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]

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

[2 marks]

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

[2 marks]

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
$F_2 + 2e^- \longrightarrow 2F^-$	+2.87
$Cl_2 + 2e^- \longrightarrow 2Cl^-$	+1.36
$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$	+1.23
$Br_2 + 2e^- \longrightarrow 2Br^-$	+1.07
$I_2 + 2e^- \longrightarrow 2I^-$	+0.54
$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$	+0.40
$SO_4^{2-} + 4H^+ + 2e^- \longrightarrow SO_2 + 2H_2O$	+0.17
$2H^+ + 2e^- \longrightarrow H_2$	0.00
$4H_2O + 4e^- \longrightarrow 4OH^- + 2H_2$	–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]

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]

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]

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]

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]

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]

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 = _____

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 _____

_____

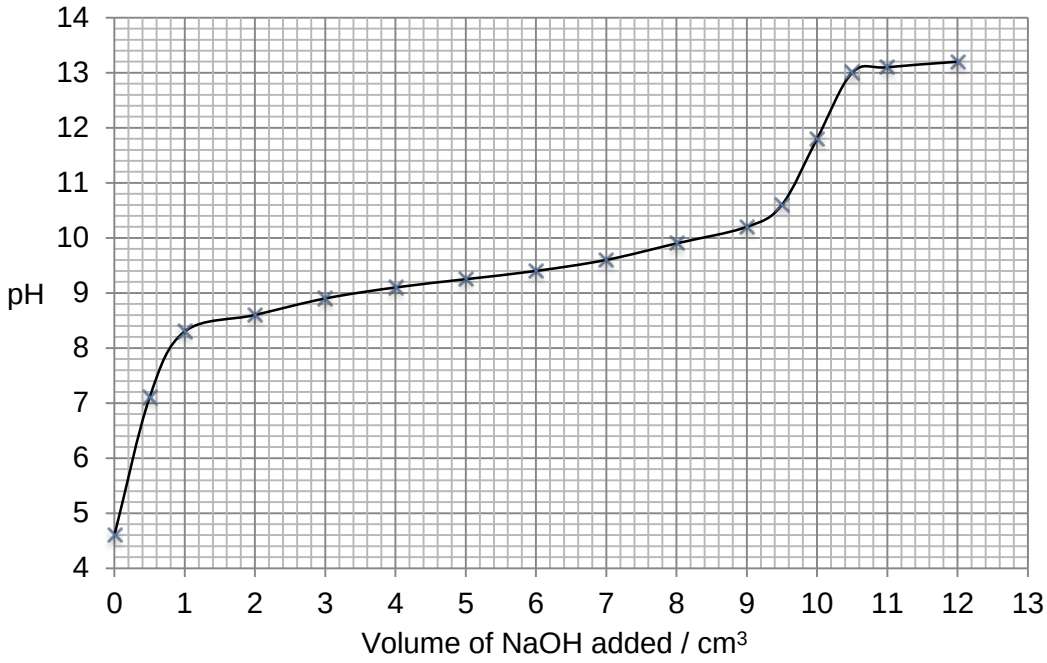
_____

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]

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

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

$$Ka = \frac{[NH^3][H^+]}{[NH_4{}^+]}$$

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= _____

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

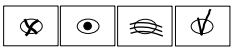
Elements **X**, **Y** and **Z** are Ca, Sc and V but not in that order.

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]

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]

Question 7 continues on the next page

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 = _____

0 8 . 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]

0 8 . 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]

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]

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]

END OF QUESTIONS