



Western Australian Certificate of Education  
Semester 1 Examination, 2020

Question/Answer Booklet

NAME

**ATAR CHEMISTRY**

**solutions**

**Unit 3**

**Time allowed for this paper**

Reading time before commencing work:

**10 minutes**

Working time for paper:

**3 hours**

**Materials required/recommended for this paper**

***To be provided by the supervisor***

This Question/Answer Booklet

Multiple-choice Answer Sheet

Chemistry Data Sheet

***To be provided by the candidate***

Standard items: pens, pencils, eraser, correction fluid/tape, ruler, highlighters

Special items: non-programmable calculators satisfying the conditions set out by the Curriculum Council for this course

**OFFICE USE ONLY**

|              | MARK | TOTAL      | % |
|--------------|------|------------|---|
| Section 1    |      | 50         |   |
| Section 2    |      | 70         |   |
| Section 3    |      | 80         |   |
| <b>TOTAL</b> |      | <b>200</b> |   |

### Structure of this paper

| Section                          | Number of questions available | Number of questions to be answered | Suggested working time (minutes) | Marks available | Percentage of examination |
|----------------------------------|-------------------------------|------------------------------------|----------------------------------|-----------------|---------------------------|
| Section One<br>Multiple-choice   | 25                            | 25                                 | 50                               | / 50            | / 25                      |
| Section Two<br>Short answer      | 8                             | 8                                  | 60                               | / 70            | / 35                      |
| Section Three<br>Extended answer | 5                             | 5                                  | 70                               | / 80            | / 40                      |
|                                  |                               |                                    |                                  |                 | / 100                     |

### Instructions to candidates

1. Write your answers in this Question/Answer booklet preferably using a blue/black pen. Do not use erasable or gel pens.
2. Answer the questions according to the following instructions.

Section One: 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. Do not use erasable or gel pens. 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.

3. When calculating numerical answers, show your working or reasoning clearly. Your working should be in sufficient detail to allow your answer to be checked readily and for marks to be awarded for reasoning. Express numerical answers to the appropriate number of significant figures and include appropriate units where applicable.
4. You must be careful to confine your answers to the specific questions asked and to follow any instructions that are specific to a particular question.
5. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.
6. The Chemistry Data booklet is not to be handed in with your Question/Answer booklet.

**Section One: Multiple-choice****25% (25 marks)**

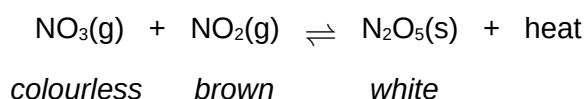
This section has **25** questions. Answer **all** questions on the separate Multiple-choice Answer Sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. If you make a mistake, place a cross through that square then shade your new answer. 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.

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**Questions 1, 2 and 3 relate to the following equilibrium system.**

Samples of  $\text{NO}_3(\text{g})$  and  $\text{NO}_2(\text{g})$  were injected into an empty flask and equilibrium was established according to the following equation.



1. While the system was establishing equilibrium, which of the following would **not** be observed?
  - (a) The brown gas colour fades.
  - (b) A white solid appears.
  - (c) The pressure in the flask increases.
  - (d) The temperature in the flask increases.
  
2. Which of the following conditions would increase the value of K for this equilibrium?
  - (a) Decreasing the temperature of the system.
  - (b) Increasing the temperature of the system.
  - (c) Decreasing the volume of the system.
  - (d) Increasing the volume of the system.
  
3. Which of the following conditions would favour a high equilibrium yield of  $\text{N}_2\text{O}_5(\text{s})$ ?
  - (i) Increased concentrations of  $\text{NO}_3(\text{g})$  and  $\text{NO}_2(\text{g})$
  - (ii) Increased volume of system
  - (iii) Increased subdivision of  $\text{N}_2\text{O}_5(\text{s})$
  - (iv) Increased temperature of system
  - (a) (i) only.
  - (b) (ii) only.
  - (c) (i) and (iii) only.
  - (d) (ii) and (iv) only.

4. 'Black powder' is typically composed of solid potassium nitrate and charcoal dust ( $\text{C}_7\text{H}_4\text{O}$ ). When this powder is ignited, the products formed are a mixture of solid potassium carbonate, carbon dioxide gas, water vapour and nitrogen gas.

Identify the element oxidised and reduced in this reaction.

|     | Oxidised | Reduced |
|-----|----------|---------|
| (a) | N        | K       |
| (b) | C        | N       |
| (c) | O        | N       |
| (d) | C        | H       |

5. Compare the four halogens in their elemental form;  $\text{F}_2(\text{g})$ ,  $\text{Cl}_2(\text{g})$ ,  $\text{Br}_2(\text{l})$  and  $\text{I}_2(\text{s})$ . Which of the following statements is **correct**?

- (a)  $\text{F}_2(\text{g})$  exists in the highest oxidation state.
- (b)  $\text{Cl}_2(\text{g})$  is the strongest reducing agent (reductant).
- (c)  $\text{Br}_2(\text{l})$  has the lowest tendency to gain electrons.
- (d)  $\text{I}_2(\text{s})$  has the lowest reduction potential.

6. How many moles of electrons are required when the following half-equation is balanced using the smallest possible coefficients?

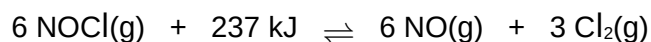


- (a) 2
- (b) 5
- (c) 10
- (d) 12

7. Using a chemical equation, the Arrhenius theory of acids and bases **would be** able to justify the pH of a solution of

- (a) nitric acid.
- (b) ammonia.
- (c) potassium carbonate.
- (d) lithium fluoride.

8. Consider the following equilibrium system.



A chemist wanted to;

- favour the reverse reaction
- decrease the rate of the reverse reaction
- maintain a constant K value

Which change should they impose on the system to satisfy all 3 criteria?

- (a) Decrease the temperature of the system.
- (b) Decrease the volume of the system.
- (c) Remove some NOCl(g) from the system.
- (d) Add some NO(g) to the system.

**Questions 9 and 10 refer to the following redox reaction.**

A small piece of potassium metal was placed into a large bowl of water, which contained a few drops of universal indicator.

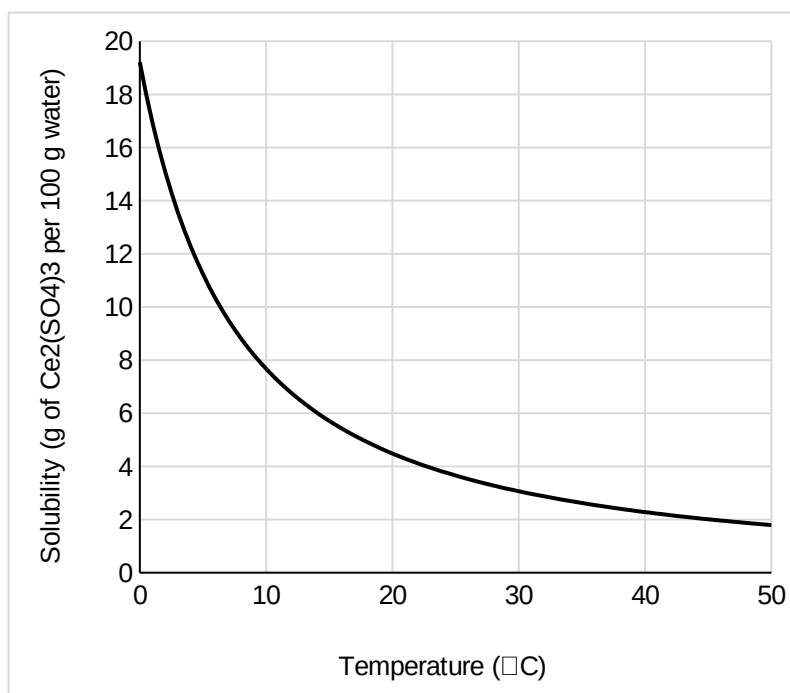
9. Which of the following would **not** be observed?

- (a) The silver metal dissolves.
- (b) A colourless, odourless gas is produced.
- (c) The solution colour changes from green to orange.
- (d) Heat is produced.

10. Select the correct statement with regards to the reaction that took place.

- (a) The oxidation number of potassium decreases.
- (b) The oxidation number of oxygen increases.
- (c) Hydrogen atoms are oxidised.
- (d) Water is the oxidising agent (oxidant).

11. Consider the following graph, which provides information regarding the solubility of cerium(III) sulfate,  $\text{Ce}_2(\text{SO}_4)_3(\text{s})$ , at various temperatures.



An 8 g sample of  $\text{Ce}_2(\text{SO}_4)_3(\text{s})$  was added to a beaker containing 100 g of water at 20 °C. Equilibrium was established according to the following equation.



If the temperature of the system is decreased, which of the following is **not** correct?

- (a) The conductivity of the solution would increase.
- (b) The rate of dissociation would increase.
- (c) The forward reaction would be favoured.
- (d) The value of K would increase.

12. The endothermic autoionisation of water can be represented by the equation below.



Distilled water at a temperature of 15 °C would have

- (a) a concentration of hydronium ions greater than  $1.0 \times 10^{-7} \text{ mol L}^{-1}$ .
- (b) a concentration of hydroxide ions greater than  $1.0 \times 10^{-7} \text{ mol L}^{-1}$ .
- (c) a  $K_w$  value greater than  $1.0 \times 10^{-14}$ .
- (d) a pH greater than 7.

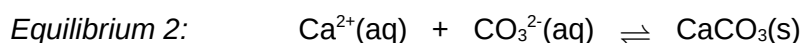
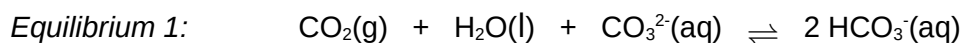
13. 'Disproportionation' refers to a redox reaction, where atoms of a particular element within a single species are simultaneously oxidised and reduced. Which of the following would **not** be regarded as a disproportionation reaction?

- (a)  $\text{Cl}_2(\text{g}) + 2 \text{OH}^-(\text{aq}) \rightarrow \text{ClO}^-(\text{aq}) + \text{Cl}^-(\text{aq}) + \text{H}_2\text{O}(\text{l})$   
 (b)  $2 \text{H}_2\text{O}_2(\text{aq}) \rightarrow 2 \text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$   
 (c)  $\text{NH}_4\text{NO}_3(\text{s}) \rightarrow \text{N}_2\text{O}(\text{g}) + 2 \text{H}_2\text{O}(\text{g})$   
 (d)  $2 \text{CuCl}(\text{s}) \rightarrow \text{CuCl}_2(\text{s}) + \text{Cu}(\text{s})$

**Questions 14 and 15 refer to the equilibria associated with calcification.**

Ocean acidification is a complex process which changes the chemistry of seawater and affects various marine organisms. Calcifying species use the  $\text{Ca}^{2+}(\text{aq})$  and  $\text{CO}_3^{2-}(\text{aq})$  in seawater to produce  $\text{CaCO}_3(\text{s})$ , which then forms structures such as the shells or exoskeletons of marine organisms.

Two of the chemical equilibria associated with the process of calcification are shown below.



14. State the effect of an increased  $\text{CO}_2(\text{g})$  concentration on the rate of each forward reaction.

|     | <b>Equilibrium 1</b> | <b>Equilibrium 2</b> |
|-----|----------------------|----------------------|
| (a) | increased rate       | decreased rate       |
| (b) | increased rate       | increased rate       |
| (c) | decreased rate       | increased rate       |
| (d) | decreased rate       | decreased rate       |

15. State the effect of an increased  $\text{CO}_2(\text{g})$  concentration on the equilibrium position of each reaction.

|     | <b>Equilibrium 1</b> | <b>Equilibrium 2</b> |
|-----|----------------------|----------------------|
| (a) | reverse favoured     | forward favoured     |
| (b) | reverse favoured     | reverse favoured     |
| (c) | forward favoured     | reverse favoured     |
| (d) | forward favoured     | forward favoured     |

16. Consider the reaction between aqueous sodium hydrogencarbonate and hydrochloric acid solution. The sodium hydrogencarbonate was present in excess and the reaction was allowed to proceed to completion.

Which of the following would **not** be correct, once the reaction was complete?

- (a)  $[\text{Na}^+(\text{aq})] > [\text{Cl}^-(\text{aq})]$   
 (b)  $[\text{HCO}_3^-(\text{aq})] > [\text{Na}^+(\text{aq})]$   
 (c)  $[\text{H}_3\text{O}^+(\text{aq})] > [\text{OH}^-(\text{aq})]$   
 (d)  $[\text{Cl}^-(\text{aq})] > [\text{H}_3\text{O}^+(\text{aq})]$

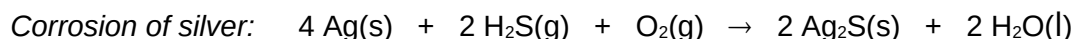
17. When zinc metal is placed into a solution of  $1 \text{ mol L}^{-1}$  nitric acid, nitrogen dioxide gas is formed and the zinc metal dissolves.

Which redox equation **best** represents the reaction occurring?

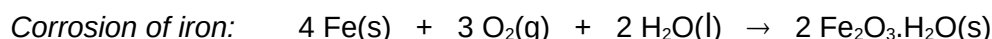
- (a)  $\text{Zn(s)} + 2 \text{HNO}_3(\text{aq}) + 2 \text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2 \text{NO}_2(\text{g}) + 2 \text{H}_2\text{O(l)}$   
 (b)  $\text{Zn(s)} + \text{NO}_3^-(\text{aq}) + 2 \text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{NO}_2(\text{g}) + 2 \text{H}_2\text{O(l)}$   
 (c)  $\text{Zn(s)} + 2 \text{NO}_3^-(\text{aq}) + 4 \text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2 \text{NO}_2(\text{g}) + 2 \text{H}_2\text{O(l)}$   
 (d)  $\text{Zn(s)} + \text{HNO}_3(\text{aq}) + 3 \text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{NO}_2(\text{g}) + 2 \text{H}_2\text{O(l)}$

### Questions 18 and 19 refer to metal corrosion.

Silver metal is particularly susceptible to a form of corrosion known as tarnishing. The chemical equation for this corrosion process is shown below.



The corrosion of iron is a particularly damaging and expensive problem, due to the extensive use of iron in modern life. The chemical equation for this corrosion process is shown below.



18. Select the option which correctly identifies the change in oxidation number of each element involved in the process of silver corrosion.

|     | Ag          | H           | S            | O           |
|-----|-------------|-------------|--------------|-------------|
| (a) | (0) to (+1) | no change   | no change    | (0) to (-2) |
| (b) | no change   | (0) to (+1) | no change    | (0) to (-2) |
| (c) | (0) to (+2) | no change   | (-2) to (-4) | no change   |
| (d) | (0) to (+1) | no change   | (-2) to (-4) | no change   |

19. Select the statement that is **not** common to both the corrosion of silver **and** the corrosion of iron.

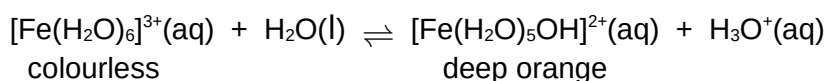
- (a) The metal is the reducing agent.  
 (b) Oxygen gas is the oxidising agent.  
 (c) The metallic element forms a compound.  
 (d) A thin layer of metallic oxide forms on the metals.





Questions 20, 21 and 22 refer to the following information.

Consider the reversible reaction involving the hexaaquairon(III) ion shown below. Assume the reaction is at equilibrium and the  $K_c$  value is approximately 1 at 25 °C.



If 20 drops of 0.5 mol L<sup>-1</sup> HCl(aq) solution was added to this system and a new equilibrium was allowed to establish;

20. Which is the **best** observation for this?

- (a) Colourless solution becomes deep orange.
- (b) Deep orange solution becomes colourless.
- (c) Orange solution darkens in colour.
- (d) Orange solution fades in colour.

21. At the new equilibrium, which of the following statements is **correct**?

- (a) The rate of the forward reaction is increased.
- (b) The rate of the forward reaction is decreased.
- (c) The rate of the forward reaction is unchanged.
- (d) The rate of the forward reaction is zero.

22. Which species will **not** have an increase in the number of moles present?

- (a)  $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$
- (b)  $\text{H}_2\text{O}(\text{l})$
- (c)  $[\text{Fe}(\text{H}_2\text{O})_5\text{OH}]^{2+}(\text{aq})$
- (d)  $\text{H}_3\text{O}^+(\text{aq})$

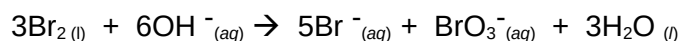
23. Four beakers (A, B, C and D) were placed on a laboratory bench, each containing distilled water and several drops of universal indicator. A small sample of a different salt was then dissolved into each beaker, according to the table below.

| Beaker A                             | Beaker B                   | Beaker C                             | Beaker D                             |
|--------------------------------------|----------------------------|--------------------------------------|--------------------------------------|
| + $\text{NH}_4\text{NO}_3(\text{s})$ | + $\text{MgF}_2(\text{s})$ | + $\text{KCH}_3\text{COO}(\text{s})$ | + $\text{Na}_3\text{PO}_4(\text{s})$ |

The colour of the solution in beaker

- (a) A would change from green to blue.
- (b) B would change from green to yellow.
- (c) C would change from green to orange.
- (d) D would change from green to purple.

24. The equation for the addition of liquid bromine to a hot, concentrated solution of sodium hydroxide is:



For this process consider the following statements

- (i) the hydrogen is reduced
- (ii) the bromine is oxidised
- (iii) the oxygen is the reducing agent
- (iv) the bromine is the oxidising agent

Which of the following is correct?

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

25. Which of these lists contains species showing oxygen in **three different** oxidation states?

|     |                               |                               |                               |
|-----|-------------------------------|-------------------------------|-------------------------------|
| (a) | O <sub>2</sub>                | H <sub>2</sub> O <sub>2</sub> | MgO                           |
| (b) | F <sub>2</sub> O              | H <sub>2</sub> O              | SO <sub>4</sub> <sup>2-</sup> |
| (c) | H <sub>2</sub> O <sub>2</sub> | SO <sub>4</sub> <sup>2-</sup> | MgO                           |
| (d) | H <sub>2</sub> O              | O <sub>2</sub>                | SO <sub>4</sub> <sup>2-</sup> |

End of Section One

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

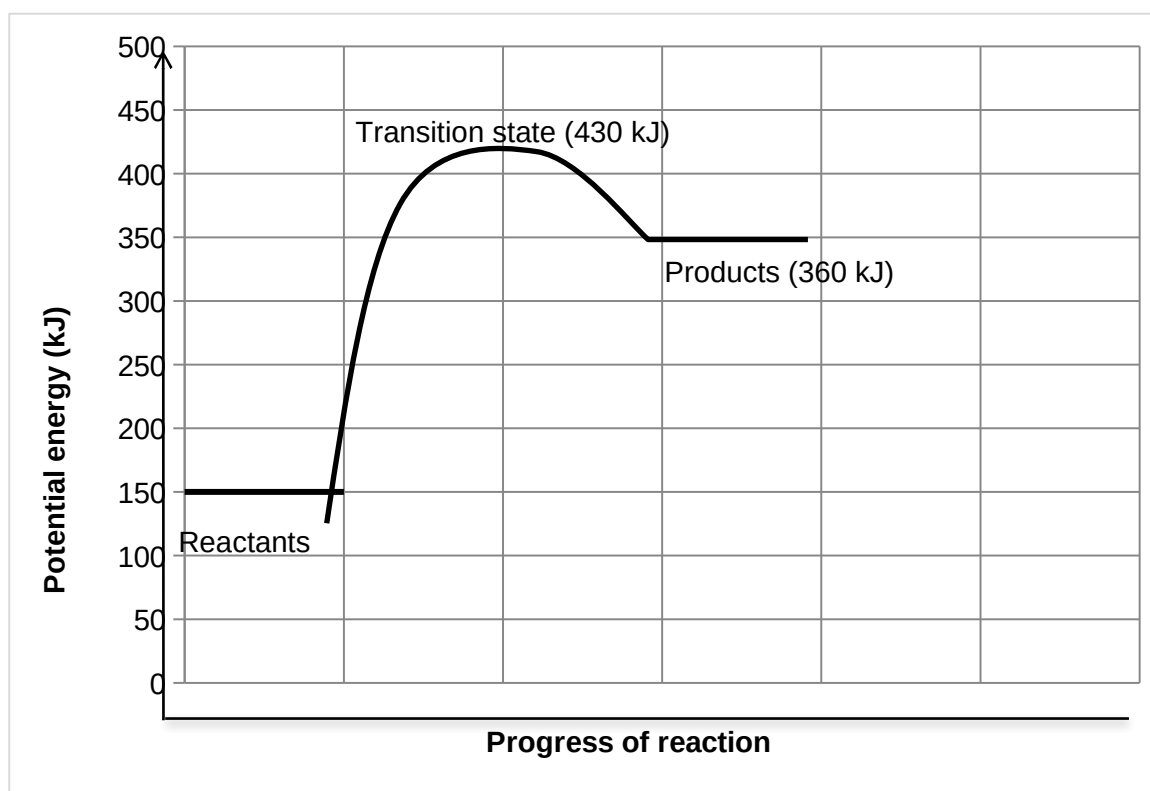
This section has **8** questions. Answer **all** questions. Write your answers in the spaces provided.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 60 minutes.

**Question 26****(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)

- transition state labelled
- transition state at 430 kJ
- products at 360 kJ

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)

- **decreased average kinetic energy of particles**
- **proportion of particles with  $E_k > E_a$  is decreased and less frequent collisions occur**
- **reaction rate therefore decreased**

- (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)

- **decrease in temp would favour exothermic i.e. reverse reaction**
- **this would increase reactant concentration/decrease product concentration**
- **this would lower the value of  $K$**

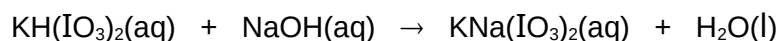
## Question 27

(7 marks)

Potassium hydrogen iodate,  $\text{KH}(\text{IO}_3)_2$ , can be used as a primary standard in acid-base titrations, providing the percentage purity of the solid is known.

An 8.435 g sample of **impure**  $\text{KH}(\text{IO}_3)_2(\text{s})$  was dissolved in distilled water, transferred to a volumetric flask and made up to 500.0 mL. Then 25.00 mL aliquots of this solution were titrated against standardised  $0.05084 \text{ mol L}^{-1} \text{ NaOH}(\text{aq})$ . An average titre of 20.70 mL was required to reach the equivalence point.

The chemical equation for the titration reaction that occurred is given below.



Calculate the percentage purity of the  $\text{KH}(\text{IO}_3)_2(\text{s})$  that was used in this experiment.

$$\begin{aligned} n(\text{NaOH}) &= cV \\ &= 0.05084 \times 0.02070 \\ &= 0.001052388 \text{ mol} \end{aligned} \quad (1)$$

$$n(\text{KH}(\text{IO}_3)_2) \text{ in 25 mL} = 0.001052388 \text{ mol} \quad (1)$$

$$\begin{aligned} n(\text{KH}(\text{IO}_3)_2) \text{ in 500 mL} &= 0.001052388 \times 500 / 25 \\ &= 0.02104776 \text{ mol} \end{aligned} \quad (1)$$

$$= n(\text{KH}(\text{IO}_3)_2 \text{ in powder sample}) \quad (1)$$

$$\begin{aligned} m(\text{KH}(\text{IO}_3)_2) &= nM \\ &= 0.02104776 \times 389.908 \end{aligned} \quad (1 \text{ for } M)$$

$$= 8.20669 \text{ g} \quad (1)$$

$$\begin{aligned} \% \text{ purity} &= 8.20669 / 8.435 \times 100 \\ &= 97.293 \% \\ &= 97.29\% \quad (4 \text{ SF}) \end{aligned} \quad (1)$$

**Question 28****(8 marks)**

Permanganic acid ( $\text{HMnO}_4$ ) can be found as an unstable red-violet solution which decomposes at temperatures above  $40^\circ\text{C}$ .

It can be made by mixing a solution containing manganese(II) ions with powdered lead dioxide,  $\text{PbO}_2$ , in the presence of sulfuric acid. This suspension is then stirred. The reaction produces permanganic acid and a precipitate of lead(II) sulfate.

- (a) Write oxidation and reduction half-equations and an overall redox equation for this reaction. You may assume the sulfuric acid is present entirely as  $\text{H}^+(\text{aq})$  and  $\text{SO}_4^{2-}(\text{aq})$ . (6 marks)

|                                |  |
|--------------------------------|--|
| Oxidation half-equation<br>(2) | $\text{Mn}^{2+} + 4 \text{H}_2\text{O} \rightarrow \text{MnO}_4^- + 8 \text{H}^+ + 5 \text{e}^- \quad (\text{x2})$ <p style="text-align: center;">OR</p> $\text{Mn}^{2+} + 4 \text{H}_2\text{O} \rightarrow \text{HMnO}_4 + 7 \text{H}^+ + 5 \text{e}^- \quad (\text{x2})$   |
| Reduction half-equation<br>(2) | $\text{PbO}_2 + 4 \text{H}^+ + \text{SO}_4^{2-} + 2 \text{e}^- \rightarrow \text{PbSO}_4 + 2 \text{H}_2\text{O} \quad (\text{x5})$   |
| Overall redox equation<br>(2)  | $2 \text{Mn}^{2+} + 4 \text{H}^+ + 5 \text{PbO}_2 + 5 \text{SO}_4^{2-} \rightarrow 2 \text{MnO}_4^- + 5 \text{PbSO}_4 + 2 \text{H}_2\text{O}$ <p style="text-align: center;">OR</p> $2 \text{Mn}^{2+} + 6 \text{H}^+ + 5 \text{PbO}_2 + 5 \text{SO}_4^{2-} \rightarrow 2 \text{HMnO}_4 + 5 \text{PbSO}_4 + 2 \text{H}_2\text{O}$ |

Permanganic acid is known to be a strong acid.

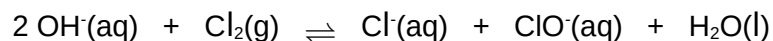
- (b) Write the  $K_a$  expression for permanganic acid and give an indication of the expected  $K_a$  value. (2 marks)

$$K_a = \frac{[\text{H}_3\text{O}^+][\text{MnO}_4^-]}{[\text{HMnO}_4]}$$

value expected to be high / greater than 1

**Question 29****(10 marks)**

Consider the following reaction that has been allowed to establish equilibrium.



The following table considers the effects of imposing different changes upon this system.

- (a) Complete the following table by predicting which direction would be favoured, as well as the resulting effect on the concentration of  $\text{ClO}^-(\text{aq})$  when compared with the original equilibrium. Consider each of the imposed changes in isolation. (8 marks)

| <b>Imposed change</b>   | <b>Favoured direction</b><br>(forward, reverse, no shift) | <b>Effect on final concentration of <math>\text{ClO}^-(\text{aq})</math></b><br>(increase, decrease, no change) |
|---|---|---|
| A small amount of $\text{NaClO}(\text{s})$ was added                                    | <b>reverse</b>  | <b>increase</b>   |
| The volume of the canister was decreased  | <b>forward</b>  | <b>increase</b>   |
| Distilled water was added   | <b>no shift</b>   | <b>decrease</b>   |
| Several drops of $2 \text{ mol L}^{-1}$ $\text{Mg}(\text{NO}_3)_2(\text{aq})$ was added | <b>reverse</b>  | <b>decrease</b>   |

A chemist decided to verify their predictions experimentally. They set up the equilibrium system described above, created the various imposed changes described in part (a) and examined the results.

- (b) Would the equilibrium system in this experiment be considered 'open' or 'closed' when the imposed changes were being made? Justify your answer. (2 marks)

**(1) open**

**(1) adding substances into system implies matter is being exchanged**



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

A water tank contained 25.0 kL of contaminated water with a pH of 10.1. A chemist decided to add some solid acetylsalicylic acid crystals to the water tank, to lower the pH. Acetylsalicylic acid is a monoprotic acid with the formula  $\text{C}_9\text{H}_8\text{O}_4$  ( $M = 180.158 \text{ g mol}^{-1}$ ).

Calculate the mass of acetylsalicylic acid crystals that should be added to the tank and dissolved in the water, to lower the pH to 7.8.

At pH 10.1;

$$[\text{H}^+] = 10^{-10.1} = 7.94328 \times 10^{-11} \text{ mol L}^{-1} \quad (1)$$

$$\begin{aligned} n(\text{H}^+) &= cV \\ &= 7.94328 \times 10^{-11} \times 25\,000 \\ &= 1.9858 \times 10^{-6} \text{ mol} \end{aligned} \quad (1)$$

At pH 7.8;

$$[\text{H}^+] = 10^{-7.8} = 1.584893 \times 10^{-8} \text{ mol L}^{-1} \quad (1)$$

$$\begin{aligned} n(\text{H}^+) &= cV \\ &= 1.584893 \times 10^{-8} \times 25\,000 \\ &= 3.9622 \times 10^{-4} \text{ mol} \end{aligned} \quad (1)$$

$$\begin{aligned} n(\text{H}^+ \text{ at pH } 10.1) - n(\text{H}^+ \text{ at pH } 7.8) &= 1.9858 \times 10^{-6} - 3.9622423 \times 10^{-4} \\ &= 3.9423 \times 10^{-4} \text{ mol} \end{aligned} \quad \begin{matrix} (1) \\ (1) \end{matrix}$$

$$\text{Therefore want to add } 3.9423 \times 10^{-4} \text{ mol of H}^+ \quad (1)$$

$$\text{Since monoprotic, need } n(\text{C}_9\text{H}_8\text{O}_4) = 3.9423 \times 10^{-4} \text{ mol of H}^+ \quad (1)$$

$$\begin{aligned} m(\text{C}_9\text{H}_8\text{O}_4) &= nM \\ &= 3.9423 \times 10^{-4} \times 180.158 \\ &= 0.0710236 \text{ g} \\ &= 7.10 \times 10^{-2} \text{ g or } 71.0 \text{ mg} \end{aligned} \quad \begin{matrix} (1) \\ (1) \end{matrix}$$

**Question 31****(11 marks)**

A chemistry class was given four (4) jars labelled A, B, C and D.

Each jar contained small pieces of a silver-coloured metal. The teacher informed the students that the metals were tin, cobalt, cadmium and nickel.

The students were asked to design an investigation that would determine the identity of the metal in each jar.

The students set up 4 test tubes, each containing 5 mL of 1.0 mol L<sup>-1</sup> lead(II) nitrate solution, Pb(NO<sub>3</sub>)<sub>2</sub>(aq). A piece of each different metal was then added to each test tube. The students' observations are recorded in the table below.

|  | Observations   |
|--|--|
| Pb(NO <sub>3</sub> ) <sub>2</sub> (aq) + metal A | A silver metal dissolves in a colourless solution.<br>A new grey solid and a green solution are produced.        |
| Pb(NO <sub>3</sub> ) <sub>2</sub> (aq) + metal B | A silver metal dissolves in a colourless solution.<br>A new grey solid is produced. Solution remains colourless. |
| Pb(NO <sub>3</sub> ) <sub>2</sub> (aq) + metal C | A silver metal dissolves in a colourless solution.<br>A new grey solid is produced. Solution remains colourless. |
| Pb(NO <sub>3</sub> ) <sub>2</sub> (aq) + metal D | A silver metal dissolves in a colourless solution.<br>A new grey solid and a pink solution are produced.         |

(a) Identify metals A and D.

(2 marks)

|   |        |
|---|--------|
| A | Nickel |
| D | Cobalt |

To distinguish between metals B and C, one student suggested adding a piece of each to separate solutions of aqueous nickel bromide,  $\text{NiBr}_2(\text{aq})$ .

- (b) Justify how this would allow metals B and C to be distinguished. Include observations for both samples and a relevant chemical equation in your answer. (5 marks)

**(1) tin metal would not react with the  $\text{NiBr}_2(\text{aq})$  where as cadmium metal would react with  $\text{NiBr}_2(\text{aq})$**

**(1) reaction with cadmium has  $\text{EMF} > 0$  / reaction is spontaneous OR reaction with tin has  $\text{EMF} < 0$  / is non-spontaneous**

**(1) observations with tin metal – solution would remain green**

**(1) observations with cadmium metal – green solution would fade as silver metal dissolves, new silver / grey metal / precipitate produced**

**(1)  $\text{Cd}(\text{s}) + \text{Ni}^{2+}(\text{aq}) \rightarrow \text{Ni}(\text{s}) + \text{Cd}^{2+}(\text{aq})$**

- (c) Using the results of this investigation, how would the students be able to identify which of the metals (A, B, C or D) was the strongest reducing agent (reductant)? (2 marks)

**(1) whichever metal of B or C that reacted with  $\text{NiBr}_2(\text{aq})$  would be the strongest reductant, ie cadmium lowest in table**

**(1) this is because it would be the metal most easily oxidised / the metal with the highest oxidation potential**

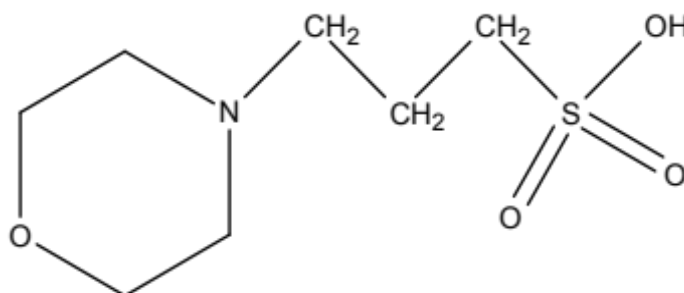
Another test tube containing  $\text{NiBr}_2(\text{aq})$  was set up and some chlorine water was added to this solution. The test tube was stoppered and gently shaken.

- (d) Write oxidation and reduction half-equations for the reaction that would occur. (2 marks)

|                         |  |
|-------------------------|--|
| Oxidation half-equation | $2 \text{Br}^- \rightarrow \text{Br}_2 + 2 \text{e}^-$ |
| Reduction half-equation | $\text{Cl}_2 + 2 \text{e}^- \rightarrow 2 \text{Cl}^-$ |

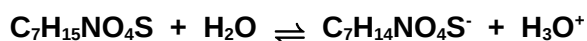
**Question 32****(6 marks)**

The name MOPS refers to the compound '3-morpholinopropane-1-sulfonic acid'. The chemical structure of MOPS is shown below.



The molecular formula of MOPS is  $C_7H_{15}NO_4S$ . MOPS is a weak, monoprotic acid.

- (a) Write a Bronsted-Lowry equation illustrating how MOPS dissolves in water. Use the molecular formula given. (2 marks)



(1) reactants and products  
(1) double arrows

MOPS is commonly used in buffer solutions. The simplest way to produce this buffer is using the sodium salt of MOPS.

- (b) Give the molecular formula of the sodium salt of MOPS. (1 mark)

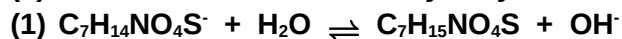
(1)  $NaC_7H_{14}NO_4S$  /  $C_7H_{14}NO_4SNa$

A solution was made by dissolving 75 g of the sodium salt of MOPS into 200 mL of distilled water.

- (c) Justify, with the use of a relevant chemical equation, whether the pH of this solution would be acidic, basic or neutral. (3 marks)


(1) Basic, weak acid salt basic in solution

(1) anion of a weak acid will hydrolyse with water to produce  $OH^-$  ions



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

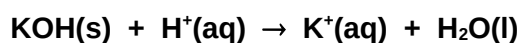
Six reactions (A-F) were carried out, as shown in the table below.

|   |  |
|---|--|
| A | $\text{Zn(s)} + \text{Ni(NO}_3)_2\text{(aq)}$  |
| 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. **rusting / corrosion / oxidation** (1 mark)

(b) In which reaction would halogen displacement occur? **B** (1 mark)

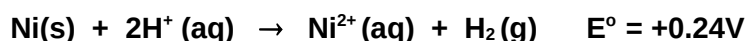
(c) Write the ionic equation for the reaction occurring in C. (1 mark)



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

- **new silver/grey metal forms as original metal dissolves**
- **green solution fades in colour**

(e) Write the equation for the reaction occurring in F, including overall  $E^\circ$ (volts). (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.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 70 minutes.

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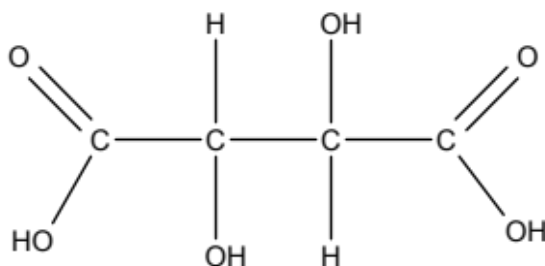
#### Question 34

(20 marks)

The pH of wine is usually between 2.9 - 3.9, depending on the type of wine and the type of grapes used to make the wine. The 'total acidity' of wine, is a measure of the total amount of all the various acids present in wine. This is also referred to as the '**total ionisable hydrogen**' present, i.e. all the hydrogen in the wine that has the ability to ionise and contribute to overall acidity.

The total acidity of wine is monitored carefully during the winemaking process. Too much acid can result in the wine being sour, whilst too little can cause the wine to taste flat and lack freshness. Total acidity is measured before the grapes are harvested, after the wine is produced, and then as the wine ages. There are many different weak acids that are found in wine, such as tartaric acid, malic acid, citric acid and succinic acid.

Generally, the most abundant acid found in wine is tartaric acid,  $C_4H_6O_6$ . Tartaric acid is a weak, diprotic acid found in grapes, as well as other fruits such as bananas, tamarinds and citrus fruits. Its chemical structure is shown below.



Grapes that are grown in a warmer climate usually contain lower concentrations of tartaric acid than those grown in cooler climates. The concentration of tartaric acid from grapes grown in warmer regions is generally in the range of  $2-3 \text{ g L}^{-1}$ , whilst for grapes grown in cooler areas the concentration is around  $6 \text{ g L}^{-1}$ .

To determine the total acidity of wine, a titration is performed. A sample of wine is titrated against a strong base, and the number of moles of  $\text{OH}^-(\text{aq})$  required to reach the equivalence point is said to be equal to the number of moles of '**total ionisable hydrogen**' present in the wine.

A 10.00 mL sample of wine was taken and made up to 100.0 mL with distilled water. Then 20.00 mL aliquots of the dilute wine were titrated against a standard solution of 0.01575 mol L<sup>-1</sup> KOH(aq). An average titre of 16.73 mL was required to reach equivalence.

- (a) Calculate the concentration of 'total ionisable hydrogen' in the 10.00 mL sample of wine. State your answer to the appropriate number of significant figures. (6 marks)

$$\begin{aligned} n(\text{KOH}) &= cV \\ &= 0.01575 \times 0.01673 \\ &= 0.000263498 \text{ mol} \end{aligned} \quad (1)$$

$$n(\text{total ionisable hydrogen in 20 mL}) = 0.000263498 \text{ mol} \quad (1)$$

$$\begin{aligned} n(\text{total ionisable hydrogen in 100 mL}) &= 0.000263498 \times (100 / 20) \\ &= 0.0013175 \text{ mol} \end{aligned} \quad (1)$$

$$= n(\text{total ionisable hydrogen in wine}) \quad (1)$$

$$\begin{aligned} c(\text{total ionisable hydrogen}) &= n / V \\ &= 0.0013175 / 0.01 \\ &= 0.131749 \text{ mol L}^{-1} \end{aligned} \quad (1)$$

$$= 0.1317 \text{ mol L}^{-1} \quad (4 \text{ SF}) \quad (1)$$

Using a digital pH meter, the pH of the wine was measured to be 3.2.

- (b) Calculate the concentration of hydronium (hydrogen) ions present in the wine. Justify why this concentration does not match the concentration of 'total ionisable hydrogen' calculated in part (a). (3 marks)

$$\begin{aligned} [\text{H}^+] &= 10^{-3.2} \\ &= 0.0006309 \text{ mol L}^{-1} \end{aligned} \quad (1)$$

The acids in wine are weak and therefore only partially ionised (1)

In a titration, all ionisable hydrogen reacts and is neutralised – the 'total ionisable hydrogen' is always therefore much greater than the concentration of hydrogen ions present in wine (1)

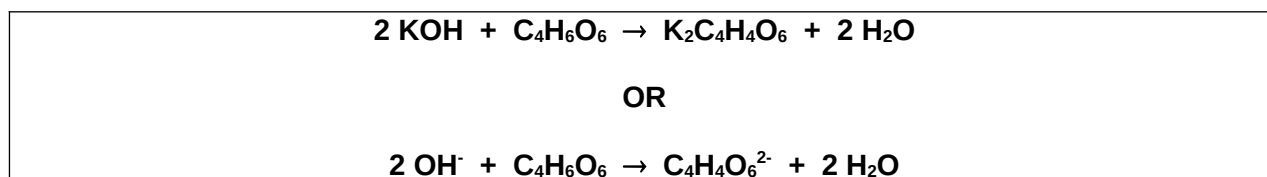
Since tartaric acid is **diprotic**, there are two possible salts that can be produced in a neutralisation reaction with potassium hydroxide solution; potassium bitartrate ( $\text{KC}_4\text{H}_5\text{O}_6$ ) and potassium tartrate ( $\text{K}_2\text{C}_4\text{H}_4\text{O}_6$ ). One of these salts is acidic and one is basic.

- (c) Complete the table below, by classifying each salt as acidic or basic. Give a relevant hydrolysis equation to support each of your choices. (4 marks)

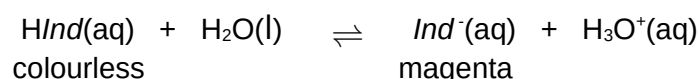
| Salt                                       | Acidic / Basic    | Equation  |
|--|-------------------|---|
| $\text{KC}_4\text{H}_5\text{O}_6$          | <b>acidic (1)</b> | $\text{C}_4\text{H}_5\text{O}_6^- + \text{H}_2\text{O} \rightleftharpoons \text{C}_4\text{H}_4\text{O}_6^{2-} + \text{H}_3\text{O}^+ \quad (1)$ |
| $\text{K}_2\text{C}_4\text{H}_4\text{O}_6$ | <b>basic</b>      | $\text{C}_4\text{H}_4\text{O}_6^{2-} + \text{H}_2\text{O} \rightleftharpoons \text{C}_4\text{H}_5\text{O}_6^- + \text{OH}^- \quad (1)$          |

The pH at the equivalence point of this titration is known to be approximately 8.2.

- (d) Use this information to write a balanced equation for the reaction that takes place between potassium hydroxide and tartaric acid in this titration. (2 marks)



The acid-base indicator phenolphthalein is used in this titration. The general equation below can be used to represent phenolphthalein indicator.



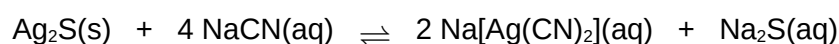
- (e) State the colour change that would be observed in the conical flask during this titration. Justify how this colour change occurs, using the equation above and Le Chatelier's principle. (5 marks)

- (1) **colourless to magenta**  
 (1) **initially only acidic wine is present, therefore an excess of  $\text{H}_3\text{O}^+(\text{aq})$**   
 (1) **thus the reverse reaction is favoured and indicator appears colourless**  
 (1) **as  $\text{KOH(aq)}$  is added this neutralises the  $\text{H}_3\text{O}^+(\text{aq})$**   
 (1) **the forward reaction is thus favoured resulting in the magenta colour**

### Question 35

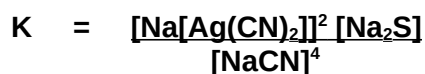
(14 marks)

Silver metal can be extracted from the ore 'argentite' which contains the compound  $\text{Ag}_2\text{S(s)}$ . In the first step of this extraction process, the ore containing  $\text{Ag}_2\text{S(s)}$  is crushed, and then a solution of sodium cyanide,  $\text{NaCN(aq)}$ , is added to leach the silver out of the ore. This forms the complex ion sodium argentocyanide,  $\text{Na[Ag(CN)}_2\text{](aq)}$ , as shown in the equation below.





- (a) Write the equilibrium constant expression for this reaction. (2 marks)



(2) if completely correct  
(1) may be allocated for minor error, such as missing 'K='  
or one index or subscript incorrect

If 12.5 kL of 5.0 g L<sup>-1</sup> NaCN(aq) was added to the leaching tank and poured over the crushed ore;

- (b) Calculate the maximum mass of Ag<sub>2</sub>S(s) that could react. (4 marks)

$$\begin{aligned} m(\text{NaCN}) &= cV \\ &= 5 \times 12500 \\ &= 62500 \text{ g} \end{aligned} \quad (1)$$

$$\begin{aligned} n(\text{NaCN}) &= m / M \\ &= 62500 / 49.01 \\ &= 1275.25 \text{ mol} \end{aligned} \quad (1)$$

$$\begin{aligned} n(\text{Ag}_2\text{S}) &= \frac{1}{4} \times n(\text{NaCN}) \\ &= \frac{1}{4} \times 1275.25 \\ &= 318.812 \text{ mol} \end{aligned} \quad (1)$$

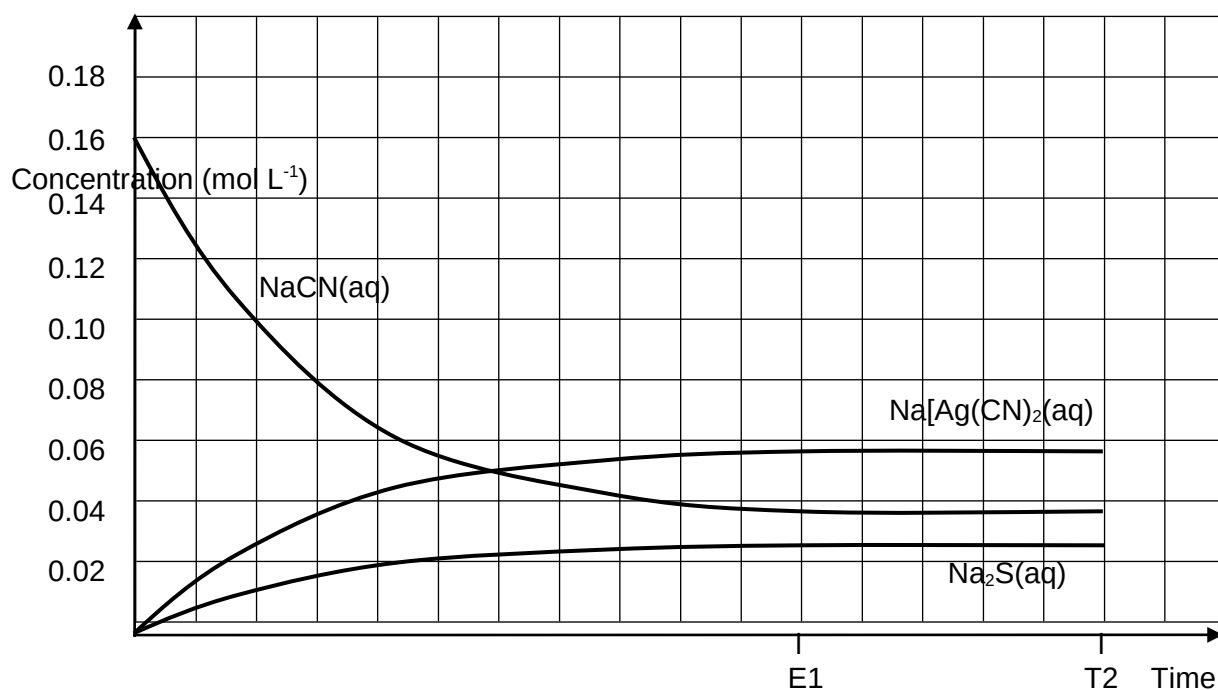
$$\begin{aligned} m(\text{Ag}_2\text{S}) &= nM \\ &= 318.812 \times 247.87 \\ &= 79024.05 \text{ g} \\ &= 79 \text{ kg} \end{aligned} \quad (1)$$

- (c) Explain, in terms of the collision theory, why the ore is crushed before mixing with the NaCN(aq) solution. (3 marks)

(1) **Crushing the ore increases surface area / state of subdivision of Ag<sub>2</sub>S(s)**  
(1) **This will increase the frequency of collision between reactants**  
(1) **Therefore a faster reaction rate occurs**

A particular leach tank contained an excess mass of crushed argentite ore containing Ag<sub>2</sub>S(s). A 0.16 mol L<sup>-1</sup> solution of NaCN(aq) was poured over the ore, and the reactants were mixed. At Time E1, equilibrium was established. The concentration of the NaCN(aq) was measured again and found to be 0.04 mol L<sup>-1</sup>.

- (d) On the axes below, sketch curves showing the concentration of all relevant species, from Time 0 until the establishment of equilibrium at Time E1. Continue your curves from Time E1 to Time T2. Label each curve. (5 marks)



- (1) NaCN line correctly drawn
- (1) Na[Ag(CN)<sub>2</sub>] line correctly drawn
- (1) Na<sub>2</sub>S line correctly drawn
- (1) Labels on each line
- (1) Horizontal lines E1 to T2

**Question 36****(18 marks)**

'Aqua regia' is a mixture of nitric acid and hydrochloric acid and is typically made by combining  $\text{HNO}_3(\text{aq})$  and  $\text{HCl}(\text{aq})$  in the optimal molar ratio of 1:3 respectively.

As soon as nitric and hydrochloric acids are mixed, the aqua regia solution produced has a yellow-orange fuming appearance. It is very reactive and quickly begins to decompose, therefore the solution needs to be prepared just before use.

A fresh batch of aqua regia was being prepared by a chemist. If the beaker already contained 165 mL of  $0.152 \text{ mol L}^{-1} \text{HNO}_3(\text{aq})$ ;

- (a) Calculate the volume of  $0.218 \text{ mol L}^{-1} \text{HCl}(\text{aq})$  that should be added to this to produce the optimum composition aqua regia. (3 marks)

$$\begin{aligned} n(\text{HNO}_3) &= cV \\ &= 0.152 \times 0.165 \\ &= 0.02508 \text{ mol} \\ \\ n(\text{HCl required}) &= 3 \times n(\text{HNO}_3) \\ &= 0.07524 \text{ mol} \\ \\ V(\text{HCl}) &= n/c \\ &= 0.07524 / 0.218 \\ &= 0.3451 \text{ L} \\ &= 0.345 \text{ L or } 345 \text{ mL} \quad (3\text{SF}) \end{aligned}$$

- (b) Calculate the pH of the aqua regia solution upon initial mixing of the two acids. (3 marks)

$$\begin{aligned} n(\text{H}^+ \text{ total}) &= n(\text{HCl}) + n(\text{HNO}_3) \\ &= 0.07524 + 0.02508 \\ &= 0.10032 \text{ mol} \\ \\ C(\text{H}^+ \text{ total}) &= n/V \\ &= 0.10032 / 0.510 \\ &= 0.1967 \text{ mol L}^{-1} \\ \\ \text{pH} &= -\log[\text{H}^+] \\ &= -\log 0.1967 \\ &= 0.706196 \\ &= 0.706 \quad (3\text{SF}) \end{aligned}$$

After the chemist had finished his laboratory work, 125 mL of the aqua regia remained. Due to its extremely reactive nature, aqua regia needs to be neutralised before disposal. If 42.0 mL of 0.545 mol L<sup>-1</sup> potassium hydroxide (KOH) solution was added to this beaker of aqua regia;

- (c) Would this be sufficient to neutralise the aqua regia solution? Support your answer with calculations, including the final pH of the mixture. (You may assume no decomposition of aqua regia has occurred before the KOH is added.) (6 marks)

$$\begin{aligned} n(\text{H}^+) &= cV \\ &= 0.1967 \times 0.125 \\ &= 0.024588 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{OH}^-) &= n(\text{KOH}) = cV \\ &= 0.545 \times 0.042 \\ &= 0.02289 \text{ mol} \end{aligned}$$

since  $n(\text{H}^+ \text{ total})$  is greater than  $n(\text{OH}^-)$  total,  $\text{H}^+$  is in excess

$$\begin{aligned} n(\text{xs } \text{H}^+) &= 0.024588 - 0.02289 \\ &= 0.001698 \text{ mol} \end{aligned}$$

$$\begin{aligned} c(\text{xs } \text{H}^+) &= n/V \\ &= 0.001698 / 0.167 \\ &= 0.0101677 \text{ mol L}^{-1} \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log[\text{H}^+] \\ &= -\log 0.0101677 \\ &= 1.99278 \\ &= 1.99 \quad (3\text{SF}) \end{aligned}$$

Therefore the KOH is not sufficient to neutralise the aqua regia

In Latin, aqua regia means “royal water” and it was given this name because of its ability to dissolve the noble metals such as gold and platinum. During World War II, a Hungarian chemist used aqua regia to dissolve the gold Nobel prizes of two physicists, in order to hide the gold and prevent the medals being confiscated by German soldiers.

The mechanism by which aqua regia dissolves gold is a two-step process involving both acids present in the mixture. During this reaction, the metallic gold is converted to the (+3) oxidation state as the complex ion,  $[\text{AuCl}_4]^-$ .

The overall equation for the reaction of aqua regia with gold is given below.



- (d) Use oxidation numbers to demonstrate which acid component of aqua regia is the oxidising agent (oxidant). (2 marks)
- **HNO<sub>3</sub> is the oxidising agent**
  - **The oxidation number of N changes from +5 to +4**  
**(no oxidation number changes occur to the atoms in HCl)**

After World War II, the Hungarian chemist returned to his laboratory to find the jars of aqua regia untouched. He then precipitated the gold out of the solution and returned it to the Nobel Foundation. The medals were recast and presented again to the two physicists.

The gold was extracted from the aqua regia mixture by bubbling sulfur dioxide (SO<sub>2</sub>) gas through the solution. This produced sulfate ions (SO<sub>4</sub><sup>2-</sup>), whilst separating the [AuCl<sub>4</sub>]<sup>-</sup> complex ion into solid gold and aqueous chloride ions.

- (e) Write oxidation and reduction half-equations for this process, and the full equation, no states required. (4 marks)

|                         |   |
|-------------------------|---|
| Oxidation half-equation | $\text{SO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l}) \rightarrow \text{SO}_4^{2-}(\text{aq}) + 4 \text{H}^+(\text{aq}) + 2 \text{e}^-$ |
| Reduction half-equation | $[\text{AuCl}_4]^{-}(\text{aq}) + 3 \text{e}^- \rightarrow \text{Au}(\text{s}) + 4 \text{Cl}^{-}(\text{aq})$                              |

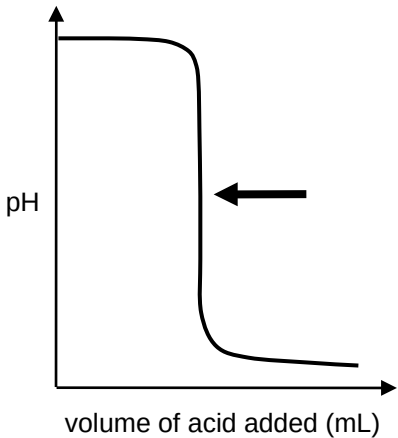
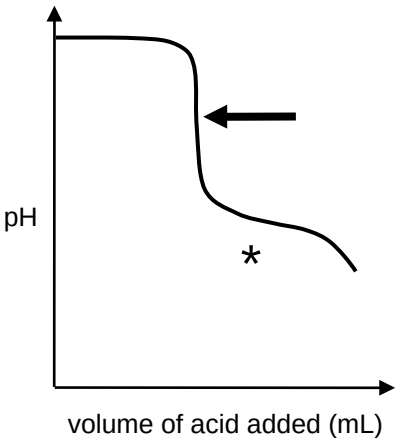
### Question 37

(10 marks)

A group of chemistry students were comparing and contrasting two different acid-base titrations. They set up 'Titration A' and 'Titration B' as follows;

- (a) In the table above, label the equivalence point on **both** titration curves. (2 marks)

|                            | Titration A                                   | Titration B                                   |
|----------------------------|---|---|
| Substance in conical flask | 20.00 mL of 0.10 mol L <sup>-1</sup> NaOH(aq) | 20.00 mL of 0.10 mol L <sup>-1</sup> NaOH(aq) |

| Substance in burette      | 0.10 mol L <sup>-1</sup> HCl(aq)   | 0.10 mol L <sup>-1</sup> CH <sub>3</sub> COOH(aq)   |
|---------------------------|--|---|
| Sketch of titration curve |  <p>pH</p> <p>volume of acid added (mL)</p> |  <p>pH</p> <p>volume of acid added (mL)</p> |

**(1) For each graph, see arrows (should be located midpoint of vertical drop)**

- (b) State the pH at the equivalence point in Titration A. Justify your answer. (3 marks)

**(1) 7**

**(1) The salt produced (NaCl) is neutral and does not hydrolyse**

**(1) Therefore the concentration of H<sub>3</sub>O<sup>+</sup>(aq) is equal to the concentration of OH<sup>-</sup>(aq)**

- (c) In Titration A, state the volume of HCl(aq) that would have been added from the burette to reach the equivalence point. (Note that a calculation is not required.) (1 mark)

**(1) 20 mL**

- (d) Would the volume of CH<sub>3</sub>COOH(aq) required to reach the equivalence point in Titration B be higher, lower or equal to the volume of HCl(aq) required in Titration A? Circle your choice below, and briefly justify your answer. (2 marks)

higher

lower

equal

**(1)**

**(1) Equal volumes and concentrations used and both acids are monoprotic (therefore will require the same moles of base to neutralise)**

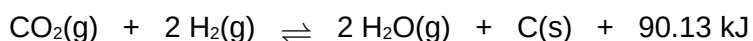
- (e) For titration B suggest a suitable indicator that could be used, and the colour change at the end point as per the titration graph. (2 marks)

**Strong base/weak acid- phenolphthalein**  
**Purple to colourless**

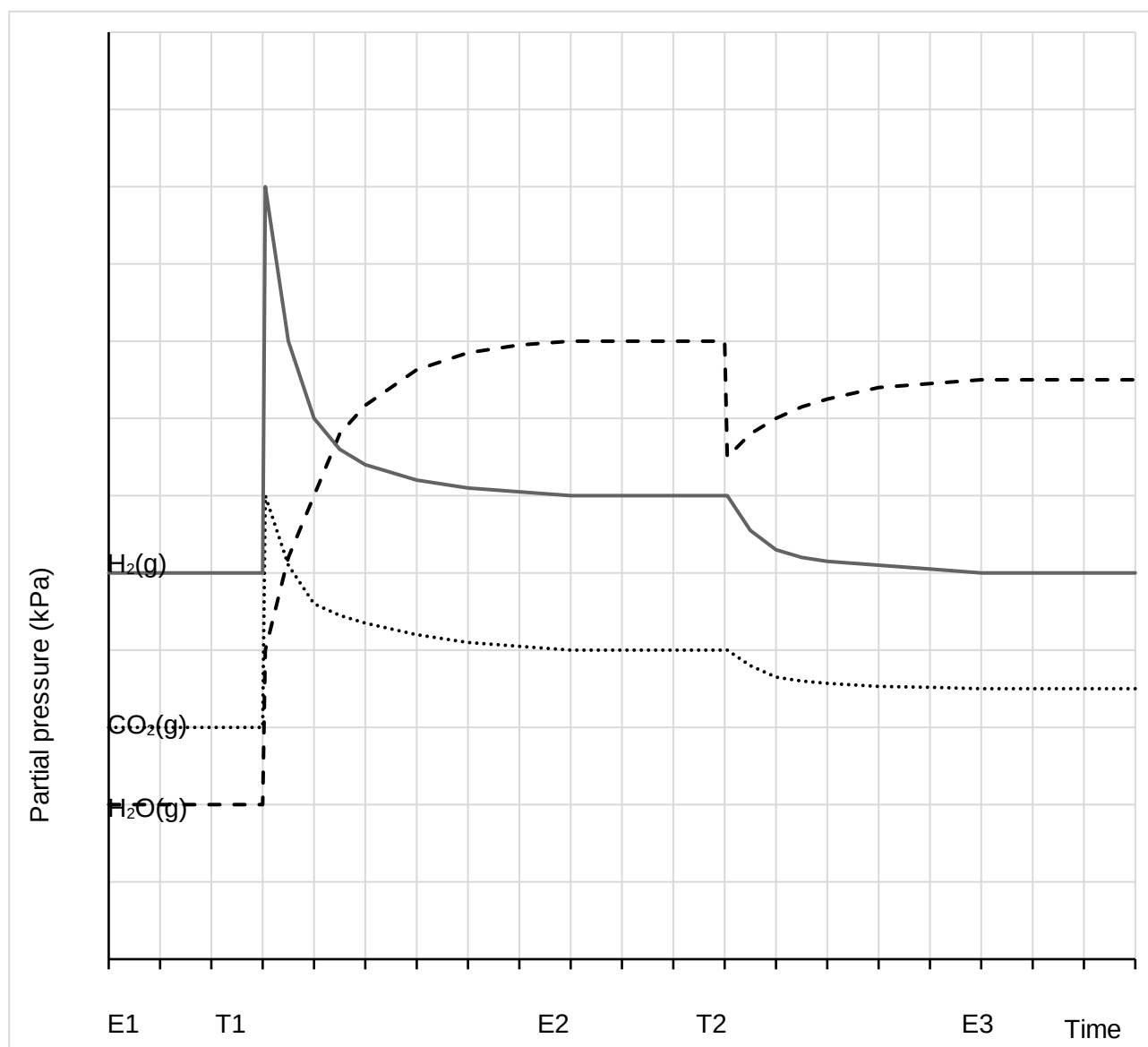
### Question 38

(18 marks)

The Bosch reaction has applications in space travel and is utilised aboard space shuttles, since it is able to remove carbon dioxide from the air and generate clean water in the process. The reaction requires a metallic catalyst such as iron, cobalt or nickel. The equation for the Bosch reaction is given below.



Consider a reaction chamber, where the Bosch reaction has been allowed to establish equilibrium. The graph below shows the effect of imposing different changes on the system.



- (a) State the change imposed on the system at Time T1. (1 mark)

**(1) Volume decreased / halved Pressure doubled**

- (b) Explain, in terms of the collision theory, the effect of the imposed change at Time T1 on the position of equilibrium. (4 marks)

**(1) Both forward and reverse reaction rates are increased**

**(1) Same amount of gas particles are in a smaller space, therefore frequency of collision is increased**

**(1) Since the ratio of gas particles is 3:2, the forward reaction rate is increased more than the reverse reaction rate**

**(1) This results in a shift to the right / the products being favoured**

- (c) State the change imposed on the system at Time T2, as well as the effect this change has on the position of equilibrium. (2 marks)

**(1) Water vapour removed**

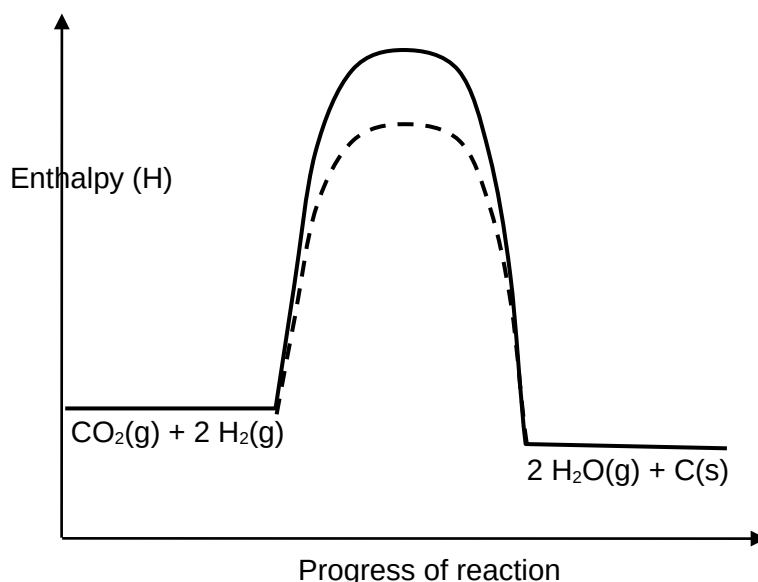
**(1) Equilibrium will shift right / favour forward reaction**

- (d) Complete the table below, regarding the changes that would be observed in reaction rate in response to the change imposed at Time T2. In each box of the table, write either 'increased', 'decreased' or 'no change'. Your answers should be stated in comparison to the previous equilibrium that had been established at Time E2. (4 marks)

|                  | <b>Immediate change in rate</b><br>(increase / decrease / no change) | <b>Final / overall change in rate</b><br>(increase / decrease / no change) |
|------------------|--|--|
| Forward reaction |  |  |
| Reverse reaction |  |  |

The energy profile diagram for the Bosch reaction is shown below. The reaction has a very high activation energy and must be carried out at a temperature greater than 450 °C. It is only mildly exothermic.





- (e) Comment on the likely reversibility of this reaction. (2 marks)

- (1) Not likely to be reversible / reverse reaction is less likely to occur than forward reaction  
 (1) Activation energy is high in the forward direction and high temperatures are required, therefore reverse reaction is unlikely to occur as reverse activation energy is even higher

(Marks may be awarded if students argue that the reverse reaction would potentially also occur, under conditions of high temperature, since the activation energy for the reverse is only slightly higher than forward)

- (f) Add to the energy profile diagram above, by indicating the effect of including metallic iron in the reaction system. (1 mark)

- (1) See dashed line on energy profile diagram above

- (g) Explain, in terms of the collision theory, the role of the iron in this reaction. (4 marks)

- (1) Provides an alternate reaction pathway  
 (1) With a lower activation energy  
 (1) Therefore a greater proportion of particles can react / have collision energy greater than activation energy  
 (1) Reaction rate is increased

(1m may be awarded for discussion of how orientation of collision can be improved by adsorption/desorption of reactants onto catalyst etc)

End of questions

Spare answer page

Question number: \_\_\_\_\_

Spare answer page

Question number: \_\_\_\_\_