20 Electron transfer reactions

Teaching plan

Sub-chapter	Approximate number of learning hours	Learning content	Resources
20.1 Redox reactions 20.2 Redox equations	3	Know the definitions of redox. Deduce oxidation states and oxidising and reducing agents in a chemical reaction. Name compounds using oxidation numbers. Write half-equations for redox reactions in acidic and neutral solutions. Predict and write balanced equations for the reactions between acids and metals.	**Coursebook** Sections 20.1–20.2 Test your understanding Questions 1, 4, 6–8 and 12 Exam-style Question 2 **Workbook** Exercises 20.1–20.2 **Teacher's resource** PowerPoint 20, slides 2–7 Worksheet 20.1 End of Chapter 20 test Questions 1–5
20.3 Arranging metals in order of reactivity 20.4 Electrochemical cells 20.5 Rechargeable batteries	3–4	Deduce the relative ease of oxidation of metals and the relative ease of reduction of halogens. Explain the construction of an electrochemical cell and label the various parts of a cell. Explain what a voltaic cell is and describe its construction. Explain how rechargeable batteries work and deduce reactions at the electrodes. Discuss the advantages and disadvantages of fuel cells, primary cells and secondary cells.	**Coursebook** Sections 20.3–20.5 **Workbook** Exercises 20.3–20.5 **Teacher's resource** PowerPoint 20, slides 8–11 Worksheet 20.2 End of Chapter 20 test Question 11

Sub-chapter	Approximate number of learning hours	Learning content	Resources
20.6 Electrolysis	1	Explain what an electrolytic cell is and how it differs from a voltaic cell. Deduce the products of electrolysis of molten salts.	**Coursebook** Section 20.6 Test your understanding Question 18 **Workbook** Exercise 20.6 **Teacher's resource** PowerPoint 20, slides 11
20.7 Redox reactions in organic chemistry 20.8 Reduction reactions	3	Describe the oxidation of alcohols using distillation or reflux. Describe the reduction of carboxylic acids, aldehydes and ketones. Know that the reduction of alkenes and alkynes with hydrogen produces less unsaturated compounds.	**Coursebook** Sections 20.7–20.8 Test your understanding Questions 20, 23, 24, 26 and 31. **Workbook** Exercises 20.7–20.8 **Teacher's resource** PowerPoint 20, slides 12–16 End of Chapter 20 test Question 15
20.9 Standard electrode potentials 20.10 Electrolysis of aqueous solutions	5	Define standard electrode potential and how it can be used to predict the ease of oxidation / reduction. Calculate standard cell potentials. Predict the spontaneity of a reaction from the standard cell potential and calculate the standard change in Gibbs energy for the reaction. Deduce the products of electrolysis of aqueous solutions using standard electrode potentials. Explain how electroplating works and deduce equations at the electrodes.	**Coursebook** Sections 20.9–20.10 Test your understanding Questions 33, 36–37 **Workbook** Exercises 20.9–20.10 **Teacher's resource** PowerPoint 20, slides 17–23 Worksheet 20.2 End of Chapter 20 test Questions 6–10, 12–14

BACKGROUND KNOWLEDGE

- Identify species that are oxidised / reduced and oxidising / reducing agents in chemical reactions based on the loss or gain of oxygen or electrons.
- Deduce the oxidation states of an atom in an ion or a compound (Chapter 10).
- Activity series of metals (how easily metals can lose electrons and are, therefore, oxidised).
- Order of reactivity of halogens (how easily halogens can gain electrons and are, therefore, reduced).
- Understand why ionic compounds conduct electricity when molten or in aqueous solution (Chapter 6).
- Know the terms cation, anion, electrode and electrolyte.
- Explain how fuel cells work and deduce the half-equations at each electrode of fuel cells (Chapter 14).
- Write ionic equations for electrolysis reactions of molten salts and half-equations at the electrodes.
- Classify primary, secondary and tertiary alcohols (Chapter 11).
- Identify functional groups of aldehydes, ketones, carboxylic acids, alkenes and alkynes (Chapter 11).

Syllabus overview

- In this chapter, the concept of redox is expanded from oxygen / hydrogen gain / loss to electron transfer and change in oxidation state (Chapter 10). Students practice how to write overall ionic equations and half-equations in acidic and neutral solutions. Redox titration calculations are very similar to acid–base titration calculations, but it is useful to perform experiments to emphasise the self-indicating properties of the redox titrations.
- Students should recognise that displacement reactions are all redox reactions. By using the periodic table and the activity series, they can predict the relative ease of oxidation and reduction of metals and halogens (Chapter 10).
- Students are introduced to an overview of electrochemical cells, including voltaic and electrolytic cells. In both cells, oxidation occurs at the anode and reduction occurs at the cathode. Voltaic cells contain spontaneous redox reactions, converting chemical energy into electrical energy, and the opposite happens in electrolytic cells. Some examples of secondary cells should be introduced to illustrate the advantages and disadvantages of these cells in comparison to fuel cells (Chapter 14). The conductivity of ionic compounds is covered in Chapter 6, and students need to be able to work out the decomposition products of molten salts in electrolytic cells.
- Organic compounds (Chapter 11) can also undergo useful redox reactions. The conversions of functional groups (alcohols to aldehydes / ketones and carboxylic acids, and the reverse; and alkenes / alkynes to alkanes) require specific oxidising / reducing agents and experimental set-ups.
- Higher Level students will further consider the use of standard electrode potentials to predict the spontaneity of reactions and how the cell potential can be related to the Gibbs energy change of a reaction numerically.
- Students should be aware that some covalent compounds, for example, acids and water, can dissociate into ions in aqueous solutions (Chapter 19). By referencing the standard electrode potential charts, the products of electrolysis of aqueous solutions can be predicted.

20.1 Redox reactions and 20.2 Redox equations

LEARNING PLAN

Learning objectives	Success criteria
Understand redox reactions in terms of electron transfer and changes in oxidation state Write half-equations for oxidation and reduction reactions Construct equations for redox reactions	Students can explain redox reactions in terms of electron transfer and changes in oxidation state, and identify oxidising and reducing agents in chemical reactions. Students understand what half-equations are and can deduce half-equations in acidic and neutral solutions. Students can write overall ionic and chemical equations for redox reactions and solve problems using these equations.

Common misconceptions

Misconceptions	How to identify	How to overcome
Students are confused between oxidised and reduced species.	Ask students to identify what is oxidised and what is reduced in the following reaction: $3CuO + 2Fe \rightarrow Fe_2O_3 + 3Cu$ Some students think Cu is being reduced rather than CuO.	Emphasise that oxidising and reducing agents must be parts of the reactants, and so, can only appear on the left-hand side of an equation. In this reaction, CuO is being reduced and is, therefore, the oxidising agent. Cu is one of the products; it is neither oxidised nor reduced, although it is correct to say that the copper element is reduced in this reaction.

Starter ideas

1 Identify the species being oxidised and reduced in the following reactions (10 minutes)

Resources: Some redox equations, for example, $2NH_3 + 3CuO \rightarrow N_2 + 3Cu + 3H_2O$ and $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$; mini-whiteboards and pens.

Description and purpose: Students identify and explain the species being oxidised and reduced in the reactions.

What to do next: Revise ionic equations and use the concept of electron transfer to explain redox.

2 Oxidation states (10 minutes)

Resources: Test your understanding Question 1 from the Coursebook.

Description and purpose: Revise knowledge covered in Chapter 10 and set a timed challenge for students to determine the oxidation states of all elements in the compounds listed.

What to do next: Introduce a new definition of redox in terms of changes in oxidation states.

Main teaching ideas

1 Identify the species oxidised, reduced, oxidising agent and reducing agent in reactions (30 minutes)

Resources: Test your understanding Question 4 from the Coursebook.

Description and purpose: The teacher first introduces the idea that, for some reactions (for example, $H_2O_2 + SO_2 \rightarrow H_2SO_4$), it is difficult to define redox using gain / loss of oxygen / hydrogen / electrons. The partial electron transfer from S to O can be more easily detected by looking at the increase and decrease in oxidation states of each element.

Differentiation ideas:

Support: Group students by ability and the teacher can provide support accordingly. Remind students how to determine oxidation states of elements (Chapter 10). Students should write out the oxidation state of each element clearly and check if the overall oxidation state of all the elements in a molecule / ion equals its charge.

Stretch and challenge: Students can work independently and self-assess their answers. They can explain their working to the rest of the class.

2 Balancing half-equations (30 minutes)

Resources: Test your understanding Questions 6–8 from the Coursebook.

1. Easy: balance half-equations in neutral solutions using Test your understanding Question 6.
2. Hard: balance half-equations in acidic solutions using Test your understanding Questions 7 and 8.

Description and purpose: Teach students how to write oxidation or reduction half-equations in neutral and acidic solutions.

Differentiation ideas:

Support: The teacher provides help by going through a step-by-step method. For example, balancing half-equations in neutral solutions can be done by balancing all the atoms, then adding e^- to the side deficient in negative charge. Balancing half-equations in acidic solutions can be done by balancing all the atoms except H and O, adding H_2O to balance O, adding H^+ to balance H and adding e^- to the side deficient in negative charge.

Stretch and challenge: Students can work independently and self-assess their answers. For something more challenging, try question 4 from the 2003 UK Chemistry Olympiad R1 (search the Royal Society of Chemistry website for Chemistry Olympiad past papers).

3 Construct overall redox equations (30 minutes)

Resources: Test your understanding Question 12 from the Coursebook.

Description and purpose: Teach students how to balance more complex redox equations.

Differentiation ideas:

Support: The teacher provides help by going through a step-by-step method. For example, splitting the reaction into oxidation and reduction halves → balancing each half separately → multiplying each balanced half-equation by the appropriate number, so the electrons can cancel out → adding the half-equations together and removing any repetitions of H^+ or H_2O on both sides.

Stretch and challenge: Students can work independently and self-assess their answers. Students can then try to balance redox equations in alkaline solutions, for example, the reduction of MnO_4^- to MnO_4^{2-} by OH^- ions.

4 Redox titration practical and calculations (60 minutes)

Resources: Search practical-science.com with the keywords 'redox iron tablet titration' for apparatus and chemicals required for this practical; Worksheet 20.1.

Description and purpose: Practical on a redox titration to calculate the iron(II) content in iron tablets. Students complete the analysis of results and evaluation of experiment questions on Worksheet 20.1.

Differentiation ideas:

Support: Group students by ability, so the teacher can provide support accordingly. The teacher can provide a table for results analysis, help to balance half-equations and the overall equation, and go through the calculations step by step. Students may need to go through a few examples of similar calculations.

Stretch and challenge: Encourage students to work with a provided method and carry out calculations with no hints given. They could also film a video on good titration techniques and explain the self-indicating property of this redox titration.

Plenary ideas

1 Oxidising and reducing agents (5 minutes)

Resources: Identify the oxidising and reducing agents in the following reaction:

$CH_4 + 4Cl_2 \rightarrow CCl_4 + 4HCl$

Description and purpose: Students can peer-assess each other's answers and explain how they arrive at their answers to their partner.

2 A multiple choice question on redox reactions (5 minutes)

Resources: Exam-style Question 2 from the Coursebook.

Description and purpose: Students should do this question under timed conditions to find the correct answer; they need to be able to spot changes in the oxidation states of elements.

20.3 Arranging metals in order of reactivity; 20.4 Voltaic cells and 20.5 Rechargeable batteries

LEARNING PLAN

Learning objectives	Success criteria
Interpret data regarding displacement reaction Understand the reactions that occur in a voltaic cell Understand how rechargeable batteries work	Students can predict the relative ease of oxidation of metals and the relative ease of reduction of halogens. Students can explain how a voltaic cell works and how it produces energy from spontaneous redox reactions. Students can explain the reversible redox reactions in rechargeable batteries.

Common misconceptions

Misconceptions	How to identify	How to overcome
Students think that electricity is carried only by electrons in a voltaic cell.	Ask students to explain how electricity is conducted in a voltaic cell.	Electricity is conducted by the delocalised electrons in the electrodes and along the electrical wires. However, further movement of ions in the two half-cells and in the salt bridge is required to complete the circuit. A salt bridge is needed to balance out the charges in the half-cells. Positive ions flow out of the anode half-cell and negative ions flow out of the cathode half-cell.

Starter ideas

1 Revision on the trend of chemical reactivities of Group I elements (10 minutes)

Resources: IB Chemistry data booklet.

Description and purpose: Ask students to comment on the trend in the chemical reactivities of alkali metal elements. This allows them to revise knowledge of periodicity from Chapter 10, and students can see how these metals fit into the reactivity series, in terms of their ease of being oxidised.

What to do next: Ask students to consider the difference between the rate of a reaction and the spontaneity of a reaction. Kinetics and thermodynamics are two different concepts, and students should understand that a reaction that can occur spontaneously does not always happen quickly.

Main teaching ideas

1 Demonstration of zinc / copper voltaic cell (60 minutes)

Resources: Zn and Cu metal strips, $ZnSO_4$ and $CuSO_4$ solutions (~ 1 mol dm^{-3}), a temperature probe, beakers, a high-resistance voltmeter (or potentiometer), wires, crocodile clips, a salt bridge (a folded piece of filter paper) soaked with saturated KNO_3 solution. Figure **20.7** from the Coursebook.

Description and purpose: The teacher starts by showing a displacement reaction between Zn and $CuSO_4$ with a temperature probe. Discuss the conversion of energy in this reaction. The teacher then demonstrates how the chemical energy from this reaction can be converted into electrical energy instead by setting up a voltaic cell: $Zn|ZnSO_4||CuSO_4|Cu$. Students draw and label a voltaic cell, write half-equations and explain the function of a salt bridge and the cell notation.

Differentiation ideas:

Support: Help students to draw and label a voltaic cell, with anode, cathode, the half-cells and the salt bridge. Check students' half-equations at each electrode.

Stretch and challenge: Independent work to label a voltaic cell and write the half-equations, using sub-chapter 20.4 of the Coursebook for reference. In addition, students can explain the direction of current flow, how electricity is conducted in the circuit, the function of a salt bridge and the cell notation to the rest of the class.

2 Practical on setting up voltaic cells (60 minutes)

Resources: Various metal strips of the same dimensions, for example, Cu, Zn, Mg and Fe strips; 1 mol dm^{-3} of solutions of the corresponding salts, for example, $CuSO_4$, $ZnSO_4$, $MgSO_4$ and $FeSO_4$; saturated solution of KNO_3; wires, crocodile clips, high-resistance voltmeter, beakers, filter paper, measuring cylinders and sandpaper, see Figure **20.8** from the Coursebook on how to set up the voltaic cells. Use $50 cm^3$ of each solution for each half-cell. Worksheet 20.2.

Description and purpose: Students can practice setting up voltaic cells with different combinations of metals and their ions and measure the corresponding voltages. Sandpaper can be used to polish the metal strips before setting up the cells. Students complete analysis of results and evaluation of results questions on Worksheet 20.2.

Differentiation ideas:

Support: Students can be put into mixed-ability groups to work collaboratively. The teacher either demonstrates or shows videos on how to set up voltaic cells. Search the Royal Society of Chemistry website with the keywords 'electrochemistry' and 'voltaic cell' and there are many videos available.

Stretch and challenge: Students can compare the experimental voltage values with literature values calculated from standard electrode potentials and comment on the random / systematic errors in this experiment.

3 Research on secondary cells and fuel cells (60 minutes)

Resources: Coursebook or the internet.

Description and purpose: Divide students into groups to research one specific type of secondary cell, for example, a lead–acid battery or nickel–cadmium battery or lithium ion battery. They need to produce a leaflet with information on 1) the oxidation and reduction reactions occurring at each electrode during the discharge of a secondary cell, 2) how the cells are recharged and 3) the nature of the electrodes and electrolytes in these cells.

Differentiation ideas:

Support: Students can work collaboratively in mixed-ability groups. The teacher supports by explaining the details of a secondary cell and comparing it with a primary cell.

Stretch and challenge: Students can compare and summarise the similarities and differences between secondary cells and fuel cells. Comment on the advantages and disadvantages of each type of cell and present to the class.

Language focus: Students can summarise information and explain scientific terms with concise language.

Plenary ideas

1 Labelling a voltaic cell (10 minutes)

Resources: A mini-whiteboard and pens.

Description and purpose: Ask students to draw a simple voltaic cell (e.g., $Zn|ZnSO_4||CuSO_4|Cu$) and annotate its anode, cathode and salt bridge. They should also work out the direction of ion movement in the salt bridge. This is to assess the learning objective on explaining how a voltaic cell works.

2 Lead–acid battery (10 minutes)

Resources: The overall reaction taking place in a lead–acid battery (a type of rechargeable battery / secondary cell) during its discharge is as follows:

$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$

Write the half-equation for the reaction that takes place at the anode during the discharge process and the equation for the reaction that occurs when the battery is being recharged.

Description and purpose: Students need to recall their knowledge on how to separate an overall redox equation into separate half-equations and that oxidation occurs on an anode. The second part of the question assesses the students' understanding of the definition of secondary cells.

20.6 Electrolysis

LEARNING PLAN

Learning objectives	Success criteria
Understand the electrolysis of molten salts	Students can explain what an electrolytic cell is and deduce the products of electrolysis of molten salts.

Common misconceptions

Misconceptions	How to identify	How to overcome
Students think that anodes are always negative	Ask students to explain which electrode is the anode in an electrolytic cell.	There are two major types of electrochemical cells: voltaic cells, where spontaneous reactions occur, and electrolytic cells, where non-spontaneous reactions occur. The anode is always where oxidation occurs. It is the negative electrode in a voltaic cell, and the positive electrode in an electrolytic cell.

Starter ideas

1 The extraction of metals (10 minutes)

Resources: Internet

Description and purpose: Ask students to research and explain why different methods are used to extract Al and Fe.

What to do next: Students should be able to recognise that, as Al is more reactive than C, therefore, it can only be extracted from its ores using electrolysis. This is why Al was not extracted until the 19th century. Fe is extracted by reducing iron ores using carbon / carbon monoxide.

Main teaching ideas

1 Demonstration of the electrolysis of a molten salt (30 minutes)

Resources: Search the Royal Society of Chemistry website with the keywords 'electrolysis of molten lead bromide'. The experiment can be adapted from the electrolysis of molten lead(II) bromide (see the Link to digital resources section). Test your understanding Question 18.

Description and purpose: Demonstrate the electrolysis of molten lead bromide, and ask students to predict the products of electrolysis of molten salts and write half-equations at each electrode.

› **Differentiation ideas:**

Support: The teacher can remind students how ionic compounds can conduct electricity when molten and show a diagram of an electrolytic cell with the anode, cathode and electrolyte annotated.

Stretch and challenge: Students can continue to write half-equations for the electrolysis of other ionic compounds; use Test your understanding Question 18.

Plenary ideas

1 Keyword glossary (15 minutes)

Resources: Give students a list of keywords covered in the chapter to define: anode, cathode, electrolyte, salt bridge, electromotive force, voltaic cell, secondary cell, fuel cell, electrolytic cell.

Description and purpose: Students produce a glossary of the words encountered in this and previous sub-chapters. An example should be given at the beginning of this activity to show the level of detail required for the definitions. This activity helps students to reflect on their understanding. To assess if students understand a word, they can write the word in a sentence and present it to the class.

› **Language focus:** Checking spelling and definitions of key terms.

20.7 Redox reactions in organic chemistry and 20.8 Reduction reactions

LEARNING PLAN

Learning objectives	Success criteria
Describe the oxidation of alcohols and aldehydes	Students can construct equations and describe the experimental set-up for the oxidation of alcohols and aldehydes.
Describe the reduction of aldehydes, ketones and carboxylic acids	Students should be able to explain the reduction of aldehydes, ketones and carboxylic acids using hydride ions.
Describe the reduction of unsaturated compounds	Students can write equations and deduce products for the reduction of alkenes and alkynes.

Common misconceptions

Misconceptions	How to identify	How to overcome
Students get confused about the experimental procedures to make carboxylic acids from the oxidation of primary alcohols.	Ask students how a carboxylic acid can be made from the oxidation of an alcohol.	Students can often recall that reflux needs to be used to ensure the complete oxidation of primary alcohols. However, to separate the carboxylic acid as a product from excess alcohol and the oxidising agent, distillation should be used following reflux.
The meaning of [O] used in the equation for the oxidation of alcohols / aldehydes in balanced equations gets confused.	Ask students to explain what [O] means in the equations; some might mistake it for atmospheric oxygen.	[O] is used to represent the oxidising agent, and this is a simplification. If students write out the reduction and oxidation half-equations for dichromate(VI) and a primary or secondary alcohol, they can then work out the full redox equation to show that no atmospheric oxygen takes part in the process.

Starter ideas

1 Primary, secondary and tertiary alcohols (10 minutes)

Resources: Test your understanding Question 20 from the Coursebook.

Description and purpose: Ask students to identify, from a list, primary, secondary and tertiary alcohols.

What to do next: Students recall knowledge from Chapter 11. They need to be able to explain how to classify the alcohols clearly before moving onto the main teaching ideas.

2 Combustion of alcohols (10 minutes)

Resources: Pens and paper.

Description and purpose: Ask students to construct equations for the complete and incomplete combustion of alcohols.

What to do next: Students recall knowledge on biofuels from Chapter 14. They can then research other ways of oxidising an alcohol (microbial or chemical oxidation), without combustion or using atmospheric oxygen.

Main teaching ideas

1 Chemical oxidation of ethanol practical (50 minutes)

Resources: Protocols are available online, for example, search with the keywords 'Pearson oxidation of ethanol' (see the Links to digital resources section). Videos for distillation and reflux can be found by searching the Royal Society of Chemistry website with the keywords 'distillation' and 'reflux'.

Description and purpose: Students follow step-by-step methods to carry out incomplete and complete chemical oxidation of ethanol using acidified sodium dichromate(VI). They should become familiar with setting up distillation and reflux apparatus safely. Students need to be able to explain why different set-ups favour the formation of different oxidation products.

Differentiation ideas:

Support: The teacher can help with setting up the apparatus and checking for safety before heating is started.

Stretch and challenge: Students carry out further experiments to identify the products, for example, using metal or metal carbonate or universal indicator paper to test for acids and using acidified sodium dichromate(VI) to see if the products can be further oxidised.

2 Redox equations for alcohols and aldehydes (45 minutes)

Resources: Test your understanding Questions 23–24 from the Coursebook.

Description and purpose: Students practise writing balanced chemical equations and half-equations for the oxidation of alcohols / aldehydes. The teacher introduces the reduction of carboxylic acids and carbonyls.

Differentiation ideas:

Support: Students start off by using [O] as a representation of oxidising agents. They can then move onto balancing half-equations for the oxidation of alcohols, using Test your understanding Question 23 for practice.

Stretch and challenge: Students can complete the questions on balancing half-equations and full redox equations on their own and self-assess their answers. They can further research into the nucleophilic addition mechanism for the reduction of carbonyls using hydride ions or BH_4^- ions and present it to the class.

3 Reduction of alkenes and alkynes (30 minutes)

Resources: Butter, margarine and vegetable oil; hexane, hexene and bromine water and molecular models. Table **20.3** from the Coursebook and Test your understanding Question 31 from the Coursebook.

Description and purpose: The teacher introduces the idea of saturated and unsaturated compounds and how hexane and hexene can be distinguished using bromine water. The concept of unsaturation extends to things we use in daily life, for example, vegetable oil can be turned into margarine and butter by reducing the level of unsaturation through hydrogenation. The teacher can demonstrate the unsaturation of margarine and vegetable oil and the saturation of butter using bromine water. The teacher introduces the concept of double bond equivalents as a measure of the degree of unsaturation, using Table **20.3** for examples.

Differentiation ideas:

Support: Students can make models of alkanes, alkenes and alkynes to count the double bond equivalents.

Challenge: Students complete Test your understanding Question 31 independently. They can then move on to deduce the degree of unsaturation for other types of organic compounds containing O, N and Cl. For example, C_3H_8O, C_4H_7N and $C_4H_6Br_2$.

Plenary ideas

1 Label a reflux vs distillation diagram (10 minutes)

Resources: Give students unlabelled diagrams for the reflux and distillation of ethanol.

Description and purpose: Students need to be able to describe the set-ups for the complete and incomplete oxidation of an alcohol. They can further describe how a difference in the set-up helps to make different oxidation products.

2 Draw the products for the reduction of carboxylic acids and carbonyls (10 minutes)

Resources: Pens and paper, Test your understanding Question 26.

Description and purpose: Students are given 5 minutes to draw out the structures for the reduction of carboxylic acids and carbonyls. They then peer-assess each other's answer.

20.9 Standard electrode potentials and 20.10 Electrolysis of aqueous solutions

LEARNING PLAN

Learning objectives	Success criteria
• Understand what a standard electrode potential is • Use standard electrode potentials to calculate cell potentials • Understand the connection between the standard Gibbs energy change and standard electrode potentials • Solve problems involving $\Delta G^\ominus$ and $E^\ominus$ • Understand the reactions that occur when aqueous solutions are electrolysed • Understand how electroplating works	Students should be able to explain how standard electrode potentials are measured and how to interpret them in terms of ease of redox. Students should be able to calculate standard cell potentials. Students can explain the relationship between $\Delta G^\ominus$ and $E^\ominus$ and interconvert them. Students can explain the products formed when aqueous solutions are electrolysed. Students can explain how electroplating works and write half-equations at the electrodes.

Common misconceptions

Misconceptions	How to identify	How to overcome
Students struggle with calculating standard cell potential	Ask students to calculate the standard cell potential for the cell $Sn(s)|Sn^{2+}(aq)||Ag^{+}(aq)|Ag(s)$, and see if they multiply the reduction potential of Ag^{+} by two.	The standard electrode potential gives the tendency for a reduction to occur, so the value does not need to be scaled up or down according to the coefficients in a balanced equation.
Students get confused about predicting whether a reaction will happen	Ask students to explain the meaning of a positive $E^{\ominus}$ or a negative $\Delta G^{\ominus}$ value. Some students might say that the reaction would happen quickly.	A positive $E^{\ominus}$ or a negative $\Delta G^{\ominus}$ means that a reaction can happen spontaneously under standard conditions. This has nothing to do with the rate of a reaction, which depends on the activation energy of the reaction. In addition, students should be aware that the spontaneity changes when the reaction deviates from standard conditions, for example, when temperature or concentration of the ions changes.

Starter ideas

1 Q&A on reactions of a metal and the ion of another metal (10 minutes)

Resources: Data on reactions of metal and metal ion.

Description and purpose: Ask students to interpret the feasibility of metal displacement reactions and explain which metal is the stronger reducing agent.

What to do next: Relate to the concept of ΔG to predict whether a reaction would be spontaneous between a metal and the compound of another metal.

Main teaching ideas

1 Calculating standard cell potentials (60 minutes)

Resources: A voltaic cell, $Zn|\ ZnSO_4||CuSO_4|Cu$, with a voltmeter to measure its cell potential; use 1 mol dm^{-3} $ZnSO_4$ and $CuSO_4$. IB Chemistry data booklet and Test your understanding Question 33.

Description and purpose: The teacher demonstrates how the overall cell potential for $Zn|ZnSO_4||CuSO_4|Cu$ can be calculated from the standard electrode potentials of Zn^{2+} and Cu^{2+}. The teacher also introduces the standard hydrogen electrode. Students then practice with different combinations of half-cells in Test your understanding Question 33.

Differentiation ideas:

Support: Complete parts i and vi of Question 33 first to work out the overall reactions and cell potentials. The teacher can provide support with comparing the standard electrode potentials and deciding in which half-cell oxidation occurs.

Stretch and challenge: Students work independently and complete parts ii, iii, iv and v to draw labelled diagrams of the cells and deduce the direction of electron and ion movements in the circuit. They can further research into how standard cell potentials can be affected by changes in temperature and concentrations, as represented by the Nernst equation.

2 Predicting the feasibility of a reaction (50 minutes)

Resources: IB Chemistry data booklet, pens, paper, calculators, Test your understanding Question 36.

Description and purpose: The teacher explains how the feasibility of a reaction can be predicted using standard electrode potential data and calculate ΔG values for standard conditions.

Differentiation ideas:

Support: Group students by ability and the teacher provides support accordingly. Give a step-by-step calculation for identifying half-equations → determining which one is oxidation → finding the reduction potential and the oxidation potential → calculating overall cell potential and deciding on feasibility → using the overall cell potential to work out ΔG from $\Delta G^{\ominus} = -nFE^{\ominus}$.

Stretch and challenge: Students work independently and complete the questions. Challenge with the following question: using the standard electrode potentials for Fe^{3+} / Fe^{2+}, I_2 / I^- and Br_2 / Br^-, explain why $FeBr_3$ is a stable compound whereas FeI_3 is not.

3 Practical on the electrolysis of aqueous solutions (60 minutes)

Resources: Search the internet for protocols for the electrolysis of aqueous solutions. Use 0.5 mol dm^{-3} $NaCl$, $CuSO_4$ and H_2SO_4 as electrolytes. Splints, lighter and damp blue litmus paper for testing the electrolysis products. See the Links to digital resources section for a microscale version of the experiment.

Description and purpose: Students practice electrolysing aqueous solutions, including acidified water (using dilute H_2SO_4). The products can be tested using a lit splint, glowing splint or damp blue litmus paper.

Differentiation ideas:

Support: Students can be assigned to mixed-ability groups. The teacher provides support by helping to identify the possible half-equations at each electrode, compare their standard potentials and determine the products that are more likely to be formed.

Stretch and challenge: Students can replace the inert graphite electrodes with copper electrodes in the electrolysis of $CuSO_4$ solution and identify the products formed.

4 Electroplating practical (45 minutes)

Resources: Figure **20.17** from the Coursebook, non-copper coins, wires, crocodile clips, powerpack, $CuSO_4$ solution and high-quality Cu metal strip as the anode.

Description and purpose: Practical on electroplating coins with copper. Students need to be able to deduce the half-equations at each electrode.

Differentiation ideas:

Support: Students can be assigned to mixed-ability groups to work collaboratively. The teacher can check the set-up of the electrochemical cells and explain the reactions occurring at each electrode.

Stretch and challenge: Students research further how to turn copper coins into 'silver' and 'gold' and perform the experiment if resources are available. Search the Royal Society of Chemistry website with the keywords 'turning copper into silver and gold' for a protocol. Please see the Links to digital resources section.

Plenary ideas

1 Summary of trends in the table of standard electrode potentials (10 minutes)

Resources: IB Chemistry data booklet.

Description and purpose: Ask students to summarise the trends shown in the table of standard electrode potentials, for example, the ease of oxidation and reduction and identifying the strongest oxidising and reducing agents. They can peer assess each other's answers and explain the trends to each other.

2 Predict the products of electrolysis of aqueous solutions (15 minutes)

Resources: Test your understanding Question 37 from the Coursebook. Red, yellow and green cards.

Description and purpose: Students can work in pairs to predict the products for the electrolysis of various solutions and self-assess the answers. They can then rate their confidence on this topic using traffic light cards.

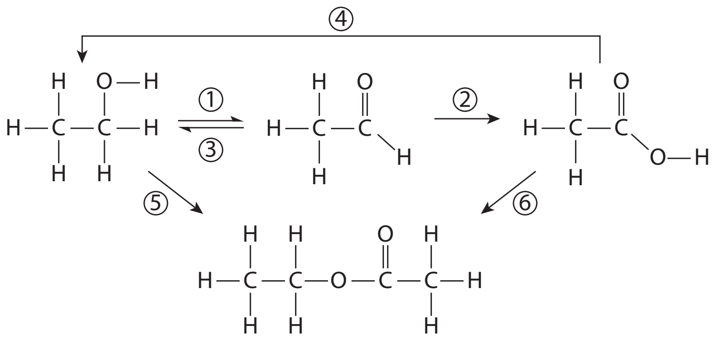
3 A multiple choice question on electroplating (10 minutes)

Resources: A past paper question on electroplating, for example, 2016 Nov TZ0 HL paper 1 question 33.

Description and purpose: Students consider the process of electroplating an iron rod with silver. By drawing analogy to copper electroplating, students should be able to understand that the iron rod needs to be the cathode (negative) and the anode is the silver metal (positive). An electrolyte containing Ag^+ should be used.

Assessment ideas

- Test your understanding questions from the Coursebook.
- Writing exam-style questions on 1) calculating standard cell potentials and 2) calculating standard Gibbs energy changes of reactions for peer assessment.
- Students can prepare a 10-minute presentation on explaining electrolysis, addressing the following questions: 1) What is an electrolytic cell and is the reaction spontaneous? 2) How can the products of electrolysis of molten salts be predicted? 3) What is electroplating? 4) How can the products of electrolysis of aqueous solutions be predicted?
- Predict whether the reactions between pairs of reactants will be spontaneous using the table of standard electrode potentials. For example, I_2 with Cl^-, Ag^+ and Cu, etc.
- Complete the following reaction sequence, steps 1–6, with reagents and conditions. Write out balanced chemical equations for each step, using [O] to represent oxidising agents and [H] for reducing agents.



Homework ideas

- Exercises 20.1–20.10 from the Workbook.
- Exam-style questions from the Coursebook.
- Draw a concept map of a voltaic cell and an electrolytic cell; summarise the similarities and differences.
- Research the recent developments in secondary cells and fuel cells, for example, all-solid-state secondary cells, sodium-ion batteries, high-power direct borohydride fuel cells etc.
- Past paper questions; search the internet for IB past paper questions on redox.

Links to digital resources

- Extension question on balancing redox reactions: question 4 on 2003 UK Chemistry Olympiad R1 paper (search the Royal Society of Chemistry website for 'Chemistry Olympiad past papers')
- Experiment instruction sheet on the redox titration of iron tablets (search practical-science.com with the keywords 'redox iron tablet titration')

- Videos showing how to set up voltaic cells (search the Royal Society of Chemistry website with the keywords 'electrochemistry' and 'voltaic cell')
- Experiment instruction sheet on the electrolysis of molten lead-(II) bromide (search the Royal Society of Chemistry website with the keywords 'electrolysis of molten lead bromide')
- Experiment instruction sheet on turning copper into silver and gold (search the Royal Society of Chemistry website with the keywords 'turning copper into silver and gold')
- Videos of reflux and distillation (search the Royal Society of Chemistry website with the keywords 'distillation' and 'reflux')
- Experiment instruction sheet for the electrolysis of aqueous solutions (search the internet for 'protocols on the electrolysis of aqueous solutions')
- Microscale electrolysis of aqueous solutions
- Past paper questions (search the internet for 'exam-mate IB past paper questions on redox')

CROSS-CURRICULAR LINKS

- Maths: Simple arithmetic calculations.
- Physics: Cells and secondary cells: investigation of simple electrolytic cells and cell technology.
- TOK: How does scientific knowledge progress? What are the meanings of oxidation states when applied to covalent compounds? What are the differences between oxidation states and formal charges? How is our understanding of redox affected by using standard hydrogen electrode? What is the impact of scientific discoveries on our environment?