

# TOPICAL PAST PAPERS

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## AS & A Level Chemistry (9701) Paper 4

[Structured questions]

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Exam Series: February/March 2018 – May/June 2025

Format Type B:

Each question is followed by its answer scheme



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# Introduction

Each Topical Past Paper Questions Workbook contains a comprehensive collection of hundreds of questions and corresponding answer schemes, presented in worksheet format. The questions are carefully arranged according to their respective chapters and topics, which align with the latest IGCSE or AS/A Level subject content. Here are the key features of these resources:

1. The workbook covers a wide range of topics, which are organized according to the latest syllabus content for Cambridge IGCSE or AS/A Level exams.
2. Each topic includes numerous questions, allowing students to practice and reinforce their understanding of key concepts and skills.
3. The questions are accompanied by detailed answer schemes, which provide clear explanations and guidance for students to improve their performance.
4. The workbook's format is user-friendly, with worksheets that are easy to read and navigate.
5. This workbook is an ideal resource for students who want to familiarize themselves with the types of questions that may appear in their exams and to develop their problem-solving and analytical skills.

Overall, Topical Past Paper Questions Workbooks are a valuable tool for students preparing for IGCSE or AS/A Level exams, providing them with the opportunity to practice and refine their knowledge and skills in a structured and comprehensive manner. To provide a clearer description of this book's specifications, here are some key details:

- Title: Cambridge AS & A Level Chemistry (9701) Paper 4 Topical Past Papers
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- Subject code: 9701
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# Chapter 1

## Chemical energetics

### 1.1 Lattice energy and Born-Haber cycles

1. 9701\_s22\_qp\_42 Q: 3

**(a) (i)** Define first electron affinity.

.....

.....

..... [2]

**(ii)** The first electron affinity of an atom is usually an exothermic process, whereas the second electron affinity is an endothermic process.

Suggest why.

.....

..... [1]

**(iii)** Describe the general trend in first electron affinities for Cl, Br and I. Explain your answer.

.....

.....

..... [2]

**(b)** Table 3.1 shows energy changes to be used in this question and in **(c)**.**Table 3.1**

| energy change                                                                           | value / kJ mol <sup>-1</sup> |
|-----------------------------------------------------------------------------------------|------------------------------|
| standard enthalpy change of atomisation of zinc                                         | +131                         |
| first ionisation energy of zinc                                                         | +906                         |
| second ionisation energy of zinc                                                        | +1733                        |
| standard enthalpy change of formation of ZnI <sub>2</sub> (s)                           | -208                         |
| lattice energy, $\Delta H_{\text{latt}}^{\circ}$ , of zinc iodide, ZnI <sub>2</sub> (s) | -2605                        |
| first ionisation energy of iodine                                                       | +1008                        |
| second ionisation energy of iodine                                                      | +1846                        |
| I–I bond energy                                                                         | +151                         |
| enthalpy change of sublimation of iodine, I <sub>2</sub> (s) → I <sub>2</sub> (g)       | +62                          |



Calculate the first electron affinity for iodine. Use relevant data from Table 3.1 in your working. It may be helpful to draw a labelled energy cycle. Show all working.

first electron affinity for iodine = .....  $\text{kJ mol}^{-1}$  [3]

- (c) Predict how  $\Delta H_{\text{latt}}^{\circ}$  of  $\text{CdI}_2(\text{s})$  differs from  $\Delta H_{\text{latt}}^{\circ}$  of  $\text{ZnI}_2(\text{s})$ . Place a tick (✓) in the appropriate box in Table 3.2.

Table 3.2

| $\Delta H_{\text{latt}}^{\circ}$ of $\text{CdI}_2(\text{s})$ is less negative than $\Delta H_{\text{latt}}^{\circ}$ of $\text{ZnI}_2(\text{s})$ | $\Delta H_{\text{latt}}^{\circ}$ of $\text{CdI}_2(\text{s})$ is the same as $\Delta H_{\text{latt}}^{\circ}$ of $\text{ZnI}_2(\text{s})$ | $\Delta H_{\text{latt}}^{\circ}$ of $\text{CdI}_2(\text{s})$ is more negative than $\Delta H_{\text{latt}}^{\circ}$ of $\text{ZnI}_2(\text{s})$ |
|-------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                 |                                                                                                                                          |                                                                                                                                                 |

Explain your answer.

.....  
 ..... [1]

[Total: 9]

Answer:

| Question | Answer                                                                                                                                                                                                       | Marks |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)(i)   | <ul style="list-style-type: none"> <li>enthalpy change / energy change</li> <li>one mole of electrons</li> <li>(gained by) <b>one mole of gaseous atoms</b></li> </ul> two for one mark, three for two marks | 2     |
| (a)(ii)  | (energy required to overcome) the repulsion between the electron and anion / negative ion                                                                                                                    | 1     |

| Question | Answer                                                                                                                                                                                                                                                                                                                                                                                                                         | Marks |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)(iii) | <ul style="list-style-type: none"> <li>less negative / less exothermic down the group</li> <li>greater the distance between the nucleus and (the shells of the) electrons<br/> <b>OR</b> atomic radii increases<br/> <b>OR</b> more shielding by inner shells</li> <li>the less <b>attraction</b> between nucleus and incoming electron (and the less energy released)</li> </ul> <p>two for one mark, three for two marks</p> | 2     |
| (b)      | <p><b>M1</b> use of correct seven numbers only in calculation / energy cycle<br/> <b>M2</b> only 2 × used correctly<br/> <b>M3</b> correct signs and evaluation ecf</p> <p> <math>-208 = 131 + 906 + 1733 + 62 + 151 + 2x - 2605</math><br/> <math>2x = -586</math><br/> <math>x = -293 \text{ kJ mol}^{-1}</math> </p>                                                                                                        | 3     |
| (c)      | <p>first box ticked<br/> <b>AND</b> <math>\text{Cd}^{2+}</math> larger / <math>\text{Cd}^{2+}</math> lower charge density<br/> <b>AND</b> less attraction between the ions / weaker ionic bonds</p>                                                                                                                                                                                                                            | 1     |

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2. 9701\_w21\_qp\_41 Q: 3

**(a)** Define the term *electron affinity*.

.....  
 ..... [2]

**(b)** Write an equation for the process corresponding to the **second** ionisation energy of calcium. Include state symbols.

..... [1]

Some data relating to calcium and oxygen are listed. Select relevant data from this list for your answers to parts **(c)**, **(d)** and **(e)**.

| process                                                                                                 | value / kJ mol <sup>-1</sup> |
|---------------------------------------------------------------------------------------------------------|------------------------------|
| first ionisation energy of oxygen                                                                       | +1310                        |
| second ionisation energy of oxygen                                                                      | +3390                        |
| first electron affinity of oxygen                                                                       | -142                         |
| second electron affinity of oxygen                                                                      | +844                         |
| enthalpy change for $\frac{1}{2}\text{O}_2(\text{g}) + 2\text{e}^- \rightarrow \text{O}^{2-}(\text{g})$ | +951                         |
| enthalpy change for $\text{Ca}(\text{s}) \rightarrow \text{Ca}^{2+}(\text{g}) + 2\text{e}^-$            | +1933                        |
| lattice energy of CaO(s)                                                                                | -3517                        |

**(c)** Oxygen exists as O<sub>2</sub> molecules.

Use the data in this question to calculate a value for the bond energy of the O=O bond.  
 Show all your working.

bond energy = ..... kJ mol<sup>-1</sup> [3]

(d) (i) Suggest why the first electron affinity of oxygen is negative.

.....  
 ..... [1]

(ii) Suggest why the second electron affinity of oxygen is positive.

.....  
 ..... [1]

(e) Calculate the enthalpy of formation of calcium oxide, CaO(s).

enthalpy of formation = ..... kJ mol<sup>-1</sup> [2]

(f) The lattice energy of lithium fluoride, LiF(s), is -1022 kJ mol<sup>-1</sup>.

Identify the factor that causes the lattice energy of calcium oxide to be more exothermic than that of lithium fluoride. Explain why this factor causes the difference in lattice energies.

.....  
 ..... [2]

[Total: 12]

Answer:

| Question | Answer                                                                                                                                                                | Marks |
|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)      | <ul style="list-style-type: none"> <li>enthalpy/energy change</li> <li>one mole of electrons gained</li> <li>by one mole of atoms</li> <li>gaseous (atoms)</li> </ul> | 2     |
| (b)      | Ca <sup>+</sup> (g) → Ca <sup>2+</sup> (g) + e <sup>-</sup> [1]                                                                                                       | 1     |

| Question | Answer                                                                                                                                                                                                                                                                                                                                                                                                                         | Marks |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (c)      | <p>M1: selecting correct data 951, 844, 142 only</p> <p>M2: evaluation to give 249 (<math>\Delta H_{\text{atom}}</math>)<br/> <b>OR</b> <math>2(951) = BE - 2(142) + 2(844)</math></p> <p>M3: evaluation to 498 (<math>2 \times 249</math>) ecf M2</p> <p><math>951 = \Delta H_{\text{atom}} - 142 + 844</math><br/> <math>\Delta H_{\text{atom}} = 249</math><br/> <math>BE = 498 \text{ (kJ mol}^{-1}\text{)}</math> [3]</p> | 3     |
| (d)(i)   | <p><b>attraction</b> between nucleus / protons / nuclear charge<br/> <b>and electron</b> [1]</p>                                                                                                                                                                                                                                                                                                                               | 1     |
| (d)(ii)  | <p><b>repulsion</b> between 1- ion / electrons of <math>O^-</math><br/> <b>and electron</b> [1]</p>                                                                                                                                                                                                                                                                                                                            | 1     |
| (e)      | <p>M1: selecting correct data 951, 1933, 3517 only (ignore signs)</p> <p>M2: evaluation to give -633 (<math>\Delta H_f</math>) ecf</p> <p><math>\Delta H_f = 951 + 1933 - 3517 = -633 \text{ (kJ mol}^{-1}\text{)}</math> [2]</p>                                                                                                                                                                                              | 2     |
| (f)      | <p>ionic charge / charge density (of the ions) [1]</p> <p>greater (attractive) force between the ions [1]</p>                                                                                                                                                                                                                                                                                                                  | 2     |

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3. 9701\_w21\_qp\_42 Q: 1

Radium is a Group 2 element.

The predicted lattice energy,  $\Delta H_{\text{latt}}^{\ominus}$ , of radium sulfide, RaS, is  $-2612 \text{ kJ mol}^{-1}$ .

(a) Define  $\Delta H_{\text{latt}}^{\ominus}$ .

.....  
 ..... [2]

Some data relating to radium and sulfur are listed. Select relevant data from this list for use in your answers to parts (b) to (e).

| process                                                                                                   | value / $\text{kJ mol}^{-1}$ |
|-----------------------------------------------------------------------------------------------------------|------------------------------|
| enthalpy change for $\text{Ra(s)} \rightarrow \text{Ra}^{2+}(\text{g}) + 2\text{e}^{-}$                   | +1619                        |
| first ionisation energy of sulfur                                                                         | +1000                        |
| second ionisation energy of sulfur                                                                        | +2260                        |
| first electron affinity of sulfur                                                                         | -200                         |
| second electron affinity of sulfur                                                                        | +532                         |
| enthalpy change for $\frac{1}{8}\text{S}_8(\text{s}) + 2\text{e}^{-} \rightarrow \text{S}^{2-}(\text{g})$ | +555                         |
| lattice energy of RaS(s)                                                                                  | -2612                        |

(b) Write an equation for the process corresponding to the **second** electron affinity of sulfur. Include state symbols.

..... [1]

(c) Sulfur exists as  $\text{S}_8$  molecules in the solid state.

Use the data in this question to calculate the enthalpy change for the reaction  $\text{S}_8(\text{s}) \rightarrow 8\text{S}(\text{g})$ .

enthalpy change = .....  $\text{kJ mol}^{-1}$  [3]

(d) Calculate the standard enthalpy change of formation,  $\Delta H_f^\ominus$ , of radium sulfide.

standard enthalpy change,  $\Delta H_f^\ominus = \dots\dots\dots$  kJ mol<sup>-1</sup> [2]

(e) (i) State the **two** major factors that affect the numerical magnitude of a lattice energy.

.....  
..... [2]

(ii) For **each** factor you have identified in (e)(i), state whether it tends to make the lattice energy of radium sulfide more or less exothermic than that of sodium chloride.

Explain your answer.

.....  
.....  
.....  
..... [2]

(iii) The lattice energies of sodium chloride, NaCl, and radium sulfide, RaS, are  $-771$  kJ mol<sup>-1</sup> and  $-2612$  kJ mol<sup>-1</sup>, respectively.

Identify the **dominant** factor in determining the relative numerical magnitudes of the lattice energies of radium sulfide and sodium chloride.

Explain your answer.

.....  
..... [1]

[Total: 13]

Answer:

| Question | Answer                                                                                                                                                                                                                                                          | Marks |
|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)      | <ul style="list-style-type: none"> <li>enthalpy / energy change / given out / evolved / released</li> <li>one mole is formed / made [1]</li> <li>of compound / solid / lattice / crystal</li> <li>(from) <b>gaseous ions</b> [1]</li> </ul>                     | 2     |
| (b)b     | $S^-(g) + e^- \rightarrow S^{2-}(g)$ [1]                                                                                                                                                                                                                        | 1     |
| (c)c     | $(555 + 200 - 532 = 223, 223 \times 8 = 1784)$<br>M1 selecting correct data 555, 200, 532 <b>only</b> , (ignore signs and multipliers) [1]<br>M2 evaluation to give +223 [1]<br>M3 multiplying M2 by 8 and evaluation ans (+) 1784 [1]                          | 3     |
| (d)      | $(1619 + 555 - 2612 = -438)$<br>M1 selecting correct data 1619 555 2612 <b>only</b> , (ignore signs and multipliers) [1]<br>M2 evaluation to give -438 [1]                                                                                                      | 2     |
| (e)(i)   | ionic radius / size / sum of ionic radii [1]<br>ionic charge / product of ionic charges [1]                                                                                                                                                                     | 2     |
| (e)(ii)  | M1 (size tends to make $\Delta H^\circ_{\text{latt}}$ of radium sulfide) less exothermic since the ions are larger [1]<br>M2 (charge tends to make $\Delta H^\circ_{\text{latt}}$ of radium sulfide) less exothermic since the ions are more highly charged [1] | 2     |
| (e)(iii) | (ionic) charge (since)<br><b>AND</b><br>$\Delta H^\circ_{\text{latt}}$ of radium sulfide is more exothermic [1]                                                                                                                                                 | 1     |

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4. 9701\_s20\_qp\_42 Q: 7

**(a) (i)** Define the term *electron affinity*.

.....

.....

..... [2]

**(ii)** Define the term *lattice energy*.

.....

.....

..... [2]

**(b)** Use the following data and relevant data from the *Data Booklet* to calculate a value for the enthalpy change of formation of zinc bromide,  $\text{ZnBr}_2(\text{s})$ .

You might find it helpful to construct an energy cycle.

|                                                            |                               |
|------------------------------------------------------------|-------------------------------|
| electron affinity of $\text{Br}(\text{g})$                 | $= -325 \text{ kJ mol}^{-1}$  |
| enthalpy change of atomisation of $\text{Zn}(\text{s})$    | $= +131 \text{ kJ mol}^{-1}$  |
| enthalpy change of vaporisation of $\text{Br}_2(\text{l})$ | $= +31 \text{ kJ mol}^{-1}$   |
| lattice energy of $\text{ZnBr}_2(\text{s})$                | $= -2678 \text{ kJ mol}^{-1}$ |

enthalpy change of formation of  $\text{ZnBr}_2(\text{s}) = \dots\dots\dots \text{ kJ mol}^{-1}$  [4]

(c) The lattice energies of  $\text{ZnBr}_2$ ,  $\text{ZnCl}_2$  and  $\text{ZnO}$  are shown.

| compound        | lattice energy / $\text{kJ mol}^{-1}$ |
|-----------------|---------------------------------------|
| $\text{ZnBr}_2$ | -2678                                 |
| $\text{ZnCl}_2$ | -2734                                 |
| $\text{ZnO}$    | -3971                                 |

(i) Explain why there is a difference between the lattice energies of  $\text{ZnBr}_2$  and  $\text{ZnCl}_2$ .

.....  
 ..... [1]

(ii) Explain why there is a difference between the lattice energies of  $\text{ZnCl}_2$  and  $\text{ZnO}$ .

.....  
 ..... [1]

[Total: 10]

Answer:

| Question | Answer                                                                                                                                                                                                                                                                                                                                                                                                          | Marks |
|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)(i)   | <ul style="list-style-type: none"> <li>energy change</li> <li>when one electron is added</li> <li>to each atom /ion in one mole of</li> <li>gaseous atoms /ions</li> </ul> <p>Award one mark for two correct statements. Award two marks for four correct statements</p>                                                                                                                                        | 2     |
| (a)(ii)  | <p><b>M1</b> energy change when 1 mole of an ionic compound is formed</p> <p><b>M2</b> from gas phase ions/ gaseous ions</p>                                                                                                                                                                                                                                                                                    | 2     |
| Question | Answer                                                                                                                                                                                                                                                                                                                                                                                                          | Marks |
| (b)      | <p><b>M1</b> use of data (with no multipliers) 31, 131, -2678</p> <p><b>M2</b> extraction of data 908, 1730, 193</p> <p><b>M3</b> use of <math>(2 \times -325)</math></p> <p><b>M4</b> evaluation of <u>their</u> expression correctly, as shown</p> <p><math>\Delta H_f(\text{ZnBr}_2) = 131 + (908 + 1730) + 193 + 31 + (2 \times -325) + (-2678)</math><br/> <math>= -335 \text{ kJ mol}^{-1}</math> [4]</p> | 4     |
| (c)(i)   | $\text{Br}^-$ is a largest ion/larger ion than $\text{Cl}^-$ so attraction between $\text{Br}^-$ and $\text{Zn}^{2+}$ is smaller                                                                                                                                                                                                                                                                                | 1     |
| (c)(ii)  | <p><math>\text{O}^{2-}</math> is a smallest ion/smaller ion than <math>\text{Cl}^-</math></p> <p><b>AND</b> <math>\text{O}^{2-}</math> has the highest charge/ higher charge than <math>\text{Cl}^-</math></p> <p>(so attraction between <math>\text{O}^{2-}</math> and <math>\text{Zn}^{2+}</math> is larger)</p>                                                                                              | 1     |

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5. 9701\_s18\_qp\_41 Q: 1

Sodium oxide,  $\text{Na}_2\text{O}$ , is a white crystalline solid with a high melting point.

- (a) Write an equation for the reaction of sodium with oxygen, forming sodium oxide. Include state symbols.

..... [2]

- (b) Explain why sodium oxide has a high melting point.

.....  
.....  
.....  
..... [2]

- (c) When sodium oxide reacts with water an alkaline solution is obtained.

- (i) Explain why the solution obtained is alkaline. You should use the Brønsted-Lowry theory of acids and bases in your answer.

.....  
.....  
.....  
..... [2]

- (ii) Calculate the pH of the solution obtained when 3.10 g of sodium oxide are added to 400  $\text{cm}^3$  of water.

pH = ..... [3]

- (d) Use the data below, and other suitable data from the *Data Booklet*, to calculate the lattice energy of sodium oxide,  $\Delta H_{\text{latt}}^{\ominus} \text{Na}_2\text{O}(\text{s})$ .

| energy change                                                                                               | value / $\text{kJ mol}^{-1}$ |
|-------------------------------------------------------------------------------------------------------------|------------------------------|
| standard enthalpy change of formation of sodium oxide, $\Delta H_f^{\ominus} \text{Na}_2\text{O}(\text{s})$ | –416                         |
| standard enthalpy change of atomisation of sodium, $\Delta H_{\text{at}}^{\ominus} \text{Na}(\text{s})$     | +109                         |
| electron affinity of $\text{O}(\text{g})$                                                                   | –142                         |
| electron affinity of $\text{O}^-(\text{g})$                                                                 | +844                         |

$$\Delta H_{\text{latt}}^{\ominus} \text{Na}_2\text{O}(\text{s}) = \dots\dots\dots \text{kJ mol}^{-1} \quad [4]$$

- (e) State how  $\Delta H_{\text{latt}}^{\ominus} \text{Na}_2\text{S}(\text{s})$  differs from  $\Delta H_{\text{latt}}^{\ominus} \text{Na}_2\text{O}(\text{s})$ .  
Indicate this by placing a tick (✓) in the appropriate box in the table.

| $\Delta H_{\text{latt}}^{\ominus} \text{Na}_2\text{S}(\text{s})$ is more exothermic than $\Delta H_{\text{latt}}^{\ominus} \text{Na}_2\text{O}(\text{s})$ | $\Delta H_{\text{latt}}^{\ominus} \text{Na}_2\text{S}(\text{s})$ is the same as $\Delta H_{\text{latt}}^{\ominus} \text{Na}_2\text{O}(\text{s})$ | $\Delta H_{\text{latt}}^{\ominus} \text{Na}_2\text{S}(\text{s})$ is less exothermic than $\Delta H_{\text{latt}}^{\ominus} \text{Na}_2\text{O}(\text{s})$ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                           |                                                                                                                                                  |                                                                                                                                                           |

Explain your answer.

.....

.....

.....

[2]

[Total: 15]

Answer:

| Question | Answer                                                                                                                                                                                                  | Marks |
|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)      | $4\text{Na(s)} + \text{O}_2\text{(g)} \rightarrow 2\text{Na}_2\text{O(s)}$                                                                                                                              |       |
|          | balanced with all formulae correct                                                                                                                                                                      | 1     |
|          | state symbols                                                                                                                                                                                           | 1     |
| (b)      | giant ionic                                                                                                                                                                                             | 1     |
|          | strong bond / attraction between<br><b>AND</b><br>positive and negative ions / anions and cations / $\text{Na}^+$ and $\text{O}^{2-}$ / oppositely charged ions                                         | 1     |
| (c)(i)   | the reaction produces sodium hydroxide / hydroxide ions / $\text{OH}^-$ ions                                                                                                                            | 1     |
|          | the hydroxide ions can receive / accept $\text{H}^+$ ions / protons                                                                                                                                     | 1     |
| (c)(ii)  | Calculation of $\text{Na}_2\text{O}$ moles $3.10 \text{ g} / 62$ <b>OR</b> $0.05$                                                                                                                       | 1     |
|          | Calculation of $[\text{OH}^-]$ $0.05 \times (2 / 0.400) = 0.25 \text{ mol dm}^{-3}$                                                                                                                     | 1     |
|          | Calculation of pH $-\log 0.25 = 0.60$<br>$14 - 0.60 = 13.40$                                                                                                                                            | 1     |
| (d)      | use of $(2 \times 109)$ or 218 and $(2 \times 494)$ or 988                                                                                                                                              | 1     |
|          | use of $(0.5 \times 496)$ or 248                                                                                                                                                                        | 1     |
|          | use of 416, 142, 844                                                                                                                                                                                    | 1     |
|          | evaluation of expression correctly<br>$\Delta H_{\text{lat}} = -416 - (2 \times 109) - (0.5 \times 496) - (2 \times 494) - (-142 + 844) = -2572$                                                        | 1     |
| (e)      | the lattice energy of $\text{Na}_2\text{S}$ is less exothermic                                                                                                                                          | 1     |
|          | the sulfide ion is larger than the oxide ion / $\text{S}^{2-}$ larger than $\text{O}^{2-}$ / ionic radii quoted 0.184 nm and 0.140 nm<br><b>AND</b> less attraction (between the ions)/bonds are weaker | 1     |

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## 1.2 Enthalpies of solution and hydration

6. 9701\_s25\_qp\_44 Q: 8

**(a) (i)** Define lattice energy,  $\Delta H_{\text{latt}}$ .

.....  
 ..... [2]

**(ii)** Define enthalpy change of solution,  $\Delta H_{\text{sol}}$ .

.....  
 ..... [1]

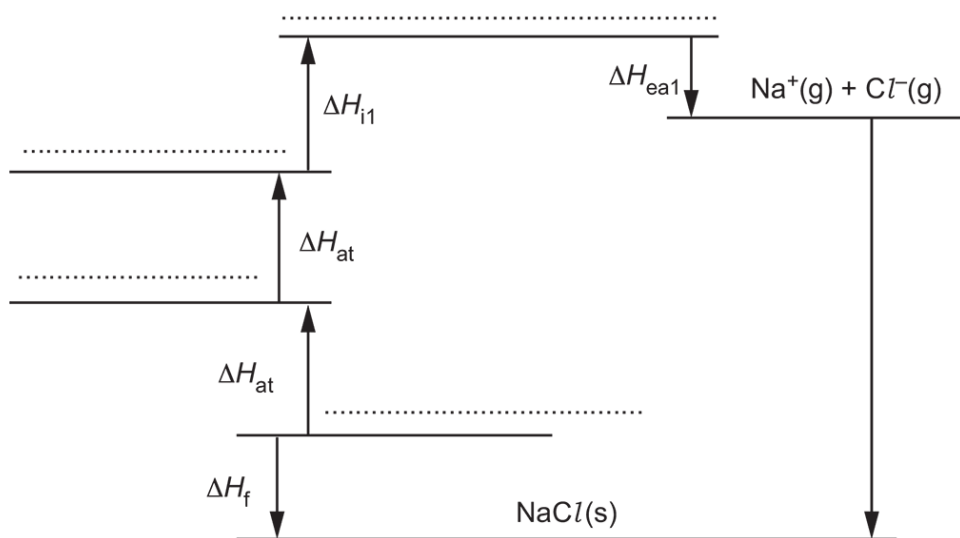
**(b)** The enthalpy change of hydration can be represented by  $\Delta H_{\text{hyd}}$ .

Write the mathematical expression for the  $\Delta H_{\text{sol}}$  of NaCl in terms of  $\Delta H_{\text{latt}}(\text{NaCl})$ ,  $\Delta H_{\text{hyd}}(\text{Na}^+)$  and  $\Delta H_{\text{hyd}}(\text{Cl}^-)$ .

$\Delta H_{\text{sol}}(\text{NaCl}) = \dots\dots\dots$  [1]

**(c)** Complete the Born–Haber cycle in Fig. 8.1 for the ionic solid NaCl.

Include state symbols of relevant species.

**Key**

$\Delta H_{i1}$  first ionisation energy

$\Delta H_{\text{ea1}}$  first electron affinity

**Fig. 8.1**

[3]

(d) Predict which of the ions,  $\text{Cl}^-$  or  $\text{NO}_3^-$ , has the more negative enthalpy change of hydration.

Explain your answer.

.....

.....

.....

.....

..... [2]

[Total: 9]

### Important values, constants and standards

|                                 |                                                                                                                                           |
|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| molar gas constant              | $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$                                                                                              |
| Faraday constant                | $F = 9.65 \times 10^4 \text{ C mol}^{-1}$                                                                                                 |
| Avogadro constant               | $L = 6.02 \times 10^{23} \text{ mol}^{-1}$                                                                                                |
| electronic charge               | $e = -1.60 \times 10^{-19} \text{ C}$                                                                                                     |
| molar volume of gas             | $V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K)<br>$V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions |
| ionic product of water          | $K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))                                                             |
| specific heat capacity of water | $c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ ( $4.18 \text{ J g}^{-1} \text{ K}^{-1}$ )                                                   |

Answer:

| Question | Answer                                                                                                                                                                                     | Marks |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)(i)   | <b>M1:</b> energy change / released when 1 mole of a (ionic) solid / lattice / crystal / compound is formed<br><b>M2:</b> from gas (phase) ions / gaseous ions (under standard conditions) | 2     |
| (a)(ii)  | (enthalpy change when) 1 mole of a substance / solid / solute / molecule <b>AND</b> dissolves in water (to give a solution of infinite dilution)                                           | 1     |
| (b)      | $\Delta H_{\text{sol}}(\text{NaCl}) = \Delta H_{\text{hyd}}(\text{Na}^+) + \Delta H_{\text{hyd}}(\text{Cl}^-) - \Delta H_{\text{latt}}(\text{NaCl})$                                       | 1     |

| Question | Answer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Marks |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (c)      | <p> <math>\text{Na}^+(\text{g}) + \text{Cl}^-(\text{g}) + \text{e}^-</math><br/> <math>\text{Na}(\text{g}) + \text{Cl}(\text{g})</math><br/> <math>\text{Na}(\text{g}) + 0.5\text{Cl}_2(\text{g})</math><br/> <math>\text{Na}(\text{s}) + 0.5\text{Cl}_2(\text{g})</math><br/> <math>\text{NaCl}(\text{s})</math> </p> <p> <math>\Delta H_{\text{at}}</math>, <math>\Delta H_{\text{at}}</math>, <math>\Delta H_{\text{ion}}</math>, <math>\Delta H_{\text{lattice}}</math>, <math>\Delta H_{\text{f}}</math> </p> <p> <b>M1 / M2:</b> any two [1] all four [2]<br/> <b>M3:</b> all state symbols for the formula are present and correct         </p> | 3     |
| (d)      | <p> <b>M1:</b> (more exothermic because) <math>\text{Cl}^-</math> OR <math>\text{NO}_3^-</math> because its (ionic) radius / size is smaller<br/> <b>M2:</b> (more exothermic because) (ion-dipole) attraction / bond between it and water is stronger<br/> <b>OR</b><br/> <b>M1:</b> <math>\text{NO}_3^-</math> because it has lone pairs on O / more lone pairs<br/> <b>M2:</b> which can form hydrogen bonds with water         </p>                                                                                                                                                                                                                | 2     |

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7. 9701 s24 qp 42 Q: 1

(a) Describe the trend in the solubility of the sulfates of magnesium, calcium and strontium.

Explain your answer.

most soluble > > least soluble

(b) Define lattice energy,  $\Delta H_{\text{latt}}$ .

..... [2]

**(c)** State and explain the main factors that affect the magnitude of lattice energies.

..... [2]

**(d)** Table 1.1 shows some energy changes.

### Table 1.1

| energy change                                                                              | value/ $\text{kJ mol}^{-1}$ |
|--------------------------------------------------------------------------------------------|-----------------------------|
| standard enthalpy change of atomisation of potassium                                       | +89                         |
| first ionisation energy of potassium                                                       | +419                        |
| second ionisation energy of potassium                                                      | +3070                       |
| standard enthalpy change of atomisation of sulfur                                          | +279                        |
| S–S bond energy                                                                            | +265                        |
| first ionisation energy of sulfur                                                          | +1000                       |
| second ionisation energy of sulfur                                                         | +2260                       |
| first electron affinity of sulfur                                                          | –200                        |
| second electron affinity of sulfur                                                         | +640                        |
| standard enthalpy change of formation of potassium sulfide, $\text{K}_2\text{S}(\text{s})$ | –381                        |

- (i) Born–Haber cycles can be used to determine the lattice energies of ionic compounds.

Complete the Born–Haber cycle in Fig. 1.1 for potassium sulfide,  $K_2S(s)$ .

Include state symbols for all of the species.

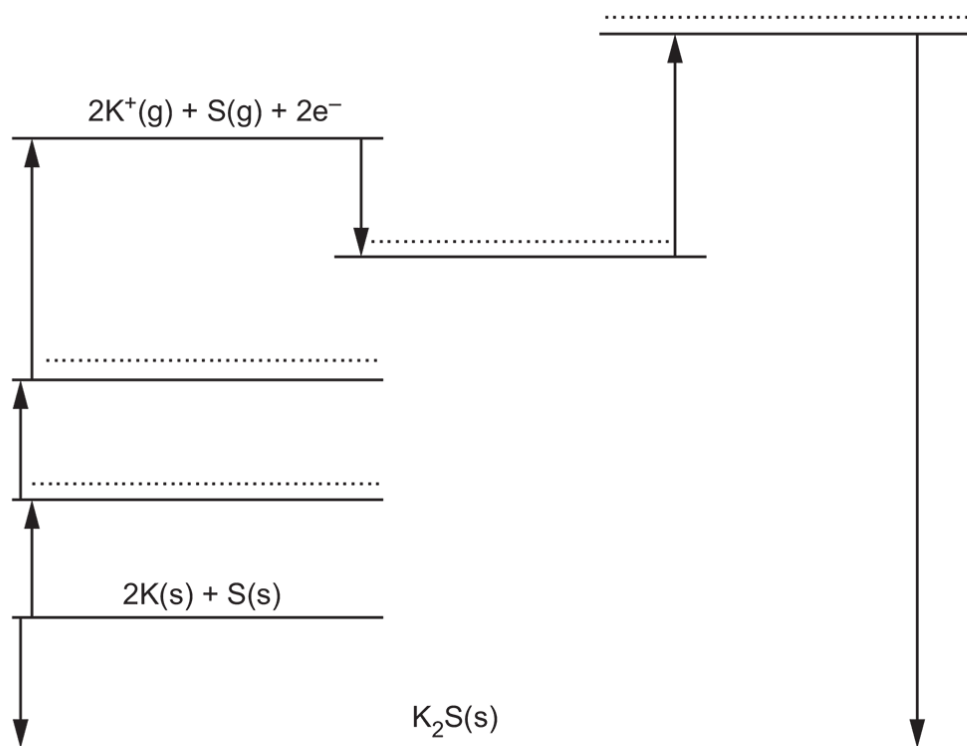


Fig. 1.1

[3]

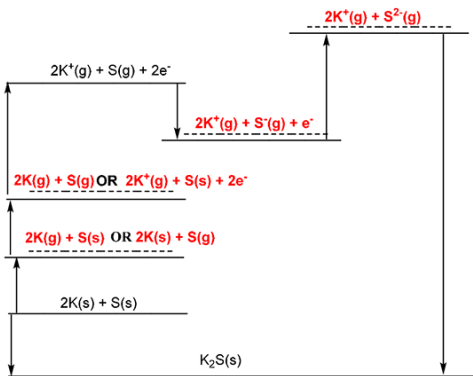
- (ii) Calculate the lattice energy,  $\Delta H_{\text{latt}}^{\ominus}$ , of  $K_2S(s)$  using relevant data from Table 1.1.

Show your working.

$$\Delta H_{\text{latt}}^{\ominus} \text{ of } K_2S(s) = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

[Total: 13]

Answer:

| Question | Answer                                                                                                                                                                                                                                                                                                                                                                   | Marks |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)      | <b>M1</b> magnesium > calcium > strontium<br><b>M2</b> $\Delta H_{\text{latt}}$ and $\Delta H_{\text{hyd}}$ both become less exothermic / less negative<br><b>M3</b> $\Delta H_{\text{latt}}$ changes less OR $\Delta H_{\text{hyd}}$ is dominant factor<br><b>M4</b> $\Delta H_{\text{sol}}$ becomes less exothermic / less negative / more positive / more endothermic | 4     |
| (b)      | <b>M1</b> $\Delta H$ / energy change when 1 mole of an ionic solid / compound is formed<br><b>M2</b> from gaseous ions (under standard conditions)                                                                                                                                                                                                                       | 2     |
| (c)      | <b>M1</b> as ionic radii increases AND $\Delta H_{\text{latt}}$ less exothermic<br><b>M2</b> as ionic charge increases AND $\Delta H_{\text{latt}}$ increases/more exothermic                                                                                                                                                                                            | 2     |
| (d)(i)   |  <p>any two [1] any three [2] all four [3]</p>                                                                                                                                                                                                                                          | 3     |
| Question | Answer                                                                                                                                                                                                                                                                                                                                                                   | Marks |
| (d)(ii)  | <b>M1</b> selection of <b>ONLY</b> six correct values (–381, 89, 419, 279, –200, 640) AND use of $\times 2$ as only multiplier with K<br><b>M2</b> correct evaluation of data used ecf<br>$-381 = (89 \times 2) + (419 \times 2) + 279 + (-200) + 640 + \Delta H^{\circ}_{\text{latt}}$<br>$\Delta H^{\circ}_{\text{latt}} = -2116 \text{ (kJ mol}^{-1}\text{)}$         | 2     |

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8. 9701\_s23\_qp\_41 Q: 8

- (a) Complete Table 8.1 by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

Table 8.1

| energy change                | always positive | always negative | can be either negative or positive |
|------------------------------|-----------------|-----------------|------------------------------------|
| lattice energy               |                 |                 |                                    |
| enthalpy change of hydration |                 |                 |                                    |
| enthalpy change of solution  |                 |                 |                                    |

[1]

- (b) Define enthalpy change of hydration.

.....

.....

..... [1]

- (c) Table 8.2 shows various energy changes which can be used in the following questions.

Table 8.2

| energy change                                                                   | value / kJ mol <sup>-1</sup> |
|---------------------------------------------------------------------------------|------------------------------|
| standard enthalpy change of atomisation of calcium                              | +178.2                       |
| first ionisation energy of calcium                                              | +590                         |
| second ionisation energy of calcium                                             | +1145                        |
| standard enthalpy change of atomisation of bromine                              | +111.9                       |
| Br–Br bond energy                                                               | +192.9                       |
| standard enthalpy change of solution of calcium bromide, CaBr <sub>2</sub> (s)  | –103.1                       |
| standard enthalpy change of formation of calcium bromide, CaBr <sub>2</sub> (s) | –682.8                       |
| standard enthalpy change of hydration of Ca <sup>2+</sup>                       | –1579                        |
| first electron affinity of bromine                                              | –324.6                       |
| first ionisation energy of bromine                                              | +1140                        |

- (i) Select and use relevant data from Table 8.2 to calculate the lattice energy,  $\Delta H_{\text{latt}}^{\ominus}$ , of  $\text{CaBr}_2(\text{s})$ .

It may be helpful to draw a labelled energy cycle.

Show your working.

$$\Delta H_{\text{latt}}^{\ominus} \text{ of } \text{CaBr}_2(\text{s}) = \dots\dots\dots \text{ kJ mol}^{-1} \quad [3]$$

- (ii) Select and use relevant data from Table 8.2 and your answer to (c)(i) to calculate the standard enthalpy change of hydration,  $\Delta H_{\text{hyd}}^{\ominus}$ , of  $\text{Br}^-$ .

It may be helpful to draw a labelled energy cycle.

If you were not able to answer (c)(i), use  $-2500 \text{ kJ mol}^{-1}$  as your value for  $\Delta H_{\text{latt}}^{\ominus}$  of  $\text{CaBr}_2(\text{s})$ . This is **not** the correct value.

Show your working.

$$\Delta H_{\text{hyd}}^{\ominus} \text{ of } \text{Br}^- = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

- (iii) The enthalpy change of hydration of the  $\text{Br}^-$  ion is more negative than the enthalpy change of hydration of the  $\text{I}^-$  ion. Explain why.

.....  
.....  
..... [2]

[Total: 9]

Answer:

| Question                 | Answer                                                                                                                                                                                                                                                                                                                              |                 |                 |                             | Marks         |                 |                 |                             |                |  |   |  |                       |  |   |  |                      |  |  |   |   |
|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-----------------|-----------------------------|---------------|-----------------|-----------------|-----------------------------|----------------|--|---|--|-----------------------|--|---|--|----------------------|--|--|---|---|
| (a)                      | <table><tr><td>energy change</td><td>always positive</td><td>always negative</td><td>either negative or positive</td></tr><tr><td>lattice energy</td><td></td><td>✓</td><td></td></tr><tr><td>enthalpy of hydration</td><td></td><td>✓</td><td></td></tr><tr><td>enthalpy of solution</td><td></td><td></td><td>✓</td></tr></table> |                 |                 |                             | energy change | always positive | always negative | either negative or positive | lattice energy |  | ✓ |  | enthalpy of hydration |  | ✓ |  | enthalpy of solution |  |  | ✓ | 1 |
|                          | energy change                                                                                                                                                                                                                                                                                                                       | always positive | always negative | either negative or positive |               |                 |                 |                             |                |  |   |  |                       |  |   |  |                      |  |  |   |   |
|                          | lattice energy                                                                                                                                                                                                                                                                                                                      |                 | ✓               |                             |               |                 |                 |                             |                |  |   |  |                       |  |   |  |                      |  |  |   |   |
|                          | enthalpy of hydration                                                                                                                                                                                                                                                                                                               |                 | ✓               |                             |               |                 |                 |                             |                |  |   |  |                       |  |   |  |                      |  |  |   |   |
|                          | enthalpy of solution                                                                                                                                                                                                                                                                                                                |                 |                 | ✓                           |               |                 |                 |                             |                |  |   |  |                       |  |   |  |                      |  |  |   |   |
| All correct for one mark |                                                                                                                                                                                                                                                                                                                                     |                 |                 |                             |               |                 |                 |                             |                |  |   |  |                       |  |   |  |                      |  |  |   |   |
| (b)                      | The energy / enthalpy change when 1 mole of gaseous ions is dissolved in water                                                                                                                                                                                                                                                      |                 |                 |                             | 1             |                 |                 |                             |                |  |   |  |                       |  |   |  |                      |  |  |   |   |
| (c)(i)                   | <b>M1</b> use of correct six numbers only<br>682.8 178.2 590 1145 111.9 324.6<br><b>M2</b> 2× used correctly with Br (2 × 111.9 and 2 × 324.6)<br><b>M3</b> correct signs and evaluation to give −2170.6 kJ mol <sup>−1</sup>                                                                                                       |                 |                 |                             | 3             |                 |                 |                             |                |  |   |  |                       |  |   |  |                      |  |  |   |   |
| Question                 | Answer                                                                                                                                                                                                                                                                                                                              |                 |                 |                             | Marks         |                 |                 |                             |                |  |   |  |                       |  |   |  |                      |  |  |   |   |
| (c)(ii)                  | <b>M1</b> use of correct three numbers only 2170.6 103.1 and 1579<br><b>M2</b> correct signs & evaluation −347 kJ mol <sup>−1</sup>                                                                                                                                                                                                 |                 |                 |                             | 2             |                 |                 |                             |                |  |   |  |                       |  |   |  |                      |  |  |   |   |
| (c)(iii)                 | <b>M1</b> Br <sup>−</sup> has a smaller ionic radius<br><b>M2</b> Br <sup>−</sup> has stronger attractive forces with water molecules                                                                                                                                                                                               |                 |                 |                             | 2             |                 |                 |                             |                |  |   |  |                       |  |   |  |                      |  |  |   |   |

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9. 9701\_s19\_qp\_41 Q: 6

- (a) Complete the table by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

| energy change                | always positive | always negative | either negative or positive |
|------------------------------|-----------------|-----------------|-----------------------------|
| bond energy                  |                 |                 |                             |
| enthalpy change of formation |                 |                 |                             |

[1]

- (b) Explain what is meant by the term *enthalpy change of atomisation*.

.....  
 ..... [1]

- (c) The overall reaction for the atomisation of liquid bromine molecules, Br<sub>2</sub>(l), is shown.



This happens via a two-step process.

- Construct a **labelled** energy cycle to represent this atomisation process, including state symbols.
- Use your cycle and relevant data from the *Data Booklet* to calculate the enthalpy change of vaporisation of Br<sub>2</sub>(l),  $\Delta H_{\text{vap}}^\ominus$ .  
 The enthalpy change of atomisation of bromine,  $\Delta H_{\text{at}}^\ominus = +112 \text{ kJ mol}^{-1}$ .

$$\Delta H_{\text{vap}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1} \quad [3]$$

- (d) Suggest how the  $\Delta H_{\text{vap}}^\ominus$  of iodine, I<sub>2</sub>(l), would compare to that of bromine, Br<sub>2</sub>(l). Explain your answer.

.....  
 ..... [1]

(e) (i) Explain what is meant by the term *enthalpy change of hydration*.

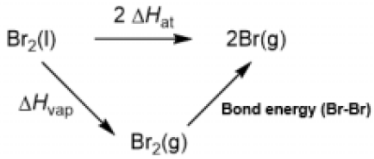
.....  
 ..... [1]

(ii) Suggest why the enthalpy change of hydration of  $\text{Br}^-(\text{g})$  is **more** exothermic than that of  $\text{I}^-(\text{g})$ .

.....  
 .....  
 ..... [2]

[Total: 9]

Answer:

| Question              | Answer                                                                                                                                                                                                                                                                                                                                                                                                                  | Marks           |                             |                 |                             |             |   |  |  |                       |  |  |   |   |
|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-----------------------------|-----------------|-----------------------------|-------------|---|--|--|-----------------------|--|--|---|---|
| (a)                   | <table><tr><td>energy change</td><td>always positive</td><td>always negative</td><td>either negative or positive</td></tr><tr><td>bond energy</td><td>✓</td><td></td><td></td></tr><tr><td>enthalpy of formation</td><td></td><td></td><td>✓</td></tr></table> <p>both ticks correct</p>                                                                                                                                | energy change   | always positive             | always negative | either negative or positive | bond energy | ✓ |  |  | enthalpy of formation |  |  | ✓ | 1 |
| energy change         | always positive                                                                                                                                                                                                                                                                                                                                                                                                         | always negative | either negative or positive |                 |                             |             |   |  |  |                       |  |  |   |   |
| bond energy           | ✓                                                                                                                                                                                                                                                                                                                                                                                                                       |                 |                             |                 |                             |             |   |  |  |                       |  |  |   |   |
| enthalpy of formation |                                                                                                                                                                                                                                                                                                                                                                                                                         |                 | ✓                           |                 |                             |             |   |  |  |                       |  |  |   |   |
| (b)                   | (energy change) when <b>1 mole</b> of <b>gaseous atoms</b> are formed (from an element in its standard state)                                                                                                                                                                                                                                                                                                           | 1               |                             |                 |                             |             |   |  |  |                       |  |  |   |   |
| (c)                   |  <p><b>M1:</b> correct cycle: formulae and state symbols</p> <p><b>M2:</b> use of <math>1 \times 193</math> and <math>2 \times (112)</math></p> <p><b>M3:</b> for the correct sum and answer ecf from M2</p> <p><math>\Delta H_{\text{vap}}^{\circ} = (2 \times 112) - (193) = +31 \text{ kJ mol}^{-1}</math> [scores M2 and M3]</p> | 3               |                             |                 |                             |             |   |  |  |                       |  |  |   |   |
| (d)                   | more endothermic <b>and</b> greater Van der Waals / London / induced dipole-dipole forces <b>both</b>                                                                                                                                                                                                                                                                                                                   | 1               |                             |                 |                             |             |   |  |  |                       |  |  |   |   |
| (e)(i)                | (energy change) when <b>1 mole</b> of <b>gaseous ions</b> is dissolved in (an excess of) water                                                                                                                                                                                                                                                                                                                          | 1               |                             |                 |                             |             |   |  |  |                       |  |  |   |   |
| (e)(ii)               | <p><b>M1:</b> Br has a smaller ionic radii</p> <p><b>M2:</b> stronger (ion-dipole) attractions with water molecules</p>                                                                                                                                                                                                                                                                                                 | 2               |                             |                 |                             |             |   |  |  |                       |  |  |   |   |

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### 1.3 Entropy change, $\Delta S$



10. 9701\_s25\_qp\_41 Q: 4

Table 4.1 gives the enthalpy changes of hydration,  $\Delta H_{\text{hyd}}$ , of three ions,  $\text{F}^-$ ,  $\text{K}^+$  and  $\text{Ca}^{2+}$ .

**Table 4.1**

| ion              | $\Delta H_{\text{hyd}}/\text{kJ mol}^{-1}$ |
|------------------|--------------------------------------------|
| $\text{F}^-$     | -506                                       |
| $\text{K}^+$     | -322                                       |
| $\text{Ca}^{2+}$ | -1650                                      |

(a) (i) Define enthalpy change of hydration.

.....  
 .....  
 ..... [1]

(ii) Explain the relative magnitudes of the enthalpy changes of hydration of  $\text{K}^+$  and  $\text{Ca}^{2+}$ .

.....  
 .....  
 .....  
 ..... [2]

(iii) Define lattice energy.

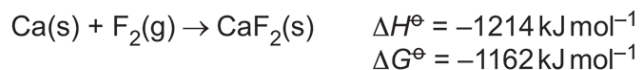
.....  
 ..... [1]

(iv) The lattice energy,  $\Delta H_{\text{latt}}$ , of calcium fluoride,  $\text{CaF}_2$ , is  $-2602 \text{ kJ mol}^{-1}$ .

Calculate the enthalpy change of solution,  $\Delta H_{\text{sol}}$ , in  $\text{kJ mol}^{-1}$ , of  $\text{CaF}_2$ .

$\Delta H_{\text{sol}}$  of  $\text{CaF}_2 = \dots\dots\dots \text{kJ mol}^{-1}$  [2]

(b) The formation of  $\text{CaF}_2$  at 298 K is shown.



Calculate the entropy change,  $\Delta S^\ominus$ , in  $\text{J K}^{-1} \text{ mol}^{-1}$ , for this reaction.

$$\Delta S^\ominus = \dots\dots\dots \text{J K}^{-1} \text{ mol}^{-1} \quad [2]$$

[Total: 8]

Answer:

| Question | Answer                                                                                                                                                             | Marks |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)(i)   | energy change when one mole of gaseous ions dissolves in water                                                                                                     | 1     |
| (a)(ii)  | <b>M1:</b> $\text{K}^+$ has larger radius <b>AND</b> $\text{K}^+$ has smaller charge<br><b>M2:</b> $\text{Ca}^{2+}$ has larger attraction for $\text{H}_2\text{O}$ | 2     |
| (a)(iii) | energy change when one mole of <b>ionic</b> solid forms from gaseous ions                                                                                          | 1     |
| (a)(iv)  | <b>M1:</b> $-1650 - (2 \times 506) + 2602$<br><b>M2:</b> $-60$                                                                                                     | 2     |
| (b)      | <b>M1:</b> $\Delta G = \Delta H - T\Delta S$ <b>AND</b> $T = 298$<br><b>M2:</b> $-174.5$ [1]                                                                       | 2     |

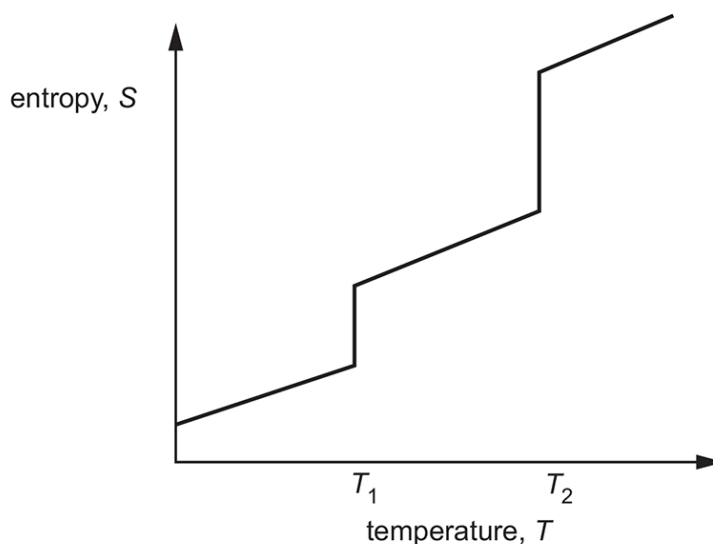
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11. 9701\_s25\_qp\_42 Q: 3

**(a)** Define entropy.

.....

..... [1]

**(b)** Fig. 3.1 shows how the entropy,  $S$ , of a pure substance changes with temperature,  $T$ .**Fig. 3.1****(i)** Identify the process occurring at each of the temperatures  $T_1$  and  $T_2$ .

$T_1$  .....  $T_2$  ..... [1]

**(ii)** Explain why the entropy change,  $\Delta S$ , at  $T_2$  is bigger than the entropy change at  $T_1$ .

.....

.....

..... [1]

- (c) The equation for the reduction of iron(III) oxide by carbon monoxide at 450 °C is shown.



Table 3.1 shows the enthalpy of formation,  $\Delta H_f^\ominus$ , and the entropy,  $S^\ominus$ , for some substances.

**Table 3.1**

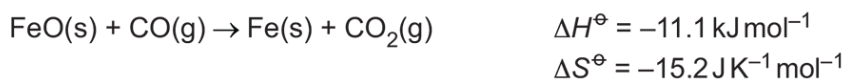
|                                              | $\text{Fe}_2\text{O}_3(\text{s})$ | $\text{CO}(\text{g})$ | $\text{Fe}(\text{s})$ | $\text{CO}_2(\text{g})$ |
|----------------------------------------------|-----------------------------------|-----------------------|-----------------------|-------------------------|
| $\Delta H_f^\ominus / \text{kJ mol}^{-1}$    | -824.2                            | -110.5                | 0.0                   | -393.5                  |
| $S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$ | 87.4                              | to be calculated      | 27.3                  | 213.8                   |

Use the data in Table 3.1 to calculate the entropy,  $S^\ominus$ , of carbon monoxide at 450 °C.

Show your working.

$$S^\ominus \text{ of CO(g)} = \dots\dots\dots \text{ JK}^{-1} \text{mol}^{-1} \quad [3]$$

- (d) Iron(II) oxide can also be reduced to iron by carbon monoxide, as shown.



State the effect of increasing temperature on the feasibility of this reaction.

Explain your answer.

.....

.....

.....

..... [2]

[Total: 8]

Answer:

| Question | Answer                                                                                                                                                                                                                                                                                                                                                                                                                           | Marks |
|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)(i)   | number of possible arrangements of particles/molecules <b>AND</b> energy in a system                                                                                                                                                                                                                                                                                                                                             | 1     |
| (b)(i)   | $T_1$ melting <b>OR</b> solid to liquid<br>$T_2$ boiling <b>OR</b> liquid to gas                                                                                                                                                                                                                                                                                                                                                 | 1     |
| (b)(ii)  | change in disorder from a liquid to a gas is much bigger than solid to liquid<br><b>OR</b><br>change in intermolecular distance between liquid & gas is much bigger than solid to liquid                                                                                                                                                                                                                                         | 1     |
| (c)      | <b>M1:</b> $\Delta H_r = (3 \times -393.5) - ((-824.2) + (3 \times -110.5)) = -24.8 \text{ (kJ mol}^{-1}\text{)}$<br><b>M2:</b> $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ <b>AND</b> $T = 723$ used<br><b>M3:</b> $(24800 - 36200) \div 723 = - [3 \times 213.8 + 2 \times 27.3] - (87.4) - (3x)$<br>$-15.8 = -608.6 + 3x$ , so $3x = 592.8$ , so $x = 197.6 / 198 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$ min 3sf | 3     |
| (d)      | <ul style="list-style-type: none"> <li>(as temperature increases) the reaction is less feasible</li> <li>as <math>\Delta G^\circ</math> becomes less negative / (more) positive</li> <li>due to <math>T\Delta S</math> becoming more negative / <math>-T\Delta S</math> (becoming more) positive</li> </ul> <b>M1 / M2:</b> any two of the above bullets [1] all three [2]                                                       | 2     |

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1.4 Gibbs free energy change,  $\Delta G$

12. 9701\_s24\_qp\_42 Q: 3

(a) Carbon disulfide,  $\text{CS}_2$ , is flammable and reacts readily with oxygen, as shown in reaction 1.

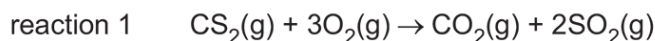


Table 3.1 shows the standard enthalpy of formation,  $\Delta H_f^\ominus$ , and the standard entropy,  $S^\ominus$ , for some substances.

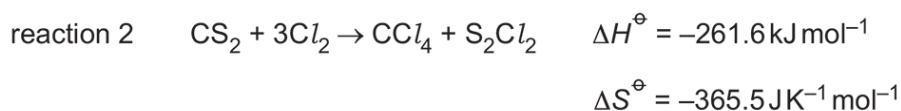
**Table 3.1**

|                                              | $\text{CS}_2(\text{g})$ | $\text{O}_2(\text{g})$ | $\text{CO}_2(\text{g})$ | $\text{SO}_2(\text{g})$ |
|----------------------------------------------|-------------------------|------------------------|-------------------------|-------------------------|
| $\Delta H_f^\ominus / \text{kJ mol}^{-1}$    | 116.7                   | 0.0                    | -393.5                  | -296.8                  |
| $S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$ | 237.8                   | 205.2                  | 213.8                   | 248.2                   |

Calculate the standard Gibbs free energy change,  $\Delta G^\ominus$ , in  $\text{kJ mol}^{-1}$ , for reaction 1 at  $25^\circ\text{C}$ .

$$\Delta G^\ominus = \dots\dots\dots \text{kJ mol}^{-1} \quad [3]$$

(b) Carbon disulfide reacts with chlorine to form tetrachloromethane, as shown in reaction 2.



Calculate the maximum temperature, in K, for reaction 2 to be feasible.

$$\text{temperature} = \dots\dots\dots \text{K} \quad [2]$$

[Total: 5]

Answer:

| Question | Answer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Marks |
|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)      | <b>M1</b> $\Delta S^\circ = (213.8 + 2 \times 248.2) - (237.8 + 3 \times 205.2)$<br>$\Delta S^\circ = -143.2 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$<br><br><b>M2</b> $\Delta H^\circ = (-393.5 + 2 \times -296.8) - (116.7)$<br>$\Delta H^\circ = -1103.8 \text{ (kJ mol}^{-1}\text{)}$<br><br><b>M3</b> $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$<br>$\Delta G^\circ = -1103.8 - (298 \times -0.1432) = -1061.1 \text{ to } -1061.4 \text{ (kJ mol}^{-1}\text{) ecf min 3sf}$ | 3     |
| (b)      | <b>M1</b> $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ <b>AND</b> $\Delta G^\circ = 0$<br><b>OR</b> $T = \Delta H^\circ / \Delta S^\circ$ [1]<br><br><b>M2</b> $T = 261.6 \div 0.3655 = 715.7 / 716 / 715 \text{ K min 3sf}$                                                                                                                                                                                                                                                           | 2     |

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13. 9701\_w24\_qp\_41 Q: 2

- (a) Predict and explain the variation in enthalpy change of hydration for the ions  $F^-$ ,  $Cl^-$ ,  $Br^-$  and  $I^-$ .

.....  
 .....  
 ..... [2]

- (b) Fig. 2.1 shows an incomplete energy cycle involving calcium fluoride,  $CaF_2$ .

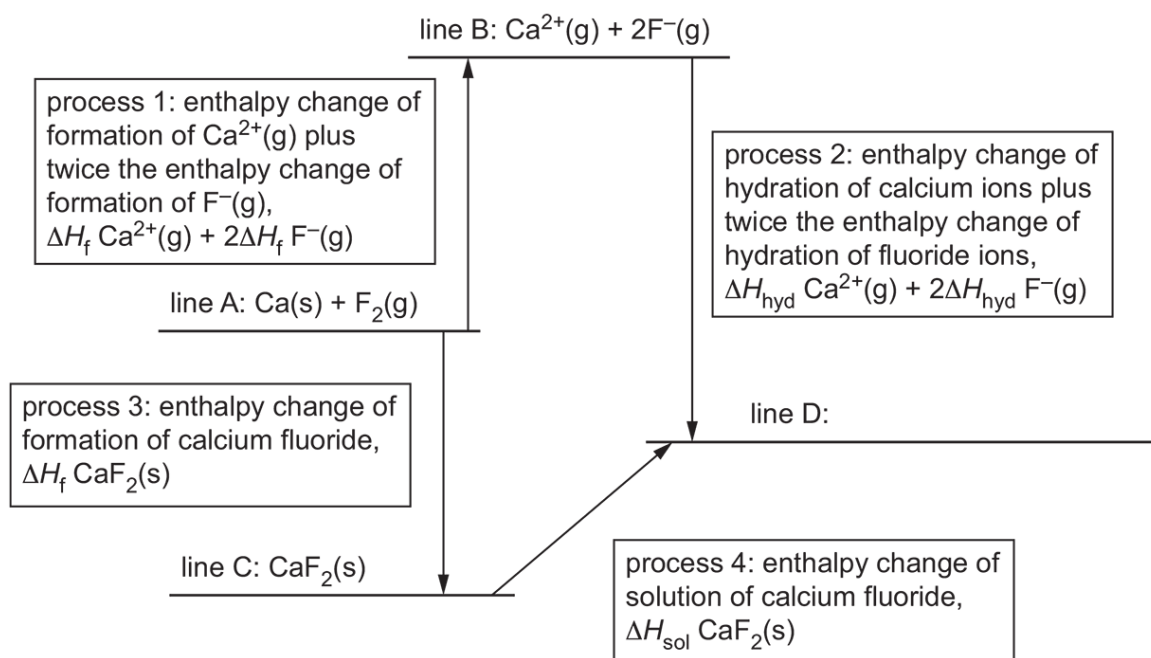
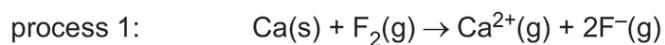


Fig. 2.1

- (i) Complete line D. Include state symbols. [1]
- (ii) The value of the enthalpy change for process 1 can be calculated using the values of **five** other enthalpy changes which are **not** referred to in Fig. 2.1.



Identify these **five** other enthalpy changes, using either names or symbols.

.....  
 .....  
 .....  
 .....  
 ..... [2]



(iii) Define lattice energy,  $\Delta H_{\text{latt}}$ .

.....  
 .....  
 ..... [2]

(iv) Complete the expression to give the mathematical relationship between  $\Delta H_{\text{latt}}$  of calcium fluoride and the enthalpy changes for processes 1 and 3.

$$\Delta H_{\text{latt}} =$$

[1]

(c) Use data from Table 2.1 to calculate a value for the hydration energy,  $\Delta H_{\text{hyd}}$ , of fluoride ions,  $\text{F}^-(\text{g})$ .

**Table 2.1**

|                                                                           | value/ $\text{kJ mol}^{-1}$ |
|---------------------------------------------------------------------------|-----------------------------|
| enthalpy change of solution of calcium fluoride, $\text{CaF}_2(\text{s})$ | +13                         |
| overall enthalpy change of process 1 in Fig. 2.1                          | +1395                       |
| enthalpy change of formation of calcium fluoride                          | -1214                       |
| enthalpy change of hydration of $\text{Ca}^{2+}(\text{g})$                | -1650                       |

$$\Delta H_{\text{hyd}} \text{F}^-(\text{g}) = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

(d) Define entropy.

.....  
 ..... [1]

- (e) At 298 K, the Gibbs free energy change,  $\Delta G$ , for the solution of compound **T** is  $+6.00 \text{ kJ mol}^{-1}$ .

The enthalpy change of solution,  $\Delta H_{\text{sol}}$ , of compound **T** is  $+30.0 \text{ kJ mol}^{-1}$  at 298 K.

Calculate the value of the entropy change,  $\Delta S$ , for the solution of compound **T** at 298 K.

$$\Delta S = \dots\dots\dots \text{ J K}^{-1} \text{ mol}^{-1} \quad [2]$$

- (f) Predict whether compound **T** becomes more or less soluble as the water is heated from 298 K to 360 K. Explain your answer.

.....  
 ..... [1]

[Total: 14]

Answer:

| Question | Answer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Marks           |
|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|
| (a)      | becomes less negative/less exothermic (down the group / from F to I)<br><b>AND</b> due to increase in (ionic) radius / size<br><br>decreased attraction to <b>water</b><br><b>OR</b> weaker ion-dipole force to water                                                                                                                                                                                                                                                                                                                                                                                                                                                | 2<br>[1]<br>[1] |
| (b)(i)   | $\text{CaF}_2(\text{aq})$ <b>OR</b> $\text{Ca}^{2+}(\text{aq}) + 2\text{F}^{-}(\text{aq})$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 1<br>[1]        |
| (b)(ii)  | <ul style="list-style-type: none"> <li>atomisation energy of <b>Ca</b> / <math>\Delta H_{\text{at}(\text{o})\text{m}})</math></li> <li>atomisation energy of <b>F</b><sub>(2)</sub> / <math>\Delta H_{\text{at}(\text{o})\text{m}})</math></li> <li><b>OR</b> F-F bond energy / BE of F-F</li> <li>first ionisation energy / IE<sub>1</sub> of <b>Ca</b> / <math>\Delta H_{\text{I1}}</math></li> <li>second ionisation energy / IE<sub>2</sub> of <b>Ca</b> / <math>\Delta H_{\text{I2}}</math></li> <li>(first) electron affinity / EA of <b>F</b> / <math>\Delta H_{\text{ea}}</math></li> </ul> <p style="text-align: right;">any three for [1] ALL five [2]</p> | 2               |

| Question | Answer                                                                                                                                                                                                           | Marks |
|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (b)(iii) | energy change / energy released<br>when one mole of an ionic compound is formed [1]<br>from its gaseous ion(s) [1]                                                                                               | 2     |
| (b)(iv)  | $(\Delta H_{\text{latt}} = )$ (change) 3 – (change) 1<br>OR<br>$(\Delta H_{\text{latt}} = ) \Delta H_f(\text{CaF}_2(\text{s})) - \Delta H_f(\text{Ca}^{2+}(\text{g})) - 2\Delta H_f(\text{F}^{-}(\text{g}))$ [1] | 1     |
| (c)      | expression involves four correct numbers (13, 1395, 1214, 1650)<br>AND 2 times [1]<br><br>$1395 - 1650 + 2x = -1214 + 13$<br>$\Delta H_f(\text{F}^{-}(\text{g})) \times = -473$ [1] ecf<br>correct answer [2]    | 2     |
| (d)      | number of possible arrangements of particles / energy in a system [1]                                                                                                                                            | 1     |
| (e)      | states or clearly uses $\Delta G = \Delta H - T\Delta S$<br>OR $6000 = 30\,000 - (298 \times \Delta S)$ [1]<br><br>$\Delta S = (+)80.5(4)$ [1] min 3sf ecf<br>correct answer [2]                                 | 2     |
| (f)      | becomes more soluble<br>AND $\Delta S$ is positive / $T\Delta S$ is positive / $-T\Delta S$ is negative (as T inc)<br>(so $\Delta G$ becomes more negative) [1]                                                  | 1     |

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14. 9701\_w24\_qp\_42 Q: 2

- (a) Predict and explain the variation in enthalpy change of hydration for the ions  $\text{Na}^+$ ,  $\text{Mg}^{2+}$  and  $\text{Al}^{3+}$ .

.....

.....

.....

.....

..... [3]

- (b) Fig. 2.1 shows an incomplete energy cycle.

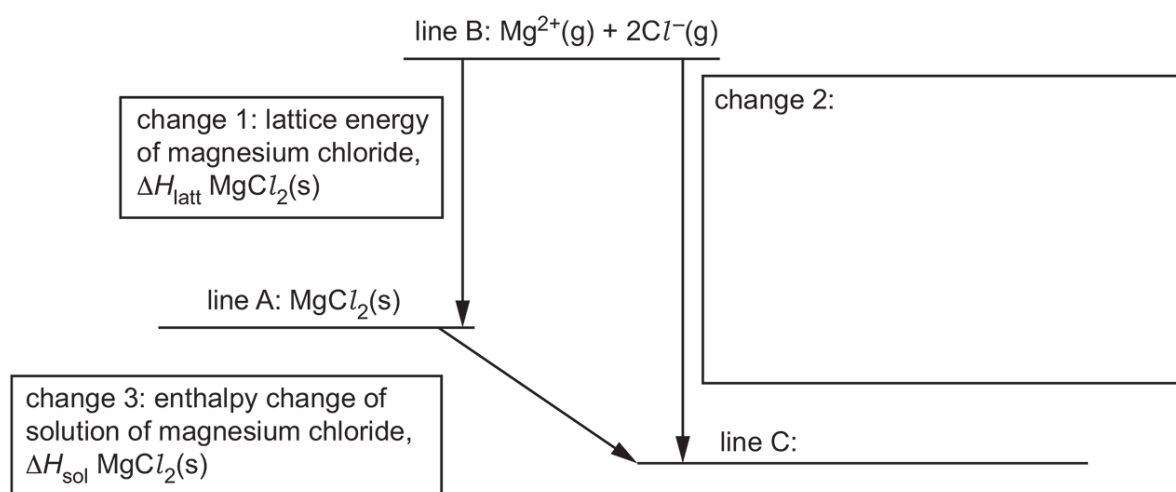


Fig. 2.1

- (i) Complete line C on Fig. 2.1. Include state symbols. [1]
- (ii) Use **both** words **and** symbols to identify change 2 on Fig. 2.1.
- Use changes 1 and 3 as examples of how this should be done.

[2]

- (iii) Calculate a value for the lattice energy of magnesium chloride,  $\Delta H_{\text{latt}} \text{MgCl}_2(\text{s})$ , by selecting and using appropriate data from Table 2.1.

**Table 2.1**

| energy change                                      | value / $\text{kJ mol}^{-1}$ |
|----------------------------------------------------|------------------------------|
| enthalpy change of solution of magnesium chloride  | –155                         |
| enthalpy change of formation of magnesium chloride | –642                         |
| first ionisation energy of magnesium               | +736                         |
| second ionisation energy of magnesium              | +1450                        |
| electron affinity of chlorine                      | –349                         |
| enthalpy change of hydration of $\text{Mg}^{2+}$   | –1920                        |
| enthalpy change of hydration of $\text{Cl}^-$      | –364                         |

$$\Delta H_{\text{latt}} \text{MgCl}_2(\text{s}) = \dots\dots\dots \text{kJ mol}^{-1} \quad [3]$$

- (c) Define entropy.

.....  
 ..... [1]

- (d) At  $25^\circ\text{C}$  the enthalpy change of solution of compound **Z** is  $+26 \text{ kJ mol}^{-1}$ . The entropy change of solution of **Z** at the same temperature is  $+52 \text{ J K}^{-1} \text{ mol}^{-1}$ .

Calculate the value of the Gibbs free energy change,  $\Delta G$ , for the solution of **Z** at  $25^\circ\text{C}$ .

$$\Delta G = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

- (e) (i) Use your answer to (d) to predict whether or not **Z** is soluble in water at 25°C. Explain your answer.

.....  
 ..... [1]

- (ii) Predict whether **Z** becomes more or less soluble as the water is heated from 25°C to 95°C. Explain your answer.

.....  
 ..... [1]

[Total: 14]

Answer:

| Question | Answer                                                                                                                                                                               | Marks                  |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|
| (a)      | $\Delta H_{\text{hyd}}$ increases from left to right due to increase in charge<br>ionic radius decreases from left to right<br>causing increased attractive force to water molecules | [1]<br>[1]<br>[1]<br>3 |
| (b)(i)   | $\text{Mg}^{2+}(\text{aq}) + 2\text{Cl}^{-}(\text{aq})$                                                                                                                              | [1]<br>1               |
| (b)(ii)  | Enthalpy change of hydration of magnesium ions and chloride ions<br>$\Delta H_{\text{hyd}}\text{Mg}^{2+} + 2\Delta H_{\text{hyd}}\text{Cl}^{-}$                                      | [1]<br>[1]<br>2        |
| (b)(iii) | Selects 155, 1920 and 364 only<br>$2 \times 364$<br>answer -2493                                                                                                                     | [1]<br>[1]<br>[1]<br>3 |
| (c)      | The number of arrangements of the particles and of the energy in the system                                                                                                          | [1]<br>1               |
| (d)      | $\Delta G = \Delta H - T\Delta S$<br>answer +10.5                                                                                                                                    | [1]<br>[1]<br>2        |
| (e)(i)   | No, $\Delta G$ is positive                                                                                                                                                           | [1]<br>1               |
| (e)(ii)  | Becomes more / soluble <b>because</b> $\Delta G$ becomes more negative / less positive / smaller / closer to zero                                                                    | [1]<br>1               |

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15. 9701\_w22\_qp\_41 Q: 1

Potassium chloride,  $KCl$ , and magnesium chloride,  $MgCl_2$ , are both ionic solids.**Table 1.1**

| energy change                                                                       | value / $\text{kJ mol}^{-1}$ |
|-------------------------------------------------------------------------------------|------------------------------|
| standard enthalpy change of solution, $\Delta H_{\text{sol}}^{\ominus}$ of $KCl$    | +15                          |
| lattice energy, $\Delta H_{\text{latt}}^{\ominus}$ of $KCl(s)$                      | -701                         |
| standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^{\ominus}$ of $K^+$   | -322                         |
| standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^{\ominus}$ of $Cl^-$  | -364                         |
| standard enthalpy change of solution, $\Delta H_{\text{sol}}^{\ominus}$ of $MgCl_2$ | -155                         |
| lattice energy, $\Delta H_{\text{latt}}^{\ominus}$ of $MgCl_2(s)$                   | -2493                        |

- (a) Complete the energy cycle involving the enthalpy change of solution and the lattice energy of potassium chloride,  $KCl$ , and the relevant enthalpy changes of hydration. Label your diagram.

State symbols should be used.

$KCl(s)$

[2]

- (b) Use the data in Table 1.1 to calculate the enthalpy change of hydration of magnesium ions,  $Mg^{2+}$ . Show your working.

 $\Delta H_{\text{hyd}}^{\ominus}$  of magnesium ions,  $Mg^{2+}$  = .....  $\text{kJ mol}^{-1}$  [2]

- (c) Explain the reasons why the lattice energy of  $\text{MgCl}_2$  is more exothermic than the lattice energy of  $\text{KCl}$ .

.....  
.....  
.....  
..... [2]

- (d) Define the following terms.

(i) enthalpy change of atomisation .....  
..... [1]

(ii) first electron affinity .....  
..... [1]

- (e) (i) Explain what is meant by entropy,  $S$ .

.....  
..... [1]

- (ii) Potassium chloride is very soluble in water at  $20^\circ\text{C}$ .

Explain the solubility of potassium chloride by reference to change in entropy,  $\Delta S$ .

.....  
..... [1]

- (iii) Use the Gibbs equation and your answer to (e)(ii) to predict whether potassium chloride is more soluble in water at  $20^\circ\text{C}$  or at  $80^\circ\text{C}$ . Explain your answer.

.....  
.....  
..... [1]

[Total: 11]



Answer:

| Question | Answer                                                                                                                                                                                                                                                                                                                                                                                                | Marks |
|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| (a)      | <div style="text-align: center;"> </div> <p>M1 <math>K^+(g)</math> and <math>Cl^-(g)</math><br/> <b>AND</b><br/> <math>KCl(aq)</math> <b>OR</b> <math>K^+(aq) + Cl^-(aq)</math></p> <p>M2 three correct directional arrows COND M1</p>                                                                                                                                                                | 2     |
| (b)      | <p>use of data <math>-155</math>, <math>-2493</math> <b>AND</b> <math>2 \times -364</math> [1]</p> <p><math>\Delta H_{hyd} Mg^{2+} = -1920</math> (<math>kJ\ mol^{-1}</math>) [1] min 3sf</p>                                                                                                                                                                                                         | 2     |
| (c)      | <ul style="list-style-type: none"> <li><math>Mg^{2+}</math> is <b>smaller</b> (than <math>K^+</math>)</li> <li><math>Mg^{2+}</math> is <b>greater charge</b> (than <math>K^+</math>)</li> <li><b>greater attraction</b> between <math>Mg^{2+}</math> and <math>Cl^-</math> / <b>between the ions</b> (in <math>MgCl_2</math>)<br/> <b>OR</b> stronger ionic bonds (in <math>MgCl_2</math>)</li> </ul> | 2     |
| (d)(i)   | <p>enthalpy change when<br/> <b>one mole of gaseous atoms</b> formed from the <b>element</b> (in its standard state at 298 K)</p>                                                                                                                                                                                                                                                                     | 1     |
| (d)(ii)  | <p>enthalpy change when<br/> every atom in one mole of gaseous atoms gains one electron<br/> <b>OR</b> one mole of gaseous atoms gains one mole of electrons</p>                                                                                                                                                                                                                                      | 1     |
| (e)(i)   | <p>number of possible arrangements of particles and energy in a system</p>                                                                                                                                                                                                                                                                                                                            | 1     |
| Question | Answer                                                                                                                                                                                                                                                                                                                                                                                                | Marks |
| (e)(ii)  | <p><math>\Delta S</math> is positive<br/> <b>AND</b> <math>KCl(s) \rightarrow K^+(aq) + Cl^-(aq)</math> /<br/> ionic lattice solid forms aqueous ions <b>OWTTE</b> [1]</p> <p><b>OR</b><br/> <math>\Delta S</math> is positive<br/> <b>AND</b> <math>\Delta G</math> is (therefore becomes) negative /<br/> <math>T\Delta S</math> is greater than <math>\Delta H_{sol}</math> <b>OWTTE</b> [1]</p>   | 1     |
| (e)(iii) | <p><b>more soluble</b><br/> <b>AND</b> <math>\Delta G</math> is more negative at higher T /<br/> <math>T\Delta S</math> is more positive at higher T /<br/> <math>-T\Delta S</math> is more negative at higher <b>ecf from (e)(ii)</b> [sign <math>\Delta S</math>]</p>                                                                                                                               | 1     |

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16. 9701\_w22\_qp\_42 Q: 1

Calcium chloride,  $\text{CaCl}_2$ , is an ionic solid.

The values of some energy changes are shown in Table 1.1.

Table 1.1

| energy change                                                              | value/ $\text{kJ mol}^{-1}$ |
|----------------------------------------------------------------------------|-----------------------------|
| lattice energy, $\Delta H_{\text{latt}}^\circ$ , $\text{CaCl}_2(\text{s})$ | -2237                       |
| standard enthalpy change of atomisation of calcium                         | +193                        |
| first ionisation energy of calcium                                         | +590                        |
| second ionisation energy of calcium                                        | +1150                       |
| standard enthalpy change of atomisation of chlorine                        | +121                        |
| first electron affinity of chlorine                                        | -364                        |

(a) Define lattice energy.

.....  
 ..... [1]

(b) Use the data in Table 1.1 to calculate the standard enthalpy change of formation,  $\Delta H_f^\circ$ , of calcium chloride. It may be helpful to draw an energy cycle. Show all your working.

$\Delta H_f^\circ(\text{CaCl}_2(\text{s})) = \dots\dots\dots \text{kJ mol}^{-1}$  [2]

- (c) Three possible values for the first electron affinity of bromine are shown in Table 1.2. One of them is correct.

Place a tick by the correct value. Explain your choice.

**Table 1.2**

| possible values           | place <b>one</b> tick (✓) in this column |
|---------------------------|------------------------------------------|
| –342 kJ mol <sup>–1</sup> |                                          |
| –364 kJ mol <sup>–1</sup> |                                          |
| –386 kJ mol <sup>–1</sup> |                                          |

explanation .....

..... [1]

- (d) The enthalpy change of hydration of the chloride ion can be calculated using the lattice energy of calcium chloride and the data shown in Table 1.3.

**Table 1.3**

| energy change                                                 | value / kJ mol <sup>–1</sup> |
|---------------------------------------------------------------|------------------------------|
| standard enthalpy change of solution of CaCl <sub>2</sub> (s) | –83                          |
| standard enthalpy change of hydration of Ca <sup>2+</sup> (g) | –1650                        |

- (i) Define the following terms.

enthalpy change of solution .....

.....

enthalpy change of hydration .....

.....

[2]

- (ii) Calculate the standard enthalpy change of hydration of the chloride ion, Cl<sup>–</sup>(g). It may be helpful to draw an energy cycle. Show all your working.

$$\Delta H_{\text{hyd}}^{\ominus}(\text{Cl}^{-}(\text{g})) = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

(e) Calcium fluoride,  $\text{CaF}_2(\text{s})$ , can be synthesised directly from its elements.

The value of  $\Delta H_f^\circ(\text{CaF}_2(\text{s}))$  is  $-1214 \text{ kJ mol}^{-1}$ .

(i) Predict the sign of the entropy change,  $\Delta S^\circ$ , for this synthesis. Explain your answer.

The sign of the entropy change is .....

explanation .....

[1]

(ii) Use the value of  $\Delta H_f^\circ(\text{CaF}_2(\text{s}))$  given in (e) and your answer to (e)(i) to predict how the feasibility for this synthesis will change with increasing temperature.

[2]

[Total: 11]

Answer:

| Question | Answer                                                                                                                   | Marks |
|----------|--------------------------------------------------------------------------------------------------------------------------|-------|
| (a)      | (energy change) when one mole of ionic solid is formed from gaseous ions                                                 | 1     |
| (b)      | $(-2237 + 193 + 590 + 1150 + (2 \times 121) - (2 \times 364))$ [1]<br>$= -790$ [1]                                       | 2     |
| (c)      | $-342$ <b>and</b><br>Br atom has larger radius                                                                           | 1     |
| (d)(i)   | energy change when one mole dissolves in water [1]<br>energy change when one mole of gaseous ions dissolves in water [1] | 2     |
| (d)(ii)  | $(-2237 - 83 + 1650) / 2$ [1]<br>$= -335$ [1]                                                                            | 2     |
| (e)(i)   | <b>negative and</b><br>reduction in number of gas molecules                                                              | 1     |
| (e)(ii)  | $T\Delta S$ becomes more negative [1]<br>less feasible <b>AND</b> $\Delta G$ becomes positive [1]                        | 2     |

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17. 9701\_s19\_qp\_42 Q: 5

- (a) Complete the table by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

| energy change                     | always positive | always negative | either negative or positive |
|-----------------------------------|-----------------|-----------------|-----------------------------|
| lattice energy                    |                 |                 |                             |
| enthalpy change of neutralisation |                 |                 |                             |

[1]

- (b) Define, in words, the term *enthalpy change of solution*.

.....  
 ..... [1]

- (c) The following enthalpy changes are given.

| enthalpy change                                                                                                                                       | value / $\text{kJ mol}^{-1}$ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| standard enthalpy change of formation, $\Delta H_f^\ominus$ , for $\text{K}_3\text{PO}_4(\text{s})$                                                   | −2035                        |
| standard enthalpy change, $\Delta H^\ominus$ , for $\text{P}(\text{s}) + 2\text{O}_2(\text{g}) + 3\text{e}^- \rightarrow \text{PO}_4^{3-}(\text{aq})$ | −1284                        |
| standard enthalpy change, $\Delta H^\ominus$ , for $\text{K}(\text{s}) \rightarrow \text{K}^+(\text{aq}) + \text{e}^-$                                | −251                         |

Determine the standard enthalpy change of solution of potassium phosphate,  $\text{K}_3\text{PO}_4(\text{s})$ . It may be helpful to draw a labelled energy cycle.

$$\Delta H_{\text{sol}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1} \quad [3]$$

(d) Some lattice energy values are shown in the table.

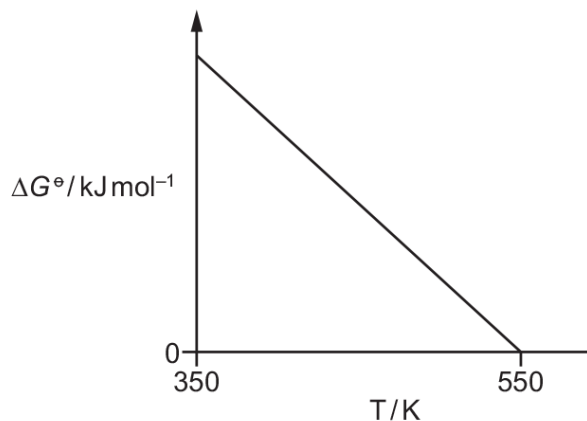
| compound                  | lattice energy value / $\text{kJ mol}^{-1}$ |
|---------------------------|---------------------------------------------|
| $\text{CaBr}_2(\text{s})$ | -2176                                       |
| $\text{KBr}(\text{s})$    | -679                                        |

Suggest an explanation for why  $\Delta H_{\text{latt}}^\circ$   $\text{CaBr}_2$  is **more** exothermic than  $\Delta H_{\text{latt}}^\circ$   $\text{KBr}$ .

.....  
 .....  
 ..... [2]

(e) For a particular gas phase reaction the variation in standard Gibbs free energy change,  $\Delta G^\circ$ , with temperature is shown.

Assume standard enthalpy change,  $\Delta H^\circ$ , and standard entropy change,  $\Delta S^\circ$ , remain constant with temperature.



(i) Write the equation that relates  $\Delta G^\circ$  to  $\Delta H^\circ$  and  $\Delta S^\circ$ .

..... [1]

(ii) Use this equation to explain why  $\Delta G^\circ$  becomes **less** positive as temperature increases in this reaction.

.....  
 ..... [1]

[Total: 9]

Answer:

| Question                   | Answer                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Marks           |                             |                 |                             |                |  |   |  |                            |  |   |  |   |
|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-----------------------------|-----------------|-----------------------------|----------------|--|---|--|----------------------------|--|---|--|---|
| (a)                        | <table><tr><td>energy change</td><td>always positive</td><td>always negative</td><td>either negative or positive</td></tr><tr><td>lattice energy</td><td></td><td>✓</td><td></td></tr><tr><td>enthalpy of neutralisation</td><td></td><td>✓</td><td></td></tr></table> <p style="text-align: right;">both [1]</p>                                                                                                                                                                 | energy change   | always positive             | always negative | either negative or positive | lattice energy |  | ✓ |  | enthalpy of neutralisation |  | ✓ |  | 1 |
| energy change              | always positive                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | always negative | either negative or positive |                 |                             |                |  |   |  |                            |  |   |  |   |
| lattice energy             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | ✓               |                             |                 |                             |                |  |   |  |                            |  |   |  |   |
| enthalpy of neutralisation |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | ✓               |                             |                 |                             |                |  |   |  |                            |  |   |  |   |
| (b)                        | (energy change) when <b>1 mole</b> of solute is dissolved in an infinite amount of <b>water</b> to form a dilute solution                                                                                                                                                                                                                                                                                                                                                         | 1               |                             |                 |                             |                |  |   |  |                            |  |   |  |   |
| (c)                        | calculation of $\Delta H^\circ_{\text{sol}}$ with $-251$ , $-1284$ and $-2035$ only and two correct signs [1]<br><br>calculation of $\Delta H^\circ_{\text{sol}}$ with $-251$ , $-1284$ and $-2035$ only and correct signs<br><b>OR</b> calculation of $\Delta H^\circ_{\text{sol}}$ with $(-251 \times 3)$ , $-1284$ and $-2035$ only and two correct signs [2]<br><br>$\Delta H^\circ_{\text{sol}} = (3 \times -251) + (-1284) - (-2035) = -2 \text{ (kJ mol}^{-1}\text{)}$ [3] | 3               |                             |                 |                             |                |  |   |  |                            |  |   |  |   |
| (d)                        | $\text{Ca}^{2+}$ have a higher charge / greater charge density [1] <b>ora</b><br><b>stronger</b> electrostatic forces between $\text{Br}^-$ and $\text{Ca}^{2+}$ [1]                                                                                                                                                                                                                                                                                                              | 2               |                             |                 |                             |                |  |   |  |                            |  |   |  |   |
| (e)(i)                     | $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ [1]                                                                                                                                                                                                                                                                                                                                                                                                                           | 1               |                             |                 |                             |                |  |   |  |                            |  |   |  |   |
| (e)(ii)                    | $T\Delta S$ is more positive<br><b>OR</b> $-T\Delta S$ becomes more negative [1]                                                                                                                                                                                                                                                                                                                                                                                                  | 1               |                             |                 |                             |                |  |   |  |                            |  |   |  |   |

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