Entropy

Question Paper 2

Level	Pre U
Subject	Chemistry
Exam Board	Cambridge International Examinations
Topic	Entropy-Free energy and entropy
Booklet	Question Paper 2

Time Allowed: **58 minutes**

Score: **/48**

Percentage: **/100**

Grade Boundaries:

1. *Aerozine 50* is a 50/50 mix of hydrazine, N_2H_4, and UDMH, $(CH_3)_2N_2H_2$. It is used as a rocket fuel, typically mixed with dinitrogen tetroxide, N_2O_4, as the oxidising agent.

The equation for the reaction of the UDMH with dinitrogen tetroxide is given in equation 2.1 and relevant thermodynamic data is in Table 2.1.

equation 2.1 $(CH_3)_2N_2H_2(l) + 2N_2O_4(l) \rightarrow 2CO_2(g) + 4H_2O(g) + 3N_2(g)$

Table 2.1

substance	$\Delta_f H^{\ominus}(298\,K)$ / $kJ\,mol^{-1}$	$S^{\ominus}(298\,K)$ / $J\,K^{-1}\,mol^{-1}$
$(CH_3)_2N_2H_2(l)$	83.3	304.7
$N_2O_4(l)$	9.1	304.4
$CO_2(g)$	–393.5	213.8
$H_2O(g)$	–241.8	188.8
$N_2(g)$	0.0	191.6

(a) Suggest an equation for the reaction between hydrazine, N_2H_4, and dinitrogen tetroxide, N_2O_4.

.... [1]

(b) Define the term *standard enthalpy change of formation*.

....

.... [2]

(c) **(i)** Calculate the enthalpy change, $\Delta_r H^{\ominus}(298\,K)$, for the reaction in equation 2.1, giving your answer to one decimal place.

$\Delta_r H^{\ominus}(298\,K)$ .... $kJ\,mol^{-1}$ [3]

(ii) The entropy change, $\Delta_r S^{\ominus}(298\,K)$, for the reaction in equation 2.1 is $+844.1\,J\,K^{-1}\,mol^{-1}$.

Explain, without calculation, why this entropy change has such a large, positive value.

....

....

.... [2]

(iii) Calculate the free energy change, $\Delta_r G^{\ominus}(298\,K)$, for the reaction in equation 2.1, giving your answer to one decimal place.

$\Delta_r G^{\ominus}(298\,K)$ .... $kJ\,mol^{-1}$ [2]

(d) Pure UDMH, $(CH_3)_2N_2H_2$, can be used as an alternative to *Aerozine 50* in thruster rockets.

The total mass of propellant (UDMH and dinitrogen tetroxide, N_2O_4, together) used in the thruster rockets in the ascent stage of a lunar module was 244 kg.

Assume that the UDMH and dinitrogen tetroxide were mixed in the molar ratio 1:2.

(i) Calculate the mass of UDMH in the propellant mixture.

mass of UDMH = ... kg [1]

(ii) Calculate the total number of moles of gas produced from the complete reaction of this mass of UDMH with dinitrogen tetroxide, as in equation 2.1.

moles of gas = ... [2]

(iii) Calculate the total volume of product gases formed from the reaction of this mass of UDMH with dinitrogen tetroxide, as in equation 2.1, at a temperature of –10.0 °C and a pressure of 600 Pa.

Give your answer to three significant figures and **include the units**.

volume of gas = ... [3]

(e) Dinitrogen tetroxide, N_2O_4, exists in equilibrium with nitrogen dioxide, NO_2, which itself can be decomposed into nitrogen monoxide, NO, and oxygen, as shown in equation 2.2.

equation 2.2 $$2NO_2(g) \rightarrow 2NO(g) + O_2(g)$$

The rate equation for this thermal decomposition is as follows.

$$\text{rate} = k[NO_2]^2$$

The rate constant, *k*, for the thermal decomposition of nitrogen dioxide was measured at five different temperatures and the results were used to plot the graph in Fig. 2.1.

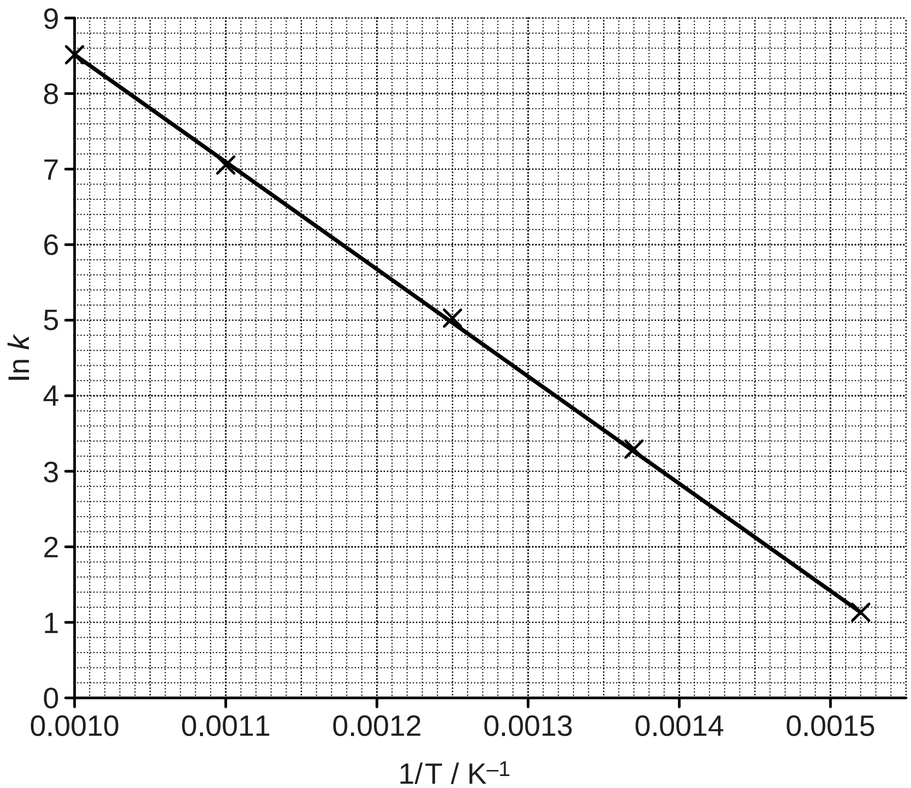

Fig. 2.1

(i) Equation 7 in the data booklet can be rewritten in the form *y* = *mx* + *c*, as follows.

$$\ln k = \frac{-E_a}{R}\frac{1}{T} + \mathrm{l} \quad A$$

Use the graph to calculate the activation energy, E_a, for the reaction in equation 2.2.

E_a = ... kJ mol^{-1} [2]

(ii) A vessel with a volume of 2.00 dm^3 is filled with 4.00 mol of NO_2 at a temperature of 650 K.

The rate constant, *k*, at this temperature is 3.16 $dm^3\,mol^{-1}\,s^{-1}$.

Calculate the initial rate of decomposition at this temperature for the reaction in equation 2.2 and **include the units**.

initial rate = ... [2]

(iii) A mechanism suggested for the thermal decomposition of nitrogen dioxide is shown.

step one $NO_2 + NO_2 \rightarrow NO + NO_3$ *slow*

step two $NO_3 \rightarrow NO + O_2$ *fast*

Explain whether or not this mechanism is consistent with the rate equation given.

....

....

.... [1]

[Total: 21]

2. The light blue colour of aqueous copper(II) sulfate is due to the presence of the hexaaquacopper(II) ion, $[Cu(H_2O)_6]^{2+}(aq)$.

Equations 4.1 and 4.2 show two different partial ligand substitution reactions of the hexaaquacopper(II) ion. In equation 4.1 'en' represents 1,2-diaminoethane, $H_2NCH_2CH_2NH_2$.

equation 4.1 $[Cu(H_2O)_6]^{2+}(aq) + en(aq) \rightarrow [Cu(en)(H_2O)_4]^{2+}(aq) + 2H_2O(l)$

$\Delta_r H^\ominus = -54\,kJ\,mol^{-1}$;

$\Delta_r S^\ominus = +23\,J\,K^{-1}\,mol^{-1}$

equation 4.2 $[Cu(H_2O)_6]^{2+}(aq) + 2NH_3(aq) \rightarrow [Cu(NH_3)_2(H_2O)_4]^{2+}(aq) + 2H_2O(l)$

$\Delta_r H^\ominus = -46\,kJ\,mol^{-1}$;

$\Delta_r S^\ominus = -8.4\,J\,K^{-1}\,mol^{-1}$

(a) Explain why the enthalpy changes, $\Delta_r H^\ominus$, of the reactions shown in equations 4.1 and 4.2 are so similar.

....

....

....

....[2]

(b) Comment on the values of the entropy changes, $\Delta_r S^\ominus$, of the reactions shown in equations 4.1 and 4.2 and explain why they are different.

....

....

....

....[2]

(c) The cation produced in the reaction shown in equation 4.2 can exist as two different isomers.

(i) State the type of isomerism exhibited by this cation.

.... [1]

(ii) Draw and label the two different isomers of this cation.

[2]

(d) Further ligand substitution leads to the production of the complex ion $[Cu(en)_3]^{2+}$, which also exhibits isomerism.

(i) State the type of isomerism exhibited by $[Cu(en)_3]^{2+}$.

.... [1]

(ii) Draw 3-D representations of the two isomers of $[Cu(en)_3]^{2+}$.

[2]

[Total: 10]

3 Fig. 3.1 is a diagram of a hydrogen/oxygen fuel cell.

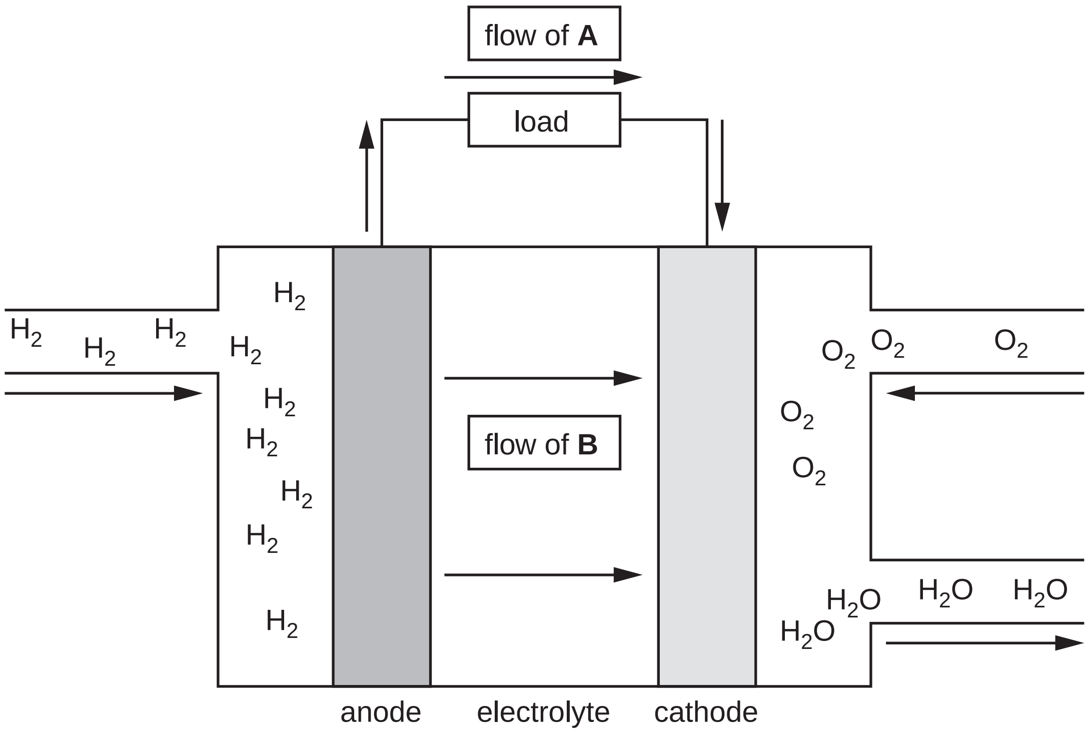

Fig. 3.1

(a) Identify the particles represented by:

A .... **B** .... [2]

(b) The cathode in this fuel cell is coated with a catalyst. Suggest a suitable material for this catalyst.

.... [1]

(c) Write the equation for the reaction occurring at each electrode.

cathode reaction ....

anode reaction .... [2]

(d) **(i)** One of the advantages of fuel cells over the use of fossil fuels is that the only by-product is water.
Suggest two **other** advantages of fuel cells over the use of fossil fuels in motor vehicles.

....

....

....

.... [2]

(ii) Apart from cost, suggest two disadvantages of using fuel cells rather than fossil fuels in motor vehicles.

....

....

....

.... [2]

(e) The zinc/silver oxide cell is used for button cells in watch batteries and is based on the following half-cells:

$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$ $\quad E^\ominus = -0.76V$

$Ag_2O(s) + H_2O(l) + 2e^- \rightleftharpoons 2Ag(s) + 2OH^-(aq)$ $\quad E^\ominus = +0.34V$

(i) Complete the left-hand side of the notation that describes this cell diagram. [1]

.... $||[Ag_2O(s) + H_2O(l)],[2Ag(s) + 2OH^-(aq)]|Ag(s)$

(ii) State which species is oxidised and which is reduced in this cell during use.

species being oxidised ....

species being reduced .... [2]

(iii) Write an overall equation for the reaction taking place in the cell during use.

.... [1]

(iv) Calculate the standard cell potential for the zinc/silver oxide cell.

$E^{\ominus}_{cell}$ = ... [1]

(v) Use your answer to part **(iv)** to calculate the standard Gibbs energy change ($\Delta_r G^{\ominus}$) for the reaction in this cell.

.... $kJ\,mol^{-1}$ [1]

(vi) Use your answer to part **(v)** to calculate the equilibrium constant (K_c) for the reaction in part **(iii)**.

K_c = ... [2]

[Total: 17]