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91166



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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.**

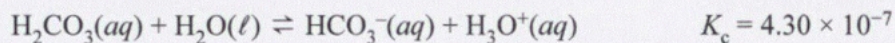
Merit

**TOTAL 16**

**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:



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

$$K_c = \frac{[\text{HCO}_3^-] + [\text{H}_3\text{O}^+]}{[\text{H}_2\text{CO}_3]}$$

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

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

There are far more reactants in this equation.

The reactants are favored (only a small amount of product)

- (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  $\Delta_r H = -3.85 \text{ kJ mol}^{-1}$ .

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.

When a change is imposed on a system its equilibrium, the system will do the opposite to counteract the change (Le Chatelier). This means that when temperature is added to the system, it will favour the endothermic side because it absorbs heat from the surroundings. Because the temp is going up and the forward reaction is exothermic, the reverse reaction will be favoured. This means that more reactants are being formed.  $\therefore$  the value of  $K_c$  will go down. (Ratio of products to reactants)

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

$$K_w = 1 \times 10^{-14} = [\text{H}_3\text{O}^+][\text{OH}^-] \quad 14 - 13.39 = \text{pH}$$

$$\frac{1 \times 10^{-14}}{0.25} = 4 \times 10^{-14} \quad \text{pH} = 0.602$$

$$\text{pOH} = 13.39$$

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

$$[\text{H}_3\text{O}^+] = 10^{-1.3} \quad 1 \times 10^{-14} \div [0.05012] = [\text{OH}^-]$$

$$= 0.05012 \quad [\text{OH}^-] = 1.99 \times 10^{-14}$$

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

(iii) Compare the pH and conductivity of hydrochloric acid, HCl and carbonic acid, H<sub>2</sub>CO<sub>3</sub>.

	Hydrochloric Acid, HCl	Carbonic Acid, H <sub>2</sub> CO <sub>3</sub>
Acid Strength	Strong	Weak
pH	1.0	4.7
Concentration	0.10 mol L <sup>-1</sup>	0.10 mol L <sup>-1</sup>

In your answer, include:

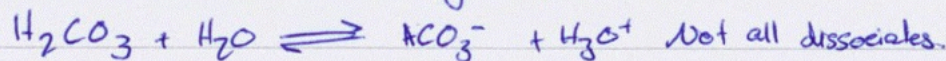
- definitions for strong and weak acids
- an explanation of the pH for each solution (HCl and H<sub>2</sub>CO<sub>3</sub>) and relevant equations
- a definition for conductivity
- an explanation for the conductivity of each solution (HCl and H<sub>2</sub>CO<sub>3</sub>).

The strength of an acid is based on its ability to completely dissociate into H<sup>+</sup> and conjugate base. Strong acids completely dissociate. Weak acids only partially.

The pH of HCl is so low because it completely dissociates

$$\text{HCl (aq)} \xrightarrow{\text{H}_2\text{O}} \text{H}^+(\text{aq}) + \text{Cl}^-(\text{aq})$$

only one arrow shows that carbonic acid is a weak acid, which means it has a higher pH. it just about goes to completion.



Conductivity is defined by a substance's ability to transfer electrons from one place to another. For this it needs mobile CHARGED particles. HCl → because it completely dissociates is a good conductor. A solution will contain a large number of ions (charged particles). H<sub>2</sub>CO<sub>3</sub> will also conduct (but sparingly) because it doesn't have as many available ions to transport electrons.

## QUESTION TWO

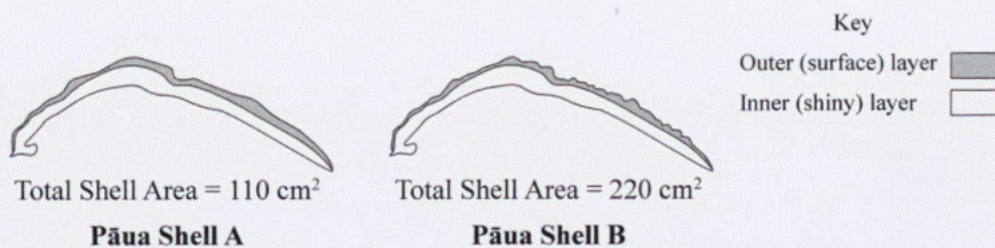
Pāua are a species of marine organism, which form their shells from layers of calcium carbonate,  $\text{CaCO}_3$ , and proteins. This layering leads to a very strong shell structure with a dull, pitted outer layer and smooth, shiny inner layer. Unfortunately, the calcium carbonate reacts with acid in 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.

Acid + Carbonate  $\rightarrow$  Salt + water + Carbon dioxide.

There will both be the dissolving of the shell, more salt in the water, and bubbles of  $\text{CO}_2$ .

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



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

In your answer, include concepts of:

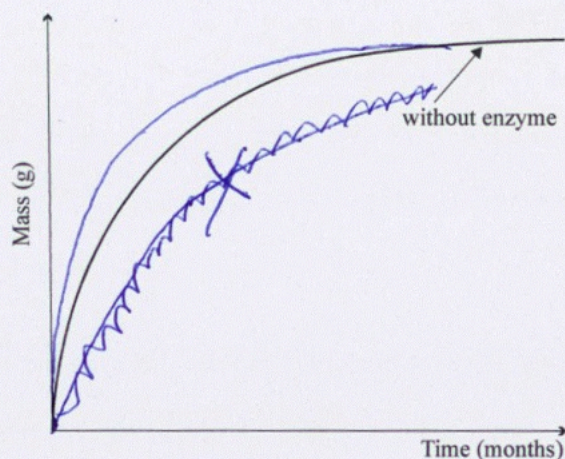
- collision theory
- rate of reaction.

Pāua Shell B is more vulnerable to ocean acidification because it contains more surface area. This is caused by bumps on the shell. Collision theory states that ~~two~~ particles must collide with sufficient force and orientation to react ~~correctly~~ <sup>effectively</sup>. This means that when there is more surface area available for collisions, more collisions are likely to be effective. ~~then~~ More particles are available for reacting. This creates a faster rate of reaction (more effective collisions) which means the Pāua is more vulnerable to being damaged.

- (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.

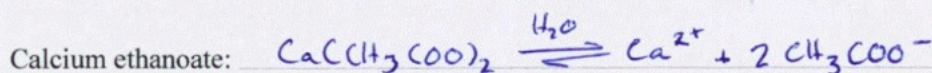
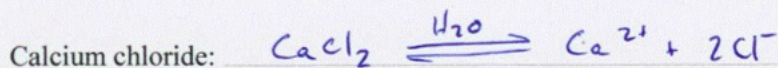
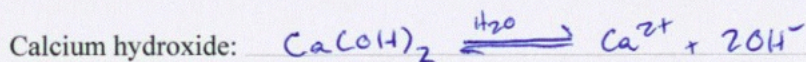
In your answer, refer to:

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

A catalyst is defined as something that offers a different pathway for the reaction, by lowering the activation energy. Activation energy is the minimum energy required for the reaction to take place. A catalyst lowers this energy meaning that more effective collisions will occur. Collision theory states that particles must collide with sufficient energy and in the right orientation. When the activation energy is lowered, more particles collide with sufficient energy to create a reaction. This means the enzyme allows the pāua to create its shell much faster. (Faster rate of reaction).

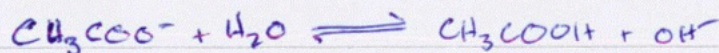
(c) Calcium hydroxide,  $\text{Ca(OH)}_2$ , calcium chloride,  $\text{CaCl}_2$ , and calcium ethanoate,  $\text{Ca(CH}_3\text{COO)}_2$ , are soluble calcium compounds.

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



(ii) Calcium ethanoate will react further once dissolved.

Write an equation for the reaction of ethanoate,  $\text{CH}_3\text{COO}^-$ .



(iii) The pH of 0.10 mol L<sup>-1</sup> solutions of these three compounds are below.

Solution	$\text{Ca(OH)}_2$	$\text{CaCl}_2$	$\text{Ca(CH}_3\text{COO)}_2$
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.

The definition of an acid is 'a proton donor'. A base is a 'proton' acceptor. pH is based on the concentration of  $\text{H}^+$  or  $\text{OH}^-$ . When an acid fully dissociates (gives lots of  $\text{H}^+$ ) the concentration of  $\text{H}^+$  goes up and the pH levels go down. Donating  $\text{H}^+$  is proton transfer. The same happens with the concentration and dissociation levels of  $\text{OH}^-$ . Lots of proton transfer  $\rightarrow$  lower pH. Acid  
Lots of proton acceptance  $\rightarrow$  higher pH. Base  
 $\text{Ca(OH)}_2$  creates lots of  $2\text{OH}^-$  molecules which can accept protons this

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

makes it a Strong Base with a high pH.

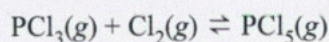
$\text{CaCl}_2$  dissociates into ions but can't accept or donate protons so creates a neutral concentration ~~of~~ with a pH of 7.

$\text{Ca}(\text{C}_2\text{H}_3\text{COO})_2$  is a weak base because, when dissolved in ions, the  $\text{C}_2\text{H}_3\text{COO}$  can only accept 1 ~~base~~  $\text{H}^+$  and not very often. This means the conc of  $\text{H}^+$  is very low and  $\text{OH}^-$  is relatively low, which gives it the weak basic ~~near~~ pH of 8.

Bases accept the proton transfer.

## QUESTION THREE

Phosphorus pentachloride,  $\text{PCl}_5$ , is a common chlorinating agent in organic chemistry. It is produced as a gas using phosphorus trichloride,  $\text{PCl}_3$ , and chlorine gas,  $\text{Cl}_2$ :



- (a) (i) During the manufacturing process, some of the  $\text{PCl}_5$  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  $\text{PCl}_5$  is removed, the system will counteract the change, trying to restore equilibrium, by creating more products. This means the reactant conc.  $\text{PCl}_3$  &  $\text{Cl}_2$  go down while  $\text{PCl}_5$  goes up.

A system in equilibrium will counteract imposed change on the system by doing the opposite.

- (ii) Explain why producing  $\text{PCl}_5$  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.

By transferring the system to a smaller vessel, you are increasing the pressure. This means that ~~a smaller number~~ the same concentration of particles are in a smaller space.

Le Chatelier's principle states that a system in equilibrium will resist changes by trying to undo them. It tries to restore equilibrium. This means that the system will favour the side with fewer gas molecules to counteract the increased pressure. Therefore, because 2 moles of  $\text{PCl}_3$  and  $\text{Cl}_2$  turn into 1 mol of  $\text{PCl}_5$ , the forward reaction will be favoured. The position of the equilibrium will shift to the right.

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

$$K_c = \frac{[\text{PCl}_5]}{[\text{PCl}_3][\text{Cl}_2]}$$

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

$$[\text{PCl}_3] = 0.016 \text{ mol L}^{-1}$$

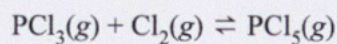
$$[\text{Cl}_2] = 0.021 \text{ mol L}^{-1}$$

$$[\text{PCl}_5] = 0.00013 \text{ mol L}^{-1}$$

$$K_c = \frac{[0.00013]}{[0.016][0.021]}$$

$$K_c = 0.387 (3 \text{ sf})$$

- (ii) Explain the effect of increasing the concentration of  $\text{Cl}_2$  on the equilibrium system AND  $K_c$  value.



If you increase the conc. of  $\text{Cl}_2$  the system will effectively try to 'get rid' of it by creating more product. This means the forward reaction is favored and the value of  $K_c$  will go up.

- (iii) The reaction is set up under new conditions, with different temperatures to favour the production of phosphorus pentachloride,  $\text{PCl}_5$ .

	Condition 1	Condition 2
Temperature	200 °C	700 °C
$K_c$	49	0.023
$[\text{PCl}_3]$	0.12 mol L <sup>-1</sup>	0.15 mol L <sup>-1</sup>
$[\text{Cl}_2]$	0.09 mol L <sup>-1</sup>	0.12 mol L <sup>-1</sup>

Use the  $K_c$  values to explain which set of conditions (1 or 2) would increase production of  $\text{PCl}_5$ .

Condition 1. Because the  $K_c$  value is higher in the first condition, the ratio of  $\frac{\text{products}}{\text{reactants}}$  has favored the products or  $\text{PCl}_5$ .

This means that 1 is better for the production of  $\text{PCl}_5$ .

- (iv) Calculate the concentration of  $\text{PCl}_5$  under each of the new conditions listed in (iii).

Condition 1.

$$49 = \frac{[\text{PCl}_5]}{[0.12][0.09]}$$

$$49 \times 0.0108 = 0.529035 \text{ mol L}^{-1}$$

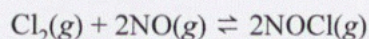
Condition 2.

$$0.023 = \frac{[\text{PCl}_5]}{[0.15][0.12]}$$

$$0.023 \times 0.018 = 4.14 \times 10^{-3} \text{ mol L}^{-1}$$

Question Three continues  
on the next page.

- (c) Chlorine gas,  $\text{Cl}_2(\text{g})$ , can also be used to produce nitrosyl chloride,  $\text{NOCl}(\text{g})$ , a catalyst and industrial bleaching agent.



The formation of  $\text{NOCl}(\text{g})$  is favoured when the temperature is decreased.

Explain why this reaction is performed at  $95^\circ\text{C}$  instead of a lower temperature (for example,  $25^\circ\text{C}$ ).

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.

Because the product was favoured when the temp went down, and the system tries to counteract the change, the forward reaction is exothermic (heat creating).

The disadvantage of using higher temperatures is that the system will favour the endothermic side (the reverse reaction) to try and lower the temperature. This means that not as much product is being formed.

The advantage of higher temperature is that the particles have more kinetic energy which means they're more likely to collide into each other and with sufficient force for a successful reaction. (Because there's nothing for the product to collide with) to create reactants) this creates more product, at a faster rate of reaction. Faster rate of successful collisions.

$\therefore 95^\circ\text{C}$  is a balance between the two, to create the most product.

## Merit

**Subject:** L2 Chemistry

**Standard:** 91166

**Total score:** 16

Q	Grade score	Marker commentary
One	A4	<p>The candidate was awarded A4 for the following reasons:</p> <p>In part (a), the candidate included a correct <math>K_c</math> expression and a brief statement about the magnitude of <math>K_c</math>. They provided a description of the effect of temperature on the forward and reverse reactions and explained the change in <math>K_c</math> linked to more products being produced.</p> <p>To gain a higher grade on this question, the responses needed to have provided more accurate and detailed explanations, particularly throughout part (b), where the candidate needed to refer to <math>H_3O^+</math> not <math>H^+</math>, include a correct / relevant equation, or link their answer to concentration, and not just electrons, in the definition of conductivity.</p>
Two	M6	<p>The candidate was awarded M6 for the following reasons:</p> <p>In part (a), the candidate demonstrated understanding of the observations of the effects of the ocean on the shells, and that shell B is more vulnerable due to having a larger surface area. The students has not linked this to the frequency of successful collisions.</p> <p>In part (b), the candidate showed a faster rate of reaction on the graph and linked the catalyst providing the alternative pathway to lowering activation energy requirement.</p> <p>In part (c), the candidate incorrectly used equilibrium arrows in (i) equations; wrote a correct equation for the reaction ethanoate; and in (iii) the candidate has not linked the degree of dissociation to any of the species.</p> <p>To gain an E7, the candidate would need to include the extent of dissociation for any species in (c) (iii) and link the concentration of <math>[OH^-]</math> to the pH for the basic species.</p>
Three	M6	<p>The candidate was awarded M6 for the following reasons:</p> <p>In part (a), the candidate answered all questions correctly.</p> <p>Part (b) shows correct <math>K_c</math> value (i) and explanation for why Condition 1 is better (iii). Though the <math>K_c</math> statement is incorrect (ii), the candidate does identify forward is favoured. One condition is correctly calculated in (iv).</p> <p>In part (c), the candidate, explained how temperature affects rate of reaction and that the forward reaction is exothermic so is disfavoured by increasing temperature.</p>

		To gain an E7, the response would have needed to include more detail on kinetic energy to clearly link frequency to successful collisions in part (c); and included correct $K_c$ statements and / or both correct condition calculations.
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