



# Carmel School

Semester 1 Examination, 2018

Question/Answer Booklet

## ATAR CHEMISTRY Unit 3

Student Name: \_\_\_\_\_

### TIME ALLOWED FOR THIS PAPER

Reading time before commencing work:

ten minutes

Working time for the paper:

three hours

### MATERIALS REQUIRED/RECOMMENDED FOR THIS PAPER

#### To be provided by the supervisor:

This Question/Answer Booklet

Multiple-choice Answer Sheet

Chemistry Data Book

#### To be provided by the candidate:

Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, eraser, correction tape/fluid, ruler, highlighters

Special items: up to three non-programmable calculators approved for use in the WACE examinations

### IMPORTANT NOTE TO CANDIDATES

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

**Structure of this paper**

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Multiple-choice	25	25	50	/50	/25
Section Two: Short answer	9	9	60	/70	/35
Section Three: Extended answer	5	5	70	/80	/40
					/100

**Instructions to candidates**

1. Answer the questions according to the following instructions.

Section One: Answer all questions on the separate Multiple-choice Answer Sheet provided. For each questions shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. If you make a mistake, place a cross through that square then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

Sections Two and Three: Write your answers in this Question/Answer Booklet.

2. When calculating numerical answers, show your working or reasoning clearly. Express numerical answers to the appropriate number of significant figures and include appropriate units where applicable.
3. You must be careful to confine your responses to the specific questions asked and to follow any instructions that are specific to a particular question.
4. Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.
  - Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
  - Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.
5. The Chemistry Data Book is **not** handed in with your Question/Answer Booklet.

## Section One: Multiple-choice

25% (50 marks)

This section has **25** questions. Answer **all** questions on the separate Multiple-choice Answer Sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. If you make a mistake, place a cross through that square then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

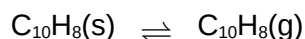
Suggested working time: 50 minutes.

1. Which of the following lists substances that are commonly used as an oxidising agent (oxidant) and a reducing agent (reductant)?

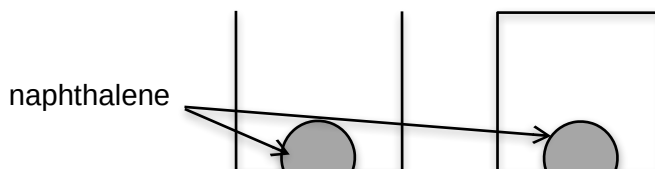
	Oxidising agent	Reducing agent
(a)	$\text{Cr}_2\text{O}_7^{2-}$	$\text{MnO}_4^-$
(b)	$\text{MnO}_4^-$	$\text{Cl}^-$
(c)	$\text{Cl}_2$	$\text{H}_2\text{C}_2\text{O}_4$
(d)	$\text{Mg}$	$\text{Cr}_2\text{O}_7^{2-}$

Questions 2 and 3 relate to the following information.

Naphthalene ( $\text{C}_{10}\text{H}_8$ ) is a component of mothballs. It is a white, flaky solid that sublimes relatively easily, according to the equation below.



Two beakers had a sample of solid naphthalene placed in them. The first beaker was left as an 'open system', whilst a lid was placed on the second beaker making it a 'closed system'.

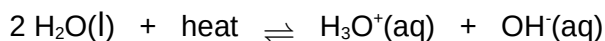


The temperature of each beaker was then increased by gently heating over a Bunsen burner.

2. When the temperature of the open system was increased, which of the following would **not** be correct?
- (a) There would be less solid present.
  - (b) The mass of the system would decrease.
  - (c) The pressure inside the beaker would remain constant.
  - (d) There would be an increase in the sublimation reaction rate.
3. When the temperature of the closed system was increased, which of the following would **not** be correct?
- (a) There would be more solid present.
  - (b) The mass of the system would remain constant.
  - (c) The pressure of the system would increase.
  - (d) There would be an increase in the average kinetic energy of the particles.



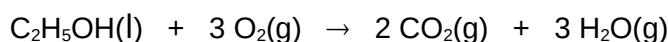
4. The following equation represents the autoionisation of water.



For pure water at 50 °C, which of the following is **correct**?

- (a) The  $\text{H}_3\text{O}^+$  concentration is greater than  $1.0 \times 10^{-7} \text{ mol L}^{-1}$ .
- (b) The  $\text{OH}^-$  concentration is less than  $1.0 \times 10^{-7} \text{ mol L}^{-1}$ .
- (c) The pH of water is greater than 7.
- (d) The  $K_w$  of water is less than  $1.0 \times 10^{-14}$ .

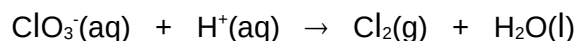
5. The combustion of ethanol can be represented by the following equation;



Which of the following statements is **correct** regarding this combustion equation?

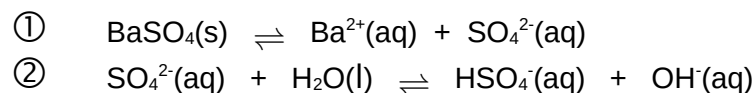
- (a) Oxygen gas is the reductant.
- (b) The oxidation number of carbon increases.
- (c) The oxidation number of hydrogen decreases.
- (d) Ethanol is reduced.

6. When this half-equation is correctly balanced, what is the coefficient of  $\text{H}^+(\text{aq})$ ?



- (a) 4
- (b) 6
- (c) 8
- (d) 12

7. A sample of barium sulfate powder is added to a beaker containing distilled water and stirred. The following chemical reactions occur;

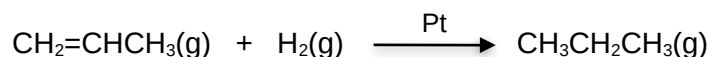


If a few drops of  $\text{HNO}_3(\text{aq})$  was added to the beaker, which of the following statements are **correct**?

- (i) Equilibrium ① shifts to the left.
  - (ii) Equilibrium ② shifts to the right.
  - (iii) The pH of the solution would increase.
  - (iv) The amount of  $\text{BaSO}_4(\text{s})$  present would decrease.
  - (v) The concentration of  $\text{Ba}^{2+}(\text{aq})$  in the solution would increase.
- (a) (i), (iii) and (v) only
  - (b) (ii), (iv), and (v) only
  - (c) (ii), (iii) and (iv) only
  - (d) (i), (ii) and (v) only

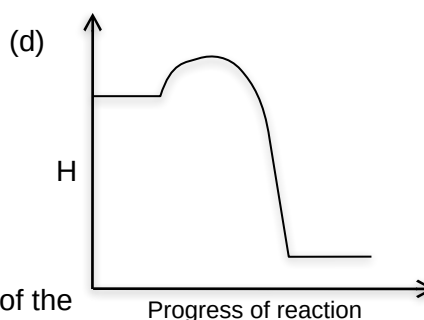
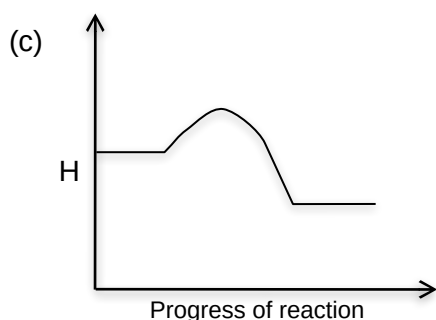
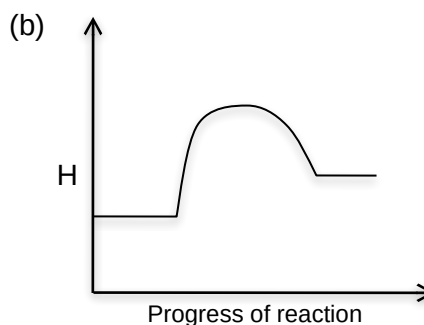
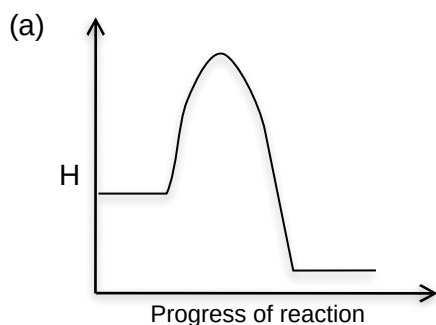
**Questions 8 and 9 relate to the following information.**

The exothermic hydrogenation of propene gas to form propane gas requires a catalyst such as platinum or nickel to be present. This reaction occurs as shown in the equation below.



Without a catalyst present this reaction only takes place at very high temperatures. The reaction is essentially irreversible.

8. Which of the following energy profile diagrams **best** represents the **uncatalysed** reaction? (You may assume each graph has the same scale on the axes.)



9. Which of the following is **not** an outcome of a platinum catalyst?

- (a) To increase the rate of reaction.
- (b) To increase the number of successful reactant collisions.
- (c) To increase the average kinetic energy of the reactant particles.
- (d) To increase the proportion of particles with enough kinetic energy to react.

10. For a reversible reaction, catalysts alter

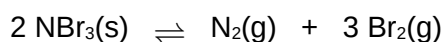
- (a) The heat of reaction for the forward reaction.
- (b) The size of the equilibrium constant.
- (c) The time taken for an equilibrium to be established.
- (d) The yield achieved at equilibrium.

11. Which of the following represents a loss of electrons?

- (a)  $\text{H}^+(\text{aq})$  forming  $\text{H}_2(\text{g})$ .
- (b)  $\text{Fe}^{2+}(\text{aq})$  forming  $\text{Fe}^{3+}(\text{aq})$ .
- (c)  $\text{Mg}^{2+}(\text{aq})$  forming  $\text{Mg}(\text{s})$ .
- (d)  $\text{Cl}_2(\text{g})$  forming  $\text{Cl}^-(\text{aq})$ .

Questions 12, 13 and 14 relate to the following information.

The equilibrium shown below represents the endothermic decomposition of nitrogen tribromide into nitrogen and bromine vapours. Nitrogen tribromide and nitrogen are colourless gases, whereas bromine is a red vapour.

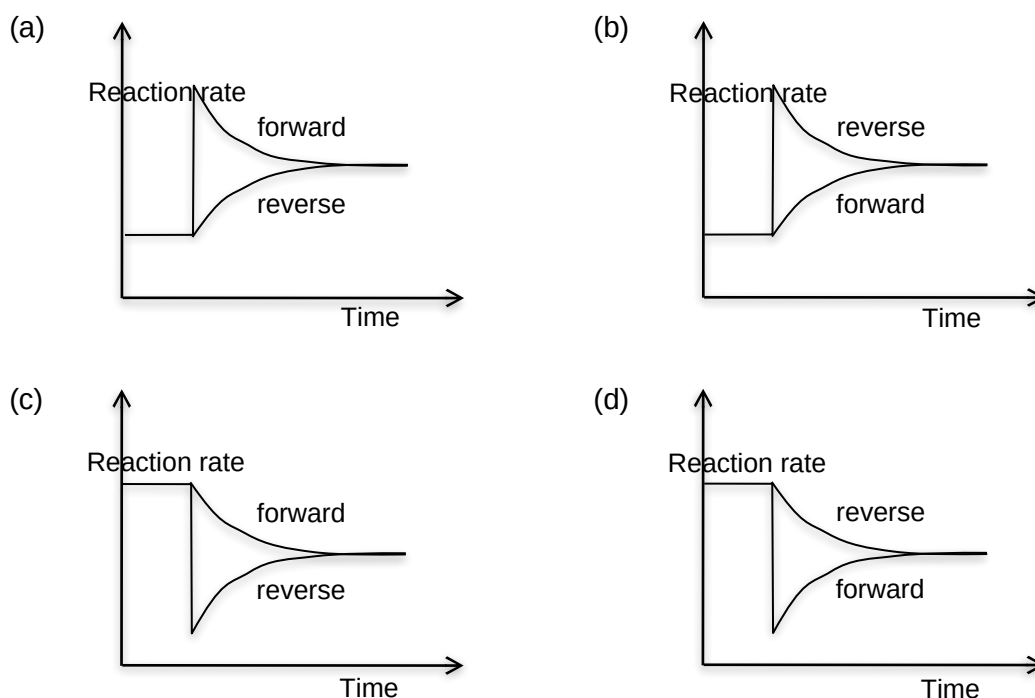


If some nitrogen tribromide is injected into an empty flask;

12. Which of the following is **not necessarily true** of the system once equilibrium is established?
- The pressure of the system would remain constant.
  - The partial pressure of  $\text{NBr}_3$  would remain constant.
  - The partial pressure of  $\text{N}_2$  would be half that of  $\text{NBr}_3$ .
  - The partial pressure of  $\text{Br}_2$  would be three times that of  $\text{N}_2$ .

Once equilibrium was established, the temperature of the system was increased.

13. Which of the following graphs **best** shows the effect of this temperature increase on reaction rate?



Once the system had re-established equilibrium, some  $\text{N}_2(\text{g})$  was removed.

14. Which of the following correctly states the effect of  $\text{N}_2$  removal on the equilibrium position, as well as the corresponding observations?

	Equilibrium position	Observations
(a)	favour reverse	darker red
(b)	favour reverse	lighter red
(c)	favour forward	darker red
(d)	favour forward	lighter red





15. For a sample of  $0.1 \text{ mol L}^{-1} \text{H}_3\text{PO}_4(\text{aq})$ , which of the following is **not** correct?
- (a)  $[\text{H}_3\text{PO}_4] > [\text{PO}_4^{3-}]$
  - (b)  $[\text{H}_3\text{O}^+] > [\text{H}_2\text{PO}_4^-]$
  - (c)  $[\text{H}_2\text{PO}_4^-] > [\text{HPO}_4^{2-}]$
  - (d)  $[\text{H}_3\text{O}^+] > [\text{H}_3\text{PO}_4]$

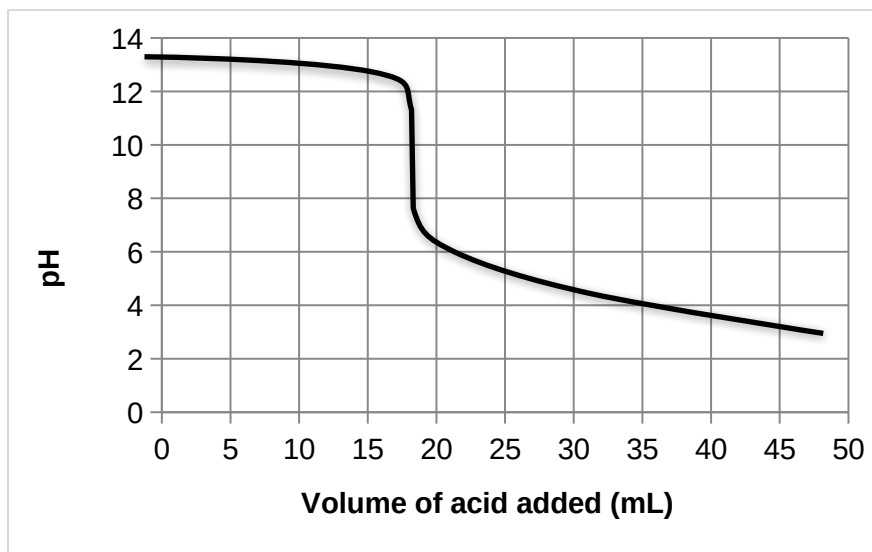
**Questions 16 and 17 refer to the information below.**

Potassium dichromate ( $\text{K}_2\text{Cr}_2\text{O}_7$ ) is a common oxidising agent (oxidant). In solid form it appears as orange-red crystals, and is very harmful to human health when ingested.

16. When potassium dichromate is said to 'act as an oxidising agent' this means that:
- (a) it will react with oxygen.
  - (b) it will be oxidised.
  - (c) its oxidation state will increase.
  - (d) it will gain electrons.
17. Which of the following substances would **not** react with a solution of acidified potassium dichromate under standard conditions?
- (a)  $\text{NaBr}(\text{aq})$
  - (b)  $\text{Ag}(\text{s})$
  - (c)  $\text{LiCl}(\text{aq})$
  - (d)  $\text{Na}(\text{s})$
18. If the equilibrium constant (K) value of a particular gaseous equilibrium system increases, which of the following **must be true**?
- (a) The pressure has been increased.
  - (b) The temperature has been increased.
  - (c) The concentration of reactants has been increased.
  - (d) The ratio of product concentration to reactant concentration has been increased.

Questions 19, 20 and 21 relate to the titration data below.

A teacher accurately performed a particular acid-base titration and, using a pH meter, was able to graph the titration curve shown below.



Four groups of chemistry students (W, X, Y, Z) then attempted to replicate the same titration. Each group performed four trials, and their titre values are shown in the table below.

	Trial 1	Trial 2	Trial 3	Trial 4
W	16.10 mL	16.05 mL	16.00 mL	16.05 mL
X	19.40 mL	19.35 mL	19.45 mL	19.40 mL
Y	19.50 mL	19.20 mL	19.30 mL	19.6 mL
Z	35.20 mL	35.25 mL	35.15 mL	35.25 mL

19. Which group of students has performed the titration **most accurately**?

- (a) W
- (b) X
- (c) Y
- (d) Z

20. Which group of students is **most likely** to have incorrectly used methyl orange indicator?

- (a) W
- (b) X
- (c) Y
- (d) Z

21. Which experimental set up was used for this titration?

- |     | <b>Burette solution</b>  | <b>Conical flask solution</b> |
|-----|--------------------------|-------------------------------|
| (a) | KOH(aq)                  | CH <sub>3</sub> COOH(aq)      |
| (b) | CH <sub>3</sub> COOH(aq) | KOH(aq)                       |
| (c) | NH <sub>3</sub> (aq)     | HCl(aq)                       |
| (d) | HCl(aq)                  | NH <sub>3</sub> (aq)          |

22. In which of the following compounds does sulfur have an oxidation number of +4?

- (i)  $\text{SO}_2$
- (ii)  $\text{H}_2\text{SO}_4$
- (iii)  $\text{H}_2\text{S}$
- (iv)  $\text{H}_2\text{SO}_3$
- (v)  $\text{Na}_2\text{S}_2\text{O}_3$

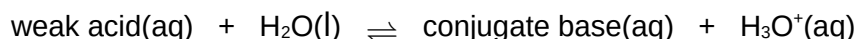
- (a) (i) only
- (b) (iii) only
- (c) (i) and (iv) only
- (d) (ii) and (v) only

23. Which of the following is **not** a redox reaction?

- (a)  $\text{HCrO}_4^- + 3 \text{H}^+ + \text{NO} \rightarrow \text{Cr}^{3+} + 2 \text{H}_2\text{O} + \text{NO}_3^-$
- (b)  $\text{Cr}_2\text{O}_7^{2-} + 2 \text{H}_2\text{O} + \text{NH}_4^+ \rightarrow 2 \text{HCrO}_4^- + \text{NH}_3 + \text{H}_3\text{O}^+$
- (c)  $\text{Cr}_2\text{O}_7^{2-} + 5 \text{H}^+ + 3 \text{HNO}_2 \rightarrow 2 \text{Cr}^{3+} + 4 \text{H}_2\text{O} + 3 \text{NO}_3^-$
- (d)  $\text{HCrO}_4^- + \text{H}^+ + 3 \text{N}_2\text{O} \rightarrow \text{Cr} + \text{H}_2\text{O} + 6 \text{NO}$

Questions 24 and 25 relate to the following information.

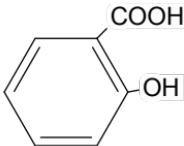
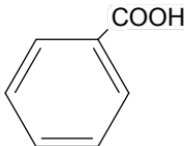
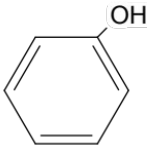
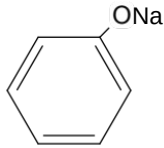
A chemist mixed  $0.1 \text{ mol L}^{-1}$  solutions of a weak, monoprotic acid and its sodium salt together in a beaker. The conjugate species formed a buffer as shown below;



24. If a few drops of  $\text{HCl(aq)}$  are added to this system, which is **correct**?

- (a) The pH falls quickly.
- (b) The concentration of the weak acid equals the concentration of the conjugate base.
- (c) The concentration of the weak acid increases.
- (d) The concentration of the weak acid remains fairly constant until the buffering capacity is exceeded.

25. Which of the following pairs of substances, when dissolved in water, could produce a buffer matching the above description?

- (a)  $\text{KHCO}_3$  and  $\text{K}_2\text{CO}_3$
- (b)  and 
- (c)  $\text{HNO}_3$  and  $\text{NaNO}_3$
- (d)  and 

End of Section One

**Section Two: Short answer****35% (70 marks)**

This section has **9** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Express numerical answers to the appropriate number of significant figures and include appropriate units where applicable.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Suggested working time: 60 minutes.

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**Question 26****(4 marks)**

For each of the following reactions, give full observations. Include any colour changes, formation of a solid or evolution of a gas. If there is no reaction you need to state this.

- (a) A potassium permanganate solution is added, dropwise, into an acidified solution of hydrogen peroxide. (2 marks)

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- (b) Cobalt carbonate is added to dilute hydrochloric acid solution. (2 marks)

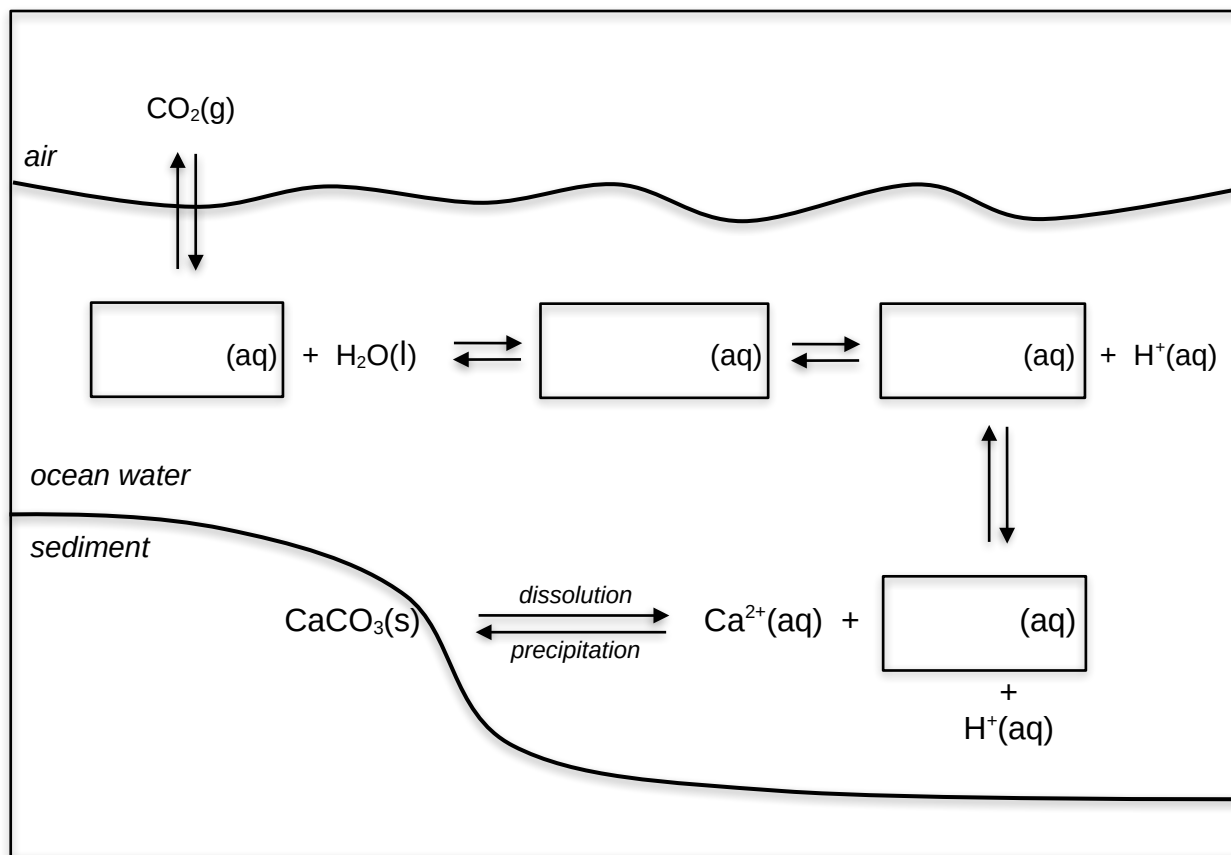
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## Question 27

(8 marks)

Examine the diagram below, which shows some of the relevant equations involved in ocean equilibria, specifically the role of carbon-containing species.



- (a) Complete the equilibrium equations on the diagram above, by writing the chemical formula of the four (4) missing carbon-containing species in the boxes. (4 marks)
- (b) Explain how higher atmospheric carbon dioxide levels cause a decrease in ocean pH, whereas the calcium carbonate present in sediment can counteract this to increase ocean pH. (4 marks)

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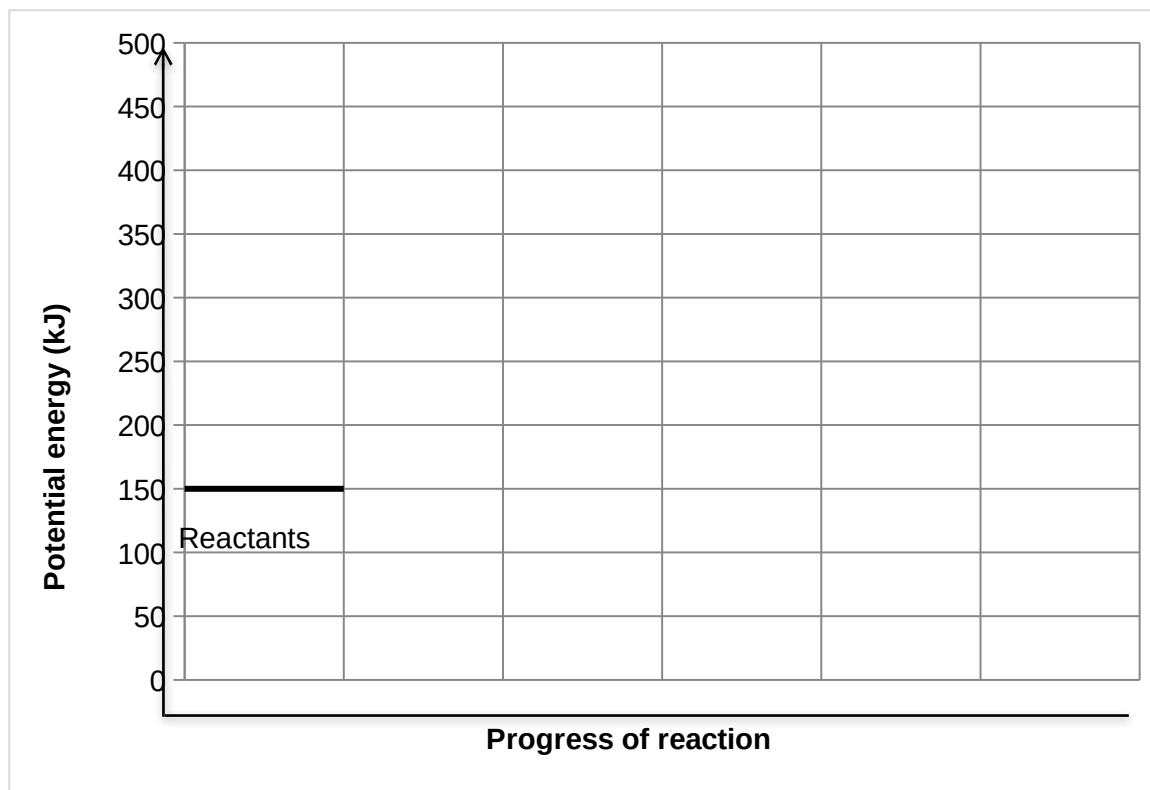
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## Question 28

(10 marks)

The first part of an energy profile diagram has been sketched on the axes below.



If the activation energy of the **reverse** reaction is 70 kJ and the heat of reaction (enthalpy change) of the **forward** reaction is  $210 \text{ kJ mol}^{-1}$ ;

- (a) Complete the energy profile diagram above. Label the products and the transition state (activated complex). (3 marks)

If a catalyst was added at the start of the reaction;

- (b) Which of the following is the **most likely** new value of the activation energy for the **forward** reaction? (circle your answer) (1 mark)

180 kJ

230 kJ

290 kJ

If the temperature of this system was decreased;

- (c) Explain, in terms of the collision theory, the effect this would have on the rate of reaction. (3 marks)

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- (d) Assuming this is a reversible reaction, what effect would this temperature decrease have on the value of the equilibrium constant,  $K$ ? Justify your answer. (3 marks)

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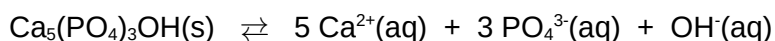
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**Question 29****(6 marks)**

Imagine snacking on a dish of ice cream, washing it down with your favourite soft drink. Delicious! The bacteria in your mouth like it too. The bacteria consume sugar and produce acids. These acids slowly dissolve the hard enamel surface on your teeth, cause plaque and eventually tooth decay.

Tooth enamel is composed of an insoluble mineral called hydroxyapatite,  $\text{Ca}_5(\text{PO}_4)_3\text{OH}(\text{s})$

When hydroxyapatite dissolves (**demineralisation**), it separates into calcium, phosphate and hydroxide ions. The dissolved ions can join back together to form the solid hydroxyapatite, this is called **re-mineralisation**. The process of demineralisation is represented as follows:



- (a) In adult teeth, these two processes (demineralisation and re-mineralisation) are in chemical equilibrium. Explain what is meant by chemical equilibrium in this context.

(2 marks)

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- (b) Write the equilibrium constant expression for the demineralisation reaction. (1 mark)

K =

- (c) In adults and children, if too much sugar is eaten, the concentration of **acid increases**. Explain the effect this will have on the equilibrium and consequently the tooth's condition.

(2 marks)

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- (d) The process of demineralisation occurs at pH below 5.5. What is the concentration of hydrogen ions at this pH? (1 mark)

**Question 30****(10 marks)**

The 'etching' of silicon is performed in the production of semiconductor materials, which are used in all forms of modern technology, such as mobile phones and computers. This etching can be achieved using the reversible chemical reaction below.



- (a) Write an equilibrium constant (K) expression for this reaction. (1 mark)

- (b) Complete the following table, for each of the imposed changes stated. In each case, state the effect on the forward reaction rate and the equilibrium position. (6 marks)

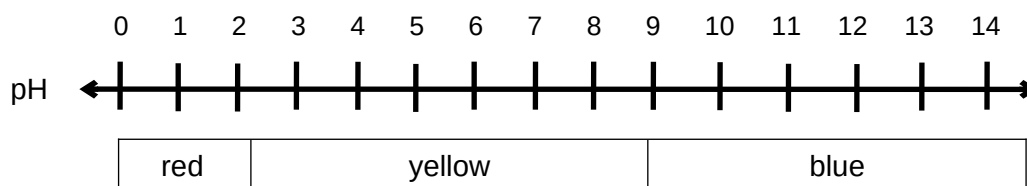
	Forward reaction rate (increase, decrease, no change)	Equilibrium position (left, right, no change)
Increase in total volume of the system		
Removal of some $\text{H}_2\text{(g)}$ from system		
Increase in temperature of the system		

- (c) Rather than blocks or cubes of silicon (Si), the silicon used in etching is in the form of extremely thin pieces called 'wafers'. Explain, in terms of the collision theory, what effect this has on both the forward reaction rate and yield of the reaction. (3 marks)

## Question 31

(10 marks)

Thymol blue is an indicator that has two distinct colour changes and displays three different colours over the pH range 0 to 14, as shown in the diagram below.



A few drops of thymol blue were added to the following  $0.2 \text{ mol L}^{-1}$  solutions;

- $\text{HNO}_3(\text{aq})$
- $\text{Mg}(\text{NO}_3)_2(\text{aq})$
- $\text{NH}_4\text{NO}_3(\text{aq})$
- $\text{KHCO}_3(\text{aq})$

- (a) Which of these substances is most likely to turn blue? Use an equation to support your answer. (2 marks)

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- (b) State two (2) solutions that **could not** be distinguished by adding thymol blue. Justify your answer using appropriate chemical equations. (4 marks)

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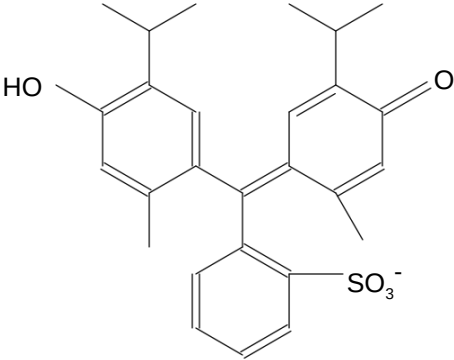
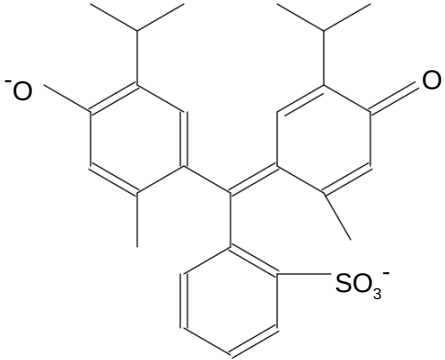
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- (c) Two forms of thymol blue, at different pH, are shown in the table below. Complete the table, by writing which structure is blue in colour and which is yellow. (1 mark)

Thymol blue structure		
Colour (blue or yellow)		

- (d) Justify your answer to (c). Include a brief description of how indicators function (i.e. how they are able to change colour). (3 marks)

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**Question 32**

**(7 marks)**

Six reactions (A-F) were carried out, as shown in the table below.

A	$\text{Zn(s)} + \text{Cu(NO}_3)_2\text{(aq)}$
B	$\text{Br}_2\text{(aq)} + \text{KI (aq)}$
C	$\text{HCl(aq)} + \text{KOH(s)}$
D	$\text{Br}_2\text{(aq)} + $  $\text{(l)}$
E	$\text{Fe(s)} + \text{H}_2\text{O(l)}$
F	$\text{Ni(s)} + \text{HCl(aq)}$

(a) Name the reaction that would occur in E. \_\_\_\_\_ (1 mark)

(b) In which reaction would halogen displacement occur? \_\_\_\_\_ (1 mark)

(c) Write the ionic equation for the reaction occurring in C. (1 mark)

\_\_\_\_\_  
\_\_\_\_\_

(d) Give full observations for the reaction occurring in A. (2 marks)

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

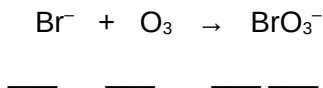
(e) Write two half-equations for the reaction occurring in B. (2 marks)

oxidation	
reduction	

**Question 33****(8 marks)**

Water is often purified by treatment with ozone. Any bromide ions present are converted to colourless bromate ions,  $\text{BrO}_3^-$ . Bromate ions are toxic, and so must be removed.

- (a) (i) Write the appropriate oxidation numbers on the lines under the equation. (2 marks)



- (ii) Identify the reducing agent and explain your choice using your answers to (i). (2 marks)

Reducing agent \_\_\_\_\_

Explanation \_\_\_\_\_

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- (b) One way of removing the toxic bromate ions is to react the bromate ions with iodide ions. Bromide ions are reformed and the solution turns brown.

Deduce the oxidation and reduction half equations and write the balanced redox equation for this reaction. (4 marks)

Oxidation half equation

Reduction half equation

Balanced redox equation

**Question 34**

**(7 marks)**

The Arrhenius theory of acids and bases introduced the relationship between acid behaviour and  $\text{H}^+(\text{aq})$  ions. Ethanoic acid ( $\text{CH}_3\text{COOH}$ ) is a common organic acid found in vinegar. It is a weak, monoprotic acid.

- (a) Write an Arrhenius equation for the ionisation of ethanoic acid. (1 mark)

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- (b) Define the term 'monoprotic' and explain why ethanoic acid is monoprotic, despite having four (4) hydrogen atoms per molecule. (2 marks)

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The Bronsted-Lowry theory of acids and bases introduced the concept of the hydronium ion,  $\text{H}_3\text{O}^+(\text{aq})$ , as well as conjugate acid-base pairs.

- (c) Explain what the ' $\text{H}_3\text{O}^+(\text{aq})$ ' notation is referring to and why it is often used in preference to the ' $\text{H}^+(\text{aq})$ ' notation. (2 marks)

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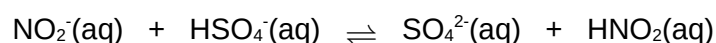


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- (d) Label and link the conjugate acid-base pairs in the equation below. (2 marks)



End of Section Two

**Section Three: Extended answer****40% (80 marks)**

This section contains **five (5)** questions. You must answer **all** questions. Write your answers in the spaces provided below.

Where questions require an explanation and/or description, marks are awarded for the relevant chemical content and also for coherence and clarity of expression. Lists or dot points are unlikely to gain full marks.

Final answers to calculations should be expressed to the appropriate number of significant figures.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Suggested working time: 70 minutes.

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**Question 35****(15 marks)**

Iodic acid ( $\text{HIO}_3$ ) is found as a white solid at room temperature. It readily dissolves in water to produce an acidic solution, with a solubility of  $2.69 \text{ kg L}^{-1}$  at  $20^\circ\text{C}$ . Iodic acid can be used in analytical chemistry to standardise alkaline solutions.

Iodic acid also acts as a strong oxidising agent under acidic conditions. When behaving as an oxidant, it can be reduced to either elemental iodine ( $\text{I}_2$ ), iodide ions ( $\text{I}^-$ ) or, under the right conditions, to the iodine trichloride dimer ( $\text{I}_2\text{Cl}_6$ ) which is golden yellow in solution.

A solution of acidified iodic acid has some toxic carbon monoxide gas bubbled through it. A brown solution is observed to form, as the carbon monoxide is converted to the less harmful carbon dioxide gas.

- (a) Write the oxidation and reduction half-equations and the overall redox equation for this reaction. (3 marks)

Oxidation half-equation	
Reduction half-equation	
Overall redox equation	



A chemistry student is experimenting with iodic acid, to investigate some of its physical and chemical properties. She wants to determine the strength of the acid, but cannot find any information about the acidity constant ( $K_a$ ) of iodic acid in her research.

- (b) Write an acidity constant expression for iodic acid and explain what information a  $K_a$  value would provide regarding the acid. (2 marks)

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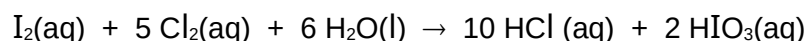
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One method used to prepare iodic acid is by reacting aqueous iodine with aqueous chlorine. This produces a mixture of iodic and hydrochloric acids, as shown in the equation below;



- (c) Identify the oxidising agent (oxidant) and reducing agent (reductant) in this reaction. Use oxidation numbers to support your answer. (4 marks)

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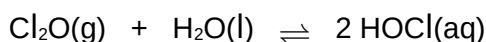
The chemistry student decided to prepare a sample of iodic acid according to the reaction above. She mixed 750 mL of  $2.15 \times 10^{-3} \text{ mol L}^{-1}$  aqueous iodine ( $\text{I}_2$ ) with 830 mL of chlorine water ( $\text{Cl}_2$ ) in a large beaker. Once the reaction had finished, a mixture of iodic and hydrochloric acids was present. She used a digital pH meter to measure the resulting pH of the solution and determined it to be 2.14.

- (d) Determine and justify whether iodic acid is a strong or weak acid. Use appropriate calculations to support your answer. (You may assume that the chlorine water was in excess and that the reaction went to completion, consuming all of the iodine.) (6 marks)

## Question 36

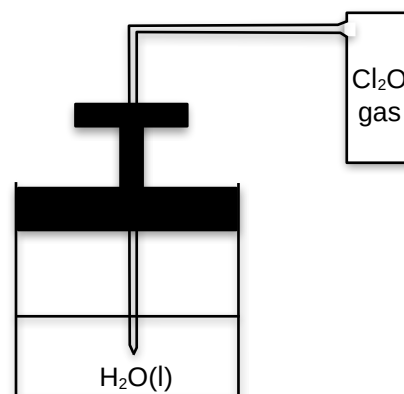
(15 marks)

Dichlorine monoxide ( $\text{Cl}_2\text{O}$ ) is a brownish-yellow gas at room temperature. It is very soluble in water and when dissolved, it reacts with water to produce weak hypochlorous acid, according to the reversible reaction below;



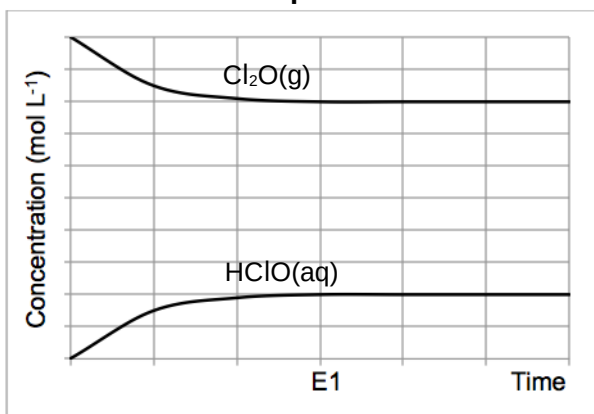
The solution of hypochlorous acid appears colourless. At room temperature (298 K) this reaction has a  $K_c$  value of 0.090.

A sample of  $\text{Cl}_2\text{O}(\text{g})$  was injected into a glass cylinder containing water, as shown in the diagram to the right, and allowed to establish equilibrium according to the equation above.

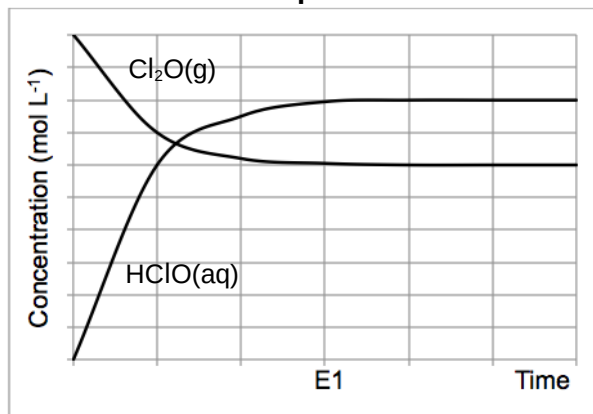


Several graphs have been sketched below, in an attempt to show the changes in concentration of  $\text{Cl}_2\text{O}(\text{g})$  and  $\text{HOCl}(\text{aq})$  from Time 0, when the gas was injected into the system, until equilibrium was first established at Time E1. You may assume the scales on both axes of each graph are identical.

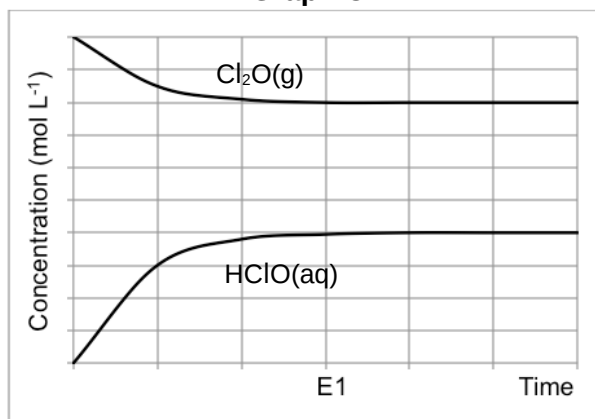
Graph A



Graph B



Graph C



- (a) Which of these graphs (A, B or C) is **most likely** to illustrate the concentration changes that would occur, from the time the  $\text{Cl}_2\text{O(g)}$  is injected into the system until the time that equilibrium is established at E1? Explain your choice below. (3 marks)

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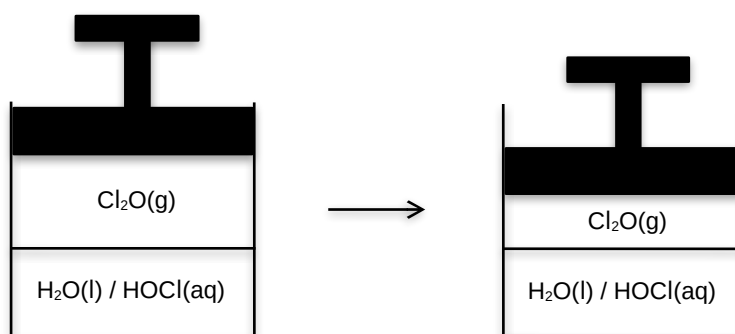
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At Time X, the pressure on the system was then increased, as shown in the diagram below.



- (b) State the effect this would have on the equilibrium position and describe any corresponding observations that would be made as a result of this imposed change. (3 marks)

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- (c) Explain what would happen to both the forward and reverse reaction rates, from the time the pressure was increased until the system re-establishes equilibrium (at E2). (3 marks)

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When the temperature of this equilibrium system is increased to 400 K, the value of  $K_c$  is 1.98.

- (d) Explain what information this provides about the heat of reaction ( $\Delta H$ ). (3 marks)

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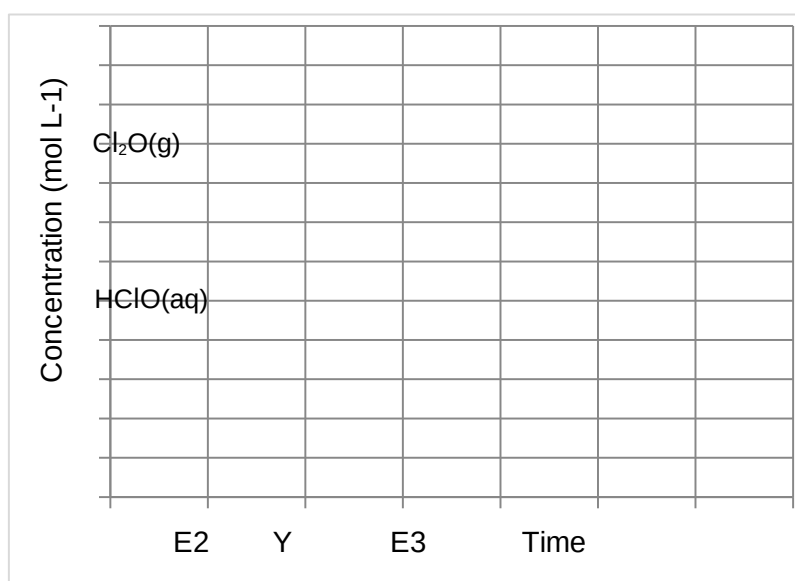
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- (e) Continue the graph below, showing the effect of a temperature increase on the system (imposed at Time Y) until equilibrium is re-established at E3. (You may assume water is still in the liquid state, as a result of the previous pressure increase.) (3 marks)



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## Question 37

(19 marks)

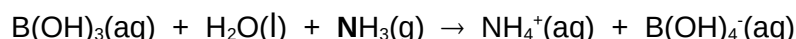
The 'Kjeldahl method' is a volumetric analysis process designed to measure the quantity of organic nitrogen (N) contained within a sample. One of the most common uses of the Kjeldahl method, is to determine the protein content in food and drink, since a measure of the nitrogen contained within a sample can be assumed to correspond directly to the amount of protein present.

Analysis by the Kjeldahl method is as follows;

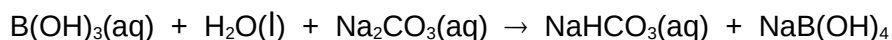
1. A sample of the food or drink is dissolved in sulfuric acid, where all the nitrogen present in the protein is converted to ammonium sulfate,  $(\text{NH}_4)_2\text{SO}_4$ . This is then distilled to ensure all the ammonium ions are liberated as ammonia,  $\text{NH}_3$ . All the nitrogen in the protein from the food/drink sample is now present as ammonia.



2. The ammonia is then captured by (dissolved into) a solution containing a known, excess quantity of boric acid, i.e. all ammonia is captured and reacts according to the following equation;



3. A back titration is then performed, to determine the amount of boric acid remaining. This titration is performed using a sodium carbonate primary standard ( $\text{Na}_2\text{CO}_3$ ) and the indicator methyl orange.



4. The amount of ammonia captured can then be calculated. From this, the quantity of nitrogen, in the sample can be determined.
5. Once the mass of nitrogen in a food or drink sample is known, it is multiplied by a conversion factor according to the protein source. Some examples are shown in the table below.

	Conversion factor
peanuts	x 5.46
rice	x 6.95
meat, eggs	x 6.25
dairy	x 6.38

e.g. if a sample of peanuts was determined to contain 3.5 g of nitrogen (N), they would therefore contain  $3.5 \text{ g} \times 5.46 = 19.11 \text{ g}$  of protein

Powdered baby formula (milk powder) must be manufactured according to very strict specifications, to ensure it contains the correct nutritional balance to sustain the healthy growth of a baby. By law, whole milk powder for babies must contain a minimum of **26.44 g of protein per 100 g of milk powder**.

A sample of powdered baby formula was analysed for quality control purposes to determine the protein content. 3.75 grams of dairy milk powder was dissolved in 50.00 mL of sulfuric acid. The ammonium sulfate formed was distilled and the liberated ammonia was then captured and absorbed into 75.00 mL of a  $0.200 \text{ mol L}^{-1}$  boric acid solution.

Three 20.00 mL aliquots of the captured boric acid solution were then titrated against a standard  $0.0650 \text{ mol L}^{-1}$  sodium carbonate solution. The results of the titration are shown in the table below.

	1	2	3
Initial reading (mL)	48.30	33.15	17.95
Final reading (mL)	33.15	17.95	2.75
Titre (mL)			

- (a) Use the titration results to calculate the number of moles of excess  $\text{B(OH)}_3$  remaining in the 75.00 mL sample **after** the capture of  $\text{NH}_3$ . (4 marks)

- (b) Use your answer from (a), as well as the **original** concentration of  $\text{B(OH)}_3$ , to calculate the number of moles of  $\text{NH}_3$  that was captured in the boric acid solution. (3 marks)



- (c) Calculate the percent composition (by mass) of nitrogen in the sample of powdered baby formula. Express your answer to the correct number of significant figures. (4 marks)

- (d) Use the appropriate conversion factor to calculate the protein content in the baby formula, and comment on whether this batch of milk powder meets the minimum requirement for protein content. (2 marks)

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As outlined previously, the back titration in the Kjeldahl method is performed using a sodium carbonate primary standard as well as the indicator methyl orange.

- (e) Define the term 'standard solution' and state two (2) characteristics of  $\text{Na}_2\text{CO}_3$  that allow it to be used as a primary standard. (3 marks)

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If the burette had been rinsed with distilled water at the start of the experiment;

- (f) What effect would this error have on the value of the titre volumes obtained (i.e. higher volumes, lower volumes or unaffected)? (1 mark)

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- (g) Is this a random or systematic error? Explain your answer. (2 marks)

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**Question 38**
**(16 marks)**

The water corporation monitors the pH of drinking water very closely. They use pH meters that are calibrated to take the temperature of the water into account when measuring the  $[H^+]$ , rather than using indicators. Water self-ionises to a small degree.

- (a) Write an equation for the self-ionisation of water. (1 mark)

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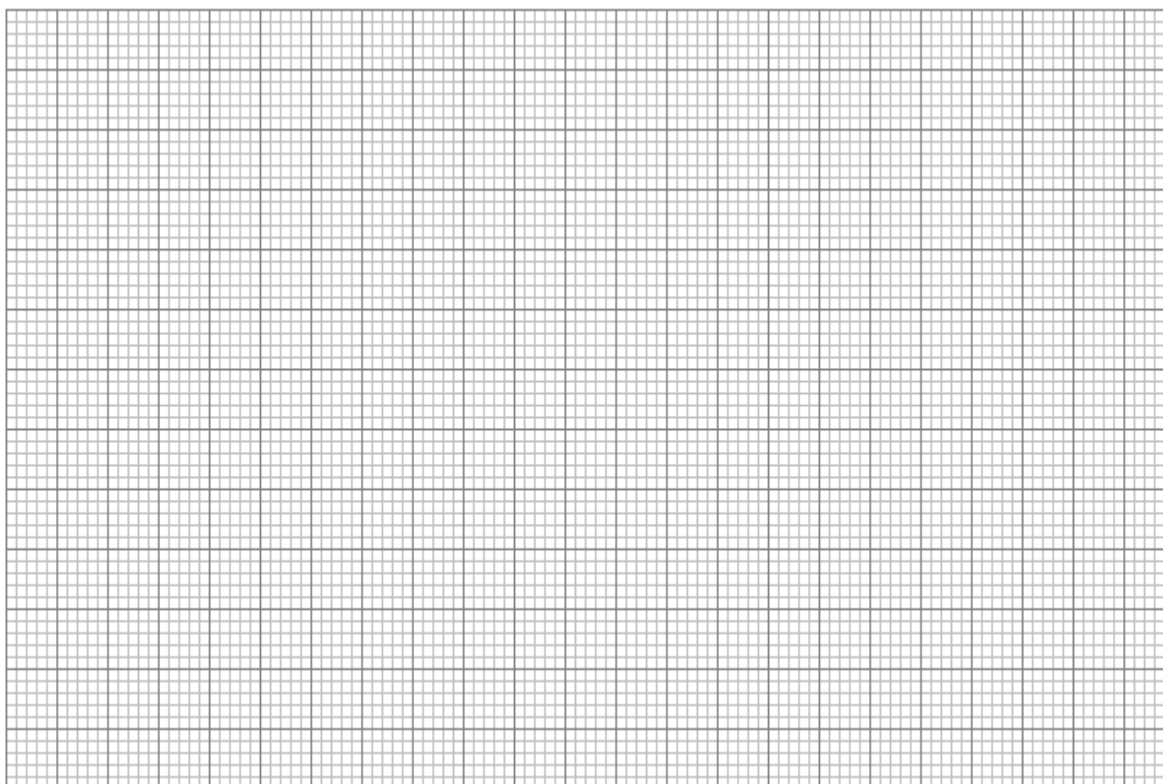
At a given temperature, the self-ionisation of water is at equilibrium. The equilibrium constant expression for this reaction is:

$$K_w = [H^+][OH^-]$$

The values for the equilibrium constant at a range of temperatures are given in the table below.

Temperature (°C)	0	10	20	25	30	40	50	100
$K_w (x 10^{-14})$	0.11	0.29	0.68	1.01	1.47	2.92	5.60	51.3
$[H^+] (x 10^{-8}) \text{ mol L}^{-1}$	3.3	5.3	8.2	10		17	24	

- (b) Plot a graph of the  $K_w$  value versus temperature. (4 marks)



- (c) Calculate the missing values for  $[H^+]$  and complete the table above. (2 marks)
- (d) Calculate the pH of water at 10°C and 40°C. (2 marks)

10°C:

40°C:

- (e) Describe the relationship between  $K_w$  and temperature. (1 mark)

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- (f) From your graph, estimate the value of  $K_w$  at 45°C. (1 mark)

- (g) What is the relationship between  $[H^+]$  and temperature in pure water? (1 mark)

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- (h) Is water acidic, basic or neutral as temperature increases? Explain. (2 marks)

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- (i) From this data, is the ionisation of water an endothermic or exothermic reaction? Justify your answer. (2 marks)

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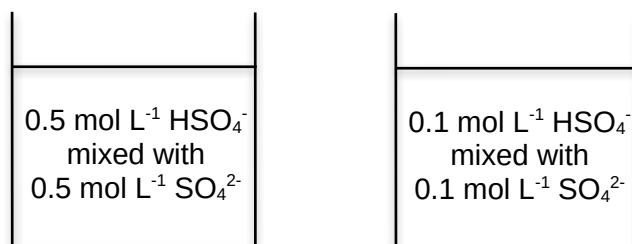
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**Question 39**

**(15 marks)**

A chemistry student was investigating what type of solutions can be mixed together to form a buffer.

Firstly, he made two different hydrogensulfate / sulfate buffers. As illustrated in the diagrams below, one beaker contained a 1 L mixture of  $0.5 \text{ mol L}^{-1} \text{ NaHSO}_4(\text{aq})$  and  $0.5 \text{ mol L}^{-1} \text{ Na}_2\text{SO}_4(\text{aq})$ . The second beaker contained a 1 L mixture of  $0.1 \text{ mol L}^{-1} \text{ NaHSO}_4(\text{aq})$  and  $0.1 \text{ mol L}^{-1} \text{ Na}_2\text{SO}_4(\text{aq})$ .



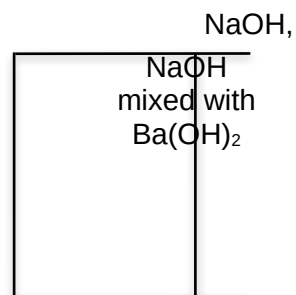
Unfortunately, the student forgot to label the beakers, and could not remember which was which.

- (a) Explain how the student could experimentally determine which beaker contained which buffer. Include a description of buffering capacity in your answer. Assume you have access to standard laboratory reagents and equipment. (6 marks)

[illegible]

Next, the student decided to mix together solutions of sodium hydroxide, and barium hydroxide,  $\text{Ba}(\text{OH})_2$ .

(b) Why doesn't this solution form a buffer? (1 mark)



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The original sodium hydroxide solution had a pH of 9.9 and the student measured 850 mL of this into a beaker. He then added 95 mL of a  $0.075 \text{ mol L}^{-1}$  barium hydroxide solution to the same beaker.

(c) Calculate the pH of the resulting solution. (8 marks)

End of questions