



VCE CHEMISTRY 2012

YEAR 12 TRIAL EXAM UNIT 4

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Time allowed: 90 Minutes

Total marks: 83

Section A

Contains 20 Multiple Choice Questions
20 marks, 21 minutes

Section B

Contains 6 Short Answer Questions
63 marks, 69 minutes

To download the Chemistry Data Book please visit the VCAA website:

http://www.vcaa.vic.edu.au/vcaa/vce/studies/chemistry/publications/chemdata_2012-w.pdf

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Student Name.....

VCE Chemistry 2012 Year 12 Trial Exam Unit 4

Student Answer Sheet

There are 20 Multiple Choice questions to be answered by circling the correct letter in the table below. Use only a 2B pencil. If you make a mistake, erase and enter the correct answer. Marks will not be deducted for incorrect answers

<i>Question 1</i>	A	B	C	D	<i>Question 2</i>	A	B	C	D
<i>Question 3</i>	A	B	C	D	<i>Question 4</i>	A	B	C	D
<i>Question 5</i>	A	B	C	D	<i>Question 6</i>	A	B	C	D
<i>Question 7</i>	A	B	C	D	<i>Question 8</i>	A	B	C	D
<i>Question 9</i>	A	B	C	D	<i>Question 10</i>	A	B	C	D
<i>Question 11</i>	A	B	C	D	<i>Question 12</i>	A	B	C	D
<i>Question 13</i>	A	B	C	D	<i>Question 14</i>	A	B	C	D
<i>Question 15</i>	A	B	C	D	<i>Question 16</i>	A	B	C	D
<i>Question 17</i>	A	B	C	D	<i>Question 18</i>	A	B	C	D
<i>Question 19</i>	A	B	C	D	<i>Question 20</i>	A	B	C	D

VCE Chemistry 2012 Year 12 Trial Exam Unit 4

SECTION A – Multiple Choice Questions

Section A consists of 20 multiple-choice questions.
Section A is worth approximately 24 per cent of the marks available.
Choose the response that is **correct** or **best answers** the question.
Indicate your choice on the answer sheet provided.

Question 1

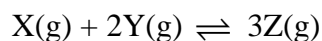
A 0.050 M solution of a weak acid has a hydroxide ion concentration of 2.6×10^{-10} M at 25°C.

The acid is

- A. hypochlorous acid.
- B. hydrochloric acid.
- C. ethanoic acid.
- D. methanoic acid.

Question 2

An equilibrium system represented by the equation below has $K = 2.3 \times 10^4$ at 30°C and $K = 92$ at 250°C.

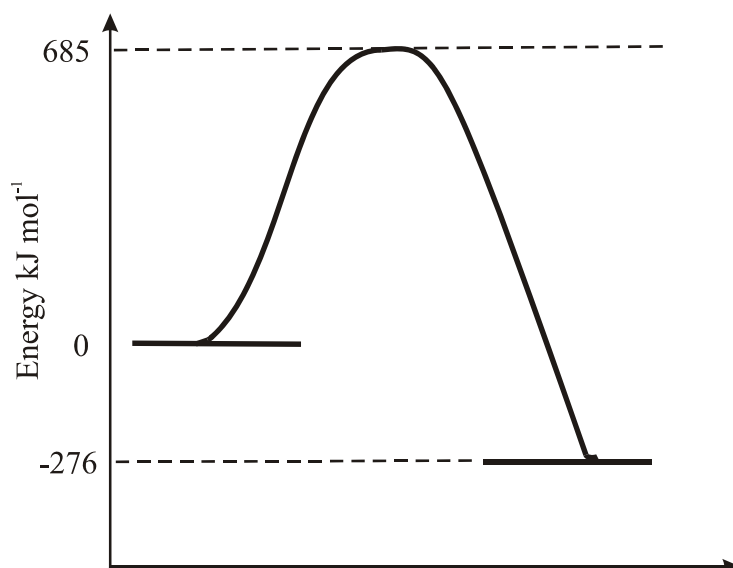


On the basis of the information supplied, the yield of Z would be increased by carrying out the reaction at

- A. high pressure.
- B. high temperature.
- C. low pressure.
- D. low temperature.

Question 3

Shown below is the energy profile for a reaction for which the equation involves only hydrogen, oxygen and water, all in the same state.



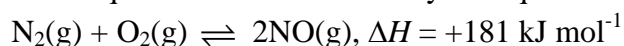
When all the bonds in 2 mol of water molecules are broken, i.e. 2 mol H₂O molecules in the gas phase are converted into hydrogen atoms and oxygen atoms, 1922 kJ of energy is absorbed.

The equation consistent with the energy profile is

- A. $2\text{H}_2\text{O}(\text{g}) \rightarrow 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})$
- B. $\text{H}_2\text{O}(\text{g}) \rightarrow \text{H}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g})$
- C. $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})$
- D. $\text{H}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{g})$

Question 4

At high temperature nitrogen and oxygen can react to produce nitrogen(II) oxide, NO. All three species can exist in equilibrium as described by the equation



At 2300 K the equilibrium constant, K_c , for this equilibrium is 1.7×10^{-3} .

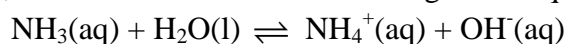
In a sealed rigid container at 2300 K the concentration of N₂ is 0.50 mol L⁻¹, the concentration of O₂ is 0.25 mol L⁻¹ and the concentration of NO is 0.050 mol L⁻¹.

As the system moves to reach equilibrium at 2300 K, the rate of the reverse reaction

- A. decreases and energy must be added to the container.
- B. decreases and energy must be removed from the container.
- C. increases and energy must be added to the container.
- D. increases and energy must be removed from the container.

Question 5

Ammonia is a weak base, which ionises in water according to the equation



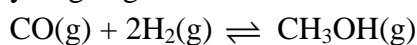
Ammonia (boiling temperature 240 K) is much more volatile than water.

When a container of an aqueous solution of ammonia at equilibrium is opened, in a fume hood, at room temperature some of the dissolved ammonia escapes from the solution. How would this affect the pH of the solution and the percentage ionisation of ammonia?

- A. pH increases, percentage ionisation increases.
- B. pH decreases, percentage ionisation increases.
- C. pH increases, percentage ionisation decreases.
- D. pH decreases, percentage ionisation decreases.

Question 6

Carbon monoxide reacts with hydrogen gas to form methanol according to the equilibrium



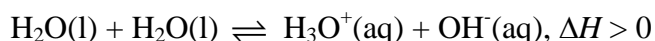
0.80 mol of CO and 0.60 mol of H₂ are added to an empty 2.0 L container and allowed to reach equilibrium in a 2.0 L container. When equilibrium has been established, analysis shows that the concentration of CH₃OH in the container is 0.060 mol L⁻¹. What is the value of the equilibrium constant, *K_c*?

- A. 0.21
- B. 0.35
- C. 1.7
- D. 5.4

Question 7

In the 1870s the German chemist Friedrich Kohlrausch found that, even after being distilled 42 times, water still carried an electric current.

We now explain the conductivity of pure water by the self-ionisation equilibrium



In order to show that pure water has a pH of 7 at 25°C, a sample of commercially available distilled water is further distilled before testing its pH. The water is found to have a pH slightly greater than 7.

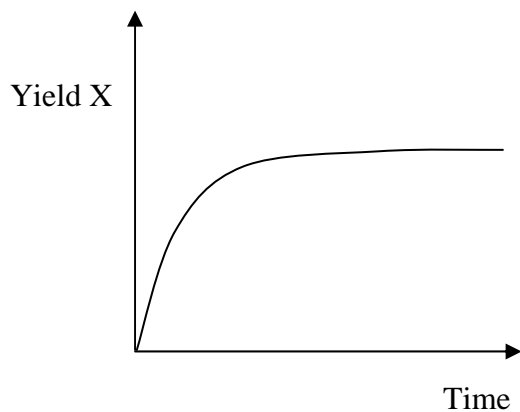
Assuming that the pH measuring equipment was reliable, which of the following possible experimental errors could lead to a higher than expected pH?

- A. The pH was measured when the water temperature was greater than 25°C.
- B. The distilled water was left open to the air and absorbed some CO₂ from the atmosphere.
- C. The pH was measured when the water temperature was less than 25°C.
- D. Some of the water was spilt prior to measuring the pH, thus reducing the *n*(H₃O⁺) present.

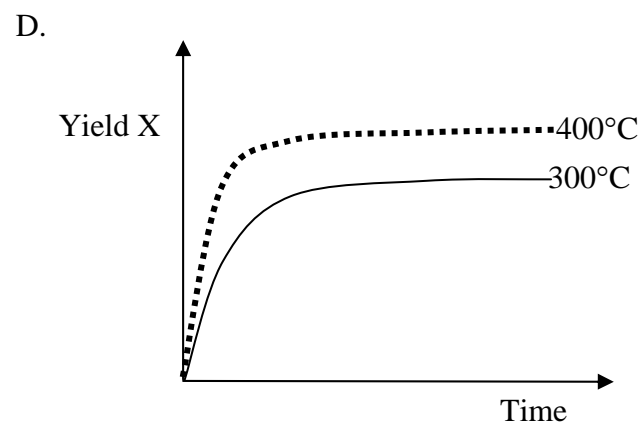
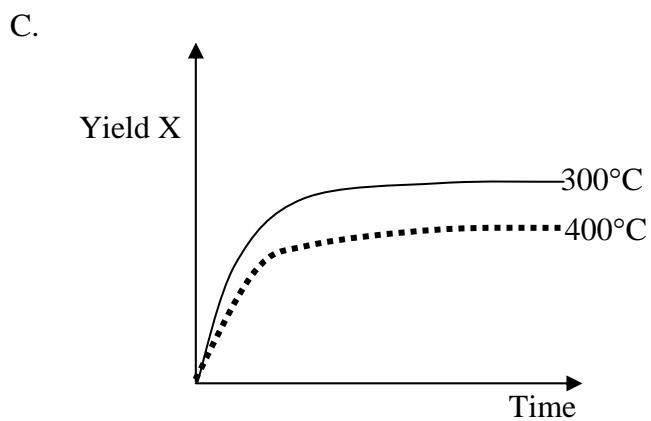
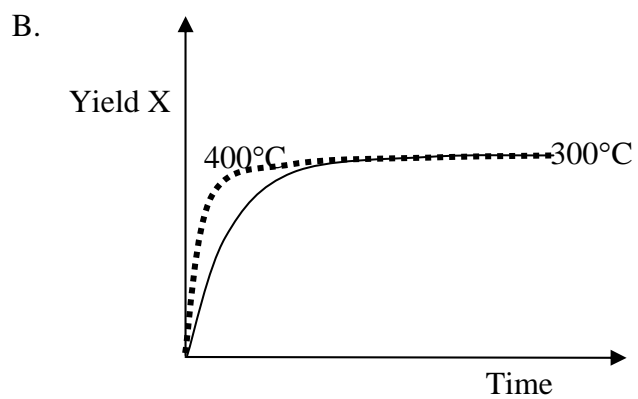
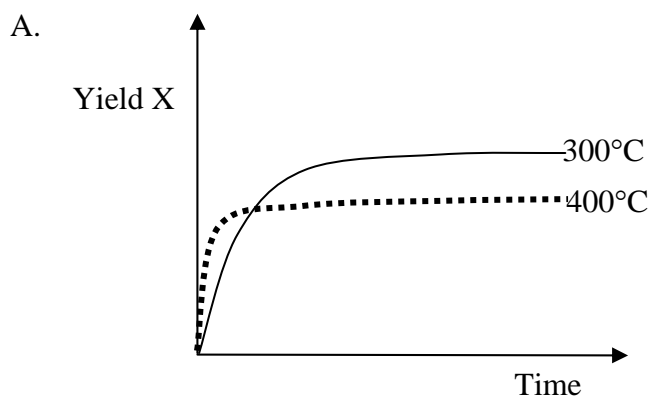
Question 8

A chemical X is produced in an exothermic equilibrium process.

The graph given below shows the change in yield of X with time at 300°C.



Which of the graphs below most accurately represents the expected change in yield of X with time at 400°C?



Question 9

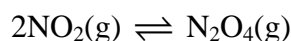
Consider the equilibrium $2\text{NH}_3(\text{g}) \rightleftharpoons \text{N}_2(\text{g}) + 3\text{H}_2(\text{g})$ for which the equilibrium constant is represented by K_c .

Which of the following expressions represents the concentration of NH_3 at equilibrium?

- A. $\left(\frac{[\text{N}_2][\text{H}_2]^3}{K_c} \right)$
- B. $\sqrt{\left(\frac{1}{K_c [\text{N}_2][\text{H}_2]^3} \right)}$
- C. $\sqrt{\left(\frac{[\text{N}_2][\text{H}_2]^3}{K_c} \right)}$
- D. $\sqrt{K_c [\text{N}_2][\text{H}_2]^3}$

Question 10

100 mL of $\text{NO}_2(\text{g})$ is collected in a gas syringe and allowed to come to equilibrium with $\text{N}_2\text{O}_4(\text{g})$ according to



The equilibrium mixture is at 102 kPa and at room temperature.

The volume of the syringe is decreased to 25 mL and the system allowed to return to the equilibrium at the new volume at constant temperature. The final pressure will be

- A. 102 kPa.
- B. higher than 102 kPa but lower than 408 kPa.
- C. 408 kPa.
- D. higher than 408 kPa.

Question 11

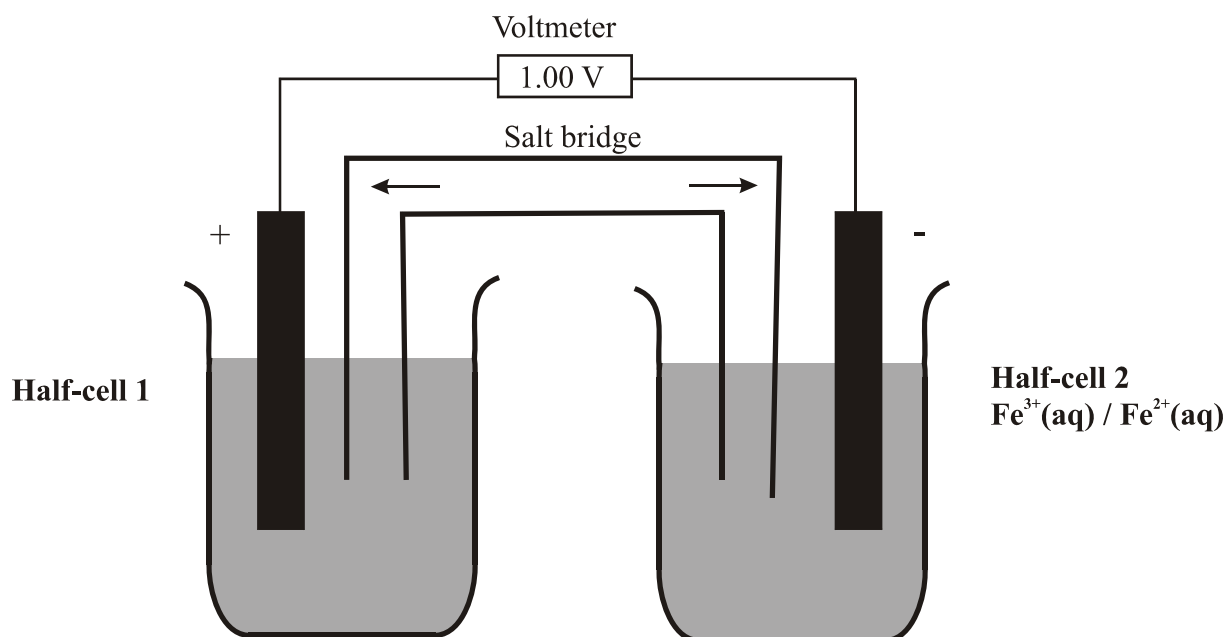
Consider the reaction $\text{Na}_2\text{S}_2\text{O}_3(\text{s}) + \text{aq} \rightarrow \text{Na}_2\text{S}_2\text{O}_3(\text{aq}); \Delta H = +7.20 \text{ kJ mol}^{-1}$

When 0.100 mol of solid $\text{Na}_2\text{S}_2\text{O}_3$ (sodium thiosulfate) is dissolved in 500 mL of water,

- A. the temperature of the water drops by approximately 1.72 °C.
- B. the temperature of the water drops by approximately 0.344 °C.
- C. the temperature of the water rises by approximately 1.72 °C.
- D. the temperature of the water rises by approximately 0.344 °C.

Question 12

Consider the galvanic cell, represented below, operating at 25°C, 101.3 kPa and using 1 M solutions.

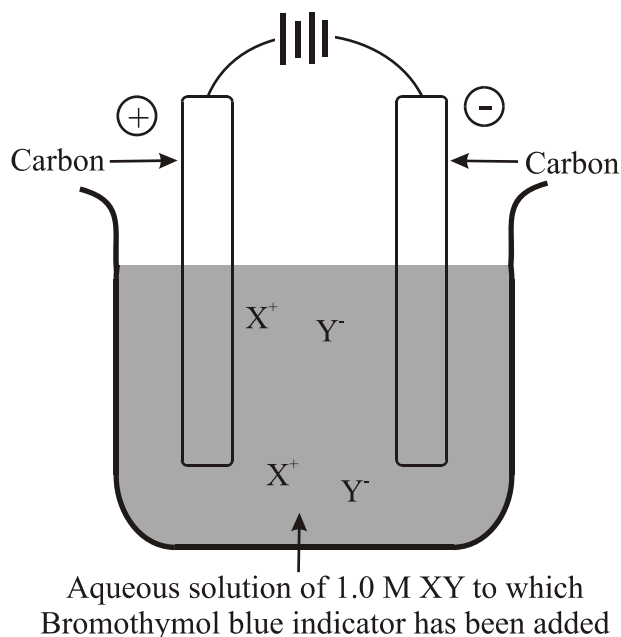


The product(s) of the half-reaction occurring in Half-cell 1 is (are)

- A. Ni(s)
- B. $\text{Ni}^{2+}(\text{aq})$
- C. $\text{H}_2\text{O}_2(\text{aq})/\text{H}^+(\text{aq})$
- D. $\text{H}_2\text{O}(\text{l})$

Question 13

Consider the electrolytic cell represented below.



When an electric current is passed through the cell, at 25 °C the solution around the (+) electrode changes from green to yellow. This suggests the compound XY was most likely

- A. sodium iodide.
- B. potassium fluoride.
- C. lithium bromide.
- D. hydrochloric acid.

Question 14

When a current of 2.30 A was passed through the electric heater of a bomb calorimeter for 1.25 minutes at a potential difference 6.00 volts, the temperature of the calorimeter rose by 1.355°C.

When 2.50×10^{-2} mol of a common fuel underwent combustion in the calorimeter, the temperature rose from 23.31 to 69.42°C.

The fuel used was

- A. ethane.
- B. ethanol.
- C. ethene.
- D. methanol.

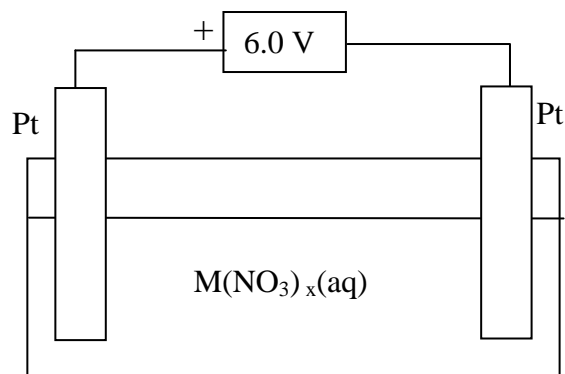
Question 15

When potassium permanganate, KMnO_4 , was used as an oxidising agent in a galvanic cell, the production of 4886 C of electricity required the consumption of 2.00 g of KMnO_4 . Which of the following could have been the product of the reduction of KMnO_4 ?

- A. K_2MnO_4
- B. MnO_2
- C. Mn_2O_3
- D. MnO

Question 16

The electrolysis cell below is used to extract metals from aqueous solutions of their nitrate salts.



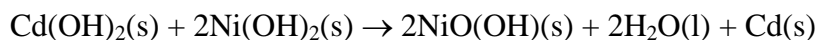
If a current of 15.0 A is passed through the cell for 24.0 minutes, from which of the following solutions would the smallest amount of metal be deposited?

- A. $\text{Co}(\text{NO}_3)_2(\text{aq})$
- B. $\text{AgNO}_3(\text{aq})$
- C. $\text{NiNO}_3(\text{aq})$
- D. $\text{LiNO}_3(\text{aq})$

The following information applies to Questions 17 and 18.

The nickel-cadmium storage battery, or nicad battery, is an alkaline secondary cell that produces around 1.3 to 1.4 volts.

The overall reaction occurring during recharging is



Question 17

The half-reaction occurring at the anode when a NiCad battery is discharging will be

- A. $\text{Cd(OH)}_2(\text{s}) + 2\text{e}^- \rightarrow \text{Cd}(\text{s}) + 2\text{OH}^-(\text{aq})$
- B. $2\text{Ni(OH)}_2(\text{s}) + 2\text{OH}^-(\text{aq}) \rightarrow 2\text{NiO(OH)}(\text{s}) + 2\text{H}_2\text{O}(\text{l}) + 2\text{e}^-$
- C. $\text{Cd}(\text{s}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Cd(OH)}_2(\text{s}) + 2\text{e}^-$
- D. $2\text{NiO(OH)}(\text{s}) + 2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightarrow 2\text{Ni(OH)}_2(\text{s}) + 2\text{OH}^-(\text{aq})$

Question 18

When a NiCad battery is being recharged, the negative terminal of the external power supply should be connected to the electrode containing

- A. Ni(OH)_2 and a voltage of 1.35 V applied.
- B. Ni(OH)_2 and a voltage greater than 1.4 V applied.
- C. Cd(OH)_2 and a voltage of 1.35 V applied.
- D. Cd(OH)_2 and a voltage greater than 1.4 V applied.

Question 19

Which of the following features of a nuclear fission power station is not a feature of a coal-fired power station?

- A. The products of the heat energy generating reaction contain elements different to those present in the reactants.
- B. Thermal energy in steam is converted into mechanical energy in a turbine.
- C. The heat energy generated from the heat energy generating reaction is used to heat water in a boiler.
- D. The final energy conversion in the power station is the conversion of mechanical energy to electrical energy in a generator.

Question 20

A Material Safety Data Sheet (MSDS) for a chemical includes amongst its risk phrases 'irritating to the respiratory system'. Which of the safety measures listed below would be best to minimise this risk?

- A. Wear a mask.
- B. Wear a face shield.
- C. Wear breathing apparatus.
- D. Use by an open window.

End of Section A

VCE Chemistry 2012 Year 12 Trial Exam Unit 4

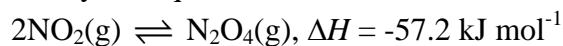
SECTION B – Short Answer Questions

*Section B consists of 6 short answer questions.
You should answer all of these questions.
This section is worth approximately 76 per cent of the total marks available.
The marks allotted are shown at the end of each part of each question.
Questions should be answered in the spaces provided.*

Question 1

The equilibrium between nitrogen dioxide, NO_2 , and dinitrogen tetroxide, N_2O_4 , is good for studying the impact of changes on a system at equilibrium because of the distinctive reddish-brown colour of NO_2 and the fact that N_2O_4 is colourless.

This equilibrium is described by the equation



- a. 0.500 mol of NO_2 was added to an empty 2.00 litre container and allowed to come to equilibrium with N_2O_4 . In getting to equilibrium, 12.8 kJ of energy was released.
- i. Why was energy released as the reaction moved to equilibrium?

(1 mark)

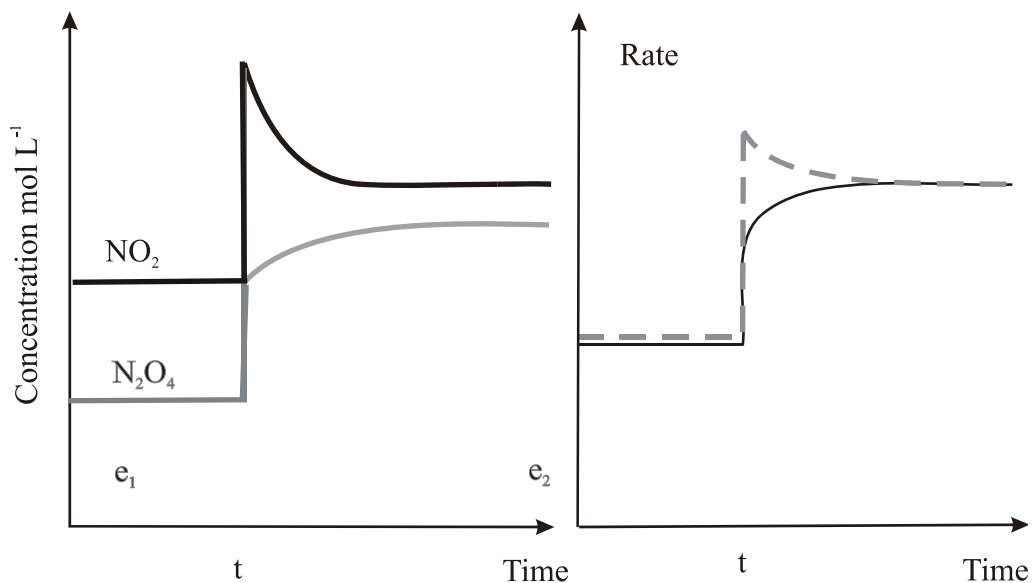
- ii. Calculate the amount, in mole, of NO_2 converted to N_2O_4 in getting to equilibrium.

(2 marks)

- iii. Calculate the value of the equilibrium constant.

(3 marks)

- b. The impact of a change imposed, at time t , on the $2\text{NO}_2(\text{g}) \rightleftharpoons \text{N}_2\text{O}_4(\text{g})$ equilibrium in a gas syringe, is represented in the concentration-time and rate-time graphs below.



- i. What change was imposed on the equilibrium at time t ?

(1 mark)

- ii. In terms of Le Chatelier's principle, how did the system respond to the change?

(3 marks)

- iii. On the rate graph label the one that represents the forward reaction and explain the shape of that graph.

(2 marks)

- iv. Insert <, = or > signs in the comparisons for the second, e2, and first, e1, equilibrium positions.



(1 mark)

Total Marks = 13 marks

Question 2

The main component of the fuel LPG (liquefied petroleum gas) is propane, C_3H_8 . A sample of LPG is found on analysis to be, by volume, 97.5 per cent propane and 2.5 per cent butane.

- a. Write balanced equations for the complete combustion of this LPG sample.

(2 marks)

- b. i. Calculate the energy available from 100.0 L of this LPG at 298 K and 101.3 kPa.

(3 marks)

- ii. Explain why the heat of combustion of commercial LPG is not given in kJ mol^{-1} and give the heat of combustion of the sample analysed in appropriate units.

(2 marks)

- c. Current developments in the use of fuel cells include LPG fuel cell boiler systems to provide domestic electricity and heat and portable fuel systems using LPG. One company developing LPG fuel cell boiler systems describes the operation of a fuel cell as *'Fuel passes over the anode side and air passes over the cathode. Sandwiched between the anode and the cathode is the very thin, gas tight, electrically insulating but ion conducting electrolyte layer. An external circuit connects the anode to the cathode to power electrical devices.'*

- i. LPG (assumed from here to be propane) fuel cells include a 'fuel processor' which extracts hydrogen from LPG by 'steam' reforming. The overall effect of this process is that propane is converted into hydrogen and carbon dioxide by reaction with steam.

Write a balanced equation for the steam reforming of propane.

(1 mark)

- ii. Calculate the maximum amount of heat energy available, at 298 K and 101.3 kPa, from the combustion of all the hydrogen produced from the steam reforming of 1.50 kg of propane.

(3 marks)

- iii. A description of an LPG fuel cell describes it as '60 per cent efficient'. Explain the term '60 per cent efficient'.

(1 mark)

- iv. The LPG fuel cell is a PEMFC, proton exchange membrane fuel cell. Write half-equations for the reactions occurring at the (-) and (+) electrodes in a LPG PEMFC fuel cell that operates at 180°C.

(2 marks)

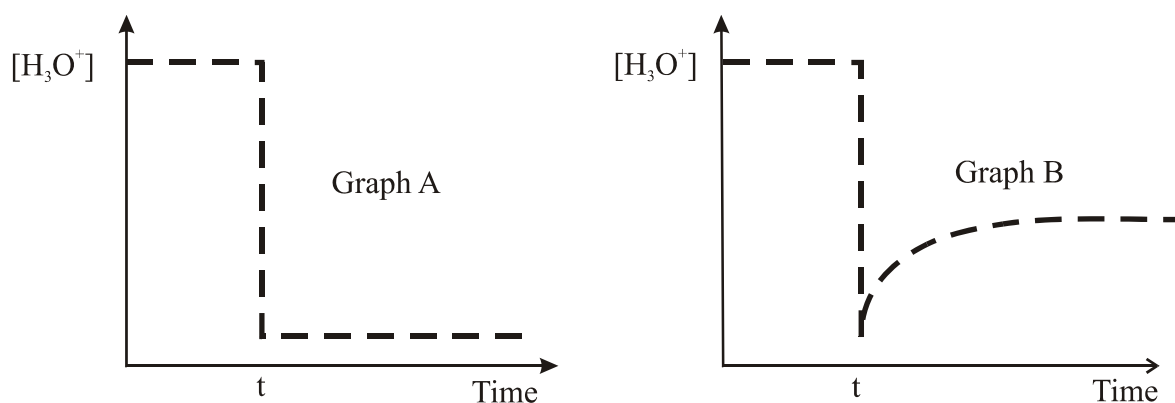
- v. Other than cost, reaction rate is one factor limiting the widespread use of fuel cells. How are fuel cells modified to improve reaction rate?

(1 mark)

Total Marks = 15 marks

Question 3

The graphs below show the impact on the $c(\text{H}_3\text{O}^+)$ of diluting 10 mL solutions of two acids, both with initial pH 3.00, to 100 mL at time 't', at 25 °C.



- a. i. Which graph represents a 'weak' acid?

(1 mark)

- ii. Explain the changes that are responsible for the shape of the graph for the weak acid.

(3 marks)

iii. Explain the shape of the graph that represents the strong acid.

(1 mark)

b. One of the solutions was initially a 0.0010 M solution of a strong monoprotic acid. The other was a solution of ethanoic acid. Determine the initial original concentration of the ethanoic acid solution.

(4 marks)

Total Marks = 9 marks

Question 4

The IUPAC (International Union of Pure and Applied Chemistry) Gold Book describes 'electrode potential' as the electromotive force (EMF) of a cell in which the electrode on the left is a standard hydrogen electrode and the electrode on the right is the electrode in question. When a $V^{3+}(aq)/V^{2+}(aq)$ half-cell was connected to the standard hydrogen electrode, the measured EMF was 0.26 V and the voltmeter needle deflected towards the standard hydrogen electrode.

These electrode potentials are shown on the electrochemical series as E° values.

a. i. List the main components and conditions in the 'standard hydrogen electrode'.

(3 marks)

ii. If $V^{3+}(aq) + e^{-} \rightleftharpoons V^{2+}(aq)$ was shown on the electrochemical series, which species would be the next strongest oxidant to $V^{3+}(aq)$?

(1 mark)

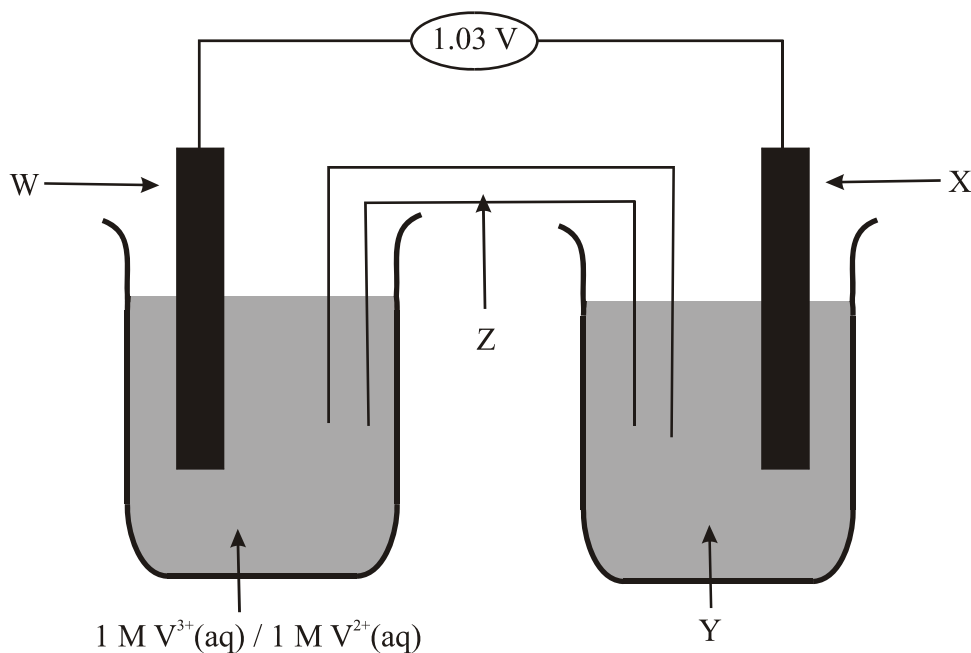
- iii. Give half-equations for the reactions you would predict to occur at the (-) and (+) electrodes during the electrolysis of a 1 M solution of vanadium(III) chloride, $\text{VCl}_3(\text{aq})$.

(-)

(+)

(2 marks)

- b. Consider the galvanic cell represented in the diagram below:



- i. Identify species or substances represented by **W**, **X**, **Y** and **Z**

W

X

Y

Z

(4 marks)

- ii. State the signs of the electrodes

W

X

(1 mark)

- iii. Write balanced half-equations describing the reactions occurring at the electrodes.

W

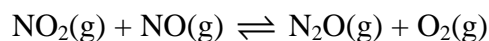
X

(2 marks)

Total Marks = 13 marks

Question 5

Consider the equilibrium system represented by the equation



- a. Investigation of the equilibrium mixture reveals that neither the addition of He gas, nor halving the volume of reaction has any effect on the position of equilibrium. Explain these observations in terms of the relationship between concentration fraction and equilibrium constant.

(2 marks)

- b. When asked to explain in terms of reaction rates why the position of equilibrium shifts to the right on the removal of $\text{O}_2(\text{g})$, a student suggests that it is due to an increase in the rate of the forward reaction. Is the student correct? Explain your answer.

(1 mark)

- c. i. Write a balanced equation describing an equilibrium reaction involved in the production of the 'industrial chemical' you studied this semester. Also indicate whether the reaction is exothermic or endothermic.

(1 mark)

- ii. State whether the product yield, in this equilibrium is favoured by high or low temperatures and discuss the relationship between the optimum temperature used and rate considerations.

(2 marks)

- iii. Would the equilibrium involved in the production of the industrial chemical respond differently to $\text{NO}_2(\text{g}) + \text{NO}(\text{g}) \rightleftharpoons \text{N}_2\text{O}(\text{g}) + \text{O}_2(\text{g})$ if the volume of the reaction vessel was decreased? Explain your answer.

(1 mark)

Total Marks = 7 marks

Question 6

The silvery look of 'white gold' results from plating with rhodium (Rh). In a particular plating exercise, a constant current of 6.18 A was passed through a solution of rhodium ions for 8.15 minutes. The plating process was 85 per cent efficient and the mass of rhodium plated out 0.916 g.

a. Calculate the charge actually used for plating.

(2 marks)

b. Calculate the amount of electrons, in mole, actually used in plating.

(1 mark)

c. Calculate the amount, in mole, of rhodium plated out.

(1 mark)

d. Establish the half-equation for rhodium plating.

(2 marks)

Total Marks = 6 marks

End of Section B

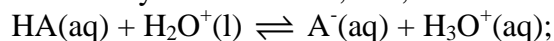
End of Trial Exam

Suggested Answers

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SECTION A – Multiple Choice (Answers)

Q1. A To identify the weak acid, HA, it is necessary to determine the K_a value



$$K_a = \frac{[\text{A}^-][\text{H}_3\text{O}^+]}{[\text{HA}]}$$

Weak acid assumptions:

$$[\text{HA}]_{\text{equilibrium}} = \text{initial} [\text{HA}] = 0.050 \text{ M}$$

$$[\text{A}^-] = [\text{H}_3\text{O}^+]$$

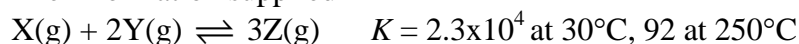
$$\text{So } K_a = \frac{[\text{H}_3\text{O}^+]^2}{0.050}$$

$$\begin{aligned} \text{Since the solution is at } 25^\circ\text{C, } [\text{H}_3\text{O}^+] &= 10^{-14} / [\text{OH}^-] \\ &= 10^{-14} / 2.6 \times 10^{-10} \\ &= 3.8 \times 10^{-5} \text{ M} \end{aligned}$$

$$\begin{aligned} \text{Hence } K_a &= (3.8 \times 10^{-5}) / 0.050 \\ &= \mathbf{2.9 \times 10^{-8}} \end{aligned}$$

From Table 12 of the Data Book this corresponds to **hypochlorous acid, HOCl**.

Q2. D The information supplied



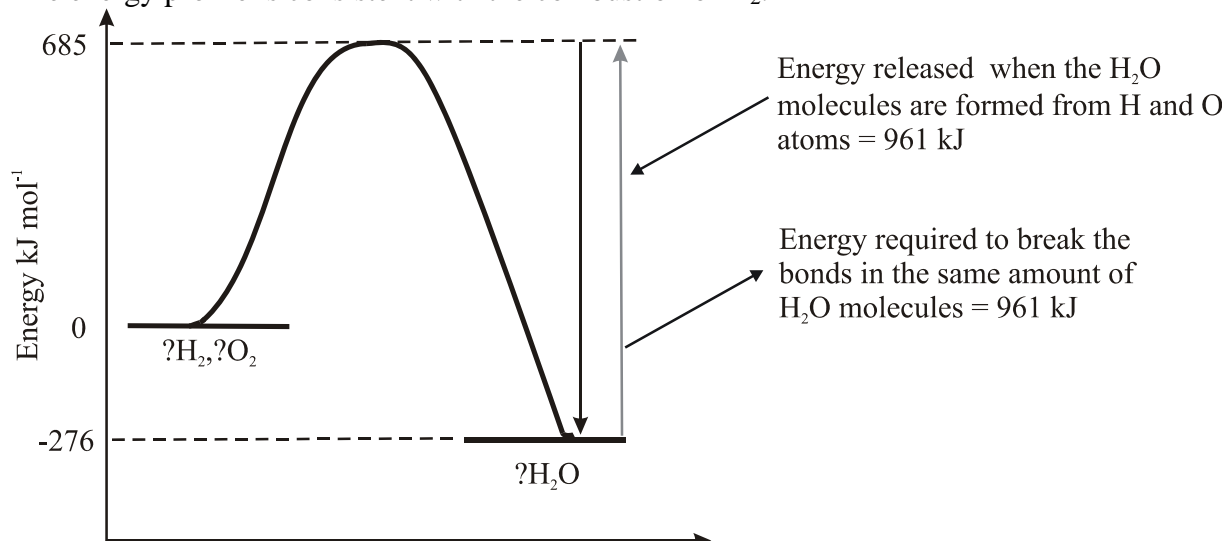
According to the data provided, the K value decreases as the temperature increases, hence the **yield of Z increases as the temperature decreases**.

Because there are 3 mol of reactant particles ($\text{X} + 2\text{Y}$) and 3 mol of product particles (3Z) and all species are in the gas phase, the position of equilibrium, and yield of Z, is **unaffected by a change in pressure**.

Q3. D The shape of the energy profile indicates that the reaction occurring is exothermic.

The only possible reactions are the production of H_2O , from H_2 and O_2 (as in the combustion of H_2), or the decomposition of H_2O , into H_2 and O_2 .

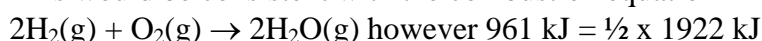
The energy profile is consistent with the combustion of H_2 .



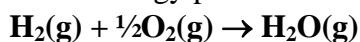
According to this profile, $685 - (-276) = 961$ kJ of energy is required to break all the bonds in the amount of water molecules produced in the reaction.

1922 kJ is absorbed in this process for 2 mol H_2O molecules.

This would be consistent with the combustion equation



So the energy profile is consistent with the combustion equation



- Q4. **B** To decide in which direction the reaction must dominate in order for the system to get to equilibrium, it is necessary to calculate the value of the reaction quotient (Q) or concentration fraction (CF) and compare it with the equilibrium constant.

$$\begin{aligned} Q &= \frac{[\text{NO}]^2}{\{[\text{N}_2] \times [\text{O}_2]\}} \\ &= \frac{(0.050)^2}{\{0.50 \times 0.25\}} \\ &= 2.0 \times 10^{-2} \end{aligned}$$

Q (2.0×10^{-2}) is greater than K_c (1.7×10^{-3}) so, for the system to get to equilibrium, Q must decrease until its value is the same as the equilibrium constant.

Since Q is effectively the ratio of product concentrations to reactant concentrations, the reaction must proceed in the reverse direction to give more reactant and less products. In order for the reaction to move to the right, the rate of the forward reaction must be less than the rate of the reverse reaction. So as the system moves to equilibrium, **the rate of the reverse reaction decreases** (due to the decreasing concentration of NO) and the rate of the forward reaction increases (due to increasing concentrations of N_2 and O_2).

Since the forward reaction is endothermic ($\Delta H = +181 \text{ kJ mol}^{-1}$) then the reverse reaction is exothermic and so as the system moves to equilibrium, energy is released and the temperature in the container increases. In order for the temperature of the container to remain at 2300 K, **energy must be removed from the container.**

- Q5. **B** $\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})$.

As some of the dissolved NH_3 escapes, the **concentration of NH_3 in the solution decreases.**

The system strives to return to equilibrium by favouring the reverse reaction.

However the **$n(\text{NH}_4^+)$ used, and the $n(\text{NH}_3)$ formed as the system returns to equilibrium will be less than the $n(\text{NH}_3)$ that escaped** from the solution. So whilst the $c(\text{NH}_3)$ will be lower than at the initial equilibrium, the **percentage ionisation of NH_3 will be higher.** *Weak bases, like weak acids, increase in percentage ionisation as the concentration of the base, or acid, decreases.*

The dominance of the reverse reaction as the system returns to equilibrium causes the concentration of $\text{OH}^-(\text{aq})$ to decrease, thus increasing the concentration of $\text{H}_3\text{O}^+(\text{aq})$ and **decreasing the pH.**

- Q6. **D** To determine the value of the equilibrium constant, the equilibrium concentrations of the reactants and products are required.

$$\begin{aligned} n(\text{CH}_3\text{OH}) \text{ at equilibrium} &= cV \\ &= 0.060 \times 2.0 \\ &= 0.12 \text{ mol} \end{aligned}$$

The $n(\text{CO})$ and $n(\text{H}_2)$ present at equilibrium can now be determined.

	$\text{CO(g)} + 2\text{H}_2\text{(g)} \rightleftharpoons \text{CH}_3\text{OH(g)}$			
<i>Initially (mol)</i>	0.80	0.60	-	
<i>Reacting (mol)</i>	0.12	0.24	\rightarrow	0.12
<i>Equilibrium (mol)</i>	0.68	0.36		0.12 mol

Equilibrium concentrations are

$$[\text{CO}] = 0.68 / 2.0 = 0.34 \text{ mol L}^{-1}$$

$$[\text{H}_2] = 0.36 / 2.0 = 0.18 \text{ mol L}^{-1}$$

$$[\text{CH}_3\text{OH}] = 0.12 / 2.0 = 0.060 \text{ mol L}^{-1}$$

$$\begin{aligned} K_c &= [\text{CH}_3\text{OH}] / \{[\text{CO}][\text{H}_2]^2\} \\ &= 0.060 / (0.34 \times 0.18^2) \\ &= \mathbf{5.4 \text{ M}^{-2}} \end{aligned}$$

- Q7. **C** $\text{pH} > 7$ means that the $c(\text{H}_3\text{O}^+) < 10^{-7} \text{ M}$ i.e. the $c(\text{H}_3\text{O}^+)$ is lower than it should be at 25°C .

In the equilibrium $2\text{H}_2\text{O(l)} \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{OH}^-(\text{aq})$ the forward reaction is endothermic, i.e. energy absorbing.

A **decrease in temperature** favours the exothermic, in this case the reverse, reaction, leading to a **decrease in $c(\text{H}_3\text{O}^+)$** and an **increase in pH**,

e.g. if $[\text{H}_3\text{O}^+] = 10^{-7} \text{ M} \rightarrow \text{pH} = 7$, but if $[\text{H}_3\text{O}^+] = 10^{-8} \text{ M} \rightarrow \text{pH} = 8$

So if the pH of the pure water was measured at a temperature lower than 25°C , the pH will be greater than 7.

Alternatives A and B would lead to a $\text{pH} < 7$.

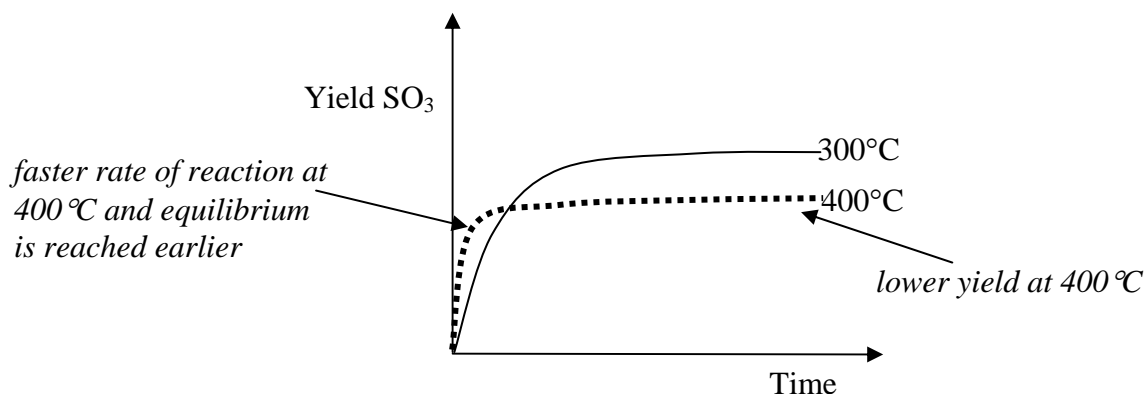
At a temperature $> 25^\circ\text{C}$ the forward reaction is favoured thus causing the $[\text{H}_3\text{O}^+]$ to increase and consequently the pH to decrease.

The absorbing of CO_2 will increase the $[\text{H}_3\text{O}^+]$ - and decrease the pH courtesy of the reaction $\text{CO}_2(\text{g}) + \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{CO}_3(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{HCO}_3^-(\text{aq})$.

Alternative D - loss of solution - does not affect the $[\text{H}_3\text{O}^+]$ and hence would have no effect on pH.

- Q8. A The forward reaction in the equilibrium that produces X is exothermic. So increasing the temperature will have conflicting effects.
- the **rate** of production of X will **increase**, but
 - the **yield** of X will **decrease** since the position of equilibrium responds to an increase in temperature by moving in the direction of the endothermic, in this case reverse, reaction.

So the correct **graph will show a faster initial rate of production (steeper gradient) levelling to a lower yield at 400°C** compared to 300°C



- Q9. C $2\text{NH}_3(\text{g}) \rightleftharpoons \text{N}_2(\text{g}) + 3\text{H}_2(\text{g})$

$$K_c = \frac{[\text{N}_2][\text{H}_2]^3}{[\text{NH}_3]^2}$$

$$K_c \times [\text{NH}_3]^2 = [\text{N}_2][\text{H}_2]^3$$

$$[\text{NH}_3]^2 = [\text{N}_2][\text{H}_2]^3 / K_c$$

$$[\text{NH}_3] = \sqrt{[\text{N}_2][\text{H}_2]^3 / K_c}$$

- Q10. B When the volume of the syringe is decreased from 100 mL to 25 mL (by a factor of four), the pressure instantaneously increases from 102 kPa to 408 kPa. However the increase in pressure upsets the equilibrium $2\text{NO}_2(\text{g}) \rightleftharpoons \text{N}_2\text{O}_4(\text{g})$. The system responds by striving to partially compensate for the increased pressure by moving the position of equilibrium towards the side with fewer particles. When equilibrium is again reached, the pressure will be **lower than 408 kPa but still higher than 102 kPa**.

Q11. **B** According to the equation, the reaction is endothermic ($\Delta H > 0$) and 7.20 kJ of energy is absorbed from the solution when one mol $\text{Na}_2\text{S}_2\text{O}_3$ dissolves. The temperature of the solution will decrease.

$$\begin{aligned}\text{Energy absorbed} &= n(\text{Na}_2\text{S}_2\text{O}_3) \times \text{energy absorbed by one mole} \\ &= 0.100 \text{ mol} \times 7.20 \text{ kJ mol}^{-1} \\ &= 0.720 \text{ kJ}\end{aligned}$$

$$\text{For water } E = 4.18 \text{ J } ^\circ\text{C}^{-1} \text{ g}^{-1} \times m(\text{H}_2\text{O}) \times \Delta T$$

$$720 \text{ J} = 4.18 \times 500 \times \Delta T$$

$$\Delta T = 720 / (4.18 \times 500)$$

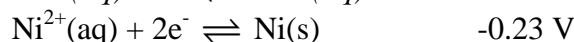
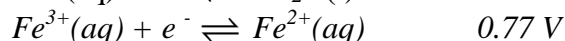
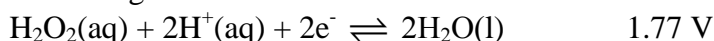
$$= \mathbf{0.344} \text{ } ^\circ\text{C}$$

This change in temperature is approximate because the calculations are based on the 500 g of water (assuming density of 1 g mL^{-1}) rather than the approximately 516 g ($\text{Na}_2\text{S}_2\text{O}_3 + \text{H}_2\text{O}$) produced. Assuming the density and specific heat of the solution are the same as for water, the temperature change would be calculated as $720 / (4.18 \times 516) = 0.334 \text{ } ^\circ\text{C}$.

Q12. **D** In order for the cell to generate 1.00 V at 25°C , 101.3 kPa and for 1 M solutions, the difference between the E° values of the two half-cells must be 1.00 V.

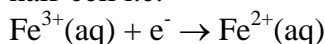
Since the $\text{Fe}^{3+}(\text{aq})/\text{Fe}^{2+}(\text{aq})$ half-cell has an E° value of 0.77 V, the other half cell must have an E° value either 1.00 V greater than 0.77 V, i.e. 1.77 V, or 1.00 V less than 0.77 V, i.e. -0.23 V.

According to the electrochemical series this is consistent with



In a galvanic cell, electrons move spontaneously from the anode (-) to the cathode (+).

So the electrode signs indicate that oxidation is occurring in the $\text{Fe}^{3+}(\text{aq})/\text{Fe}^{2+}(\text{aq})$ half-cell i.e.



Since electrons leave the site of oxidation and go to the site of reduction, the left-hand half-cell must contain the oxidant, in this case $\text{H}_2\text{O}_2(\text{aq}), \text{H}^+(\text{aq})$, i.e. 1.00 V higher up on the electrochemical series than the reductant $\text{Fe}^{2+}(\text{aq})$.

$\text{H}_2\text{O}(\text{l})$ is the product of the reaction in Half-cell 1, because the oxidant

$\text{H}_2\text{O}_2(\text{aq})$ is reduced to $\text{H}_2\text{O}(\text{l})$ according to $\mathbf{\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})}$

Alternatively:

Since $E(\text{cell}) = E^\circ(\text{oxidant half-cell}) - E^\circ(\text{reductant half-cell})$

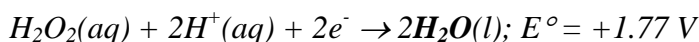
$$1.00 \text{ V} = E^\circ(\text{oxidant}) - E^\circ(\text{Fe}^{3+}(\text{aq})/\text{Fe}^{2+}(\text{aq}))$$

$$= E^\circ(\text{oxidant}) - (0.77 \text{ V})$$

$$\text{Hence } E^\circ(\text{oxidant}) = 1.00 + 0.77$$

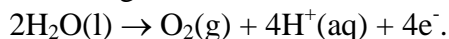
$$= 1.77 \text{ V}$$

From the electrochemical series

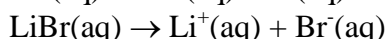
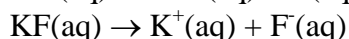
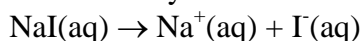


Q13. **B** According to the Data Book the initial green colour of Bromothymol blue shows that solution in the cell had an initial pH very close to 7. Thus XY cannot be hydrochloric acid because the pH of 1.0 M HCl(aq) is zero.

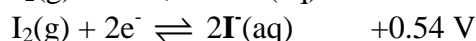
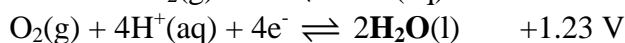
The change in indicator colour from green to yellow around the (+) electrode, indicates that the $[H^+]$ increases at this electrode during the electrolysis. The only way that $H^+(aq)$ can be produced in this cell is by the oxidation of $H_2O(l)$, according to



This can only occur if the strongest reductant in the cell is $H_2O(l)$



The relative positions of the reductants, $I^-(aq)$, $F^-(aq)$, $Br^-(aq)$ and $H_2O(l)$ on the electrochemical series are



Since H_2O is a stronger reductant than $F^-(aq)$ only, **the compound XY must be KF, potassium fluoride.**

Q14. **C** Calibration Factor = Energy added during heating / ΔT_c

$$= VIt / \Delta T_c$$

$$= 6.00 \times 2.30 \times 75.0 / 1.355$$

$$= 1035 / 1.355$$

$$= 764 \text{ J } ^\circ\text{C}^{-1}$$

$$\text{Energy released by fuel} = CF \times \Delta T_r$$

$$= 764 \text{ J } ^\circ\text{C}^{-1} \times (69.42 - 23.31) ^\circ\text{C}$$

$$= 764 \times 46.11 ^\circ\text{C}$$

$$= 3.52 \times 10^4 \text{ J}$$

$$\text{Energy per mol of fuel} = 3.52 \times 10^4 \text{ J} / 2.50 \times 10^{-2} \text{ mol}$$

$$= 1.41 \times 10^6 \text{ J}$$

$$= 1.41 \times 10^3 \text{ kJ}$$

So the fuel has a molar enthalpy (ΔH_c) of combustion of **$-1.41 \times 10^3 \text{ kJ mol}^{-1}$.**

According to Table 13 in the Data Book. ($\Delta H_c(\text{ethene}) = -1409 \text{ kJ mol}^{-1}$)

- Q15. C If KMnO_4 acts as the oxidising agent then it is reduced in the reaction. To identify the product you need to determine the $n(\text{KMnO}_4)$ reacted and the $n(e^-)$ used in the reduction.

$$n(\text{KMnO}_4) \text{ consumed} = 2.0 / (39.1 + 54.9 + 4 \times 16.0) \\ = 0.0127 \text{ mol}$$

$$n(e^-) \text{ transferred} = Q / F \\ = 4886 / 96500 \\ = 0.0506 \text{ mol}$$

$$\text{Ratio } n(e^-) / n(\text{KMnO}_4) = 0.0506 / 0.0127 \\ = 4$$

So the half-equation for the reduction of KMnO_4 must contain $4e^-$ for each 1 KMnO_4 (MnO_4^-). This is consistent with the oxidation number of Mn decreasing by 4 as $\text{MnO}_4^-(\text{aq})$ causes oxidation and is itself reduced. The **oxidation number of Mn** in MnO_4^- (KMnO_4) is +7 and so it **decreases to +3**.

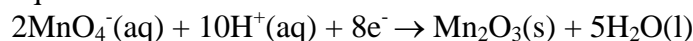
K_2MnO_4 – oxidation number of Mn is +6

MnO_2 - oxidation number of Mn is +4

Mn_2O_3 - oxidation number of Mn is +3

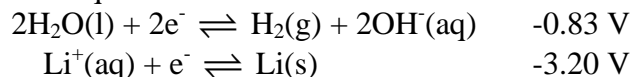
MnO - oxidation number of Mn is +2

Hence the product could be Mn_2O_3 , which would be produced via the half-equation



- Q16. D This is a question where a lot of time could be wasted through unnecessary calculations. When asked to determine the amount of metal produced by electrolysis of aqueous solutions, the first thing that should be done is to **use the electrochemical series to check that the metal cations are a stronger oxidant, or higher on the left hand side of the series, than H_2O** .

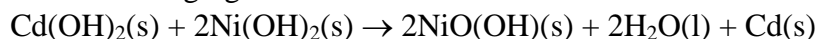
Whilst $\text{Co}^{2+}(\text{aq})$, $\text{Ag}^+(\text{aq})$ and $\text{Ni}^{2+}(\text{aq})$ are all stronger oxidants than H_2O , the two half-equations



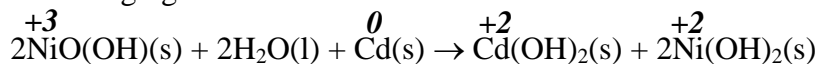
indicate that $\text{H}_2\text{O}(\text{l})$ is a stronger oxidant than $\text{Li}^+(\text{aq})$ and so would be preferentially reduced, to $\text{H}_2(\text{g})$ and $\text{OH}^-(\text{aq})$, during electrolysis.

So the smallest amount of metal would be deposited from the electrolysis of $\text{LiNO}_3(\text{aq})$.

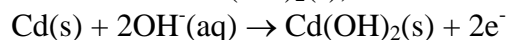
- Q17. C Given the overall recharging reaction



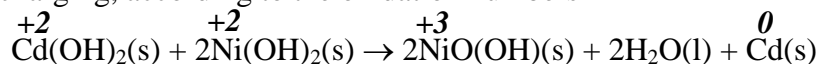
The overall discharging reaction must be



Since oxidation occurs at the anode and, according to the oxidation numbers $\text{Cd}(\text{s})$ is oxidised to $\text{Cd}(\text{OH})_2(\text{s})$, the oxidation half-equation must be



Q18. **D** During recharging, according to the oxidation numbers



$\text{Cd}(\text{OH})_2$ is being reduced and during recharging (electrolysis) reduction occurs at the (-) electrode.

Since the negative terminal of power supply must be attached to the (-) terminal of the battery, it must be **connected to the electrode containing $\text{Cd}(\text{OH})_2$** .

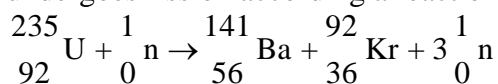
During recharging a voltage greater than that generated during discharging must be applied to the cell to force the electrons to flow in the opposite direction.

Hence a **voltage greater than 1.4 V** must be applied.

Q19. **A** Both nuclear fission and coal fired power stations use heat energy to boil water to produce steam; the steam is then used to drive a turbine, thus converting thermal energy into mechanical energy; mechanical energy is then converted into electrical energy in a generator.

However, the process by which the initial thermal energy is generated is different.

In a **nuclear fission** power station, the fuel is usually uranium-235, which undergoes fission according a reaction such as



This shows that the **elements in the products are different to those in the reactants**.

In a coal-fired power station, during the combustion of coal as represented by the equation

$\text{C}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g})$ there is **no change in the elements** present.

Q20. **C** Because one cannot be sure of the extent or impact of the irritation, the best safety measures must be implemented. In many instances chemicals that may be irritating to the respiratory system are used under fume hoods which minimise the user's exposure. However, if available, the best safety measure would be a protective **breathing apparatus**.

Face shields are used to protect the face and eyes but provide minimal protection against irritating vapours.

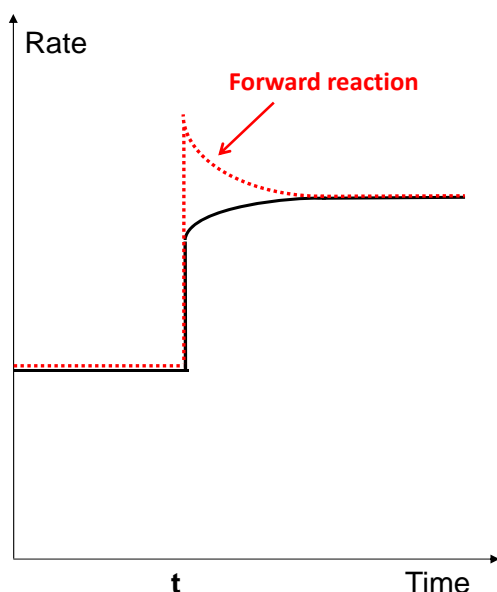
Masks may protect from dust or powders but provide minimal protection against irritating vapours.

SECTION B – Short Answer (Answers)

Question 1

- a. i. Energy was released in getting to equilibrium because, according to the sign of ΔH the **forward reaction is exothermic.** ①
- ii. Energy released in getting to equilibrium = 12.8 kJ
According to the equation; 2 mol NO_2 reacting releases 57.2 kJ
So 1 mol $\text{NO}_2 \rightarrow 57.2 / 2 = 28.6$ kJ ①
 $n(\text{NO}_2)$ reacting = energy released / energy from 1 mol NO_2
= $12.8 / 28.6$
= **0.448 mol** ①
- iii. $n(\text{N}_2\text{O}_4)$ at equilibrium = $\frac{1}{2} \times n(\text{NO}_2)$ reacting
= $\frac{1}{2} \times 0.448$
= 0.224 mol
 $c(\text{N}_2\text{O}_4)$ at equilibrium = $0.224 / 2.00$
= **0.112 M** ①
 $n(\text{NO}_2)$ at equilibrium = initial $n(\text{NO}_2) - n(\text{NO}_2)$ reacted
= $0.500 - 0.448$
= 0.052 mol
 $c(\text{NO}_2)$ at equilibrium = $0.052 / 2.00$
= **0.026 M** ①
 $K = [\text{N}_2\text{O}_4] / [\text{NO}_2]^2$
= $0.112 / (0.026)^2$
= **166** ①
- b. i. Since the concentrations of NO_2 and N_2O_4 have both doubled, the **volume of the gas syringe has been halved (decreased).** ①
- ii. Le Chatelier's principle predicts that the **system** pushed out of equilibrium by the imposed change **will move to partially compensate for the imposed change and return to equilibrium.** ①
Because a **decrease in volume of the gaseous system causes an increase in pressure**, the **system moves to decrease the pressure by favouring the side with fewer particles.** ① This is why the concentration-time graphs show the $[\text{NO}_2]$ **decreasing and the $[\text{N}_2\text{O}_4]$ increasing as the system returns to equilibrium.** ①

iii.



When the volume was decreased, the rates of both the forward and reverse reactions increased.

As the system returns to equilibrium, the rate of the forward reaction decreases since the decreasing $[\text{NO}_2]$ reduces the number of successful collisions **1** (collisions with energy greater than the activation energy) and the rate of the reverse reaction increases.

iv. $[\text{NO}_2]_{e2} > [\text{NO}_2]_{e1}$;

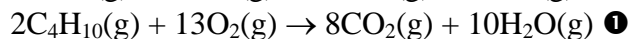
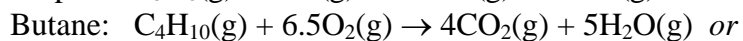
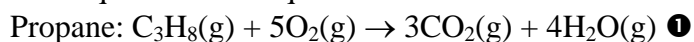
$m(\text{NO}_2)_{e2} < m(\text{NO}_2)_{e1}$ **1**

As the system returns to equilibrium NO_2 is consumed as the forward reaction dominates. However the system returns to equilibrium before the $[\text{NO}_2]$ decreases back to its original value.

So whilst the $m(\text{NO}_2)$ is lower at the new equilibrium then it was before the volume decrease the $[\text{NO}_2]$ is still higher.

Question 2

a. Two equations are required.



Two equations cannot be combined because this would produce incorrect fuel to oxygen ratios.

- b. i. 298 K and 101.3 kPa are SLC conditions, so the $n(\text{C}_3\text{H}_8)$ and $n(\text{C}_4\text{H}_{10})$ can be calculated and combined with molar enthalpy of combustion data from the data book.
- $$100.0 \text{ L LPG} \rightarrow 97.50 \text{ L C}_3\text{H}_8 \text{ and } 2.500 \text{ L C}_4\text{H}_{10}$$
- $$n(\text{C}_3\text{H}_8) = 97.50 \text{ L} / 24.5 \text{ L mol}^{-1}$$
- $$= \mathbf{3.98 \text{ mol} \text{ ①}}$$
- $$\text{Energy available from C}_3\text{H}_8 = 3.98 \text{ mol} \times 2217 \text{ kJ mol}^{-1} \text{ (from Data Book)}$$
- $$= \mathbf{8.82 \times 10^3 \text{ kJ} \text{ ①}}$$
- $$n(\text{C}_4\text{H}_{10}) = 2.500 \text{ L} / 24.5 \text{ L mol}^{-1}$$
- $$= 0.102 \text{ mol}$$
- $$\text{Energy available from C}_4\text{H}_{10} = 0.102 \text{ mol} \times 2874 \text{ kJ mol}^{-1} \text{ ...from Data Book}$$
- $$= 2.93 \times 10^2 \text{ kJ}$$
- $$\text{Total energy available from 100 L LPG} = 8.82 \times 10^3 + 2.93 \times 10^2$$
- $$= \mathbf{9.11 \times 10^3 \text{ kJ} \text{ ①}}$$
- ii. Because LPG is a mixture of compounds, and the composition varies according to the source, it does not have a representative molar mass ① so the heat of combustion is expressed in kJ L^{-1} .
- $$\text{The heat of combustion of the 100 L sample analysed} = 9.11 \times 10^3 \text{ kJ} / 100 \text{ L}$$
- $$= \mathbf{9.11 \text{ kJ L}^{-1} \text{ ①}}$$
- c. i. $\text{C}_3\text{H}_8(\text{g}) + 6\text{H}_2\text{O}(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 10\text{H}_2(\text{g}) \text{ ①}$
- ii. $n(\text{C}_3\text{H}_8) = m(\text{C}_3\text{H}_8) / M(\text{C}_3\text{H}_8)$
- $$= 1.50 \times 10^3 / 44.0$$
- $$= 34.1 \text{ mol} \text{ ①}$$
- $$n(\text{H}_2) \text{ produced} = 10 \times 34.1$$
- $$= 341 \text{ mol} \text{ ①}$$
- $$\text{Energy available} = 341 \text{ mol} \times 286 \text{ kJ mol}^{-1} \text{ ... from Data Book}$$
- $$= 9.75 \times 10^4 \text{ kJ}$$
- $$= \mathbf{97.5 \text{ MJ} \text{ ①}}$$
- iii. 60 % efficient means that **60 per cent of the chemical energy available from the fuel is converted into electrical energy.** ① The remainder of the chemical energy is converted mainly into heat energy.
- iv. In a fuel cell electrons flow spontaneously from the (-) electrode to the (+) electrode. So oxidation of the fuel occurs at (-) electrode and reduction of oxygen at the (+) electrode.
- $$\text{(-) } \text{H}_2(\text{g}) \rightarrow 2\text{H}^+(\text{pem}) + 2\text{e}^- \text{ ①}$$
- $$\text{(+) } \text{O}_2(\text{g}) + 4\text{H}^+(\text{pem}) + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{g}) \text{ ①}$$
- The H^+ ions are released at one side of the PEM, travel through it and are consumed at the other side.
- v. Reaction rate is improved by **adding catalysts to the surfaces of the electrodes.** ①

Question 3

- a. i. Graph B ①
- ii. The $[\text{H}_3\text{O}^+]$ decreases at time 't' because of the increase in volume. ①
As a weak acid, HA (aq), only a small amount has ionised prior to dilution. Whilst the concentrations of A^- (aq) and HA(aq) also decrease on dilution, the concentration fraction $\{[\text{A}^-][\text{H}_3\text{O}^+] / [\text{HA}]\}$ becomes $< K$. ①
To get back to equilibrium, ionisation of the acid increases causing the $[\text{H}_3\text{O}^+]$ to increase until equilibrium is again established. ①
- iii. Because the strong acid is fully ionised, the $[\text{H}_3\text{O}^+]$ decreases on dilution and remains at the lower concentration. ①
- b. $\text{CH}_3\text{COOH}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
 $K_a = 1.7 \times 10^{-5}$ – from data booklet
 $\text{pH} = 3.00 \rightarrow [\text{H}_3\text{O}^+] = 10^{-3.00}$
 $= 1.0 \times 10^{-3} \text{ M}$ ①
Since CH_3COOH (aq) is a weak acid we may assume that
 $[\text{CH}_3\text{COO}^-] = [\text{H}_3\text{O}^+]$ ①
 $[\text{CH}_3\text{COOH}]_e = [\text{CH}_3\text{COOH}]_{\text{initially}}$
 $K_a = [\text{CH}_3\text{COO}^-]_e \times [\text{H}_3\text{O}^+]_e / [\text{CH}_3\text{COOH}]_e$
 $1.7 \times 10^{-5} = (1.0 \times 10^{-3})^2 / [\text{CH}_3\text{COOH}]$ ①
 $[\text{CH}_3\text{COOH}] = (1.0 \times 10^{-3})^2 / (1.7 \times 10^{-5})$
 $= 0.059 \text{ M}$ ①

Question 4

- a. i. Pt electrode, ①
1 M H^+ (aq), ①
 H_2 (g) at 101.3 kPa and 25°C ①
- ii. Since the voltmeter needle deflected towards the standard hydrogen electrode this shows that electrons were moving towards it. This indicates that H^+ (aq) is a stronger oxidant than V^{3+} (aq) and so on the electrochemical series $\text{V}^{3+}/\text{V}^{2+}$ will be below H^+/H_2 at
 $\text{V}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{2+}(\text{aq}), E^0 = -0.26 \text{ V}$
Next strongest oxidant is immediately above V^{3+} (aq) on the electrochemical series, so the next strongest oxidant is Ni^{2+} (aq) ①

- iii. $\text{VCl}_3(\text{aq}) \rightarrow \text{V}^{3+}(\text{aq}) + 3\text{Cl}^-(\text{aq})$. Electrolysis will involve the strongest oxidant present, $\text{V}^{3+}(\text{aq})$, and the strongest reductant present, $\text{H}_2\text{O}(\text{l})$. Electrons are moved from the (+) electrode to the (-) electrode.
 (-) electrode, reduction: $\text{V}^{3+}(\text{aq}) + \text{e}^- \rightarrow \text{V}^{2+}(\text{aq})$ ①
 (+) electrode, oxidation: $2\text{H}_2\text{O}(\text{l}) \rightarrow \text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^-$ ①
- b. The 'other' half-cell containing X and Y can be identified from the cell voltage and the electrode potential of $\text{V}^{3+}(\text{aq})/\text{V}^{2+}(\text{aq})$.
 $E(\text{cell}) = E^\circ(\text{V}^{3+}/\text{V}^{2+}) - E^\circ(\text{other half-cell})$ or $E^\circ(\text{other half-cell}) - E^\circ(\text{V}^{3+}/\text{V}^{2+})$
 $1.03 \text{ V} = -0.26 - E^\circ(\text{other half-cell})$ or $E^\circ(\text{other half-cell}) - (-0.26)$
 So
 $1.03 + E^\circ(\text{other half-cell}) = -0.26$ or $1.03 = E^\circ(\text{other half-cell}) + 0.26$
 $E^\circ(\text{other half-cell}) = -0.26 - 1.03$ or $E^\circ(\text{other half-cell}) = 1.03 - 0.26$
 $E^\circ(\text{other half-cell}) = -1.29 \text{ V}$ or $E^\circ(\text{other half-cell}) = +0.77 \text{ V}$
 According to the electrochemical series there is no half-cell with $E^\circ = -1.29 \text{ V}$, so the other half-cell is the $\text{Fe}^{3+}(\text{aq})/\text{Fe}^{2+}(\text{aq})$ half-cell which has $E^\circ = +0.77 \text{ V}$
- i. W – **platinum, Pt** ① or carbon (graphite), C
 X – **platinum, Pt** ① or carbon (graphite), C
 Y – **1 M $\text{Fe}^{3+}(\text{aq})$, 1 M $\text{Fe}^{2+}(\text{aq})$** ① or 1 M $\text{Fe}(\text{NO}_3)_3(\text{aq})$, 1 M $\text{Fe}(\text{NO}_3)_2(\text{aq})$
 or similar
 Z – **$\text{KNO}_3(\text{aq})$** ① or saturated potassium nitrate solution.
Because there are no metals as part of the redox pairs in the half-cells, both require an inert electrode. Half-cells must contain both the oxidant and reductant shown in the electrochemical series half-equations. Potassium nitrate is the most commonly used salt bridge solution because both $\text{K}^+(\text{aq})$ and $\text{NO}_3^-(\text{aq})$ are very unreactive.
- ii. W – **negative (-)** X – **positive (+)** ①
Electrons are moving from the less positive half-cell ($\text{V}^{3+}(\text{aq})/\text{V}^{2+}(\text{aq})$) to the more positive half-cell ($\text{Fe}^{3+}(\text{aq})/\text{Fe}^{2+}(\text{aq})$).
- iii. W – $\text{V}^{2+}(\text{aq}) \rightarrow \text{V}^{3+}(\text{aq}) + \text{e}^-$ ①
 X – $\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightarrow \text{Fe}^{2+}(\text{aq})$ ①

Question 5

- a. The position of equilibrium will only shift if the concentration fraction $[\text{N}_2\text{O}][\text{O}_2] / \{[\text{NO}_2][\text{NO}]\}$ becomes smaller or larger than K, when a change is imposed.
 Adding **He** has **no effect on the concentrations of any of the species** so the concentration fraction does not change. ①
Halving the volume doubles the concentrations of all the species present but because there are the **same number of particles on both sides of the equilibrium**, the concentration fraction does not change. ①
- b. No, the student is not correct. **The decrease in $[\text{O}_2]$ decreases the rate of the reverse reaction, so the forward reaction is faster than the reverse reaction but its rate has not increased.** ① Because of the higher relative rate of the forward reaction, the system shifts right to compensate for the loss of O_2 .

c.

N.B. In i. all states are (g).

	1.	2.	3.	4.
i.	$\text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3$	$2\text{NO} + \text{O}_2 \rightleftharpoons 2\text{NO}_2$	$\text{C}_2\text{H}_6 \rightleftharpoons \text{C}_2\text{H}_4 + \text{H}_2$ $\text{C}_3\text{H}_8 \rightleftharpoons \text{C}_2\text{H}_4 + \text{CH}_4$	$2\text{SO}_2 + \text{O}_2 \rightleftharpoons 2\text{SO}_3$
①	exothermic	exothermic	endothermic	exothermic
ii. ① ①	low temperatures rate decreases at low temperatures 350-500°C and a porous iron catalyst is used.	low temperatures rate increases at low temperatures, so yield and rate both favoured. 30°C used.	high temperatures rate increases at high temperatures, so yield and rate both favoured. 750-900 °C used.	low temperatures rate decreases at low temperatures 400-500°C and a V_2O_5 catalyst is used.
iii. ①	Increase pressure – system favours side with fewer particles, more NH_3	Increase pressure – system favours side with fewer particles, more NO_2	Increase pressure – system favours side with fewer particles, less C_2H_4	Increase pressure – system favours side with fewer particles, more SO_3

Question 6

a. Charge passed $Q = It$

$$= 6.18 \times (8.15 \times 60)$$

$$= 3.02 \times 10^3 \text{ C } \textcircled{1}$$

Charge actually used in plating = $0.85 \times 3.02 \times 10^3$

$$= 2.57 \times 10^3 \text{ C } \textcircled{1}$$

b. $n(e^-)$ used in plating = Q / F

$$= 2.57 \times 10^3 / 96500$$

$$= 0.0267 \text{ mol } \textcircled{1}$$

c. $n(\text{Rh})$ plated = $0.916 / 102.9$

$$= 0.00890 \text{ mol } \textcircled{1}$$

d. Ratio $n(e^-)/n(\text{Rh}) = 0.00267 / 0.00890 = 3 \textcircled{1}$

Half-equation $\text{Rh}^{3+}(\text{aq}) + 3e^- \rightarrow \text{Rh}(\text{s}) \textcircled{1}$

End of Suggested Answers