Topic 17 – Redox

Subject content

(a)	define oxidation and reduction (redox) in terms of oxygen/hydrogen gain/loss
(b)	define redox in terms of electron transfer and changes in oxidation state
(c)	identify redox reactions in terms of oxygen/hydrogen gain/loss, electron gain/loss and changes in oxidation state
(d)	describe the use of aqueous potassium iodide and acidified potassium manganate(VII) in testing for oxidising and reducing agents from the resulting colour changes

Redox reaction: oxidation of a substance + reduction of another substance

Oxidation & reduction

Characteristics	**Oxidation**	**Reduction**
1. **Oxygen**	gain	loss
2. **Hydrogen**	loss	gain
3. **Electrons**	loss	gain
4. **Oxidation state**	increase	decrease

Oxidising agent & reducing agent

Oxidising agent	**Reducing agent**
causes oxidation of other substances, itself is reduces	causes reduction of other substances, itself is oxidised
• gives oxygen • removes hydrogen • removes electrons • increases oxidation state of another reactant	• removes oxygen • gives hydrogen • gives electrons • decreases oxidation state of another reactant

17.1 Examples of Oxidation & Reduction

Oxidation & reduction:

Type	Reaction	Oxidation	Reduction
gain/loss of oxygen	Mg (s) + H_2O (g) → MgO (s) + H_2 (g)	Mg gained oxygen to form MgO. Thus, Mg is oxidised to MgO.	H_2O lost oxygen to form H_2. Thus, H_2O is reduced to H_2.
	CuO (s) + H_2 (g) → Cu (s) + H_2O (l)	H_2 gained oxygen to form H_2O. Thus, H_2 is oxidised to H_2O.	CuO lost oxygen to form Cu. Thus, CuO is reduced to Cu.
	2 Cu (s) + O_2 (g) → 2 CuO (s)	Cu gained oxygen to form CuO. Thus, Cu is oxidised to CuO.	O_2 lost oxygen. Thus, O_2 is reduced.
loss/gain of hydrogen	Cl_2 (g) + 2 HI (aq) → 2 HCl (aq) + I_2 (aq)	I in HI lost hydrogen to form I_2. Thus, HI is oxidised to I_2.	Cl_2 gained hydrogen to form HC*l*. Thus, Cl_2 is reduced to HC*l*.
	2 NH_3 (g) + CuO (s) → N_2 (g) + 3 Cu (s) + 3 H_2O (g)	N in NH_3 lost hydrogen to form N_2. Thus, NH_3 is oxidised to N_2.	CuO lost oxygen to form Cu. Thus, CuO is reduced to Cu.
loss/gain of electrons	Cu (s) + 2 $AgNO_3$ (aq) → $Cu(NO_3)_2$ (aq) + 2 Ag (s)	Cu lost electrons to form Cu^{2+} in $Cu(NO3)_2$. Thus, Cu is oxidised to $Cu(NO_3)_2$. $Cu \rightarrow Cu^{2+} + 2\ e^-$	Ag^+ in $AgNO_3$ gained electrons to form Ag. Thus, $AgNO_3$ is reduced to Ag. $Ag^+ + e^- \rightarrow Ag$
	2 Na (s) + Cl_2 (g) → 2 NaC*l* (s)	Na lost electrons to form Na^+ in NaC*l*. Thus, Na is oxidised to NaC*l*. $Na \rightarrow Na^+ + e^-$	C*l* gained electrons to form Cl^- in NaC*l*. Thus, C*l* is reduced to NaC*l*. $Cl_2 + 2\ e^- \rightarrow 2Cl^-$
	2 KI (aq) + Cl_2 (g) → 2 KC*l* (aq) + I_2 (s)	I^- in KI lost electrons to form I_2. Thus, KI is oxidised to I_2. $2\ I^- \rightarrow I_2 + 2\ e^-$	Cl_2 gained electrons to form Cl^- in KC*l*. Thus, Cl_2 is reduced to KC*l*. $Cl_2 + 2\ e^- \rightarrow 2\ Cl^-$

17.2 Increase or Decrease of Oxidation State

Oxidation state: an arbitrary charge of an atom if it existed as an ion
Guideline:

Guideline	Example	Oxidation state
1. OS of element = 0	Na	0
	O_2	0
2. OS of simple ion = charge of ion	Fe^{2+}	+2
	Cl^-	-1
3. Fixed OS of elements in compounds	All Grp I elements in compounds	+1
	All Grp II elements in compounds	+2
	H in most compounds	+1
	O in most compounds	-2
4. Sum of OS of atoms / ions in compound = 0	Na*Cl*	+1 + (-1) = 0
	H_2O	(+1) x 2 + (-2) = 0
5. Sum of OS of atoms in polyatomic ion = charge of ion	OH^-	(-2) + (+1) + -1

Presentation for working of calculation:

Calculate the oxidation state of chromium (Cr) in chromic acid (H_2CrO_4).

Let the oxidation state of Cr in H2CrO4 be x.
(+1) x 2 + x + (-2) x 4 = 0
+2 + x - 8 = 0
x = +8 - 2
x = +6

* do not omit +ve / -ve signs for oxidation states in working

Polyatomic ions:

Ion	Name	Ion	Name
OH^-	hydroxide ion	**ClO_3^-**	chlorate ion
NO_3^-	nitrate ion	**ClO_4^-**	perchlorate ion
SO_4^{2-}	sulfate ion	**CrO4^{2-}**	chromate ion
SO_3^{2-}	sulfite ion	**$Cr_2O_7^{2-}$**	dichromate ion
CO_3^{2-}	carbonate ion	**MnO_4^-**	permanganate ion
PO_4^{3-}	phosphate ion		
HCO_3^-	hydrogencarbonate ion		
NH_4^+	ammonium ion		

Determine if a chemical reaction is a redox reaction: (use change in oxidation state of element)

Non-redox reactions	Redox reactions
• Precipitation reaction • Neutralisation reaction • Acid-base reaction • Acid-carbonate reaction	• Displacement reaction (of halogens, metals) • Grp I metal-water reaction • Synthesis reaction • Acid-metal reaction • Disproportionation reaction • Comproportionation reaction

Examples of types of redox reactions:

- Br_2 (g) + 2 I^- (aq) → 2 Br^- (aq) + I_2 (s) [displacement rxn of halogens]
- Cu^{2+} (aq) + Zn (s) → Cu (s) + Zn^{2+} (aq) [displacement rxn of metals]
- Mg (s) + 2 HC*l* (aq) → MgCl_2 (aq) + H_2 (g) [acid-metal rxn]
- 2 Na (s) + Cl_2 (g) → 2 NaC*l* (s) [synthesis rxn]

17.3 Oxidising Agent and Reducing Agent

Examples of oxidising agents & reducing agents:

Oxidising agents	Reducing agents
• **potassium manganate(VII) ($KMnO_4$)** • bromine (Br_2) • chlorine (Cl_2) • concentrated sulfuric acid (H_2SO_4) • nitric acid (HNO_3) • **oxygen (O_2)** • **potassium dichromate(VI) ($K_2Cr_2O_7$)** • **hydrogen peroxide (H_2O_2)**	• **potassium iodide (KI)** • carbon (C) • **carbon monoxide (CO)** • hydrogen (H_2) • hydrogen sulfide (H_2S) • metals • **sulfur dioxide (SO_2)** • ammonia (NH_3) • **hydrogen peroxide (H_2O_2)**

Test for presence of oxidising agent

Procedure	Add **aqueous potassium iodide (KI)** to unknown solution
Observation	**colourless** (KI) → **brown** (I_2)
Explanation	$\mathbf{2\ I^-}$ (aq) → $\mathbf{I_2}$ (aq) + 2 e^- Iodide ions in aqueous KI are oxidised to iodine by the oxidising agent. Thus, iodide is formed and dissolves in water to give brown solution.

Test for presence of reducing agent

Procedure	Add **acidified potassium manganate(VII) ($KMnO_4$)** to unknown solution
Observation	Decolourised: **purple** (Mn^{7+}) → **colourless** (Mn^{2+})
Explanation	$\mathbf{MnO_4^-}$ (aq) + 8 H^+ (aq) + 5 e^- → $\mathbf{Mn^{2+}}$ (aq) + 4 H_2O (*l*) Manganate(VII) ion in acidified potassium manganate(VII) is reduced by the reducing agent to manganese ion, which is colourless.
Procedure	Add **potassium dichromate(VI) ($K_2Cr_2O_7$)** to unknown solution
Observation	orange (Cr^{6+}) → green (Cr^{3+})
Explanation	$\mathbf{Cr_2O_7^{2-}}$ (aq) + 14 H^+ (aq) + 6 e^- (aq) → 2 $\mathbf{Cr^{3+}}$ (aq) + 7 H_2O (*l*) Dichromate(VI) ion in potassium dichromate(VI) is reduced by the reducing agent to chromium ion, which is green.

Disproportionation & comproportionation reaction:

Disproportionation reaction	**Comproportionation reaction**
1 compound of intermediate oxidation state converts to 2 compounds, one of higher and one of lower oxidation states	2 reactants containing same element with different oxidation state, form product in which elements reach same oxidation state
2 A → A' + A"	A' + A" → 2 A
2 NO_2 + H_2O → HNO_3 + HNO_2	IO_3^- + 5 I^- + 6 H^+ → 3 I_2 + 3 H_2O

Typical questions

Multiple choice questions

1 The equation below shows the reaction that occurs between iron(III) chloride and hydrogen sulfide.

$$2\ FeCl_3\ (aq) + H_2S\ (g) \rightarrow 2\ FeCl_2\ (aq) + 2\ HCl\ (aq) + S\ (s)$$

Which element is oxidised in the reaction?

A Iron
B Chloride
C Hydrogen
D Sulfur

2 In which pair of substances does the named element have the same oxidation state?

A Copper in Cu_2O and Cu
B Iron in FeO and Fe_2O_3
C Manganese in MnO_2 and $KMnO_4$
D Sulfur in SO_3 and H_2SO_4

3 In which reaction does the oxidation state of chlorine increase by one?

A $2\ KClO_3\ (s) \rightarrow 2\ KCl\ (s) + 3\ O_2\ (g)$
B $Cl_2\ (g) + 2\ NaOH\ (aq) \rightarrow NaCl\ (aq) + NaClO\ (aq) + H_2O\ (l)$
C $Cl_2\ (g) + H_2\ (g) \rightarrow 2\ HCl\ (g)$
D $NaCl\ (aq) + AgNO_3\ (aq) \rightarrow AgCl\ (s) + NaNO_3\ (aq)$

4 Which reaction is a redox reaction?

A Barium chloride + potassium sulfate → barium sulfate + potassium chloride
B Potassium hydroxide + hydrochloric acid → potassium chloride + water
C Potassium iodide + chlorine → potassium chloride + iodine
D Silver nitrate + potassium chloride → silver chloride + potassium nitrate

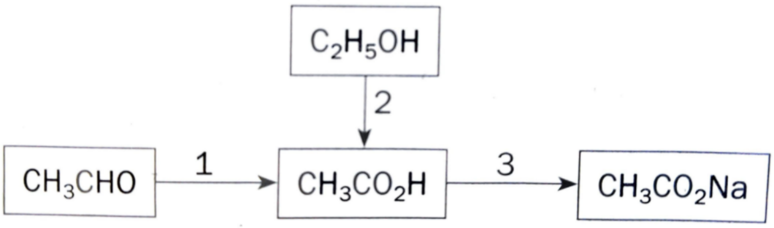
5 What colour changes occur when sulfur dioxide is passed through aqueous potassium iodide and acidified potassium manganate(VII) separately?

	Aqueous potassium iodide	Acidified potassium manganate(VII)
A	colourless to brown	no change
B	colourless to brown	purple to colourless
C	no change	no change
D	no change	purple to colourless

6 Hydrogen peroxide reacts with acidified potassium iodide to form iodine as one of the products. It also turns acidified potassium manganate(VII) from purple to colourless.
Which statement is true about hydrogen peroxide in both reactions?

A Hydrogen peroxide acts as both an oxidising agent and a reducing agent.
B Hydrogen peroxide acts only as a reducing agent.
C Hydrogen peroxide acts only as an oxidising agent.
D Hydrogen peroxide is neither an oxidising agent nor a reducing agent.

7 Which reactions are oxidation reactions?



A 1 and 2
B 1 and 3
C 2 and 3
D 1, 2 and 3

Reaction 3: CH_3CO_2H (acid) → CH_3CO_2Na (salt) Charges of CH3COO$^-$ does not change

Structured questions

1 The reaction between ammonium perchlorate ($NH_4Cl O_4$), and aluminium metal is used to propel space shuttles. The equation for the reaction is shown below.

$$6\ NH_4ClO_4\ (s) + 10\ Al\ (s) \rightarrow 4\ Al_2O_3\ (s) + 2\ AlCl_3\ (s) + 12\ H_2O\ (l) + 3\ N_2\ (g)$$

(a) State the oxidation numbers of nitrogen and chlorine in ammonium perchlorate.

Let the oxidation number of nitrogen in ammonium perchlorate be x.
Since NH_4^+ has a +1 charge and the oxidation number of hydrogen is +1,
$x + 4(+1) = +1$
$x = -3$
Thus, the oxidation number of nitrogen in NH_4ClO_4 is **-3**.

Let the oxidation number of chlorine be y.
Since ClO_4^- has a -1 charge and the oxidation number of oxygen is -2,
$y + 4(-2) = -1$
$y = +7$
Thus, the oxidation number of chlorine in NH_4ClO_4 is **+7**.

(b) Identify the oxidising agent in the above reaction. Give a reason for your answer.

Ammonium perchlorate is the oxidising agent. It oxidises aluminium to aluminium oxide and aluminium chloride. The oxidation number of aluminium increases from 0 to Al to +3 in Al_2O_3 and $AlCl_3$.