkali used at the equivalence point depend on the original concentrations of the acids, rather than the concentrations of hydrogen ions.

Starter ideas

1 Salt formation (10 minutes)

Resources: Pens and paper.

Description and purpose: Students suggest the parent acid and parent base that could be used to make the following salts: KNO_3, $NaHCO_3$, CH_3NH_3Cl, $HCOONH_4$.

What to do next: Ask students to put the salts into four categories based on their formation from a strong acid and a strong base, from a strong acid and a weak base, from a strong base and a weak acid, and from a weak acid and a weak base.

Main teaching ideas

1 Measuring and explaining the pH of a salt solution (60 minutes)

Resources: 0.1 mol dm^{-3} aqueous solutions of NaCl, CH_3COONa, NH_4Cl and CH_3COONH_4. Pens, paper, a pH meter and a data logger, Coursebook sub-chapter 19.13 or the internet for research.

Description and purpose: Students can be divided into four groups to research one type of salt each (NaCl – formed from a strong acid and a strong base; CH_3COONa – formed from a weak acid and a strong base; NH_4Cl – formed from a strong acid and a weak base; CH_3COONH_4 – formed from a weak acid and a weak base). They will measure the pH of the 0.1 mol dm^{-3} solutions and explain to the rest of the class why their salts are of the pH values measured.

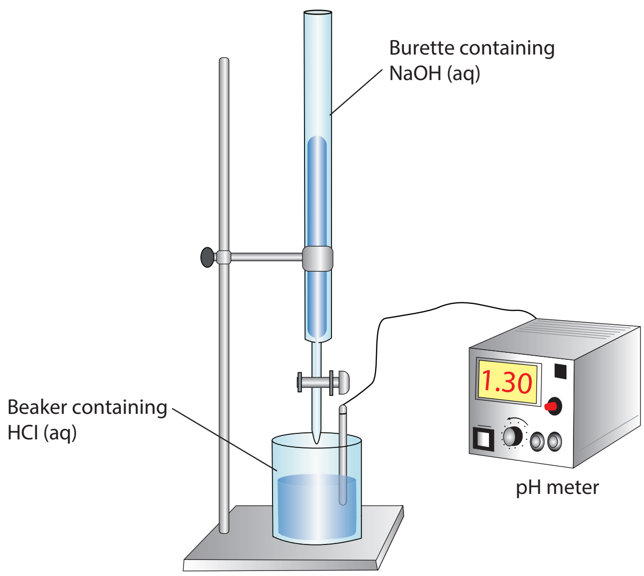
› **Differentiation ideas:**

Support: Students can be allocated to mixed-ability groups and work collaboratively. The teacher can help by showing how a pH meter works and giving a stepwise guide to explain salt hydrolysis. For example, start with working out the ions present in the aqueous solutions and consider the strengths of the ions based on their conjugate acids / bases. If an ion is formed from a strong acid / base, then it itself is weak. If an ion is formed from a weak acid / base, then it itself is relatively strong and can ionise water. The teacher can help with writing equations to explain the hydrolysis process.

Stetch and challenge: Students work independently for the research part. They can then move onto working out the pH of salt solutions using Test your understanding Questions 60–62.

2 More acid–base titrations (90 minutes)

Resources: 0.1 mol dm^{-3} aqueous solutions of NaOH, HCl, NH_3 and CH_3COOH; pH meters and data loggers; pens and graph paper; Worksheet 19.1. The apparatus can be set up as shown in the diagram below.



Description and purpose: Students carry out acid / base titrations in groups (4 combinations of strong and weak acid and base, using a pH meter with a data logger to record the pH for every 0.5 cm^3 of alkali added to 25cm^3 of an acid in a beaker). Note that the pH meter should be calibrated with buffers before use. After the practical, students complete the analysis of results and evaluation of experiment questions on Worksheet 19.1.

› **Differentiation ideas:**

Support: Students can be allocated to groups based on ability, and the teacher can support accordingly. The teacher can help by showing a step-by-step titration method and provide a results table in which to record the pH values.

Stretch and challenge: Students work independently for the practical part. Ask students to explain the pH values of the reaction mixtures at volume = 0 cm^3, at half the equivalence point, at the equivalence point and the final value the pH approaches. Students complete the extension of experiment questions on Worksheet 19.1.

3 Acid–base indicators (60 minutes)

Resources: Coursebook sub-chapter 19.14 or the internet.

Description and purpose: Students research and make a leaflet on how acid–base indicators change colour with pH and how to select a suitable indicator for different types of acid–base titration. The leaflet needs to contain information on the pH range of an indicator and how it is related to the pK_a of the indicator, and the difference between the end point and the equivalence point in a titration.

› **Language focus:** Writing clear information and using the correct terms related to acid–base indicators.

› **Differentiation ideas:**

Support: Students can be allocated to mixed-ability groups to work collaboratively. Different groups can peer assess each other's work with two stars and a wish.

Stretch and challenge: Students can research how phenolphthalein changes colour under acidic and basic conditions due to the change in its chemical structure.

Plenary ideas

1 Predict the pH of a salt solution (10 minutes)

Resources: Test your understanding Question 58 from the Coursebook.

Description and purpose: Students can self-assess and explain their answers to their peers.

2 Sketch a titration curve (10 minutes)

Resources: Mini-whiteboards, pens.

Description and purpose: Student need to sketch a pH titration curve for adding 0.1 mol dm^{-3} CH_3COOH to 25 cm^3 of 0.2 mol dm^{-3} NaOH. They can self-assess: 1) the starting pH should be above 13; 2) the final pH is above 1 (should be around 2.9); 3) the equivalence point is at 50 cm^3 with pH > 7; and 4) the curve is steep around the equivalence point.

3 Finding suitable indicators for acid / base titrations (10 minutes)

Resources: Test your understanding Question 68 from the Coursebook.

Description and purpose: Students can self-assess their answers and explain to the rest of the class their choices of indicators.

19.15 Buffer solutions

LEARNING PLAN

Learning objectives	Success criteria
Understand what a buffer solution is and explain how it works Solve problems involving buffer solutions	Students should be able to explain what a buffer solution is and how it resists changes in pH. Students can calculate the pH of a buffer solution from the relative concentrations of the acid / base and its salt and vice versa.

Common misconceptions

Misconceptions	How to identify	How to overcome
Students think a pH never changes for a buffer solution	Ask students to explain the application of buffer solutions and how they work	A buffer solution can only resist changes in pH when small amounts of acid or alkali are added. From the calculation of pH of a buffer solution, it should be clear that the relative concentrations of the constituent acid or base to its salt must change very little if the buffer is to function properly.

Starter ideas

1 Calculating pH of a weak acid / base solution (10 minutes)

Resources: Mini-whiteboards, pens, IB Chemistry data booklet.

Description and purpose: Ask students to calculate the pH of a 0.1 mol dm^{-3} aqueous solution of a weak acid or a weak base using its pK_a or pK_b value.

What to do next: This activity allows students to recap knowledge from previous sub-chapters. They should be able to explain the assumptions used in the calculations – negligible ionisation of the acid or the base and negligible dissociation of water.

Main teaching ideas

1 Practical on making buffers and testing their capacities (60 minutes)

Resources: 0.4 mol dm^{-3} CH_3COOH solution, 0.4 mol dm^{-3} CH_3COONa solution, 0.5 mol dm^{-3} NaOH solution, measuring cylinders, burettes, pH meters and data loggers; Coursebook or the internet for research; Worksheet 19.2.

Description and purpose: Students should prepare buffer solutions of different compositions (for example, 45 cm^3 CH_3COOH with 5 cm^3 CH_3COONa, 35 cm^3 CH_3COOH with 15 cm^3 CH_3COONa, 25 cm^3 CH_3COOH with 25 cm^3 CH_3COONa, 15 cm^3 CH_3COOH with 35 cm^3 CH_3COONa, and 5 cm^3 CH_3COOH with 45 cm^3 CH_3COONa) and test their buffering capacities by investigating how much the pH changes when 10 cm^3 of 0.5 mol dm^{-3} NaOH are added to the buffer solution in 0.5 cm^3 drops. They should also research and explain how a buffer works to resist pH changes when small amounts of acids / alkalis are added using suitable equations. Students complete the analysis of results and evaluation of experiment sections on Worksheet 19.2.

› **Differentiation ideas:**

Support: Students can work collaboratively in mixed-ability groups. The teacher provides support by giving equations to explain how buffering works.

Stretch and challenge: Students can calculate the expected pH for each buffer composition using the worked examples in Coursebook sub-chapter 19.15. They can also explain how a buffer works and why the one made above is most effective when there are equal concentrations of the weak acid and its salt.

2 Calculations involving the pH of a buffer solution (60 minutes)

Resources: Pens; paper; Test your understanding Questions 70, 71, 74, 75 and 79.

1. easy: Questions 70 and 71, calculations based on the concentrations of a weak acid / base and its salt
2. medium: Questions 74 and 75, calculations to work out the relative concentrations of a weak acid / base and its salt from the pH value of a buffer
3. hard: Question 79, calculations on the change in pH values when a small amount of acid / alkali is added to a buffer.

Description and purpose: The teacher goes through a few examples of the buffer pH calculations on the board, explaining, for example, how the assumption of $[H^+] = [A^-]$ is no longer valid in the K_a expression of a buffer. The teacher can also explain the Henderson–Hasselbalch equation but must emphasise that these equations are not given in data booklet and must be remembered correctly.

› **Differentiation ideas:**

Support: Start with the easy questions and the teacher can give verbal support accordingly. Give guidance on how to work out the concentrations of a weak acid / base and its salt and substitute them into the K_a / K_b expression or the Henderson–Hasselbalch equation.

Stretch and challenge: Students calculate independently and self-assess their answers.

Plenary ideas

1 A multiple choice question on the making of buffer solutions (5 minutes)

Resources: Which of the following will make a buffer solution if combined in equal volume?

I 0.10 mol dm^{-3} KOH + 0.10 mol dm^{-3} HNO_3

II 0.10 mol dm^{-3} KOH + 0.20 mol dm^{-3} CH_3COOH

III 0.10 mol dm^{-3} CH_3COOK + 0.10 mol dm^{-3} CH_3COOH

A **I** only

B **III** only

C **II** and **III** only

D **I**, **II** and **III**

Description and purpose: Students can self-assess their answers (the correct answer is C) and reflect on their understanding of how buffers are made.

2 Traffic lights to rate confidence on the topic (5 minutes)

Resources: Red, yellow and green cards.

Description and purpose: Students can self-assess their understanding of the topic and show how confident they are with the calculations of the pH of a buffer solution.

› **Assessment ideas:** Use of traffic light cards, thumbs up or down, or a scale of 1–10.

Assessment ideas

- Give students a list of different Brønsted–Lowry acid–base reactions and ask them to identify the conjugate acid–base pairs.
- Quiz on pH and pOH of solutions (working out from $[H^+]$ or $[OH^-]$) and determine whether they are acidic / basic / neutral.
- Students summarise how to work out the pH of a weak acid or the pOH of a weak base from their concentrations and pK_a and pK_b values. Students should be familiar with the assumptions used in the calculations.
- Give students a list of weak acids to sort into order of acidity and they can explain to others the relative strengths of the conjugate bases.
- Students can write a summary of the information they can extract from pH titration curves, explaining clearly what they can work out from the initial pH values, the pH values at the equivalence and half-equivalence points, the volumes at the equivalence points, and the pH values the curves approach. They can also add information on how to choose an appropriate indicator.
- Correct mistakes in buffer pH calculations.
- Test your understanding questions from the Coursebook.

Homework ideas

- Draw a mind map to include definitions of acids, bases, general reactions of acids, pH, definitions of strong and weak acids and bases, indicators, and titration curves. This can be peer assessed, and students can add to each other's mind map using Post-its.
- Exercises 19.1–19.15 from the Workbook.
- Exam-style questions from the Coursework.
- Use a titration simulator to revise the shapes of titration curves and understand why not all indicators work for specific combinations of titrations. See the digital resource links.
- Past paper questions; search the internet for IB past paper questions on acids and bases.
- Students can reflect on how well they know all the p values (pH, pOH, pK_a, pK_b), and if they are able to explain to another student how to calculate them, and how some of the values are related to each other.
- Students can reflect on what they knew about acids / bases / salts before the start of this chapter and how their ideas of these substances have changed after going through the learning contents. For example, how to determine if a solution is neutral and how indicators work.
- Students can reflect on their knowledge of buffer solutions and how confident they are with the calculations of pH values of buffer solutions.

Links to digital resources

- Titration screen experiment (search the Royal Society of Chemistry website with the keywords 'titration screen experiment')
- Titration simulator with indicators (search the internet with the keywords 'titration simulator')
- Past paper questions (search the internet for 'exam-mate' and 'IB past paper questions on acids and bases')

CROSS-CURRICULAR LINKS

- Using a data logger and pH probe.
- Maths: Arithmetic calculations, including solving logarithmic functions and their inverse. Plotting graphs; drawing curves of best fit; interpreting graphs, including logarithmic graphs.
- TOK: How does scientific knowledge progress? Why are the laws in the natural sciences sometimes represented using mathematical language? How is our perception of acids and bases affected by the use of pH scales and pH curves? How do we decide on which theory to use to explain the behaviours of acids and bases?