Contents

Chapters

1 Redox Chemistry 3
Notes p. 4 · Practice p. 21 · Answers p. 275

2 The Reactivity Series and Rusting 33
Notes p. 34 · Practice p. 52 · Answers p. 279

3 Chemical Energetics 67
Notes p. 68 · Practice p. 83 · Answers p. 283

4 Rate of Reactions 94
Notes p. 95 · Practice p. 113 · Answers p. 286

5 Fuels, Crude Oil and Hydrocarbons 128
Notes p. 129 · Practice p. 150 · Answers p. 291

6 Alcohols, Carboxylic Acids and Polymers 164
Notes p. 165 · Practice p. 185 · Answers p. 295

7 Maintaining Air Quality 198
Notes p. 199 · Practice p. 217 · Answers p. 299

Data Sheet

Metal hydroxide colours and the Periodic Table 231

Preliminary Examination 1

P1 Paper 1: multiple-choice questions 234
Answers and mark scheme p. 303

P3 Paper 3: structured and free-response questions 239
Answers and mark scheme p. 305

Preliminary Examination 2

P1 Paper 1: multiple-choice questions 254
Answers and mark scheme p. 311

P3 Paper 3: structured and free-response questions 260
Answers and mark scheme p. 313

Answers and Mark Schemes

Chapters 1 to 7 and both examinations 274

Name: _____ Class: _____ Date: _____

SECONDARY 4 · CHEMISTRY · REDOX CHEMISTRY

Redox Chemistry

Theory and worked examples

Recap from Sec 3: ideas this chapter uses

Redox questions in Sec 4 papers often mix in ideas from Sec 3. Read this recap first: every practice question in this chapter can be answered from these notes and this recap.

Sec 3 idea	What to remember
Ions	Metal atoms lose electrons to form positive ions (Na → Na^+, Mg → Mg^{2+}). Non-metal atoms gain electrons to form negative ions (Cl → Cl^-, O → O^{2-}).
Common ions	Na^+, K^+, H^+, Ag^+, Mg^{2+}, Ca^{2+}, Zn^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, Al^{3+}; Cl^-, Br^-, I^-, OH^-, O^{2-}, NO_3^-, SO_4^{2-}, CO_3^{2-}
Ionic equations	Show only the particles that change. Ions that stay the same on both sides (spectator ions, e.g. SO_4^{2-}, K^+) are left out.
Group 17 (halogens)	Reactivity decreases down the group: chlorine > bromine > iodine. A more reactive halogen displaces a less reactive halogen from a solution of its halide. Chlorine is a greenish-yellow gas; bromine solution is orange; iodine solution is brown.
Moles	M_r = the sum of the A_r of all the atoms in the formula (CuO: 64 + 16 = 80). Number of moles = mass ÷ M_r (or A_r). The equation gives the mole ratio of reactants and products.
Gas volume	One mole of any gas occupies 24 dm^3 (24 000 cm^3) at room temperature and pressure (r.t.p.).
Test for hydrogen	A lighted splint is put out with a 'pop'.

TRY THIS

How many moles of copper atoms are in 3.2 g of copper? (A_r: Cu 64)

Answer: 3.2 ÷ 64 = 0.050 mol

Oxidation and reduction: gain and loss of oxygen

The simplest way to spot oxidation and reduction is to follow the oxygen. A substance that gains oxygen is oxidised. A substance that loses oxygen is reduced. When hydrogen is passed over heated black copper(II) oxide, the copper(II) oxide loses its oxygen to the hydrogen: the black solid turns into reddish-brown copper, and droplets of water form further along the tube.

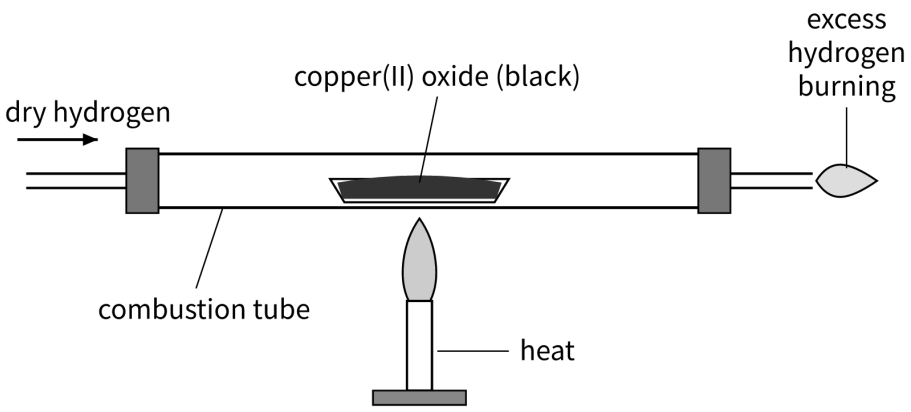
KEY IDEA

Gain of oxygen = oxidation. Loss of oxygen = reduction. In these reactions, the oxygen lost by one substance is gained by another, so oxidation and reduction happen together.

- Burning magnesium: $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$. Magnesium gains oxygen, so magnesium is oxidised.
- Heating a metal oxide with carbon: $2PbO(s) + C(s) \rightarrow 2Pb(s) + CO_2(g)$. Lead(II) oxide loses oxygen (reduced); carbon gains oxygen (oxidised).
- Heating a metal oxide with carbon monoxide: $Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$. Iron(III) oxide is reduced; carbon monoxide is oxidised.

WORDS TO KNOW

oxidation	gain of oxygen by a substance (more definitions follow in this chapter)
reduction	loss of oxygen by a substance
redox reaction	a reaction in which oxidation and reduction take place at the same time



WORKED EXAMPLE

Dry hydrogen is passed over heated copper(II) oxide, as in the diagram. The equation is $CuO(s) + H_2(g) \rightarrow Cu(s) + H_2O(g)$. (a) Describe what is seen in the boat. (b) Using the idea of oxygen, state which substance is oxidised and which is reduced. Explain your answer.

1. What is asked: an observation, then the substance oxidised and the substance reduced, judged by oxygen.
2. Observation: copper(II) oxide is black; copper is reddish-brown.
3. Follow the oxygen: CuO starts with oxygen and ends as Cu, with none. H_2 has no oxygen and ends as H_2O.

(a) The black solid turns reddish-brown. (b) Hydrogen is oxidised because it gains oxygen to form water. Copper(II) oxide is reduced because it loses oxygen to form copper.

TRY THIS

In $2PbO + C \rightarrow 2Pb + CO_2$, which substance is reduced?

Answer: Lead(II) oxide, PbO, because it loses oxygen.

Gain and loss of hydrogen

Some redox reactions have no oxygen in them, so we follow hydrogen instead. The hydrogen definitions are the opposite way round to the oxygen ones: a substance that loses hydrogen is oxidised, and a substance that gains hydrogen is reduced.

KEY IDEA

Loss of hydrogen = oxidation. Gain of hydrogen = reduction (the opposite of the oxygen rules).

- Hydrogen sulfide and chlorine: $H_2S(g) + Cl_2(g) \rightarrow S(s) + 2HCl(g)$.
- Ammonia burning in oxygen: $4NH_3(g) + 3O_2(g) \rightarrow 2N_2(g) + 6H_2O(g)$. Ammonia loses hydrogen (oxidised); oxygen gains hydrogen (reduced).

	Oxygen	Hydrogen
Oxidation	gain of oxygen	loss of hydrogen
Reduction	loss of oxygen	gain of hydrogen

WORKED EXAMPLE

Hydrogen sulfide reacts with chlorine: $H_2S(g) + Cl_2(g) \rightarrow S(s) + 2HCl(g)$. Explain, in terms of hydrogen, which substance is oxidised and which is reduced.

1. What is asked: use hydrogen only, and name both substances.
2. Follow the hydrogen: H_2S has hydrogen and ends as S, with none. Cl_2 has no hydrogen and ends as HCl.
3. Apply the rules: loss of hydrogen is oxidation; gain of hydrogen is reduction.

Hydrogen sulfide is oxidised because it loses hydrogen to form sulfur. Chlorine is reduced because it gains hydrogen to form hydrogen chloride.

TRY THIS

When hydrogen reacts with chlorine, $H_2 + Cl_2 \rightarrow 2HCl$, is chlorine oxidised or reduced? Explain using hydrogen.

Answer: Reduced, because chlorine gains hydrogen.

Electron transfer: OIL RIG

In many reactions no oxygen or hydrogen is involved at all, but electrons move from one particle to another. Oxidation is the loss of electrons. Reduction is the gain of electrons. When sodium burns in chlorine, each sodium atom loses one electron to become a sodium ion, Na^+, and each chlorine atom gains one electron to become a chloride ion, Cl^-. The electrons lost by sodium are exactly the electrons gained by chlorine.

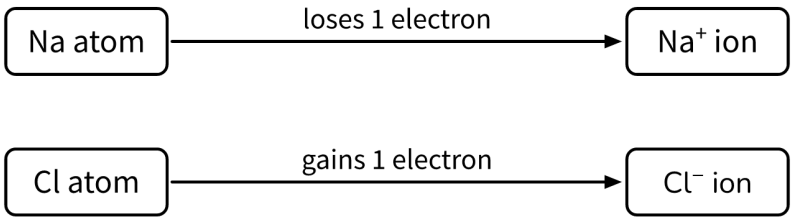
KEY IDEA

Oxidation Is Loss of electrons; Reduction Is Gain of electrons. The number of electrons lost always equals the number gained.

- Metals react by losing electrons, so a metal that forms ions is oxidised: $Mg \rightarrow Mg^{2+}$ (loses 2 electrons).
- When halogens and oxygen react with metals, they gain electrons, so they are reduced: $Cl_2 \rightarrow 2Cl^-$ (gains 2 electrons).
- Ions can be oxidised or reduced too: $Fe^{2+} \rightarrow Fe^{3+}$ is oxidation (loses 1 electron); $Cu^{2+} \rightarrow Cu$ is reduction (gains 2 electrons).

WORDS TO KNOW

OIL RIG	Oxidation Is Loss (of electrons), Reduction Is Gain (of electrons)



WORKED EXAMPLE

Sodium burns in chlorine: $2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$. Explain, in terms of electrons, why this is a redox reaction.

1. What is asked: show both oxidation and reduction using electrons.
2. Sodium chloride is made of Na^+ and Cl^- ions. A sodium atom (Na) has become Na^+; a chlorine atom has become Cl^-.
3. Apply OIL RIG: sodium lost an electron (oxidised); chlorine gained an electron (reduced). Both happen together.

Each sodium atom loses one electron to form a Na^+ ion, so sodium is oxidised. Each chlorine atom gains one electron to form a Cl^- ion, so chlorine is reduced. Since oxidation and reduction occur at the same time, the reaction is a redox reaction.

TRY THIS

Is $Fe^{3+} \rightarrow Fe^{2+}$ oxidation or reduction? Explain.

Answer: Reduction, because the Fe^{3+} ion gains one electron.

Rules for oxidation states

An oxidation state is a number given to each atom in a substance to keep track of its electrons. It is written with the sign first: +2, −1, 0 (not 2+, which is how we write the charge on an ion). Use these rules in order.

KEY IDEA

Elements 0; simple ions = charge; O usually −2; H usually +1; total = 0 for a compound and = charge for an ion. Write the sign first: +3, not 3+.

CHAPTER 1

Practice Questions

Part 2: Redox Chemistry



In the practice questions

22 questions, 66 marks. For each multiple-choice question, write the letter of the correct option (A, B, C or D) in the brackets. Write your other answers on the lines given. The answers are on page 275.

- Section A: Multiple-Choice Questions: 15 questions, 15 marks
- Section B: Structured Questions: 5 questions, 31 marks
- Section C: Free-Response Questions: 2 questions, 20 marks

Name: _____ Class: _____ Date: _____

SECONDARY 4 · CHEMISTRY · REDOX CHEMISTRY

Redox Chemistry

INSTRUCTIONS

- 22 questions, 66 marks in total.
- Answer all questions in the spaces provided.
- For MCQs, write the letter (A, B, C or D) in the brackets.
- Write your other answers on the lines given, in full sentences.

Section A: Multiple-Choice Questions

1 Which change is an oxidation? ( ) [1]

(A) Copper(II) oxide changing to copper
(B) Magnesium changing to magnesium oxide
(C) Chlorine changing to chloride ions
(D) Iron(III) ions changing to iron(II) ions

2 What is the oxidation state of manganese in potassium manganate(VII), $KMnO_4$? ( ) [1]

(A) +2 (B) +4 (C) +6 (D) +7

3 What is the oxidation state of nitrogen in the nitrate ion, NO_3^-? ( ) [1]

(A) −3 (B) +3 (C) +5 (D) +6

4 Hydrogen is passed over heated copper(II) oxide.

$CuO(s) + H_2(g) \rightarrow Cu(s) + H_2O(g)$

Which statement is correct? ( ) [1]

(A) Hydrogen is oxidised and copper(II) oxide is reduced.
(B) Copper(II) oxide is oxidised and hydrogen is reduced.
(C) Copper is oxidised and water is reduced.
(D) Water is oxidised and copper is reduced.

5 Which reaction is not a redox reaction? ( ) [1]

(A) $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

(B) $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$

(C) $2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$

(D) $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$

6 Chlorine water is added to aqueous potassium iodide.

$Cl_2(aq) + 2KI(aq) \rightarrow 2KCl(aq) + I_2(aq)$

Which row is correct? ( ) [1]

	Oxidising agent	Colour change of the solution
A	potassium iodide	colourless to brown
B	potassium iodide	brown to colourless
C	chlorine	colourless to brown
D	chlorine	brown to colourless

(A) A (B) B (C) C (D) D

7 Which statements about a reducing agent are correct?

1 It loses electrons.

2 It is oxidised in the reaction.

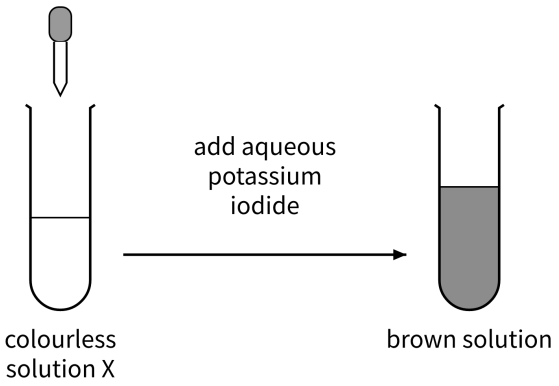
3 Its oxidation state decreases. ( ) [1]

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

8 A few drops of aqueous potassium iodide are added to a colourless solution X.

The solution turns brown, as shown.

What does this show? ( ) [1]



(A) X is a reducing agent.

(B) X is an acid.

(C) X contains iodine.

(D) X is an oxidising agent.

9 Which solution turns acidified potassium manganate(VII) from purple to colourless? ( ) [1]

(A) aqueous iron(II) sulfate
(B) aqueous sodium chloride
(C) dilute sulfuric acid
(D) aqueous copper(II) sulfate

10 Iron(II) chloride reacts with chlorine.

$2FeCl_2(aq) + Cl_2(g) \rightarrow 2FeCl_3(aq)$

What is the change in the oxidation state of iron? ( ) [1]

(A) 0 to +2 (B) +2 to +3 (C) +3 to +2 (D) +2 to 0

11 Which change is a reduction? ( ) [1]

(A) $Fe^{2+} \rightarrow Fe^{3+}$ (B) $Cu \rightarrow Cu^{2+}$ (C) $2Br^- \rightarrow Br_2$ (D) $Fe^{3+} \rightarrow Fe^{2+}$

12 Magnesium is added to aqueous zinc sulfate.

$Mg(s) + ZnSO_4(aq) \rightarrow MgSO_4(aq) + Zn(s)$

Which statement is correct? ( ) [1]

(A) Magnesium atoms gain electrons.
(B) Zinc ions are oxidised.
(C) Magnesium is the reducing agent.
(D) Sulfate ions are reduced.

13 Magnesium burns in oxygen.

$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

What volume of oxygen, at r.t.p., reacts with 4.8 g of magnesium? (A_r: Mg 24; one mole of gas occupies 24 dm^3 at r.t.p.) ( ) [1]

(A) 1.2 dm^3 (B) 2.4 dm^3 (C) 4.8 dm^3 (D) 9.6 dm^3

14 Hydrogen peroxide turns aqueous potassium iodide brown. It also turns acidified potassium manganate(VII) colourless.

Which statements are correct?

1 Hydrogen peroxide is an oxidising agent in the reaction with potassium iodide.
2 Hydrogen peroxide is reduced in the reaction with potassium manganate(VII).
3 Hydrogen peroxide is a reducing agent in the reaction with potassium manganate(VII). ( ) [1]

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

15 In which substance does chlorine have the highest oxidation state? ( ) [1]

(A) $KClO_3$ (B) Cl_2 (C) HCl (D) NaClO