5.2 Hess's Law

Question Paper

Course	DP IB Chemistry
Section	5. Energetics / Thermochemistry
Topic	5.2 Hess's Law
Difficulty	Medium

Time allowed: 70

Score: /51

Percentage: /100

Question 1a

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

[3 marks]

Question 1b

b) State Hess's Law.

[2 marks]

Question 1c

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]

Question 1d

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

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

[3 marks]

Question 2a

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

[3 marks]

Question 2b

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

[2 marks]

Question 2c

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]

Question 2d

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]

Question 3a

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, $\Delta H_r^{\ominus}$.

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

[2 marks]

Question 3b

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.

[3 marks]

Question 3c

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.

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

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

$H_2\ (g) + 0.5O_2\ (g) \rightarrow H_2O\ (l)$ $\quad \Delta H^{\ominus}_r = -286\ kJ\ mol^{-1}$

[3 marks]

Question 3d

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.

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

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

[3 marks]

Question 4a

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

[2 marks]

Question 4b

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.

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

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

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

[4 marks]

Question 4c

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

[3 marks]

Question 4d

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

[1 mark]

Question 5a

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.

[1 mark]

Question 5b

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

[4 marks]

Question 5c

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

[3 marks]

Question 5d

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.

[1 mark]