Born-Haber Cycles

Question Paper 5

Level	International A Level
Subject	Chemistry
Exam Board	CIE
Topic	Chemical Energetics
Sub-Topic	Born-Haber Cycles
Paper Type	Theory
Booklet	Question Paper 5

Time Allowed: **64 minutes**

Score: **/53**

Percentage: **/100**

Grade Boundaries:

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

1 (a) Write equations, with state symbols, to definethefollowing.

(i) the C–Br bond energy in CH_3Br

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(ii) the A*l*–C*l* bond energy in A*l*C*l*$_3$

.....

[3]

(b) Describe and explain the trend in bond energies of the bonds in C*l*$_2$, Br_2 and I_2.

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.....

(ii) Fluorine, F_2, does **not** follow this trend.
Suggest a possible reason why.

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[3]

(c) Use data from the *Data Booklet* to calculate the enthalpy change of the following reaction.

$$H_2(g) + X_2(g) \rightarrow 2HX(g)$$

when X = C*l*

ΔH = ... kJ mol^{-1}

when X = I

ΔH = ... kJ mol^{-1}

(ii) Use these results to describe and explain the trend in the thermal stabilities of the hydrides of Group VII.

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[5]

(d) Bromine reacts with hot NaOH(aq) to give a solution which on cooling produces white crystals of compound **A**.
A has the following percentage composition by mass: Na, 15.2; O, 31.8; Br, 53.0.

The remaining solution contains mostly NaBr, with a little of compound **A**.

(i) Calculate the empirical formula of **A**.

(ii) Construct an equation for the reaction between Br_2 and hot NaOH(aq).

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[4]

[Total: 15]

2 Alcohols such as methanol, CH_3OH, are considered to be possible replacements for fossil fuels because they can be used in car engines.

(a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of combustion, $\Delta H_c^{\ominus}$, for methanol at 298 K.

equation .....

definition .....

.....

..... [3]

Methanol may be synthesised from carbon monoxide and hydrogen. Relevant $\Delta H_c^{\ominus}$ values for this reaction are given in the table below.

compound	$\Delta H_c^{\ominus}$ / kJ mol^{-1}
CO(g)	–283
H_2(g)	–286
CH_3OH(g)	–726

(b) Use these values to calculate $\Delta H_{reaction}^{\ominus}$ for the synthesis of methanol, using the following equation. Include a sign in your answer.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(g)$$

$\Delta H_{reaction}^{\ominus}$ = ...kJ mol^{-1}

[3]

(c) The operating conditions for this reaction are as follows.

pressure	200 atmospheres (2×10^7 Pa)
temperature	600 K
catalyst	oxides of Cr, Cu, and Zn

In the spaces below, explain how **each** of these conditions affects the **rate of formation** of methanol.

pressure

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temperature

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catalyst

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[6]

[Total: 12]

3 Carbon monoxide, CO, occurs in the exhaust gases of internal combustion engines.

(a) Suggest a dot-and-cross diagram for CO.

(ii) Suggest **one** reason why CO is produced in addition to CO_2 in some internal combustion engines.

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(iii) Carbon monoxide can be removed from the exhaust gases by a catalytic converter. Write an equation for a reaction that occurs in a catalytic converter that removes CO.

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[3]

(b) The standard enthalpy change of formation, $\Delta H_f^{\ominus}$, of CO is –111 kJ mol^{-1}, and that of CO_2 is –394 kJ mol^{-1}.
Calculate the standard enthalpy change of the following reaction.

$$C(s) + CO_2(g) \rightarrow 2CO(g)$$

$\Delta H^{\ominus}$ = ... kJ mol^{-1}

[2]

(c) Carbon monoxide reacts with a ruthenium(II) chloride complex according to the equation

$$[Ru(H_2O)_2Cl_4]^{2-} + CO \rightarrow [Ru(H_2O)(CO)Cl_4]^{2-} + H_2O.$$

(i) Describe the *type of reaction* that is occurring here.

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(ii) During the reaction, the colour of the solution changes from deep blue to green.
Explain the origin of colour in transition element complexes, and why different complexes often have different colours.

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The following table shows how the initial rate of this reaction varies with different concentrations of reactants.

$[[Ru(H_2O)_2Cl_4]^{2-}]$ / mol dm^{-3}	[CO] / mol dm^{-3}	rate / mol dm^{-3} s^{-1}
1.1×10^{-2}	1.7×10^{-3}	1.6×10^{-7}
1.6×10^{-2}	3.6×10^{-3}	2.3×10^{-7}
2.2×10^{-2}	2.7×10^{-3}	3.2×10^{-7}

(iii) Use these data to determine the order of reaction with respect to each reagent, and write the rate equation for the reaction.

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There are three possible mechanisms for this reaction, which are described below.

mechanism 1 $[Ru(H_2O)_2Cl_4]^{2-} + CO \xrightarrow{\text{slow}} [Ru(H_2O)(CO)Cl_4]^{2-} + H_2O$

mechanism 2 $[Ru(H_2O)_2Cl_4]^{2-} \xrightarrow{\text{slow}} [Ru(H_2O)Cl_4]^{2-} + H_2O$

$[Ru(H_2O)Cl_4]^{2-} + CO \xrightarrow{\text{fast}} [Ru(H_2O)(CO)Cl_4]^{2-}$

mechanism 3 $[Ru(H_2O)_2Cl_4]^{2-} + CO \xrightarrow{\text{slow}} [Ru(H_2O)_2(CO)Cl_4]^{2-}$

$[Ru(H_2O)_2(CO)Cl_4]^{2-} \xrightarrow{\text{fast}} [Ru(H_2O)(CO)Cl_4]^{2-} + H_2O$

(iv) Deduce which of these three mechanisms is consistent with the rate equation you suggested in part **(iii)**. Explain your answer.

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[10]

[Total: 15]

4 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.

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..... [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.

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(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.

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..... [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.

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(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]