IB • DP • Chemistry

2 hours 14 questions

Structured Questions: Paper 2

5.2 Hess's Law

5.2.1 Hess's Law / 5.2.2 Using Hess's Law - Cycles / 5.2.3 Using Hess's Law - Equations / 5.2.4 Using ΔHf° to Find Enthalpy Changes

Easy (5 questions)	/45
Medium (5 questions)	/51
Hard (4 questions)	/40
Total Marks	**/136**

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Easy Questions

1 (a) State Hess's Law.

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(1 mark)

(b) State the type of system in which the total amount of matter present is always constant.

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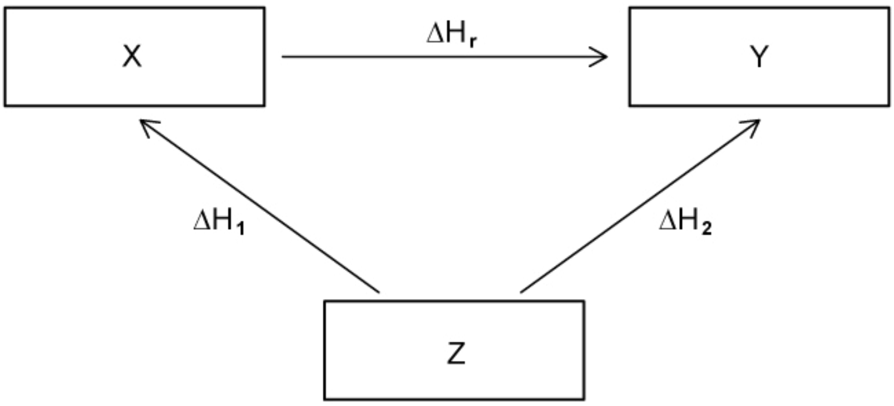
(1 mark)

(c) Using the image below, construct an equation that can be used to determine ΔH_r from ΔH_1 and ΔH_2.



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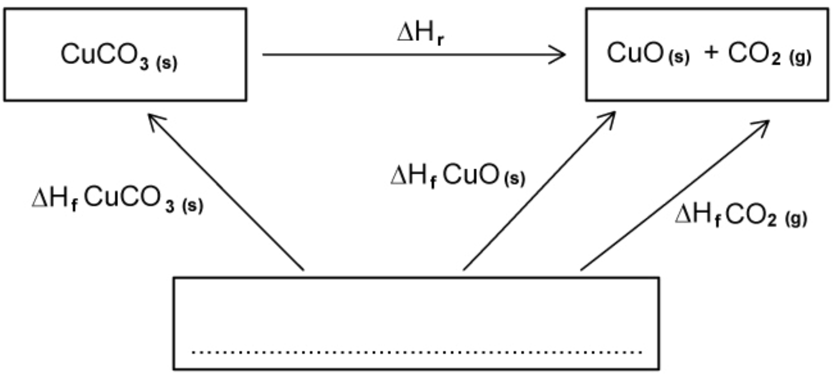
(1 mark)

(d) Complete the following Hess's Law cycle for the decomposition of copper carbonate.



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(3 marks)

2 (a) Define *standard enthalpy of formation*, ΔH_f.

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(2 marks)

(b) Write an equation to show the enthalpy of formation of 1 mole of the following compounds. Include state symbols in your equations.

Methanol, CH_3OH ....

Carbon dioxide, CO_2 ....

Ethane, C_2H_6 ....

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(8 marks)

(c) Using the equations given, construct a Hess's Law cycle for the following reaction. Include the values for ΔH_f in your cycle.

$$BaCl_2\,(s) + Zn\,(s) \rightarrow Ba\,(s) + ZnCl_2\,(s)$$

$Ba\,(s) + Cl_2\,(g) \rightarrow BaCl_2\,(s)$ $\Delta H_f = -858.6 \text{ kJ mol}^{-1}$

$Zn\,(s) + Cl_2\,(g) \rightarrow ZnCl_{2\,(s)}$ $\Delta H_f = -415.1 \text{ kJ mol}^{-1}$

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(3 marks)

(d) Calculate the enthalpy of reaction, ΔH_r, for the reaction given in part (c).

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(3 marks)

3 (a) Aluminium oxide reacts with magnesium to form magnesium oxide and aluminium in a displacement reaction via the following reaction.Construct a Hess's Law cycle for this reaction

$$Al_2O_3\ (s) + 3Mg\ (s) \rightarrow 3MgO\ (s) + 2Al\ (s)$$

Enthalpy of formation	**Enthalpy of formation (kJ mol^{-1})**
$\Delta H_f\ (Al_2O_3)$	-1675.7
$\Delta H_f\ (MgO)$	-601.7
$\Delta H_f\ (Mg)$	
$\Delta H_f\ (Al)$	

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(4 marks)

(b) Outline why no values are listed for Al (s) and Mg (s) in the table given in part (a).

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(1 mark)

(c) Calculate the enthalpy change of reaction, ΔH_r, for the reaction in part (a).

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(2 marks)

4 (a) Determine the enthalpy change of reaction, ΔH_r, for the following equations if they are reversed.

$2Na + Cl_2 \rightarrow 2NaCl$ ΔH_r = -790 kJ ....

$C_2H_4 + H_2 \rightarrow C_2H_6$ ΔH_r = -65.6 kJ ....

$2H_2O \rightarrow 2H_2 + O_2$ ΔH_r = +571 kJ ....

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(3 marks)

(b) Using the information given in part (a), determine the enthalpy change for the following reaction.

$$2C_2H_4 + 2H_2 \rightarrow 2C_2H_6$$

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(1 mark)

(c) Using the information in the table, deduce which equation should be reversed to determine the enthalpy change for the following reaction.

$$SiO_2 + 3C \rightarrow SiC + 2CO$$

Equation number	Equation	Enthalpy change (kJ)
1	$Si + O_2 \rightarrow SiO_2$	-911
2	$2C + O_2 \rightarrow 2CO$	-211
3	$Si + C \rightarrow SiC$	-65.3

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(1 mark)

(d) Use the information in part (c) to produce an overall cancelled down equation which can be used to determine the overall enthalpy change for the following reaction.

$$SiO_2 + 3C \rightarrow SiC + 2CO$$

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(2 marks)

(e) Deduce the overall enthalpy change, in kJ, using the information in part (c) for the reaction $SiO_2 + 3C \rightarrow SiC + 2CO$

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(2 marks)

5 (a) State the equation required to calculate the enthalpy change of reaction, ΔH_r, given enthalpy of formation, ΔH_f, data.

(1 mark)

(b) Using section 12 in the data booklet and the data in the table calculate the enthalpy change of reaction, ΔH_r, for the following reaction.

$$SO_2\,(g) + 2H_2S\,(g) \rightarrow 3S\,(s) + 2H_2O\,(l)$$

	SO_2 (g)	**H_2S (g)**
ΔH_f (kJ mol^{-1})	-297	-20.2

(3 marks)

(c) Show how the equations can be used to produce an alternative route for this reaction.

$$C_2H_4 + H_2 \rightarrow C_2H_6$$

	ΔH (kJ mol^{-1})
$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$	-1411
$C_2H_6 + 3½O_2 \rightarrow 2CO_2\,(g) + 3H_2O$	-1560
$H_2 + ½O_2 \rightarrow H_2O$	-285.8

(2 marks)

(d) Calculate ΔH

(1 mark)

Medium Questions

1 (a) Define the term *standard enthalpy of formation*, $\Delta H^{\ominus}{}_{f}$.

(3 marks)

(b) State Hess's Law.

(2 marks)

(c) The following equation represents the second step in the extraction of titanium, using the Kroll process:

$$TiCl_4\ (g) + 4Na\ (l) \rightarrow 4NaCl\ (s) + Ti\ (s)$$

Use the standard formation data shown in **Table 1** to calculate the enthalpy change for the reaction, $\Delta H^{\ominus}{}_{r}$.

Table 1

	$TiCl_4$ (g)	**Na (l)**	**NaCl (s)**	**Ti (s)**
$\Delta H^{\ominus}{}_{f}$ (kJ mol^{-1})	-720	+3	-411	0

(2 marks)

(d) Construct a Hess's Law cycle for the reaction of calcium fluoride, CaF_2 (s) , and sulfuric acid, H_2SO_4 (aq).

$$CaF_2 (s) + H_2SO_4 (aq) \rightarrow 2HF (g) + CaSO_4 (s)$$

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(3 marks)

2 (a) Define the term *standard enthalpy of combustion,* $\Delta H^{\ominus}_c$.

(3 marks)

(b) Write an equation for the complete combustion of propanol, $CH_3CH_2CH_2OH$ (l).

(2 marks)

(c) Construct a Hess's Law cycle for the complete combustion of propanol.

Table 1

	$CH_3CH_2CH_2OH$ (l)	O_2 (g)	CO_2 (g)	H_2O (l)
$\Delta H^{\ominus}_f$ (kJ mol^{-1})	-303	0	-393.5	-285.8

(3 marks)

(d) Use the data given in **Table 1** in part (d) to calculate the enthalpy change of the reaction, $\Delta H^{\ominus}_r$.

(3 marks)

3 (a) Urea can be used as a fertiliser and is manufactured by the reaction of ammonia and carbon dioxide via the following equation.

$$2NH_3\,(g) + CO_2\,(g) \rightarrow NH_2CONH_2\,(s) + H_2O\,(l)$$

Using the data in **Table 1** calculate the enthalpy change for the formation of urea, ΔH_r^θ.

Table 1

	NH_3 (g)	NH_2CONH_2 (s)	CO_2 (g)	H_2O (l)
$\Delta H^\ominus_f$ (kJ mol^{-1})	-46.2	-333.2	-393.5	-285.8

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(2 marks)

(b) Ammonia reacts with oxygen to produce steam and nitrogen(II) oxide. Draw a Hess's Law cycle which could be used to calculate the enthalpy change of the reaction using formation data.

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(3 marks)

(c) Use Hess's Law and the information below to calculate the enthalpy change, $\Delta H^\ominus_r$, for the conversion of one mole of ethene and one mole of hydrogen to one mole of ethane.

$C_2H_4\,(g) + 3O_2\,(g) \rightarrow 2CO_2\,(g) + 2H_2O\,(l)$ $\Delta H^\ominus_r$ = -1411 kJ mol^{-1}

$C_2H_6\,(g) + 3.5O_2\,(g) \rightarrow 2CO_2\,(g) + 3H_2O\,(l)$ $\Delta H^\ominus_r$ = -1560 kJ mol^{-1}

$H_2\,(g) + 0.5O_2\,(g) \rightarrow H_2O\,(l)$ $\Delta H^\ominus_r$ = –286 kJ mol^{-1}

(3 marks)

(d) Use Hess's Law and the information below to calculate the enthalpy change for the conversion of one mole of solid carbon into carbon monoxide.

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H^{\ominus}_r = -393.5 \text{ kJ mol}^{-1}$

$CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g)$ $\Delta H^{\ominus}_r = -283.5 \text{ kJ mol}^{-1}$

(3 marks)

4 **(a)** Define the term *standard enthalpy of reaction*, $\Delta H^{\ominus}_r$.

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(2 marks)

(b) Use Hess's Law and the information below to calculate the enthalpy change, $\Delta H^{\ominus}_r$, for the conversion of methane and ammonia to form hydrogen cyanide and hydrogen.

$N_2 (g) + 3H_2 (g) \rightarrow 2NH_3 (g)$ $\Delta H^{\ominus}_r$ = -91.8 kJ

$C (s) + 2H_2 (g) \rightarrow CH_4 (g)$ $\Delta H^{\ominus}_r$ = -74.9 kJ

$H_2 (g) + 2C (g) + N_2 (g) \rightarrow 2HCN (g)$ $\Delta H^{\ominus}_r$ = 270.3 kJ

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(4 marks)

(c) Using your answer to part (b) draw a reaction profile diagram for the reaction outlined.

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(3 marks)

(d) Draw the Lewis structure for hydrogen cyanide, HCN.

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(1 mark)

5 (a) Butane, C_4H_{10}, is typically used as fuel for cigarette lighters and portable stoves, a propellant in aerosols, a heating fuel, a refrigerant, and in the manufacture of a wide range of products.

Write an equation for the complete combustion of butane.

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(1 mark)

(b) Determine the enthalpy of formation of butane, C_4H_{10} , using the enthalpy of combustion data below.

$C (s) + O_2 (g) \rightarrow CO_2 (g)$ $\Delta H^{\ominus}{}_f = -394$ kJ

$H_2 (g) + 0.5O_2 (g) \rightarrow H_2O (l)$ $\Delta H^{\ominus}{}_f = -286$ kJ

$C_4H_{10} (g) + 6.5O_2 (g) \rightarrow 4CO_2 (g) + 5H_2O (l)$ $\Delta H^{\ominus}{}_f = -2878$ kJ

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(4 marks)

(c) Butane can be formed from the hydrogenation of butene. Using the data in **Table 1**, determine a value for the enthalpy of formation.

Table 1

Bond	Mean Bond Enthalpy $\Delta H^{\ominus}$ (kJ mol^{-1})
C-C	346
C-H	414
H-H	436
C=C	614

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(3 marks)

(d) The data book value for the hydrogenation of butene is -126 kJ mol-1. Suggest why your answer to part (c) may be different to this value.

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(1 mark)

Hard Questions

1 (a) Vanadium is commonly found in different ores such as magnetite, vanadinite and patronite. The vanadium is commonly extracted from these ores by reduction and displacement.

Vanadium can be extracted by the reduction of vanadium pentoxide, V_2O_5, with calcium at high temperatures, according to the following equation.

$$V_2O_5\ (s) + 5Ca\ (s) \rightarrow 2V\ (s) + 5CaO\ (s)$$

The enthalpy of formation of vanadium pentoxide is -1560 kJ mol^{-1} and the standard enthalpy change for the reaction is -1615 kJ mol^{-1}.

Construct a Hess's Law cycle for this reaction.

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(2 marks)

(b) Use the data in part a) to calculate the enthalpy of formation, ΔH_f, of calcium oxide in kJ mol^{-1}.

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(3 marks)

Define *standard enthalpy of neutralisation*, ΔH_{neut}.

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(c) .... **(2 marks)**

2 (a) The compound diborane, B_2H_6, is used as a rocket fuel. The equation for the combustion of diborane is shown below.

$$B_2H_6\ (g) + 3O_2\ (g) \rightarrow B_2O_3\ (s) + 3H_2O\ (l)$$

Calculate the standard enthalpy change of this reaction using the following data

I. $2B\ (s) + 3H_2\ (g) \rightarrow B_2H_6\ (g)$ ΔH = 36 kJ mol^{-1}
II. $H_2\ (g) + ½O_2\ (g) \rightarrow H_2O\ (l)$ ΔH = -286 kJ mol^{-1}

III. $2B\ (s) + 1½O_2\ (g) \rightarrow B_2O_3\ (s)$ ΔH = -1274 kJ mol^{-1}

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(3 marks)

(b) Ethyne, C_2H_2, is a useful gas as it gives a high temperature flame when burnt with oxygen. State the equation for the combustion of ethyne gas.

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(1 mark)

(c) Use your answer to part b) to construct a Hess's Law cycle for the combustion of ethyne gas.

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(3 marks)

(d) Use sections 12 and 13 in the data booklet to determine the enthalpy of formation, ΔH_f, of ethyne gas.

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(3 marks)

3 (a) Coal gasification converts coal into a combustible mixture of carbon monoxide and hydrogen known as coal gas, in a gasifier.

$$H_2O\ (l) + C\ (s) \rightarrow CO\ (g) + H_2\ (g)$$

Using the following equations, calculate the enthalpy change of reaction, ΔH_r, in kJ for cola gasification.

I. $2C\ (s) + O_2\ (g) \rightarrow 2CO\ (g)$ $\Delta H = -222$ kJ

II. $2H_2\ (g) + O_2\ (g) \rightarrow 2H_2O\ (g)$ $\Delta H = -484$ kJ

III. $H_2O\ (l) \rightarrow H_2O\ (g)$ $\Delta H = +44$ kJ

[3]

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(3 marks)

(b) This coal gas can be used as a fuel as the following equation shows.

$$CO\ (g) + H_2\ (g) + O_2\ (g) \rightarrow CO_2\ (g) + H_2O\ (g)$$

Calculation the enthalpy change of reaction, ΔH_r, in kJ for this combustion reaction from the following equations.

I. $2C\ (s) + O_2\ (g) \rightarrow 2CO\ (g)$ $\Delta H = -222$ kJ

II. $C\ (s) + O_2\ (g) \rightarrow CO_2\ (g)$ $\Delta H = -394$ kJ

III. $2H_2\ (g) + O_2\ (g) \rightarrow 2H_2O\ (g)$ $\Delta H = -484$ kJ

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(3 marks)

(c) Blending amounts of alternative fuel with conventional fuel is one way to replace petroleum. A fuel blend of 51% to 83% ethanol and the remaining being gasoline is known as E85.

If the fuel blend is vaporised before combustion, predict whether the amount of energy released would be greater, less or the same. Explain your answer.

(2 marks)

(d) Use sections 6 and 13 of the Data booklet to calculate the following.

i) The amount, in moles, of ethanol in 1 kg of E85 containing 60% ethanol.

[2]

ii) The energy released, in kJ, by ethanol if 1 kg of E85 is burnt.

[1]

(3 marks)

4 (a) Strontium salts have a number of applications such as fireworks, flares, glow in the dark paint and toothpaste for sensitive teeth. The strontium required for these salts can be extracted from the ore strontia, SrO, by displacement with powdered aluminium in a vacuum.

i) Write a balanced symbol equation, including state symbols, for the reaction of strontia with aluminium.

[2]

ii) State the role of the aluminium in this reaction.

[1]

(3 marks)

(b) The standard enthalpy change for this extraction of strontium is 99.3 kJ mol^{-1} and the standard enthalpy of formation of aluminium oxide is -1676.7 kJ mol^{-1}

Use this information to calculate the standard enthalpy of formation, ΔH_f, in kJ mol^{-1} of strontia.

(3 marks)

(c) Manganese is too brittle for use as a pure metal, so it is often alloyed with other metals. Manganese is used in steel to increase the strength and resistance to wear. Manganese steel (13% Mn) is extremely strong and used for railway tracks, safes and prison bars. Alloys of 1.5% manganese with aluminium are used to make drinks cans due to the improved corrosion resistance of the alloy.

Manganese is extracted from different ores by reduction with carbon monoxide.

$$Mn_2O_3\ (s) + 3CO\ (g) \rightarrow 2Mn\ (s) + 3CO_2\ (g)$$

The enthalpy of formation, ΔH_f, of Mn_2O_3 (s) is −971 kJ mol^{-1}. Use this information and section 12 of the data booklet to calculate the enthalpy change of reaction, ΔH_r, in kJ mol^{-1}.

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(3 marks)

(d) The reaction in part c) reaches equilibrium at high temperatures.

Use your answer to part c) to explain how temperature can be altered to increase the yield of the reaction and explain the effect that this would have on the rate of reaction.

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(3 marks)