Write your name here

| Surname | Other names |
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| | |

**Pearson Edexcel Level 3 GCE**

Centre Number | | | | | |

Candidate Number | | | | |

# Chemistry

## Advanced

## Paper 1: Advanced Inorganic and Physical Chemistry

Sample Assessment Materials for first teaching September 2015

**Time: 1 hour 45 minutes**

Paper Reference **9CH0/01**

**You must have:**
Data Booklet
Scientific calculator, ruler

Total Marks

### Instructions

- Use **black** ink or ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*

### Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- You may use a scientific calculator.
- For questions marked with an *****, marks will be awarded for your ability to structure your answer logically showing the points that you make are related or follow on from each other where appropriate.
- A Periodic Table is printed on the back cover of this paper.

### Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.
- Show all your working in calculations and include units where appropriate.

*Turn over* ▶

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**Answer ALL questions.**

**Write your answers in the spaces provided.**

**Some questions must be answered with a cross in a box ☒.**
**If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.**

**1** This question is about the bonding and structure of molecules.

(a) Which element exists as discrete molecules in its solid state?

**(1)**

☒ **A** aluminium

☒ **B** iodine

☒ **C** silicon

☒ **D** sodium

(b) Which compound has non-polar molecules?

**(1)**

☒ **A** ammonia

☒ **B** carbon dioxide

☒ **C** hydrogen sulfide

☒ **D** water

(c) Which is the best reason for why the boiling temperature of HF is much higher than that of HCl?

**(1)**

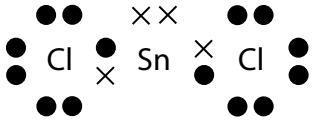
☒ **A** the instantaneous dipole-induced dipole (London) forces are stronger in HF

☒ **B** HF molecules have a smaller mass

☒ **C** there are intermolecular hydrogen bonds in HF

☒ **D** HF molecules have fewer electrons

(d) The dot-and-cross diagram for a molecule of tin(II) chloride, $SnCl_2$, in the gaseous state is:




(i) Using the electron-pair repulsion theory, explain the shape of this molecule.

**(2)**

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(ii) Predict a value for the Cl—Sn—Cl bond angle.

Justify your answer.

**(2)**

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**(Total for Question 1 = 7 marks)**

**2** This question is about energy changes involved in the formation of ionic compounds.

(a) What is the order of increasing first ionisation energy for the elements beryllium, helium and lithium?

**(1)**

☒ **A** lithium < helium < beryllium

☒ **B** beryllium < lithium < helium

☒ **C** helium < beryllium < lithium

☒ **D** lithium < beryllium < helium

(b) The **second** ionisation energy of calcium has a magnitude of 1150 kJ $mol^{-1}$.

Which of the following represents the **second** ionisation energy of calcium?

**(1)**

☒ **A** $Ca(g) \rightarrow Ca^{2+}(g) + 2e^-$ $\Delta H^{\ominus} = +1150$ kJ $mol^{-1}$

☒ **B** $Ca^+(g) \rightarrow Ca^{2+}(g) + e^-$ $\Delta H^{\ominus} = +1150$ kJ $mol^{-1}$

☒ **C** $Ca(g) \rightarrow Ca^{2+}(g) + 2e^-$ $\Delta H^{\ominus} = -1150$ kJ $mol^{-1}$

☒ **D** $Ca^+(g) \rightarrow Ca^{2+}(g) + e^-$ $\Delta H^{\ominus} = -1150$ kJ $mol^{-1}$

(c) The formation of potassium ions can be represented by the equation

$$K(s) \rightarrow K^+(g) + e^-$$

Which statement corresponds to the energy change for this process?

**(1)**

☒ **A** the first electron affinity of potassium

☒ **B** the first ionisation energy of potassium

☒ **C** the sum of the enthalpy change of atomisation of potassium and the first electron affinity of potassium

☒ **D** the sum of the enthalpy change of atomisation of potassium and the first ionisation energy of potassium

(d) The table shows the ionic radius and charge of each of six ions.

| **Ion** | $D^+$ | $E^+$ | $G^{2+}$ | $X^-$ | $Y^-$ | $Z^{2-}$ |
|---|---|---|---|---|---|---|
| **Ionic radius / nm** | 0.14 | 0.18 | 0.15 | 0.14 | 0.18 | 0.15 |

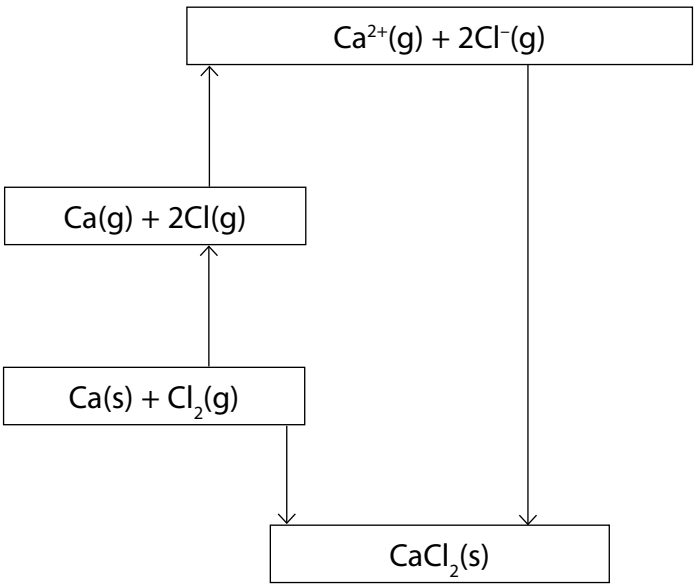
The ionic solids DX, EY and GZ have the same lattice structure.

Deduce the order of magnitude of their lattice energies, giving the most exothermic first.

Justify your answer.

**(3)**

(e) The diagram shows a Born-Haber cycle for calcium chloride, $CaCl_2$.




| | **kJ mol$^{-1}$** |
|---|---|
| Enthalpy of formation of $CaCl_2(s)$ | –796 |
| Lattice energy of $CaCl_2(s)$ | –2258 |
| Enthalpy of atomisation of $Ca(s) \rightarrow Ca(g)$ | 178 |
| Enthalpy of atomisation of $\frac{1}{2}Cl_2(g) \rightarrow Cl(g)$ | 122 |
| First ionisation energy of Ca(g) | 590 |
| Electron affinity of Cl(g) | –349 |

Calculate the second ionisation energy of calcium, in kJ mol$^{-1}$.

**(2)**

**(Total for Question 2 = 8 marks)**

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**3** Vanadium is a transition metal that forms ions with several oxidation numbers. Four of these ions are shown in the table.

| Formula of ion | Oxidation number of vanadium | Colour of ion |
|---|---|---|
| $V^{2+}$ | +2 | violet |
| $V^{3+}$ | +3 | green |
| $VO^{2+}$ | +4 | blue |
| $VO_2^+$ | +5 | yellow |

(a) Complete the electronic configuration for the vanadium atom and the $V^{3+}$ ion.

**(2)**

V $1s^2\ 2s^2\ 2p^6\ 3s^2$ .....

$V^{3+}$ $1s^2\ 2s^2\ 2p^6\ 3s^2$ .....

(b) The table shows the standard electrode (redox) potentials, $E^{\ominus}$, for some half-cell reactions.

| Redox system | Half-cell reaction | $E^{\ominus}$ / V |
|---|---|---|
| 1 | $V^{2+}(aq) + 2e^- \rightleftharpoons V(s)$ | −1.20 |
| 2 | $V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$ | −0.26 |
| 3 | $VO^{2+}(aq) + 2H^+(aq) + e^- \rightleftharpoons V^{3+}(aq) + H_2O(l)$ | +0.34 |
| 4 | $VO_2^+(aq) + 2H^+(aq) + e^- \rightleftharpoons VO^{2+}(aq) + H_2O(l)$ | +1.00 |
| 5 | $SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightleftharpoons SO_2(g) + 2H_2O(l)$ | +0.17 |

(i) Explain, using information from the table, the colour changes that take place when $SO_2$ gas is bubbled slowly through an acidified solution containing $VO_2^+$ ions.

Equations are not required.

**(3)**

(ii) Explain, using information in the table, whether the disproportionation of $V^{2+}(aq)$ into $V^{3+}(aq)$ and V(s) is feasible under standard conditions.

**(2)**

**(Total for Question 3 = 7 marks)**

**4** Aqueous copper(II) sulfate reacts with an excess of aqueous ammonia to give a dark blue solution.

The dark blue solution contains the octahedral complex ion, $[Cu(NH_3)_x(H_2O)_y]^{2+}$.

The formula of this complex ion is determined by colorimetry, using this method:

- Make up six different mixtures of 1.00 mol $dm^{-3}$ aqueous ammonia and 0.500 mol $dm^{-3}$ aqueous copper(II) sulfate and water.
- Filter the mixtures to remove any precipitate that forms.
- The filtrate is a dark blue solution that contains the complex ion, $[Cu(NH_3)_x(H_2O)_y]^{2+}$.
- Place the dark blue solution into a colorimeter and measure the absorbance of the solution.

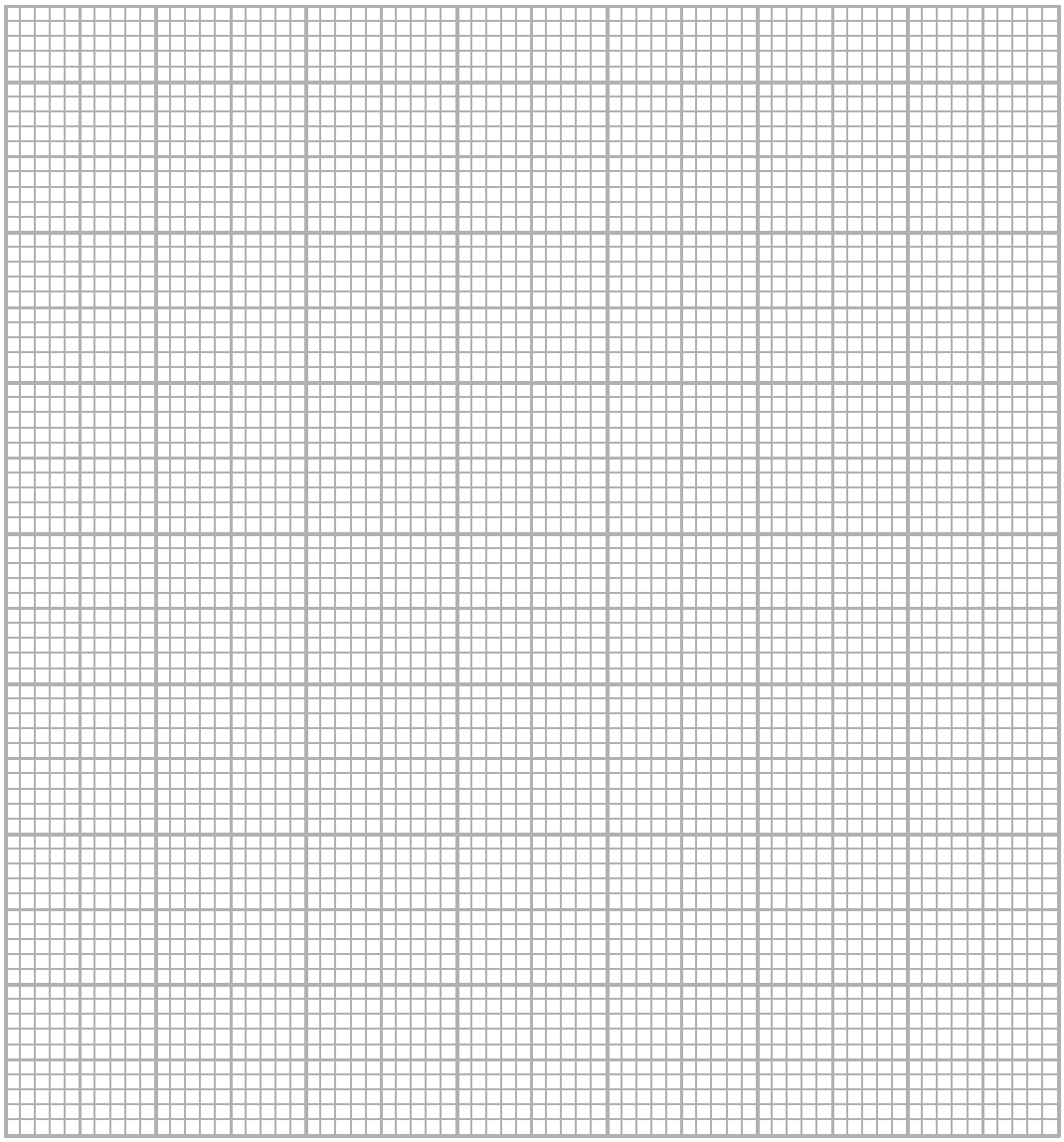
The table shows the absorbance of each mixture.

| | **Mixture** | | | | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** |
| Volume of 0.500 mol $dm^{-3}$ $CuSO_4(aq)$ / $cm^3$ | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Volume of 1.00 mol $dm^{-3}$ $NH_3(aq)$ / $cm^3$ | 3.00 | 6.00 | 9.00 | 12.00 | 15.00 | 18.00 |
| Volume of $H_2O(l)$ / $cm^3$ | 17.00 | 14.00 | 11.00 | 8.00 | 5.00 | 2.00 |
| Absorbance | 0.25 | 0.50 | 0.76 | 0.84 | 0.84 | 0.84 |

(a) Plot a graph of absorbance against volume of $NH_3(aq)$ on the grid opposite.

Draw a straight line of best fit through the first three points and another straight line of best fit through the last three points. Extend both lines so that they cross.

**(2)**



(b) (i) Use the graph to determine the smallest volume of 1.00 mol $dm^{-3}$ $NH_3(aq)$ required to completely react with 5.00 $cm^3$ of 0.500 mol $dm^{-3}$ of $CuSO_4$ solution.

**(1)**

(ii) Calculate the amount, in moles, of $CuSO_4$ in 5.00 $cm^3$ of 0.500 mol $dm^{-3}$ solution.

**(1)**

(iii) Calculate the amount of $NH_3$, in moles, present in the volume of $NH_3(aq)$ in (b)(ii).

**(1)**

(iv) Deduce the values of x and y in the formula of the complex ion $[Cu(NH_3)_x(H_2O)_y]^{2+}$.

**(1)**

x = ..... y = .....

(c) The precipitate formed when some of the mixtures are made is copper(II) hydroxide.

Write an ionic equation to show the formation of copper(II) hydroxide from its ions. Include state symbols.

**(2)**

**(Total for Question 4 = 8 marks)**

**5** Chlorine and bromine are elements in Group 7 of the Periodic Table.

Both elements exist in a number of different oxidation numbers and therefore are involved in many redox reactions.

(a) Write an equation for the reaction between chlorine and cold, dilute aqueous sodium hydroxide. State symbols are not required.

**(1)**

(b) Chlorine dioxide reacts with cold, dilute aqueous sodium hydroxide.

The ionic equation for the reaction is:

$$2ClO_2(aq) + 2OH^-(aq) \rightarrow ClO_2^-(aq) + ClO_3^-(aq) + H_2O(l)$$

Using oxidation numbers, explain why the chlorine in $ClO_2$ has undergone disproportionation.

**(3)**

(c) Chloride ions ($Cl^-$) can be oxidised to chlorine molecules ($Cl_2$) by manganate(VII) ions.

A dilute solution containing manganate(VII) ions ($MnO_4^-$) and an excess of dilute sulfuric acid is added to the solution containing chloride ions.

As the manganate(VII) ion solution is added, it changes from purple to colourless.

(i) The formula of the manganese species that is formed during this reaction is

**(1)**

☒ **A** $Mn^{2+}(aq)$

☒ **B** $Mn^{3+}(aq)$

☒ **C** $Mn^{4+}(aq)$

☒ **D** $MnO_4^{2-}(aq)$

(ii) Using oxidation numbers, deduce the molar ratio of $MnO_4^-$ to $Cl^-$ that would appear in the balanced chemical equation for the reaction.

**(2)**

(d) Potassium bromide reacts with concentrated sulfuric acid. Three of the products of the reaction are hydrogen bromide, bromine and sulfur dioxide.

(i) Explain why the hydrogen bromide, which is a colourless gas, appears as misty fumes when it makes contact with moist air.

**(2)**

(ii) State the type of reaction that occurs in the formation of sulfur dioxide.

**(1)**

**(Total for Question 5 = 10 marks)**

**6** Sodium can form three oxides:

sodium oxide, $Na_2O$

sodium peroxide, $Na_2O_2$

sodium superoxide, $NaO_2$

It has been suggested that sodium superoxide could be used in spacecraft to regenerate oxygen.

Oxygen needs to be replaced in a spacecraft because an astronaut oxidises glucose, according to the equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Sodium superoxide can regenerate oxygen according to the equation:

$$4NaO_2 + 2CO_2 \rightarrow 2Na_2CO_3 + 3O_2$$

In order to maintain the correct percentage of oxygen in the air, any excess carbon dioxide could be removed by using sodium oxide.

$$Na_2O + CO_2 \rightarrow Na_2CO_3$$

(a) Calculate the mass of sodium oxide that would be required to remove the excess carbon dioxide when exactly 880 g of sodium superoxide is reacted per day.

You can assume that an astronaut oxidises 2 mol of glucose each day.

**(4)**

(b) Using a dot-and-cross diagram, explain why the superoxide ion, O—$O^-$, is a radical.

**(2)**

(c) A 0.403 g sample of sodium peroxide was reacted with water:

$$Na_2O_2 + 2H_2O \rightarrow 2NaOH + H_2O_2$$

The hydrogen peroxide produced was determined by titration with a solution containing cerium(IV) ions. In this reaction the hydrogen peroxide is converted into oxygen.

$$H_2O_2 \rightarrow 2H^+ + O_2 + 2e^-$$

The hydrogen peroxide solution reacted with exactly 24.85 $cm^3$ of a 0.420 mol $dm^{-3}$ solution of cerium(IV) ions, $Ce^{4+}$.

Deduce the formula of the cerium ion present in the final solution. Support your answer with a calculation.

**(4)**

**(Total for Question 6 = 10 marks)**

**7** The following reversible reaction is used in industry to make methanol, $CH_3OH$:

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H = -91 \text{ kJ mol}^{-1}$$

(a) Which change would affect both the value of the equilibrium constant, $K_c$, and the proportion of methanol present in an equilibrium mixture of the three gases?

**(1)**

- ☒ **A** adding a catalyst
- ☒ **B** changing the temperature
- ☒ **C** increasing the concentration of carbon monoxide
- ☒ **D** increasing the pressure

(b) The expression for the equilibrium constant, $K_c$, for this reaction is

$$K_c = \frac{[CH_3OH(g)]}{[CO(g)][H_2(g)]^2}$$

0.200 mol of CO(g) and 0.400 mol of $H_2(g)$ are mixed in a sealed container of volume 1.2 $dm^3$ at a temperature of 500 K and a pressure of 100 atmospheres and allowed to reach equilibrium.

The equilibrium mixture is found to contain 0.086 mol of $CH_3OH(g)$.

(i) Calculate $K_c$ for this reaction. Give your answer to an appropriate number of significant figures and state the units.

**(5)**

(ii) The equilibrium mixture of CO(g), $H_2$(g) and $CH_3OH$(g) is heated in the same sealed container to a temperature higher than 500 K. Since the gas volume remains the same, the increased temperature results in an increase in pressure.

Explain why it is difficult to predict the effect on the yield of $CH_3OH$.

**(3)**

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**(Total for Question 7 = 9 marks)**

**8** Acids can be classified as weak or strong acids.

(a) A mixture of concentrated sulfuric and nitric acids is used in the nitration of benzene.

The following equilibrium is set up:

$$H_2SO_4 + HNO_3 \rightleftharpoons H_2NO_3^+ + HSO_4^-$$

Which statement about this equilibrium is correct?

**(1)**

☒ **A** $HNO_3$ and $H_2NO_3^+$ are a conjugate acid-base pair

☒ **B** the nitric acid acts as an acid

☒ **C** the nitric acid acts as an oxidising agent

☒ **D** the sulfuric acid acts as a dehydrating agent

(b) Sulfuric acid ionises in two stages.

Stage 1: $H_2SO_4(aq) \rightarrow H^+(aq) + HSO_4^-(aq)$

Stage 2: $HSO_4^-(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$

(i) Explain, with reference to the equations, why the $HSO_4^-$ ion is classified as a weak acid.

**(2)**

(ii) A 0.100 mol $dm^{-3}$ solution of sulfuric acid has a pH of 0.97.

Calculate the concentration of hydrogen ions in this solution.

**(1)**

(c) Ethanoic acid, $CH_3COOH$, is a weak acid.

A student prepares 600 $cm^3$ of a buffer solution by mixing 400 $cm^3$ of 0.500 mol $dm^{-3}$ ethanoic acid solution with 200 $cm^3$ of 0.500 mol $dm^{-3}$ sodium ethanoate solution, $CH_3COONa$.

Calculate the pH of the buffer solution produced.

($K_a$ for ethanoic acid = $1.74 \times 10^{-5}$ mol $dm^{-3}$)

**(4)**

**(Total for Question 8 = 8 marks)**

**9** Prussian Blue, $[Fe_4[Fe(CN)_6]_3]$, is a dark blue pigment used in painting and dyeing.

It was discovered around 1700 AD in the German state of Prussia.

Prussian Blue is formed when an iron(III) salt is added to a solution containing the complex ion $[Fe(CN)_6]^{4-}$.

The cyanide ion has the formula $CN^-$.

(a) (i) The oxidation number of Fe in the $[Fe(CN)_6]^{4-}$ ion is

**(1)**

☒ **A** +2

☒ **B** +3

☒ **C** +4

☒ **D** +6

(ii) Draw a diagram to show the shape of a $[Fe(CN)_6]^{4-}$ ion, using the structure $CN^-$ to represent a cyanide ligand and showing how the cyanide ligands bond to the central iron ion.

**(2)**

(b) A solution containing $[Fe(CN)_6]^{3-}$ ions can be made from $[Fe(H_2O)_6]^{2+}$ ions in two steps as shown:

Step 1 $[Fe(H_2O)_6]^{2+}(aq) + 6CN^-(aq) \rightleftharpoons [Fe(CN)_6]^{4-}(aq) + 6H_2O(l)$

Step 2 $2[Fe(CN)_6]^{4-}(aq) + Cl_2(aq) \rightarrow 2[Fe(CN)_6]^{3-}(aq) + 2Cl^-(aq)$

Name the type of reaction taking place in each of Steps 1 and 2.

**(2)**

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(c) In a separate reaction, aqueous sodium hydroxide was added to a solution containing iron(II) sulfate. A green precipitate formed that turned brown on standing in air.

Identify the green precipitate and explain why it turns brown on standing in air.

**(3)**

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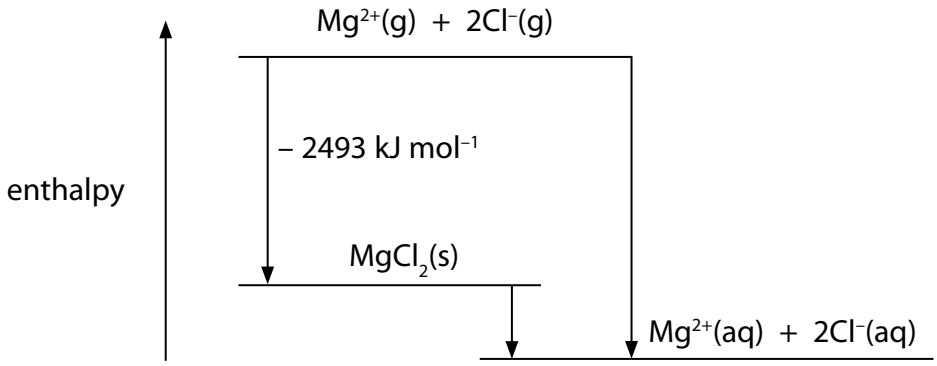
**(Total for Question 9 = 8 marks)**

**10** This question is about some Group 2 compounds.

(a) Explain the trend in the thermal stability of carbonates in Group 2.

**(3)**

(b) Magnesium chloride is soluble in water. The enthalpy level diagram for the dissolving of magnesium chloride is




The enthalpy changes of hydration of the ions are:

$Mg^{2+}$ $-1920\ kJ\ mol^{-1}$

$Cl^-$ $-364\ kJ\ mol^{-1}$

Calculate the enthalpy change of solution, $\Delta H_{solution}$, of $MgCl_2(s)$ in $kJ\ mol^{-1}$.

**(2)**

(c) The table shows some data relating to the dissolving of magnesium sulfate, $MgSO_4$, in water at 298 K.

| $\Delta H^{\ominus}_{solution}$ / kJ mol$^{-1}$ | $\Delta S^{\ominus}_{system}$ / J K$^{-1}$ mol$^{-1}$ |
|---|---|
| –87 | –210 |

(i) Explain why the dissolving of magnesium sulfate in water is exothermic by considering the enthalpy changes involved.

**(2)**

(ii) Use the data in the table to calculate $\Delta G^{\ominus}$ when magnesium sulfate dissolves in water at 298 K. State the significance of your answer.

**(2)**

*(d) The table shows some data relating to the dissolving of barium sulfate and calcium sulfate in water at 298 K.

| Salt | $\Delta H^{\ominus}_{solution}$ / kJ mol$^{-1}$ | $T\Delta S^{\ominus}_{system}$ / kJ mol$^{-1}$ |
|---|---|---|
| $BaSO_4$ | +19 | –31 |
| $CaSO_4$ | – 18 | –43 |

Comment on the relative solubility in water of barium sulfate and calcium sulfate at 298 K, using data from the table.

**(6)**

**(Total for Question 10 = 15 marks)**

**TOTAL FOR PAPER = 90 MARKS**

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# The Periodic Table of Elements

| 1 | 2 | | | | | | | | | | | 3 | 4 | 5 | 6 | 7 | 0 (8) (18) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 1.0 H hydrogen 1 | | | | | | | | | | 4.0 He helium 2 |
| (1) | (2) | | Key | | | | | | | | | (13) | (14) | (15) | (16) | (17) | |
| 6.9 Li lithium 3 | 9.0 Be beryllium 4 | | relative atomic mass<br>atomic symbol<br>name<br>atomic (proton) number | | | | | | | | | 10.8 B boron 5 | 12.0 C carbon 6 | 14.0 N nitrogen 7 | 16.0 O oxygen 8 | 19.0 F fluorine 9 | 20.2 Ne neon 10 |
| 23.0 Na sodium 11 | 24.3 Mg magnesium 12 | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | 27.0 Al aluminium 13 | 28.1 Si silicon 14 | 31.0 P phosphorus 15 | 32.1 S sulfur 16 | 35.5 Cl chlorine 17 | 39.9 Ar argon 18 |
| 39.1 K potassium 19 | 40.1 Ca calcium 20 | 45.0 Sc scandium 21 | 47.9 Ti titanium 22 | 50.9 V vanadium 23 | 52.0 Cr chromium 24 | 54.9 Mn manganese 25 | 55.8 Fe iron 26 | 58.9 Co cobalt 27 | 58.7 Ni nickel 28 | 63.5 Cu copper 29 | 65.4 Zn zinc 30 | 69.7 Ga gallium 31 | 72.6 Ge germanium 32 | 74.9 As arsenic 33 | 79.0 Se selenium 34 | 79.9 Br bromine 35 | 83.8 Kr krypton 36 |
| 85.5 Rb rubidium 37 | 87.6 Sr strontium 38 | 88.9 Y yttrium 39 | 91.2 Zr zirconium 40 | 92.9 Nb niobium 41 | 95.9 Mo molybdenum 42 | [98] Tc technetium 43 | 101.1 Ru ruthenium 44 | 102.9 Rh rhodium 45 | 106.4 Pd palladium 46 | 107.9 Ag silver 47 | 112.4 Cd cadmium 48 | 114.8 In indium 49 | 118.7 Sn tin 50 | 121.8 Sb antimony 51 | 127.6 Te tellurium 52 | 126.9 I iodine 53 | 131.3 Xe xenon 54 |
| 132.9 Cs caesium 55 | 137.3 Ba barium 56 | 138.9 La* lanthanum 57 | 178.5 Hf hafnium 72 | 180.9 Ta tantalum 73 | 183.8 W tungsten 74 | 186.2 Re rhenium 75 | 190.2 Os osmium 76 | 192.2 Ir iridium 77 | 195.1 Pt platinum 78 | 197.0 Au gold 79 | 200.6 Hg mercury 80 | 204.4 Tl thallium 81 | 207.2 Pb lead 82 | 209.0 Bi bismuth 83 | [209] Po polonium 84 | [210] At astatine 85 | [222] Rn radon 86 |
| [223] Fr francium 87 | [226] Ra radium 88 | [227] Ac* actinium 89 | [261] Rf rutherfordium 104 | [262] Db dubnium 105 | [266] Sg seaborgium 106 | [264] Bh bohrium 107 | [277] Hs hassium 108 | [268] Mt meitnerium 109 | [271] Ds darmstadtium 110 | [272] Rg roentgenium 111 | | | | | | | |

Elements with atomic numbers 112-116 have been reported but not fully authenticated

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * Lanthanide series | 140 Ce cerium 58 | 141 Pr praseodymium 59 | 144 Nd neodymium 60 | [147] Pm promethium 61 | 150 Sm samarium 62 | 152 Eu europium 63 | 157 Gd gadolinium 64 | 159 Tb terbium 65 | 163 Dy dysprosium 66 | 165 Ho holmium 67 | 167 Er erbium 68 | 169 Tm thulium 69 | 173 Yb ytterbium 70 | 175 Lu lutetium 71 |
| * Actinide series | 232 Th thorium 90 | [231] Pa protactinium 91 | 238 U uranium 92 | [237] Np neptunium 93 | [242] Pu plutonium 94 | [243] Am americium 95 | [247] Cm curium 96 | [245] Bk berkelium 97 | [251] Cf californium 98 | [254] Es einsteinium 99 | [253] Fm fermium 100 | [256] Md mendelevium 101 | [254] No nobelium 102 | [257] Lr lawrencium 103 |

## CHEMISTRY A LEVEL PAPER 1 MARK SCHEME

| Question number | Answer | Additional guidance | Marks |
|---|---|---|---|
| **1(a)** | B | | **1** |
| **1(b)** | B | | **1** |
| **1(c)** | C | | **1** |
| **1(d)(i)** | An explanation that makes reference to the following points:<br>• the shape is V-shaped/bent (1)<br>• because the three electron pairs on Sn repel one another (1) | First marking point can be awarded for a correctly-drawn diagram | **2** |
| **1(d)(ii)** | • prediction: any value between 95 and 119º (1)<br>• justification: lone pair – bond pair repulsion is greater than bond pair – bond pair repulsion (and hence the angle is less than 120º) (1) | | **2** |

**(Total for Question 1 = 7 marks)**

| Question number | Answer | Additional guidance | Marks |
|---|---|---|---|
| **2(a)** | D | | **1** |
| **2(b)** | B | | **1** |
| **2(c)** | D | | **1** |
| **2(d)** | • order: GZ > DX > EY (1)<br><br>Justification:<br>• the ions in GZ have higher charges (than those in both EY and DX) (1)<br><br>• the ions in DX are smaller than those in EY (1) | | **3** |
| **2(e)** | • construction of balanced cycle (1)<br><br>• substitution and evaluation of $2^{nd}$ IE (1) | Example calculation<br><br>$-2258 = -590 - 2^{nd}\text{ IE} + 2(349) - 178 - 2(122) - 796$<br><br>hence $2^{nd}$ IE = (+) 1148 ( kJ $mol^{-1}$)<br><br>correct answer, no working scores 2 marks | **2** |

**(Total for Question 2 = 8 marks)**

| Question number | Answer | Additional guidance | Marks |
|---|---|---|---|
| **3(a)** | • (V) $(1s^2 2s^2 2p^6 3s^2) 3p^6 3d^3 4s^2$ (1)<br>• $(V^{3+})$ $(1s^2 2s^2 2p^6 3s^2) 3p^6 3d^2$ (1) | Allow $4s^2 3d^3$ | **2** |
| **3(b)(i)** | An explanation that makes reference to the following points:<br>• $E^{\ominus}$ of redox system 5 is more negative / less positive than that of both redox systems 4 and 3 (but not than that of redox systems 2 and 1) (1)<br>• therefore $SO_2$ releases electrons to / reduces $VO_2^+$ to $VO^{2+}$ and then $VO^{2+}$ to $V^{3+}$ (1)<br>• (yellow to) blue <u>then</u> green (1) | Accept explanations based on calculating $E^{\ominus}_{cell}$ for the reactions<br>Accept correct use of anticlockwise rule<br>Ignore green colour before blue | **3** |
| **3(b)(ii)** | The reaction is **<u>not</u>** feasible because:<br>• $E^{\ominus}$ of redox system 2 is less negative than that of redox system 1 (1)<br>• therefore $V^{2+}$ ions in system 2 will not release electrons to the $V^{2+}$ ions in system 1 (1) | Accept explanations based on calculating $E^{\ominus}_{cell}$ for the reactions<br>Accept correct use of anticlockwise rule | **2** |

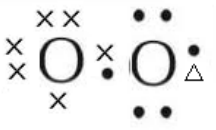
**(Total for Question 3 = 7 marks)**

| Question number | Answer | Additional Guidance | Marks |
|---|---|---|---|
| **4(a)** | • axes: correct way round, labelled, suitable scale (1)<br>• all points plotted correctly to nearest gridline AND straight line through first 3 points, straight line through last 3 points, and the two lines intersect (1) | The scale is suitable if the distance between the first point plotted and the last point plotted covers more than half of the graph paper on each axis. | **2** |
| **4(b)(i)** | 10 ($cm^3$) (1) | Award mark for a value read correctly from the candidate's graph | **1** |
| **4(b)(ii)** | (0.005 x 0.5) = 2.5(0) x $10^{-3}$ / 0.0025 (mol) (1) | | **1** |
| **4(b)(iii)** | (0.010 x 1.00) = 1 x $10^{-2}$ / 0.01 (mol) (1) | Answer to (iii) csq on (ii) | **1** |
| **4(b)(iv)** | x = 4 and y = 2 (1) | Answer to (iv) csq on (i) and (ii), but x + y must total 6 | **1** |
| **4(c)** | $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$<br>• correctly balanced equation (1)<br>• state symbols (1) | Allow<br>$[Cu(H_2O)_6]^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(H_2O)_4(OH)_2(s) + 2H_2O(l)$ | **2** |

**(Total for Question 4 = 8 marks)**

| Question number | Answer | Additional guidance | Marks |
|---|---|---|---|
| **5(a)** | $Cl_2 + 2NaOH \rightarrow NaOCl + NaCl + H_2O$ (1) | Accept $Cl_2 + 2OH^- \rightarrow OCl^- + Cl^- + H_2O$<br><br>Ignore state symbols | **1** |
| **5(b)** | An explanation that makes reference to the following points:<br><br>• Cl has oxidation number +4 to in $ClO_2$ (1)<br><br>• Cl (in $ClO_2$) changes oxidation number to +3 ($ClO_2^-$) and +5 ($ClO_3^-$) (1)<br><br>• (therefore) chlorine/it (in $ClO_2$) has been both oxidised and reduced (1) | <br><br>Accept 4+<br><br>Accept 3+ and 5+<br><br>Allow answers in any order | **3** |
| **5(c)(i)** | A | | **1** |
| **5(c)(ii)** | An answer that makes reference to the following points:<br><br>• Mn changes from +7 to +2 and Cl changes from -1 to 0 (1)<br><br>• therefore ratio is $MnO_4^-$ to $5Cl^-$ /the ratio of $MnO_4^-$ to $Cl^-$ is 1 to 5 (1) | <br><br>Accept 7+ and 2+<br><br>Accept 1– | **2** |
| **5(d)(i)** | An explanation that makes reference to the following points:<br><br>• the HBr dissolves in water (in the air) (1)<br><br>• and forms droplets (of hydrobromic acid) (1) | | **2** |
| **5(d)(ii)** | • the (conc.) $H_2SO_4$ is reduced to $SO_2$ (1) | Accept redox | **1** |

**(Total for Question 5 = 10 marks)**

| Question number | Answer | Additional guidance | Marks |
|---|---|---|---|
| **6(a)** | • determines number of mol of $CO_2$ produced (1)<br><br>• calculates number of mol $NaO_2$ in 880 g (1)<br><br>• calculates the number of mol of $CO_2$ reacted with $NaO_2$ and hence determines the number of mol of $CO_2$ in excess (1)<br><br>• calculation of mass of $Na_2O$ = 248 g (1) | <u>Example of calculation</u><br><br>2 mol glucose produces 12 mol $CO_2$<br>880 g $NaO_2$ = 16 mol<br>16 mol $NaO_2$ remove 8 mol $CO_2$ (therefore 4 mol $CO_2$ is excess)<br>mass of $Na_2O$ required is (4 x 62) = 248 g<br><br>3rd mark is csq on answers given in 1st and 2nd marks<br>4th mark is csq on answer given in 3rd mark<br><br>Correct answer with units and no working scores 4 marks. | **4** |
| **6(b)** | An explanation that makes reference to the following points:<br><br>  <br>(1)<br><br>• it is a radical because it has an unpaired electron (1) | Accept any other symbols in place of dots and crosses, including a minus sign to replace the triangle | **2** |

| Question number | Answer | Additional guidance | Marks |
|---|---|---|---|
| **6(c)** | • calculation of number of moles $Na_2O_2$ (= mols $H_2O_2$) (1)<br>• calculation of number of moles $Ce^{4+}$ (1)<br>• determination of the ratio $H_2O_2$ : $Ce^{4+}$ (1)<br>• formula of cerium ion is $Ce^{3+}$ (1) | Example of answer<br>$n(Na_2O_2) = (0.403 \div 78.0) = 5.17 \times 10^{-3}$<br>$n(Ce^{4+}) = (24.85 \div 1000 \times 0.420)$<br>$= 1.04 \times 10^{-2}$<br>$n(Ce^{4+}) : n(H_2O_2) = 1.04 \times 10^{-2} : 5.17 \times 10^{-3}$<br>$= 2 : 1$<br><br>1st and 2nd mark: accept answers to any significant figures, except 1s.f<br><br>3rd mark csq on answers given in 1st and 2nd marks<br>4th mark csq on answer given in 3rd mark | **4** |

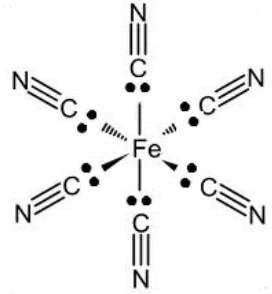
**(Total for Question 6 = 10 marks)**

| Question number | Answer | Additional guidance | Marks |
|---|---|---|---|
| **7(a)** | B | | **1** |
| **7(b)(i)** | • calculation of $n$(CO) at equilibrium and $n(H_2)$ at equilibrium (1)<br>• converting number of moles to concentration (1)<br>• evaluation of $K_c$ by substitution (1)<br>• correct answer to 3 sf (1)<br>• units: $dm^6\ mol^{-2}$ (1) | Example of calculation<br>$n$(CO) at equilibrium = 0.114 (mol)<br>$n(H_2)$ at equilibrium = 0.228 (mol)<br>$[CO] = 0.0950\ moldm^{-3}$, $[H_2] = 0.190\ moldm^{-3}$, $[CH_3OH] = 0.0717\ mol\ dm^{-3}$<br>$K_c = 0.0717 \div (0.0950 \times 0.190^2) = 20.9068\ldots..$<br>$= 20.9\ dm^6\ mol^{-2}$<br><br>Allow $mol^{-2}\ dm^6$<br><br>3rd and 4th marks csq on answers given in 1st and 2nd marks<br><br>Correct final answer to 3 sf with units but no working scores 5 marks | **5** |
| **7(b)(ii)** | An explanation that makes reference to the following points:<br>• an increase in temperature shifts the equilibrium to the left (1)<br>• an increase in pressure shifts the equilibrium to the right (1)<br>• these changes produce opposing effects, so to predict the effect on the yield it is necessary to know the relative effects of each one (1) | | **3** |

**(Total for Question 7 = 9 marks)**

| Question number | Answer | Additional guidance | Marks |
|---|---|---|---|
| **8(a)** | A | | **1** |
| **8(b)(i)** | An explanation that makes reference to the following points:<br><br>• stage 2 is an equilibrium reaction / only partial ionisation occurs (1)<br><br>• therefore fewer hydrogen ions are formed (1) | Accept dissociation for ionisation | **2** |
| **8(b)(ii)** | • rearrangement of equation pH = - log $[H^+]$ and substitution to give final answer (1) | Example calculation:<br>$[H^+] = 10^{-pH}$<br>$10^{-0.97} = 0.107$ (mol $dm^{-3}$)<br><br>Allow 0.11 (mol $dm^{-3}$)<br><br>Correct answer with no working scores 1 mark | **1** |
| **8(c)** | • rearrangement of $K_a$ expression (1)<br><br>• calculation of $[CH_3COOH]$ and $[CH_3COO^-]$ (1)<br><br>• substitution, and evaluation of $[H^+]$ in the buffer solution (1)<br><br>• conversion of $[H^+]$ to pH for buffer solution (1) | Example of calculation :<br>$[H^+] = K_a \frac{[CH_3COOH]}{[CH_3COO^-]}$<br><br>$[CH_3COOH] = 0.333$ mol $dm^{-3}$ and<br>$[CH_3COO^-] = 0.167$ mol $dm^{-3}$<br><br>$[H^+] = 1.74 \times 10^{-5} \times 0.333 / 0.167$<br>$= 3.48 \times 10^{-5}$ (mol $dm^{-3}$)<br>so pH = -lg $3.48 \times 10^{-5} = 4.46$<br><br>Accept answers that use forms of the Henderson-Hasselbach equation<br><br>Correct answer with no working scores 4 marks | **4** |

**(Total for Question 8 = 8 marks)**

| Question number | Answer | Additional guidance | Marks |
|---|---|---|---|
| **9(a)(i)** | A | | **1** |
| **9(a)(ii)** |  <br>• 3D shape correctly shown (1)<br>• electron pairs shown OR all six bonds shown clearly to the carbons (1) | Charge and square brackets not required<br><br>Allow dotted lines for the wedges going backwards<br><br>Allow arrows to represent dative covalent bonds instead of electron pairs | **2** |
| **9(b)** | • step 1 – ligand substitution/ligand exchange (1)<br>• step 2 – redox (1) | Allow reduction **and** oxidation | **2** |
| **9(c)** | • identification: green precipitate is iron(II) hydroxide (1)<br><br>Explanation:<br>• precipitate turns brown because iron(II) hydroxide is oxidised by oxygen (and water) in the air (1)<br>• to form iron(III) hydroxide (1) | Allow $Fe(OH)_2$ / $Fe(H_2O)_4(OH)_2$<br><br>Allow $Fe(OH)_3$ / $Fe(H_2O)_3(OH)_3$ | **3** |

**(Total for Question 9 = 8 marks)**

| Question number | Answer | Additional guidance | Marks |
|---|---|---|---|
| **10(a)** | An explanation that makes reference to the following points:<br>• they get more stable down the group (1)<br>• because the size of the cations increases/charge density of cations decreases (1)<br>• and so carbonate ions are less polarised (1) | | **3** |
| **10(b)** | • rearrangement of equation (1)<br>• calculation of $\Delta H_{solution}$ (1) | Example of calculation<br>$-2493 + \Delta H_{solution} = -1920 + (-2 \times 364)$<br>$\Delta H_{solution} = -155$ (kJ $mol^{-1}$)<br>Correct sign must be given in final answer<br>Correct answer and sign with no working scores 2 marks | **2** |
| **10(c)(i)** | An explanation that makes reference to the following points:<br>• breaking the lattice is endothermic and the hydration of ions is exothermic (1)<br>• (therefore the dissolving of magnesium sulphate is exothermic) because the enthalpy of hydration (of the ions) is greater in magnitude than the lattice energy (of $MgSO_4$) (1) | | **2** |
| **10(c)(ii)** | • $\Delta G^{\ominus} = -87 - (298 \times -0.210)$<br>$= -24(.42)$ (kJ $mol^{-1}$) (1)<br>• since $\Delta G$ is negative the process/reaction is spontaneous/feasible (1) | | **2** |

<table>
<tr><th>Question number</th><th>Answer</th><th>Additional guidance</th><th>Marks</th></tr>
<tr><td>*10(d)</td><td>This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.<br><br>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.<br><br>The following table shows how the marks should be awarded for indicative content.<br><br>
<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5–4</td><td>3</td></tr>
<tr><td>3–2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
</td><td>Guidance on how the mark scheme should be applied:<br>The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).<br>If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).</td><td>6</td></tr>
</table>

<table>
<tr><th>Question number</th><th>Answer</th><th>Additional guidance</th><th>Marks</th></tr>
<tr><td>*10(d) cont.</td><td>The following table shows how the marks should be
<table>
<tr><td></td><td>Number of marks awarded for structure of answer and sustained line of reasoning</td></tr>
<tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout.</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning.</td><td>1</td></tr>
<tr><td>Answer has no linkages between points and is unstructured.</td><td>0</td></tr>
</table>
awarded for structure and lines of reasoning.<br>Indicative content<br>($\Delta G^{\ominus}_{solution} = \Delta H^{\ominus}_{solution} - T\Delta S^{\ominus}_{system}$)<br>• for $BaSO_4$: $\Delta H^{\ominus}_{solution}$ and $-T\Delta S^{\ominus}_{system}$ are both positive (1)<br>• for $CaSO_4$: $\Delta H^{\ominus}_{solution}$ is negative and $-T\Delta S^{\ominus}_{system}$ is positive (1)<br>• but the magnitude of $-T\Delta S^{\ominus}_{system}$ is greater than that of $\Delta H^{\ominus}_{solution}$ (1)<br>• therefore $\Delta G^{\ominus}_{solution}$ for both salts is positive (1)<br>• when $\Delta G^{\ominus}_{solution}$ is positive the salt is only slightly soluble (1)<br>• $BaSO_4$ is less soluble than $CaSO_4$ because $\Delta G^{\ominus}_{solution}$ is more positive (1)</td><td></td><td></td></tr>
</table>

**(Total for Question 10 = 15 marks)**