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NZQA | Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 2 Chemistry 2025

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 margins (⁝⁝⁝). 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

Ocean acidification occurs due to carbon dioxide in the atmosphere dissolving into seawater and forming various acids.

One step of this process is shown below:

$$H_2CO_3(aq) + H_2O(\ell) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq) \qquad K_c = 4.30 \times 10^{-7}$$

(a) (i) Write the equilibrium constant expression for this reaction.

$$K_c = \frac{[HCO_3^-][H_3O^+]}{[H_2CO_3][H_2O]}$$

(ii) The value of the equilibrium constant is 4.30×10^{-7}.

Explain what this indicates about the ratio of products and reactants.

Since $K_c = \frac{\text{products}}{\text{reactants}}$, and it is much less than one, this tell us that there is a much higher concentration of reactants than products.

(iii) Global oceanic temperatures have been increasing since the industrial revolution.

Predict the impact on the position of equilibrium as temperature increases, if the enthalpy of this reaction is $\Delta_r H = -3.85$ kJ mol^{-1}.

In your answer:

- describe the effect of temperature on the forward and reverse reactions
- explain any changes that would occur to the value of K_c.

You do not need to perform any calculations.

Since $\Delta_r H < 0$, this means that the forward reaction is exothermic, meaning that the reverse reaction is endothermic. When the the temperature of the system (ocean) increases, the system will try to minimize the effects of this change by favouring the endothermic reaction, in order to remove the added heat from the ocean. Since the reverse reaction is endothermic, this means that the reverse reaction will be favoured. (i.e reverse reaction rate is increased) This increases the concentration of reactants and decreases the ~~product~~ concentration of products. Since $K_c = \frac{\text{products}}{\text{reactants}}$, this means that K_c will decrease.

(b) (i) Calculate the pH of a 0.25 mol L^{-1} solution of hydrochloric acid, HCl.

~~pOH = 14~~ $pH = -\log(0.25)$

$pH = 0.602$ (3sf)

(ii) Calculate the concentration of hydroxide ions, OH^-, in a solution of hydrochloric acid, HCl, with a pH of 1.3.

$pOH = 14 - pH$ or

$= 14 - 1.3 = 12.7$

$[OH^-] = 10^{-12.7} = 2.00 \times 10^{-13}$ mol L^{-1} (3 sf)

(iii) Compare the pH and conductivity of hydrochloric acid, HCl and carbonic acid, H_2CO_3.

	Hydrochloric Acid, HCl	Carbonic Acid, H_2CO_3
Acid Strength	Strong	Weak
pH	1.0	4.7
Concentration	0.10 mol L^{-1}	0.10 mol L^{-1}

In your answer, include:

- definitions for strong and weak acids
- an explanation of the pH for each solution (HCl and H_2CO_3) and relevant equations
- a definition for conductivity
- an explanation for the conductivity of each solution (HCl and H_2CO_3).

~~An acid~~ ~~has~~ HCl is a strong acid, as it completely dissociates in water forming H_3O^+ as a product. Since pH is equal to the $-\log[H_3O^+]$, this means that a lower pH equals a higher $[H_3O^+]$. Since HCl fully dissociates, this means that $[HCl] = [H_3O^+]$. This means that $[H_3O^+] = 0.1$, and $pH = -\log(0.1) = 1$. In order to conduct electricity, a solution must contain free moving charged particles (ions). ~~Conductivity~~ How good the conductivity of a solution is depends on its concentration of ions. ~~Since~~ Since HCl fully dissociates in solution, it releases a high concentration of ions, as every single HCl molecule is dissociated into Cl^- ions and H_3O^+ ions. This means that a solution of HCl has a high concentration of ions and therefore good electrical conductivity.

equation: $HCl_{(aq)} + H_2O_{(l)} \rightarrow Cl^-_{(aq)} + H_3O^+_{(aq)}$.

H_2CO_3, on the other hand, is a weak acid, as it only partially dissociates into its ions forming a lower concentration of H_3O^+. Since there is a lower concentration of H_3O^+, the pH is therefore higher, at 4.7. Since H_2CO_3 only partially dissociates into its ions, a solution of it has a low concentration of ions. Therefore H_2CO_3 has poor electrical conductivity.

equations: $H_2CO_{3(aq)} + H_2O_{(l)} \rightleftharpoons HCO_3^-{}_{(aq)} + H_3O^+_{(aq)}$

$HCO_3^-{}_{(aq)} + H_2O \rightleftharpoons CO_3^{2-}{}_{(aq)} + H_3O^+_{(aq)}$

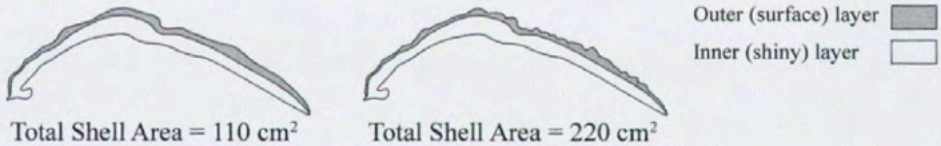
QUESTION TWO

Pāua are a species of marine organism, which form their shells from layers of calcium carbonate, $CaCO_3$, and proteins. This layering leads to a very strong shell structure with a dull, pitted outer layer and smooth, shiny inner layer. Unfortunately, the calcium carbonate reacts with acid in the oceans leading to degradation of their shells.

(a) (i) Describe the chemical observations made when the calcium carbonate shells react with acid in the ocean.

Calcium carbonate reacts with acid to form water, a calcium salt, and CO_2 gas. The released CO_2 gas forms bubbles in the ocean.

(ii) Cross-sectional views of two different pāua shells are shown below.



Total Shell Area = 110 cm^2 — **Pāua Shell A**

Total Shell Area = 220 cm^2 — **Pāua Shell B**

Explain which pāua shell is more vulnerable to the effects of ocean acidification.

In your answer, include concepts of:

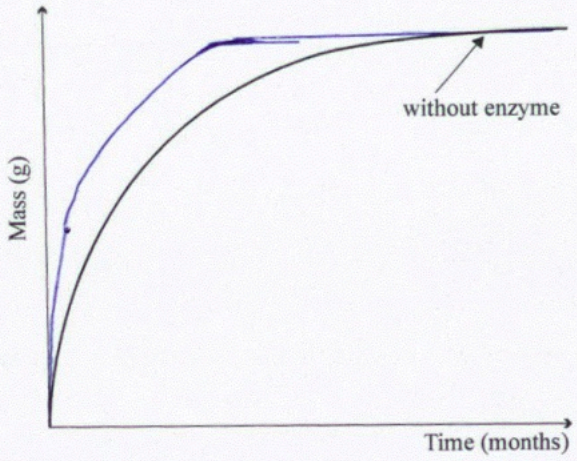
- collision theory
- rate of reaction.

Shell B has a larger surface area. This means that on shell B, there are more $CaCO_3$ molecules available to react with acid. Since there are more $CaCO_3$ molecules available to react, collisions between reactants occur more often ($CaCO_3$ is a reactant). This means that there are more successful ~~reacted~~ collisions between $CaCO_3$ molecules and acid, so there is therefore a higher reaction rate. This means that shell B will degrade faster, and is therefore more vulnerable to the effects of ocean acidification.

(b) Pāua use enzymes like carbonic anhydrase to help form their shells. Enzymes are biomolecules that act as catalysts for specific reactions.

The graph shows the change in the mass of the pāua shell over time without the use of an enzyme to build the shell.

(i) Add a second line to the graph to predict the change in mass over time when using the enzyme.



(ii) Discuss how the carbonic anhydrase enzyme affects the rate of the reaction to form pāua shell.

In your answer, refer to:

- the role of a catalyst
- collision theory
- activation energy.

The Carbonic anhydrase enzyme is a catalyst. A catalyst provides an alternate reaction pathway with a lower activation energy. This means that with a catalyst, there are more collisions per second with enough energy to overcome the activation energy, and therefore more successful collisions per second. This leads to a higher reaction rate. This means that with carbonic anhydrase, the shell's mass will increase faster. However, it will still end at the same point as the same mass of reactants is used.

(c) Calcium hydroxide, $Ca(OH)_2$, calcium chloride, $CaCl_2$, and calcium ethanoate, $Ca(CH_3COO)_2$, are soluble calcium compounds.

(i) Write an equation to show the complete dissociation of each of these compounds in water.

Calcium hydroxide: $Ca(OH_2)_{(aq)} \rightarrow Ca^{2+}_{(aq)} + 2OH^-_{(aq)}$

Calcium chloride: $CaCl_{2(aq)} \rightarrow Ca^{2+}_{(aq)} + 2Cl^-_{(aq)}$

Calcium ethanoate: $Ca(CH_3COO)_{2(aq)} \rightarrow Ca^{2+}_{(aq)} + 2CH_3COO^-_{(aq)}$

(ii) Calcium ethanoate will react further once dissolved.

Write an equation for the reaction of ethanoate, CH_3COO^-.

$CH_3COO^-_{(aq)} + H_2O_{(l)} \rightleftarrows CH_3COOH_{(aq)} + OH^-_{(aq)}$

(iii) The pH of 0.10 mol L^{-1} solutions of these three compounds are below.

Solution	$Ca(OH)_2$	$CaCl_2$	$Ca(CH_3COO)_2$
pH	13.2	7	8

Discuss the differences in their pH.

In your answer:

- give a definition for acids and bases
- explain how proton transfer is linked to pH
- discuss any ability for these compounds to transfer protons.

An acid is a proton donor, meaning that it donates an H^+ (proton) ion to water to form H_3O^+. A base is a proton acceptor, meaning that it accepts an H^+ (proton) ion. Bases often release hydroxide (OH^-), or accept a proton from water to form hydroxide. pH is the $-\log[H_3O^+]$. This means that an acid has a lower pH, as it increases the concentration of H_3O^+ in the solution. Bases, on the other hand, have a higher pH, as they release OH^-, and since $[H_3O^+] = \frac{10^{-14}}{[OH^-]}$, they decrease the concentration of H_3O^+ in the solution. $CaCl_2$ has a neutral pH of 7, meaning that $[OH^-] = [H_3O^+]$. This is because $CaCl_2$ neither accepts or donates protons, meaning that it doesn't increase or decrease $[H_3O^+]$

There is more space for your answer on the next page.

$Ca(OH)_2$ has a high pH of 13.2. This is because when it dissociates in water, it releases a ~~high concentration~~ large amount of OH^- ions, which react with H_3O^+ ions to form water. ~~This decreases the concentration~~. In this reaction, the OH^- ion accepts a proton from the H_3O^+ ion, forming water. This significantly decreases the concentration of H_3O^+ in the solution, meaning that a solution of $Ca(OH)_2$ has a high pH of 13.2.

$Ca(CH_3COO)_2$ has a lower pH of 8. This is because it only partially dissociates in water to release a lower amount ~~concentration~~ of OH^- ions. These OH^- ions accept protons from H_3O^+ ions, forming water. This slightly decreases the concentration of H_3O^+ ions, as only a small amount of OH^- ions were released. Therefore a solution of $Ca(CH_3COO)_2$ has a lower pH of 8.

QUESTION THREE

Phosphorus pentachloride, PCl_5, is a common chlorinating agent in organic chemistry. It is produced as a gas using phosphorus trichloride, PCl_3, and chlorine gas, Cl_2:

$$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$$

(a) (i) During the manufacturing process, some of the PCl_5 is removed from the reaction vessel.

Explain, using equilibrium principles, how the system responds to restore equilibrium.

In your answer, refer to each of the species present.

When some PCl_5 (a product) is removed from the system, the system will try to minimize the effects of this change by favouring the forward reaction, in order to ~~take~~ replace the lost PCl_5. This decreases the concentration of PCl_3 and Cl_2, as the forward reaction is favoured, while increasing the concentration of PCl_5.

(ii) Explain why producing PCl_5 is favoured when the reaction is transferred to a vessel with a much smaller volume.

In your answer, include:

- a description of the changes occurring
- an explanation of equilibrium principles
- what happens to the position of equilibrium when the pressure is increased.

When the reaction is transferred to a vessel with much smaller volume, the pressure of the system increases. Equilibrium principles state that the system will try to minimize the effect of any change made to it by either increasing the reaction rate of the forward reaction or the reverse reaction. In this case, ~~the forward reaction~~ the system will try to favour the reaction that produces the least amount of gas, in order to decrease the pressure. The ~~forward~~ reverse reaction produces 2 moles of gas, while the forward reaction produces only one. This means that the forward reaction would be favoured, increasing the concentration of PCl_5.

(b) (i) The equilibrium expression for the reaction is shown below.

$$K_c = \frac{[PCl_5]}{[PCl_3][Cl_2]}$$

Calculate the equilibrium constant at 300 °C if the concentrations are as follows:

$[PCl_3] = 0.016$ mol L^{-1}

$[Cl_2] = 0.021$ mol L^{-1}

$[PCl_5] = 0.00013$ mol L^{-1}

$K_c = \frac{0.00013}{0.016 \times 0.021}$

$K_c = 0.387$ (3SF)

(ii) Explain the effect of increasing the concentration of Cl_2 on the equilibrium system AND K_c value.

$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$

When the concentration of Cl_2 is increased, the system will try to minimize the effects of the change by favouring the forward reaction, in order to ~~decrease the concentration~~ get rid of the added Cl_2. ~~This will increase the concentra~~ K_c will not change as the temperature of the system has not changed, and temperature is the only thing that can change K_c.

(iii) The reaction is set up under new conditions, with different temperatures to favour the production of phosphorus pentachloride, PCl_5.

	Condition 1	Condition 2
Temperature	200 °C	700 °C
K_c	49	0.023
$[PCl_3]$	0.12 mol L^{-1}	0.15 mol L^{-1}
$[Cl_2]$	0.09 mol L^{-1}	0.12 mol L^{-1}

Use the K_c values to explain which set of conditions (1 or 2) would increase production of PCl_5.

$K_c = \frac{\text{products}}{\text{reactants}}$. This means that a higher K_c means that there is a higher concentration of PCl_5 and (product) and a lower concentration of PCl_3 and Cl_2 (reactants), meaning that the forward reaction (production of PCl_5) has been favoured. Also, if $K_c > 1$, this means that $[PCl_5] > [PCl_3] \times [Cl_2]$, meaning that there is a higher concentration of PCl_5 than PCl_3 and Cl_2. Since the K_c for condition 1 is >1 and $>$ than the K_c for condition 2, this means that condition 1 would increase the production of PCl_5. *

(iv) Calculate the concentration of PCl_5 under each of the new conditions listed in (iii).

$[PCl_5] = K_c \times [PCl_3] \times [Cl_2]$

Condition 1:

$[PCl_5] = 49 \times 0.12 \times 0.09 = 0.529\ mol\ L^{-1}$ (3sf)

Condition 2:

$[PCl_5] = 0.023 \times 0.15 \times 0.12 = 4.14 \times 10^{-4}\ mol\ L^{-1}$ (3sf)

* also, K_c for condition 1 is $>$ the original K_c of 0.387.

Question Three continues on the next page.

(c) Chlorine gas, $Cl_2(g)$, can also be used to produce nitrosyl chloride, NOCl(g), a catalyst and industrial bleaching agent.

$$Cl_2(g) + 2NO(g) \rightleftharpoons 2NOCl(g)$$

The formation of NOCl(g) is favoured when the temperature is decreased.

Explain why this reaction is performed at 95 °C instead of a lower temperature (for example, 25 °C).

In your answer:

- identify whether the forward reaction is exothermic or endothermic
- explain any disadvantages of a higher temperature using equilibrium concepts
- explain any advantages of using a higher temperature for a reaction using collision theory and rate of reaction principles.

When the temperature is decreased, the system will favour the exothermic reaction in order to ~~release~~ minimize the effects of the change by releasing heat back into the system. Since the forward reaction is favoured when the temperature is decreased, this means that the forward reaction is exothermic while the reverse reaction is endothermic. At a higher temperature such as 95°C, ~~the endothermic reaction is favoured in order to remove extra heat from the system. This increases Since the reverse reaction is~~ The system favours the endothermic reaction until equilibrium is reached, in order to remove ~~heat from~~ the extra heat from the system. ~~This mean~~ Since the reverse reaction is endothermic, this means that at equilibrium at 95°C, there will be a higher concentration of reactants (Cl_2 and NO) and a lower concentration of ~~re~~ products (the desired NOCl) than an equilibrium at 25°C. This is a disadvantage for the production of NOCl as there is a lower concentration of it.

However, temperature ~~is~~ is a measure of the average kinetic energy within a substance. This means that at a higher temperature, the reactants ~~and~~ are (and products) are moving faster and with more energy. This means that there are more collisions per second between reactants (and between products) and collisions as they are moving faster, and there are more successful collisions per second between reactants (and between products) as they ~~are~~ have more energy and are therefore more likely to collide with enough energy to overcome the activation energy. This increases the reaction rate of both the forwards and backwards reactions. Since the forward reaction rate has increased, NOCl is produced faster, which is beneficial to ~~the~~ its production

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

QUESTION NUMBER

3.

c. Since increasing the temp to 98°C only decreases the concentration of NOCl but increases its rate of production, it is beneficial for the reaction to be performed at 98°C, as NOCl is formed faster.

Excellence

Subject: L2 Chemistry

Standard: 91166

Total score: 22

Q	Grade score	Marker commentary
One	E8	The candidate was awarded E8 for the following reasons: In part (a) the candidate incorrectly included H_2O in the expression (i), though provided a full description of the effect of temperature on the forward and reverse reactions and explained the change in K_c linked to more products being produced (iii). In part (b) correct value and $[OH^-]$ was shown as well as a justification of both properties (pH and conductivity).
Two	M6	The candidate was awarded M6 for the following reasons: In part (a), the candidate identified that shell B was more vulnerable and linked more exposed particles to the increase in the frequency of successful collisions. In part (b), the candidate drew a line showing a faster rate of reaction, and related the alternative pathway to lower activation energy, and the increase in the frequency of successful collisions that are able to overcome activation energy. In part (c), the candidate completed (i) correctly and the equilibrium equation in part (ii), however the candidate has not linked the degree of dissociation of two species to the amount of $[OH^-]$ To gain a higher grade, the candidate needed to either further explain the successful collision to time/ frequency in part (a) and / or include dissociation of $CaCl_2$ or full dissociation of $Ca(OH)_2$ in part (c).
Three	E8	The candidate was awarded E8 for the following reasons: In part (a), full explanation of equilibrium principles of pressure increase, and moles of gas linked to equation, justifying favouring production of $PC1_5$. In part (c), the candidate fully explained the forward reaction as exothermic and included the balance of increased temperature favouring the reverse reaction as a disadvantage.