# Chemical Equilibrium

Chapter **7**

**1. [7 marks]** *(2009:05)*

Solid magnesium hydroxide is added to a beaker of water. The water is stirred and the contents of the beaker left to settle. A saturated solution is formed, with undissolved magnesium hydroxide at the bottom of the beaker. The system can be shown by the following equation:

$$Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2\,OH^-(aq)$$

(a) The system is allowed to come to equilibrium. Explain why the amount of solid present remains constant. *1.3* [1]

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(b) The changes indicated in the table below are now imposed on the system. Predict and explain the effect these changes have on the amount of solid magnesium hydroxide in the beaker once equilibrium is re-established. *1.9* [6]

| **Imposed change** | **Effect on solid $Mg(OH)_2$ (write 'increase', 'decrease' or 'no change')** | **Explanation** |
|---|---|---|
| A little concentrated sodium hydroxide solution is added to the beaker | | |
| Some sodium phosphate solution is added to the beaker | | |
| More water is added to the beaker | | |

**2. [6 marks]** *(2010:26)*

Consider the following system:

$$CO(g) + 2\,H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -92\ kJ$$

(a) Predict whether the following changes will increase, decrease or have no effect on the rate of attainment of equilibrium. *1.1* [3]

| Change | Effect |
|---|---|
| Decreasing the temperature | |
| Increasing the pressure of hydrogen | |
| Adding a catalyst | |

(b) Predict whether the following changes will increase, decrease or have no effect on the equilibrium yield of the reaction. *1.9* [3]

| Change | Effect |
|---|---|
| Increasing the temperature | |
| Increasing the pressure of the system | |
| Adding a catalyst | |

**3. [2 marks]** *1.10 (2010:27)*

Write the equilibrium constant expression for the following equilbria:

(a) [1]

| **Equation** | $BaSO_4(s) \rightleftharpoons Ba^{2+}(aq) + SO_4^{2-}(aq)$ |
|---|---|
| **Equilibrium constant expression** | |

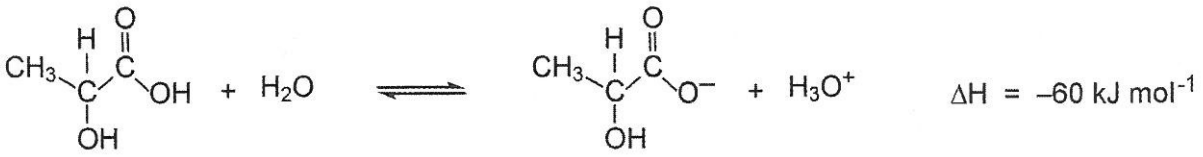
(b) [1]

| **Equation** | $2\ CrO_4^{2-}(aq) + 2\ H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(\ell)$ |
|---|---|
| **Equilibrium constant expression** | |

**4. [4 marks]** *(2011:27b,c)*

Lactic acid produced by muscles during exercise, is found in many milk products and is used in the brewing of beer. It is also added to a number of canned food items as a buffer.

The equation for the reaction of lactic acid with water is shown below.




The value of the equilibrium constant for the above reaction, at 25°C, is approximately $7.9 \times 10^{-5}$.

(a) State whether the ratio of organic products to organic reactants will be equal to one, less than one (< 1) or greater than one (> 1) for this system at equilibrium at 25°C. *1.11* [1]

(b) Predict the direction in which the equilibrium will shift immediately after the changes indicated in the table below. Write 'left', 'right' or 'no change'. *1.9* [3]

| Change | Direction of initial equilibrium shift |
|---|---|
| Decreasing the temperature | |
| Adding hydrochloric acid | |
| Adding sodium hydroxide | |

**5. [8 marks]** *1.9 (2011:28)*

Chloromethane can be produced industrially by the reaction of methanol and hydrogen chloride at high temperature in the presence of a catalyst. The equation for this reaction is shown below.

$$CH_3OH + HC\ell \rightleftharpoons CH_3C\ell + H_2O$$

The boiling points and melting points for each of the species involved in the reaction are shown below.

| Species | Boiling point (°C) | Melting point (°C) |
|---|---|---|
| $CH_3OH$ | 65 | –98 |
| $HC\ell$ | –85 | –114 |
| $CH_3C\ell$ | –24 | –98 |
| $H_2O$ | 100 | 0 |

Write the phase, i.e., solid (*s*), liquid ($\ell$) or gas (*g*), of each species in this system at the temperatures shown in the table below, and predict the effect of an increase in total pressure on this equilibrium at each of the temperatures.

| Temperature (°C) | Phase (*s*, $\ell$ or *g*) | | | | Shift in equilibrium (right, left or no change) |
|---|---|---|---|---|---|
| | $CH_3OH$ | $HC\ell$ | $CH_3C\ell$ | $H_2O$ | |
| –50 | | | | | |
| 40 | | | | | |
| 70 | | | | | |
| 110 | | | | | |

**6. [6 marks]** *1.9 (2012:29)*

The white solid bismuth oxychloride reacts with concentrated hydrochloric acid to establish the following equilibrium:

$$BiOC\ell(s) + 2\,H^+(aq) \rightleftharpoons Bi^{3+}(aq) + C\ell^-(aq) + H_2O(\ell)$$

Three test tubes of the equilibrium system, 'A', 'B' and 'C' were prepared by adding excess $BiOC\ell$ to concentrated hydrochloric acid.

Complete the table below by indicating the direction of the expected shift in equilibrium immediately following the changes stated in the table. Using Collision theory explain your choice of shift.

| **Test tube** | **Change** | **Direction of shift in equilibrium ('left', 'right' or 'no change')** | **Explanation** |
|---|---|---|---|
| A | 3 mL of water is added | | |
| B | A few drops of concentrated nitric acid are added | | |
| C | A few drops of concentrated silver nitrate solution are added | | |

**7. [6 marks]** *(2012:30)*

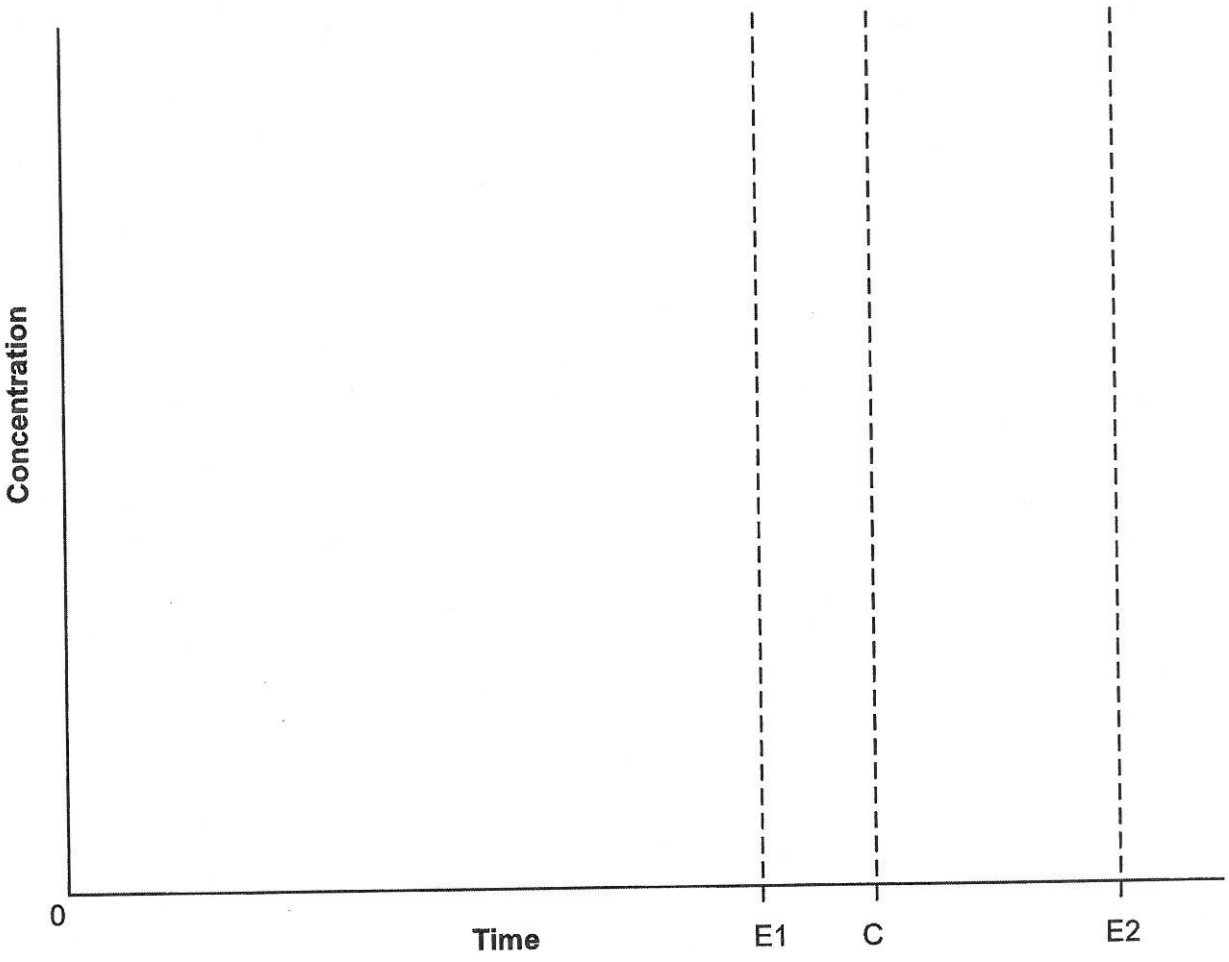
Silver chloride, $AgC\ell(s)$, is very sparingly soluble in water. However, it is soluble in ammonia solutions, due to the formation of the $[Ag(NH_3)_2]^+$ ion as shown in the equilibrium below:

$$AgC\ell(s) + 2\ NH_3(aq) \rightleftharpoons [Ag(NH_3)_2]^+(aq) + C\ell^-(aq)$$

The equilibrium constant, K, for this system is greater than 1 (>1).

A student mixes the reactants at time t = 0.

(a) On the axes below, draw separate curves to show how the concentrations of $NH_3(aq)$ and $[Ag(NH_3)_2]^+(aq)$ change with time as the system approaches, and finally reaches, equilibrium (Time E1). Clearly label your curve for $NH_3(aq)$ and your curve for $[Ag(NH_3)_2]^+(aq)$. Continue your curves from Time E1 to Time C. *1.4* [3]




(b) At Time = C, as shown on the axis, a small quantity of concentrated $NaC\ell$ solution is added to the system, and the system is then again allowed to reach equilibrium at Time E2. On the same axes above, show how the concentrations of $NH_3(aq)$ and $[Ag(NH_3)_2]^+(aq)$ would change in response to the addition of $NaC\ell$ solution from Time C until equilibrium is reached at Time E2. *1.9* [3]

8. **[4 marks]** *1.10 (2013:29)*

Write the equation and the expression for the equilibrium constant for each of the equilibrium processes below.

| **Equilibrium process** | **Equation** | **Equilibrium constant expression** |
|---|---|---|
| Vaporisation of water | | |
| Dissolution of solid aluminium sulfate in water | | |

**9. [8 marks]** *1.8 (2013:30)*

Consider the following system at equilibrium.

$$4\ NH_3(g) + 5\ O_2(g) \rightleftharpoons 4\ NO(g) + 6\ H_2O(g) + 920\ kJ$$

Indicate in the table below whether there would be an increase, decrease, or no change in the concentration of $NH_3(g)$ after the changes given in the table are imposed on the system and **equilibrium has been re-established**. Provide a brief explanation for the observation.

| Change | Change in concentration of $NH_3(g)$ (circle the correct response) | Brief explanation |
|---|---|---|
| The volume of the reaction vessel is doubled | • increase<br>• decrease<br>• no change | |
| The temperature of the reaction system is doubled | • increase<br>• decrease<br>• no change | |
| $N_2(g)$ is injected into the reaction system while keeping the volume constant | • increase<br>• decrease<br>• no change | |
| Water vapour is injected into the reaction system while keeping the volume constant | • increase<br>• decrease<br>• no change | |

**10. [6 marks]** *1.4, 1.7 (2015:30)*

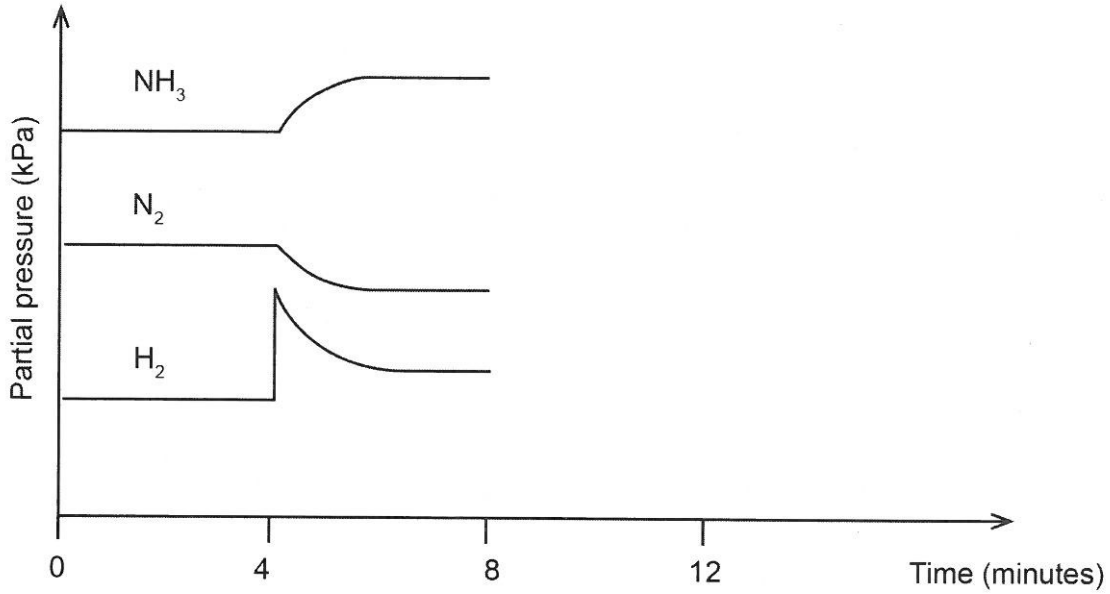
Ammonia exists in equilibrium with hydrogen and nitrogen as shown by the following exothermic equation.

$$N_2(g) + 3\,H_2(g) \rightleftharpoons 2\,NH_3(g) \qquad \Delta H = -92\ kJ\ mol^{-1}$$

As they exist in the gaseous state, the relative concentrations can be given in terms of the partial pressure (kPa) of each gas.

Nitrogen, hydrogen and ammonia gases are placed in a rigid container and allowed to reach equilibrium. The graph below shows the partial pressures of the gaseous system initially at equilibrium. After the experiment operates for 4 minutes, a change is imposed upon it.

**Partial pressures of $NH_3$, $N_2$ and $H_2$ over time**




(a) What characteristic of equilibrium is indicated on the graph by the section from 0 to 4 minutes? [1]

(b) A change was imposed on the system at the 4 minute mark. What imposed change could have produced the results indicated on the graph? [1]

(c) The system was **suddenly** cooled at 8 minutes and then reached equilibrium again at 12 minutes. Using this information, complete the graph above from the 8 to the 12 minute mark. [4]

**11. [16 marks]** *(2015:38)*

The two different coloured cobalt(II) complex ions, $Co(H_2O)_6^{2+}$ and $CoC\ell_4^{2-}$, exist together in equilibrium in solution in the presence of chloride ions. This is represented by the equation below.

$$\underset{\text{pink}}{Co(H_2O)_6^{2+}(aq)} + 4\ C\ell^-(aq) \rightleftharpoons \underset{\text{blue}}{CoC\ell_4^{2-}(aq)} + 6\ H_2O(\ell)$$

An experiment is conducted to investigate the effects on the equilibrium position by imposing a series of changes on the system. The shift in equilibrium position can be indicated by any colour change of the solution.

| Colour chart | |
|---|---|
| **Species** | **Colour** |
| $Co(H_2O)_6^{2+}(aq)$ | pink |
| $CoC\ell_4^{2-}(aq)$ | blue |
| Initial equilibrium mixture | purple |

After a 3.00 mL sample of an initial equilibrium mixture was placed in each of three test tubes, changes to each system were made by adding a different substance, as indicated in the table below.

| Test tube | Substance added to the test tube |
|---|---|
| 1 | 10 to 12 drops of distilled water |
| 2 | 20 to 25 drops of concentrated hydrochloric acid |
| 3 | 20 to 25 drops of 0.200 mol $L^{-1}$ silver nitrate solution, $AgNO_3(aq)$ |

(a) Complete the table below by predicting the:
- change in concentration, if any, of each of the ions in solution compared to the initial solution, after a new equilibrium position is reached.
- colour change, if any, that takes place from the initial purple-coloured solution. [6]

| Additions to the test tube | Change in concentration from initial equilibrium to final equilibrium (increase, decrease, unchanged) | | | Colour favoured (pink, blue or unchanged) |
|---|---|---|---|---|
| | $[Co(H_2O)_6^{2+}]$ | $[C\ell^-]$ | $[CoC\ell_4^{2-}]$ | |
| 1. add $H_2O(\ell)$ | | | | |
| 2. add $HC\ell(aq)$ | | | | |
| 3. add $AgNO_3(aq)$ | | | | |

(b) Other than a colour change, what else should be observed in test tube 3? [1]

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(c) Using Collision Theory, explain your predicted observations when hydrochloric acid is added to test tube 2 [3]

Another experiment was conducted to investigate the effect that changing the temperature had on the equilibrium mixture. When 3.00 mL of the original equilibrium mixture was placed in a test tube and then in an ice bath, the solution became pink.

(d) Determine whether the forward reaction, as illustrated by the equation below, is exothermic or endothermic. Use Le Châtelier's Principle to justify your answer. [4]

$$\underset{\text{pink}}{Co(H_2O)_6^{2+}(aq)} + 4\ C\ell^-(aq) \rightleftharpoons \underset{\text{blue}}{CoC\ell_4^{2-}(aq)} + 6\ H_2O(\ell)$$

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(e) State **one** specific hazard to the environment that the disposal of chemicals from this experiment poses and state what could be done in the laboratory to reduce this hazard. [2]

**12. [6 marks]** *1.0 (2016 SP:34)*

Ocean acidification results from carbon dioxide dissolving in water and an equilibrium being established between the water and carbon dioxide to produce carbonic acid, ($H_2CO_3$).

(a) Write a balanced equation for this equilibrium. [2]

(b) The formation of carbonic acid leads to an increase in the hydronium ion ($H_3O^+$) concentration in water. Show the equilibrium that results in the formation of hydronium ions when carbonic acid reacts with water. [1]

(c) State **one** problem ocean acidification is causing for marine organisms. Explain how this problem arises and support your answer with an appropriate balanced equation. [3]

**13. [18 marks]** *1.11 (2016:41)*

Nitrogen dioxide is toxic to humans when inhaled and is a significant component of air pollution. It can be formed by the combustion of nitrogen in the air at high temperatures; firstly forming nitric oxide NO(*g*) and on further oxidation, forming nitrogen dioxide, $NO_2(g)$. The overall equation for this process is given here:

$$N_2(g) + 2\,O_2(g) \rightleftharpoons 2\,NO_2(g)$$

The following questions relate to the equilibrium system represented by this equation.

(a) Write the equilibrium expression for this reaction when it is in equilibrium. [2]

(b) Assuming all other conditions remain constant, what happens to the equilibrium constant after the pressure of the system is lowered and equilibrium is re-established? [1]

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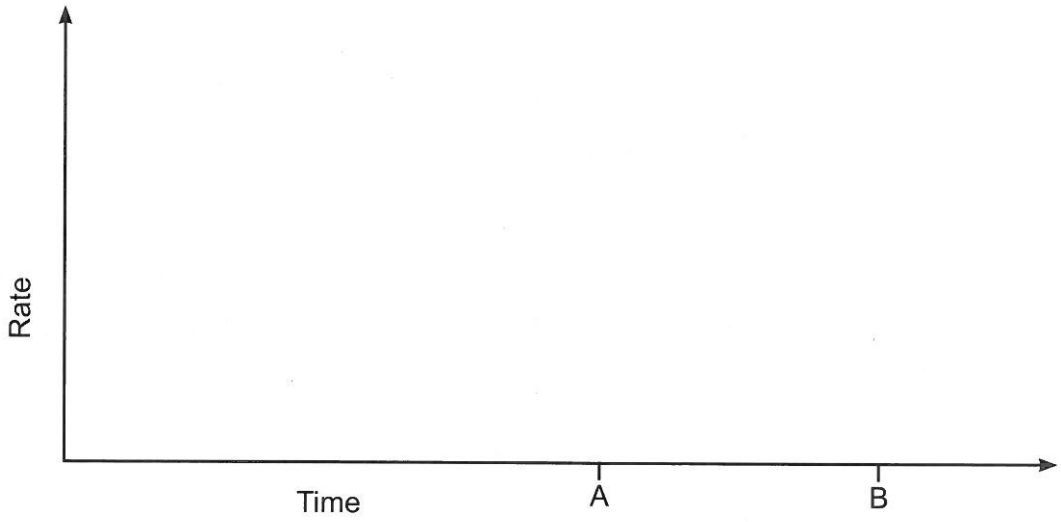
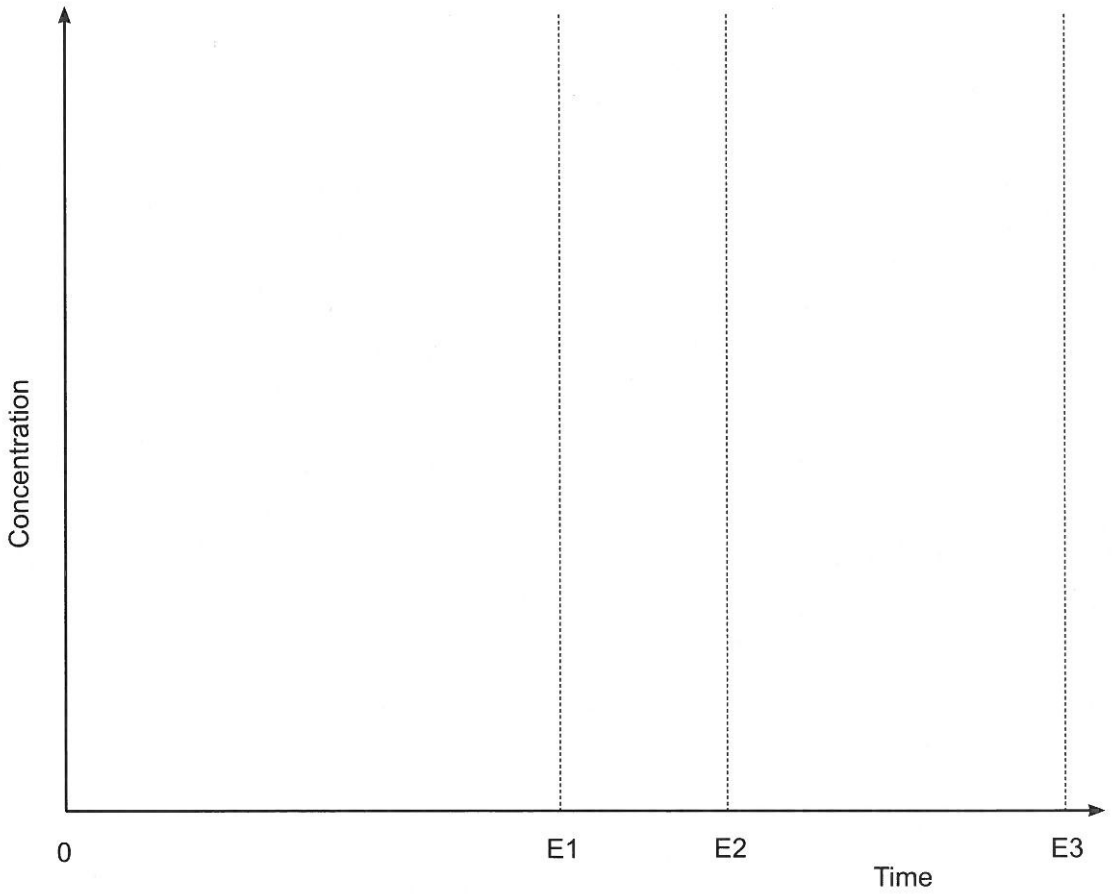
(c) (i) On the axes below, draw the forward (—) and reverse (- - -) reaction rates, starting at the moment the oxygen and nitrogen gases begin to react with each other until after equilibrium has been established at time A. Continue the graph until time B. [3]




(ii) On the same axes above, draw and label clearly the effect of conducting the same reaction at a higher temperature. [2]

(d) On the axes below, draw separate curves to show how the concentrations of the **three** gases change with time, starting at the moment the oxygen and nitrogen gases begin to react with each other until the system reaches equilibrium at Time E1. Continue the graph from Time E1 to Time E2. Assume that the initial concentrations of oxygen and nitrogen are identical.

Label clearly the line for each gas. [5]




(e) At Time E2 shown on the axis, the reaction vessel is doubled in volume, and the system is then again allowed to reach equilibrium at Time E3. On the same graph above, show how the concentrations of the three gases would change in response to the change in volume, from Time E2 until equilibrium is re-established at Time E3. [3]

The reaction between nitrogen gas and oxygen gas occurs at high temperatures such as those found in the combustion engines of cars. The atmosphere is composed of 78% nitrogen and 21% oxygen and has been stable for millions of years.

(f) What does the stability of this composition indicate about the equilibrium constant and energy requirements of the reaction between nitrogen and oxygen gases? [2]

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