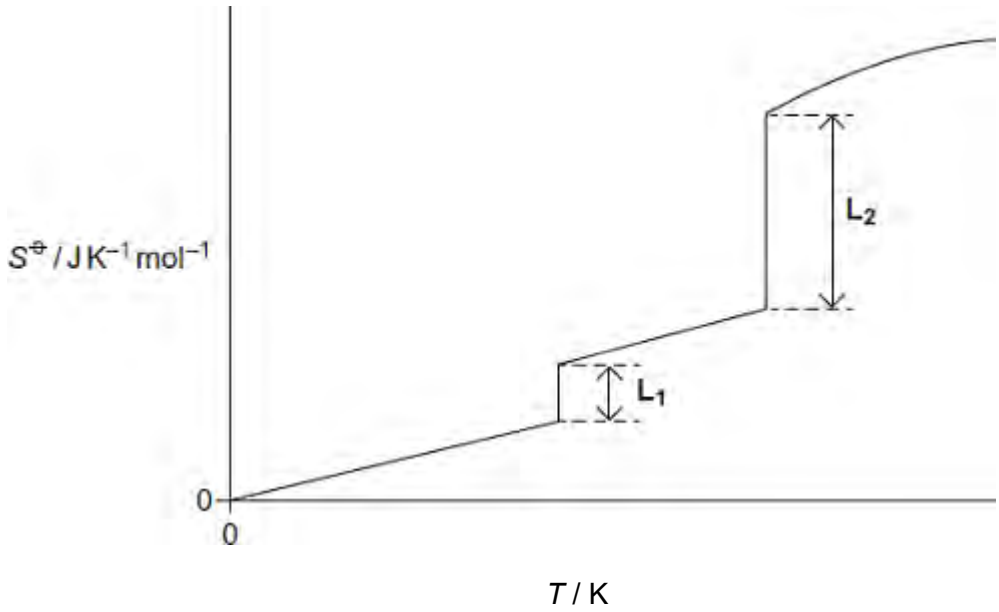
Q1.(a) **Figure 1** shows how the entropy of a molecular substance **X** varies with temperature.

Figure 1



(i) Explain, in terms of molecules, why the entropy is zero when the temperature is zero Kelvin.

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(Extra space) .....

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(2)

(ii) Explain, in terms of molecules, why the first part of the graph in **Figure 1** is a line that slopes up from the origin.

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(Extra space) .....

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(2)

(iii) On **Figure 1**, mark on the appropriate axis the boiling point (T_b) of substance **X**.

(1)

(iv) In terms of the behaviour of molecules, explain why $\mathbf{L_2}$ is longer than $\mathbf{L_1}$ in **Figure 1**.

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(Extra space) .....

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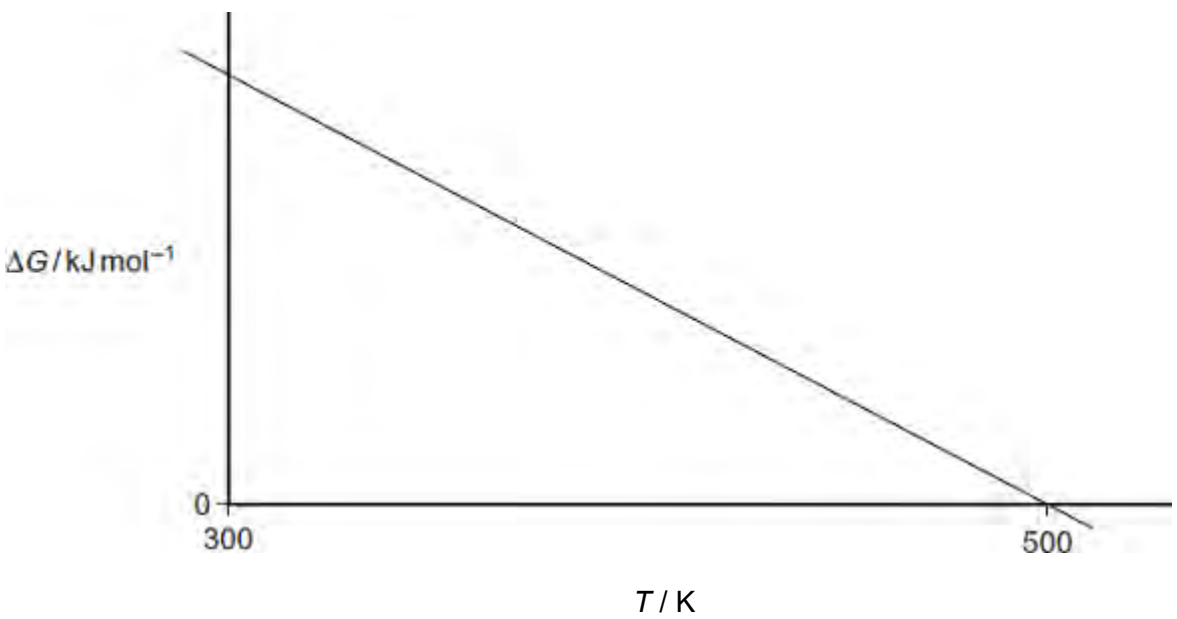
(2)

(b) **Figure 2** shows how the free-energy change for a particular gas-phase reaction varies with temperature.

Figure 2



(i) Explain, with the aid of a thermodynamic equation, why this line obeys the

mathematical equation for a straight line, $y = mx + c$.

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(2)

(ii) Explain why the magnitude of ΔG decreases as T increases in this reaction.

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(1)

(iii) State what you can deduce about the feasibility of this reaction at temperatures lower than 500 K.

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(1)

(c) The following reaction becomes feasible at temperatures above 5440 K.

$$H_2O(g) \longrightarrow H_2(g) + \frac{1}{2}O_2(g)$$

The entropies of the species involved are shown in the following table.

	$H_2O(g)$	$H_2(g)$	$O_2(g)$
S / J K^{-1} mol^{-1}	189	131	205

(i) Calculate the entropy change ΔS for this reaction.

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(1)

(ii) Calculate a value, with units, for the enthalpy change for this reaction at 5440 K.

(If you have been unable to answer part (c)(i), you may assume that the value of the entropy change is +98 J K^{-1} mol^{-1}. This is **not** the correct value.)

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(3)
(Total 15 marks)

Q2. The feasibility of a physical or a chemical change depends on the balance between the thermodynamic quantities of enthalpy change (ΔH), entropy change (ΔS) and temperature (T).

(a) Suggest how these quantities can be used to predict whether a change is feasible.

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(2)

(b) Explain why the evaporation of water is spontaneous even though this change is endothermic.
In your answer, refer to the change in the arrangement of water molecules and the entropy change.

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(4)

(c) This table contains some thermodynamic data for hydrogen, oxygen and water.

	$S^{\ominus}$ / J K^{-1} mol^{-1}	$\Delta H_f^{\ominus}$/ kJ mol^{-1}
$H_2(g)$	131	0
$O_2(g)$	205	0
$H_2O(g)$	189	−242
$H_2O(l)$	70	

(i) Calculate the temperature above which the reaction between hydrogen and oxygen to form gaseous water is **not** feasible.

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(4)

(ii) State what would happen to a sample of gaseous water that was heated to a temperature higher than that of your answer to part (c)(i).

Give a reason for your answer.

What would happen to gaseous water .....

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Reason .....

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(2)

(d) When hydrogen is used as a fuel, more heat energy can be obtained if the gaseous water formed is condensed into liquid water.

Use entropy data from the table in part (c) to calculate the enthalpy change when one mole of gaseous water is condensed at 373 K.
Assume that the free-energy change for this condensation is zero.

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(3)
(Total 15 marks)

Q3. Consider the following process that represents the melting of ice.

$H_2O(s) \longrightarrow H_2O(l)$ $\Delta H^{\ominus} = +6.03$ kJ mol^{-1}, $\Delta S^{\ominus} = +22.1$ J K^{-1} mol^{-1}

(a) State the meaning of the symbol $^{\ominus}$ in $\Delta H^{\ominus}$.

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(1)

(b) Use your knowledge of bonding to explain why $\Delta H^{\ominus}$ is positive for this process.

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(2)

(c) Calculate the temperature at which $\Delta G^{\ominus} = 0$ for this process. Show your working.

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(3)

(d) The freezing of water is an exothermic process. Give **one** reason why the temperature of a sample of water can stay at a constant value of 0 °C when it freezes.

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(1)

(e) Pure ice can look pale blue when illuminated by white light. Suggest an explanation for this observation.

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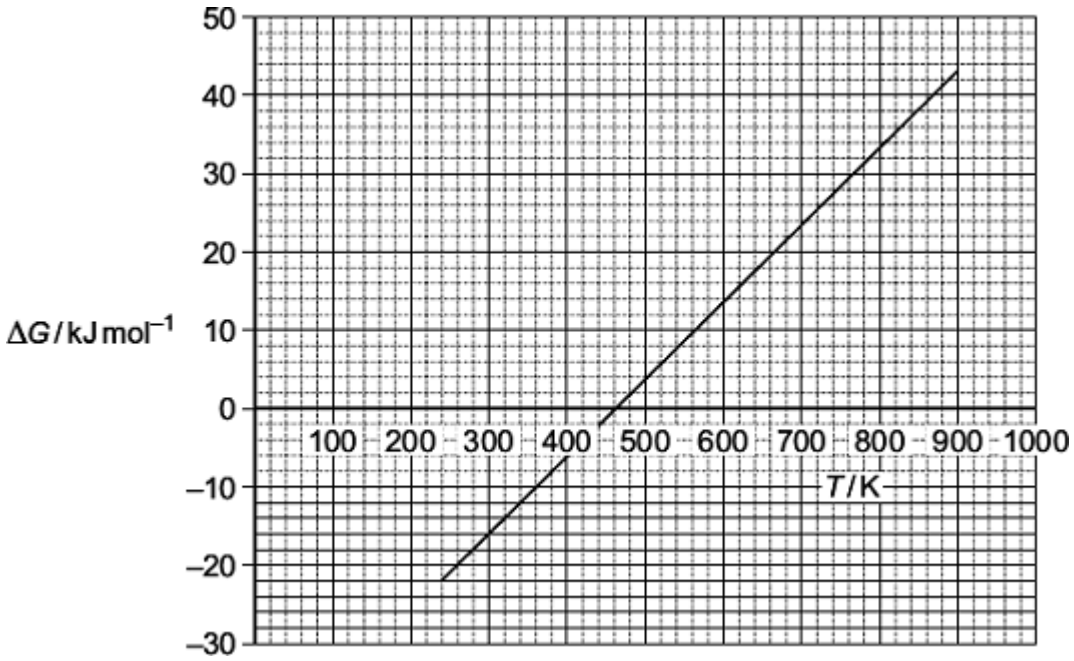
(2)
(Total 9 marks)

Q4. The following equation shows the formation of ammonia.

$$\frac{1}{2}N_2(g) + \frac{3}{2}H_2(g) \longrightarrow NH_3(g)$$

The graph shows how the free-energy change for this reaction varies with temperature above 240 K.



(a) Write an equation to show the relationship between ΔG, ΔH and ΔS.

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(1)

(b) Use the graph to calculate a value for the slope (gradient) of the line. Give the units of this slope and the symbol for the thermodynamic quantity that this slope represents.

Value of the slope .....

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Units .....

Symbol .....

(3)

(c) Explain the significance, for this reaction, of temperatures below the temperature value where the line crosses the temperature axis.

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(2)

(d) The line is not drawn below a temperature of 240 K because its slope (gradient) changes at this point.

Suggest what happens to the ammonia at 240 K that causes the slope of the line to change.

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(1)
(Total 7 marks)

Q5. The oxides nitrogen monoxide (NO) and nitrogen dioxide (NO_2) both contribute to atmospheric pollution.

The table gives some data for these oxides and for oxygen.

	$S^{\ominus}$ / JK^{-1} mol^{-1}	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$O_2(g)$	211	0
NO(g)	205	+90
$NO_2(g)$	240	+34

Nitrogen monoxide is formed in internal combustion engines. When nitrogen monoxide

comes into contact with air, it reacts with oxygen to form nitrogen dioxide.

$$NO(g) + \frac{1}{2}O_2(g) \longrightarrow NO_2(g)$$

(a) Calculate the enthalpy change for this reaction.

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(2)

(b) Calculate the entropy change for this reaction.

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(2)

(c) Calculate the temperature below which this reaction is spontaneous.

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(2)

(d) Suggest **one** reason why nitrogen dioxide is **not** formed by this reaction in an internal combustion engine.

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(1)

(e) Write an equation to show how nitrogen monoxide is formed in an internal combustion engine.

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(1)

(f) Use your equation from part (e) to explain why the free-energy change for the reaction to form nitrogen monoxide stays approximately constant at different temperatures.

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(2)
(Total 10 marks)