15.2 Entropy & Spontaneity

Question Paper

Course	DP IB Chemistry
Section	15. Energetics/Thermochemistry (HL only)
Topic	15.2 Entropy & Spontaneity
Difficulty	Medium

Time allowed: **80**

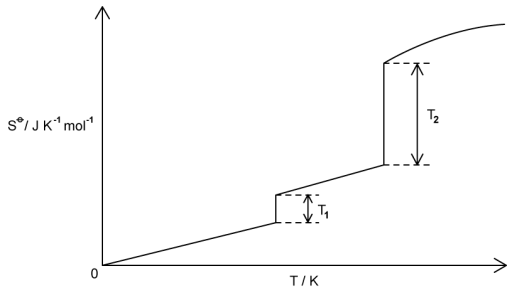
Score: **/64**

Percentage: **/100**

Question 1a

a)

This question looks at how the entropy change of water varies with temperature.



i)

The entropy of water is zero when the temperature is zero Kelvin. Explain why, with reference to the water molecules in your answer.

ii)

Explain why the entropy change, ΔS, is larger at temperature T_2 than at temperature T_1

iii)

On the figure, draw the boiling point (T_b) of water on the appropriate axis.

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[5 marks]

Question 1b

b)

Standard entropies can be used to calculate the entropy change of a reaction, ΔS.

For example, for the formation of nitrogen monoxide from nitrogen and oxygen.

$$NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)$$

Substance	Entropy value ($J\,K^{-1}\,mol^{-1}$)
$NO(g)$	210.8
$O_2(g)$	205.2
$NO_2(g)$	240.0
$O_3(g)$	238.9

Use the data given to calculate the entropy change of the reaction between nitric oxide and ozone at 298K.

[2 marks]

Question 1c

c)
The contact process is a method used industrially to form sulfur trioxide, by reacting sulfur dioxide and oxygen together over a vanadium(V) oxide catalyst.

The equation for this reaction is shown below:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

Substance	Formation enthalpy values ($kJ\,mol^{-1}$)
$SO_2(g)$	-297
$SO_3(g)$	-395

i)
Calculate the standard enthalpy change of the contact process reaction using the data provided.

ii)
The standard entropy change of this reaction is $-189\ J\,K^{-1}\,mol^{-1}$. Use this value and your enthalpy value from part (i) calculate a value for the free energy change for this reaction at 298K.

iii)
Use your answer to part (ii) to explain whether the reaction is feasible at 298 K.

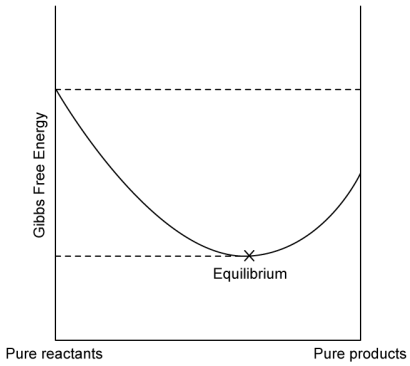
[6 marks]

Question 1d

d)
The value for the free energy change is an indication whether the forward or backwardreaction is favoured.

The curve that we would expect to see for the reaction between sulfur dioxide and oxygen is shown below.

Explain why the curve for this reaction is shifted to the right hand side.



[2 marks]

Question 2a

a)
The enthalpy of solution of sodium chloride is +4 kJ mol^{-1}. Explain why the free energy change for dissolving sodium chloride in water is negative, despite the enthalpy change being a positive value.

[3 marks]

Question 2b

b)

Calcium carbonate thermally decomposes to form calcium oxide and carbon dioxide, as shown below:

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

The enthalpy change of the above reaction is $\Delta H^{\ominus} = +178\ kJ\ mol^{-1}$ and the entropy change is $\Delta S^{\ominus} = +161\ J\ K^{-1}\ mol^{-1}$

Calculate the temperature at which the free-energy change, $\Delta G^{\ominus}$, for this process is zero.

[3 marks]

Question 2c

c)

Some ionic compounds such as potassium chloride, KCl, will dissolve in water at room temperature in an endothermic process.

$$KCl(s) \rightarrow K^+(aq) + Cl^-(aq) \qquad \Delta H = +16\ kJ\ mol^{-1}$$

Substance	Entropy value $J\ K^{-1}\ mol^{-1}$
$KCl(s)$	+83
$K^+(aq)$	+103
$Cl^-(aq)$	+57

i)

Using the data provided, prove that this process is feasible at 298 K.

ii)

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

[6 marks]

Question 2d

d)
Diamond and graphite are both allotropes of carbon.

The conversion of graphite into diamond is represented as follows

Carbon (graphite) → Carbon (diamond)

Use this data below to calculate values for ΔH and ΔS for the reaction. Use these values to explain why this reaction is **not** feasible under standard pressure at any temperature.

	C (graphite)	**C (diamond)**
ΔH (kJ mol^{-1})	0	+1.9
ΔS (J K^{-1} mol^{-1})	+5.7	+2.4

[3 marks]

Question 3a

a)
Ethanol is used in large quantities in the production of alcoholic beverages and as a fuel.

The combustion of ethanol is represented by the equation

$$CH_3CH_2OH\,(l) + 3O_2\,(g) \rightarrow 2CO_2\,(g) + 3H_2O\,(g)$$

The standard entropy, S^{Θ}, of $O_2\,(g)$ is $205.2\ J\ K^{-1}\ mol^{-1}$

Using the data given and Section 12 in the Data Booklet, determine the entropy change, ΔS^{Θ}, for the combustion of ethanol at 298K.

[3 marks]

Question 3b

b)
Using the enthalpy of combustion for ethanol from Section 13 in the Data Booklet and the ΔS^{Θ} determined in part (a), calculate the standard free energy for the combustion of ethanol.

[3 marks]

Question 3c

c)
Explain whether changing the temperature for the combustion of ethanol will alter the spontaneity of the reaction.

[3 marks]

Question 3d

d)
Using Section 12 of the Data Booklet, explain the difference in the standard entropy values between methanol, CH_3OH and ethanol, CH_3CH_2OH.

[1 mark]

Question 4a

a)
Ammonia, NH_3, is produced by the Haber process and is an important chemical in the manufacture of fertilisers and clearing products.

Ammonia gas can react with oxygen to produce nitrogen monoxide and steam, and is the first step in the Ostwald process which produces nitric acid.

i)
Write an equation for the reaction of ammonia with oxygen to produce nitrogen monoxide and steam.

ii)
Using the given values determine the entropy for change for this reaction at 298 K.

Substance	Entropy values ($J\,K^{-1}\,mol^{-1}$)
$NH_3\,(g)$	192.8
$O_2\,(g)$	205.2
$H_2O\,(g)$	188.8
$NO\,(g)$	210.8

[5 marks]

Question 4b

b)
Explain why the standard entropy change for the reaction is positive.

[1 mark]

Question 4c

c)
The second step in the Ostwald process produces nitrogen dioxide as shown in the equation

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g) \qquad \Delta H^{\ominus} = -112\ kJ\ mol^{-1}$$

The standard entropy for $NO_2(g)$ is $240.0\ J\ K^{-1} mol^{-1}$

Determine the value for the free energy change for this reaction at 298 K using the information given

[6 marks]

Question 4d

d)
Explain whether changing the temperature for the production of nitrogen dioxide will alter the spontaneity of the reaction

[2 marks]

Question 5a

a)
The boiling point of a liquid is the temperature at which its solid and liquid phases are in equilibrium as shown in the equation for the vaporisation of water.

$$H_2O\,(l) \rightarrow H_2O\,(g)$$

Use Section 12 of the Data Booklet to determine values for the enthalpy change, $\Delta H^{\ominus}$, and entropy change, $\Delta S^{\ominus}$, for the reaction at 298 K.

[4 marks]

Question 5b

b)
Use your answer to part (a) to estimate a temperature, in K, that the reaction becomes feasible.

[3 marks]

Question 5c

c)
Explain how your answer to part (b) could be made more accurate.

[1 mark]

Question 5d

d)
Explain why the reaction is spontaneous above the boiling point of water.

[2 marks]