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Since 2005
School of Chemistry

UNIVERSITY OF CAMBRIDGE

Cambridge A2 Level

ENERGETICS

Topical Questions

Compiled by :

Chembase School of Chemistry

1 **(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]

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

.....

..... [1]

(c) The overall reaction for the atomisation of liquid bromine molecules, $Br_2(l)$, is shown.

$$Br_2(l) \rightarrow 2Br(g)$$

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 $Br_2(l)$, $\Delta H^{\ominus}_{vap}$.
  The enthalpy change of atomisation of bromine, ΔH_{at}, = +112 kJ mol^{-1}.

$\Delta H^{\ominus}_{vap}$ = ... kJ mol^{-1} [3]

(d) Suggest how the $\Delta H^{\ominus}_{vap}$ of iodine, $I_2(l)$, would compare to that of bromine, $Br_2(l)$. Explain your answer.

.....

..... [1]

2 **(a)** Explain what is meant by the term *entropy of a system*.

.....

..... [1]

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(b) State and explain whether the entropy change of each of the following processes is positive or negative. Do not consider the entropy change of the surroundings.

- liquid water at 80 °C is cooled to 60 °C

The entropy change is ..... because .....

.....

- solid calcium chloride is added to water and the mixture is stirred

The entropy change is ..... because .....

.....

- the change corresponding to the lattice energy of calcium chloride, ΔH_{latt} $CaCl_2(s)$, takes place

The entropy change is ..... because .....

.....

[3]

(c) The reaction $ZnCO_3(s) \rightarrow ZnO(s) + CO_2(g)$ is not spontaneous at room temperature.

(i) Give the full name for the term $\Delta G^{\ominus}$.

..... [1]

(ii) Describe how the temperature at which the reaction becomes spontaneous can be calculated. Include an equation in your answer.

equation .....

.....

.....

.....

[2]

[Total: 7]

3 **(a)** The lattice energies of three ionic compounds are given.

compound	lattice energy / kJ mol^{-1}
LiF(s)	–1022
CaO(s)	–3513
SrO(s)	–3310

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(i) Define the term *lattice energy*.

.....

.....

..... [2]

(ii) Explain why the lattice energy of CaO is more exothermic than the lattice energy of LiF.

.....

.....

..... [1]

(iii) Use the data in the table to estimate approximate values for the lattice energies of magnesium oxide and barium oxide.

ΔH_{latt}MgO(s) = ... kJ mol^{-1}

ΔH_{latt}BaO(s) = ... kJ mol^{-1}
[1]

(b) **(i)** Write an equation for the reaction between BaO and H_2O.
Include state symbols.

..... [1]

(ii) State and explain how the solubilities of the hydroxides of the Group 2 elements vary down the group.

.....

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.....

.....

..... [4]

4 (e) The standard entropies, $S^\ominus$, of three species are given in the table.

species	$S^\ominus$ / J K^{-1} mol^{-1}
$H_2O(l)$	+70
$H_2(g)$	+131
$O_2(g)$	+205

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(i) Calculate $\Delta S^\ominus$ for the reaction $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$.

$\Delta S^\ominus$ = ... J K^{-1} mol^{-1} [1]

(ii) $\Delta H^\ominus$ for the reaction $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$ is +572 kJ mol^{-1}.

Calculate $\Delta G^\ominus$ for this reaction at 298 K.

$\Delta G^\ominus$ = ... kJ mol^{-1} [2]

(iii) Predict the effect of increasing temperature on the spontaneity of this reaction.
Explain your answer.

.....

..... [1]

[Total: 9]

5 **(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]

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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^{-1}
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 $\frac{1}{2}O_2(g) + 2e^- \rightarrow O^{2-}(g)$	+951
enthalpy change for $Ca(s) \rightarrow Ca^{2+}(g) + 2e^-$	+1933
lattice energy of CaO(s)	–3517

(c) Oxygen exists as O_2 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^{-1} [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]

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

enthalpy of formation = ... $kJ\,mol^{-1}$ [2]

(f) The lattice energy of lithium fluoride, LiF(s), is $-1022\,kJ\,mol^{-1}$.

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]

6 (i) The equation for the formation of a gaseous sulfate ion is shown.

$$S(s) + 2O_2(g) + 2e^- \rightarrow SO_4^{2-}(g) \quad \Delta H = \Delta H_f^\ominus \text{ of } SO_4^{2-}(g)$$

Calculate the standard enthalpy change of formation, $\Delta H_f^\ominus$, of $SO_4^{2-}(g)$. It may be helpful to draw a labelled energy cycle. Use relevant data from Table 1.1 in your calculations.

Table 1.1

energy change	value / kJ mol^{-1}
lattice energy of barium sulfate, $BaSO_4(s)$	–2469
standard enthalpy change of formation of barium sulfate	–1473
standard enthalpy change of atomisation of barium	+180
first ionisation energy of barium	+503
second ionisation energy of barium	+965
standard enthalpy change of atomisation of sulfur	+279
standard enthalpy change for $S(g) \rightarrow S^{2-}(g)$	+440
standard enthalpy change for $O(g) \rightarrow O^{2-}(g)$	+657
O=O bond energy	+496

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$\Delta H_f^\ominus$ of $SO_4^{2-}(g)$ = ... kJ mol^{-1} [3]

7 Potassium chloride, KC*l*, and magnesium chloride, $MgCl_2$, are both ionic solids.

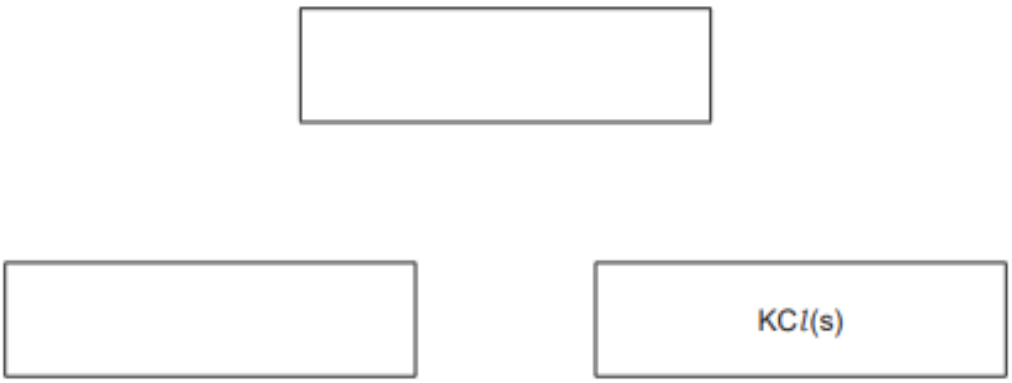
Table 1.1

energy change	value/kJ mol^{-1}
standard enthalpy change of solution, $\Delta H^{\ominus}_{sol}$, of KC*l*	+15
lattice energy, $\Delta H^{\ominus}_{latt}$, of KC*l*(s)	–701
standard enthalpy change of hydration, $\Delta H^{\ominus}_{hyd}$, of K^+	–322
standard enthalpy change of hydration, $\Delta H^{\ominus}_{hyd}$, of Cl^-	–364
standard enthalpy change of solution, $\Delta H^{\ominus}_{sol}$, of $MgCl_2$	–155
lattice energy, $\Delta H^{\ominus}_{latt}$, of $MgCl_2$(s)	–2493

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

State symbols should be used.



[2]

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

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

(c) Explain the reasons why the lattice energy of $MgCl_2$ is more exothermic than the lattice energy of KCl.

.....

.....

.....

..... [2]

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(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 °C.

Explain the solubility of potassium chloride by reference to change in entropy, ΔS.

.....

..... [1]

(iii) Use the Gibbs equation and your answer to **(e)(ii)** to predict whether potassium chloride is more soluble in water at 20 °C or at 80 °C. Explain your answer.

.....

.....

..... [1]

[Total: 11]

8 Hydrogen peroxide is a liquid at 298 K. It is moderately stable under room conditions but will decompose quickly if a catalyst is added.

reaction 1 $2H_2O_2(l) \rightarrow 2H_2O\,(l) + O_2\,(g)$

(a) (i) Define entropy.

.....

..... [1]

(ii) Predict the sign of the standard entropy change of reaction 1.

Explain your answer.

sign .....

explanation .....

.....

[1]

(b) Some bond energy data are shown in Table 3.1.

Table 3.1

type of bond	bond energy / kJ mol^{-1}
O–O	150
O–H	460
O=O	496

Use the data in Table 3.1 to show that the enthalpy change of the following reaction is –196 kJ mol^{-1}.

$$2H_2O_2(g) \rightarrow 2H_2O(g) + O_2(g)$$

[1]

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(c) Some standard entropies, $S^{\ominus}$, are shown in Table 3.2.

Table 3.2

substance	$S^{\ominus}$ / $JK^{-1}mol^{-1}$
$H_2O_2(l)$	+102
$H_2O(l)$	+70

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The enthalpy change and Gibbs free energy change for the following reaction are shown.

$$2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g) \qquad \Delta H^{\ominus} = -196\,kJ\,mol^{-1}, \quad \Delta G^{\ominus} = -238\,kJ\,mol^{-1}$$

Use the data given to calculate the standard entropy of oxygen, $S^{\ominus}$, $O_2(g)$.

$S^{\ominus}$, $O_2(g)$ = ... $JK^{-1}mol^{-1}$ [3]

(g) (i) Define enthalpy change of hydration, ΔH_{hyd}.

.....

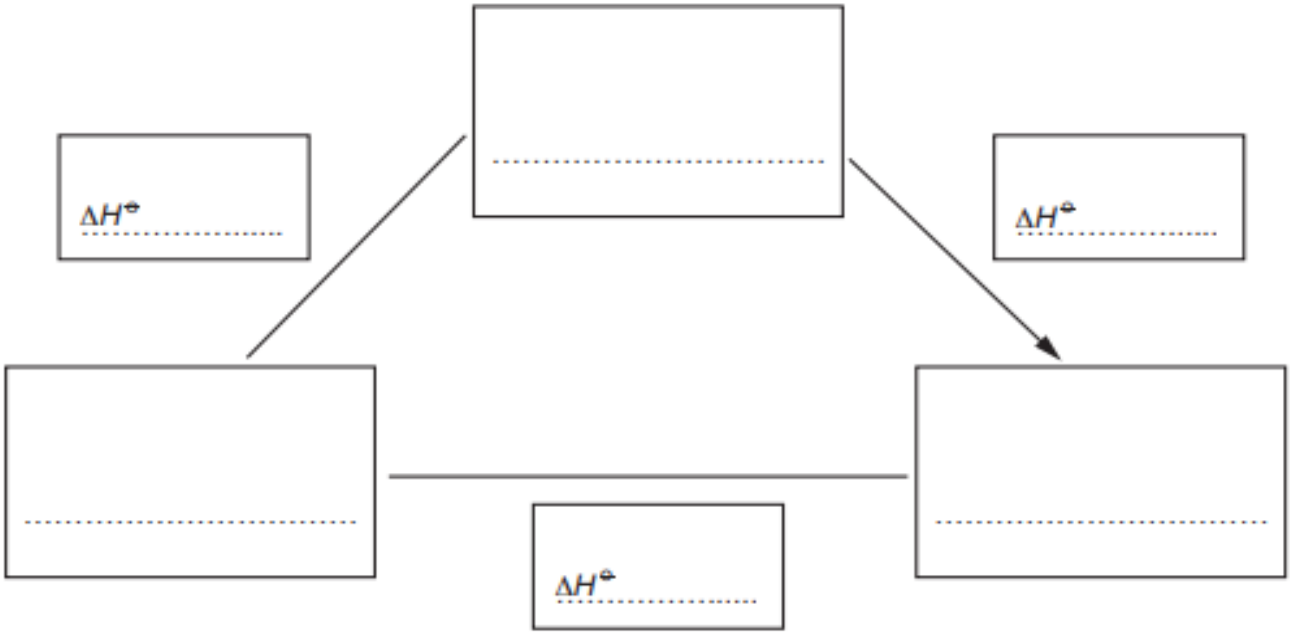
..... [1]

(ii) Aluminium fluoride, AlF_3, is an ionic solid.

Complete and label the energy cycle to show the relationship between:

- the enthalpy change of solution of AlF_3, $\Delta H^{\ominus}_{sol}$
- the lattice energy of AlF_3, $\Delta H^{\ominus}_{latt}$
- the enthalpy changes of hydration of Al^{3+} and F^-, $\Delta H^{\ominus}_{hyd}$.

Include state symbols for all substances and ions.



[2]

(iii) Relevant data for this question are given.

$\Delta H^{\ominus}_{sol} AlF_3 = -209\,kJ\,mol^{-1}$

$\Delta H^{\ominus}_{hyd} Al^{3+} = -4690\,kJ\,mol^{-1}$

$\Delta H^{\ominus}_{hyd} F^- = -506\,kJ\,mol^{-1}$

Use these data and your energy cycle in **(g)(ii)** to calculate the $\Delta H^{\ominus}_{latt}$ of AlF_3.

$\Delta H^{\ominus}_{latt}$ of AlF_3 = ... $kJ\,mol^{-1}$ [1]

[Total: 17]

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9 **(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.

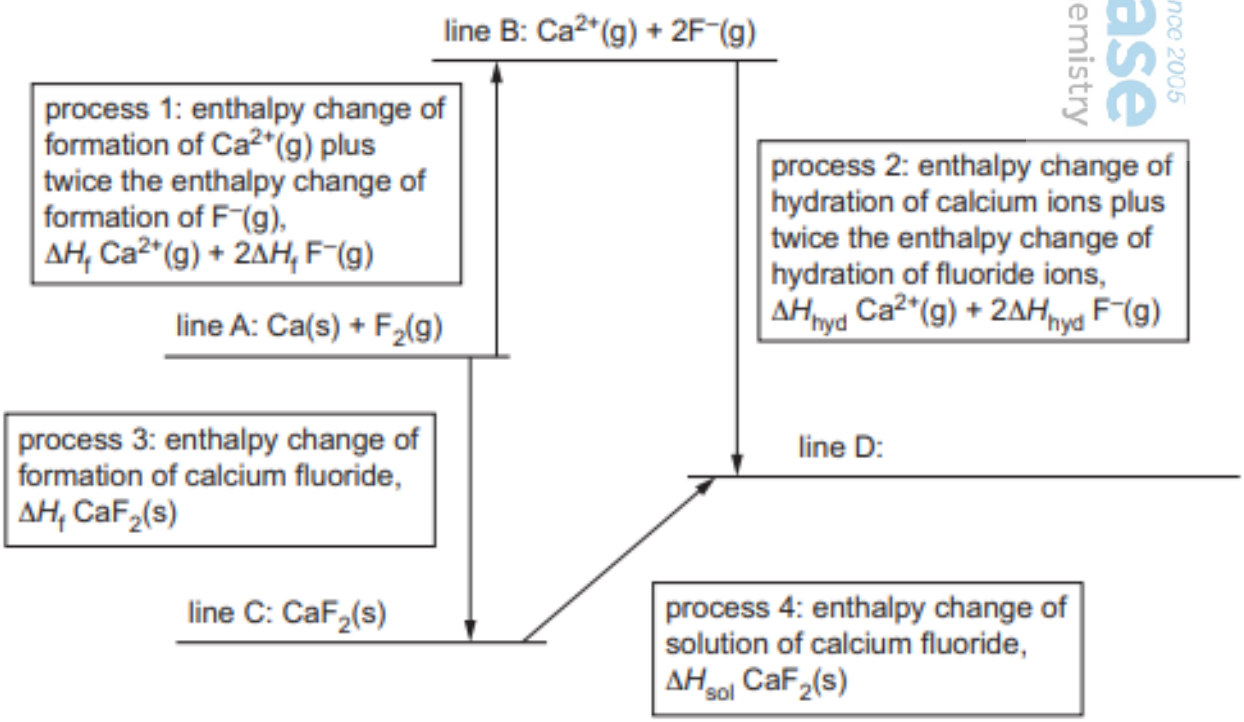


Fig. 2.1

(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.

process 1: $Ca(s) + F_2(g) \rightarrow Ca^{2+}(g) + 2F^-(g)$

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

.....

.....

.....

.....

..... [2]

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(iii) Define lattice energy, ΔH_{latt}.

.....

.....

..... [2]

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

ΔH_{latt} =

[1]

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

Table 2.1

	value / kJ mol^{-1}
enthalpy change of solution of calcium fluoride, $CaF_2(s)$	+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 $Ca^{2+}(g)$	–1650

ΔH_{hyd} $F^-(g)$ = ... kJ mol^{-1} [2]

(d) Define entropy.

.....

..... [1]

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

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

Calculate the value of the entropy change, ΔS, for the solution of compound **T** at 298 K.

ΔS = ... J K^{-1} mol^{-1} [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]

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10 **(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]

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

.....

..... [1]

(c) The following enthalpy changes are given.

enthalpy change	value / kJ mol^{-1}
standard enthalpy change of formation, $\Delta H_f^\ominus$, for $K_3PO_4(s)$	–2035
standard enthalpy change, $\Delta H^\ominus$, for $P(s) + 2O_2(g) + 3e^- \rightarrow PO_4^{3-}(aq)$	–1284
standard enthalpy change, $\Delta H^\ominus$, for $K(s) \rightarrow K^+(aq) + e^-$	–251

Determine the standard enthalpy change of solution of potassium phosphate, $K_3PO_4(s)$. It may be helpful to draw a labelled energy cycle.

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

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

compound	lattice energy value / kJ mol^{-1}
$CaBr_2(s)$	–2176
KBr(s)	–679

Suggest an explanation for why $\Delta H^{\ominus}_{latt}$ $CaBr_2$ is **more** exothermic than $\Delta H^{\ominus}_{latt}$ KBr.

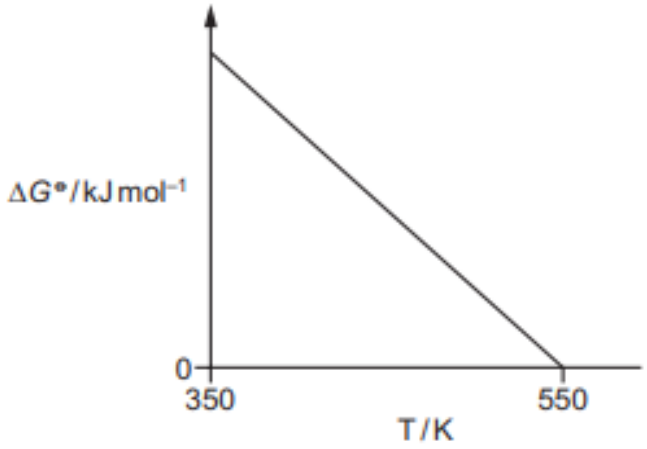
.....

.....

..... [2]

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

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



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

..... [1]

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

.....

..... [1]

[Total: 9]

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11 The table shows some standard entropy data.

substance	standard entropy, $S^\ominus$ / $JK^{-1}mol^{-1}$
$PbO_2(s)$	77
$PbO(s)$	69
$O_2(g)$	205

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Lead(IV) oxide, PbO_2, decomposes to lead(II) oxide, PbO, and oxygen when heated.

$$2PbO_2(s) \rightarrow 2PbO(s) + O_2(g) \qquad \Delta H^\ominus = +118\ kJ\,mol^{-1}$$

(a) Use the data to calculate the value of $\Delta S^\ominus$ for this reaction.

$\Delta S^\ominus$ = ... $JK^{-1}mol^{-1}$ [2]

(b) Use the value of $\Delta H^\ominus$ and your answer to **(a)** to calculate the temperature at which this reaction becomes feasible.

T = ... K [3]

(c) Solid lead(II) oxide can be made by heating lead metal in air.

Predict the **sign** of the standard entropy change of this reaction. Explain your answer.

.....

..... [1]

[Total: 6]

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

.....

.....

..... [2]

(ii) Define the term *lattice energy*.

.....

.....

..... [2]

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(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, $ZnBr_2(s)$.

You might find it helpful to construct an energy cycle.

electron affinity of Br(g)	= –325 kJ mol^{-1}
enthalpy change of atomisation of Zn(s)	= +131 kJ mol^{-1}
enthalpy change of vaporisation of $Br_2(l)$	= +31 kJ mol^{-1}
lattice energy of $ZnBr_2(s)$	= –2678 kJ mol^{-1}

enthalpy change of formation of $ZnBr_2(s)$ = ... kJ mol^{-1} [4]

(c) The lattice energies of $ZnBr_2$, $ZnCl_2$ and ZnO are shown.

compound	lattice energy / kJ mol^{-1}
$ZnBr_2$	–2678
$ZnCl_2$	–2734
ZnO	–3971

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(i) Explain why there is a difference between the lattice energies of $ZnBr_2$ and $ZnCl_2$.

.....

..... [1]

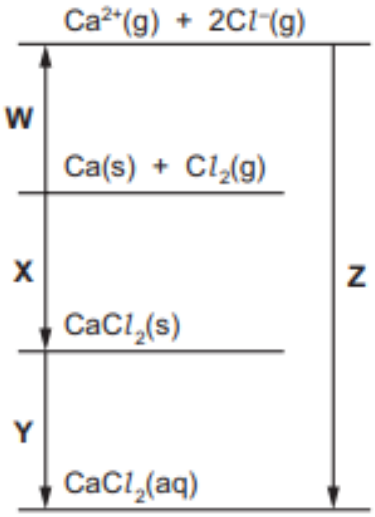
(ii) Explain why there is a difference between the lattice energies of $ZnCl_2$ and ZnO.

.....

..... [1]

[Total: 10]

13 **(a)** The energy cycle shown can be used, along with suitable data, to calculate the enthalpy change of hydration of $Ca^{2+}(g)$.
Each arrow indicates a transformation, **W**, **X**, **Y** and **Z**. Each transformation consists of one or more steps.



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The following data and data from the *Data Booklet* should be used.

electron affinity of $Cl(g)$	$= -349\,kJ\,mol^{-1}$
enthalpy change of atomisation of Ca(s)	$= +193\,kJ\,mol^{-1}$
enthalpy change of formation of $CaCl_2(s)$	$= -795\,kJ\,mol^{-1}$
enthalpy change of solution of $CaCl_2(s)$	$= -83\,kJ\,mol^{-1}$
enthalpy change of hydration of $Cl^-(g)$	$= -364\,kJ\,mol^{-1}$

(i) Calculate the value of the enthalpy change corresponding to transformation **W**.
Show your working.

enthalpy change **W** = ... $kJ\,mol^{-1}$ [2]

(ii) Use your answer to **(a)(i)** and other data to calculate the value of the enthalpy change corresponding to transformation **Z**.

enthalpy change **Z** = ... $kJ\,mol^{-1}$ [2]

(iii) Use your answer to **(a)(ii)** to calculate the enthalpy change of hydration of $Ca^{2+}(g)$.

enthalpy change of hydration of $Ca^{2+}(g)$ = ... $kJ\,mol^{-1}$ [2]

(iv) Write an expression, in terms of **W**, **X**, **Y** and/or **Z**, to show how the enthalpy changes of **two** of the transformations can be used to calculate the lattice energy of $CaCl_2(s)$.

lattice energy of $CaCl_2(s)$ = ... [1]

(v) State whether the lattice energy of $CaCl_2(s)$ is more or less exothermic than the lattice energy of $MgF_2(s)$.

Explain your answer.

.....

.....

..... [1]

(b) The sulfates of the Group 2 elements vary in solubility down Group 2.

(i) Give the names of **two** solutions that could be mixed to form barium sulfate.

..... [1]

(ii) State and explain how the solubilities of the sulfates of the Group 2 elements vary down Group 2.

.....

.....

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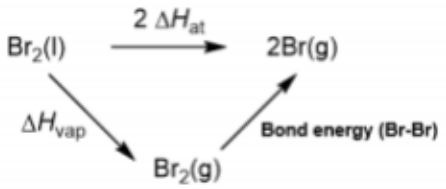
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..... [4]

[Total: 13]

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1

Question	Answer	Marks
(a)	<table><tr><th>energy change</th><th>always positive</th><th>always negative</th><th>either negative or positive</th></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> **both** ticks correct	1
(b)	(energy change) when **1 mole** of **gaseous atoms** are formed (from an element in its standard state)	1
(c)	 **M1**: correct cycle: formulae and state symbols **M2**: use of 1 × 193 **and** 2 × (112) **M3**: for the correct sum and answer ecf from M2 $\Delta H^{\ominus}_{vap}$ (= (2 × 112) – (193)) = **+31** kJ mol^{-1} [scores M2 and M3]	3
(d)	more endothermic **and** greater Van der Waals / London / induced dipole-dipole forces **both**	1

2

Question	Answer	Marks
(a)	a **measure / degree** of **disorder / randomness** of a system	1
(b)	**M1:** negative – molecules have less energy in the system **M2:** positive – solid being converted into an aqueous solution **M3:** negative – gaseous ions being converted into a solid	3
(c)(i)	(standard) Gibbs free energy change	1
(c)(ii)	**M1:** $(\Delta)G = \Delta H - T\Delta S$ **M2:** description of calculating the minimum value of T for which ΔG is zero / becomes negative **OR** $T = \Delta H / \Delta S$ [1]	2

3

Question	Answer	Marks
(a)(i)	**M1** energy released when 1 mole of an ionic compound is formed [1] **M2** from gaseous ions (under standard conditions) [1]	2
(a)(ii)	Ca^{2+} & O^{2-} have a higher charge / charge density (than Li^+ and F^-) [1]	1
(a)(iii)	MgO –3600 or more negative **AND** BaO –3200 or less negative **BOTH** [1]	1
(b)(i)	$BaO(s) + H_2O(l) \rightarrow Ba(OH)_2(aq)$ [1]	1
(b)(ii)	**M1** (solubility) increases (down the group) [1] **M2** both ΔH_{latt} and ΔH_{hyd} become less exothermic / less negative [1] **M3** ΔH_{latt} changes more / is dominant factor [1] **M4** ΔH_{sol} becomes more negative / more exothermic [1]	4

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(e)(i)	ΔS = 262 + 205 – 140 = (+) **327** (J K^{-1} mol^{-1}) [1]	**1**
(e)(ii)	ΔG = ΔH – TΔS **OR** use of Gibbs equation [1] ΔG = 572 – (298 × 0.327) = (+)**474.6** (kJ mol^{-1}) [1] min 3sf ecf 1e(i)	**2**
(e)(iii)	becomes more feasible / spontaneous as TΔS is more positive / –TΔS becomes more negative • ✓	**1**

5

Question	Answer	Marks
(a)	• enthalpy/energy change • one mole of electrons gained • by one mole of atoms • gaseous (atoms)	**2**
(b)	$Ca^{+}(g) \rightarrow Ca^{2+}(g) + e^{-}$ [1]	**1**

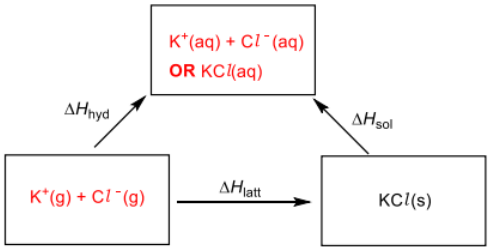
Question	Answer	Marks
(c)	M1: selecting correct data 951, 844, 142 only M2: evaluation to give 249 (ΔH_{atom}) **OR** 2(951) = BE – 2(142) + 2(844) M3: evaluation to 498 (2 × 249) ecf M2 951 = ΔH_{atom} –142 + 844 ΔH_{atom} = 249 BE = **498** (kJ mol^{-1}) [3]	**3**
(d)(i)	**attraction** between nucleus / protons / nuclear charge **and** electron [1]	**1**
(d)(ii)	**repulsion** between 1– ion / electrons of O^{-} **and** electron [1]	**1**
(e)	M1: selecting correct data 951, 1933, 3517 only (ignore signs) M2: evaluation to give –633 (ΔH_f) ecf ΔH_f = 951 + 1933 – 3517 = **–633** (kJ mol^{-1}) [2]	**2**
(f)	ionic charge / charge density (of the ions) [1] greater (attractive) force between the ion**s** [1]	**2**

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(i)	–1473 = 180 + 503 + 965 + $\Delta H^{\ominus}_f$ – 2469 $\Delta H^{\ominus}_f$ of SO_4^{2-}(g) = –652 kJ mol^{-1} **M1** correct five values used [1] **M2** only correct five values used [1] **M3** correct signs and evaluation [1]	**3**

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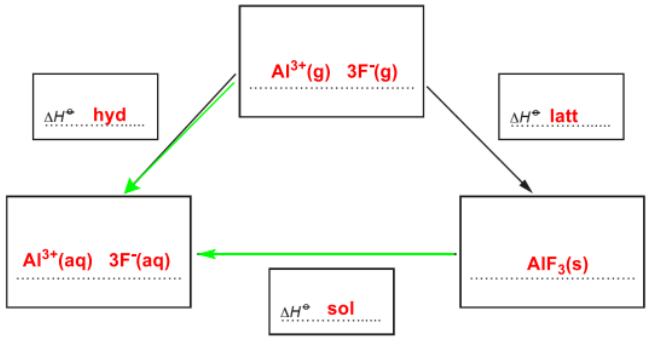
7

Question	Answer	Marks
(a)	 M1 K^+ (g) and Cl^- (g) **AND** KCl (aq) **OR** K^+ (aq) + Cl^- (aq) M2 three correct directional arrows COND M1	**2**
(b)	use of data –155, –2493 **AND** 2 × –364 [1] ΔH_{hyd} Mg^{2+} = **–1920** (kJ mol^{-1}) [1] min 3sf	**2**
(c)	• Mg^{2+} is **smaller** (than K^+) • Mg^{2+} is **greater charge** (than K^+) • greater **attraction** between Mg^{2+} and Cl^- **/between the ions** (in $MgCl_2$) **OR** stronger ionic bonds (in $MgCl_2$)	**2**
(d)(i)	enthalpy change when **one mole** of **gaseous atoms** formed from the **element** (in its standard state at 298 K)	**1**
(d)(ii)	enthalpy change when every atom in one mole of gaseous atoms gains one electron **OR** one mole of gaseous atoms gains one mole of electrons	**1**
(e)(i)	number of possible arrangements of particles and energy in a system	**1**
(e)(ii)	ΔS is positive **AND** KCl(s) → K^+(aq) + Cl^-(aq) / ionic lattice solid forms aqueous **ions OWTTE** [1] **OR** ΔS is positive **AND** ΔG is (therefore becomes) negative / TΔS is greater than ΔH_{sol} **OWTTE** [1]	**1**
(e)(iii)	**more soluble** **AND** ΔG is more negative at higher T / TΔS is more positive at higher T / –TΔS is more negative at higher **ecf from (e)(ii)** [sign ΔS]	**1**

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Question	Answer	Marks
(a)(i)	(number of possible) arrangements of particles / energy in a system OR measure / degree of disorder in / of a system [1]	1
(a)(ii)	positive / + AND more gas molecules / particles in products OR more moles / molecules in products / RHS [1]	1
(b)	$\Delta H = (2 \times 150) - (1 \times 496)$ (= –196) [1] OR $\Delta H = (2 \times 150) + (4 \times 460) - (1 \times 496) - (4 \times 460)$ (= –196)	1
(c)	$\Delta G = \Delta H - T\Delta S$ seen or used with correct signs[1] $-238 = -196 - 298\Delta S$ $\Delta S = 42 / 298$ ΔS = (+)0.141 / 0.1409 (kJ K–1 mol–1) OR (+)141 / 140.9 (J K–1 mol–1) [1] ecf from $\Delta G = \Delta H + T\Delta S$ $141 = (2 \times 70) + S(O2(g)) - (2 \times 102)$ S, O2(g) = 205 / 204.94 ($J K^{-1} mol^{-1}$) [1] ecf	3
(g)(i)	enthalpy change when one mole of gaseous ions forms an aqueous solution / dissolves in water [1]	1

Question	Answer	Marks
(g)(ii)	Substances with state symbols: • AlF3(s) • AlF3(aq) OR Al3+(aq) + (3)F⁻(aq) • Al3+(g) (3)F⁻(g) [1] changes identified and three correct arrow directions (one given) [1]  	2
(g)(iii)	$\Delta H_{latt} = -4690 + (3 \times -506) - (-209) = -5999$ (kJ mol–1)	1

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Question	Answer	Marks
(a)	becomes less negative/less exothermic (down the group / from F to I) **AND** due to increase in (ionic) radius / size [1] decreased attraction to **water** **OR** weaker ion-dipole force to water [1]	2
(b)(i)	$CaF_2(aq)$ **OR** $Ca^{2+}(aq) + 2F^-(aq)$ [1]	1
(b)(ii)	• atomisation energy of **Ca** / $\Delta H_{at(o)m)}$ • atomisation energy of **F**$_{(2)}$ / $\Delta H_{at(o)m)}$ **OR F-F** bond energy / BE of **F-F** • first ionisation energy / IE_1 of **Ca** / ΔH_{i1} • second ionisation energy / IE_2 of **Ca** / ΔH_{i2} • (first) electron affinity /EA of **F** / ΔH_{ea} any three for [1] ALL five [2]	2

Question	Answer	Marks
(b)(iii)	energy change / energy released when one mole of an ionic compound is formed [1] from its **gas**eous **ion(s)** [1]	**2**
(b)(iv)	(ΔH_{latt} =) (change) 3 – (change) 1 [1] **OR** (ΔH_{latt} =) $\Delta H_f(CaF_2(s)) - \Delta H_f(Ca^{2+}(g)) - 2\Delta H_f(F^-(g))$	**1**
(c)	expression involves four correct numbers (13, 1395, 1214, 1650) **AND** 2 times [1] 1395 – 1650 + 2x = –1214+13 $\Delta H_f(F^-(g))$ × = –473 [1] ecf correct answer [2]	**2**
(d)	number of possible **arrangements** of **particles / energy** in a **system** [1]	**1**
(e)	states or clearly uses $\Delta G = \Delta H - T\Delta S$ [1] **OR** 6000 = 30 000 – (298 × ΔS) ΔS = (+)80.5(4) [1] min 3sf ecf correct answer [2]	**2**
(f)	becomes **more** soluble **AND** ΔS is positive / $T\Delta S$ is positive / $-T\Delta S$ is negative (as T inc) [1] (so ΔG becomes more negative)	**1**

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Question	Answer	Marks
(a)	<table><tr><th>energy change</th><th>always positive</th><th>always negative</th><th>either negative or positive</th></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> **both** [1]	**1**
(b)	(energy change) when **1 mole** of solute is dissolved in an infinite amount of **water** to form a dilute solution	**1**
(c)	calculation of $\Delta H^{\ominus}_{sol}$ with –251, –1284 and –2035 only and two correct signs [1] calculation of $\Delta H^{\ominus}_{sol}$ with –251, –1284 and –2035 only and correct signs **OR** calculation of $\Delta H^{\ominus}_{sol}$ with (–251 × 3), –1284 and –2035 only and two correct signs [2] $\Delta H^{\ominus}_{sol}$ = (3 × –251) + (–1284) – (–2035) = **–2** (kJ mol^{-1}) [3]	**3**
(d)	Ca^{2+} have a higher charge / greater charge density [1] **ora** **stronger** electrostatic forces between Br^- and Ca^{2+} [1]	**2**
(e)(i)	$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ [1]	**1**
(e)(ii)	$T\Delta S$ is more positive **OR** $-T\Delta S$ becomes more negative [1]	**1**

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Question	Answer	Marks
(a)	**M1:** correct use of stoichiometry **M2:** answer + 189	**2**
(b)	**M1:** States or uses correct form of Gibbs equation $\Delta G = \Delta H - T\Delta S$ **M2:** appreciates / includes $\Delta G = 0$ at temperature required **M3:** uses 1000 correctly and answer +624(.339) Award 3 marks for correct answer	**3**
(c)	negative **and** decrease in number / amount of gas molecules	**1**

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Question	Answer	Marks
(a)(i)	• energy change • when one electron is added • to each atom /ion in one mole of • gaseous atoms /ions Award one mark for two correct statements. Award two marks for four correct statements	2
(a)(ii)	**M1** energy change when 1 mole of an ionic compound is formed **M2** from gas phase ions/ gaseous ions	2

Question	Answer	Marks
(b)	**M1** use of data (with no multipliers) 31, 131, -2678 **M2** extraction of data 908, 1730, 193 **M3** use of (2 x-325) **M4** evaluation of <u>their</u> expression correctly, as shown $\Delta H_f(ZnBr_2)$ = 131 + (908 +1730) + 193 + 31 + (2 x-325) + (-2678) = **-335** kJ mol^{-1} [4]	4
(c)(i)	Br^- is a largest ion/larger ion than Cl^- so attraction between Br^- and Zn^{2+} is smaller	1
(c)(ii)	O^{2-} is a smallest ion/smaller ion than Cl^- **AND** O^{2-} has the highest charge/ higher charge than Cl^- (so attraction between O^{2-} and Zn^{2+} is larger)	1

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Question	Answer	Marks
(a)(i)	(+193 + 242 + 590 + 1150 + (2 × –349)) [1] answer (+)1477 [1]	2
(a)(ii)	(–795 – 83 – 1477) [1] –2355 [1]	2
(a)(iii)	(–2355 –(2 × –364)) [1] –1627 [1]	2
(a)(iv)	Z–Y or X–W [1]	1
(a)(v)	less (exothermic) and both ions (in $CaCl_2$) are larger [1]	1
(b)(i)	soluble barium salt **AND** soluble sulfate [1]	1
(b)(ii)	less soluble (down the group) [1] ΔH_{lat} and ΔH_{hyd} both decrease down the group [1] ΔH_{hyd} decreases more / faster / is dominant factor [1] ΔH_{sol} gets less exo / more endo [1]	4

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