A-level
CHEMISTRY
(7405/1)

Paper 1: Inorganic and Physical Chemistry

Specimen 2015	Session	Time allowed: 2 hours

Materials

For this paper you must have:
* the Data Booklet, provided as an insert
* a ruler
* a calculator.

Instructions
* Answer **all** questions.
* Show **all** your working.

Information
* The maximum mark for this paper is 105.

Please write clearly, in block capitals, to allow character computer recognition.

Centre number ☐☐☐☐☐   Candidate number ☐☐☐☐

Surname ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Forename(s) ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Candidate signature _____

Answer **all** questions.

| 0 | 1 | . | 1 | Explain how the electron pair repulsion theory can be used to deduce the shape of, and the bond angle in, PF_3

[6 marks]

0 1 . 2 State the full electron configuration of a cobalt(II) ion.

[1 mark]

0 1 . 3 Suggest **one** reason why electron pair repulsion theory **cannot** be used to predict the shape of the $[CoCl_4]^{2-}$ ion.

[1 mark]

0 1 . 4 Predict the shape of, and the bond angle in, the complex rhodium ion $[RhCl_4]^{2-}$

[2 marks]

Shape

Bond angle

Turn over for the next question

0 2 . 1 Explain why the atomic radii of the elements decrease across Period 3 from sodium to chlorine.

[2 marks]

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0 2 . 2 Explain why the melting point of sulfur (S_8) is greater than that of phosphorus (P_4).

[2 marks]

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0 2 . 3 Explain why sodium oxide forms an alkaline solution when it reacts with water.

[2 marks]

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<table>
<tr><td>0 2 . 4</td><td>Write an ionic equation for the reaction of phosphorus(V) oxide with an excess of sodium hydroxide solution.</td></tr>
</table>

[1 mark]

_____

Turn over for the next question

3 Fuel cells are an increasingly important energy source for vehicles. Standard electrode potentials are used in understanding some familiar chemical reactions including those in fuel cells.

Table 1 contains some standard electrode potential data.

Table 1

Electrode half-equation	$E^\ominus$/ V
$F_2 + 2e^- \longrightarrow \quad 2F^-$	+2.87
$Cl_2 + 2e^- \longrightarrow \quad 2Cl^-$	+1.36
$O_2 + 4H^+ + 4e^- \longrightarrow \quad 2H_2O$	+1.23
$Br_2 + 2e^- \longrightarrow \quad 2Br^-$	+1.07
$I_2 + 2e^- \longrightarrow \quad 2I^-$	+0.54
$O_2 + 2H_2O + 4e^- \longrightarrow \quad 4OH^-$	+0.40
$SO_4^{2-} + 4H^+ + 2e^- \longrightarrow \quad SO_2 + 2H_2O$	+0.17
$2H^+ + 2e^- \longrightarrow \quad H_2$	0.00
$4H_2O + 4e^- \longrightarrow \quad 4OH^- + 2H_2$	−0.83

0 3 . 1 A salt bridge was used in a cell to measure electrode potential.

Explain the function of the salt bridge.

[2 marks]

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_____

_____

_____

0 3 . 2 Use data from **Table 1** to deduce the halide ion that is the weakest reducing agent.

[1 mark]

_____

0 3 . 3 Use data from **Table 1** to justify why sulfate ions should **not** be capable of oxidising bromide ions.

[1 mark]

_____

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0 3 . 4 Use data from **Table 1** to calculate a value for the EMF of a hydrogen–oxygen fuel cell operating under alkaline conditions.

[1 mark]

EMF = _____ V

0 3 . 5 There are two ways to use hydrogen as a fuel for cars. One way is in a fuel cell to power an electric motor, the other is as a fuel in an internal combustion engine.

Suggest the major advantage of using the fuel cell.

[1 mark]

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Turn over for the next question

4 Many chemical processes release waste products into the atmosphere. Scientists are developing new solid catalysts to convert more efficiently these emissions into useful products, such as fuels. One example is a catalyst to convert these emissions into methanol. The catalyst is thought to work by breaking a H–H bond.

An equation for this formation of methanol is given below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \qquad \Delta H = -49 \text{ kJ mol}^{-1}$$
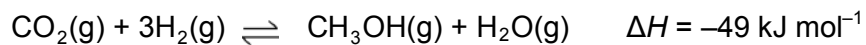
Some mean bond enthalpies are shown in **Table 2**.

Table 2

Bond	C=O	C–H	C–O	O–H
Mean bond enthalpy / kJ mol^{-1}	743	412	360	463

0 4 . 1 Use the enthalpy change for the reaction and data from **Table 2** to calculate a value for the H–H bond enthalpy.

[3 marks]

H–H bond enthalpy = _____ kJ mol^{-1}

0 4 . 2 A data book value for the H–H bond enthalpy is 436 kJ mol^{-1}.

Suggest **one** reason why this value is different from your answer to Question **4.1**.

[1 mark]

_____

_____

_____

0 4 . 3 Suggest **one** environmental advantage of manufacturing methanol fuel by this reaction.

[1 mark]

_____

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_____

0 4 . 4 Use Le Chatelier's principle to justify why the reaction is carried out at a high pressure rather than at atmospheric pressure.

[3 marks]

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0 4 . 5 Suggest why the catalyst used in this process may become less efficient if the carbon dioxide and hydrogen contain impurities.
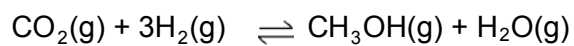
[1 mark]

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_____

Question 4 continues on the next page

0 4 . **6** In a laboratory experiment to investigate the reaction shown in the equation below, 1.0 mol of carbon dioxide and 3.0 mol of hydrogen were sealed into a container. After the mixture had reached equilibrium, at a pressure of 500 kPa, the yield of methanol was 0.86 mol.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Calculate a value for K_p
Give your answer to the appropriate number of significant figures.
Give units with your answer.

[7 marks]

K_p = _____ Units = _____

Turn over for the next question
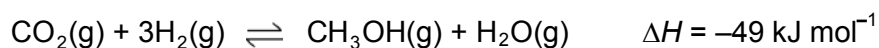
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ANSWER IN THE SPACES PROVIDED**

5   **Table 3** contains some entropy data relevant to the reaction used to synthesise methanol from carbon dioxide and hydrogen. The reaction is carried out at a temperature of 250 °C.

Table 3

Substance	$CO_2(g)$	$H_2(g)$	$CH_3OH(g)$	$H_2O(g)$
Entropy ($S^\ominus$) / J K^{-1} mol^{-1}	214	131	238	189

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \qquad \Delta H = -49 \text{ kJ mol}^{-1}$$

0 5 . 1 Use this enthalpy change and data from **Table 2** to calculate a value for the free-energy change of the reaction at 250 °C.
Give units with your answer.

[4 marks]

Free-energy change = _____ Units = _____

| 0 | 5 | . | 2 | Calculate a value for the temperature when the reaction becomes feasible.

[2 marks]

Temperature = _____ K

| 0 | 5 | . | 3 | Gaseous methanol from this reaction is liquefied by cooling before storage.

Draw a diagram showing the interaction between two molecules of methanol.
Explain why methanol is easy to liquefy.
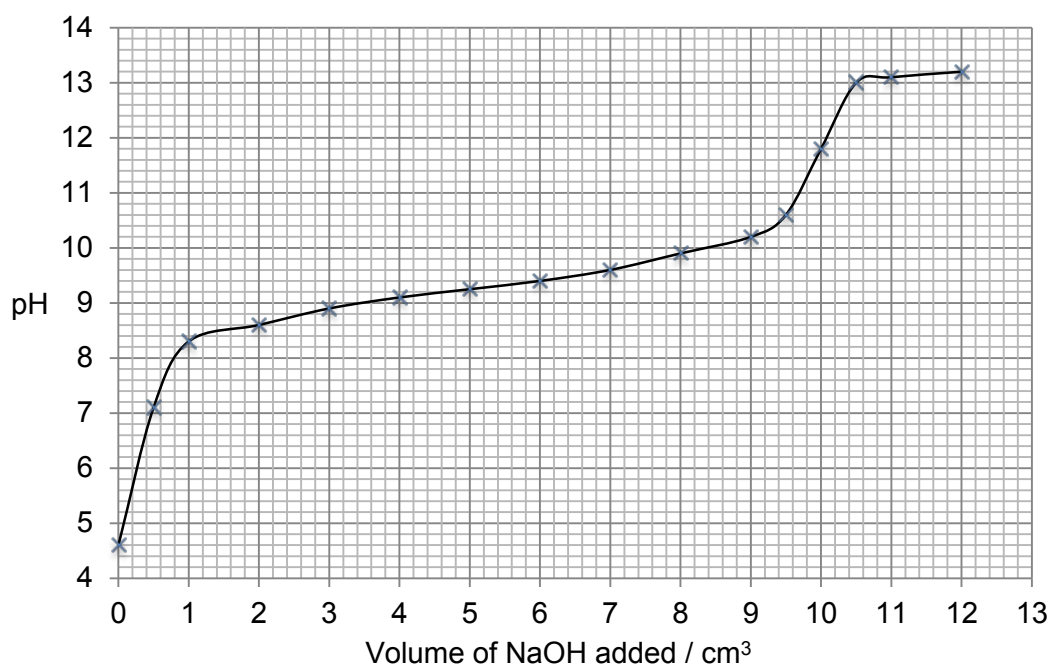
[4 marks]

Diagram

Explanation _____

_____

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Turn over ▶

6   Ammonium chloride, when dissolved in water, can act as a weak acid as shown by the following equation.

$$NH_4^+(aq) \rightleftharpoons NH_3(aq) + H^+(aq)$$

Figure 1 shows a graph of data obtained by a student when a solution of sodium hydroxide was added to a solution of ammonium chloride. The pH of the reaction mixture was measured initially and after each addition of the sodium hydroxide solution.

Figure 1

0 6 . **1** Suggest a suitable piece of apparatus that could be used to measure out the sodium hydroxide solution.
Explain why this apparatus is more suitable than a pipette for this purpose.

[2 marks]

Apparatus _____

Explanation _____

_____

_____

| 0 | 6 | . | 2 | Use information from the curve in **Figure 1** to explain why the end point of this reaction would be difficult to judge accurately using an indicator.

[2 marks]

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| 0 | 6 | . | 3 | The pH at the end point of this reaction is 11.8

Use this pH value and the ionic product of water, $K_w = 1.0 \times 10^{-14}$ mol^2 dm^{-6}, to calculate the concentration of hydroxide ions at the end point of the reaction.

[3 marks]

Concentration = _____ mol dm^{-3}

Question 6 continues on the next page

Turn over ▶

0 6 . 4 The expression for the acid dissociation constant for aqueous ammonium ions is

$$K_a = \frac{[NH_3][H^+]}{[NH_4^+]}$$

The initial concentration of the ammonium chloride solution was 2.00 mol dm^{-3}.

Use the pH of this solution, before any sodium hydroxide had been added, to calculate a value for K_a

[3 marks]

$K_a =$ _____ mol dm^{-3}

0 6 . 5 A solution contains equal concentrations of ammonia and ammonium ions.

Use your value of K_a from Question **6.4** to calculate the pH of this solution. Explain your working.

(If you were unable to calculate a value for K_a you may assume that it has the value 4.75×10^{-9} mol dm^{-3}. This is **not** the correct value.)

[2 marks]

pH= _____

Turn over for the next question

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7   **Table 4** shows some successive ionisation energy data for atoms of three different elements **X**, **Y** and **Z**.

Elements **X**, **Y** and **Z** are Ca, Sc and V but not in that order.

Table 4

	First	Second	Third	Fourth	Fifth	Sixth
X	648	1370	2870	4600	6280	12 400
Y	590	1150	4940	6480	8120	10 496
Z	632	1240	2390	7110	8870	10 720

For questions **7.1** and **7.2**, only **one** answer per question is allowed.

For each answer, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD   ●   WRONG METHODS   ⊗ ⊙ ⊜ ⦸

If you want to change your answer you must cross out your original answer as shown.   ⊠

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.   ⊗

| 0 | 7 | . | 1 | Which element is calcium?

[1 mark]

X   ⬭

Y   ⬭

Z   ⬭

| 0 | 7 | . | 2 | Which element is vanadium?

[1 mark]

X   ⬭

Y   ⬭

Z   ⬭

| 0 | 7 | . | 3 | Justify your choice of vanadium in Question **7.2**

[1 mark]

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| 0 | 7 | . | 4 | An acidified solution of NH_4VO_3 reacts with zinc.

Explain how observations from this reaction show that vanadium exists in at least two different oxidation states.

[2 marks]

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Question 7 continues on the next page

Turn over ▶

0 7 . 5 The vanadium in 50.0 cm^3 of a 0.800 mol dm^{-3} solution of NH_4VO_3 reacts with 506 cm^3 of sulfur(IV) oxide gas measured at 20.0 °C and 98.0 kPa.

Use this information to calculate the oxidation state of the vanadium in the solution after the reduction reaction with sulfur(IV) oxide.
Explain your working.
The gas constant R = 8.31 J K^{-1} mol^{-1}.

[6 marks]

Oxidation state = _____

Turn over for the next question

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08 . 1 A co-ordinate bond is formed when a transition metal ion reacts with a ligand.

Explain how this co-ordinate bond is formed.

[2 marks]

08 . 2 Describe what you would observe when dilute aqueous ammonia is added dropwise, to excess, to an aqueous solution containing copper(II) ions.
Write equations for the reactions that occur.

[4 marks]

0 8 . 3 When the complex ion $[Cu(NH_3)_4(H_2O)_2]^{2+}$ reacts with 1,2-diaminoethane, the ammonia molecules but not the water molecules are replaced.

Write an equation for this reaction.

[1 mark]

0 8 . 4 Suggest why the enthalpy change for the reaction in Question **8.3** is approximately zero.

[2 marks]

0 8 . 5 Explain why the reaction in Question **8.3** occurs despite having an enthalpy change that is approximately zero.

[2 marks]

Turn over for the next question

9 A 5.00 g sample of potassium chloride was added to 50.0 g of water initially at 20.0 °C. The mixture was stirred and as the potassium chloride dissolved, the temperature of the solution decreased.

0 9 . 1 Describe the steps you would take to determine an accurate minimum temperature that is **not** influenced by heat from the surroundings.

[4 marks]

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0 9 . 2 The temperature of the water decreased to 14.6 °C.

Calculate a value, in kJ mol^{-1}, for the enthalpy of solution of potassium chloride.

You should assume that only the 50.0 g of water changes in temperature and that the specific heat capacity of water is 4.18 J K^{-1} g^{-1}.
Give your answer to the appropriate number of significant figures.

[4 marks]

Enthalpy of solution = _____ kJ mol^{-1}

0 9 . 3 The enthalpy of solution of calcium chloride is –82.9 kJ mol^{-1}.
The enthalpies of hydration for calcium ions and chloride ions are –1650 and –364 kJ mol^{-1}, respectively.

Use these values to calculate a value for the lattice enthalpy of dissociation of calcium chloride.

[2 marks]

Lattice enthalpy of dissociation = _____ kJ mol^{-1}

0 9 . 4 Explain why your answer to Question **9.3** is different from the lattice enthalpy of dissociation for magnesium chloride.

[2 marks]

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10　　**Table 5** shows observations of changes from some test-tube reactions of aqueous solutions of compounds **Q**, **R** and **S** with five different aqueous reagents. The initial colours of the solutions are not given.

Table 5

	$BaCl_2$ + HCl	$AgNO_3$ + HNO_3	NaOH	Na_2CO_3	HCl (conc)
Q	no change observed	pale cream precipitate	white precipitate	white precipitate	no change observed
R	no change observed	white precipitate	white precipitate, dissolves in excess of NaOH	white precipitate, bubbles of a gas	no change observed
S	white precipitate	no change observed	brown precipitate	brown precipitate, bubbles of a gas	yellow solution

1 0 . 1　Identify each of compounds **Q**, **R** and **S**.
You are **not** required to explain your answers.

[6 marks]

Identity of **Q** _____

_____

Identity of **R** _____

_____

Identity of **S** _____

_____

1 0 . **2** Write ionic equations for each of the positive observations with **S**.

[4 marks]

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END OF QUESTIONS

There are no questions printed on this page

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