CHEMISTRY
Stage 6

Module 5: Equilibrium and Acid Reactions
Static and Dynamic Equilibrium

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Exam Equivalent Time: 66 minutes *(based on allocation of 1.5 minutes per mark)*

Questions

1. CHEMISTRY, M5 2021 HSC 1 MC

Which pair of components must be equal for a chemical system to be at equilibrium?

A. The rate of the forward reaction and the rate of the reverse reaction
B. The concentrations of the reactants and the concentrations of the products
C. The enthalpy of the forward reaction and the enthalpy of the reverse reaction
D. The time that an atom exists in a reactant molecule and in a product molecule

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2. CHEMISTRY, M5 2022 HSC 3 MC

Which of the following features is NOT a characteristic of a state of equilibrium?

A. Equilibrium is achieved in a closed system.
B. Equilibrium position depends on temperature.
C. Equilibrium can be reached from either direction.
D. Equilibrium concentrations of reactants and products are equal.

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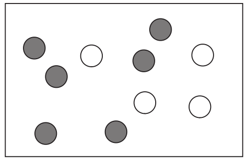
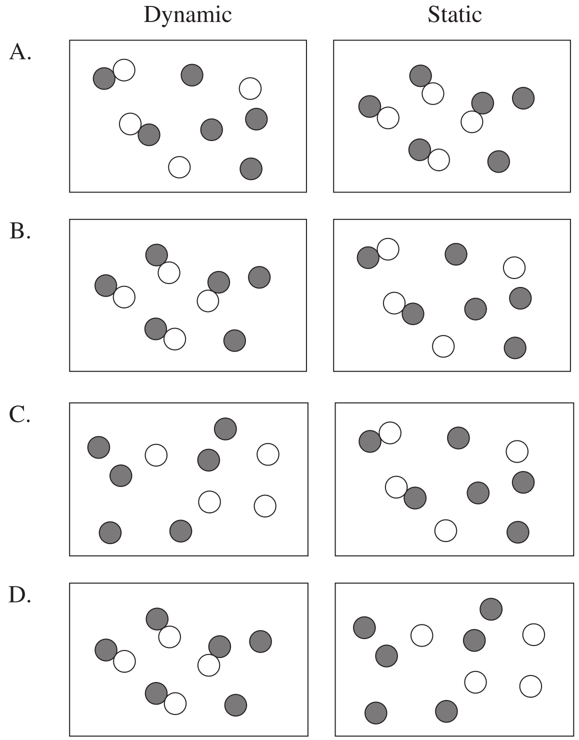
3. CHEMISTRY, M5 EQ-Bank 4 MC

Particle ○ reacts with particle ● to form the molecule ●○. The system comes to an equilibrium.

The diagram shows the initial reactants.



Which combination of diagrams best represents the molecule in a dynamic equilibrium and a static equilibrium?



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4. CHEMISTRY, M5 2015 HSC 12 MC

A transuranic element can be produced in a nuclear reactor according to this equation:

$$^{239}_{94}\mathrm{Pu} + 2\mathrm{X} \rightarrow {}^{241}_{94}\mathrm{Pu} \rightarrow {}^{241}_{95}\mathrm{Am} + \mathrm{Y}$$

Which row of the table correctly identifies $\mathbf{X}$ and $\mathbf{Y}$?

	X	Y
A.	Neutron	Electron
B.	Proton	Neutron
C.	Neutron	Proton
D.	Proton	Electron

5. CHEMISTRY, M5 2019 HSC 11 MC

A saturated solution of barium carbonate was stored in a flask. Solid barium carbonate containing radioactive carbon-14 was added to the solution. The mixture was allowed to stand for several days and was then filtered.

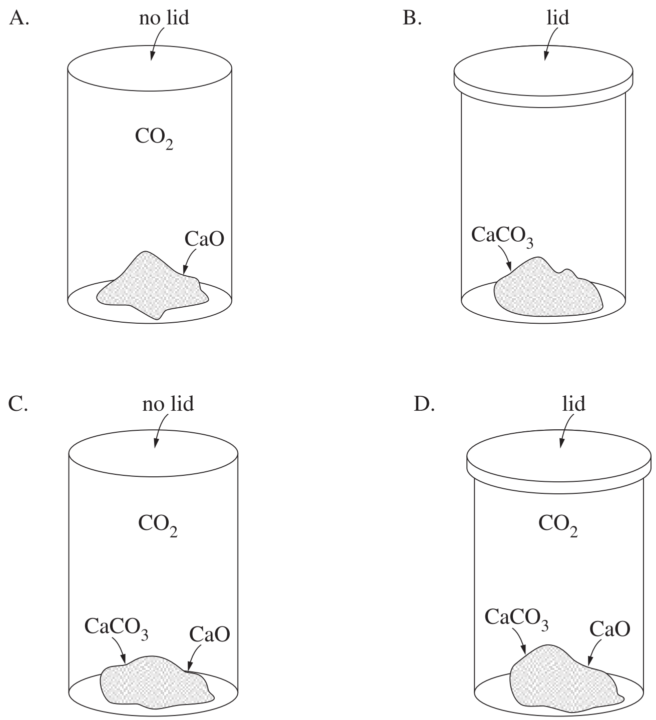
Radioactivity could reasonably be expected to be found in

- **A.** the filtrate only.
- **B.** the residue only.
- **C.** both residue and filtrate.
- **D.** neither residue nor filtrate.

6. CHEMISTRY, M5 EQ-Bank 5 MC

The conversion of calcium carbonate to calcium oxide and carbon dioxide is a reversible reaction and will reach equilibrium under certain conditions.

In which diagram is the system most likely to have reached equilibrium?



7. CHEMISTRY, M5 EQ-Bank 21

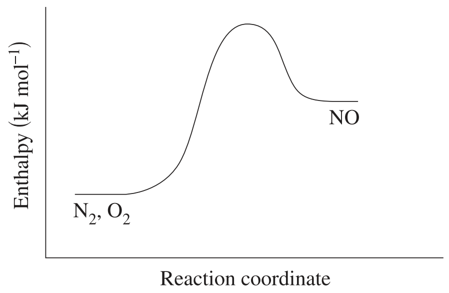
Potassium chloride readily dissolves in water. With the use of a labelled diagram, describe the changes in bonding and entropy that occurs during this process. ***(4 marks)***

8. CHEMISTRY, M5 2020 HSC 26

Nitric oxide gas (NO) can be produced from the direct combination of nitrogen gas and oxygen gas in a reversible reaction.

a. Write the balanced chemical equation for this reaction. ***(1 mark)***

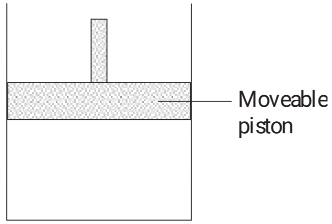
b. The energy profile diagram for this reaction is shown.



Explain, using collision theory, how an increase in temperature would affect the value of K_{eq} for this system. Refer to the diagram in your answer. ***(4 marks)***

9. CHEMISTRY, M5 2023 HSC 33

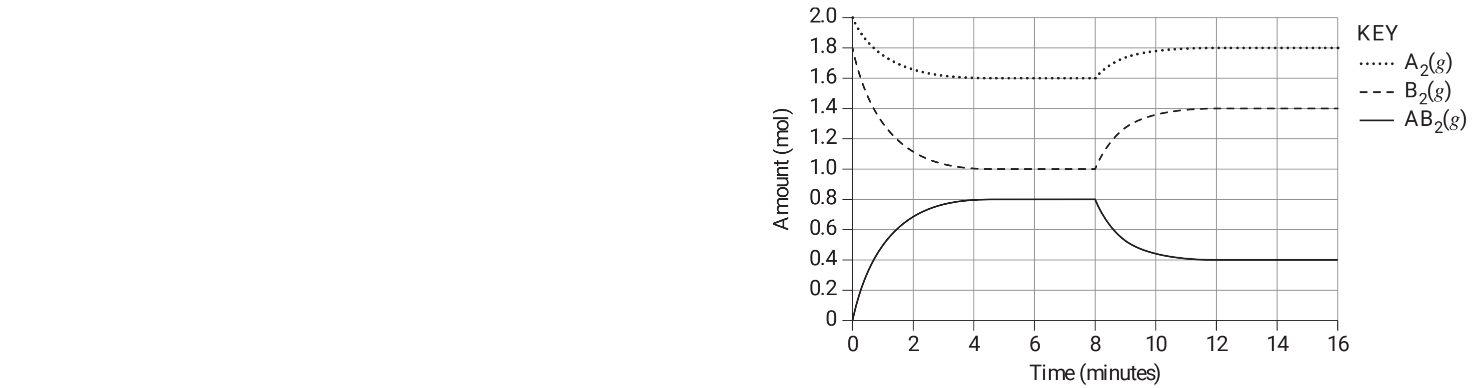
Gases A_2 and B_2 are placed in a closed container of variable volume, as shown.



The reaction between these substances is as follows.

$$A_2\,(g) + 2\,B_2\,(g) \rightleftharpoons 2\,AB_2\,(g) \quad \Delta H = -10\,kJ\,mol^{-1}$$

The following graph shows changes in the amounts (in mol) of these three substances over time in this container.



a. Explain what is happening in this system between 6 minutes and 8 minutes. ***(2 marks)***

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b. Explain TWO different factors that could result in the disturbance at 8 minutes. ***(4 marks)***

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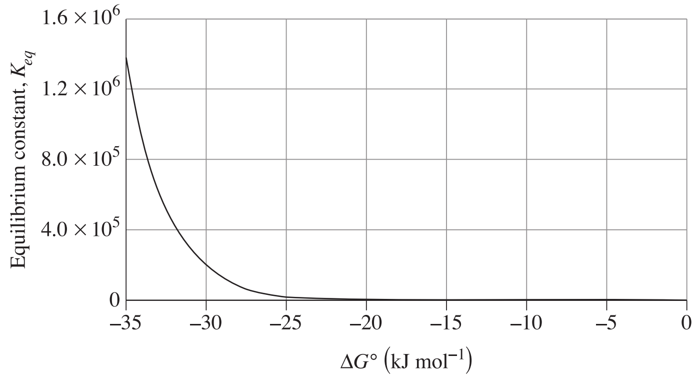
10. CHEMISTRY, M5 2024 HSC 37

The relationship between the equilibrium constant, K_{eq}, and ΔG° for any reaction is shown in the graph, for a limited range of ΔG° values.



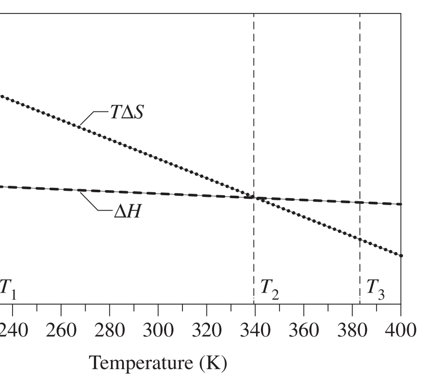
The ΔH° and $T\Delta S^\circ$ values for the reaction between copper(I) sulfide and oxygen are provided.

$$Cu_2S\,(s) + O_2\,(g) \rightarrow 2\,Cu\,(s) + SO_2\,(g) \qquad \begin{array}{l} \Delta H^\circ = -\,217\ \text{kJ mol}^{-1} \\ \Delta S^\circ = -\,3\ \text{kJ mol}^{-1} \end{array}$$

Explain, with reference to the information provided, why this reaction proceeds to completion rather than coming to equilibrium. ***(3 marks)***

11. CHEMISTRY, M5 2021 HSC 33

The relationships between ΔH and $T\Delta S$ with temperature for a chemical system are displayed in the graph.



a. Calculate ΔG for this system at 300 K. ***(2 marks)***

b. What can be deduced about the system when the temperature is T_1, T_2 and T_3? Support your answer with reference to the graph. ***(4 marks)***

12. CHEMISTRY, M5 2022 HSC 36

Consider the equilibrium system shown.

$$H_2O\,(l) \rightleftharpoons H_2O\,(g)$$

In a laboratory at 23°C, a 100 mL sample of water is held in a beaker and another 100 mL sample is held in a sealed bottle.

Explain the differences in evaporation for these TWO samples. In your answer, consider changes in enthalpy and entropy for this process. ***(4 marks)***

13. CHEMISTRY, M5 2018 HSC 30

Over the last 50 years, scientists have recorded increases in the following:

- the amount of fossil fuels burnt
- atmospheric carbon dioxide levels
- average global air temperature and ocean temperature
- the volume of carbon dioxide dissolved in the oceans.

Analyse the factors that affect the equilibrium between carbon dioxide in the air and carbon dioxide in the oceans. In your answer, make reference to the scientists' observations and include relevant equations. ***(7 marks)***

14. CHEMISTRY, M5 2019 HSC 30

The following data apply to magnesium fluoride and magnesium chloride dissolving in water at 298 K.

	Magnesium fluoride	*Magnesium chloride*
$\Delta_{sol} H^{\ominus}\,(\mathrm{kJ\ mol^{-1}})$	-7.81	-160
$\Delta_{\mathrm{sol}}\, S^{\ominus}\,(\mathrm{J\ K^{-1}} mol^{-1})$	-223	-115
$T\Delta_{\mathrm{sol}}\, S^{\ominus}\,(\mathrm{kJ\ mol^{-1}})$	-66.4	-34.2
$\Delta_{\mathrm{sol}}\, G^{\ominus}\,(\mathrm{kJ\ mol^{-1}})$	$+58.6$	-125

Compare the effects of enthalpy and entropy on the solubility of these salts. ***(3 marks)***

Worked Solutions

1. CHEMISTRY, M5 2021 HSC 1 MC

→ Rate of forward = rate of reverse reaction (dynamic equilibrium)

$\Rightarrow A$

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2. CHEMISTRY, M5 2022 HSC 3 MC

The concentration of the reactants and products remains constant but is not required to be equal at equilibrium.

$\Rightarrow D$

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3. CHEMISTRY, M5 EQ-Bank 4 MC

→ In dynamic state, some particles have not yet combined to form a molecule.

→ In static state, all particles that could react have formed molecules.

$\Rightarrow A$

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4. CHEMISTRY, M5 2015 HSC 12 MC

→ A balanced equation requires the sum of top and bottom numbers to be equal on both sides.

→ X is a neutron $\left({}_0^1n\right)$

→ Y is an electron $\left({}_{-1}^{0}e\right)$

$\Rightarrow A$

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5. CHEMISTRY, M5 2019 HSC 11 MC

$\mathrm{BaCO_3\,(s)} \rightleftharpoons \mathrm{Ba^{2+}\,(aq)} + \mathrm{CO_3{}^{2-}\,(aq)}$

→ In a saturated solution, a dynamic equilibrium exists whereby the solid barium carbonate is dissolving into the solution and the solution is depositing back onto the solid.

→ If the solid barium carbonate contains a radioactive isotope, such as carbon–14, this isotope will be present in both the solid residue and the filtrate solution due to the process of the dynamic equilibrium described above.

$\Rightarrow C$

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6. CHEMISTRY, M5 EQ-Bank 5 MC

→ In order to reach equilibrium, the reaction must occur in a closed system. In this system, a lid must be on the container.

→ When the reaction $\mathrm{CaCO_3\,(s)} \rightleftharpoons \mathrm{CaO\,(s)} + \mathrm{CO_2\,(g)}$ has reached equilibrium, both the forwards and reverse reactions will be occurring.

→ All three species will be present.

$\Rightarrow D$

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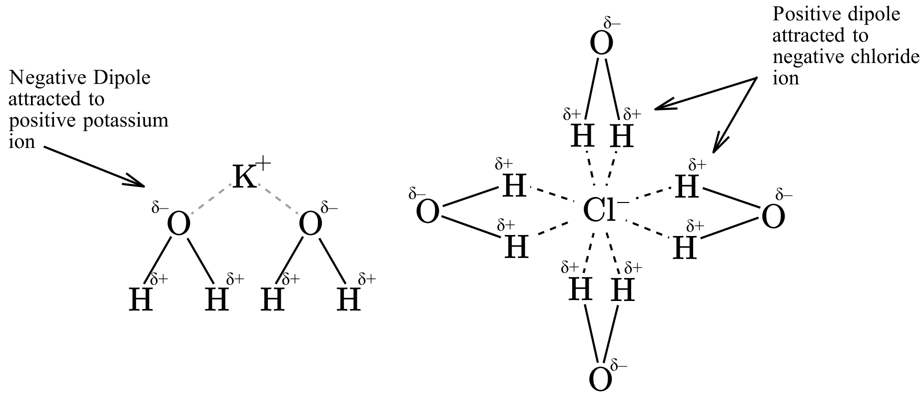
7. CHEMISTRY, M5 EQ-Bank 21



→ Potassium chloride has a high tendency to dissociate into $\mathrm{K^+}$ and $\mathrm{Cl^-}$ ions when mixed with water (i.e. it is highly soluble).

→ Water is a dipolar molecule because each atom has a partial charge, as shown in the diagram.

→ The oxygen dipole in water has a partial negative charge and is attracted to the potassium ion. The hydrogen dipoles have a partial negative charge and are attracted to the chloride ion.

→ This attraction breaks the ionic bonds and forms ion-dipole bonds.

→ The entropy of the system is increased as the ionic bonds of the KCl are broken and the $\mathrm{K^+}$ and $\mathrm{Cl^-}$ ions disperse throughout the solution.

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8. CHEMISTRY, M5 2020 HSC 26

a. $\mathrm{N_2\,(g)} + \mathrm{O_2\,(g)} \rightleftharpoons 2\,\mathrm{NO\,(g)}$

b. → From the graph, the forward reaction is endothermic.

→ The activation energy of the forward endothermic reaction is greater than the activation energy of the reverse exothermic reaction.

→ An increase in temperature would cause the rates of both the forward and reverse reaction due to the higher average kinetic energy, resulting in a larger likelihood of a successful collisions.

→ However, the rate of the forward reaction would increase to a higher extent than the reverse reaction, since it is an endothermic reaction.

→ Using $K_{eq} = \dfrac{[\mathrm{NO}]^2}{[\mathrm{N_2}]\,[\mathrm{O_2}]}$, as the equilibrium shifts right, the equilibrium constant would increase.

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9. CHEMISTRY, M5 2023 HSC 33

a. Between 6 and 8 minutes:

→ The system is in equilibrium.

→ The horizontal lines of each reactant in the graph indicate that the amount of reactants and products remain constant and hence the forward and reverse reactions are proceeding at the same rate.

b. After 8 minutes $\mathrm{AB_2}$ is consumed, and $\mathrm{A_2}$ and $\mathrm{B_2}$ are produced.

Factor 1:

→ An increase in temperature that decreases the equilibrium constant, K.

→ In this case, the reaction quotient Q will be greater than K. This will result in $\mathrm{AB_2}$ being consumed and $\mathrm{A_2}$ and $\mathrm{B_2}$ being produced until Q approaches K and the system reaches equilibrium again.

Factor 2:

→ Increase in volume of the container.

→ This will increase the reaction quotient Q while K stays the same. Again, this will cause $\mathrm{AB_2}$ to be consumed and $\mathrm{A_2}$ and $\mathrm{B_2}$ to be produced until Q approaches K and the system reaches equilibrium again.

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10. CHEMISTRY, M5 2024 HSC 37

Calculating ΔG:

$$\Delta G = \Delta H - T\Delta S = -217 - (-3) = -214\ \text{kJ mol}^{-1}$$

→ The graph shows that large negative values of ΔG correspond to large K_{eq} values. Large K_{eq} values represent that the concentration of the products is significantly higher than the concentration of the reactants. i.e. the reaction runs to completion.

→ The ΔG value for the reaction (see above) is significantly negative and would correspond to a significantly high K_{eq} value.

→ This reaction proceeds to completion primarily because of its significantly large, negative ΔH value, while the $T\Delta S$ term is relatively small and has minimal influence.

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11. CHEMISTRY, M5 2021 HSC 33

a. At Temperature = 300K:

$$T\Delta S = -78\ \text{kJ/mol},\ \ \Delta H = -93\ \text{kJ/mol}$$

$$\begin{aligned}\Delta G &= \Delta H - T\Delta S \\ &= -93 - (-78) \\ &= -15\ \text{kJ/mol}\end{aligned}$$

b. → For all three reactions $\Delta H < 0$ (all are exothermic).

Mean mark (b) 55%.

→ The entropy of the reaction, ΔS is negative as $T\Delta S$ is negative ($T > 0$).

→ From the relationship $\Delta G = \Delta H - T\Delta S$, we can deduce whether the reaction will be spontaneous ($\Delta G < 0$) or non-spontaneous ($\Delta G > 0$).

→ At $\mathrm{T_1}$: ΔH is more negative than $-T\Delta S$, and so $\Delta G < 0$. Thus the reaction is spontaneous.

→ At $\mathrm{T_2}$: ΔH is equal to $-T\Delta S$, and so $\Delta G = 0$. Thus the system is in equilibrium.

→ At $\mathrm{T_3}$: ΔH is less negative than $-T\Delta S$, and so $\Delta G < 0$. Thus the reaction is non-spontaneous.

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12. CHEMISTRY, M5 2022 HSC 36

→ The evaporation of water absorbs energy, hence is an endothermic reaction and results in a positive change in enthalpy ($\Delta H > 0$).

♦ Mean mark 49%.

→ Additionally, the process converts a liquid into a gaseous state, and thus increases the disorder of the system, as a result, entropy increases ($\Delta S > 0$).

→ Since enthalpy and entropy are both positive, according to $\Delta G = \Delta H - T\Delta S$, the evaporation of water is spontaneous at high temperatures, ie when $\Delta G < 0$.

Beaker sample:

→ The evaporation of water in a beaker represents an open system, where vapour molecules are able to escape the system.

→ As a result, there would be a continuous disturbance to the equilibrium, and according to Le Chatelier's Principle, the equilibrium will shift to counteract the change, and thus produce more gaseous water until there is no liquid water left.

→ Thus, dynamic equilibrium will not be established in a beaker.

Sealed bottle sample:

→ On the other hand, the evaporation of water in a sealed bottle represents a closed system where the water vapour cannot escape from the system.

→ In this reaction liquid water would evaporate, shifting the equilibrium to the right until the rate of the forward reaction and the rate of the reverse reaction is equal.

→ At this point, there would be virtually no change in the concentration of liquid water and gaseous water, and thus dynamic equilibrium will be established.

13. CHEMISTRY, M5 2018 HSC 30

Fossil fuel combustion:

→ Combustion of fossil fuels releases CO_2 and heat energy, both of which are released into the atmosphere.

♦♦ Mean mark 41%.

→ Increased burning of fossil fuels will contribute to further rises in atmospheric CO_2, as described in the equation for the combustion of octane

$$2\,C_8H_{18} + 25\,O_2 \longrightarrow 16\,CO_2 + 18\,H_2O \qquad \triangle H \ -ve$$

Carbon dioxide and other climate interactions:

→ CO_2 combines with water according to the following equilibrium in an exothermic reaction.

$$CO_2\,(g) + H_2O\,(l) \rightleftharpoons H_2CO_3\,(aq) \rightleftharpoons H^+\,(aq) + HCO^{3-}\,(aq) \qquad \triangle H \ -ve$$

→ This is an equilibrium and by Le Chatelier's principle when a system is changed, the system will adjust to oppose the change.

→ Factors that affect equilibrium in this system are temperature, pressure and concentration of reactants and products.

→ The increase of CO_2 in the air due to the combustion of fossil fuels described above, increases the pressure due to CO_2 in the system. By Le Chatelier's principle, the system will oppose this by absorbing more CO_2 into the oceans.

→ Scientists have been measuring the level of CO_2 in oceans due to this effect and confirmed the increase in CO_2.

→ However, this equilibrium is exothermic and as it causes temperature rises, by Le Chatelier's principle, the reverse reaction may be subsequently favoured. This would have the effect of decreasing the amount of CO_2 dissolving in the oceans.

→ In summary, if global temperatures continue to rise and CO_2 in the atmosphere becomes stable or reduces, the system may adjust so that oceans may release CO_2 rather than absorbing it.

14. CHEMISTRY, M5 2019 HSC 30

→ Magnesium chloride dissolves in water spontaneously as it has a negative $\triangle_{\text{sol}} G^{\ominus}$ (– 125 kJ mol $^{-1}$).

→ Magnesium flouride however does not dissolve in water spontaneously which is shown by its corresponding $\triangle_{\text{sol}} G^{\ominus}$ of +58.6 kJ mol $^{-1}$.

→ Both salts have a negative $\triangle_{\text{sol}} S^{\ominus}$, resulting in a net positive $-T\triangle_{\text{sol}} S^{\ominus}$ contribution to $\triangle_{\text{sol}} G^{\ominus}$.

→ Both salts have a negative $\triangle_{\text{sol}} H^{\ominus}$. It should be noted however that magnesium chloride's negative value is significantly more negative at $\triangle_{\text{sol}} H^{\ominus}$ (– 160 kJ mol $^{-1}$). This is greater than the $-T\triangle_{\text{sol}} S^{\ominus}$ contribution (+34.2 kJ mol $^{-1}$), resulting in a negative $\triangle_{\text{sol}} G^{\ominus}$.

→ This can be compared to magnesium fluoride that has a relatively small negative $\triangle_{\text{sol}} H^{\ominus}$ (– 7.81 kJ mol $^{-1}$) which is smaller than the $-T\triangle_{\text{sol}} S^{\ominus}$ contribution (+66.4 kJ mol $^{-1}$), resulting in a positive $\triangle_{\text{sol}} G^{\ominus}$.

♦♦ Mean mark 34%.