A-Level Chemistry

Hess's Law

Question Paper

Time available: 61 minutes
Marks available: 58 marks

1. This question is about 1-chloropropane.

(a) Define the term standard enthalpy of formation.

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(2)

(b) The equation for a reaction used to manufacture 1-chloropropane is

$$3\ CH_3CH_2CH_2OH(l) + PCl_3(l) \rightarrow 3\ CH_3CH_2CH_2Cl(l) + H_3PO_3(s)$$

The enthalpy change for this reaction, ΔH, is –114 kJ mol^{-1}

The table contains some standard enthalpy of formation data.

Substance	$PCl_3(l)$	$CH_3CH_2CH_2Cl(l)$	$H_3PO_3(s)$
$\Delta fH^{\ominus}$ / kJ mol^{-1}	–339	–130	–972

Calculate a value for the standard enthalpy of formation of propan-1-ol using the enthalpy change for the reaction and data from the table.

Standard enthalpy of formation _____ kJ mol^{-1}

(3)

(c) 1-chloropropane can also be produced by the reaction between propane and chlorine in the presence of ultraviolet light.

State why ultraviolet light is needed for this reaction to occur.

Give an equation for each propagation step in the formation of 1-chloropropane from propane.

Why ultraviolet light is needed _____

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_____

Propagation step 1 _____

_____

Propagation step 2 _____

_____

(3)

(d) The C–Cl bond in 1-chloropropane is polar because carbon and chlorine have different electronegativities.

Define the term electronegativity.

_____

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_____

(1)

(e) Ammonia reacts with 1-chloropropane to form propylamine.

Name and outline the mechanism for this reaction.

Name of mechanism _____

Outline of mechanism

(5)
(Total 14 marks)

2. This question is about enthalpy changes.

(a) A student determined the enthalpy of combustion of cyclohexane (C_6H_{12}).

The student
- placed a pure sample of cyclohexane in a spirit burner
- placed the spirit burner under a beaker containing 50.0 g of water and ignited the cyclohexane
- extinguished the flame after a few minutes.

The results for the experiment are shown in **Table 1**.

Table 1

Initial temperature of the water / °C	19.1
Initial mass of spirit burner and cyclohexane / g	192.730
Final mass of spirit burner and cyclohexane / g	192.100

The student determined from this experiment that the enthalpy of combustion of cyclohexane is –1216 kJ mol^{-1}

Use the data to calculate the final temperature of the water in this experiment.

The specific heat capacity of water = 4.18 J K^{-1} g^{-1}
The relative molecular mass (M_r) of cyclohexane = 84.0

Final temperature of the water _____ °C

(4)

(b) A data book value for the enthalpy of combustion of cyclohexane is –3920 kJ mol^{-1}

The student concluded that the temperature rise recorded in the experiment was smaller than it should have been.

Suggest a practical reason for this.

_____

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_____

(1)

(c) **Table 2** gives some values of standard enthalpies of combustion ($\Delta_c H^{\ominus}$).

Table 2

Substance	C(s)	$H_2(g)$	$C_6H_{12}(l)$
Standard enthalpy of combustion, $\Delta_c H^{\ominus}$ / kJ mol^{-1}	−394	−286	−3920

Use the data in **Table 2** to calculate the enthalpy change for the reaction represented by this equation

$$6\ C(s) + 6\ H_2(g) \rightarrow C_6H_{12}(l)$$

Enthalpy change _____ kJ mol^{-1}

(3)

(Total 8 marks)

3. This question is about energetics.

(a) Write an equation, including state symbols, for the reaction with an enthalpy change equal to the enthalpy of formation for iron(III) oxide.

_____

(1)

(b) **Table 1** contains some standard enthalpy of formation data.

Table 1

	CO(g)	$Fe_2O_3(s)$
$\Delta_f H^{\ominus}$ / kJ mol^{-1}	−111	−822

$Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(s) + 3CO_2(g)$ $\Delta H = -19$ kJ mol^{-1}

Use these data and the equation for the reaction of iron(III) oxide with carbon monoxide to calculate a value for the standard enthalpy of formation for carbon dioxide.

Show your working.

$\Delta_f H^{\ominus}$ _____ kJ mol^{-1}

(3)

(c) Some enthalpy data are given in **Table 2**.

Table 2

Process	**ΔH / kJ mol^{-1}**
$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$	−92
$N_2(g) \longrightarrow 2N(g)$	+944
$H_2(g) \longrightarrow 2H(g)$	+436

Use the data from **Table 2** to calculate the bond enthalpy for N−H in ammonia.

N−H bond enthalpy _____ kJ mol^{-1}

(3)

(d) Give one reason why the bond enthalpy that you calculated in part (c) is different from the mean bond enthalpy quoted in a data book (388 kJ mol^{-1}).

_____

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_____

(1)

(Total 8 marks)

4. (a) Write an equation, including state symbols, for the reaction with enthalpy change equal to the standard enthalpy of formation for $CF_4(g)$.

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(1)

(b) Explain why CF_4 has a bond angle of 109.5°.

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(2)

(c) **Table 1** gives some values of standard enthalpies of formation ($\Delta_f H^{\ominus}$).

Table 1

Substance	$F_2(g)$	$CF_4(g)$	HF(g)
$\Delta_f H^{\ominus}$ / kJ mol^{-1}	0	−680	−269

The enthalpy change for the following reaction is −2889 kJ mol^{-1}.

$$C_2H_6(g) + 7F_2(g) \longrightarrow 2CF_4(g) + 6HF(g)$$

Use this value and the standard enthalpies of formation in **Table 1** to calculate the standard enthalpy of formation of $C_2H_6(g)$.

Standard enthalpy of formation of $C_2H_6(g)$ = _____ kJ mol^{-1}

(3)

(d) Methane reacts violently with fluorine according to the following equation.

$$CH_4(g) + 4F_2(g) \longrightarrow CF_4(g) + 4HF(g) \quad \Delta H = -1904 \text{ kJ mol}^{-1}$$

Some mean bond enthalpies are given in **Table 2**.

Table 2

Bond	C−H	C−F	H−F
Mean bond enthalpy / kJ mol^{-1}	412	484	562

A student suggested that one reason for the high reactivity of fluorine is a weak F−F bond.

Is the student correct? Justify your answer with a calculation using these data.

(4)

(Total 10 marks)

5. This question is about the extraction of metals.

(a) Manganese can be extracted from Mn_2O_3 by reduction with carbon monoxide at high temperature.

(i) Use the standard enthalpy of formation data from the table and the equation for the extraction of manganese to calculate a value for the standard enthalpy change of this extraction.

	$Mn_2O_3(s)$	$CO(g)$	$Mn(s)$	$CO_2(g)$
$\Delta H_f^{\ominus}$/ kJ mol^{-1}	−971	−111	0	−394

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

(3)

(ii) State why the value for the standard enthalpy of formation of Mn(s) is zero.

(1)

(b) Titanium is extracted in industry from titanium(IV) oxide in a two-stage process.

(i) Write an equation for the first stage of this extraction in which titanium(IV) oxide is converted into titanium(IV) chloride.

(2)

(ii) Write an equation for the second stage of this extraction in which titanium(IV) chloride is converted into titanium.

(2)

(c) Chromium is extracted in industry from chromite ($FeCr_2O_4$).

(i) In the first stage of this extraction, the $FeCr_2O_4$ is converted into Na_2CrO_4 Balance the equation for this reaction.

.....$FeCr_2O_4$ + ...Na_2CO_3 + ...O_2 ⟶ .....Na_2CrO_4 + $2Fe_2O_3$ + $8CO_2$

(1)

(ii) In the final stage, chromium is extracted from Cr_2O_3 by reduction with aluminium.

Write an equation for this reaction.

_____

(1)

(Total 10 marks)

6. The table below contains some standard enthalpy of formation data.

Substance	C(s)	$N_2(g)$	$H_2O(g)$	$CO_2(g)$	$NH_4NO_3(s)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	0	0	–242	–394	–365

(a) Why are the values of the standard enthalpy of formation for carbon and nitrogen zero?

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(1)

(b) State Hess's Law.

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(2)

(c) Use $\Delta H_f^{\ominus}$ data from the table to calculate a value for the enthalpy change for the following reaction.

$NH_4NO_3(s) + \frac{1}{2}C(s) \rightarrow N_2(g) + 2H_2O(g) + \frac{1}{2}CO_2(g)$

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(3)

(Total 6 marks)