Surname	Centre Number	Candidate Number
First name(s)		2

GCE A LEVEL

S24-1410U30-1

1410U30-1

MONDAY, 10 JUNE 2024 – MORNING

CHEMISTRY – A2 unit 3
Physical and Inorganic Chemistry

1 hour 45 minutes

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1. to 5.**	**10**	
Section B	**6.**	**9**	
	7.	**10**	
	8.	**18**	
	9.	**13**	
	10.	**20**	
	Total	**80**	

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ADDITIONAL MATERIALS

- A calculator, pencil and ruler
- **Data Booklet** supplied by WJEC

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen or correction fluid.

You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Section A Answer **all** questions.
Section B Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

The number of marks is given in brackets at the end of each question or part-question.

The maximum mark for this paper is 80.

Your answers must be relevant and must make full use of the information given to be awarded full marks for a question.

The assessment of the quality of extended response (QER) will take place in **Q10**(c)(ii).

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SECTION A

Answer **all** questions.

1. (a) Write an equation, including state symbols, that represents the enthalpy change of lattice formation of solid magnesium chloride. [1]

.....

(b) Complete the following equation: [1]

standard enthalpy change of solution = [..... / .....] − standard enthalpy change of lattice formation

2. When chlorine is bubbled into cold sodium hydroxide solution, the following reaction occurs.

$$Cl_2(g) + 2NaOH(aq) \longrightarrow NaCl(aq) + NaOCl(aq) + H_2O(l)$$

(a) Show that this is a disproportionation reaction. [2]

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(b) Give **one** common use for sodium chlorate(I). [1]

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3. Calcium hydroxide, $Ca(OH)_2$, is a strong base that is sparingly soluble in water. A saturated solution of calcium hydroxide has a concentration of $2.34 \times 10^{-2}\,mol\,dm^{-3}$ at 298 K.

Find the pH of this solution. [2]

pH = ...

4. One proposal to reduce the carbon dioxide emissions from public transport is to replace diesel trains with trains powered by hydrogen fuel cells. Give **one** *other* advantage of using hydrogen fuel cells. [1]

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.....

5. Bismuth is the heaviest naturally occurring element in Group 5. Suggest which oxidation state of bismuth would be most stable. Give a reason for your answer. [2]

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SECTION B

Answer **all** questions.

6. Ammonia is a versatile compound produced on a large scale. It is used in fertilisers and cleaning products and to make a range of other nitrogen-containing compounds.

(a) Ammonia is an example of a weak base.

(i) State what is meant by a base and explain why the ammonia molecule is able to act as a base. [2]

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(ii) Ammonia can be used as part of a mixture that forms a buffer.

I. Suggest a compound that could be added to ammonia solution to form a buffer. [1]

.....

II. Suggest a use for a buffer. [1]

.....

(b) Ammonia can form a compound with borane (BH_3).

(i) Draw a dot and cross diagram of the compound formed. [1]

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(ii) Boron-nitrogen bonds are also present in boron nitride. One form of boron nitride (hexagonal boron nitride) is sometimes called white graphite.

Complete the table below giving similarities and differences in the structure and bonding of hexagonal boron nitride and graphite. One similarity has been included for you. [2]

	Similarity between hexagonal boron nitride and graphite	Difference between hexagonal boron nitride and graphite
Structure	....	....
Bonding	each atom is bonded by covalent bonds to three others in both graphite and BN	....

(c) Nitrogen forms a range of compounds such as NH_3 and NF_3 which have three covalent bonds. Phosphorus can form compounds such as PF_3 which has three covalent bonds and PF_5 which has five covalent bonds.

Explain this difference in the chemistry of nitrogen and phosphorus. [2]

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7. One method of studying the rates of chemical reactions is to use a clock reaction.

One clock reaction involves the reaction between iodate(V) ions, IO_3^-, and hydrogensulfate(IV) ions, HSO_3^-.

A student is given the following three solutions:

- sodium hydrogensulfate(IV) solution containing HSO_3^-(aq)
- potassium iodate(V) solution containing IO_3^-(aq)
- starch solution

He is also provided with deionised water.

The student combines the following volumes of solutions and measures the time taken for the colour to change.

Volume of HSO_3^- / cm^3	Volume of IO_3^- / cm^3	Volume of starch / cm^3	Volume of deionised water / cm^3	Time / s
10	10	5	25	164
10	20	5	15	82
10	30	5	.....	55

(a) Complete the table to show the volume of deionised water that should be used in the final experiment. Give a reason for the value you have chosen. [1]

.....

.....

(b) Find the order of reaction with respect to iodate(V) ions. Explain how you reached your conclusion. [2]

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.....

(c) The reaction is fourth order overall. Suggest a rate equation for the reaction. [2]

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(d) Suggest a rate determining step for the reaction. [1]

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(e) Addition of lead(II) ions to the mixture after the reaction produces a mixture of products including lead(II) iodide and lead(II) iodate(V).

(i) Give the colour of lead(II) iodide. [1]

.....

(ii) A sample of lead(II) iodate(V) decomposes on heating to give a mixture of solids and a mixture of oxygen gas and iodine vapour.

At a temperature of 200 °C, the volume of gas is 220 cm^3, but when cooled to 20 °C the iodine solidifies and the volume of gas is 110 cm^3.

Calculate the number of moles of gas at these two temperatures and hence find the percentage of iodine molecules in the original gas mixture. [3]

[All volumes are measured at a pressure of 1.01×10^5 Pa]

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Number of moles of gas at 200 °C = ... mol

Number of moles of gas at 20 °C = ... mol

Percentage of iodine molecules = ... %

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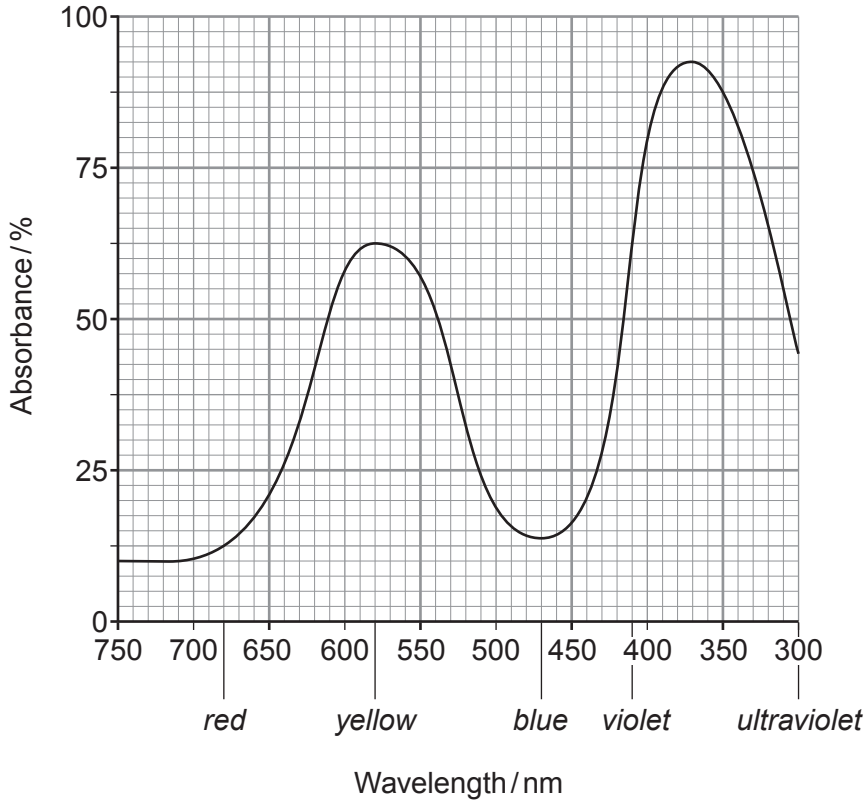
8. Vanadium is a transition element that forms compounds with a wide range of oxidation states. Its compounds are also used in a number of catalysts.

(a) State why transition elements can form a range of oxidation states in their compounds. [1]

.....

.....

(b) The visible spectrum of an aqueous solution of a compound containing V^{3+} ions is shown below.



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(i) Suggest the colour expected for aqueous solutions of V^{3+} compounds.

Give a reason for your answer. [2]

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(ii) In aqueous solutions, most vanadium ions form complexes with water acting as a ligand.

I. Give the meaning of the term ligand. [1]

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II. Describe the bonding that occurs between the ligand and the transition metal ion. [2]

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(c) VO_2^+ ions can be reduced to VO^{2+} ions by iodide ions as shown below.

$$2VO_2^+ + 4H^+ + 2I^- \longrightarrow 2VO^{2+} + 2H_2O + I_2$$

(i) Write the half-equation for the oxidation of iodide ions. [1]

.....

(ii) Write the half-equation for the reduction of VO_2^+ ions in acid solution. [1]

.....

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(d) Vanadium(V) oxide, V_2O_5, is used as a heterogeneous catalyst in the contact process.

(i) State what is meant by the term heterogeneous in this context. [1]

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.....

(ii) This catalyst is used to catalyse the oxidation of sulfur dioxide.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H^\theta = -197\,kJ\,mol^{-1}$$

$$\Delta S^\theta = -187\,J\,K^{-1}\,mol^{-1}$$

I. The standard enthalpy change of formation of sulfur dioxide is $-297\,kJ\,mol^{-1}$. Calculate the standard enthalpy change of formation of sulfur trioxide, SO_3. [2]

$\Delta_f H^\theta$ = ... $kJ\,mol^{-1}$

II. A student calculates the value at which $\Delta G = 0$ and states that this is the minimum temperature needed for the reaction to occur.

Find the temperature at which $\Delta G = 0$ and state, giving a reason, whether this is the **minimum** temperature needed for the reaction to occur. [3]

Temperature = ... K

.....

.....

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III. Samples of 0.040 mol of SO_2 and 0.040 mol of O_2 are placed in a sealed vessel of volume 2.00 dm^3. The reaction is allowed to come to equilibrium, giving a concentration of 0.014 mol dm^{-3} of SO_3.

Calculate the value of the equilibrium constant, K_c, under these conditions, giving its unit. [4]

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

K_c = ...

Unit .....

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9. (a) Addition of a solution containing $Ag^+(aq)$ to solutions containing halide ions such as chloride, bromide or iodide causes precipitates to form.

(i) Give the colours of the precipitates formed with chloride, bromide and iodide ions. [1]

chloride ions .....

bromide ions .....

iodide ions .....

(ii) The standard enthalpy change of formation of AgCl(s) is $-127.1\,kJ\,mol^{-1}$.

Use the data below to calculate the standard enthalpy change of formation of AgBr(s) and hence show which of the two silver halides is more stable with respect to its elements. You **must** show your working. [4]

Reaction	Standard enthalpy change, ΔH^θ / $kJ\,mol^{-1}$
$Ag(s) \longrightarrow Ag^+(aq) + e^-$	+105.6
$Br_2(l) + 2e^- \longrightarrow 2Br^-(aq)$	–243.1
$AgBr(s) \longrightarrow Ag^+(aq) + Br^-(aq)$	+84.4

.....

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(b) The standard electrode potential for the half-equation below is +0.80 V.

$$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$$

(i) When a piece of copper metal is placed in a solution of silver nitrate, a displacement reaction occurs.

I. Write the **ionic** equation for this displacement reaction. [1]

.....

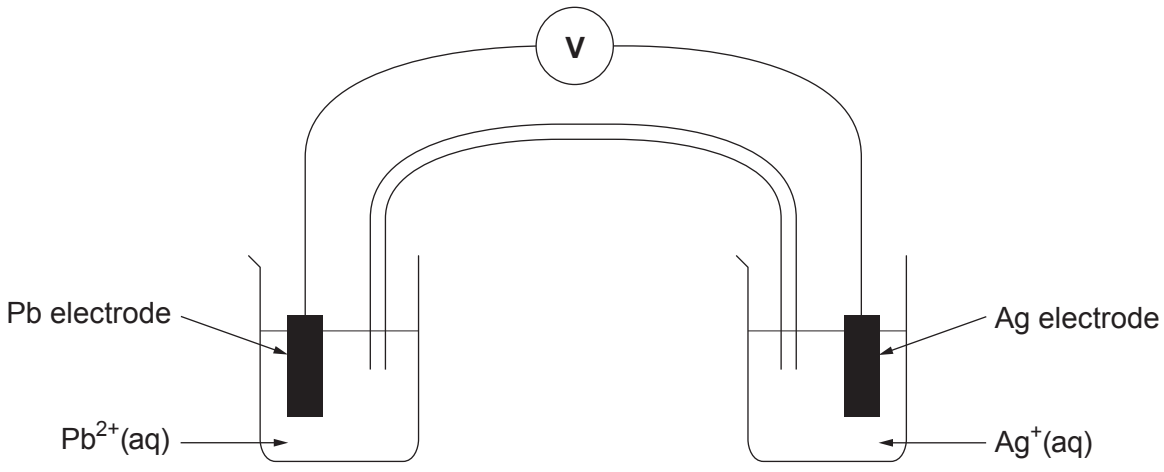
II. State what information this provides regarding the standard electrode potential for the $Cu(s)|Cu^{2+}(aq)$ half-cell. Give a reason for your answer. [2]

.....

.....

.....

(ii) The apparatus below was assembled with the $Pb(s)|Pb^{2+}(aq)$ half-cell under standard conditions connected to the $Ag(s)|Ag^+(aq)$ half-cell. The silver is the positive electrode.



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The value on the high-resistance voltmeter was recorded with different concentrations of silver ions used in the $Ag(s)\,|\,Ag^{+}(aq)$ half-cell. The results are shown below.

Concentration of $Ag^{+}(aq)$ / $mol\,dm^{-3}$	Value recorded on high-resistance voltmeter / V
1.0	0.93
0.1	0.87
0.01	0.81
0.001	0.75
0.0001	0.69

I. Calculate the value of the standard electrode potential for the $Pb(s)\,|\,Pb^{2+}(aq)$ half-cell. [2]

E^{θ} = ... V

II. Explain why the value recorded on the voltmeter becomes less positive as the concentration of silver ions decreases. [3]

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10. Abandoned metal mines in Wales contribute to the pollution of some rivers and streams. The mines on Parys mountain on Anglesey have led the Afon Goch stream to become acidic and carry a range of metal ions.

(a) The pH of the initial stretch of Afon Goch was found to be 3.24. Calculate the concentration of H^+ ions in this water. [2]

$[H^+]$ = ... $mol\,dm^{-3}$

(b) The three main metals contaminating the water of Afon Goch are iron, copper and zinc. A research group wishes to find the concentrations of all three metals in a water sample from the river.

An initial reduction step converts all the iron ions present to Fe^{2+} and all the copper ions present to copper metal. The **amphoteric** zinc ions are not affected. This produces test water **A**.

Two students are asked to find the concentration of Fe^{2+} ions in test water **A**.

(i) The reduction step produced 4.55 mg of copper metal from a 250 cm^3 sample of river water.

Suggest how this could be separated from test water **A**. [1]

.....

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(ii) One student attempts to find the iron content in 25.0 cm^3 of test water **A** by gravimetric analysis. He adds excess aqueous sodium hydroxide, filters and then heats the precipitate in an oxygen-rich atmosphere.

I. Give **two** reasons why the aqueous sodium hydroxide that is added must be in excess. [2]

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II. The experiment produced 14.5 mg of Fe_2O_3. Use this value to show that the concentration of Fe^{2+} ions in test water **A** is 7.27×10^{-3} mol dm^{-3}. [2]

$M_r(Fe_2O_3) = 159.6$

III. The total error when measuring the mass of Fe_2O_3 by difference was 0.2 mg.

Find the percentage error in this measurement. [1]

Percentage error = ... %

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(iii) The second student titrated 25.0 cm^3 samples of test water **A** against a solution of acidified potassium manganate(VII) of concentration 2.10×10^{-3} mol dm^{-3}.

$$MnO_4^- + 5Fe^{2+} + 8H^+ \longrightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$$

The mean volume of acidified potassium manganate(VII) solution required for reaction was 18.10 cm^3 and the percentage error in the titration was 0.8%.

I. State what observation would be made at the end-point of the titration. [1]

.....

II. Calculate the concentration of Fe^{2+} ions in the sample of test water **A**. [2]

Concentration = ... mol dm^{-3}

(iv) The two students compared their results and decided that they are in agreement.

Calculate the percentage difference between the concentrations of Fe^{2+} ions found by the two students in parts (ii) and (iii) and hence show whether the students' decision is valid. [2]

Percentage difference = ... %

.....

.....

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QUESTION CONTINUES ON PAGE 20

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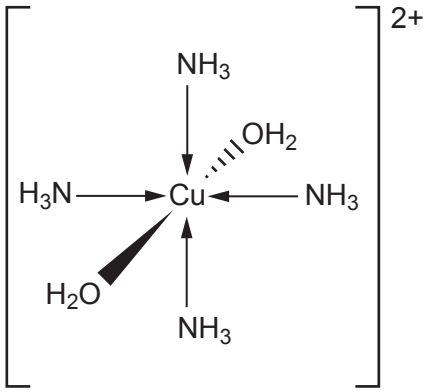
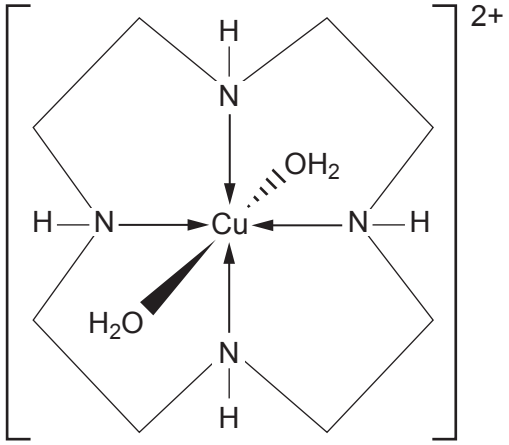
(c) One method of determining the concentration of copper ions present in a solution is to form a complex ion with a characteristic colour and measure the concentration of this using colorimetry. Two such copper complexes are $[Cu(NH_3)_4(H_2O)_2]^{2+}$ and $[Cu(cyclen)(H_2O)_2]^{2+}$.

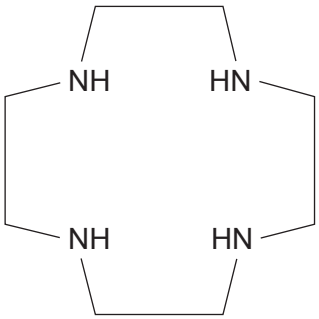


$[Cu(NH_3)_4(H_2O)_2]^{2+}$



$[Cu(cyclen)(H_2O)_2]^{2+}$

Cyclen is a cyclic tetradentate ligand with four nitrogen atoms that can bond to a transition metal ion. The structure of the cyclen ligand is shown below.



cyclen

(i) Give the colour of the $[Cu(NH_3)_4(H_2O)_2]^{2+}$ complex. [1]

.....

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(ii) An equilibrium exists between $[Cu(NH_3)_4(H_2O)_2]^{2+}$ and $[Cu(cyclen)(H_2O)_2]^{2+}$ in aqueous solution.

$$[Cu(NH_3)_4(H_2O)_2]^{2+}(aq) + cyclen(aq) \rightleftharpoons [Cu(cyclen)(H_2O)_2]^{2+}(aq) + 4NH_3(aq)$$

$$\Delta H^{\theta} = +1.2\,kJ\,mol^{-1}$$

Measurements show that the strengths of the Cu—N bonds in $[Cu(NH_3)_4(H_2O)_2]^{2+}$ and $[Cu(cyclen)(H_2O)_2]^{2+}$ are similar and that the Gibbs free energy change for the equilibrium is negative.

Discuss the information given above. Your answer should:

- explain why the enthalpy change for the reaction is very small
- suggest why the Gibbs free energy change for this equilibrium would be negative
- state and explain the effect of a negative Gibbs free energy change on the value of K_c for an equilibrium [6 QER]

END OF PAPER

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