IB · HL · Chemistry

5 hours   30 questions

Structured Questions

Energy Cycles in Reactions

Bond Enthalpy Calculations / Hess's Law / Hess's Law Calculations / Calculate Enthalpy Changes Using ΔHf⊖ (HL) / Calculate Enthalpy Changes Using ΔHc⊖ (HL) / Born-Haber Cycles (HL) / Born-Haber Cycle Calculations (HL)

Easy (10 questions)	/87
Medium (11 questions)	/103
Hard (9 questions)	/83
Total Marks	**/273**

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Easy Questions

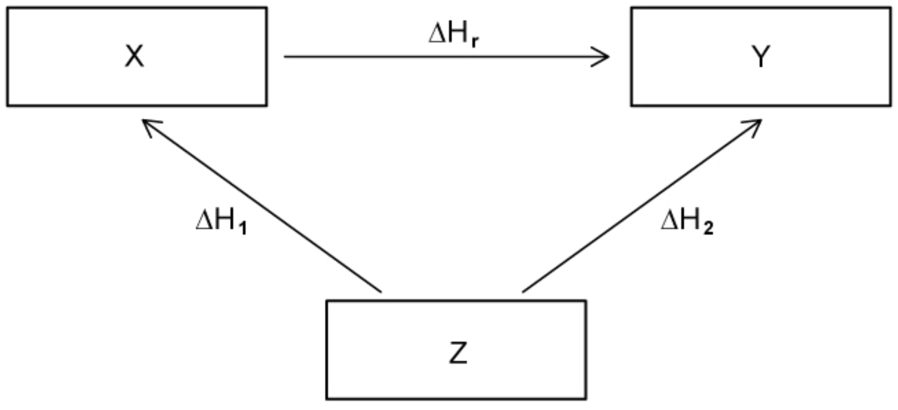
1 (a) State Hess's Law.

(1 mark)

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

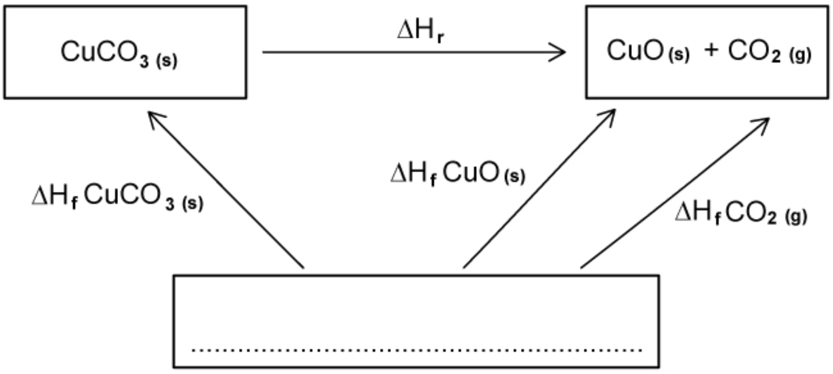
(1 mark)

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



(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) → Ba (s) + $ZnCl_2$ (s)

Ba (s) + Cl_2 (g) → $BaCl_2$ (s) ΔH_f = -858.6 kJ mol^{-1}

Zn (s) + Cl_2 (g) → $ZnCl_{2\,(s)}$ ΔH_f = -415.1 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.

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

....

(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.

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(1 mark)

(b) Using section 13 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

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(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

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(2 marks)

(d) Calculate ΔH

....

(1 mark)

6 **(a)** State the formula for calculating the standard enthalpy change of reaction, ΔH_r, using bond energies.

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(1 mark)

(b) Use section 12 of the data booklet to calculate the enthalpy change, in kJ mol^{-1}, for the following reaction.

$$Cl_2 + H_2 \rightarrow 2HCl$$

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(4 marks)

(c) State whether the energy change for the reaction in part (b) is endothermic or exothermic.

....

(1 mark)

(d) Using section 12 of the data booklet, calculate the enthalpy change of reaction, ΔH_r, in kJ mol^{-1} for the following reaction.

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

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(4 marks)

7 (a) Using molecular formulae, write the equation for the reaction of ethene with water to form ethanol.

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(2 marks)

(b) Using section 12 in the data booklet calculate the enthalpy change of reaction, ΔH_r, for the reaction of ethene with water.

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(4 marks)

(c) Define *bond dissociation energy*.

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(1 mark)

8 (a) Write one equation to represent each the following changes:

Atomisation of sodium ....

First ionisation energy of magnesium ....

First electron affinity of chlorine ....

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(3 marks)

(b) Give the definition of the term *enthalpy of lattice formation.*

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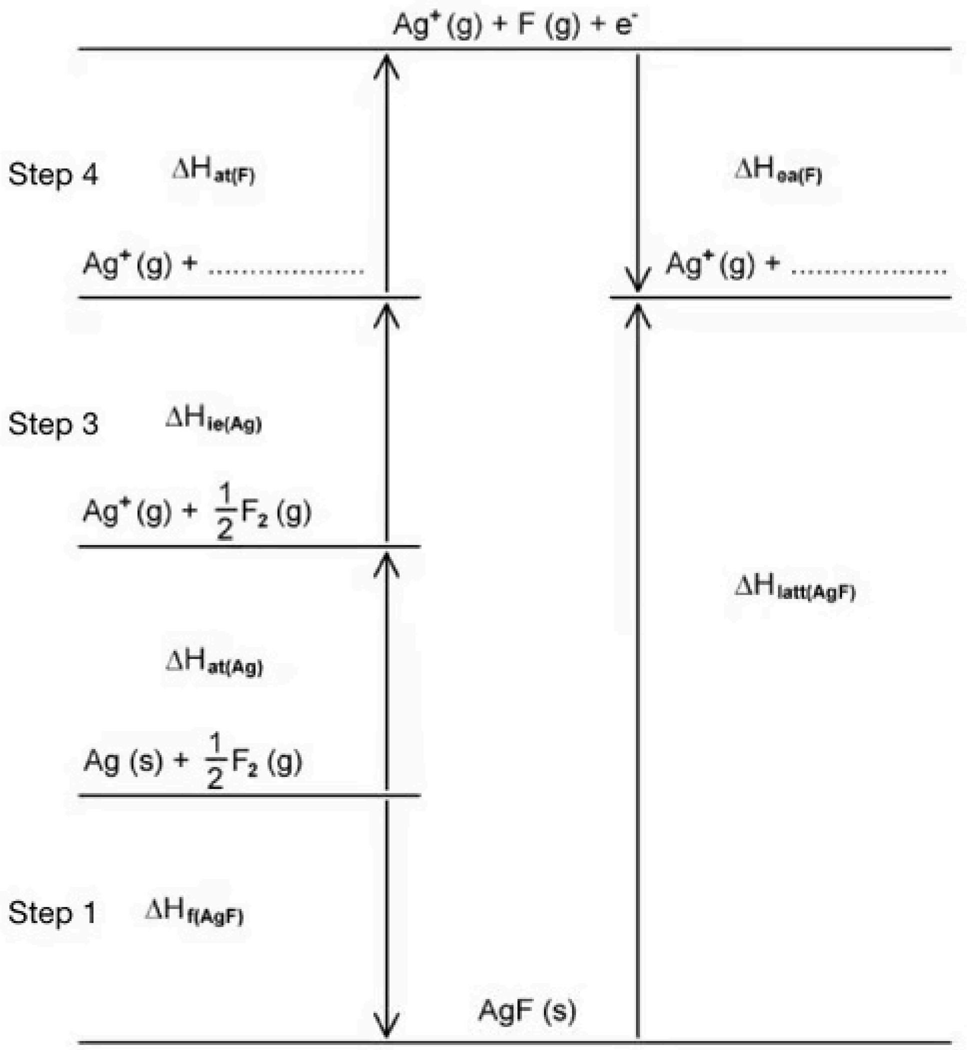
(2 marks)

(c) Study the following Born-Haber cycle.



State the enthalpy changes for the following steps:

Step 1 ....

Step 3 ....

Step 4 ....

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(3 marks)

(d) The enthalpy of lattice formation of potassium fluoride and caesium fluoride is -829 kJ mol^{-1} and -759 kJ mol^{-1} respectively.

With reference to the ions in the structure, explain why the enthalpy of lattice formation is more exothermic for potassium fluoride.

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(3 marks)

9 (a) State the definition of electron affinity, ΔH_{ea}.

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(3 marks)

(b) Electron affinities can be represented using equations.

i) State the equation which represents the first electron affinity of oxygen. [1]

ii) State the equation which represents the second electron affinity of oxygen. [1]

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(2 marks)

(c) The first and second electron affinities of oxygen are shown in the table below.

First electron affinity of O	-141 kJ mol^{-1}	Exothermic
Second electron affinity of O	+753kJ mol^{-1}	Endothermic

State why the second electron affinity of oxygen is an endothermic process.

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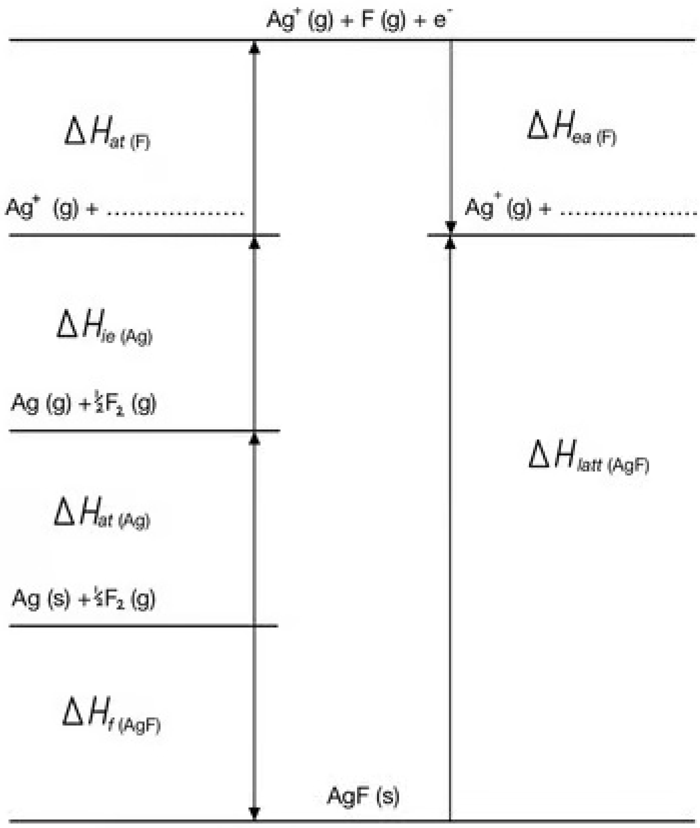
(2 marks)

10 (a) The incomplete Born-Haber cycle for silver fluoride, AgF, is shown below.



Complete the Born Haber cycle.

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(2 marks)

(b) Use the Born-Haber cycle in part a) and sections 8 and 11 in the data booklet to determine the enthalpy changes, in kJ mol^{-1}, of the following.

The enthalpy of atomisation of silver, $\Delta H_{at(Ag)}$, is +289 kJ mol^{-1}

The enthalpy of atomisation of fluorine, $\Delta H_{at(F)}$, is +79 kJ mol^{-1}

$\Delta H_{at(Ag)} + \Delta H_{ie(Ag)}$ ....

$\Delta H_{at(F)} + \Delta H_{ea(F)}$ ....

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(2 marks)

(c) Use your answer to part b) and the lattice enthalpy of silver fluoride, $\Delta H_{latt(AgF)}$, in section 18 in the data booklet to determine the enthalpy of formation of silver fluoride, $\Delta H_{f(AgF)}$, in kJ mol^{-1}.

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(3 marks)

Medium Questions

1 (a) Nitrogen oxides produced by combustion are largely nitrogen monoxide or nitrogen dioxide.

Draw Lewis diagrams for nitrogen monoxide and nitrogen dioxide and use the diagrams to explain the meaning of the term free radical.

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(3 marks)

(b) Platinum and rhodium are found in catalytic converters and facilitate the conversion of Carbon monoxide and nitrogen monoxides to nitrogen and carbon dioxide.

Write an equation for the reaction and state the changes in oxidation state for each carbon and nitrogen.

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(2 marks)

(c) Use your answer to part (c) and the bond enthalpy data given in **Table 1** to determine the enthalpy change for the reaction between carbon monoxide and nitrogen monoxide.

Table 1

C≡O	N=O	N≡N	C=O
1077 kJ mol^{-1}	587 kJ mol^{-1}	945 kJ mol^{-1}	804 kJ mol^{-1}

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(4 marks)

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

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(3 marks)

(b) State Hess's Law.

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(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

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(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)

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

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(3 marks)

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

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(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	-394	-286

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(3 marks)

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

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(3 marks)

4 **(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)
ΔH^Θ_f (kJ mol^{-1})	-46.2	-333.2	-393.5	-285.8

(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.

(3 marks)

(c) Use Hess's Law and the information below to calculate the enthalpy change, ΔH^Θ_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) → $2CO_2$ (g) + $2H_2O$ (l) ΔH^Θ_r = -1411 kJ mol^{-1}

C_2H_6 (g) + $3.5O_2$ (g) → $2CO_2$ (g) + $3H_2O$ (l) ΔH^Θ_r = -1560 kJ mol^{-1}

H_2 (g) + $0.5O_2$ (g) → H_2O (l) ΔH^Θ_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 kJ mol^{-1}

$CO (g) + ½O_2 (g) \rightarrow CO_2 (g)$ $\Delta H^\ominus_r$ = - 283.5 kJ mol^{-1}

(3 marks)

5 (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) → $2NH_3$ (g) $\Delta H^{\ominus}_{r}$ = -91.8 kJ

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

H_2 (g) + 2C (g) + N_2 (g) → 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)

6 (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)

(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)

7 (a) Enthalpy changes can be found using bond enthalpy data. Some bond enthalpy values are shown below in **Table 1**.

Table 1

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

The balanced equation for the reaction between methane and propane is

$$CH_4\,(g) + CH_3CH_2CH_3\,(g) \rightarrow CH_3CH_2CH_2CH_3\,(g) + H_2\,(g)$$

Use the equation and bond enthalpy data to calculate the enthalpy change for the above reaction.

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(3 marks)

(b) Define the term *average bond enthalpy*.

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(1 mark)

(c) Enthalpy changes can be found using bond enthalpy data. Some bond enthalpy values are shown below in **Table 2**.

Table 2

Bond	Mean Bond Enthalpy $\Delta H^{\ominus}$ (kJ mol^{-1})
C=C	614
C-H	414
O-H	463
C=O	804
O=O	498

The balanced equation for the combustion of ethene is

$$C_2H_4\,(g) + 3O_2\,(g) \rightarrow 2CO_2\,(g) + 2H_2O\,(l)$$

Use the equation and bond enthalpy data to calculate the enthalpy of combustion of ethene.

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(3 marks)

(d) Bond enthalpies can be found using Hess's Law or from experimental data.

Outline the difference between the two ways of finding bond enthalpy.

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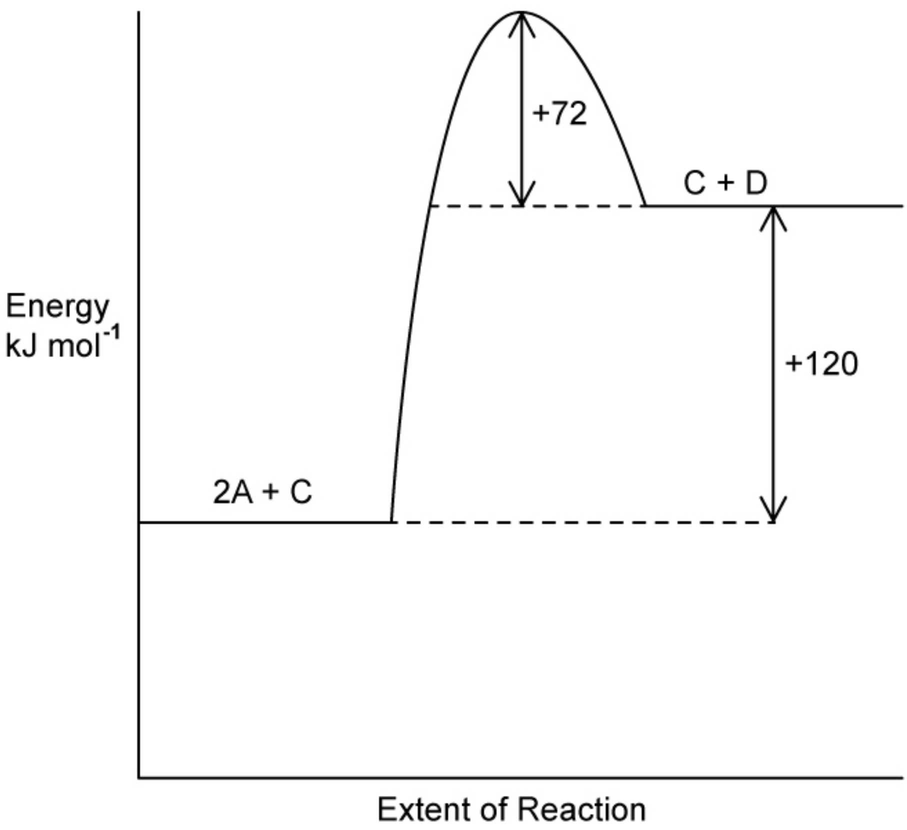
(1 mark)

8 (a) Use the energy level diagram to determine the activation energy, E_a, for the given reaction in **Figure 1**.

Figure 1



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(1 mark)

(b) Ethene can be hydrated via the following reaction:

$$C_2H_4\ (g) + H_2O\ (g) \rightarrow C_2H_5OH\ (g)$$

Table 1

Bond	**C-C**	**C=C**	**C-H**	**C-O**	**O-H**
Mean bond enthalpy (kJ mol^{-1})	346	614	414	358	463

Use the data in **Table 1** to calculate the enthalpy change for the hydration of ethene.

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(3 marks)

(c) Explain why the value to your answer to part (b) is different from the data book value for the hydration of ethene.

$$C_2H_4\ (g) + H_2O\ (g) \rightarrow C_2H_5OH\ (g)$$

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(2 marks)

(d) **Table 2** below has some enthalpy data for a different chemical reaction. Hydrazine, N_2H_4 can react with hydrogen peroxide in an exothermic reaction, as shown below.

$$N_2H_4(g) + 2H_2O_2 \rightarrow N_2(g) + 4H_2O(g) \qquad \Delta H^{\ominus}_r = -789\ kJ\ mol^{-1}$$

The structure of hydrazine is shown in **Figure 1**.

Figure 1

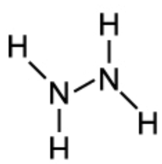

Table 2

Bond	Mean Bond Enthalpy $\Delta H^{\ominus}$ (kJ mol^{-1})
N-N	+158
N≡N	+945
O-H	+463
O-O	+144

Using the reaction equation and the data in the table above, calculate the value of the N-H bond in hydrazine.

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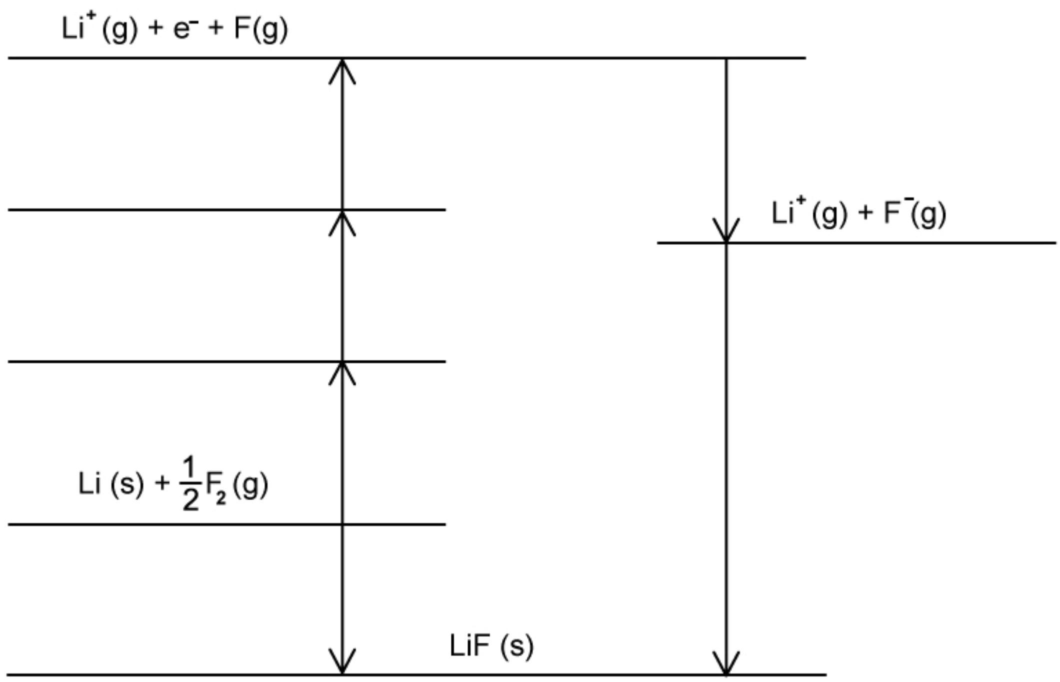
(3 marks)

9 (a) Pure crystals of lithium fluoride are used in X-ray monochromator.



i) Define the term enthalpy of atomisation.

[1]

ii) Explain why the enthalpy of atomisation of fluorine is positive.

[1]

iii) Complete the Born–Haber cycle for lithium fluoride by adding the missing species on the lines.

[2]

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(4 marks)

(b) Use the data in the following table and your completed Born–Haber cycle from part (a) to answer the questions below.

Name of enthalpy change	Energy change / kJ mol-1
Li (s) → Li (g)	+216
Li (g) → Li^+ (g) + e^-	+520
F_2 (g) → 2F (g)	+158
F (g) + e^- → F^- (g)	-348
Li (s) + ½F_2 (g) → LiF (s)	-594

i) Calculate the enthalpy of lattice formation of lithium fluoride.

[2]

ii) Explain and justify how the enthalpy of lattice formation of LiBr compares with that of LiF. You must refer to the size of the ions in your answer.

[3]

(5 marks)

10 (a) Calcium chloride has many uses including as an agent to lower the freezing point of water. It is very effective for preventing ice formation on road surfaces and as a deicer.

i) Define the term ionisation energy.

[2]

ii) Explain why the second ionisation energy of calcium is greater than the first ionisation energy.

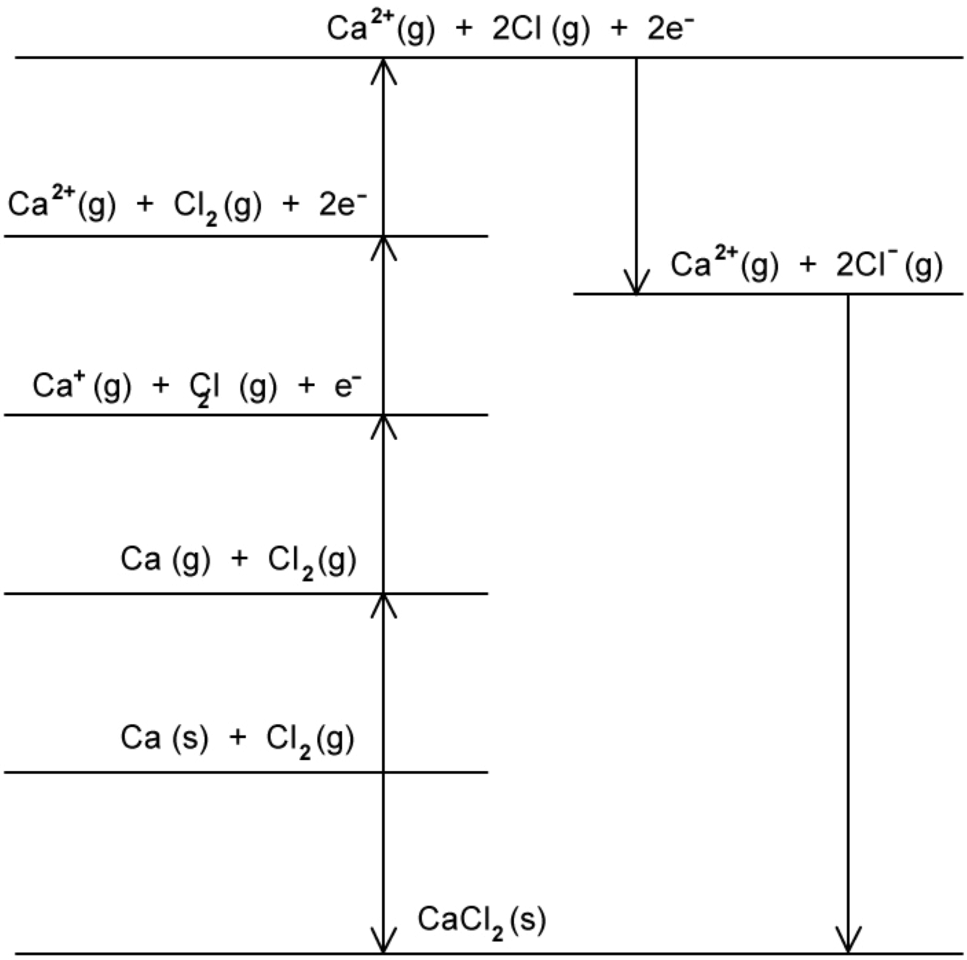
[3]

(5 marks)

(b) Describe the structure and bonding in calcium chloride.

(2 marks)

(c) The Born-Haber cycle for $CaCl_2$ is shown:



Using Section 9 in the Data Booklet and the following information, calculate the enthalpy change for the following conversions.

- ΔH^{θ}_{IE2} Ca = 1145 kJ mol^{-1}
- ΔH^{θ}_{at} Ca = 178 kJ mol^{-1}
- ΔH^{θ}_{BE} Cl_2 = 242 kJ mol^{-1}

i) Ca (s) → Ca^{2+} (g) + $2e^-$

[1]

ii) Cl_2 (g) + $2e^-$ → $2Cl^-$ (g)

[1]

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(2 marks)

(d) Using Section 16 of the Data Booklet, calculate the value for the enthalpy of formation for calcium chloride, ΔH^{θ}_{f} $CaCl_2$.

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(2 marks)

11 (a) This question is about fluorine and the associated energy changes when it reacts with magnesium to form magnesium fluoride.

i) Define the term electron affinity.

[2]

ii) Using Sections 9 and 12 in the Data Booklet and showing your working, determine the electron affinity of a fluorine atom, ΔH^{θ}_{EA}

[3]

Name of enthalpy change	**Energy change (kJ mol^{-1})**
Enthalpy of atomisation of magnesium	+150
Second ionisation energy of magnesium	+1450
Enthalpy of formation of magnesium fluoride	-642
Lattice enthalpy of formation of magnesium fluoride	-2493

(5 marks)

(b) Suggest why the first electron affinity of fluorine is an exothermic change.

(2 marks)

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}.

....

(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. $2B\ (s) + 3H_2\ (g) \rightarrow B_2H_6\ (g)$ $\Delta H = 36\ kJ\ mol^{-1}$
II. $H_2\ (g) + ½O_2\ (g) \rightarrow H_2O\ (l)$ $\Delta H = -286\ kJ\ mol^{-1}$
III. $2B\ (s) + 1½O_2\ (g) \rightarrow B_2O_3\ (s)$ $\Delta H = -1274\ kJ\ mol^{-1}$

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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 section 13 in the data booklet to determine the enthalpy of combustion, ΔH_c, of ethyne gas.

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

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

III. $H_2O\ (l) \rightarrow H_2O\ (g)$ ΔH = +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. $2C\ (s) + O_2\ (g) \rightarrow 2CO\ (g)$ ΔH = -222 kJ

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

III. $2H_2\ (g) + O_2\ (g) \rightarrow 2H_2O\ (g)$ ΔH = -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 7 and 14 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]

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(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.

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(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 13 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)

5 (a) Define the term *average bond enthalpy*.

(2 marks)

(b) Determine the bond dissociation energy, in kJ mol^{-1}, for one mole of O−F bonds using the following equation and section 12 of the data booklet. Give your answer to 3 significant figures.

$$F_2 (g) + ½O_2 (g) \rightarrow OF_2 (g) \quad \Delta H_r = +28 \text{ kJ mol}^{-1}$$

(3 marks)

(c) The reaction of ethanoyl chloride, CH_3COCl , and ethanol form an ester. State the equation for this reaction.

(2 marks)

(d) Use section 12 in the data booklet to deduce the energy required, in kJ mol^{-1}, to break the bonds.

(2 marks)

(e) Deduce the energy released, in kJ mol^{-1}, when the bonds are formed and therefore the enthalpy change for the reaction.

(3 marks)

6 (a) Methane reacts violently with fluorine to form carbon tetrafluoride and hydrogen fluoride

Formulate the equation for this reaction.

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(2 marks)

(b) Use your answer to part a) and section 12 of the data booklet to calculate the following:

i) The energy required, in kJ, to break the bonds for the reaction between methane and fluorine.

[1]

ii) The energy released, in kJ, to form the bonds for the reaction between methane and fluorine.

[1]

iii) The enthalpy change, ΔH_r, in kJ mol^{-1} for this reaction.

[2]

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(4 marks)

(c) Sketch a labelled energy diagram for the reaction of methane and fluorine.

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(3 marks)

7 (a) Hydrazine has the formula N_2H_4 and is used as a rocket fuel (e.g. for the Apollo moon rockets). It burns in the following reaction for which the enthalpy change is -583 kJ mol^{-1}.

$$N_2H_4\ (g) + O_2\ (g) \rightarrow N_2\ (g) + 2H_2O\ (g)$$

Sketch the Lewis structure of hydrazine, N_2H_4.

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(2 marks)

(b) Use section 12 of the Data booklet and the information in part a) to deduce the bond enthalpy, in kJ mol^{-1}, for the N-N bond.

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(3 marks)

(c) Outline why the value of enthalpy of reaction calculated from bond enthalpies is less accurate.

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(1 mark)

8 **(a)** Lattice enthalpies can be determined experimentally using a Born–Haber cycle and theoretically using calculations based on electrostatic principles.

The experimental lattice enthalpies of magnesium chloride, $MgCl_2$, calcium chloride, $CaCl_2$, strontium chloride, $SrCl_2$, and barium chloride, $BaCl_2$ are given in section 16 of the data booklet. Explain the trend in the values.

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(2 marks)

(b) Explain why strontium chloride, $SrCl_2$, has a much greater lattice enthalpy than rubidium chloride, RbCl.

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(2 marks)

(c) Strontium is used as a red colouring agent in fireworks as it provides a very intense red colour. Use sections 9 and 16 to calculate the enthalpy of atomisation for chlorine in strontium chloride.

Enthalpy change	**Enthalpy change (kJ mol^{-1})**
Sr (s) → Sr (g)	164.0
Sr (s) + Cl_2 (g) → $SrCl_2$ (s)	-828.9
Sr^+ (g) → Sr^{2+} (g) + e^-	1064.3

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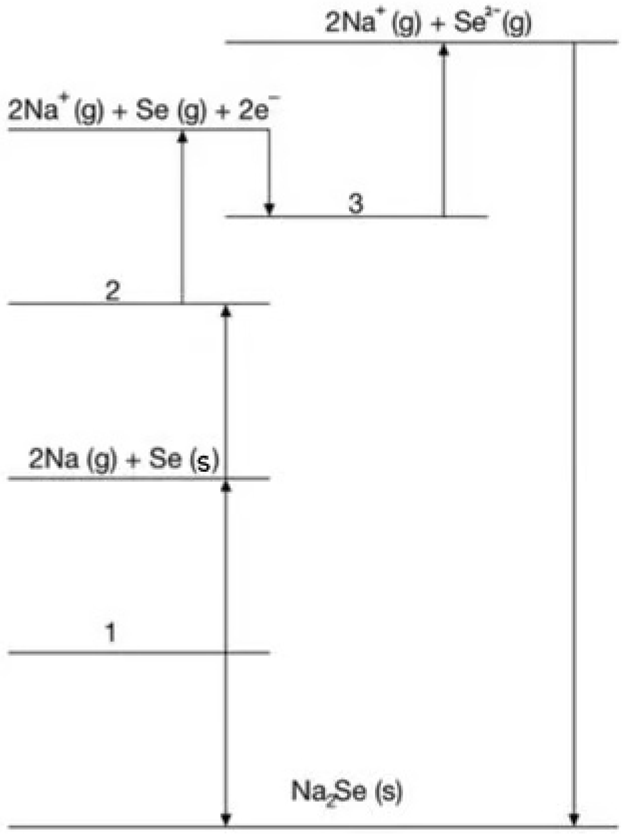
(3 marks)

9 (a) The incomplete Born-Haber cycle for sodium selenide is shown below.

State the equations for processes 1, 2 and 3.



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(3 marks)

(b) If sulfur is used as opposed to selenium in the lattice, what would you expect to happen to the value of the enthalpy of lattice dissociation. Explain your answer.

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(3 marks)

(c) Use section 9 in the data booklet and the information in the table to calculate the lattice enthalpy of aluminium oxide.

Enthalpy change	Energy change (kJ mol^{-1})
Atomisation of aluminium	+326
Atomisation of oxygen	+249
Second ionisation energy of aluminium	+1817
Third ionisation energy of aluminium	+2745
Formation of aluminium oxide	-1670

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(3 marks)