Chemical energetics - 2023 A2 Chemistry 9701

1. Nov/2023/Paper_9701/41/No.3(a, b, c, g)

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

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

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

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

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

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

....

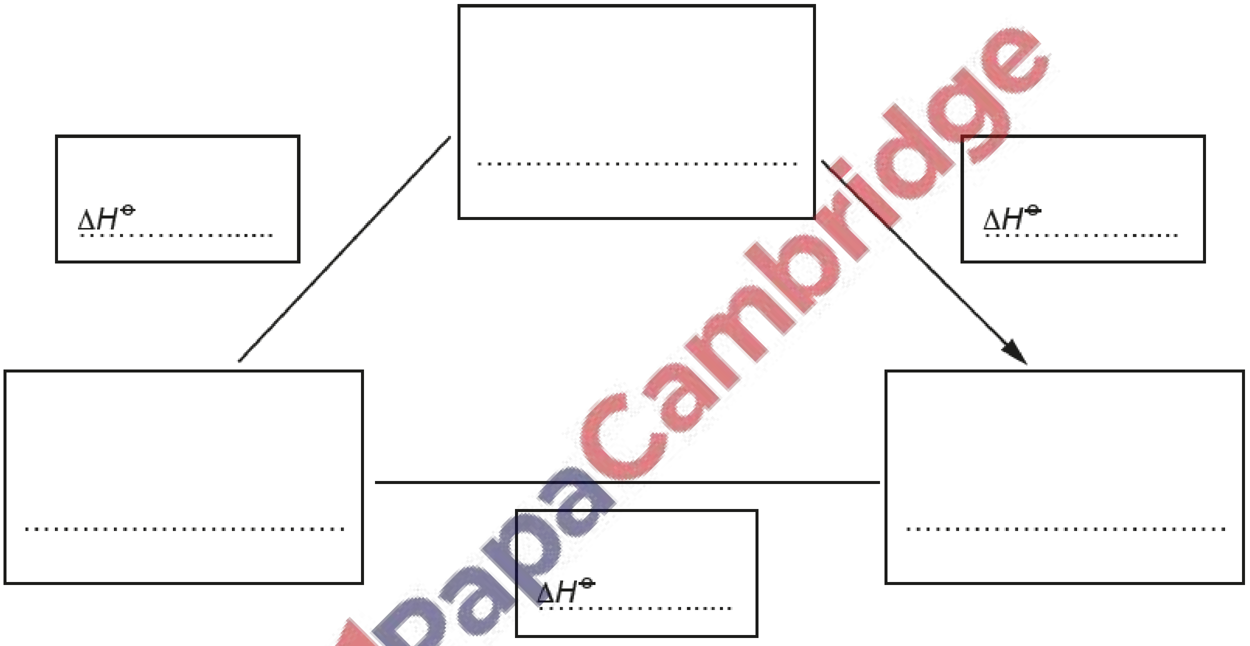
.... [1]

(ii) Aluminium fluoride, $\mathrm{A}l\mathrm{F}_3$, is an ionic solid.

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

- the enthalpy change of solution of $\mathrm{A}l\mathrm{F}_3$, $\Delta H^{\ominus}_{\text{sol}}$
- the lattice energy of $\mathrm{A}l\mathrm{F}_3$, $\Delta H^{\ominus}_{\text{latt}}$
- the enthalpy changes of hydration of $\mathrm{A}l^{3+}$ and F^-, $\Delta H^{\ominus}_{\text{hyd}}$.

Include state symbols for all substances and ions.



[2]

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(iii) Relevant data for this question are given.

$\Delta H^{\ominus}_{\text{sol}}\,\mathrm{A}l\mathrm{F}_3 = -209\,\text{kJ mol}^{-1}$

$\Delta H^{\ominus}_{\text{hyd}}\,\mathrm{A}l^{3+} = -4690\,\text{kJ mol}^{-1}$

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

Use these data and your energy cycle in **(g)(ii)** to calculate the $\Delta H^{\ominus}_{\text{latt}}$ of $\mathrm{A}l\mathrm{F}_3$.

$\Delta H^{\ominus}_{\text{latt}}$ of $\mathrm{A}l\mathrm{F}_3$ = ... kJ mol^{-1} [1]

2. June/2023/Paper_9701/41/No.5(b), (c)

(b) The exhaust systems of many diesel-fuelled cars contain an additional system to reduce vehicle emissions. This uses a liquid that is added to the exhaust system.

This liquid contains urea, $(NH_2)_2CO$, which decomposes on heating to isocyanic acid, HNCO, and ammonia.

reaction 1 $(NH_2)_2CO \rightarrow HNCO + NH_3$

Isocyanic acid reacts with water vapour to form ammonia and carbon dioxide.

reaction 2 $HNCO(g) + H_2O(g) \rightarrow NH_3(g) + CO_2(g)$

Some values for standard enthalpy changes of formation, $\Delta H_f^{\ominus}$, and standard entropies, $S^{\ominus}$, are given in Table 5.1.

Table 5.1

compound	$\Delta H_f^{\ominus}$ / kJ mol^{-1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
HNCO(g)	–101.7	+238.2
$H_2O(g)$	–241.8	+188.8
$NH_3(g)$	–45.9	+192.8
$CO_2(g)$	–393.5	+213.8

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

....

.... [1]

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(ii) Use the data in Table 5.1 to calculate $\Delta G^{\ominus}$ for **reaction 2** at 25 °C.
Show your working.

$\Delta G^{\ominus}$ = ... kJ mol^{-1} [4]

(c) The ammonia formed in reactions 1 and 2 can be used to remove nitrogen dioxide from exhaust emissions, as shown.

reaction 3 $$8NH_3 + 6NO_2 \rightarrow 7N_2 + 12H_2O$$

Use the equations for reactions 1, 2 and 3 to construct an overall equation for the reduction of NO_2 by $(NH_2)_2CO$.

.... [1]

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3. June/2023/Paper_9701/41/No.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^{-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

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(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.

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$\Delta H^{\ominus}_{hyd}$ 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.

....

....

.... [2]

[Total: 9]

4. June/2023/Paper_9701/42/No.1(a _ b)

(a) Group 2 carbonates decompose when heated to form the metal oxide and carbon dioxide.

(i) Suggest a mechanism for the decomposition of the carbonate ion by adding **two** curly arrows in Fig. 1.1.

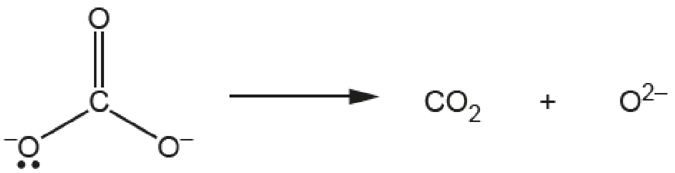

Fig. 1.1

[1]

(ii) Describe the variation in the thermal stability of Group 2 carbonates. Explain your answer.

....

....

....

....

.... [3]

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

....

....

.... [2]

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

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

$\Delta H^{\ominus}_{\mathrm{latt}}(\mathrm{MCO_3})$ and $\Delta H^{\ominus}_{\mathrm{latt}}(\mathrm{MO})$ 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]

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5. June/2023/Paper_9701/42/No.3(a _f)

(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.

....

....

.... [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

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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

....

....

....

[2]

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(e) Silver sulfite, $Ag_2SO_3(s)$, is sparingly soluble in water.

(i) Give an expression for the solubility product, K_{sp}, of Ag_2SO_3.

K_{sp} =

[1]

(ii) Calculate the equilibrium concentration of Ag^+ in a saturated solution of Ag_2SO_3 at 298 K.

[K_{sp}: Ag_2SO_3, 1.50×10^{-14} mol^3 dm^{-9} at 298 K]

$[Ag^+]$ = ... mol dm^{-3} [1]

(f) The standard enthalpy change of solution, $\Delta H^{\ominus}_{sol}$, of $AgNO_3(s)$ in water is +22.6 kJ mol^{-1}.

Suggest how the feasibility of dissolving $AgNO_3(s)$ in water changes with temperature.

Explain your answer.

....

....

....

.... [2]

[Total: 12]

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6. March/2023/Paper_9701/42/No.1

(a) The most common zinc mineral contains zinc(II) sulfide, ZnS.

(i) Complete the electrons in boxes diagram in Fig. 1.1 to show the electronic configuration of a zinc(II) ion.

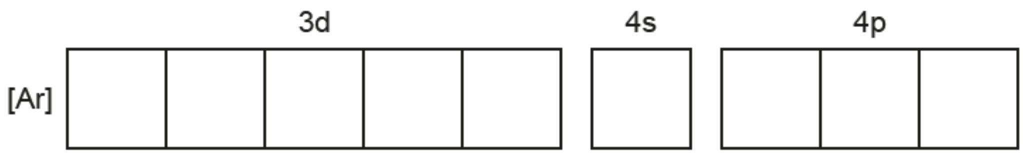

Fig. 1.1

[1]

(ii) Complete Fig. 1.2 to show the Born–Haber diagram for the ionic solid ZnS.

Include state symbols of relevant species.

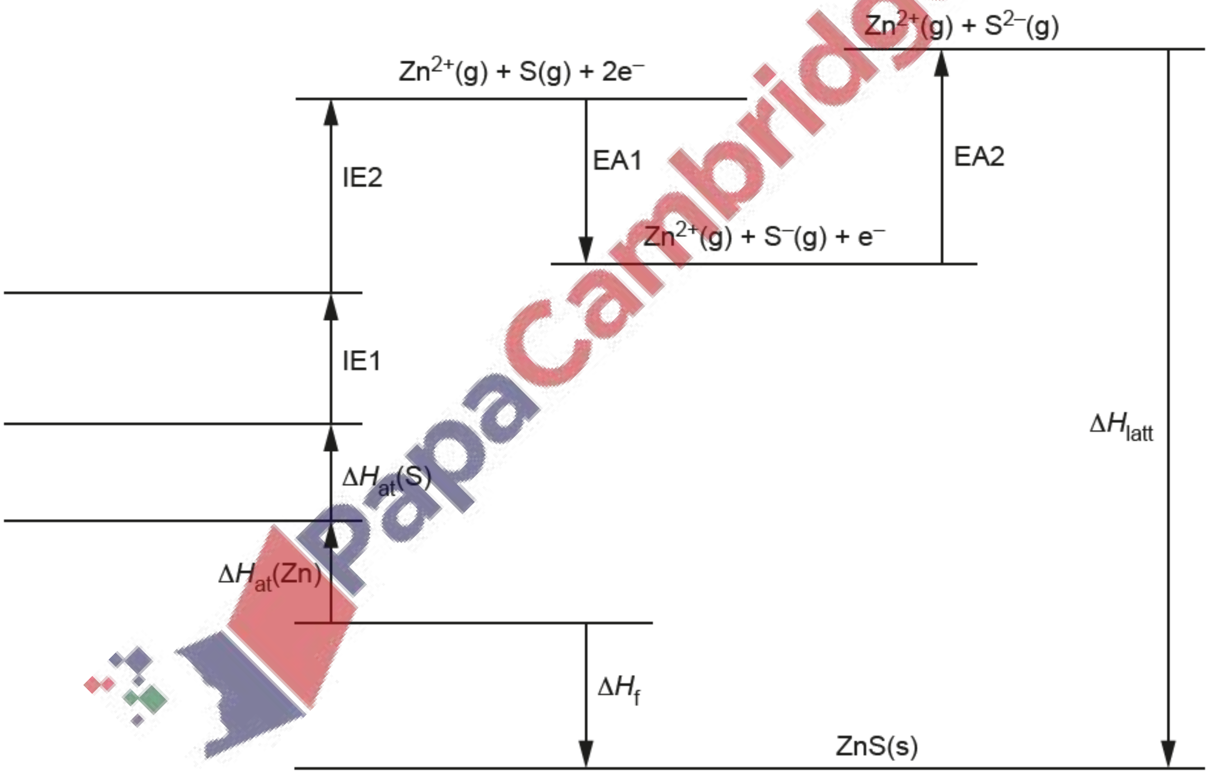

Fig. 1.2

[3]

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(iii) Describe the trend in the first electron affinity of the Group 16 elements S to Te.

Explain your answer.

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....

....

.... [2]

(iv) Explain why the lattice energy, ΔH_{latt}, of ZnO is more exothermic than that of ZnS.

....

....

....

.... [2]

(b) Zinc metal can be obtained in a two-step process as shown.

step 1 $2ZnS(s) + 3O_2(g) \longrightarrow 2ZnO(s) + 2SO_2(g)$

step 2 $ZnO(s) + C(s) \longrightarrow Zn(l) + CO(g)$

The reactions are carried out at 800 °C.

(i) Predict the sign of the entropy change, $\Delta S^{\ominus}$, of the reaction in **step 1**.

Explain your answer.

....

.... [1]

(ii) Use the data in Table 1.1 to calculate $\Delta S^{\ominus}$ of the reaction shown in **step 2**.

Table 1.1

chemical	ZnO(s)	C(s)	Zn(l)	CO(g)
$S^{\ominus}$ / $J K^{-1} mol^{-1}$	43.7	5.7	50.8	197.7

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

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(iii) An equation for the direct reduction of ZnS by carbon is shown.

$$2ZnS(s) + C(s) \longrightarrow 2Zn(l) + CS_2(g) \qquad \begin{aligned}\Delta H^{\ominus} &= +733\,\text{kJ mol}^{-1}\\ \Delta S^{\ominus} &= +218\,\text{J K}^{-1}\,\text{mol}^{-1}\end{aligned}$$

This reaction is **not** feasible at 800 °C.

Calculate $\Delta G^{\ominus}$ for this reaction at 800 °C.

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

(c) $Zn(NO_3)_2$ undergoes thermal decomposition when heated. The reaction is similar to the thermal decomposition of Group 2 nitrates.

(i) Construct an equation for the thermal decomposition of $Zn(NO_3)_2$.

.... [1]

(ii) The radii of some Group 2 cations and Zn^{2+} are shown in Table 1.2.

Table 1.2

cation	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	Zn^{2+}
radius / pm	65	99	113	135	74

State and explain the trend in thermal stability of the Group 2 nitrates down the group.

....

....

.... [2]

(iii) Use Table 1.2 to suggest which Group 2 nitrates are **less** thermally stable than zinc nitrate.

.... [1]

[Total: 16]

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