Student Number……………………………..

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# Chemistry

## 2022 Term 4

## Working Scientifically

General Instructions

- Reading time – 5 minutes
- Working time – 70 minutes
- Write using black pen
- Draw diagrams using pencil
- NESA approved calculators may be used
- A Formulae sheet, data sheet and Periodic Table are provided
- Answer questions in the spaces provided. These spaces provide guidance for the expected length of your response
- Show all relevant working in questions involving calculations
- Extra working space is provided at the back of the exam booklet. If you use this space, clearly indicate which question you are answering.

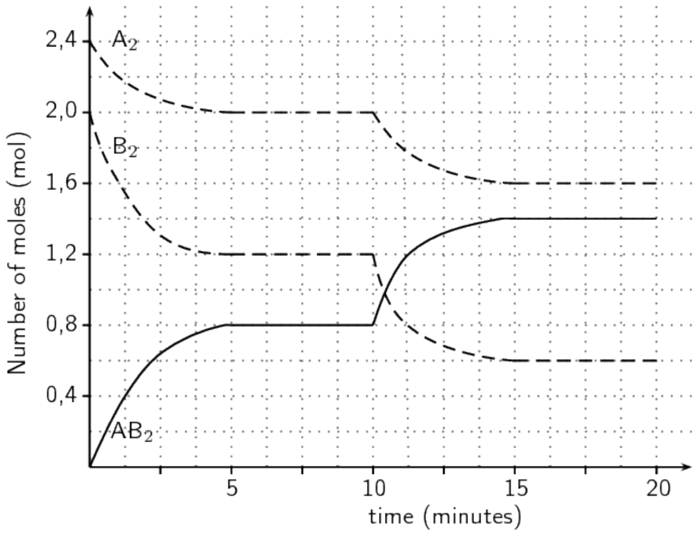
**Attempt Questions 1 – 9**

**Total Marks – 40**

**Question 1** (3 marks)

A reaction was carried out between gases $A_2$ and $B_2$ to form gas $AB_2$ in a 5 L vessel. **3**

The reaction first achieved equilibrium, 5 minutes after the start.




Calculate the equilibrium constant for the reaction at 5 minutes.

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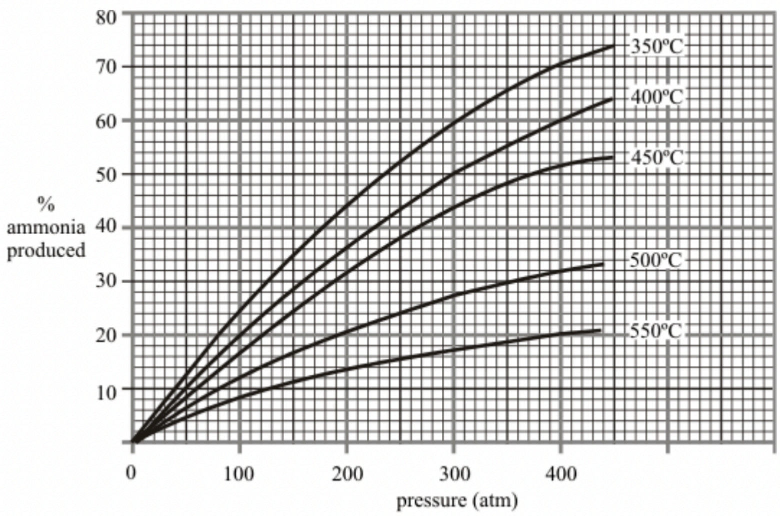
**Question 2** (5 marks)

The Haber process is used industrially to produce ammonia from nitrogen and hydrogen. **5**

The reaction is an equilibrium and temperature and pressure affect the production of ammonia in the process.

The graph below indicates the % yield of ammonia for different temperatures and pressures.




(a) Use the graph to determine the temperature and pressure conditions that will give the greatest % yield of ammonia. **1**

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(b) Adjustments are made to the optimum conditions in the industrial production of ammonia.

Justify the industrial conditions of 250 atm and 450ºC used for the Haber process. **4**

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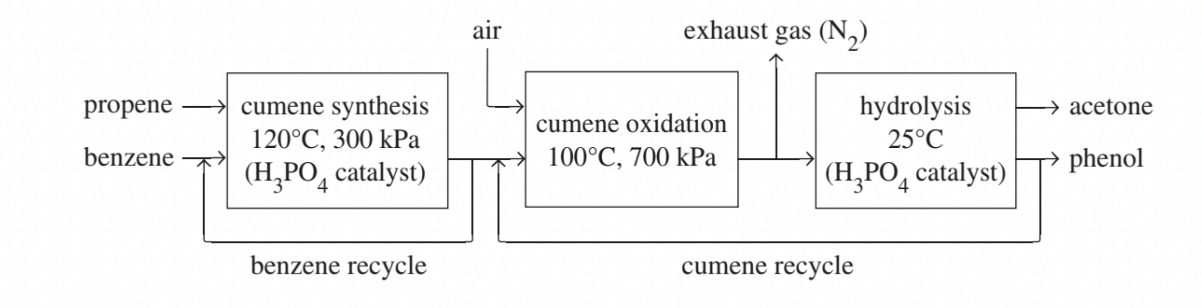
**Question 3** (6 marks)

Phenol is a compound used in the manufacture of a wide range of industrial chemicals. **6**

A reaction process pictured in the flow chart results in 98% conversion of benzene to phenol.




Using the information provided, outline THREE factors that may have been considered in the design of this reaction process.

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**Question 4** (4 marks)

The following series of diagrams displays a range of different equilibrium systems.

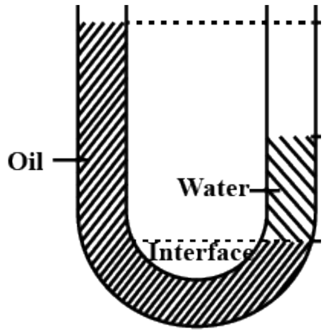


Diagram A

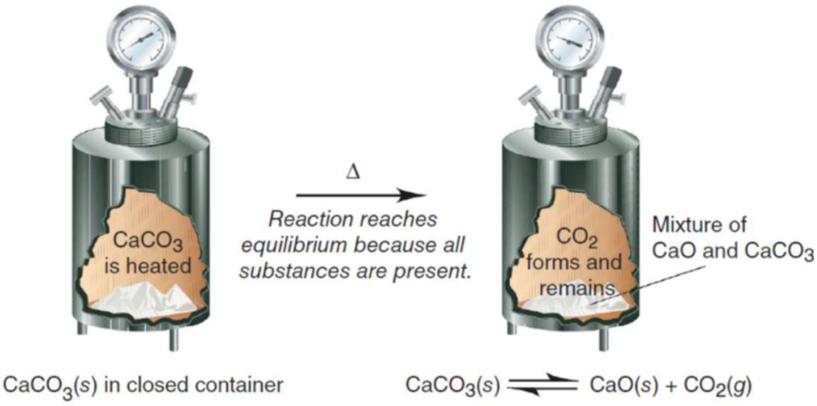


Diagram B

Identify the type of equilibrium systems illustrated in each of the diagrams, A and B and describe TWO features of each system. **4**

Diagram A:

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Diagram B:

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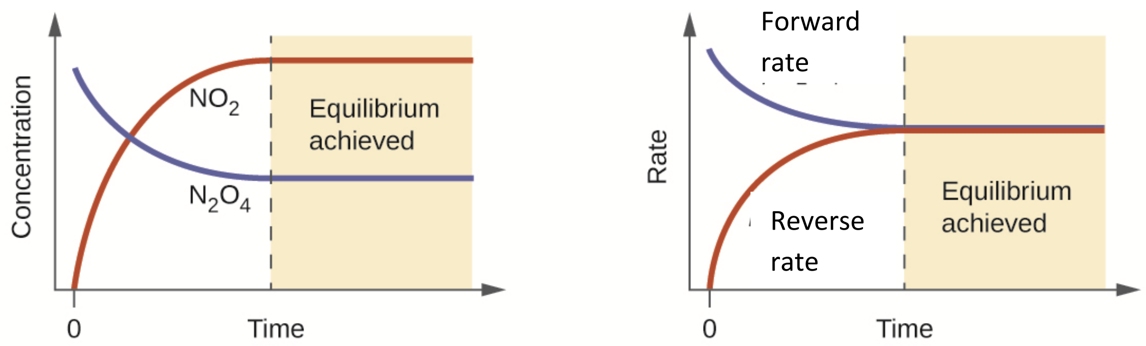
**Question 5** (6 marks)

The graphs below show the changes in concentration and rate of reaction for the reaction.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g) \quad \Delta H = 58 \text{ kJ mol}^{-1}$$

colourless  brown




(a) Account for the changes in the shapes of the graphs in terms of collision theory. **4**

(b) Use Le Chatelier's principle to explain the change in the macroscopic properties when the temperature of the system is cooled. **2**

**Question 6** (2 marks)

A system is at equilibrium when $\Delta G$ is zero.

Calculate the temperature at which a system is at equilibrium if the $\Delta H$ value is $-112.5$ kJ $mol^{-1}$ and the $\Delta S$ value is $-165$ J $K^{-1}$. **2**

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**Question 7** (4 marks)

A solution was prepared by mixing 18 mL of 0.0833 mol $L^{-1}$ sodium hydroxide solution with 32 mL of 0.0117 mol $L^{-1}$ calcium nitrate solution in a small beaker. **4**

Predict and explain the observation for the reaction taking place in the beaker. Support your response with the relevant chemical equation and calculations.

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**Question 8** (5 marks)

Lead iodide is considered sparingly soluble in water. **5**

Compare the molar solubility of lead iodide in pure water and a 0.25 mol $L^{-1}$ solution of lead nitrate.

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**Question 9** (5 marks)

A precipitation experiment was carried out where solutions of silver nitrate and potassium phosphate were combined in a small beaker to make a 20 mL solution with a considerable amount of silver phosphate precipitate. **5**

This system was at equilibrium at time $T_0$, where the concentration of silver ions was found to be $1.2 \times 10^{-4}$ mol $L^{-1}$ and phosphate at $0.4 \times 10^{-4}$ mol $L^{-1}$.

At time $T_1$, a disturbance was imposed on this equilibrium system where 5 mL of water was added to the beaker, after which the system re-established equilibrium at time $T_2$.

Perform the relevant calculations and graph the changes in concentration for both the silver and phosphate ions on the grid provided.

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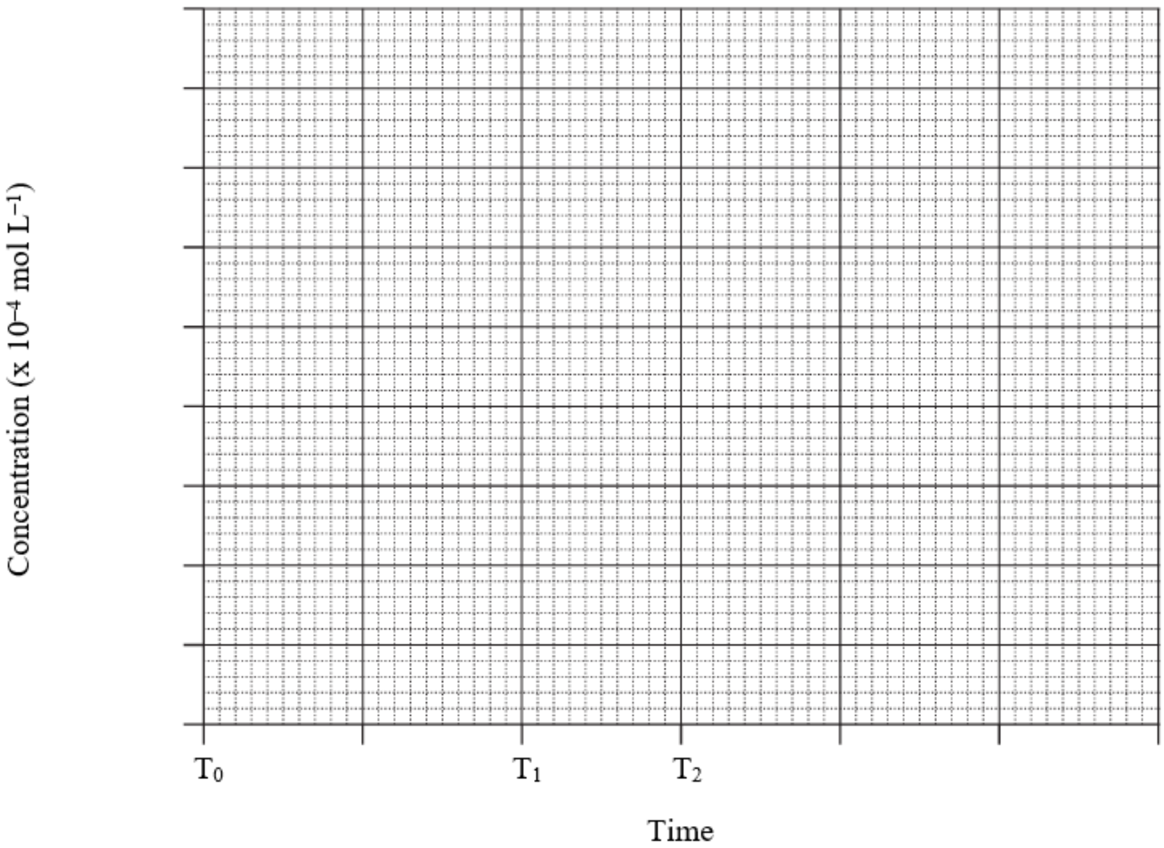

**Extra writing space**
If you use this space, clearly indicate which question you are answering.

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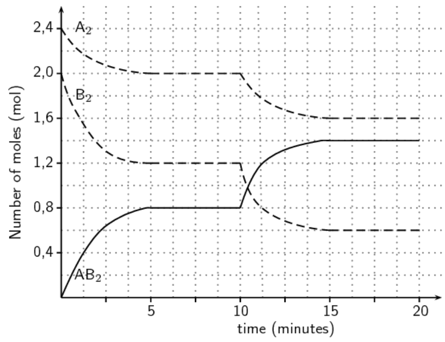
2022 JRAHS Chemistry Working Scientifically Term 4 answers

**Question 1** (3 marks)
A reaction was carried out between gases $A_2$ and $B_2$ to form gas $AB_2$ in a 5L vessel.
The reaction first achieved equilibrium, 5 minutes after the start.



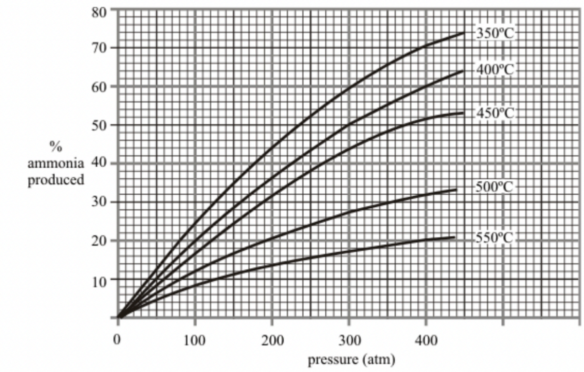

Calculate the equilibrium constant for the reaction at 5 minutes.
**Sample answer:**

$$A_2 + 2B_2 \rightleftharpoons 2AB_2$$

$[A_2]$ = n/V = 2/5 = 0.4 mol $L^{-1}$
$[B_2]$ = n/V = 1.2/5 = 0.24 mol $L^{-1}$
$[AB_2]$ = n/V = 0.8/5 = 0.16 mol $L^{-1}$
K = $[AB_2]^2/[A_2][B_2]^2 = (0.16)^2/0.4 \times 0.24^2 = 1.11$

| *Marking Criteria* | *Mark(s)* |
|---|---|
| • Correctly calculates the equilibrium constant showing all relevant calculations and the K expression. | 3 |
| • Carries out some correct calculations | 2 |
| • Some relevant working shown | 1 |

**Question 2** (5 marks)
The Haber process is used industrially to produce ammonia from nitrogen and hydrogen in an exothermic reaction.
The reaction is an equilibrium and temperature and pressure affect the production of ammonia in the process.
The graph below indicates the % yield of ammonia for different temperatures and pressures.



(a) Use the graph to determine the temperature and pressure conditions that will give the greatest % yield of ammonia.**1**

**Sample Answer:**

*450 atm and 350°C*

(b) Justify the industrial conditions of 250 atm and 450°C used for the Haber process.**4**

**Sample Answer:**

*The conditions in (a) will give a yield of 74%. The conditions used in the Haber process will yield 38%. Even though this is much lower, the industrial conditions will allow for a sufficient yield at a good rate.*

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

*The 250 (high) atm of pressure will drive the equilibrium to the right towards the side with fewer gas moles (4:2) (Le Chatelier), increasing the yield of ammonia without the expensive of higher pressure systems required for 450 atm.*

*Even though the reaction is exothermic and low temperatures would favour the production of ammonia, this reaction is too slow, so a higher temperature of 450°C is used to* ***increase the rate of reaction and reach equilibrium faster.***

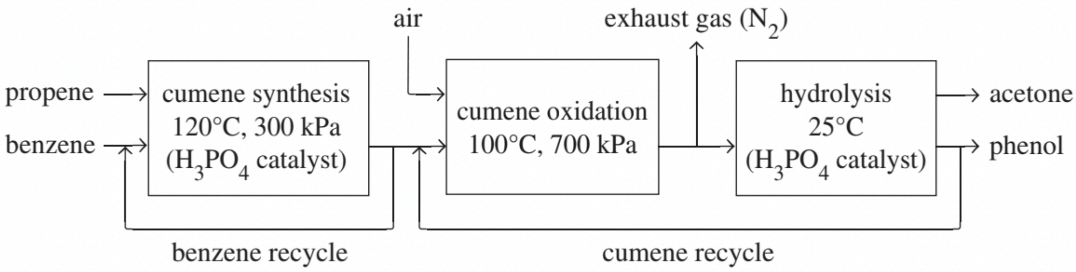
| *Marking Criteria* | *Mark(s)* |
|---|---|
| • Justifies the conditions of temperature and pressure<br>• Includes an equilibrium equation for the reaction (PTE) | 4 |
| • Justifies the conditions of temperature and pressure<br>• Justifies one condition and gives an equilibrium equation for the reaction<br>PT or PE or TE or ptE | 3 |
| • Justifies one condition OR<br>• Outlines the benefit of two conditions<br>T or P or pT or Pt or pE or tE | 2 |
| • Gives some relevant information R or p or t | 1 |

E = correct equation
P = correct pressure justification    p = relevant pressure information
T = correct temperature justification    t = relevant temperature information

**Question 3** (6 marks)

Phenol is a compound used in the manufacture of a wide range of industrial chemicals.**6**

A reaction process pictured in the flow chart results in 98% conversion of benzene to phenol.



Using the information provided, outline THREE factors that may have been considered in the design of this reaction process.

**Sample answers:**

*The process includes two recycle loops, benzene and cumene, to ensure no loss of reactants.*
*$H_3PO_4$ catalysts are used in two steps of the process to speed up the reactions.*
*Temperatures are quite low ($120^o$ and $25^o$). Reaction rates are faster with the catalysts, so the temperatures needn't be too high to assist with increasing the rate.*
*The exhaust gas is nitrogen which is a harmless gas in the atmosphere.*
*Acetone is also produced which is a useful by- product so waste is minimised.*
*High pressure of 700kPa in the oxidation chamber to increase reaction rate.*
*Air is readily available for the oxidation process.*

| *Marking Criteria* | *Mark(s)* |
|---|---|
| • Outlines three design considerations (e.g. temperature, catalyst, recycling reactants, useful products, harmless exhaust gas) using the information in the flowchart. (F= specific data in the flowchart) (√√√) | 6 |
| • Outlines two design considerations (e.g. temperature, catalyst, recycling reactants, useful products, harmless exhaust gas) using the information in the flowchart and identifies a third. (I) | 5 |
| • Outlines at least two design considerations. | 4 |
| • Identifies three design considerations OR<br>• Outlines one design consideration | 3 |
| • Identifies two design considerations | 2 |
| • Provides some relevant information. | 1 |

| 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|
| | √ I | √ √ | √ √ I F | √ √ √F |
| I I | √ F | √ √ F | | |
| F I | I I I | √ √ I | | |
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**Question 4** (4 marks)
The following series of diagrams displays a range of different equilibrium systems.

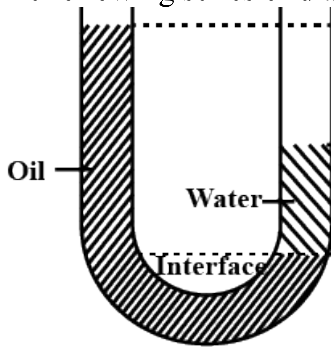


Diagram A

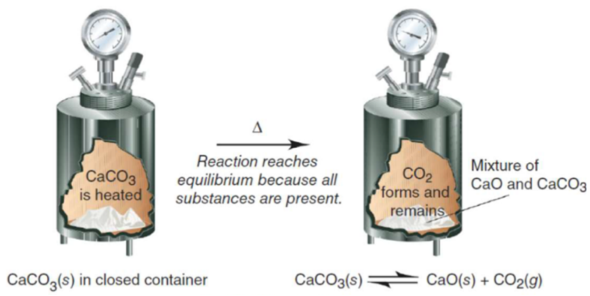


Diagram B

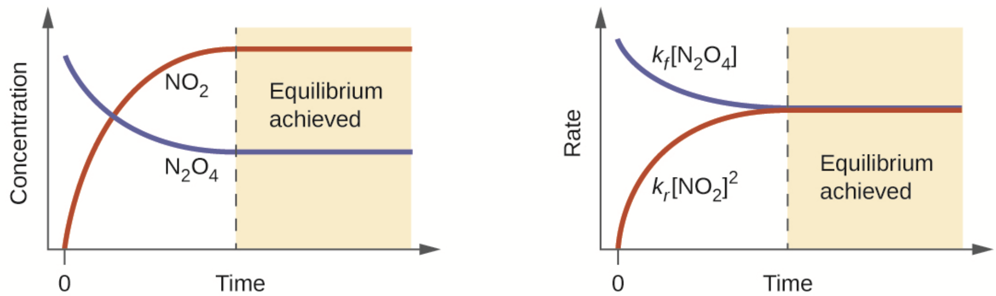
Identify the type of equilibrium systems illustrated in each of the diagrams A, and B **4**
and describe TWO features of each system.

**Sample Answer:**
A = Static equilibrium, features = no change in level of oil and water, no interaction between oil and water molecules. Both water and oil at rest. Reaction rate = 0
B = Dynamic equilibrium, features = closed system with a reversible reaction where reactants combine to form products and products combine to form reactants. Reaction is equal for both forward and reverse reaction.

| *Marking Criteria* | *Mark(s)* |
|---|---|
| • Correctly identifies two systems and describes two features of two systems | 4 |
| • describes 3 features | 3 |
| • Correctly identifies two systems OR two features | 2 |
| • Provides some correct relevant information. | 1 |

**Question 5** (6 marks)
The graphs below show the changes in concentration and rate of reaction for the reaction.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g) \quad \Delta H = 58 \text{ kJ mol}^{-1}$$
colourless brown




(a) Account for the changes in the shapes of the graphs in terms of collision theory.**4**
**Sample Answer:**
Initially there is a high concentration of $N_2O_4$ reactant and low concentration of $NO_2$ product. As the reaction starts there are a large number of reactant molecules that have reached exceeded the activation energy and high number of successful collisions result in a sharp decrease in the amount of reactant and correlating large increase in the number of product molecules hence corresponding sharp increase and decrease in rate of the reaction. The rate of the reaction slows as there are an equal number of successful collisions for both the forward and reverse reactions until the reaction reaches dynamic equilibrium where the rate of successful collisions for both forward and reverse reactions are the same shown by the straight line in the rate graph. This dynamic equilibrium is shown in the corresponding concentration graphs where the concentration of reactants and products remain constant(straight line sections of the graphs) as the forward and reverse reaction occur at the same rate.

| *Marking Criteria* | *Mark(s)* |
|---|---|
| • Accounts for the shapes of both graphs in terms of collision theory<br>• Includes references to both graphs | 4 |
| • Accounts for the shapes of one graph thoroughly and refers to the other graph<br>• Includes references to one graph | 3 |
| • Accounts for the shape of one graph thoroughly | 2 |
| • Gives some relevant information for either graph | 1 |

(b) Use Le Chatelier's principle to explain the change in the macroscopic property of the equilibrium system when the temperature of the system is cooled.

**Sample Answer:**

This is an endothermic reaction in the forward direction so cooling the system will cause a shift toward the LHS to replace the heat removed(according to Le Chatelier's Principle) and there will be more $N_2O_4$ produced and the container will become a lighter colour.

NB: If direction is incorrect and the colour change corresponds to incorrect direction then students got one mark for a follow through error.

| *Marking Criteria* | *Mark(s)* |
|---|---|
| • Correctly explanation according to Le Chatelier's Principle and description of colour change | 2 |
| • Correct description of the change or colour change | 1 |

**Question 6** (2 marks)

A system is at equilibrium when $\Delta G$ is zero.

Calculate the temperature at which a system is at equilibrium if the $\Delta H$ value is $-112.5$ kJ mol$^{-1}$ and the $\Delta S$ value is $-$ 165 J K$^{-1}$.

**Sample Answer:**

$\Delta G = \Delta H - T\Delta S$

Convert $\Delta S$ from J to kJ $= -165/1000 = 0.165$

$\Delta G = 0$ at Equilibrium

$0 = -112.5 - (T \text{ x} - 0.165)$

Solve for T = 682K

NB : Temperature must be in Kelvin.

| *Marking Criteria* | *Mark(s)* |
|---|---|
| • Correctly calculates the temperature at Equilibrium | 2 |
| • Shows some relevant working | 1 |

**Question 7** (4 marks)

A solution was prepared by mixing 18 mL of 0.0833 mol L$^{-1}$ sodium hydroxide solution with 32 mL of 0.0117 mol L$^{-1}$ calcium nitrate solution in a small beaker.

Predict and explain the observation for the reaction taking place in the beaker. Support your response with the relevant chemical equation and calculations.

**Sample answer:**
$Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + 2OH^-(aq)$
$Q = [Ca^{2+}][OH^-]^2 = (0.0117 \text{ x } 0.032 / 0.05) \text{ x } (0.0833 \text{ x } 0.018 / 0.05)^2 = 6.73 \text{ x } 10^{-6}$
Since $Q > K_{sp}$ ($5.02 \text{ x } 10^{-6}$)
Formation of the calcium hydroxide precipitate will be observed in the small beaker.

| *Marking Criteria* | *Mark(s)* |
|---|---|
| • Correctly predicts the formation of a precipitate.<br>• Provides a balanced chemical equation with states.<br>• Provides an explanation for precipitate formation supported by a complete calculation (dilute conc, Ksp expression, Q value). | 4 |
| • Provides a balanced chemical equation.<br>• Provides some relevant calculation steps. | 3 |
| • Provides a chemical equation and a relevant calculation step (mole calc). | 2 |
| • Provides some relevant information. | 1 |

**Question 8** (4 marks)
Lead iodide is considered sparingly soluble in water. Compare the molar solubility of lead iodide in pure water and a 0.25 mol L$^{-1}$ solution of lead nitrate.
**Sample answer:**
$PbI_2(s) \rightleftharpoons Pb^{2+}(aq) + 2I^-(aq)$
$K_{sp} = 9.8 \text{ x } 10^{-9} = [Pb^{2+}][I^-]^2 = [s][2s]^2 = 4s^3$
$s(\text{in } H_2O) = \sqrt[3]{\frac{(9.8 \, x \, 10^{-9})}{4}} = 1.35 \text{ x } 10^{-3} \text{ mol L}^{-1}$

| | $PbI_2$ | $Pb^{2+}$ | $2I^-$ |
|---|---|---|---|
| initial | – | 0.25 | 0 |
| change | – | + s | + 2s |
| equilibrium | – | 0.25 + s | 2s |

assume the change in x is small where $0.25 + x \approx 0.25$
$K_{sp} = 9.8 \text{ x } 10^{-9} = [Pb^{2+}][I^-]^2 = (0.25)(2s)^2 = s^2$
$s(\text{in } Pb(NO_3)_2) = \sqrt{9.8 \, x \, 10^{-9}} = 9.90 \text{ x } 10^{-5} \text{ mol L}^{-1}$
The molar solubility of lead iodide is greater in pure water ($1.35 \text{ x } 10^{-3}$ mol L$^{-1}$) than the lead nitrate solution ($9.90 \text{ x } 10^{-5}$ mol L$^{-1}$).

| *Marking Criteria* | *Mark(s)* |
|---|---|
| • Provides a comparison for the molar solubility of lead iodide in water and the lead nitrate solution.<br>• Correctly calculates the molar solubility in each instance providing appropriate units and showing all relevant working out (chemical equation, Ksp expression, ICE table, small change assumption, x / s). | 5 |
| • Provides a calculation for the molar solubility in each instance (chemical equation, Ksp expression, ICE table, small change assumption, x / s). | 4 |
| • Provides a complete calculation for the molar solubility of lead iodide in water OR the lead nitrate solution. | 3 |

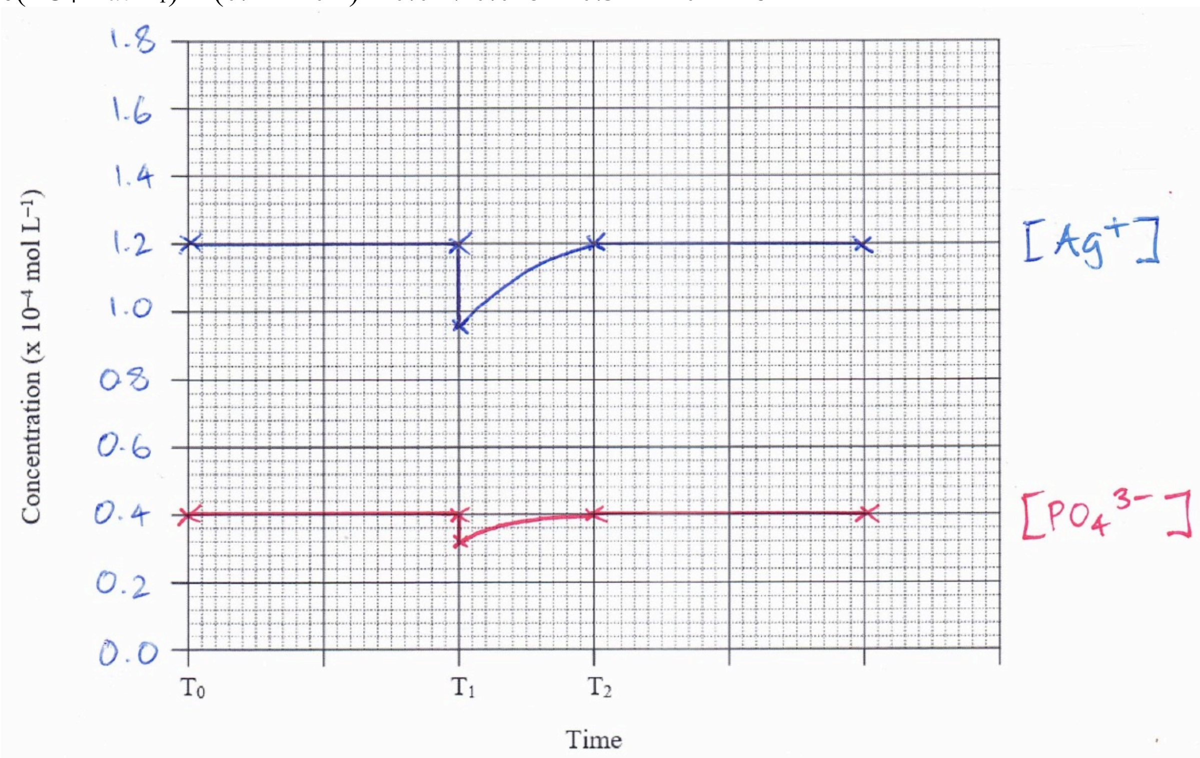
| | |
|---|---|
| • Provides some relevant calculation steps. | 2 |
| • Provides some relevant information. | 1 |

**Question 9** (5 marks)
A precipitation experiment was carried out where solutions of silver nitrate and potassium phosphate were combined in a small beaker to make a 20 mL solution with a considerable amount of silver phosphate precipitate.
This system was at equilibrium at time $T_0$, where the concentration of silver ions was found to be $1.2 \times 10^{-4}$ mol $L^{-1}$ and phosphate at $0.4 \times 10^{-4}$ mol $L^{-1}$.
At time $T_1$, a disturbance was imposed on this equilibrium system where 5 mL of water was added to the beaker, after which the system re-established equilibrium at time $T_2$.
Perform the relevant calculations and graph the changes in concentration for both the silver and phosphate ions on the grid provided.

**Sample answer:**

$$Ag_3PO_4(s) \rightleftharpoons \underset{+3s}{3Ag^+(aq)} + \underset{+s}{PO_4^{3-}(aq)}$$

$c(Ag^+ \text{ at } T_1) = (1.2 \times 10^{-4}) \times 0.02 / 0.025 = 0.96 \times 10^{-4}$ mol $L^{-1}$
$c(PO_4^{3-} \text{ at } T_1) = (0.4 \times 10^{-4}) \times 0.02 / 0.025 = 0.32 \times 10^{-4}$ mol $L^{-1}$




| *Marking Criteria* | *Mark(s)* |
|---|---|
| • Correctly illustrates the changes in concentration for the silver and phosphate ions (equilibrium, disturbance, shift direction & shape).<br>• Provides correct calculations for the concentrations of both the silver and phosphate ions after the disturbance is applied. | 5 |

| | |
|---|---|
| • Provides some correct features of the graph (at least TWO of the above).<br>• Provides the main steps in the calculations for the concentration of silver and / or phosphate ions after the disturbance is applied. | 4 |
| • Provides some correct features of the graph (at least TWO of the above) supported with a relevant calculation step.<br>**OR**<br>• Provides a correct feature of the graph (at least ONE of the above).<br>• Provides the main steps in the calculations for the concentration of silver and / or phosphate ions after the disturbance is applied. | 3 |
| • Provides a correct feature of the graph supported with a relevant calculation step.<br>**OR**<br>• Provides the main steps in the calculations for the concentration of silver and / or phosphate ions after the disturbance is applied. | 2 |
| • Provides some relevant information. | 1 |