23. Chemical energetics

23.2 Enthalpies of solution and hydration

Paper 4

Question Paper

1 **(c)** Define enthalpy change of solution, $\Delta H^{\ominus}_{sol}$.

.....

..... [1]

(d) Some relevant energy changes for $AgNO_3$ are shown in Table 4.1.

Table 4.1

energy change	value / kJ mol^{-1}
enthalpy change of solution of $AgNO_3$(s)	+22.6
enthalpy change of hydration of silver ions	–475
enthalpy change of hydration of nitrate ions	–314

(i) Complete the energy cycle in Fig. 4.1 to show the relationship between the lattice energy, $\Delta H^{\ominus}_{latt}$, of $AgNO_3$(s) and the energy changes shown in Table 4.1.

Include state symbols for all the species.

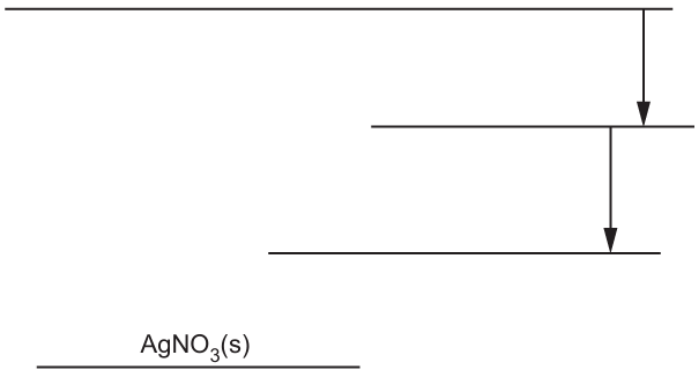

Fig. 4.1

[2]

(ii) Calculate the lattice energy, $\Delta H^{\ominus}_{latt}$, of $AgNO_3$(s).

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

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

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..... [3]

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

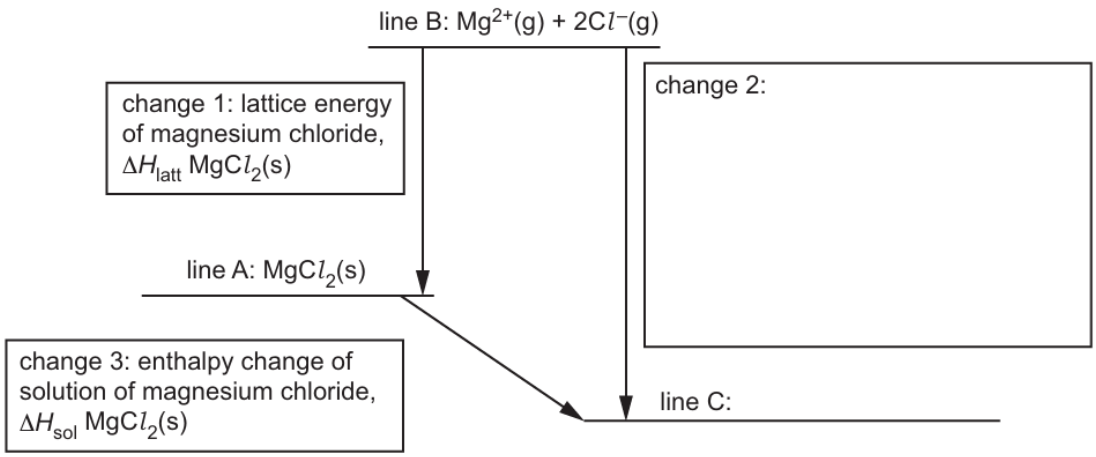

Fig. 2.1

(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, ΔH_{latt} $MgCl_2(s)$, by selecting and using appropriate data from Table 2.1.

Table 2.1

energy change	value / 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 Mg^{2+}	–1920
enthalpy change of hydration of Cl^-	–364

ΔH_{latt} $MgCl_2(s)$ = ... kJ mol^{-1} [3]

(c) Define entropy.

.....

..... [1]

3 **(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^{-1}
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, $CaBr_2(s)$	–103.1
standard enthalpy change of formation of calcium bromide, $CaBr_2(s)$	–682.8
standard enthalpy change of hydration of Ca^{2+}	–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, $\Delta H^{\ominus}_{latt}$, of $CaBr_2(s)$.

It may be helpful to draw a labelled energy cycle.

Show your working.

$\Delta H^{\ominus}_{latt}$ of $CaBr_2(s)$ = ... $kJ\,mol^{-1}$ [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, $\Delta H^{\ominus}_{hyd}$, of Br^-.

It may be helpful to draw a labelled energy cycle.

If you were not able to answer **(c)(i)**, use $-2500\,kJ\,mol^{-1}$ as your value for $\Delta H^{\ominus}_{latt}$ of $CaBr_2(s)$. This is **not** the correct value.

Show your working.

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

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

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.....

..... [2]

4 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 $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$

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

.....

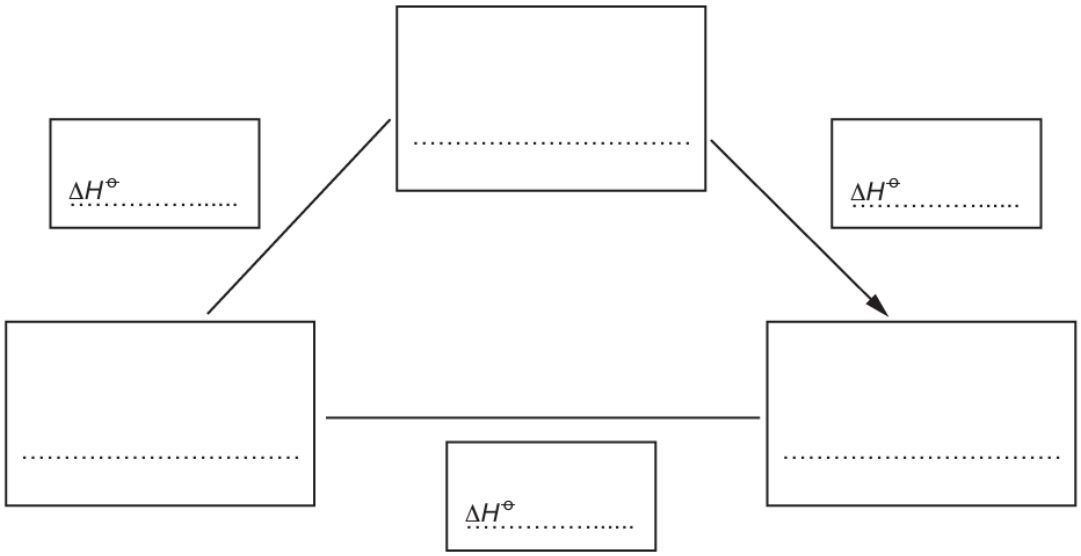
..... [1]

(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]

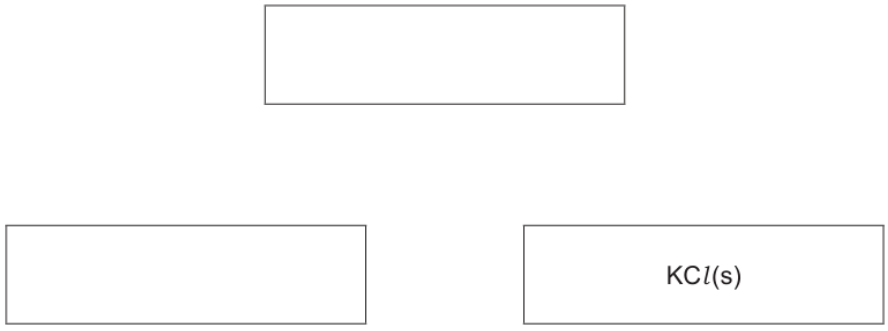
5 Potassium chloride, KCl, and magnesium chloride, MgCl_2, are both ionic solids.

Table 1.1

energy change	value / kJ mol^{-1}
standard enthalpy change of solution, $\Delta H^{\ominus}_{sol}$, of KCl	+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 MgC$l_2$(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.



[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]

6 Calcium chloride, $CaCl_2$, is an ionic solid.

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

Table 1.1

energy change	value / kJ mol^{-1}
lattice energy, $\Delta H^{\ominus}_{latt}$, $CaCl_2(s)$	–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

(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^{-1}
standard enthalpy change of solution of $CaCl_2(s)$	–83
standard enthalpy change of hydration of $Ca^{2+}(g)$	–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, $Cl^-(g)$. It may be helpful to draw an energy cycle. Show all your working.

$\Delta H^{\ominus}_{hyd}(Cl^-(g))$ = ... kJ mol^{-1} [2]

7 **(a)** **(ii)** Use the following data to calculate a value for the enthalpy change of solution of copper(II) chloride, $CuCl_2(s)$. You might find it helpful to construct an energy cycle.

enthalpy change of hydration of Cl^- = –378 kJ mol^{-1}
enthalpy change of hydration of Cu^{2+} = –2099 kJ mol^{-1}
lattice energy of $CuCl_2(s)$ = –2824 kJ mol^{-1}

enthalpy change of solution of $CuCl_2(s)$ = ... kJ mol^{-1} [2]

(iii) The enthalpy change of hydration of Ca^{2+} is –1579 kJ mol^{-1}.

Use the *Data Booklet* to suggest why there is a big difference in the values of ΔH_{hyd} for Ca^{2+} and Cu^{2+}.

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..... [2]

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

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..... [1]

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

.....

.....

..... [2]

9 **(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]