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

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.

Merit

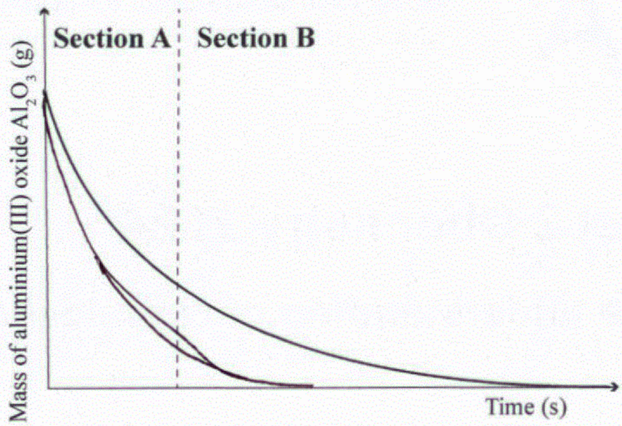
TOTAL 14

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.

Increasing the concentration of NaOH will result in a faster frequency of reaction. The mass of Al_2O_3 ~~is~~ starts at the same point, ~~and~~ But the lower concentration will take sagnificantly longer to react then the higher concentration (2 mol L^{-1}). It reacts faster because there are more NaOH particles in the solution that are ready to react with the Al_2O_3. This means the odds of a collision with sufficent energy is increased, therefor the frequency of successful collisions is increased, and the time taken for the ~~extract~~ reaction is decreased sagnificantly.

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

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

×2 ($1 \times 10^{-14} = [H_3O^+] \times 0.5$)×2

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

2×10^{-14} mol L^{-1} = $[H_3O^+]$ concentration

(ii) the pH.

pH = $-\log[2 \times 10^{-14}]$

pH = 13.69

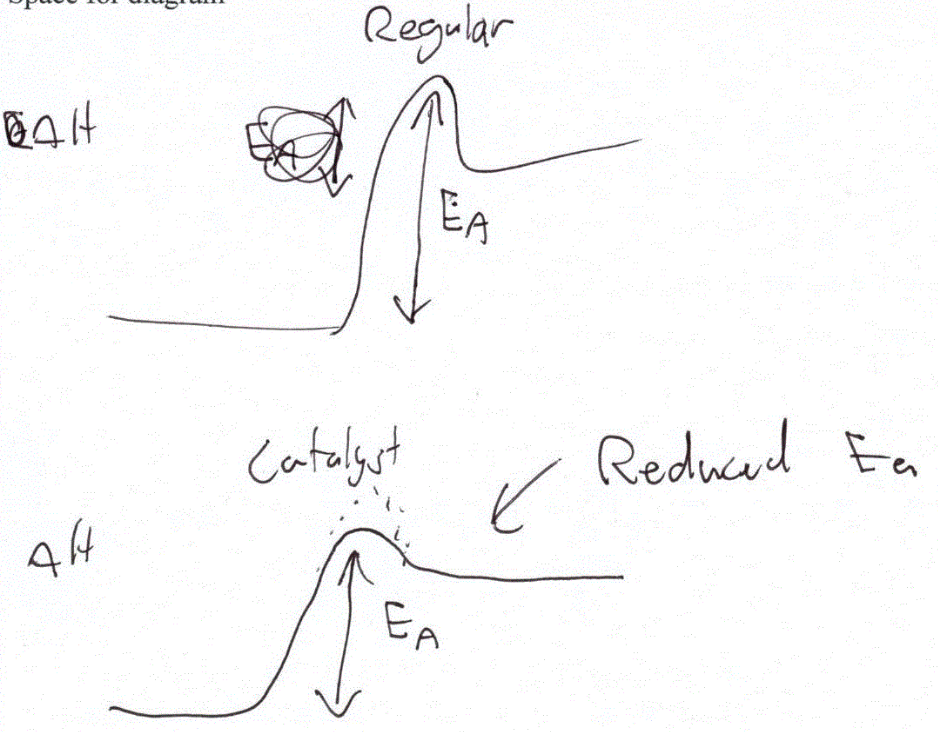
pH = 13.7

(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 pathway for a reaction that requires less activation energy. (Ea) Reducing EA means less energy is required for a successful collision, therefor the odds of a successful collision is increased. The frequency of reactions is increased for the production of $NaAlO_2$.

Space for diagram



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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:

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

Products / Reactants

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

$2SO_2 + O_2 \rightleftharpoons 2SO_3$

(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}.

$32.7 = \frac{0.5^2}{(0.17^2)(O_2)}$

$(32.7)(0.17^2)(O_2) = 0.25$

$0.945(O_2) = 0.25$

$O_2 = 0.265 \text{ mol L}^{-1}$

(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.

$Kc = \frac{(0.620)^2}{(0.53^2)(0.71)} = 1.927$

$Kc = 1.93$

Not at equilibrium as $Kc \neq 32.7$

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

The concentration of SO_3 must increase as the Kc is smaller then 32.7 and $Kc = \frac{\text{Products}}{\text{Reactants}}$. SO_3 is the product.

(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**

Equilibrium will counter the change made to the system. More H_2SO_4 will be made to counter the increased H_2O.

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

Circle your choice:

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

$NaOH \xrightarrow{H_2O} Na^+ + OH^-$

Na^+ is a spectator ion.

OH^- does not react.

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

Explain why this is beneficial to the manufacturing process.

There are 2 moles of gas on the reactant side and there is 1 mole of gas on the product side. If pressure is high the equilibrium will react to minimise it. It does this by favouring the reaction with the least moles of gas, which is the forwards reaction. This is beneficial as more H_2SO_4 will be made in the production.

QUESTION THREE

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

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

(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: SO_4^{2-}
Base: CO_3^{2-}	Conjugate acid: HCO_3^-

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

$Kc = \frac{Products}{Reactants}$ $Kc = \frac{[SO_4^{2-}][HCO_3^-]}{[HSO_4^-][CO_3^{2-}]}$

(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.

Products ↑

endo

Explain whether the forward reaction is exothermic or endothermic.

The equilibrium will act against the change made to the system. If the temperature increased the equilibrium will favour the reaction that is endothermic. This means that the forwards reaction is endothermic.

$\uparrow Kc = \frac{Products \uparrow}{Reactants}$

Kc increases as products is favoured.

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(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: ~~NH3~~ $NH_3 + H_2O \rightleftharpoons NH_4^+ \; OH^-$

Weak base pH = 9-10

as it contains OH^- but does not fully dissociate. Therefor its pH is about 9-10. weak basic.

HNO_3: $HNO_3 + H_2O \longrightarrow NO_3^- + H_3O^+$

Strong acid pH = 1-2

as it contains H_3O^+ and it fully dissociates. Therefor its pH is 1-2. Acidic

$NH_4Cl \xrightarrow{H_2O} NH_4^+ + Cl^-$

NH_4Cl: $NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$

Weak acid pH = 4-5

as it contains H_3O^+ but does not fully dissociate. Therefor its pH is 4-5. Weak Acidic.

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).

There needs to be free moving charged ions for a solution to be conductive.

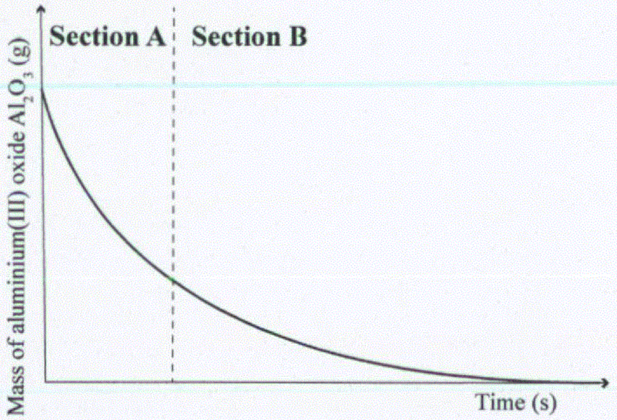
- $NH_4Cl \xrightarrow{H_2O} NH_4^+ + Cl^-$
  NH4Cl is a good conductor as ~~all of the~~ it fully dissociates into positively and negatively charged ions, NH_4^+ and Cl^-.

- $HNO_3 + H_2O \longrightarrow NO_3^- + H_3O^+$
  HNO_3 is a good conductor as it fully dissociates into positively and negatively charged ions, NO_3^- and H_3O^+.

- $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$
  Unlike HNO_3 and NH_4Cl, NH_3 is a poor conductor as it does not fully dissociate into the charged ions NH_4^+ and OH^-.

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.



Merit

Subject: Chemistry

Standard: 91166

Total score: 14

Q	Grade score		Marker commentary
One	A4	a.	(i) Correct line drawn (ii) Student has stated mass of Al_2O_3 stays the same on the graph and increase in concentration will increase the rate of reaction. Student achieved the M point as the student has linked frequency to successful collisions. Student hasn't compared sections A and B, however, hasn't linked back to the 0.5 mol L^{-1} or the 2.0 mol L^{-1} for second M point.
		b.	(i) and (ii) Correct calculation for M.
		c.	Student has an incorrect graph and not linked to rate of reaction of M.
Two	M6	a.	(i) Correct equation (ii) Correct calculation and significant figures for M point (ii) with evidence from (i), the student has stated that the new value is not in equilibrium, forwards reaction not sated does not meet E criteria.
		b.	(i) Correct for the addition of water vapour and stated equilibrium will counter the change for M. NaOH is incorrect. (ii) Criteria met for E
Three	A4	a.	(i) Correct conjugate pairs (ii) Correct Kc expression (iii) Correct identification of endothermic reaction for A. Not linked to direction or minimising change for M.
		b.	(i) Meets A criteria, student hasn't linked pH to concentration or amount of hydronium/hydroxide ions for M. (ii) Student can define conductivity correctly, and has linked dissociation for each species correctly for M. Student has not linked the amount/concentration of ions for E.