OXFORD

INTERNATIONAL
AQA EXAMINATIONS

Please write clearly in block capitals.

Centre number | | | | | | Candidate number | | | | |

Surname _____

Forename(s) _____

Candidate signature _____

I declare this is my own work.

INTERNATIONAL A-LEVEL

CHEMISTRY (9620)

Unit 3: Inorganic 2 and Physical 2

Thursday 12 January 2023 07:00 GMT Time allowed: 1 hour 30 minutes

Materials

For this paper you must have:
- the Periodic Table/Data Sheet, provided as an insert
- a ruler with millimetre measurements
- a scientific calculator, which you are expected to use where appropriate.

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 80.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
8	
TOTAL	

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Answer **all** questions in the spaces provided.

0 1 This question is about the enthalpy of lattice formation of barium chloride.

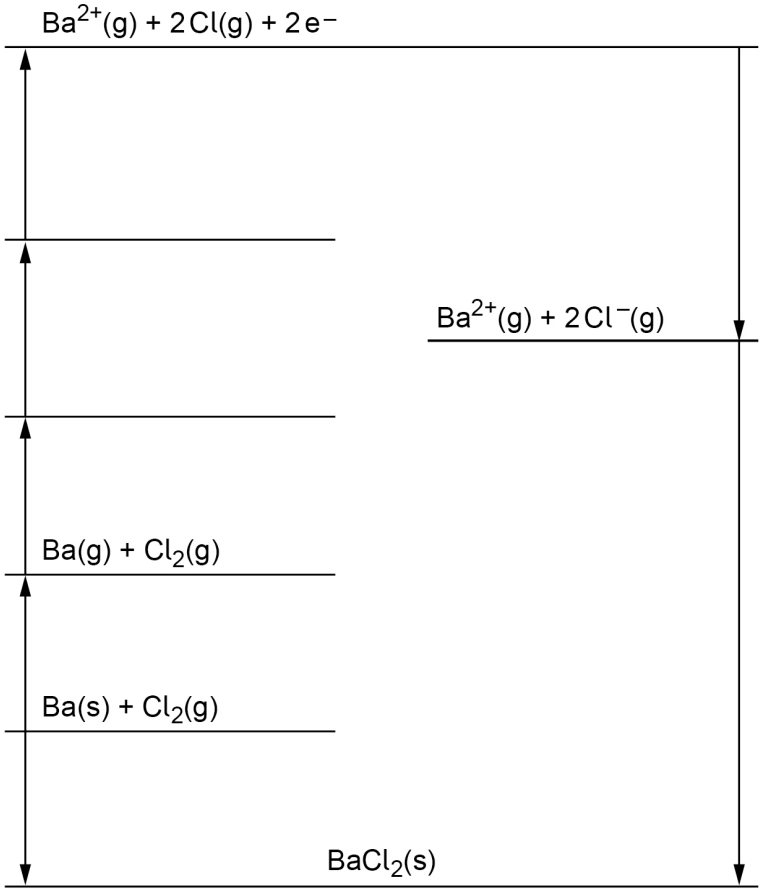
0 1 . 1 Define enthalpy of lattice formation.

[2 marks]

0 1 . 2 **Figure 1** shows an incomplete Born–Haber cycle for barium chloride, $BaCl_2$

The Born–Haber cycle is not to scale.

Figure 1



Write the formulas, including state symbols, of the appropriate species on each of the two blank horizontal lines in **Figure 1**.

[2 marks]

Do not write outside the box

0 1 . 3 **Table 1** shows enthalpy changes from the Born–Haber cycle for barium chloride.

Table 1

Enthalpy change	$\Delta H^{\ominus}$ **/ kJ mol^{-1}**
Enthalpy of atomisation of barium	+176
First ionisation enthalpy of barium	+502
Enthalpy of atomisation of chlorine	+121
First electron affinity of chlorine	–364
Enthalpy of lattice formation of barium chloride	–2018
Enthalpy of formation of barium chloride	–860

Use the data in **Table 1** to calculate the **second** ionisation enthalpy of barium.

Explain why this value for the **second** ionisation enthalpy of barium is different from the value for the **first** ionisation enthalpy of barium given in **Table 1**.

[4 marks]

Calculation

Second ionisation enthalpy _____ kJ mol^{-1}

Explanation _____

_____

_____

_____

_____

_____

Turn over ►

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0 1 . 4 The enthalpy of lattice formation for barium chloride in **Table 1** was determined from experimental values.

The value calculated from theoretical data is almost the same as this experimental value.

Use your knowledge of the bonding in barium chloride to explain why these two values are almost the same.

[1 mark]

0 1 . 5 **Table 2** shows some enthalpy data for barium chloride and its ions.

Table 2

Enthalpy change	**$\Delta H^{\ominus}$ / kJ mol^{-1}**
Enthalpy of hydration of $Ba^{2+}(g)$	–1360
Enthalpy of hydration of $Cl^{-}(g)$	–364
Enthalpy of lattice formation of barium chloride	–2018

Use the data in **Table 2** to calculate the standard enthalpy of solution of barium chloride.

[2 marks]

Enthalpy of solution _____ kJ mol^{-1}

11

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Turn over for the next question

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0 2 This question is about the thermodynamics of osmium (Os) and its oxide (OsO_4).

0 2 . 1 Which is the correct classification for the element osmium?

Tick (✓) **one** box.

[1 mark]

s block ☐

p block ☐

d block ☐

f block ☐

0 2 . 2 Osmium reacts slowly with atmospheric oxygen to form crystals of white osmium tetroxide, OsO_4

$$Os(s) + 2\,O_2(g) \rightarrow OsO_4(s)$$

Table 3 shows thermodynamic data for this reaction.

Table 3

$\Delta G^{\ominus}$ / kJ mol^{-1}	Temperature / K
–339	150
–250	450
–160	750
–71	1050
18	1350

Use these data to plot a graph of free-energy change, ΔG, (y-axis) against temperature (x-axis) on the grid in **Figure 2**.

Calculate the gradient of the line on your graph.

Use $\Delta G = \Delta H - T\Delta S$ and your gradient to calculate the entropy change (ΔS) in J K^{-1} mol^{-1} for the reaction.

Determine the enthalpy change (ΔH) in kJ mol^{-1} for the reaction.

[5 marks]

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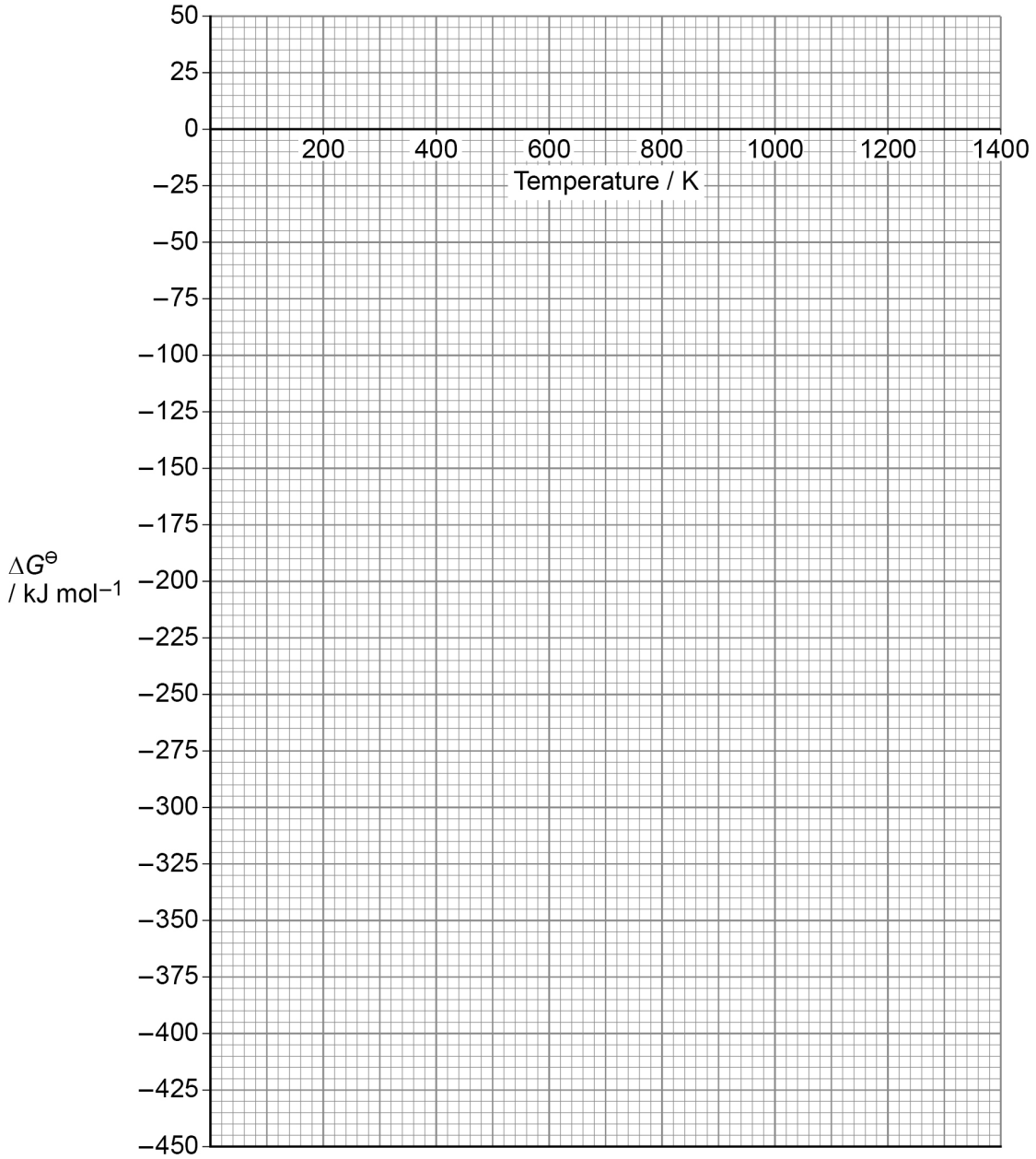
Figure 2



ΔS _____ J K^{-1} mol^{-1}

ΔH _____ kJ mol^{-1}

Turn over ►

Do not write outside the box

0 2 . 3 Under different conditions, the same reactants form crystals of yellow osmium tetroxide.

The arrangement of the particles in crystals of yellow osmium tetroxide is different from the arrangement of the particles in crystals of white osmium tetroxide.

Table 4 shows the standard entropy values.

Table 4

Substance	**$S^{\ominus}$ / J K^{-1} mol^{-1}**
yellow $OsO_4(s)$	124
white $OsO_4(s)$	145

Use the data in **Table 4** to explain the difference in the entropy of the two different forms of osmium tetroxide.

[1 mark]

0 2 . 4 The entropy change for the reaction between osmium and oxygen to form crystals of yellow osmium tetroxide is –319 J K^{-1} mol^{-1}

$$Os(s) + 2\,O_2(g) \rightarrow OsO_4(s)$$

Table 5 shows some standard entropy data.

Table 5

Substance	**$S^{\ominus}$ / J K^{-1} mol^{-1}**
$O_2(g)$	205
yellow $OsO_4(s)$	124

Calculate the standard entropy, in J K^{-1} mol^{-1}, of the element osmium.

[2 marks]

$S^{\ominus}$ _____ J K^{-1} mol^{-1}

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0 2 . 5 It is suggested that white osmium tetroxide can be reduced to osmium by reaction with hydrogen gas according to the equation

$$OsO_4(s) + 4\ H_2(g) \rightarrow Os(s) + 4\ H_2O(l) \quad \Delta H = -584\ kJ\ mol^{-1}$$

The entropy change for the reaction was calculated to be $-120\ J\ K^{-1}\ mol^{-1}$

State whether this reaction is feasible at 298 K
Justify your answer with a calculation.

[2 marks]

11

Turn over for the next question

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0 3 This question is about acids, bases and buffer solutions.

0 3 . 1 Define Brønsted–Lowry base.

[1 mark]

0 3 . 2 Write an equation, including state symbols, for the reaction of sodium with water.

[1 mark]

0 3 . 3 0.150 g of sodium metal is carefully added to some water. After the reaction, more water is added to give a solution with a final volume of 2000 cm^3

Calculate the pH of this solution at 25 °C
Give your answer to **two** decimal places.

The ionic product of water, $K_w = 1.00 \times 10^{-14}$ $mol^2\,dm^{-6}$ at 25 °C

[4 marks]

pH _____

Do not write outside the box

0 3 . 4 The value of K_w is 1.47×10^{-14} mol^2 dm^{-6} at 30 °C

Calculate the pH of pure water at 30 °C
Give your answer to **two** decimal places.

State why water is neutral, even though the pH at 30 °C is **not** 7.00

[3 marks]

pH _____

Reason why water is neutral _____

_____

0 3 . 5 10.0 cm^3 of 0.150 mol dm^{-3} sodium hydroxide solution are added to 10.0 cm^3 of 0.205 mol dm^{-3} propanoic acid.

For propanoic acid, pK_a = 4.87

Calculate the pH of the buffer solution that is formed.
Give your answer to **two** decimal places.

[6 marks]

pH _____

15

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0 4 This question is about Period 3 elements and their compounds.

0 4 . 1 Write an equation for the reaction between phosphorus and chlorine to make phosphorus(V) chloride.

[1 mark]

0 4 . 2 Write an equation for the reaction of phosphorus(V) chloride with water to make phosphoric(V) acid.

[1 mark]

0 4 . 3 Draw the displayed formula of phosphoric(V) acid.

[1 mark]

0 4 . 4 Write an equation to show how phosphoric(V) acid forms an acidic solution in water.

[1 mark]

Do not write outside the box

Aluminium oxide is amphoteric.

0 4 . 5 Define amphoteric.

[1 mark]

0 4 . 6 Write an equation to show how aluminium oxide can act as a base.

[1 mark]

0 4 . 7 Sulfur dioxide reacts with water to form an acid.

State the formula of the acid.

Suggest the approximate pH of a 0.1 mol dm^{-3} solution of this acid.

[2 marks]

Formula _____

pH _____

8

Turn over for the next question

Do not write outside the box

0 5 This question is about ligands and complexes.

0 5 . 1 Transition metal complexes have different shapes.

Complete **Table 6** to name the shape of each complex.

[4 marks]

Table 6

Complex	Name of shape
$[CoCl_4]^{2-}$	
$Pt(NH_3)_2Cl_2$	
$[Ag(NH_3)_2]^+$	
$[Cu(EDTA)]^{2-}$	

0 5 . 2 Ethanedioate ions ($C_2O_4^{2-}$) can act as bidentate ligands.

Draw the displayed formula of an ethanedioate ion.

Show on your diagram the lone pairs of electrons that form the co-ordinate bonds when the ion is acting as a ligand.

[2 marks]

0 5 . 3 When ethanedioate ions are added to an aqueous solution containing iron(II) ions, a ligand substitution reaction takes place.

Write an equation for the reaction that occurs when all six water ligands in the aqueous iron(II) complex are replaced by ethanedioate ions.

[1 mark]

Do not write outside the box

0 5 . 4 1,2-diaminoethane is also a bidentate ligand.

When 1,2-diaminoethane is added to an aqueous solution containing copper(II) ions, incomplete substitution takes place to form the complex $[Cu(NH_2CH_2CH_2NH_2)_2(H_2O)_2]^{2+}$

What type of isomerism does this complex show?

Tick (✓) **one** box.

[1 mark]

Cis-trans only ☐

Optical only ☐

Cis-trans and optical ☐

0 5 . 5 Haem is a complex that contains a multidentate ligand.

Identify the metal ion in this complex.

Explain how the complex allows oxygen to be transported in the body.

[2 marks]

Metal ion _____

Explanation _____

_____

_____

10

Turn over for the next question

Do not write outside the box

0 6 This question is about reactions of metal ions in aqueous solution.

Table 7 shows the observations from some test-tube reactions of an aqueous copper(II) salt.

Table 7

	Test	Observations
1	Add acidified $BaCl_2$(aq)	White precipitate
2	Add NaOH(aq)	Blue precipitate
3	Add excess HCl(aq)	Yellow-green solution

0 6 . 1 Use the observation from **Test 1** to identify the anion in the salt.

[1 mark]

0 6 . 2 Write an ionic equation for the reaction in **Test 2**.

[1 mark]

0 6 . 3 The reaction in **Test 3** involves a change in the co-ordination number of the complex ion.

Write an equation for the reaction in **Test 3**.

Explain why there is a change in the co-ordination number.

[2 marks]

Equation

Explanation

Do not write outside the box

0 6 . 4 **Table 8** shows two further test-tube reactions of the aqueous copper(II) salt.

Table 8

	Test	Observation
4	Add a few drops of $NH_3(aq)$	
5	Add excess $NH_3(aq)$	

Complete **Table 8** to state the observation in each test.

Give the formula of the copper-containing complex ion formed in **Test 5**.

[3 marks]

Formula of copper-containing complex ion _____

An aqueous solution of sodium carbonate is added to separate samples of aqueous iron(II) sulfate and aqueous iron(III) chloride.

0 6 . 5 Describe what you would observe in the reaction with iron(II) sulfate.

Write an equation for the reaction with iron(III) chloride.

[2 marks]

Observation with iron(II) sulfate _____

Equation with iron(III) chloride

_____

0 6 . 6 Explain why aqueous iron(III) chloride is more acidic than aqueous iron(II) sulfate.

[2 marks]

_____

_____

_____

_____

11

Turn over ►

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0 7 Under some conditions, nitrate(V) ions (NO_3^-) can oxidise Mn^{2+} ions to MnO_2 and the nitrate(V) ions are reduced.

An experiment is used to find the oxidation state of nitrogen at the end of the reaction.

In this experiment, 24.0 cm^3 of 0.150 mol dm^{-3} aqueous solution of Mn^{2+} ions react with exactly 15.0 cm^3 of 0.0960 mol dm^{-3} aqueous solution of NO_3^- ions.

Write a half-equation for the oxidation of Mn^{2+} to MnO_2

Calculate the simplest whole-number reacting ratio of Mn^{2+} ions to NO_3^- ions.

Determine the oxidation state of N at the end of the reaction.

[5 marks]

Half-equation

Calculation

Reacting ratio

Mn^{2+} : NO_3^-

_____ : _____

Oxidation state of N at the end of the reaction

5

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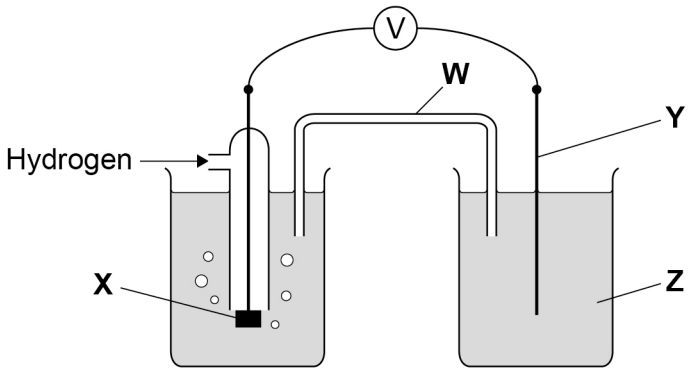
0 8 **Figure 3** shows the electrochemical cell used to measure the standard electrode potential for the Zn^{2+}/Zn electrode.

Figure 3



0 8 . 1 Identify a substance used in **W**.

Give the purpose of **W**.

[2 marks]

Substance _____

Purpose _____

_____

0 8 . 2 Identify substances **X**, **Y** and **Z**.

[3 marks]

X _____

Y _____

Z _____

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Table 9 shows some electrode half-equations and their standard electrode potentials.

Table 9

Electrode half-equation	$E^{\ominus}$ / V
$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O(l)$	+1.23
$VO_2^+(aq) + 2H^+(aq) + e^- \rightarrow VO^{2+}(aq) + H_2O(l)$	+1.00
$Ag^+(aq) + e^- \rightarrow Ag(s)$	+0.80
$VO^{2+}(aq) + 2H^+(aq) + e^- \rightarrow V^{3+}(aq) + H_2O(l)$	+0.34
$Pb^{2+}(aq) + 2e^- \rightarrow Pb(s)$	–0.13
$V^{3+}(aq) + e^- \rightarrow V^{2+}(aq)$	–0.26
$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$	–0.76
$V^{2+}(aq) + 2e^- \rightarrow V(s)$	–1.20

An excess of zinc reacts with an acidified solution containing aqueous VO_2^+ ions.

Several colour changes are seen as the reaction mixture is observed.

The final reaction mixture contains Zn^{2+} ions and V^{2+} ions.

0 8 . 3 Explain why there are several colour changes.

[2 marks]

Question 8 continues on the next page

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Table 9 is repeated here.

Table 9

Electrode half-equation	$E^{\ominus}$ / V
$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O(l)$	+1.23
$VO_2^+(aq) + 2H^+(aq) + e^- \rightarrow VO^{2+}(aq) + H_2O(l)$	+1.00
$Ag^+(aq) + e^- \rightarrow Ag(s)$	+0.80
$VO^{2+}(aq) + 2H^+(aq) + e^- \rightarrow V^{3+}(aq) + H_2O(l)$	+0.34
$Pb^{2+}(aq) + 2e^- \rightarrow Pb(s)$	–0.13
$V^{3+}(aq) + e^- \rightarrow V^{2+}(aq)$	–0.26
$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$	–0.76
$V^{2+}(aq) + 2e^- \rightarrow V(s)$	–1.20

0 8 . 4 The unreacted zinc is removed from the mixture.
This mixture is then left to stand in air.
A colour change is observed in the mixture that has been left to stand in air.

Use data from **Table 9** to explain this observation.

[2 marks]

9

END OF QUESTIONS

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