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Draw a cross through the box (☒) if you have NOT written in this booklet

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NZQA

Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 2 Chemistry 2024

91166 Demonstrate understanding of chemical reactivity

Credits: Four

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of chemical reactivity.	Demonstrate in-depth understanding of chemical reactivity.	Demonstrate comprehensive understanding of chemical reactivity.

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should attempt ALL the questions in this booklet.

A periodic table and other reference material are provided in the Resource Booklet L2–CHEMR.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–16 in the correct order and that none of these pages is blank.

Do not write in any cross-hatched area (▨). This area will be cut off when the booklet is marked.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

Excellence

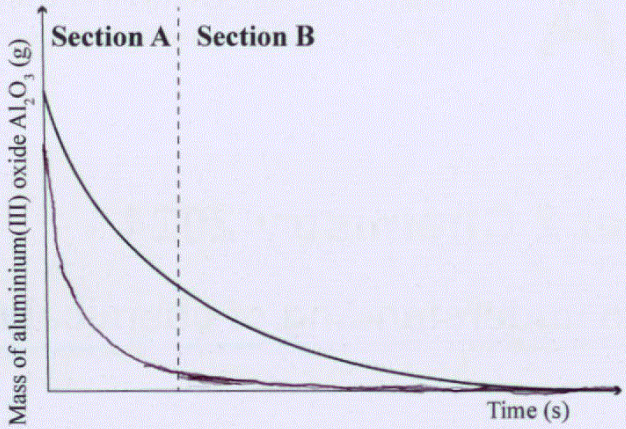
TOTAL 22

QUESTION ONE

Tiwai Point in the South Island of New Zealand extracts large amounts of aluminium sourced from an ore called bauxite, which contains the mineral aluminium(III) oxide, Al_2O_3. One step of the main extraction process is as follows:

$$Al_2O_3(s) + 2NaOH(aq) \rightarrow 2NaAlO_2(aq) + H_2O(\ell)$$

The graph below shows the mass of aluminium(III) oxide, Al_2O_3, as it reacts with 0.5 mol L^{-1} NaOH.



If you need to redraw your response, use the graph on page 11.

(a) (i) Add a second line to the graph to predict the rate of decline in mass of aluminium(III) oxide if 2 mol L^{-1} NaOH were used in the reaction instead.

Assume both reactions started with the same mass of ore.

(ii) With reference to the line you have drawn, explain the effect that this change in concentration of NaOH from 0.5 mol L^{-1} to 2 mol L^{-1} would have on the rate of this reaction.

In your answer you should include reference to:

- mass of Al_2O_3
- each section of the line
- collision theory.

The Increase in [NaOH] caused the rate of reaction with Al_2O_3 to Increase. This is because a higher concentration of NaOH means there are more NaOH particles In a given amount of volume, assuming the volume has not changed then more NaOH particles are in the same amount of volume. This Increases the rate of Reaction as the NaOH particles are closer to the Al_2O_3 particles, meaning the frequency of collisions Increases as it is more

likely for the reactant particles to collide, therefore the rate of successful collisions increases as collisions are ouring more frequently, resulting in a higher Rate of Reaction. This is shown on the graph where at section A the gradient of the 2 ~~2~~ $moll^{-1}$ NaOH line is much steeper than the $0.5 moll^{-1}$ line as the rate of Reaction is much higher, meaning the Reactants are converting into products quicker at $2 moll^{-1}$ NaOH than at $0.5 moll^{-1}$ which ~~is~~ shows the increase in [NaOH] is causing the higher Rate of Reaction. At Section B the Gradient of the $2 moll^{-1}$ NaOH has flattened out into a horizontal line while the $0.5 moll^{-1}$ Gradient is still quite high ~~shown~~ meaning the reactants have ~~was~~ stopped ~~&~~ colliding In the $2 moll^{-1}$ line, indicating that all of the Reactants have turned into products, while at $0.5 moll^{-1}$ ~~there~~ not all of the reactants have been converted into products, further showing that increasing the [NaOH] increased the Rate of Reaction. ~~Then~~ In both Reactions the mass of Al_2O_3 will →

(b) For the 0.5 mol L^{-1} NaOH solution, calculate:

(i) the hydronium ion, H_3O^+, concentration

$NaOH \rightarrow Na^+ + OH^-$

$[H_3O^+] = \frac{1 \times 10^{-14}}{0.5} = 2 \times 10^{-14}$ $molL^{-1}$

(ii) the pH.

$[H_3O^+] = 2 \times 10^{-14}$ $molL^{-1}$

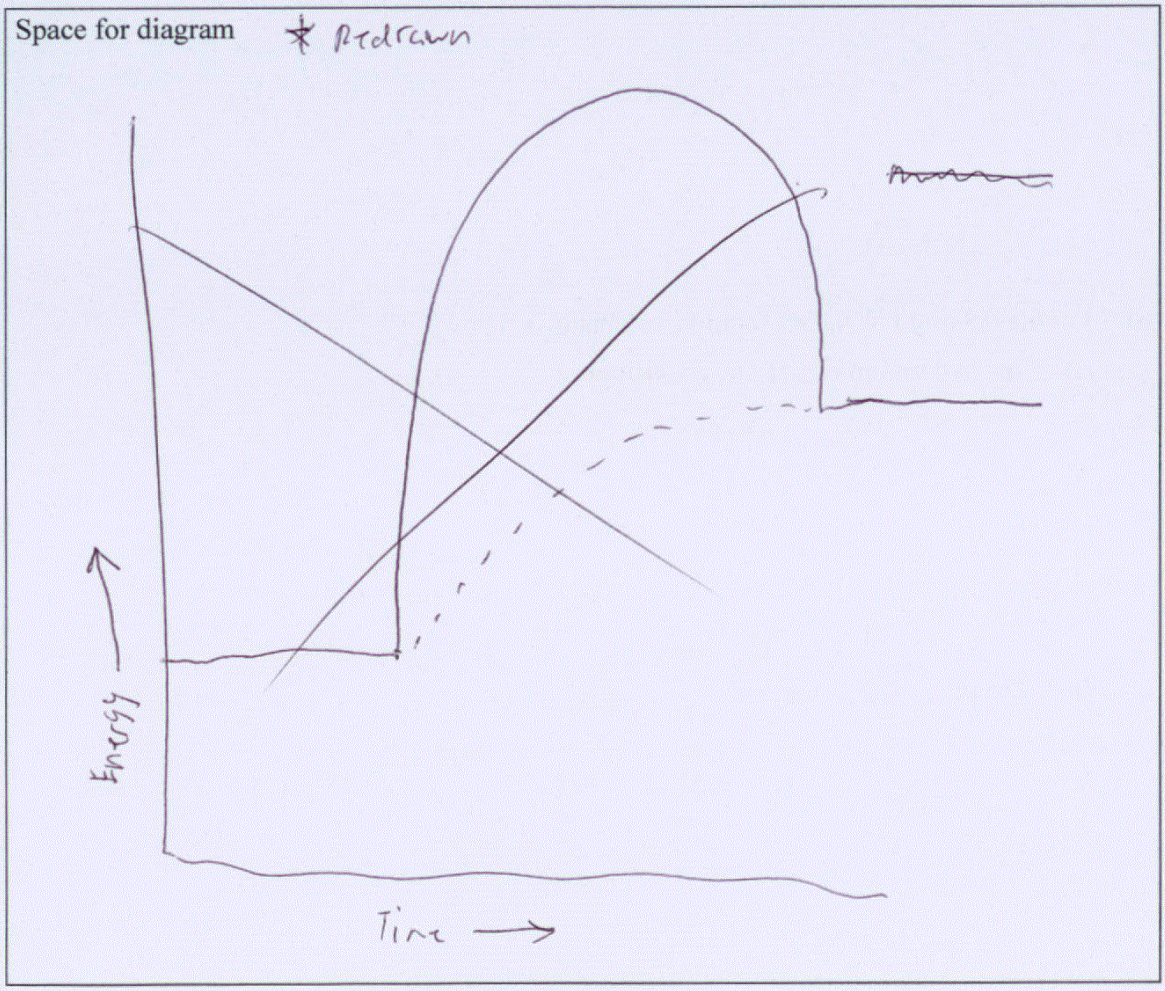
$pH = -\log(2 \times 10^{-14}) = 13.7$

(c) Using the principles of collision and particle theories, explain why using a catalyst would help to increase the rate of production of sodium aluminium salt ($NaAlO_2$).

You should include an energy profile diagram to support your answer.

A Catalyst Provides an alternative Reaction Pathway ~~for the reacts~~ which requires a lower activation energy for the reactants to successfully collide. This increases the rate of successful collisions as more of the reactant Particles will contain energy at or above the activation energy which results in an increase in Rate of Production of $NaAlO_2$. As more Al_2O_3 and $NaOH$ Particles will contain sufficient amount of energy more of the collisions will be successful so $NaAlO_2$ will be produced quicker.

Space for diagram * Redrawn



QUESTION TWO

Superphosphate fertiliser is manufactured in New Zealand using phosphorite rocks and sulfuric acid. The sulfuric acid is often produced on site, and includes a reaction involving oxygen, $O_2(g)$, sulfur dioxide, $SO_2(g)$, and sulfur trioxide, $SO_3(g)$, which is represented by the equilibrium constant expression below:

$$K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]} \qquad K_c = 32.7 \text{ at } 25\,^\circ\text{C}$$

(a) (i) Give the equation for this reaction.

$2SO_{2(g)} + O_{2(g)} \rightarrow 2SO_{3(g)}$

(ii) The reaction is set up and allowed to reach equilibrium.

Calculate the concentration of oxygen, O_2, at equilibrium if the concentration of sulfur dioxide, SO_2, is 0.17 mol L^{-1} and sulfur trioxide, SO_3, is 0.50 mol L^{-1}.

$\frac{(0.50)^2}{(0.17)^2 X} = 32.7$ $[O_2] = 0.265 \text{ mol L}^{-1}$

$\frac{(0.50)^2}{(0.17)^2} = 32.7x$

(b) The reaction is set up differently, with concentrations of each component as indicated below.

$[SO_2] = 0.530$ mol L^{-1}

$[O_2] = 0.710$ mol L^{-1}

$[SO_3] = 0.620$ mol L^{-1}

(i) Using a calculation, explain why this reaction is not at equilibrium.

$\frac{(0.620)^2}{(0.530)^2 X (0.710)} = 1.93$

As the K_c at these concentrations do not equal 32.7, the system is not in equilibrium.

(ii) Explain what must occur for equilibrium to be established.

$K_c = \frac{\text{Products}}{\text{Reactants}}$ as K_c value is bellow 32.7 it means there is more Reactants than products, to establish equilibrium the system will need to Increase $[SO_3]$ and decrease the $[SO_2]$ and $[O_2]$ until the forwards Reaction Rate is equal with the Reverse Reaction Rate.

(c) Sulfuric acid, H_2SO_4, can be manufactured using the following reaction:

$SO_3(g) + H_2O(g) \rightleftharpoons H_2SO_4(g)$

(i) Using equilibrium principles, identify, then describe, the effect on the position of the equilibrium when:

- water vapour, $H_2O(g)$, is added to the reaction mixture

Circle ~~your choice~~:

Forward is favoured **No Change** **Reverse is favoured**

When $H_2O_{(g)}$ is added to the system, equilibrium will shift to favour the forwards reaction to minimise the change in $[H_2O]$ by producing more products. This means more $H_2SO_{4(g)}$ will be produced to counter the increase in $[H_2O]$.

- sodium hydroxide, NaOH(*aq*), is added to the reaction mixture.

Circle your choice:

Forward is favoured **No Change** **Reverse is favoured**

NaOH contains OH^- ions, so by adding it to the system, the system becomes ~~basic~~ basic. To counter this increase in PH level, the system will produce more products as H_2SO_4 contains H_3O^+ ions which will counter the rise in PH. Thus, equilibrium will shift to favour the forwards Reaction to produce more H_2SO_4 to minimise the change in PH level, allowing equilibrium to be Re-established.

(ii) This reaction can be performed under high pressure.

Explain why this is beneficial to the manufacturing process.

If pressure is increased on a system in equilibrium, the equilibrium will shift to favour the side with the fewest number of gaseous moles to minimise the change in pressure. As the Reactants side has a total of 2 gaseous moles and the products have a total of 1 gaseous mole, equilibrium will shift to favour the forwards Reaction to produce more H_2SO_4. This is beneficial in the manufacturing of H_2SO_4 as it means more products can be produced while using the same amount of Reactants, which increases the efficiency of manufacturing H_2SO_4. The yield of H_2SO_4 is higher.

QUESTION THREE

(a) A reaction of HSO_4^- is shown below:

$HSO_4^-(aq) + CO_3^{2-}(aq) \rightleftharpoons SO_4^{2-}(aq) + HCO_3^-(aq)$

Acid base base Acid

(i) Identify the species acting as an acid and the species acting as a base in the above equation, and their conjugate pairs:

Acid: HSO_4^-	Conjugate base: ~~HSO_4^-~~ SO_4^{2-}
Base: ~~CO_3^{2-}~~ CO_3^{2-}	Conjugate acid: HCO_3^-

(ii) Write the equilibrium constant expression, K_c for this process:

$$K_c = \frac{[SO_4^{2-}][HCO_3^-]}{[HSO_4^-][CO_3^{2-}]}$$

(iii) This reaction was initially performed at 25 °C to determine the K_c value. When the reaction temperature was increased to 50 °C, the K_c value increased.

Explain whether the forward reaction is exothermic or endothermic.

When temperature is increased on a system in equilibrium, the equilibrium will shift to favour the endothermic reaction to use up the added heat. $K_c = \frac{\text{Products}}{\text{Reactants}}$, this means if K_c ~~value~~ value increased then more products are being made, so [products] increase and [Reactants] decrease. If more products are being made then ~~the forwards reaction is favoured so~~ Equilibrium favours the forwards Reaction and as equilibrium favours the endothermic Reaction when temperature is increased, the forwards Reaction must be endothermic, as it is being favoured to produce more products.

(b) Solutions of 0.1 mol L^{-1} concentration were made of each of the following three substances:

NH_3 HNO_3 NH_4Cl

(i) Explain the pH of each of these solutions.

Include:

- a choice of pH value for each substance from the options below
- a classification for each substance
- any equations to explain the pH value.

pH options: 1–2 4–5 7 9–10 13–14

NH_3: $NH_{3(aq)} + H_2O_{(l)} \rightleftharpoons NH_4^+_{(aq)} + OH^-_{(aq)}$

NH_3 solution will have a pH level of 9-10, as NH_3 is a weak base meaning it only partially dissociates into it's ions, OH^- and NH_4^+. This means the $[OH^-]$ is greater than the $[H_3O^+]$ making the solution basic, however as NH_3 only partially dissociates the $[OH^-]$ is not high enough to make the solution extremely basic.

HNO_3: $HNO_{3(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + NO_3^-_{(aq)}$

HNO_3 solution will have a low PH of 1-2 as it is a strong acid. This means it will fully dissociates into it's ions, H_3O^+ and NO_3^-, meaning the $[H_3O^+]$ is very high. As PH is the measure of $[H_3O^+]$ the HNO_3 solution will have a low PH as it's very acidic

NH_4Cl: $NH_4Cl_{(s)} \rightarrow NH_4^+_{(aq)} + Cl^-_{(aq)}$

$NH_4^+_{(aq)} + H_2O_{(l)} \rightleftharpoons NH_{3(aq)} + H_3O^+_{(aq)}$

NH_4Cl is a salt which will fully dissociate into NH_4^+ and Cl^-. NH_4^+ is a weak acidic ion and so will react with H_2O to form a small amount of H_3O^+. This makes the solution slightly acidic as the $[H_3O^+]$ is higher than the $[OH^-]$, however the difference is not that large so the solution will have a PH of 4-5.

Question Three continues on the next page.

(ii) Discuss the conductivity of the solutions:

NH_3 HNO_3 NH_4Cl

Note they are all equal in concentration.

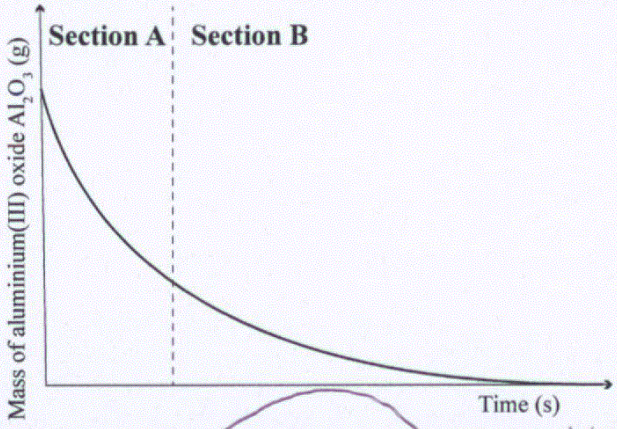
In your answer you should:

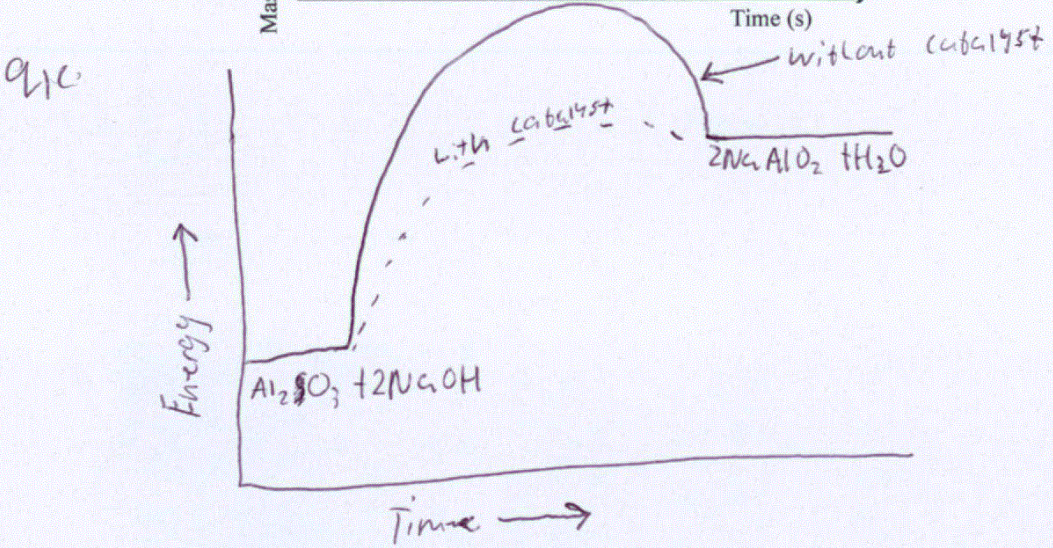
- explain the requirements for a solution to conduct electricity
- compare the extent of conductivity of each substance
- reference the relevant equations from your previous answer to part (b)(i).

for a solution to conduct electricity it must contain free-moving charged particles, how well the solution can conduct depends on how high the [ions] is, more ions mean more free-moving charged particles, so better electrical conductivity. HNO_3 will have high conductivity as it fully dissociates into it's ions, this means the [ions] is very high allowing the solution to conduct very well. $HNO_{3(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + NO_3^-{}_{(aq)}$, this equation shows it fully dissociates. NH_4Cl will also have good conductivity as it is a salt. This means it will fully dissociate into it's ions, NH_4^+ and Cl^- shown in the equation: $NH_4Cl_{(s)} \rightarrow NH_4^+{}_{(aq)} + Cl^-{}_{(aq)}$, this means the [ions] will be very high and will allow the solution to conduct very well. However NH_3 will have poor conductivity, due to the fact that it only partially dissociates. This means not all of the NH_3 turn into NH_4^+ or OH^- ions, so the [ions] is low causing the solution to have poor conductivity as there arent many free moving charged particles. $NH_{3(aq)} + H_2O_{(l)} \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$ shows that the solution partially dissociates.

SPARE DIAGRAMS

If you need to redraw your response to Question One (a)(i), use the graph below. Make sure it is clear which answer you want marked.





Energy Profile

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

Q3 bi ~~contains a high~~ $[H_3O^+]$ is very high. making it very acidic.

Q1Aii be the same ~~as~~ when both Reactions had as they both ~~used~~ had the same amount of mass. The only difference is how fast ~~it~~ each Reaction will decrease in mass. Having a higher [NaOH] means the rate of Reaction is faster at $2 mol L^{-1}$ than $0.5 mol L^{-1}$ so the $2 mol L^{-1}$ Reaction will ~~as~~ cause Al_2O_3 to loss it's mass much quicker.

Excellence

Subject: Chemistry

Standard: 91166

Total score: 22

Q	Grade score	Marker commentary
One	E7	a. (i) Incorrect line as it starts to far down on the y-axis. (ii) Student has met the E criteria and compared the different concentrations to sections A and B on the graph. b. (i) and (ii) both calculations correct c. Explanation is at the E criteria, the graph is missing labels for activation energy, E minor.
Two	E8	a. (i) Equation is incorrect (ii) Calculation correct b. (i) Calculation correct (ii) Evidence used from(i), links the new calculation to not being in equilibrium. Forwards direction is not stated for E. c. (i) Student has correctly linked minimising change to added water vapour and increase in products. NaOH not met, as incorrect reasoning used. (ii) E criteria met
Three	E7	a. (i) Correct conjugate pairs (ii) Correct Kc expression (iii) Student has identified the endothermic reaction linked to absorption of heat and direction. Kc is not linked to temperature for E. b. (i) The student meets the E criteria and has linked the concentration of hydronium/hydroxide to pH and used equations. (ii) The student meets the E criteria and has linked the conductivity to extent of dissociation and concentration of ions.