Enthalpy Change & Hess's Law

Question Paper 1

Level	International A Level
Subject	Chemistry
Exam Board	CIE
Topic	Chemical Energetics
Sub-Topic	Enthalpy Change & Hess's Law
Paper Type	Theory
Booklet	Question Paper 1

Time Allowed:	**78 minutes**
Score:	**/65**
Percentage:	**/100**

Grade Boundaries:

A*	A	B	C	D	E	U
>85%	777.5%	70%	62.5%	57.5%	45%	<45%

1 Ethane reacts with chlorine to form chloroethane.

$$C_2H_6(g) + Cl_2(g) \rightarrow C_2H_5Cl(g) + HCl(g)$$

(a) Use bond energies from the *Data Booklet* to calculate the enthalpy change for this reaction. Include a sign in your answer.

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

(ii) State the conditions needed for this reaction to occur.

..... [1]

(iii) Use a series of equations to describe the mechanism of this reaction including the names of each stage and an indication of how butane can be produced as a minor by-product.

.....

.....

.....

.....

.....

..... [5]

(b) Chloroethane can be converted back into ethane by a two-stage process via an intermediate compound, **X**.

$$C_2H_5Cl \xrightarrow{\text{reaction 1}} \mathbf{X} \xrightarrow{\text{reaction 2}} C_2H_6$$

(i) Give the name of **X**.

..... [1]

(ii) Suggest the reagent and conditions needed for reaction 1.

..... [2]

(iii) Suggest the reagent and conditions needed for reaction 2.

..... [1]

[Total: 13]

2 **(a)** Silver sulfate, Ag_2SO_4, is sparingly soluble in water. The concentration of its saturated solution is 2.5×10^{-2} mol dm^{-3} at 298 K.

(i) Write an expression for the solubility product, K_{sp}, of Ag_2SO_4, and state its units.

K_{sp} = units: ..... [1]

(ii) Calculate the value for $K_{sp}(Ag_2SO_4)$ at 298 K.

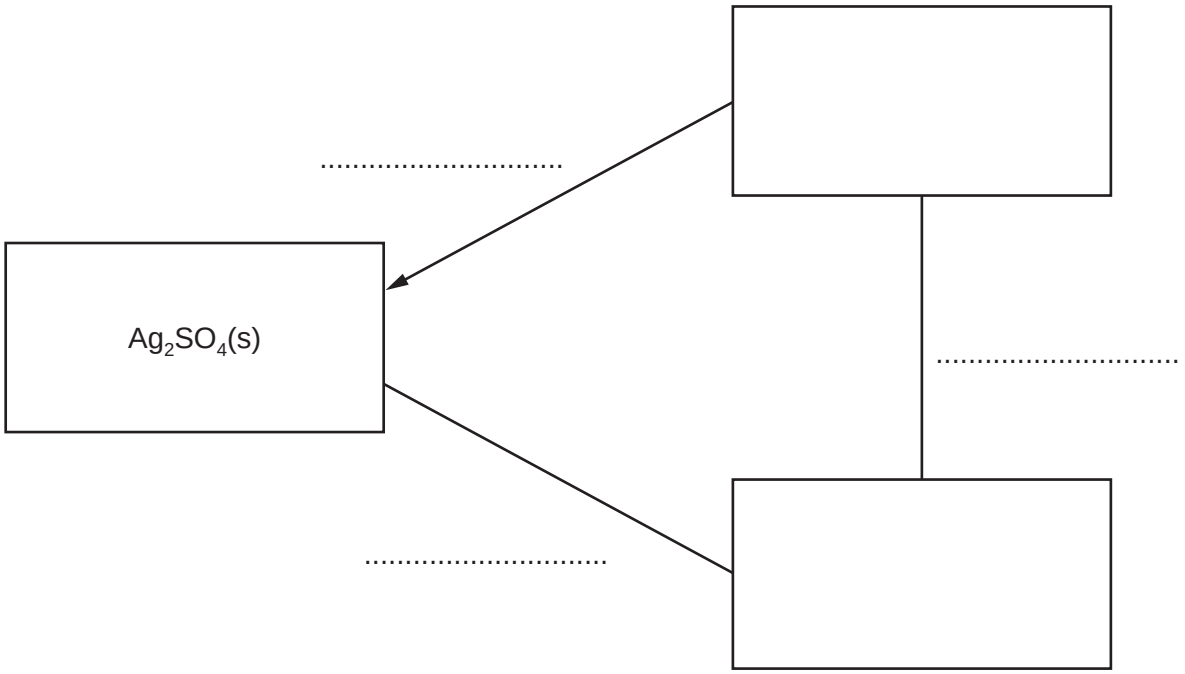
K_{sp} = ... [1]

(b) Using Ag_2SO_4 as an example, complete the following Hess' Law energy cycle relating the

- lattice energy, $\Delta H^{\ominus}_{latt}$,
- enthalpy change of solution, $\Delta H^{\ominus}_{sol}$, and
- enthalpy change of hydration, $\Delta H^{\ominus}_{hyd}$.

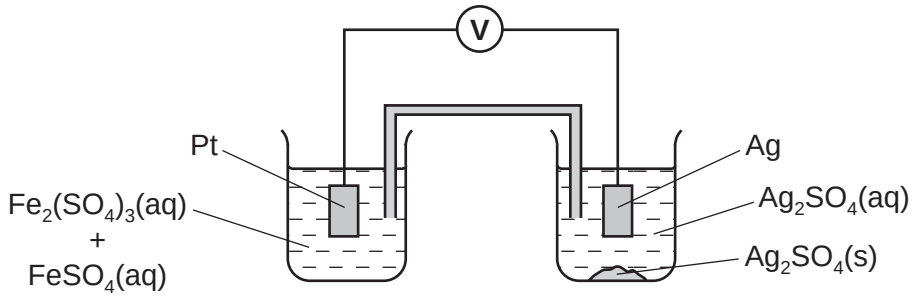
On your diagram:

- include the relevant species in the two empty boxes,
- label each enthalpy change with its appropriate symbol,
- complete the remaining two arrows showing the correct direction of enthalpy change.



[4]

(c) An electrochemical cell is set up as follows.



(i) Use the *Data Booklet* to calculate the value of $E^{\ominus}_{cell}$ under standard conditions, stating which electrode is the positive one.

$E^{\ominus}_{cell}$ = ... positive electrode: ..... [1]

(ii) How would the actual E_{cell} of the above cell compare to the $E^{\ominus}_{cell}$ under standard conditions? Explain your answer.

.....

..... [1]

(iii) How would the E_{cell} of the above cell change, if at all, if a few cm^3 of concentrated Na_2SO_4(aq) were added to

- the beaker containing Fe^{3+}(aq) + Fe^{2+}(aq),

.....

- the beaker containing Ag_2SO_4(aq)?

.....
[2]

(iv) Explain any changes in E_{cell} you have stated in **(iii)**.

.....

..... [1]

(d) Solutions of iron(III) sulfate are acidic due to the following equilibrium.

$$[Fe(H_2O)_6]^{3+}(aq) \rightleftharpoons [Fe(H_2O)_5(OH)]^{2+}(aq) + H^+(aq) \qquad K_a = 8.9 \times 10^{-4}\,mol\,dm^{-3}$$

Calculate the pH of a 0.1 mol dm^{-3} solution of iron(III) sulfate, $Fe_2(SO_4)_3$.

pH = ...
[2]

[Total: 13]

3 **(a)** Natural phosphorus consists of one isotope, ^{31}P. Chlorine exists naturally as two isotopes, ^{35}Cl and ^{37}Cl, in the relative abundance ratio of 3 : 1.

(i) The mass spectrum of PCl_3 contains several peaks corresponding to a number of molecular fragments.

Suggest the isotopic composition of the fragments with the following mass numbers.

mass number	isotopic composition
101	
103	
105	

(ii) Predict the relative ratios of the peak heights of the three peaks corresponding to these fragments.

.....

[4]

(b) Phosphorus reacts with chlorine to form a variety of chlorides.
PCl_5 is an example of a compound that exists as two structures depending on the conditions.

$$2PCl_5(g) \rightleftharpoons [PCl_4]^+[PCl_6]^-(s)$$

(i) Draw a 'dot-and-cross' diagram to show the bonding in PCl_5. Show the outer electrons only.

(ii) Draw diagrams to suggest the shapes of $[PCl_4]^+$ and $[PCl_6]^-$.

$[PCl_4]^+$ $[PCl_6]^-$

[3]

(c) Phosphorus(III) oxide, P_4O_6, contains no P–P or O–O bonds.
In the P_4O_6 molecule, all oxygen atoms are divalent and all phosphorus atoms are trivalent.

Sketch a structure for P_4O_6.

(ii) P_4O_6 can act as a ligand.

What is meant by the term *ligand*?

.....

.....

[2]

(d) Phosphate ions in water can be removed by adding a solution containing $Ca^{2+}(aq)$ ions, which form a precipitate of calcium phosphate, $Ca_3(PO_4)_2$.

(i) Write an expression for the K_{sp} of $Ca_3(PO_4)_2$.

K_{sp} =

(ii) The solubility of $Ca_3(PO_4)_2$ is 2.50×10^{-6} mol dm^{-3} at 298 K.

Calculate the solubility product, K_{sp}, of $Ca_3(PO_4)_2$ at this temperature. Include the units.

K_{sp} = ... units .....

[4]

(e) What is meant by the term *lattice energy*?

.....

.....

(ii) Explain why the lattice energy of calcium phosphate is **less** exothermic than that of magnesium phosphate.

.....

.....

[3]

[Total: 16]

4 **(a)** **(i)** What is meant by the term *lattice energy*?

.....

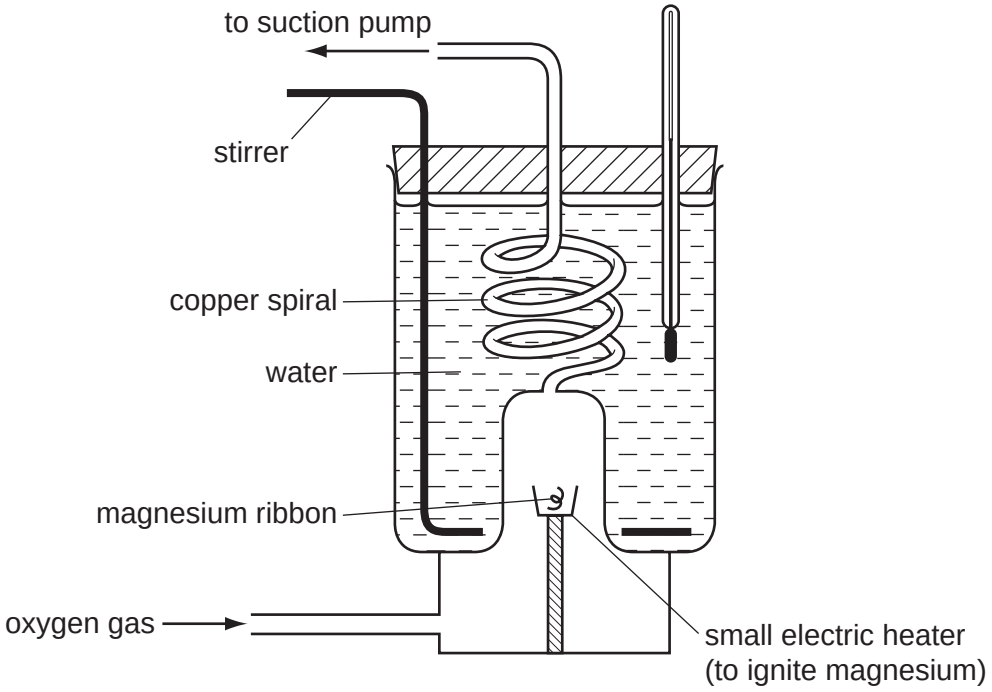
.....

(ii) Write an equation to represent the lattice energy of MgO.

.....

[3]

(b) The apparatus shown in the diagram can be used to measure the enthalpy change of formation of magnesium oxide, $\Delta H_f^{\ominus}$(MgO).



List the measurements you would need to make using this apparatus in order to calculate $\Delta H_f^{\ominus}$(MgO).

.....

.....

.....

..... [3]

(c) Use the following data, together with appropriate data from the *Data Booklet*, to calculate a value of $\Delta H_f^{\ominus}$(MgO).

lattice energy of MgO(s)	=	–3791 kJ mol^{-1}
enthalpy change of atomisation of Mg	=	+148 kJ mol^{-1}
electron affinity of the oxygen atom	=	–141 kJ mol^{-1}
electron affinity of the oxygen anion, O^-	=	+798 kJ mol^{-1}

$\Delta H_f^{\ominus}$(MgO) = ... kJ mol^{-1}
[3]

(d) Write equations, including state symbols, for the reactions, if any, of the following two oxides with water. Suggest values for the pH of the resulting solutions.

oxide	equation	pH of resulting solution
Na_2O		
MgO		

[3]

[Total: 12]

5 For some chemical reactions, such as the thermal decomposition of potassium hydrogencarbonate, $KHCO_3$, the enthalpy change of reaction cannot be measured directly.

In such cases, the use of Hess' Law enables the enthalpy change of reaction to be calculated from the enthalpy changes of other reactions.

(a) State Hess' Law.

.....

.....

..... [2]

In order to determine the enthalpy change for the thermal decomposition of potassium hydrogencarbonate, two separate experiments were carried out.

experiment 1

30.0 cm^3 of 2.00 mol dm^{-3} hydrochloric acid (an excess) was placed in a conical flask and the temperature recorded as 21.0 °C.
When 0.0200 mol of potassium carbonate, K_2CO_3, was added to the acid and the mixture stirred with a thermometer, the maximum temperature recorded was 26.2 °C.

(b) (i) Construct a balanced equation for this reaction.

.....

(ii) Calculate the quantity of heat produced in **experiment 1**, stating your units.
Use relevant data from the *Data Booklet* and assume that all solutions have the same specific heat capacity as water.

(iii) Use your answer to **(ii)** to calculate the enthalpy change per mole of K_2CO_3.
Give your answer in kJ mol^{-1} and include a sign in your answer.

(iv) Explain why the hydrochloric acid must be in an excess.

.....

..... [4]

experiment 2

The experiment was repeated with 0.0200 mol of potassium hydrogencarbonate, $KHCO_3$.
All other conditions were the same.
In the second experiment, the temperature fell from 21.0 °C to 17.3 °C.

(c) (i) Construct a balanced equation for this reaction.

.....

(ii) Calculate the quantity of heat absorbed in **experiment 2**.

(iii) Use your answer to **(ii)** to calculate the enthalpy change per mole of $KHCO_3$.
Give your answer in kJ mol^{-1} and include a sign in your answer.

[3]

(d) When $KHCO_3$ is heated, it decomposes into K_2CO_3, CO_2 and H_2O.

$$2KHCO_3 \rightarrow K_2CO_3 + CO_2 + H_2O$$

Use Hess' Law and your answers to **(b)(iii)** and **(c)(iii)** to calculate the enthalpy change for this reaction.
Give your answer in kJ mol^{-1} and include a sign in your answer.

[2]

[Total: 11]