23. Chemical energetics

23.1 Lattice energy and Born-Haber cycles

Paper 4

Question Paper

1 **(e)** Suggest the trend in the magnitude of the lattice energies of the metal nitrates, $NaNO_3(s)$, $Mg(NO_3)_2(s)$ and $RbNO_3(s)$.

Explain your answer.

....
most exothermic least exothermic

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.... [3]

2 **(b)** Define lattice energy, ΔH_{latt}.

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.... [2]

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

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.... [2]

(d) Table 1.1 shows some energy changes.

Table 1.1

energy change	value / $kJ\,mol^{-1}$
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, $K_2S(s)$	–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.

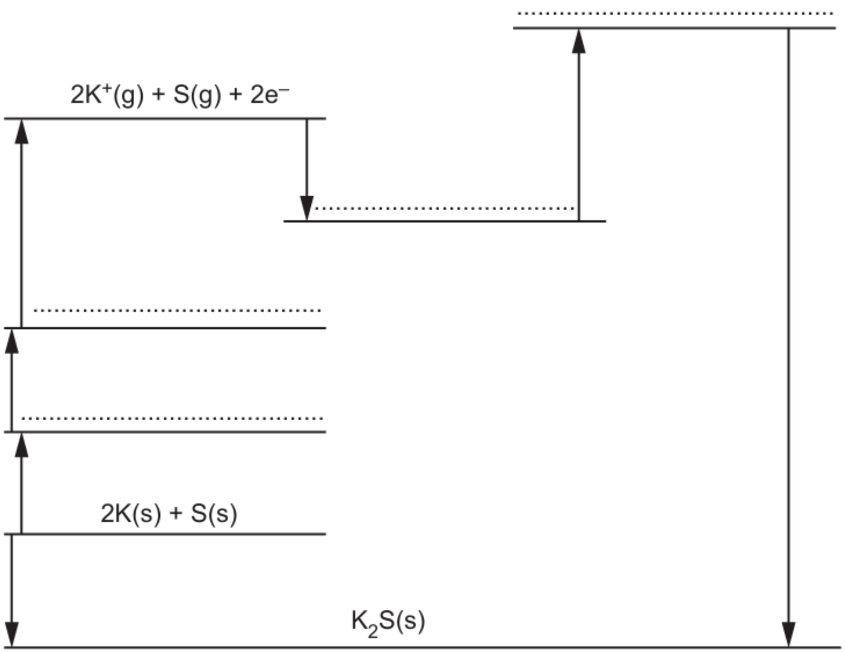

Fig. 1.1

[3]

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

Show your working.

$\Delta H^{\ominus}_{latt}$ of $K_2S(s)$ = ... kJ mol^{-1} [2]

3 **(b)** **(i)** Define lattice energy.

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....

.... [2]

(ii) The lattice energy of the Group 2 carbonates, $\Delta H^{\ominus}_{\text{latt}}(MCO_3)$, becomes less exothermic down the group.

The lattice energy of the Group 2 oxides, $\Delta H^{\ominus}_{\text{latt}}(MO)$, also becomes less exothermic down the group.

$\Delta H^{\ominus}_{\text{latt}}(MCO_3)$ and $\Delta H^{\ominus}_{\text{latt}}(MO)$ change by **different** amounts going down the group.

Suggest how the standard enthalpy change of the decomposition reaction for Group 2 carbonates changes down the group.

Explain your reasoning in terms of the relative sizes of the anions and the relative changes in lattice energy down the group.

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.... [2]

4 **(a)** Complete Table 3.1 by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

Table 3.1

energy change	always positive	always negative	can be either negative or positive
bond energy			
enthalpy change of atomisation			
enthalpy change of formation			

[1]

(b) Define standard enthalpy change of atomisation.

....

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.... [2]

(c) Table 3.2 shows some energy changes.

Table 3.2

energy change	value / kJ mol^{-1}
standard enthalpy change of atomisation of silver	+285
first ionisation energy of silver	+731
second ionisation energy of silver	+2074
bond energy of O=O	+496
bond energy of O–O	+150
first electron affinity of oxygen	–141
second electron affinity of oxygen	+798
first ionisation energy of oxygen	+1314
standard enthalpy change of formation of silver oxide, $Ag_2O(s)$	–31

Calculate the lattice energy, $\Delta H^{\ominus}_{latt}$, of $Ag_2O(s)$ using relevant data from Table 3.2.

It may be helpful to draw a labelled energy cycle.

Show your working.

$\Delta H^{\ominus}_{latt}$ of $Ag_2O(s)$ = ... $kJ\,mol^{-1}$ [3]

(d) Suggest the trend in the magnitude of the lattice energies of the silver compounds Ag_2S, Ag_2O and Ag_2Se.

Explain your answer.

....	....	....
least exothermic		most exothermic

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....

[2]

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

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

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

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

(ii) Suggest how the lattice energy of $BaSO_4(s)$ differs from the lattice energy of $Cs_2SO_4(s)$. Explain your answer.

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.... [2]

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

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.... [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.

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.... [1]

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

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.... [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^{-1}
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 $ZnI_2(s)$	–208
lattice energy, $\Delta H^{\ominus}_{latt}$, of zinc iodide, $ZnI_2(s)$	–2605
first ionisation energy of iodine	+1008
second ionisation energy of iodine	+1846
I–I bond energy	+151
enthalpy change of sublimation of iodine, $I_2(s) \rightarrow I_2(g)$	+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 = ... kJ mol^{-1} [3]

(c) Predict how $\Delta H^{\ominus}_{\text{latt}}$ of $CdI_2(s)$ differs from $\Delta H^{\ominus}_{\text{latt}}$ of $ZnI_2(s)$.
Place a tick (✓) in the appropriate box in Table 3.2.

Table 3.2

$\Delta H^{\ominus}_{\text{latt}}$ of $CdI_2(s)$ is less negative than $\Delta H^{\ominus}_{\text{latt}}$ of $ZnI_2(s)$	$\Delta H^{\ominus}_{\text{latt}}$ of $CdI_2(s)$ is the same as $\Delta H^{\ominus}_{\text{latt}}$ of $ZnI_2(s)$	$\Delta H^{\ominus}_{\text{latt}}$ of $CdI_2(s)$ is more negative than $\Delta H^{\ominus}_{\text{latt}}$ of $ZnI_2(s)$

Explain your answer.

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.... [1]

7 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, ΔH°_{sol}, of KCl	+15
lattice energy, ΔH°_{latt}, of $KCl(s)$	–701
standard enthalpy change of hydration, ΔH°_{hyd}, of K^+	–322
standard enthalpy change of hydration, ΔH°_{hyd}, of Cl^-	–364
standard enthalpy change of solution, ΔH°_{sol}, of $MgCl_2$	–155
lattice energy, ΔH°_{latt}, of $MgCl_2(s)$	–2493

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

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.... [2]

(d) Define the following terms.

(i) enthalpy change of atomisation ....

.... [1]

(ii) first electron affinity ....

.... [1]

8 A transition element is a d-block element which forms one or more stable ions with incomplete d-orbitals.

(c) Iron(II) carbonate, $FeCO_3$, and nickel(II) carbonate, $NiCO_3$, both decompose when heated.

$FeCO_3$ decomposes at a lower temperature than $NiCO_3$.

Suggest a possible reason for this difference. Explain your answer.

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.... [2]

9 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

(a) Define lattice energy.

....

.... [1]

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

$\Delta H^{\ominus}_{f}(CaCl_2(s))$ = ... 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 **one** tick (✓) in this column
$-342\,kJ\,mol^{-1}$	
$-364\,kJ\,mol^{-1}$	
$-386\,kJ\,mol^{-1}$	

explanation ....

.... [1]

10 **(a)** **(i)** Define the term *lattice energy*.

....

....

.... [2]

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

....

.... [2]

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

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.... [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^{-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]

12 Radium is a Group 2 element.

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

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

....

.... [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 / kJ mol^{-1}
enthalpy change for $Ra(s) \rightarrow Ra^{2+}(g) + 2e^-$	+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 $\frac{1}{8}S_8(s) + 2e^- \rightarrow S^{2-}(g)$	+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 S_8 molecules in the solid state.

Use the data in this question to calculate the enthalpy change for the reaction $S_8(s) \rightarrow 8S(g)$.

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

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

standard enthalpy change, $\Delta H_f^{\ominus}$ = ... kJ mol^{-1} [2]

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

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.... [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.

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....

.... [2]

(iii) The lattice energies of sodium chloride, NaC*l*, and radium sulfide, RaS, are –771 kJ mol^{-1} and –2612 kJ mol^{-1}, respectively.

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

Explain your answer.

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.... [1]

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

....

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.... [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, $ZnBr_2(s)$.

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

(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]

14 **(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

(i) Define the term *lattice energy*.

....

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.... [2]

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

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.... [1]

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

$\Delta H_{latt}MgO(s)$ = ... $kJ\,mol^{-1}$

$\Delta H_{latt}BaO(s)$ = ... $kJ\,mol^{-1}$

[1]

(c) Use the following data and relevant data from the *Data Booklet* to calculate a value for the lattice energy of magnesium fluoride, $MgF_2(s)$.

You might find it helpful to construct an energy cycle.
Show your working.

electron affinity of F(g) = –348 kJ mol^{-1}
enthalpy change of atomisation of Mg(s) = +147 kJ mol^{-1}
enthalpy change of formation of $MgF_2(s)$ = –1102 kJ mol^{-1}

$\Delta H_{latt} MgF_2(s)$ = ... [3]

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

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.... [2]

(ii) The electron affinity of carbon, C(g), is –120 kJ mol^{-1}.

Suggest an explanation for the difference between the electron affinity of fluorine and the electron affinity of carbon.

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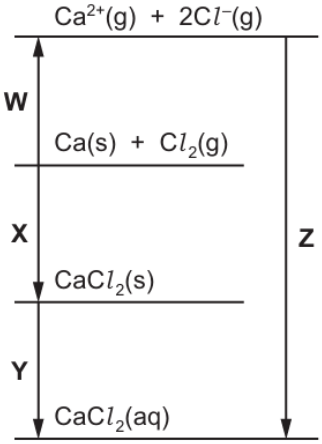
.... [1]

15 **(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.



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.

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.... [1]

16 **(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]

17 **(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]

(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.

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.... [2]

18 Sodium oxide, Na_2O, is a white crystalline solid with a high melting point.

(d) Use the data below, and other suitable data from the *Data Booklet*, to calculate the lattice energy of sodium oxide, $\Delta H^{\ominus}_{\text{latt}}$ $Na_2O(s)$.

energy change	value / kJ mol^{-1}
standard enthalpy change of formation of sodium oxide, $\Delta H^{\ominus}_{\text{f}}$ $Na_2O(s)$	–416
standard enthalpy change of atomisation of sodium, $\Delta H^{\ominus}_{\text{at}}$ Na(s)	+109
electron affinity of O(g)	–142
electron affinity of O^-(g)	+844

$\Delta H^{\ominus}_{\text{latt}}$ $Na_2O(s)$ = ... kJ mol^{-1} [4]

(e) State how $\Delta H^{\ominus}_{\text{latt}}$ $Na_2S(s)$ differs from $\Delta H^{\ominus}_{\text{latt}}$ $Na_2O(s)$.
Indicate this by placing a tick (✓) in the appropriate box in the table.

$\Delta H^{\ominus}_{\text{latt}}$ $Na_2S(s)$ is more exothermic than $\Delta H^{\ominus}_{\text{latt}}$ $Na_2O(s)$	$\Delta H^{\ominus}_{\text{latt}}$ $Na_2S(s)$ is the same as $\Delta H^{\ominus}_{\text{latt}}$ $Na_2O(s)$	$\Delta H^{\ominus}_{\text{latt}}$ $Na_2S(s)$ is less exothermic than $\Delta H^{\ominus}_{\text{latt}}$ $Na_2O(s)$

Explain your answer.

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[2]