1. Which redox reaction contains the largest change in oxidation state for sulfur?

– = ox. state of sulfur

– = ox. state of other elements.

+2 +6 −8 +2 −2

A $H_2SO_4 + 8HI \rightarrow H_2S + 4I_2 + 4H_2O$ (−8)

0 +4 −4

B $S + O_2 \rightarrow SO_2$ (+4)

+2 −6 +4 0

C $S_2O_3^{2-} + 2H^+ \rightarrow SO_2 + S + H_2O$ (2)

0 +6

D $S + 6HNO_3 \rightarrow H_2SO_4 + 6NO_2 + 2H_2O$ (+6)

$O_4 \rightarrow O = -2$

$-2 \times 4 = -8.$

Your answer $\boxed{A}$

[1]

2. Two tests are carried out on an aqueous solution of copper(II) sulfate, $CuSO_4(aq)$.

Test 1: Addition of potassium iodide solution
Test 2: Addition of barium chloride solution → test for SO_4^{2-} → ✓ white ppt. ($BaSO_{4(s)}$)

Which of the following statements is/are true?

✓ **1:** **Test 1** produces an off-white precipitate ($CuI_{(s)}$) and a brown solution ($I_{2(aq)}$).

✓ **2:** **Test 2** produces a white precipitate.

✗ **3:** **Test 1** ✓ and **Test 2** ✗ are both redox reactions.

off-white ppt. ↑ brown sol. ↑

① redox: $2Cu^{2+}_{(aq)} + 4I^-_{(aq)} \rightarrow 2CuI_{(s)} + I_{2(aq)}$

(white ppt.)

② $Ba^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)} \rightarrow BaSO_{4(s)}$

↳ no change in ox. states ∴ not redox.

A 1, 2 and 3

B Only 1 and 2

~~**C**~~ Only 2 and 3

~~**D**~~ Only 1

Your answer B

[1]

3. What is the oxidation number of Mn in K_2MnO_4? $\leftarrow -2$ oxidation state of oxygen

$+1$ x

oxidation state of potassium

A +4

B +5

C +6

D +7

Your answer C **[1]**

$$(+1 \times 2) + (-2 \times 4) + x = 0$$

$$2 + -8 + x = 0$$

$$x = +6$$

4. A student plans to determine the enthalpy change of **reaction 3.1** shown below.

$Na_2O(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l)$ **reaction 3.1**

This enthalpy change can be determined indirectly using Hess' Law from the enthalpy changes of **reaction 3.2** and **reaction 3.3** shown below.

$Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$ **reaction 3.2**

$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l) \quad \Delta_r H = -57.6\,kJ\,mol^{-1}$ **reaction 3.3**

The student will determine the enthalpy change of **reaction 3.2** as outlined below.

- Weigh a bottle containing $Na_2O(s)$ and weigh a polystyrene cup.
- Add about $25\,cm^3$ of water to the polystyrene cup and measure its temperature.
- Add the $Na_2O(s)$, stir the mixture, and measure the maximum temperature reached.
- Weigh the empty bottle and weigh the polystyrene cup with the final solution.

Mass readings

Mass of bottle + $Na_2O(s)$	= 16.58 g
Mass of empty bottle	= 15.34 g
Mass of empty polystyrene cup	= 21.58 g
Mass of polystyrene cup + final solution	= 47.33 g

Temperature readings

Initial temperature of water	= 20.5 °C
Maximum temperature of final solution	= 55.5 °C

The density and specific heat capacity, *c*, of the solution are the same as for water.

$\Delta H\, 3.1 = \Delta H\, 3.2 + (\Delta H\, 3.3) \times 2$

(a)* Calculate the enthalpy change of **reaction 3.2** and the enthalpy change of **reaction 3.1**.

Show all your working.

$mc\Delta T = E$ (joules)

mass of $Na_2O = 16.58 - 15.34$
$= 1.24g$

mass of solution $= 47.33 - 21.58$
$= 25.75g$

$\Delta T = 55.5 - 20.5 = 35°C$

$25.75 \times 4.18 \times 35 = 3767.225J$
$= 3.767225kJ$

-ve ΔH value

$mol = \frac{1.24}{(23\times2)+16} = 0.02 mol$

ΔH 3.2:

$3.767225 \div 0.02 = -188 kJmol^{-1}$

$\Delta H\,3.1 = -188 + (2\times -57.6) = -303.2 kJmol^{-1}$ **[6]**

(b) The uncertainty in each temperature reading is ±0.1 °C.

The uncertainty in each mass reading is ±0.005 g.

Determine whether the mass of Na_2O or the temperature change has the greater percentage uncertainty.

Show all your working.

mass balance was used twice to find mass of Na_2O

mass: $\frac{0.005\times2}{1.24}\times100$
$= 0.81\%$

temperature: $\frac{0.1\times2}{35}\times100 = 0.57\%$

So mass of Na_2O has the greater percentage uncertainty **[2]**

(c) Suggest a modification to this experiment, using the **same** apparatus, which would reduce the percentage errors in the measurements.

larger denominator = smaller number

Explain your reasoning.

greater mass of Na_2O and a larger ΔT because both would reduce % uncertainty

[2]

(d) Sodium oxide, Na_2O, can be prepared by the redox reaction of $NaNO_2$ and sodium metal. Nitrogen gas is also formed.

(i) What is the systematic name for $NaNO_2$?

Sodium nitrate **[1]**

(ii) Using oxidation numbers, with signs, show the element that is oxidised and the element that is reduced in this reaction.

$2NaNO_2 + 6Na \rightarrow 4Na_2O + N_2$

+1 +3 −2 0 +1 −2 0

oxidation numbers in a compound must add up to 0

Element oxidised ....Na....

Oxidation number change from ...0.... to ....+1..

Element reduced ....N....

Oxidation number change from ..+3.. to ....0...

[2]

(iii) Construct the equation for this reaction.

Equation $2NaNO_2 + 6Na \rightarrow 4Na_2O + N_2$ **[1]**

5. In the compound $[ICl_2]^+ [SbCl_6]^-$, the oxidation number of chlorine is –1.

What are the oxidation numbers of I and Sb in the compound?

	I	Sb
~~A~~	+1	+5
~~B~~	+1	+7
C	+3	+5
~~D~~	+3	+7

$[ICl_2]^+$ $[SbCl_6]^-$

+3 $(-1 \times 2) = -2$ +5 $(-1 \times 6) = -6$

Your answer C **[1]**

6. What is the oxidation number of N in $Mg(NO_2)_2 \cdot 3H_2O$?

neutral => oxidation number of 0

A +2

B +3

C +4

D +5

$Mg(NO_2)_2$

+2

means NO_2 has a −1 oxidation number

NO_2

+3

$-2 \times 2 = -4$

means oxidation number overall = −1

Your answer B

[1]

7. Which reaction is a redox reaction?

~~A~~ $\overset{+1\,-1}{NaCl} + \overset{+1}{Ag}\overset{-1}{[NO_3]} \rightarrow \overset{+1\,-1}{AgCl} + \overset{+1}{Na}[NO_3]^{-1}$

~~B~~ $\overset{+1}{Na}[NO_2]^{-1} + \overset{+1\,-1}{HCl} \rightarrow \overset{+1\,-1}{NaCl} + \overset{+1}{H}[NO_2]^{-1}$

~~C~~ $\overset{+2\,+4\,-2}{CaSO_3} + 2\overset{+1\,-1}{HCl} \rightarrow \overset{+2\,-1}{CaCl_2} + \overset{+1\,-2}{H_2O} + \overset{+4\,-2}{SO_2}$

D $3\overset{+2\,-2}{CuO} + 2\overset{-3\,+1}{NH_3} \rightarrow 3\overset{0}{Cu} + 3\overset{+1\,-2}{H_2O} + \overset{0}{N_2}$ → Cu: $+2 \rightarrow 0$ reduction
N: $-3 \rightarrow 0$ oxidation

Your answer D **[1]**

8. Iodide ions, $I^-(aq)$, react with $MnO_4^-(aq)$. The unbalanced equation is shown below.

$$\overset{-1}{I^-}(aq) + \overset{+7}{Mn}O_4^-(aq) + H_2O(l) \rightarrow \overset{+1}{I}O^-(aq) + \overset{+4}{Mn}O_2(s) + OH^-(aq)$$

What is the ratio of $MnO_2(s)$ to $OH^-(aq)$ in the balanced equation?

A 1 : 3

B 1 : 2

C 1 : 1

D 3 : 2

red. $3e^- + MnO_4^- + 2H_2O \longrightarrow MnO_2 + 4OH^-$

ox. $I^- + 2OH^- \longrightarrow IO^- + H_2O + 2e^-$

$\cancel{6e^-} + 2MnO_4^- + \overset{1}{\cancel{4}}H_2O \longrightarrow 2MnO_2 + \overset{2}{\cancel{8}}OH^-$

$3I^- + \cancel{6OH^-} \longrightarrow 3IO^- + \cancel{3H_2O} + \cancel{6e^-}$

$3I^- + 2MnO_4^- + H_2O \longrightarrow 3IO^- + 2MnO_2 + 2OH^-$

$2 : 2 = 1 : 1$

Your answer C

[1]

9. This question is about reactions and uses of the weak acids methanoic acid, HCOOH, and ethanoic acid, CH_3COOH.

(a) A student adds magnesium metal to an aqueous solution of ethanoic acid, CH_3COOH.
A redox reaction takes place.

Write the overall equation for this reaction and explain, in terms of oxidation numbers, which element has been oxidised and which element has been reduced.

Equation $\overset{0}{Mg} + 2\overbrace{CH_3COO}^{-1}\overset{+1}{H} \longrightarrow (\overbrace{CH_3COO}^{-1})_2\overset{+2}{Mg} + \overset{0}{H_2}$

Oxidation Mg : $0 \longrightarrow +2$

Reduction H : $+1 \longrightarrow 0$

[3]

(b) The K_a values of HCOOH and CH_3COOH are shown in **Table 18.1**.

Weak acid	K_a / mol dm^{-3}
HCOOH	1.82×10^{-4}
CH_3COOH	1.78×10^{-5}

stronger acid

3.74

4.75

$pKa = pH$

$pKa = -\log_{10} Ka$

Table 18.1

A student adds methanoic acid to ethanoic acid.

An equilibrium is set up containing two acid-base pairs.

Complete the equilibrium and label the conjugate acid-base pairs as **A1**, **B1** and **A2**, **B2**.

$HCOOH + CH_3COOH \rightleftharpoons HCOO^- + CH_3COOH_2^+$

A1 B2 B1 A2

[2]

$10^{-pH} = [H^+]$

$\frac{[H^+]^2}{[HA]} = Ka$

rearrange for $[HA] = [CH_3COOH]$

(c) Use **Table 18.1** to answer the following questions.

(i) The student measures the pH of $CH_3COOH(aq)$ as 2.72.

Show that the concentration of the $CH_3COOH(aq)$ is $0.204\ mol\ dm^{-3}$.

$10^{-2.72} = 1.905 \times 10^{-3}\ mol\ dm^{-3} = [H^+]$

$[CH_3COOH] = \frac{(1.905 \times 10^{-3})^2}{1.78 \times 10^{-5}} = 0.204\ mol\ dm^{-3}$

[2]

(ii) The student plans to make a buffer solution of pH 4.00 from a mixture of $CH_3COOH(aq)$ and sodium ethanoate, $CH_3COONa(aq)$.

The student mixes $400\ cm^3$ of $0.204\ mol\ dm^{-3}$ $CH_3COOH(aq)$ with $600\ cm^3$ of $CH_3COONa(aq)$.

Calculate the concentration of $CH_3COONa(aq)$ needed to prepare this buffer solution of pH 4.00.

$10^{-pH} = [H^+]$

part (i) $[H^+]_{buffer} = 10^{-4} = 1 \times 10^{-4}\ mol\ dm^{-3}$

$= 400\ cm^3 = 0.4\ dm^3$

$\frac{0.204}{1} \times 0.4 = 8.16 \times 10^{-2} = [CH_3COOH]_{buffer}$

$= 1\ dm^3 = 1000\ cm^3$

$\frac{[H^+][A^-]}{[HA]} = Ka$

$1.78 \times 10^{-5} = \frac{[1 \times 10^{-4}][CH_3COO^-]}{8.16 \times 10^{-2}}$

$[CH_3COO^-]_{buffer} = \frac{1.78 \times 10^{-5} \times 8.16 \times 10^{-2}}{1 \times 10^{-4}} = 1.5 \times 10^{-2}\ mol\ dm^{-3}$

calculator answer

$\frac{1.452... \times 10^{-2} \times 1}{0.6} = 2.4 \times 10^{-2} = [CH_3COO^-]_{initial}$

opposite actions to part (i)

concentration = 2.4×10^{-2} $mol\ dm^{-3}$ **[4]**

10. A student carries out an investigation to identify two metals, **M** and **X**, by two different methods.

(a) The student is provided with a sample of metal **M**.

The student analyses metal **M** using a 'back-titration' technique:

- The metal is reacted with excess acid.
- The resulting solution is titrated to determine the amount of acid remaining after the reaction.

Stage 1
The student adds $100\,cm^3$ of $2.10\,mol\,dm^{-3}$ $HCl(aq)$ to 6.90 g of **M**.
An excess of $HCl(aq)$ has been used to ensure that all of metal **M** reacts.

A redox reaction occurs, forming a solution containing **M** in the +2 oxidation state.

Stage 2
The resulting solution from **Stage 1** is made up to $250.0\,cm^3$ with distilled water.

Stage 3
A $25.00\,cm^3$ sample of the diluted solution from **Stage 2** is titrated with $0.320\,mol\,dm^{-3}$ $NaOH(aq)$.

The $NaOH(aq)$ reacts with excess $HCl(aq)$ that remains in **Stage 1**:

1 : 1 molar ratio

$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

The student repeats the titration to obtain concordant titres.

Titration results (The trial titre has been omitted.)
The burette readings have been recorded to the nearest $0.05\,cm^3$.

	1	2	3
Final reading / cm³	27.80	37.55	32.20
Initial reading / cm³	0.50	10.00	5.00
titre / cm3	27.30	27.55	27.20

concordant

(i) In **Stage 1**, a redox reaction takes place between **M** and $HCl(aq)$, forming hydrogen and a solution containing **M** in the +2 oxidation state.

Write an overall equation, with state symbols, for this reaction. Write half-equations for the oxidation and reduction processes.

molar ratio 1 : 2

Overall equation $\overset{0}{M}_{(s)} + 2\overset{+1}{H}\overset{-1}{Cl}_{(aq)} \rightarrow \overset{+2}{M}\overset{-1}{Cl}_{2(aq)} + \overset{0}{H}_{2(g)}$

Oxidation half-equation $M \rightarrow M^{2+} + 2e^-$

(increase oxidation state)

Reduction half-equation $2H^+ + 2e^- \rightarrow H_2$ OR $H^+ + e^- \rightarrow \frac{1}{2}H_2$

(decrease oxidation state)

[3]

(ii) In **Stage 1**, suggest **two** observations that would confirm that all of metal **M** has reacted.

1 bubbles/ effervesense stops

2 M/ metal disappears

[2]

(iii) In **Stage 3**, write the ionic equation for the reaction taking place in the titration.

$H^+ + OH^- \longrightarrow H_2O$ **[1]**

neutralisation reaction: acid + base → salt + water

(iv) Metal **M** can be identified following the steps below.

1. The amount, in mol, of excess HC*l*(aq) that remains after the reaction of **M** with HC*l*(aq).
2. The amount, in mol, of HC*l*(aq) that reacted with **M**.
3. The identity of metal **M**.

Analyse the results to identify metal **M**.

$\frac{27.30 + 27.20}{2} = 27.25\text{ cm}^3$ mean titre

n / V×C

$27.25 \times 10^{-3} \times 0.320$
$= 8.72 \times 10^{-3}$ mol in 25 cm³ (HCl)

$8.72 \times 10^{-3} \times 10 = 8.72 \times 10^{-2}$ mol in 250 cm³ (HCl)

$100 \times 10^{-3} \times 2.10$

$0.210 - 8.72 \times 10^{-2} = 0.1228$ mol HCl reacted with M

$\frac{0.1228}{2} = 0.0614$ mol of M reacted

$\frac{6.90}{0.0614} = 112.4 = $ Cd

mass / mol × RFM

Metal **M** = Cd **[6]**

(b) The student is provided with the carbonate of an unknown metal, $\mathbf{X}_2CO_3$.

The student measures the mass loss when the $\mathbf{X}_2CO_3$ is reacted with an **excess** of hydrochloric acid. The equation is shown below.

1 : 1 molar ratio

$$\mathbf{X}_2CO_3(s) + 2HCl(aq) \rightarrow 2\mathbf{X}Cl(aq) + CO_2(g) + H_2O(l)$$

The reaction is carried out using this method:

Step 1 Add 100 cm^3 HC*l*(aq) to a conical flask and weigh.

Step 2 Add $\mathbf{X}_2CO_3$ to the conical flask and immediately reweigh.

Step 3 After 5 minutes, reweigh the conical flask and contents.

Results

Mass of conical flask + HC*l*(aq)	172.93 g
Mass of conical flask + $\mathbf{X}_2CO_3$ + HC*l*(aq) before reaction	187.50 g
Mass of conical flask + contents after 5 minutes	184.75 g

(i) Calculate the amount, in mol, of CO_2 released in the reaction.

$187.50 - 184.75 = 2.75$ g of CO_2

mass / mol x RFM

$$\frac{2.75}{12+(16\times2)} = 0.0625$$

Amount of CO_2 = 0.0625 mol **[1]**

(ii) Calculate the molar mass of $\mathbf{X}_2CO_3$ and identify metal **X**.

0.0625 mol of X_2CO_3

$187.50 - 172.93 = 14.57$ g of X_2CO_3

$$\frac{14.57}{0.0625} = 233.12 \text{ g mol}^{-1}$$

X = Rb

$$\frac{233.12 - (12 + ((6\times3))}{2} = 86.56 = \text{Rb}$$

Molar mass of $\mathbf{X}_2CO_3$ = 233.12 g mol^{-1} Metal **X** = Rb **[3]**

(c) After analysing the results, the student was told that their molar mass of $\mathbf{X}_2CO_3$ was incorrect.

The student evaluated the experiment for possible reasons for the incorrect result.

(i) The student wondered whether the reaction was complete when the mass was recorded after 5 minutes (**Step 3**).

How could the student modify the experimental procedure to be confident that the reaction was complete?

reweigh to constant mass

[1]

(ii) The student finds out that carbon dioxide is slightly soluble in water.

State and explain how the solubility of CO_2 would affect the calculated molar mass of $\mathbf{X}_2CO_3$.

• mass (CO_2) loss would be smaller / mass X_2CO_3 reacted seems to be less

• molar mass would be greater **[2]**