Q1. (a) A Born–Haber cycle for the formation of magnesium(II) chloride is shown below.

$$Mg^{2+}(g) + 2Cl(g) + 2e^-$$

(iii)

(iv)

$$Mg^{2+}(g) + 2Cl^-(g)$$

$$Mg^+(g) + 2Cl(g) + e^-$$

$$Mg(g) + 2Cl(g)$$

(v)

(ii)

$$Mg(g) + Cl_2(g)$$

(i)

$$Mg(s) + Cl_2(g)$$

$$MgCl_2(s)$$
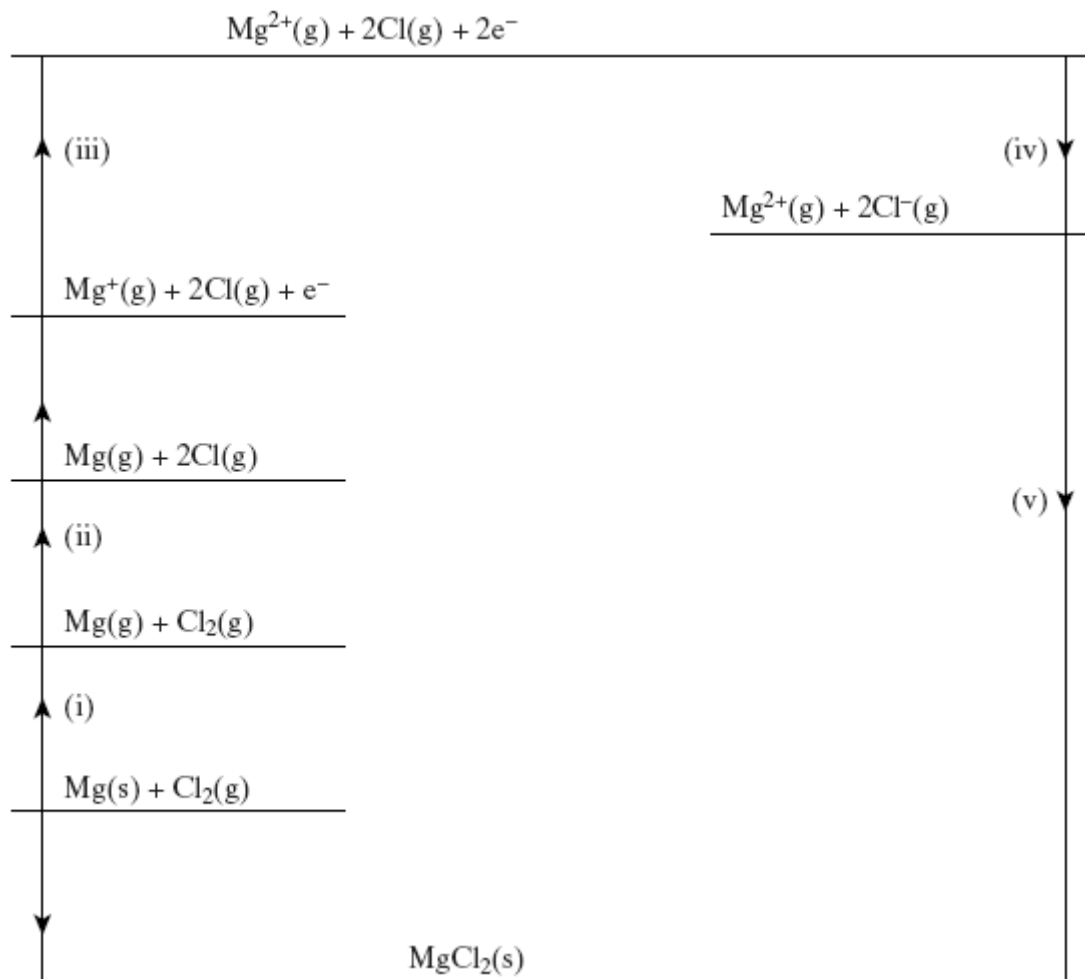
Taking care to note the direction of the indicated enthalpy change and the number of moles of species involved, give each of the enthalpy changes (i) to (v) above.

Enthalpy change (i) ....

Enthalpy change (ii) ....

Enthalpy change (iii) ....

Enthalpy change (iv) ....

Enthalpy change (v) ....

(5)

(b) Write an equation for the decomposition of MgCl(s) into $MgCl_2(s)$ and Mg(s) and use the following data to calculate a value for the enthalpy change of this reaction.

$$\Delta H_f^{\ominus} MgCl(s) = -113 \text{ kJ mol}^{-1}$$

Page 2

$$\Delta H_f^{\ominus} MgCl_2(s) = -653 \text{ kJ mol}^{-1}$$

Equation ....

Calculation ....

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(4)

(c)   Use the data below to calculate a value for the molar enthalpy of a solution of $MgCl_2(s)$.

Lattice formation enthalpy of $MgCl_2(s)$ $= -2502 \text{ kJ mol}^{-1}$

$\Delta H_{hydration}^{\ominus}$ of $Mg^{2+}(g)$ $= -1920 \text{ kJ mol}^{-1}$

$\Delta H_{hydration}^{\ominus}$ of $Cl^-(g)$ $= -364 \text{ kJ mol}^{-1}$
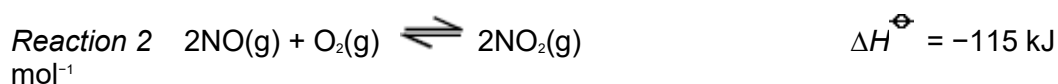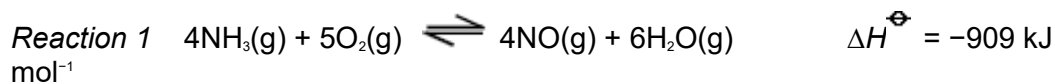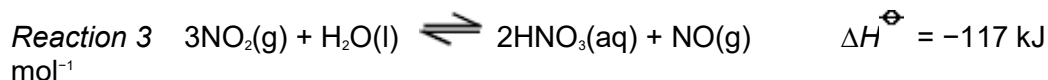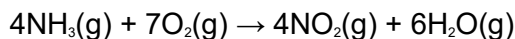
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(3)
(Total 12 marks)

Q2. The data below refer to the industrial production of nitric acid from ammonia.

Reaction 1 $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $\Delta H^{\ominus} = -909 \text{ kJ mol}^{-1}$

Reaction 2 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H^{\ominus} = -115 \text{ kJ mol}^{-1}$

Reaction 3 $3NO_2(g) + H_2O(l) \rightleftharpoons 2HNO_3(aq) + NO(g)$ $\Delta H^{\ominus} = -117$ kJ mol^{-1}

The direct oxidation of ammonia to nitrogen dioxide can be represented by the equation

$$4NH_3(g) + 7O_2(g) \rightarrow 4NO_2(g) + 6H_2O(g)$$

for which the standard enthalpy change, in kJ mol^{-1}, is

A   −1139

B   −1024

C   −794

D   −679

(Total 1 mark)

Q3.   (a)   The gaseous reactants **W** and **X** were sealed in a flask and the mixture left until the following equilibrium had been established.

$$2W(g) + X(g) \rightleftharpoons 3Y(g) + 2Z(g) \qquad \Delta H = -200 \text{ kJ mol}^{-1}$$
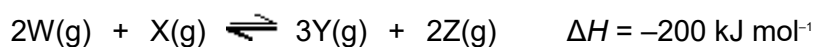
Write an expression for the equilibrium constant, K_p, for this reaction.
State one change in the conditions which would both increase the rate of reaction and decrease the value of K_p. Explain your answers.
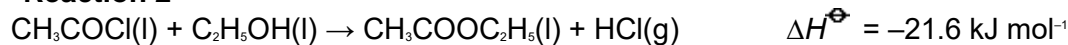
(7)

(b)   Ethyl ethanoate can be prepared by the reactions shown below.

Reaction 1
$CH_3COOH(l) + C_2H_5OH(l) \rightleftharpoons CH_3COOC_2H_5(l) + H_2O(l)$ $\Delta H^{\ominus} = -2.0$ kJ mol^{-1}

Reaction 2
$CH_3COCl(l) + C_2H_5OH(l) \rightarrow CH_3COOC_2H_5(l) + HCl(g)$ $\Delta H^{\ominus} = -21.6$ kJ mol^{-1}

(i)   Give one advantage and one disadvantage of preparing ethyl ethanoate by **Reaction 1** rather than by **Reaction 2**.

(ii)   Use the information given above and the data below to calculate values for the standard entropy change, $\Delta S^{\ominus}$, and the standard free-energy change, $\Delta G^{\ominus}$, for **Reaction 2** at 298 K.
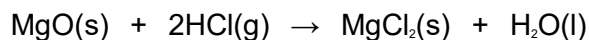
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	CH$_3$COCl(l)	C$_2$H$_5$OH(l)	CH$_3$COOC$_2$H$_5$(l)	HCl(g)
$S^{\ominus}$/JK^{-1}mol^{-1}	201	161	259	187

(8)
(Total 15 marks)

Q4. (a) Define the term *standard enthalpy of formation*.

(3)

(b) State Hess's Law and use it, together with the data given in the table below, to calculate the standard enthalpy change for the following reaction.

MgO(s) + 2HCl(g) → MgCl$_2$(s) + H$_2$O(l)

	MgO	HCl(g)	MgCl$_2$	H$_2$O
$\Delta H_f^{\ominus}$/kJ mol^{-1}	−602	−92	−642	−286

(4)

(c) In an experiment, an excess of solid magnesium oxide was added to 50 cm^3 of 3.0 mol dm^{-3} hydrochloric acid. The initial temperature of the solution was 21 °C. After reaction, the temperature had risen to 53 °C. (The specific heat capacity of water is 4.2 J K^{-1} g^{-1})

Use this information to calculate the enthalpy change for the reaction of one mole of magnesium oxide with hydrochloric acid. For your calculation you should assume that all the heat from the reaction is used to raise the temperature of 50 g of water.

(8)
(Total 15 marks)

Q5.   Chlorine is formed in a reversible reaction as shown by the equation

$$4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$$

(a)   Use the data below to calculate the standard enthalpy change, $\Delta H^{\ominus}$, and the standard entropy change, $\Delta S^{\ominus}$, for this reaction.

Substance	HCl(g)	O_2(g)	Cl_2(g)	H_2O(g)
$\Delta H_f^{\ominus}$/kJ mol^{-1}	−92	0	0	−242
$S^{\ominus}$/ J K^{-1} mol^{-1}	187	205	223	189

Standard enthalpy change, $\Delta H^{\ominus}$ ....

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Standard entropy change, $\Delta S^{\ominus}$ ....

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(6)

(b)   The data below apply to a different gas phase reversible reaction.

Standard enthalpy change, $\Delta H^{\ominus}$ = +208 kJ mol^{-1}
Standard entropy change, $\Delta S^{\ominus}$ = +253 J K^{-1} mol^{-1}

(i)   Deduce the effect of an increase in temperature on the position of the equilibrium in this reaction. Use Le Chatelier's principle to explain your answer.
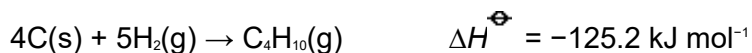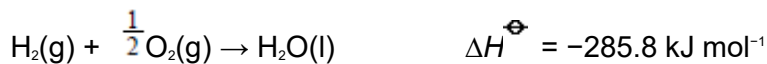
Effect ....

Explanation ....

(ii)   Calculate the minimum temperature at which this reaction is feasible.

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(7)
(Total 13 marks)

Q6. Use the information below to answer this question.

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

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ $\quad\quad \Delta H^{\ominus} = -285.8 \text{ kJ mol}^{-1}$

$3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$ $\quad\quad \Delta H^{\ominus} = -104.0 \text{ kJ mol}^{-1}$

$4C(s) + 5H_2(g) \rightarrow C_4H_{10}(g)$ $\quad\quad \Delta H^{\ominus} = -125.2 \text{ kJ mol}^{-1}$
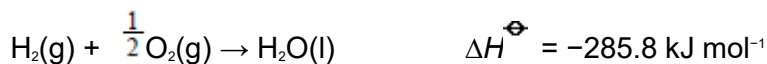
The value in kJ mol^{-1} of the enthalpy of thermal dissociation when butane forms propane, hydrogen and carbon is

A   −26.3

B   −17.5

C   +17.5

C   +21.2

(Total 1 mark)

Q7. Use the information below to answer this question.

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

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ $\quad\quad \Delta H^{\ominus} = -285.8 \text{ kJ mol}^{-1}$

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$3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$ $\Delta H^{\ominus} = -104.0 \text{ kJ mol}^{-1}$

$4C(s) + 5H_2(g) \rightarrow C_4H_{10}(g)$ $\Delta H^{\ominus} = -125.2 \text{ kJ mol}^{-1}$

The value in kJ mol⁻¹ for the enthalpy of combustion of propane is

A −211.7

B −419.7

C −2220

C −2878

(Total 1 mark)