CHEMISTRY
Stage 6

Module 5: Equilibrium and Acid Reactions

Equilibrium Constant

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Exam Equivalent Time: 108 minutes *(based on allocation of 1.5 minutes per mark)*

Questions

1. CHEMISTRY, M5 2019 HSC 16 MC

At equilibrium, a 1.00 L vessel contains 0.0430 mol of H_2, 0.0620 mol of I_2, and 0.358 mole of HI. The system is represented by the following equation:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

Which of the following is closest to the value of the equilibrium constant, K_{eq}, for this reaction?

A. 0.0208

B. 48.1

C. 134

D. 269

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2. CHEMISTRY, M5 EQ-Bank 3 MC

Consider the following reaction.

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g).$$

What is the equilibrium expression for this reaction?

A. $\dfrac{2[NO][Cl_2]}{2[NOCl]}$

B. $\dfrac{[NO]^2[Cl_2]}{[NOCl]^2}$

C. $\dfrac{2[NOCl]}{2[NO][Cl_2]}$

D. $\dfrac{[NOCl]^2}{2[NO]^2[Cl_2]}$

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3. CHEMISTRY, M5 2022 HSC 13 MC

Nitrosyl bromide decomposes according to the following equation.

$$2NOBr(g) \rightleftharpoons 2NO(g) + Br_2(g)$$

A 0.64 mol sample of $NOBr$ is placed in an evacuated 1.00 L flask. After the system comes to equilibrium, the flask contains 0.46 mol $NOBr$.

What are the concentrations of NO and Br_2 in the flask at equilibrium?

	$[NO]\,(mol\,L^{-1})$	$[Br_2]\,(mol\,L^{-1})$
A.	0.18	0.09
B.	0.18	0.18
C.	0.36	0.18
D.	0.92	0.46

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4. CHEMISTRY, M5 2022 HSC 8 MC

A system is described as follows.

$$2NaHCO_3(s) \rightleftharpoons Na_2CO_3(s) + CO_2(g) + H_2O(g)$$

What is the equilibrium expression for this system?

A. $K_{eq} = [CO_2]$

B. $K_{eq} = [CO_2][H_2O]$

C. $K_{eq} = \dfrac{1}{[CO_2][H_2O]}$

D. $K_{eq} = \dfrac{[Na_2CO_3][CO_2][H_2O]}{[NaHCO_3]^2}$

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5. CHEMISTRY, M5 2023 HSC 7 MC

A mixture of 0.8 mol of $CO(g)$ and 0.8 mol of $H_2(g)$ was placed in a sealed 1.0 L container. The following reaction occurred.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

When equilibrium was established, the mixture contained 0.5 mol of $CO(g)$.

What amount of $H_2(g)$ was present at equilibrium?

A. 0.2 mol

B. 0.4 mol

C. 0.6 mol

D. 1.0 mol

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6. CHEMISTRY, M5 EQ-Bank 10 MC

At a certain temperature, the K_{eq} for the following reaction is 75.

$$2\,O_3\,(g) \rightleftharpoons 3\,O_2\,(g)$$

0.4 mol of O_3 and 1.2 mol of O_2 were introduced to a 5 L reaction vessel.

Which row of the table correctly identifies the direction of the equilibrium shift and the reason for the shift?

	Direction favoured	*Reason*
A.	Left	$Q > K_{eq}$
B.	Left	$Q < K_{eq}$
C.	Right	$Q > K_{eq}$
D.	Right	$Q < K_{eq}$

7. CHEMISTRY, M6 2020 HSC 14 MC

The equation for the autoionisation of water is shown.

$$2\,H_2O\,(l) \rightleftharpoons H_3O^+\,(aq) + OH^-\,(aq)$$

At 50°C the water ionisation constant, K_w, is 5.5×10^{-14}.

What is the pH of water at 50°C?

A. 5.50

B. 6.63

C. 6.93

D. 7.00

8. CHEMISTRY, M5 2019 HSC 17 MC

A student makes a solution with a final volume of 200 mL by mixing 100 mL of 0.0500 mol L $^{-1}$ barium nitrate solution with 100 mL of 0.100 mol L $^{-1}$ sodium hydroxide solution.

Which row of the table correctly identifies if a precipitate will form under these conditions and the reason?

	Will a precipitate form?	*Reason*
A.	Yes	$Q > K_{sp}$
B.	Yes	$Q < K_{sp}$
C.	No	$Q > K_{sp}$
D.	No	$Q < K_{sp}$

9. CHEMISTRY, M5 2021 HSC 19 MC

A quantity of silver nitrate is added to 250.0 mL of 0.100 mol L $^{-1}$ potassium sulfate at 298 K in order to produce a precipitate. Silver nitrate has a molar mass of 169.9 g mol $^{-1}$.

What mass of silver nitrate will cause precipitation to start?

A. 0.00510 g

B. 0.186 g

C. 0.465 g

D. 0.854 g

10. CHEMISTRY, M5 2023 HSC 20 MC

Nitrogen monoxide and oxygen combine to form nitrogen dioxide, according to the following equation.

$$2\,NO\,(g) + O_2\,(g) \rightleftharpoons 2\,NO_2\,(g) \qquad K_{eq} = 2.47 \times 10^{12}$$

A 2.00 L vessel is filled with 1.80 mol of $NO_2\,(g)$ and the system is allowed to reach equilibrium.

What is the equilibrium concentration of $NO\,(g)$?

A. $0.00\ \text{mol L}^{-1}$

B. $4.34 \times 10^{-5}\ \text{mol L}^{-1}$

C. $6.90 \times 10^{-5}\ \text{mol L}^{-1}$

D. $8.69 \times 10^{-5}\ \text{mol L}^{-1}$

11. CHEMISTRY, M5 2024 HSC 15 MC

The thermal decomposition of lithium peroxide (Li_2O_2) is given by the equation shown.

$$2\,Li_2O_2\,(s) \rightleftharpoons 2\,Li_2\,O\,(s) + O_2\,(g)$$

Mixtures of Li_2O_2, Li_2O and O_2 were allowed to reach equilibrium in two identical, closed containers, P and Q, at the same temperature. The amount of $Li_2O_2\,(s)$ in container P is double that in container Q. The amount of $Li_2O\,(s)$ is the same in each container.

What is the ratio of $[O_2\,(g)]$ in container P to $[O_2\,(g)]$ in container Q?

A. $1:1$

B. $2:1$

C. $3:2$

D. $5:4$

12. CHEMISTRY, M5 2024 HSC 18 MC

A reaction mixture, not at equilibrium, is composed of both $N_2O_4\,(g)$ and $NO_2\,(g)$ in a closed container. The reaction quotient for the system, Q, is given.

$$Q = \frac{[NO_2]^2}{[N_2O_4]}$$

The rate of the forward reaction is initially greater than the rate of the reverse reaction.

Which diagram shows how Q changes over time for this mixture?

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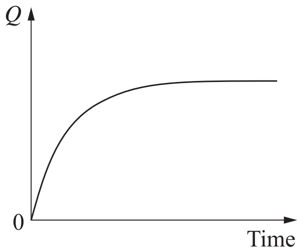

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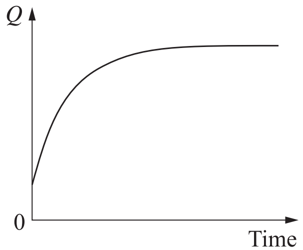

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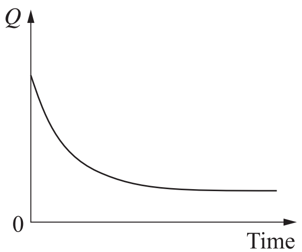

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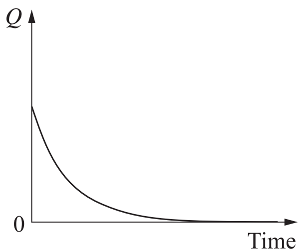

13. CHEMISTRY, M5 EQ-Bank 13 MC

0.20 moles of phosphorus pentachloride were heated to 200°C in a 2 L container in the presence of a vanadium catalyst according to the following reaction.

$$PCl_5\,(g) \rightleftharpoons PCl_3\,(g) + Cl_2\,(g)$$

At equilibrium, the mixture was found to contain 0.16 moles of chlorine.

Which of the following is the equilibrium constant for this reaction at this temperature?

A. 0.32

B. 0.64

C. 1.56

D. 3.13

14. CHEMISTRY, M5 EQ-Bank 22

Hydrogen gas reacts with iodine gas to form hydrogen iodide according to the following equation.

$$H_2\,(g) + I_2\,(g) \rightleftharpoons 2\,HI\,(g) \text{ at 700 k}$$

At equilibrium, the concentrations for H_2, I_2 and HI are as follows: 0.326 mol L^{-1}, 0.326 mol L^{-1} and 2.39 mol L^{-1} respectively.

What is the value of the equilibrium constant for this reaction? ***(2 marks)***

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15. CHEMISTRY, M5 2019 HSC 31

The following reaction occurs in an aqueous solution.

$$HgCl_4{}^{2-}\,(aq) + Cu^{2+}\,(aq) \rightleftharpoons CuCl_4{}^{2-}\,(aq) + Hg^{2+} \qquad K_{eq} = 4.55 \times 10^{-11}$$

A solution containing a mixture of $HgCl_4{}^{2-}\,(aq)$ and $Cu^{2+}\,(aq)$ ions is prepared. The initial concentration of each ion is 0.100 mol L^{-1} and there are no other ions present.

Calculate the concentration of $Hg^{2+}\,(aq)$ ions once the system has reached equilibrium. ***(4 marks)***

16. CHEMISTRY, M5 2024 HSC 23

Consider the following equilibrium system.

$$[Co\,(H_2O)_6]^{2+}\,(aq) + 4\,Cl^-\,(aq) \rightleftharpoons [CoCl_4]^{2-}\,(aq) + 6\,H_2O\,(l)$$

$[Co(H_2O)_6]^{2+}\,(aq)$ is pink and $[CoCl_4]^{2-}\,(aq)$ is blue. When a solution of these ions and chloride ions is heated, the mixture becomes more blue.

Relate the observed colour change to the change in K_{eq}. ***(3 marks)***

17. CHEMISTRY, M5 EQ-Bank 23

Butanoic acid is a natural product and a component of human sweat.

Calculate the value of K_a for butanoic acid if a 0.10 mol L^{-1} solution has a pH of 2.9 at 298 K. ***(3 marks)***

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18. CHEMISTRY, M5 EQ-Bank 24

When a sample of solid silver chloride is added to a 1.00×10^{-2} mol L^{-1} sodium chloride solution, only some of the silver chloride dissolves.

Calculate the equilibrium concentration of silver ions in the resulting solution, given that the K_{sp} of silver chloride is 1.8×10^{-10}. ***(3 marks)***

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19. CHEMISTRY, M5 2023 HSC 31

Copper(II) ions (Cu^{2+}) form a complex with lactic acid $(C_3H_6O_3)$, as shown in the equation.

$$Cu^{2+}(aq) + 2\,C_3H_6O_3(aq) \rightleftharpoons \left[Cu(C_3H_6O_3)_2\right]^{2+}(aq)$$

This complex can be detected by measuring its absorbance at 730 nm. A series of solutions containing known concentrations of $\left[Cu(C_3H_6O_3)_2\right]^{2+}$ were prepared, and their absorbances measured.

Concentration of $\left[Cu(C_3H_6O_3)_2\right]^{2+}$ (mol L^{-1})	*Absorbance*
0.000	0.00
0.010	0.13
0.020	0.28
0.030	0.43
0.040	0.57
0.050	0.72

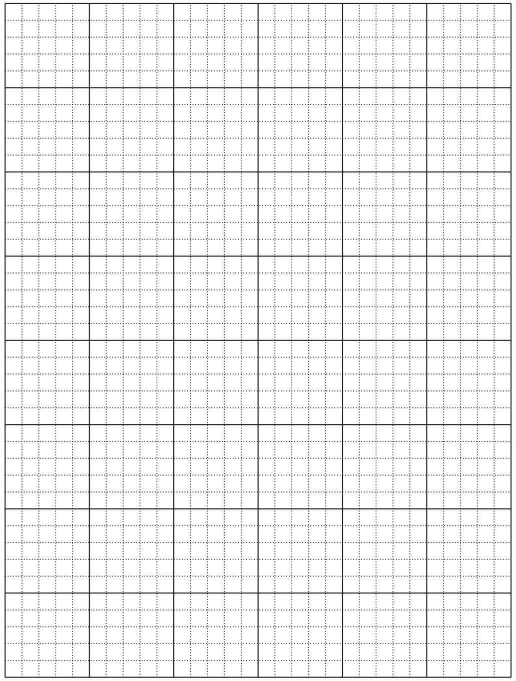
Two solutions containing Cu^{2+} and $C_3H_6O_3$ were mixed. The initial concentrations of each in the resulting solution are shown in the table.

Species	*Initial Concentration* (mol L^{-1})
Cu^{2+}	0.056
$C_3H_6O_3$	0.111

When the solution reached equilibrium, its absorbance at 730 nm was 0.66.

You may assume that under the conditions of this experiment, the only species present in the solution are those present in the equation above, and that $\left[Cu(C_3H_6O_3)_2\right]^{2+}$ is the only species that absorbs at 730 nm.

With the support of a line graph, calculate the equilibrium constant for the reaction. ***(7 marks)***



20. CHEMISTRY, M6 2019 HSC 27

The relationship between the acid dissociation constant, K_a, and the corresponding conjugate base dissociation constant, K_b, is given by:

$$K_a \times K_b = K_w$$

Assume that the temperature for part (a) and part (b) is 25°C.

a. The K_a of hypochlorous acid (HOCl) is 3.0×10^{-8}.

Show that the K_b of the hypochlorite ion, OCl^-, is 3.3×10^{-7}. ***(1 mark)***

b. The conjugate base dissociation constant, K_b, is the equilibrium constant for the following equation:

$$\mathrm{OCl}^-(aq) + \mathrm{H_2O}(l) \rightleftharpoons \mathrm{HOCl}(aq) + \mathrm{OH}^-(aq)$$

Calculate the pH of a 0.20 mol L^{-1} solution of sodium hypochlorite (NaOCl). ***(4 mark)***

21. CHEMISTRY, M5 2020 HSC 35

In aqueous solution, iodide ions (I^-) react rapidly with iodine $(\mathrm{I_2})$ to form triiodide ions $\mathrm{I_3^-}$, making the equilibrium system shown in the chemical equation:

$$\mathrm{I}^-(aq) + \mathrm{I_2}(aq) \rightleftharpoons \mathrm{I_3^-}(aq)$$

The following relationships can be derived from the reaction mechanism:

$$[\mathrm{I}^-]_{eq} = 2[\mathrm{I_2}]_{eq}$$

$$[\mathrm{I}^-]_{initial} = 4[\mathrm{I_2}]_{eq} + 3[\mathrm{I_3^-}]_{eq}$$

where *'initial'* designates the initial concentration and *'eq'* designates the equilibrium concentration.

The absorbance of the solution in the UV-Vis spectrum is given by:

$$A = [\mathrm{I_3^-}] \times 2.76 \times 10^4$$

Determine the value of the equilibrium constant, given that $A = 0.745$ at equilibrium and $[\mathrm{I}^-]_{initial} = 7.00 \times 10^{-4}\ \mathrm{mol\ L^{-1}}$. ***(4 marks)***

22. CHEMISTRY, M5 2021 HSC 31

Ammonia is produced according to the following equilibrium equation.

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

There are 4.50 moles of nitrogen gas, 1.00 mole of hydrogen gas and 5.80 moles of ammonia in a 10.0 L vessel. The system is at equilibrium at 298 K. The value of K_{eq} at this temperature is 748 .

How many moles of nitrogen gas need to be added to the vessel to increase the amount of ammonia by 0.050 moles? ***(4 marks)***

23. CHEMISTRY, M5 2024 HSC 30

An equilibrium mixture of hydrogen, carbon dioxide, water and carbon monoxide is in a closed, 1 L container at a fixed temperature as shown:

$$\mathrm{H_2\,(g) + CO_2\,(g) \rightleftharpoons H_2O\,(g) + CO\,(g)} \qquad K_{eq} = 1.600$$

The initial concentrations are $[\mathrm{H_2}] = 1.000\ \mathrm{mol\ L^{-1}}$, $[\mathrm{CO_2}] = 0.500\ \mathrm{mol\ L^{-1}}$, $[\mathrm{H_2O}] = 0.400\ \mathrm{mol\ L^{-1}}$ and $[\mathrm{CO}] = 2.000\ \mathrm{mol\ L^{-1}}$.

An unknown amount of $\mathrm{CO\,(g)}$ was added to the same container, and the temperature was kept constant. After the new equilibrium had been established, the concentration of $\mathrm{H_2O\,(g)}$ was found to be 0.200 mol L^{-1}.

Using this information, calculate the unknown amount (in mol) of $\mathrm{CO\,(g)}$ that was added to the container. ***(4 marks)***

24. CHEMISTRY, M5 2020 HSC 27

A student makes up a solution of propan-2-amine in water with a concentration of 1.00 mol L^{-1}.

a. Using structural formulae, complete the equation for the reaction of propan-2-amine with water. ***(2 marks)***

$$\boxed{} + H_2O \rightleftharpoons \boxed{} + OH^-$$

b. The equilibrium constant for the reaction of propan-2-amine with water is 4.37×10^{-4}.

Calculate the concentration of hydroxide ions in this solution. ***(3 marks)***

25. CHEMISTRY, M6 2020 HSC 33

Excess solid calcium hydroxide is added to a beaker containing 0.100 L of 2.00 mol L^{-1} hydrochloric acid and the mixture is allowed to come to equilibrium.

a. Show that the amount (in mol) of calcium hydroxide that reacts with the hydrochloric acid is 0.100 mol. ***(2 marks)***

b. It is valid in this instance to make the simplifying assumption that the amount of calcium ions present at equilibrium is equal to the amount generated in the reaction in part (a).

Calculate the pH of the resulting solution. ***(4 marks)***

26. CHEMISTRY, M5 2023 HSC 37

When performing industrial reductions with $CO(g)$, the following equilibrium is of great importance.

$$2\,CO\,(g) \rightleftharpoons CO_2\,(g) + C\,(s) \qquad K_{eq} = 10.00 \text{ at } 1095\,K$$

A 1.00 L sealed vessel at a temperature of 1095 K contains $CO\,(g)$ at a concentration of 1.10 × 10^{-2} mol L^{-1}, $CO_2\,(g)$ at a concentration of 1.21 × 10^{-3} mol L^{-1}, and excess solid carbon.

a. Is the system at equilibrium? Support your answer with calculations. ***(2 marks)***

b. Carbon dioxide gas is added to the system above and the mixture comes to equilibrium. The equilibrium concentrations of $CO\,(g)$ and $CO_2\,(g)$ are equal. Excess solid carbon is present and the temperature remains at 1095 K.

Calculate the amount (in mol) of carbon dioxide added to the system. ***(3 marks)***

27. CHEMISTRY, M5 2024 HSC 39

Water and octan-1-ol do not mix. When an aqueous solution of bromoacetic acid $(\mathrm{BrCH_2COOH})$ is shaken with octan-1-ol, an equilibrium system is established between bromoacetic acid dissolved in the octan-1-ol and in the water.

$$\mathrm{BrCH_2COOH\,(aq)} \rightleftharpoons \mathrm{BrCH_2COOH}\mathit{(octan\text{-}l\text{-}ol)}$$

The equilibrium constant expression for this system is

$$K_{eq} = \frac{[\mathrm{BrCH_2COOH}\mathit{(octan\text{-}l\text{-}ol)}]}{[\mathrm{BrCH_2COOH}\mathit{(aq)}]}.$$

An aqueous solution of bromoacetic acid with an initial concentration of 0.1000 mol L $^{-1}$ is shaken with an equal volume of octan-1-ol. Bromoacetic acid does not dissociate in octan-1-ol but does dissociate in water, with $K_a = 1.29 \times 10^{-3}$. When the system has reached equilibrium, the $[\mathrm{H}^+]$ is 9.18×10^{-3} mol L^{-1}.

Calculate the equilibrium concentration of aqueous bromoacetic acid and hence, or otherwise, calculate the K_{eq} for the octan-1-ol and water system. ***(4 marks)***

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Worked Solutions

1. CHEMISTRY, M5 2019 HSC 16 MC

$$\begin{aligned} K_{eq} &= \frac{[\mathrm{HI}]^2}{[\mathrm{H_2}][\mathrm{I_2}]} \\ &= \frac{0.358^2}{(0.0430)(0.0620)} \\ &= 48.1 \end{aligned}$$

$\Rightarrow B$

2. CHEMISTRY, M5 EQ-Bank 3 MC

→ All elements in the reaction are included in the K_{eq} expression (i.e. no solids or pure liquids are present which would be omitted)

$$K_{eq} = \frac{[\mathrm{NO}]^2[\mathrm{Cl_2}]}{[\mathrm{NOCl}]^2}$$

$\Rightarrow B$

3. CHEMISTRY, M5 2022 HSC 13 MC

	NOBr	NO	Br_2
Initial	0.64	0	0
Change	−0.18	+0.18	+0.09
Equilibrium	0.46	0.18	0.09

$[\mathrm{NO}] = 0.18\ \mathrm{mol\,L^{-1}}$

$[\mathrm{Br_2}] = 0.09\ \mathrm{mol\,L^{-1}}$

$\Rightarrow A$

4. CHEMISTRY, M5 2022 HSC 8 MC

→ The concentrations of solids and pure liquids are omitted from the equilibrium expression because they have a constant concentration.

→ Thus, the equilibrium expression is:

$$K_{eq} = [\mathrm{CO_2}][\mathrm{H_2O}]$$

$\Rightarrow B$

5. CHEMISTRY, M5 2023 HSC 7 MC

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$

	$CO\,(g)$	$2\,H_2\,(g)$	CH_3OH
Initial	0.8	0.8	0
Change	$-x$	$-2x$	$+x$
Equilibrium	0.5	0.2	0.03

$x = 0.3$

$\Rightarrow A$

6. CHEMISTRY, M5 EQ-Bank 10 MC

$$O_2:\ c = \frac{n}{V} = \frac{1.2}{5} = 0.24\,\text{mol L}^{-1}$$

$$O_3:\ c = \frac{n}{V} = \frac{0.4}{5} = 0.08\,\text{mol L}^{-1}$$

$$K_{eq} = \frac{[O_2]^3}{[O_2]^2} = 75\,(\text{given})$$

$$Q = \frac{0.24^3}{0.08^2} = 2.16$$

Since $Q < K_{eq}$, the reaction will shift right to favour the products until $Q = K_{eq}$

$\Rightarrow D$

7. CHEMISTRY, M6 2020 HSC 14 MC

$K_w = [H_3O^+][OH^-]$

Since $[H_3O^+] = [OH^-]$:

$$[H_3O^+]^2 = 5.5 \times 10^{-14}$$

$$[H_3O^+] = 2.3 \times 10^{-7}\ \text{mol L}^{-1}$$

$$\text{pH} = -\log_{10}(2.3 \times 10^{-7}) = 6.63$$

$\Rightarrow B$

8. CHEMISTRY, M5 2019 HSC 17 MC

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

$K_{sp} = 2.55 \times 10^{-4}$

♦♦♦ Mean mark 36%.

$$[Ba^{2+}] = \frac{(0.05)(0.1)}{(0.2)} = 0.025\,\text{M}$$

$$[OH^-] = \frac{(0.1)(0.1)}{(0.2)} = 0.05\,\text{M}$$

$$\begin{aligned} Q &= [Ba^{2+}][OH^-]^2 \\ &= (0.025)(0.05)^2 \\ &= 6.25 \times 10^{-6} \end{aligned}$$

Since $Q < K_{sp}$, no precipitate forms.

$\Rightarrow D$

9. CHEMISTRY, M5 2021 HSC 19 MC

The reaction when silver nitrate is added to potassium sulfate is:

$2AgNO_3(aq) + K_2SO_4(aq) \rightarrow Ag_2SO_4(s) + 2KNO_3(aq)$

♦ Mean mark 45%.

Since each K_2SO_4 molecule has 1 sulfate ion

$[SO_4^{2-}] = K_2SO_4 = 0.100\ \text{mol L}^{-1}$

$Ag_2SO_4(s) \leftrightharpoons 2Ag^+(aq) + SO_4^{2-}(aq)$

$K_{sp} = [Ag^+]^2[SO_4^{2-}]$

From the data sheet:

$K_{sp} = 1.20 \text{ x } 10^{-5}$

$1.20 \text{ x } 10^{-5} = [Ag^+]^2 \times [SO_4^{2-}]$

$1.20 \text{ x } 10^{-5} = [Ag^+]^2 \times [0.100]$

$[Ag^+] = 0.01095\ldots\ \text{mol L}^{-1}$

$[Ag^+] = [AgNO_3]$

$n(AgNO_3) = c \times V = 0.01095\ldots \times 0.250 = 0.00273\ldots\ \text{mol}$

$m(AgNO_3) = n \times MM = 0.00273\ldots \times 169.9 = 0.465\ \text{g}$

$\Rightarrow C$

10. CHEMISTRY, M5 2023 HSC 20 MC

♦♦ Mean mark 34%.

→ As 1.80 mol of $NO_2\,(g)$ is added to the solution, the reverse reaction can be used to determine the equilibrium concentration of $NO\,(g)$.

$$2\,NO_2\,(g) \rightleftharpoons 2\,NO\,(g) + O_2\,(g)$$

→ Reverse reaction $K_{eq} = \dfrac{[O_2][NO]^2}{[NO_2]^2}$

→ Forward reaction K_{eq} is the inverse of K_{eq} of the reverse reaction:

$$K_{eq} = \frac{1}{2.47 \times 10^{12}} = 4.0486 \times 10^{-13}$$

	$2\,NO_2\,(g)$	$2\,NO\,(g)$	$O_2\,(g)$
Initial	0.9	0	0
Change	$-2x$	$+2x$	$+x$
Equilibrium	$0.9-2x$	$2x$	x

→ $-2x$ is very small as the K_{eq} for the reaction is very small, thus $0.9 - 2x \approx 0.9$.

→ By substituting the values into the K_{eq} for the reverse reaction:

$$\begin{aligned} 4.0486 \times 10^{-13} &= \frac{(x)(2x)^2}{(0.9)^2} \\ &= \frac{4x^3}{(0.9)^2} \\ 4x^3 &= 3.279 \times 10^{-13} \\ x &= 4.344 \times 10^{-5} \end{aligned}$$

→ $[NO_2] = 2 \times 4.344 \times 10^{-5} = 8.69 \times 10^{-5}\ \text{mol L}^{-1}$

$\Rightarrow D$

11. CHEMISTRY, M5 2024 HSC 15 MC

♦♦ Mean mark 39%.

→ When calculating the K_{eq} of a system, substances in solid states are all given a value of 1.

→ The equilibrium constant of the above reaction is $K_{eq} = [O_2\,(g)]$.

→ As both mixtures reached equilibrium, the K_{eq} values for each mixture is the same, hence the ratio of $[O_2\,(g)]$ in each container is $1:1$.

$\Rightarrow A$

12. CHEMISTRY, M5 2024 HSC 18 MC

♦ Mean mark 43%.

→ When calculating the reaction quotient of a chemical reaction, the formula is $\dfrac{products}{reactants}$.

→ The equation for the reaction taking place is:

$$N_2O_4\,(g) \rightleftharpoons 2\,NO_2\,(g)$$

→ As the rate of the forward reaction is greater than the rate of the reverse reaction, $[NO_2]^2$ will increase and $[N_2O_4]$ will decrease.

→ Hence the value for the reaction quotient, $\dfrac{[NO_2]^2}{[N_2O_4]}$, will increase.

→ As it states both $N_2O_4\,(g)$ and $NO_2\,(g)$ are present in the intial system, the value for Q will not be zero.

$\Rightarrow B$

13. CHEMISTRY, M5 EQ-Bank 13 MC

$$PCl_5\,(g) \rightleftharpoons PCl_3\,(g) + Cl_2\,(g)$$

$$[PCl_5]_{\text{init}} = \frac{n}{V} = \frac{0.20}{2} = 0.10\,\text{mol L}^{-1}$$

	$[PCl_5]$	$[PCl_3]$	$[Cl_2]$
Initial	0.10	0	0
Change	-0.08	$+0.08$	$+0.08$
Equilibrium	0.02	0.08	0.08

$$K_{eq} = \frac{[PCl_3][Cl_2]}{[PCl_5]} = \frac{0.08^2}{0.02} = 0.32$$

$\Rightarrow A$

14. CHEMISTRY, M5 EQ-Bank 22

$$K_{eq} = \frac{[HI]^2}{[H_2][I_2]} = \frac{2.39^2}{[0.326][0.326]} = 53.7$$

15. CHEMISTRY, M5 2019 HSC 31

$$K_{eq} = \frac{[CuCl_4{}^{2-}][Hg^{2+}]}{[HgCl_4{}^{2-}][Cu^{2+}]}$$

	$[HgCl_4{}^{2-}]$	$[Cu^{2+}]$	$[CuCl_4{}^{2-}]$	$[Hg^{2+}]$
Initial	0.100	0.100	0	0
Change	$-x$	$-x$	$+x$	$+x$
Equilibrium	$0.100 - x$	$0.100 - x$	x	x

Since x is small $\Rightarrow 0.100 - x \approx 0.100$

$$4.55 \times 10^{-11} = \frac{x \times x}{(0.100 - x)(0.100 - x)}$$

$$4.55 \times 10^{-11} = \frac{x^2}{(0.100)^2}$$

$$x^2 = 4.55 \times 10^{-11} \times (0.100)^2$$

$$x = \sqrt{4.55 \times 10^{-11} \times (0.100)^2}$$

$$= 6.75 \times 10^{-7} \text{ mol L}^{-1}$$

$$\therefore [Hg^{2+}] = 6.75 \times 10^{-7} \text{ mol L}^{-1}$$

16. CHEMISTRY, M5 2024 HSC 23

→ When the solution is heated and the mixture becomes more blue, it suggests that the concentration of $[CoCl_4]^{2-}$ (aq) is increasing.

→ The increase in temperature favoured the forward endothermic reaction and shifts the equilibrium position to the products.

→ Therefore the concentrations of $[Co(H_2O)_6]^{2+}$ (aq) and Cl^- (aq) will decrease.

→ As $K_{eq} = \dfrac{[[CoCl_4]^{2-}]}{[[Co(H_2O)_6]^{2+}][Cl^-]^4}$, K_{eq} will increase.

17. CHEMISTRY, M5 EQ-Bank 23

$$C_3H_7COOH\,(aq) \rightleftharpoons C_3H_7COO^-\,(aq) + H^+\,(aq)$$

$$K_a = \frac{[C_3H_7COO^-][H^+]}{[C_3H_7COOH]}$$

$$[H^+] = 10^{-pH}$$
$$= 10^{-2.9}$$
$$= 1.26 \times 10^{-3} \text{ mol L}^{-1}$$

	$[C_3H_7COOH]$	$[C_3H_7COO^-]$	$[H^+]$
Initial	0.10	0	0
Change	-1.26×10^{-3}	$+1.26 \times 10^{-3}$	$+1.26 \times 10^{-3}$
Equilibrium	0.0987	1.26×10^{-3}	1.26×10^{-3}

$$K_a = \frac{(1.26 \times 10^{-3})^2}{0.0987}$$
$$= 1.6 \times 10^{-5}$$

18. CHEMISTRY, M5 EQ-Bank 24

$$AgCl\,(s) \rightleftharpoons Ag^+\,(aq) + Cl^-\,(aq)$$

	$[AgCl\,(s)]$	$[Ag^+\,(aq)]$	$[Cl^-\,(aq)]$
Initial		0	1.00×10^{-2}
Change		$+x$	$+x$
Equilibrium		x	$1.00 \times 10^{-2} + x$

Let $x = [Ag^+]$

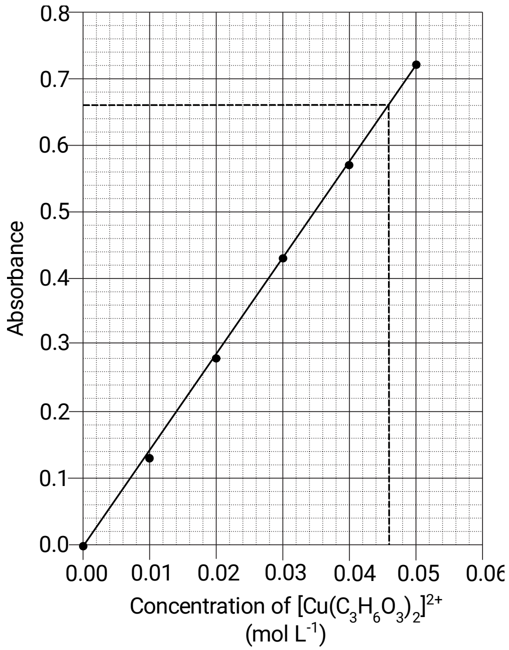
$K_{sp} = [Ag^+][Cl^-]$

$K_{sp} = x(1.00 \times 10^{-2} + x) = 1.80 \times 10^{-10}$

Since x is small, $1.00 \times 10^{-2} + x \approx 1.00 \times 10^{-2}$

$$x\,(1.00 \times 10^{-2}) = 1.80 \times 10^{-10}$$
$$x = 1.80 \times 10^{-8}$$
$$\therefore [Ag^+] = 1.80 \times 10^{-8} \text{ mol L}^{-1}$$

19. CHEMISTRY, M5 2023 HSC 31



From graph:

0.66 absorbance $\Rightarrow$ $\left[[\mathrm{Cu(C_3H_6O_3)_2}]^{2+}\right] = 0.046\ \mathrm{mol\ L^{-1}}$

	Cu^{2+}	$2\,C_3H_6O_3\,(aq)$	$[Cu(C_3H_6O_3)_2]^{2+}\,(aq)$
Initial	0.056	0.111	0
Change	−0.046	−0.092	+0.046
Equilibrium	0.010	0.019	0.046

$$K_{eq} = \frac{\left[[\mathrm{Cu(C_3H_6O_3)_2}]^{2+}\right]}{[\mathrm{Cu^{2+}}][\mathrm{C_3H_6O_3}]^2} = \frac{0.046}{0.010 \times 0.019^2} = 1.3 \times 10^4$$

20. CHEMISTRY, M6 2019 HSC 27

a. $K_a \times K_b = K_w \quad \Rightarrow \quad K_b = \dfrac{K_w}{K_a}$

$$K_b = \frac{1.0 \times 10^{-14}}{3.0 \times 10^{-8}} = 3.3 \times 10^{-7}$$

b. $\mathrm{OCl^-\,(aq) + H_2O\,(l) \rightleftharpoons HOCl\,(aq) + OH^-\,(aq)}$

♦ Mean mark (b) 45%.

	OCl^-	HOCl	OH^-
Initial	0.20	0	0
Change	$-x$	$+x$	$+x$
Equilibrium	$0.20 - x$	x	x

$$K_b = \frac{[\mathrm{HOCl}][\mathrm{OH^-}]}{[\mathrm{OCl^-}]} = \frac{x^2}{(0.20 - x)}$$

Assume $0.20 - x \approx 0.20$ because x is negligible:

$$3.3 \times 10^{-7} = \frac{x^2}{0.20 - x}$$

$$x = \sqrt{3.3 \times 10^{-7} \times 0.20} = 2.5690 \times 10^{-4}\ \mathrm{mol\ L^{-1}}$$

$[\mathrm{OH^-}] = 2.5690 \times 10^{-4}\ \mathrm{mol\ L^{-1}}$

$\mathrm{pOH} = -\log_{10}[\mathrm{OH^-}] = -\log_{10}(2.5690 \times 10^{-4}) = 3.59$

$\therefore \mathrm{pH} = 14 - 3.59 = 10.41$

21. CHEMISTRY, M5 2020 HSC 35

Mean mark 55%.

$$\text{A} = [\text{I}_3{}^-]_{\text{eq}} \times 2.76 \times 10^4$$
$$0.745 = [\text{I}_3{}^-]_{\text{eq}} \times 2.76 \times 10^4$$
$$[\text{I}_3{}^-]_{\text{eq}} = 2.70 \times 10^{-5}\ \text{mol L}^{-1}$$

$$[\text{I}^-]_{\text{initial}} = 4\,[\text{I}_2]_{\text{eq}} + 3\,[\text{I}_3{}^-]_{\text{eq}}$$
$$7.00 \times 10^{-4} = 4[\text{I}_2]_{\text{eq}} + \left(3 \times 2.70 \times 10^{-5}\right)$$
$$[\text{I}_2]_{\text{eq}} = \frac{7.00 \times 10^{-4} - \left(3 \times 2.70 \times 10^{-5}\right)}{4}$$
$$= 1.55 \times 10^{-4}\ \text{mol L}^{-1}$$

$$[\text{I}^-]_{\text{eq}} = 2[\text{I}_2]_{\text{eq}} = 2 \times \left(1.55 \times 10^{-4}\right) = 3.10 \times 10^{-4}\ \text{mol L}^{-1}$$

$$K_{\text{eq}} = \frac{[\text{I}_3{}^-]_{\text{eq}}}{[\text{I}^-]_{\text{eq}} \times [\text{I}_2]_{\text{eq}}}$$
$$= \frac{2.70 \times 10^{-5}}{3.10 \times 10^{-4} \times 1.55 \times 10^{-4}}$$
$$= 564$$

22. CHEMISTRY, M5 2021 HSC 31

	N_2	+ $3H_2$	$\leftrightharpoons$ $2NH_3$
Initial	$(4.5 + x)$ moles	1.0 moles	5.8 moles
Change	-0.025 moles	-0.075 moles	$+0.05$ moles
Equilibrium	$(4.475 + x)$ moles	0.925 moles	5.85 moles
Equilibrium concentration	$\frac{4.475 + x}{10}$ mol L^{-1}	0.0925 mol L^{-1}	0.585 mol L^{-1}

♦ Mean mark 44%.

$$K_{eq} = \frac{[NH_3]^2}{[N_2][H_2]^3}$$
$$748 = \frac{0.585^2}{\frac{4.475+x}{10} \times 0.0925^3}$$
$$748 \times \frac{4.475 + x}{10} \times 0.0925^3 = 0.585^2$$
$$\frac{4.475 + x}{10} = \frac{0.585^2}{748 \times 0.0925^3}$$
$$4.475 + x = \frac{10 \times 0.585^2}{748 \times 0.0925^3}$$
$$x = \frac{10 \times 0.585^2}{748 \times 0.0925^3} - 4.475$$
$$= 1.3 \text{ moles (1 d.p.)}$$

∴ 1.3 moles of nitrogen must be added to the equilibrium mixture.

23. CHEMISTRY, M5 2024 HSC 30

→ $n_{\text{intial}}(CO(g)) = 0.400$ and $n_{\text{final}}(CO(g)) = 0.200$.

♦ Mean mark 55%.

→

Change in the number of moles in $CO(g) = 0.400 - 0.200 = 0.200$ mol in 1 L

	$H_2(g)$	$CO_2(g)$	$H_2O(g)$	$CO_2(g)$
Initial	1	0.5	0.4	$2+x$
Change	$+0.2$	$+0.2$	-0.2	-0.2
Equilibrium	1.2	0.7	0.2	$1.8+x$

→ Since all substances are present in a 1 L container, the concentrations of each substance is equal to the number of moles of that substance present at equilibrium

$$K_{eq} = \frac{[H_2O(g)][CO(g)]}{[H_2(g)][CO_2(g)]}$$

$$1.600 = \frac{0.2 \times (1.8+x)}{1.2 \times 0.7}$$

$$1.8 + x = 1.6 \times \frac{1.2 \times 0.7}{0.2}$$

$$x = 6.72 - 1.8$$

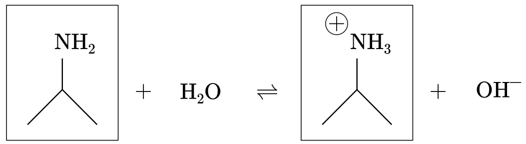
$$= 4.92 \text{ mol}$$

→ 4.92 mol of $CO(g)$ were added to the container.

24. CHEMISTRY, M5 2020 HSC 27

a.

♦ Mean mark (a) 48%.



b.

Mean mark (b) 51%.

	$C_3H_7NH_2$	$C_3H_7NH_3$	OH^-
Initial	1.00	0	0
Change	$-x$	$+x$	$+x$
Equilibrium	$1.00-x$	x	x

$$K_b = \frac{[C_3H_7NH_3{}^+][OH^-]}{[C_3H_7NH_2]} = \frac{x^2}{(1.00-x)}$$

Assume $1.00 - x = 1.00$ because x is negligible:

$$4.37 \times 10^{-4} = \frac{x^2}{1.00}$$

$$x = \sqrt{4.37 \times 10^{-4}}$$

$$= 0.0209 \text{ mol L}^{-1}$$

$\Rightarrow [OH^-] = 0.0209 \text{ mol L}^{-1}$

25. CHEMISTRY, M6 2020 HSC 33

a. $Ca(OH)_2\,(s) + 2\,HCl\,(aq) \longrightarrow CaCl_2\,(aq) + 2\,H_2O\,(l)$

$n(HCl) = c \times V = 2.00 \times 0.100 \; = 0.200 \text{ mol}$

$$n(Ca(OH)_2) = \frac{n(HCL)}{2} = \frac{0.200}{2} = 0.100\,\text{mol}$$

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

♦♦♦ Mean mark (b) 20%.

$$[Ca^{2+}] = \frac{n}{V} = \frac{0.100}{0.100} = 1.00 \text{ mol L}^{-1}$$

$$\begin{aligned} K_{sp} &= [Ca^{2+}][OH^-]^2 \\ 5.02 \times 10^{-6} &= 1.00 \times [OH^-]^2 \\ [OH^-] &= \sqrt{5.02 \times 10^{-6}} \\ &= 2.24 \times 10^{-3} \text{ mol L}^{-1} \\ pOH &= -\log_{10}(2.24 \times 10^{-3}) \\ &= 2.650 \end{aligned}$$

$\therefore\ pH = 14 - 2.650 = 11.35$

26. CHEMISTRY, M5 2023 HSC 37

a. $$\begin{aligned} Q &= \frac{[CO_2]}{[CO]^2} \\ &= \frac{1.21 \times 10^{-3}}{(1.10 \times 10^{-2})^2} \\ &= 10.0 \end{aligned}$$

Since $Q = K_{eq}$, system is in equilibrium.

♦♦♦ Mean mark (b) 24%.

b. Given $[CO] = [CO_2]$,

$$K_{eq} = \frac{[CO_2]}{[CO]^2} = \frac{1}{[CO]} = 10.00$$

$$\Rightarrow [CO] = \frac{1}{10.00} = 0.1000\,\text{mol L}^{-1}$$

$$\Rightarrow [CO_2] = 0.1000\,\text{mol L}^{-1}$$

From this point, the change in CO and CO_2 concentrations can be calculated...

	$2\,CO\,(g)$	$CO_2\,(g)$	$C\,(s)$
Initial	1.10×10^{-2}	1.21×10^{-3}	
Change	$+0.0890$	$+0.0988$	
Equilibrium	0.1000	0.1000	

However, the change in moles of CO_2 in the system consists of:

- Change in CO_2 concentration
- Change in CO concentration (as some of the added CO_2 was converted into CO)

$n(CO_2)$ required to increase $[CO]$ by 0.0988 mol (1 litre vessel)

Formula ratio shows $CO_2 : CO = 1 \text{ mol} : 2 \text{ mol}$

$n(CO_2)$ to add to increase $[CO_2] = 0.0988$ mol (1 litre vessel)

$n(CO_2)_{\text{total to add}} = 0.0988 \text{ mol} + n(CO_2 \text{ to make } CO)$

$$n(CO_2) \text{ to add to increase } [CO] = \frac{0.0890}{2} = 0.0445 \text{ mol}$$

$n(CO_2)_{\text{total to add}} = 0.0988 + 0.0445 = 0.143 \text{ mol}$

27. CHEMISTRY, M5 2024 HSC 39

→ The ionisation of bromoacetic acid in water is:

$$\mathrm{BrCH_2COOH\,(aq)} \rightleftharpoons \mathrm{BrCH_2COO^-\,(aq)} + \mathrm{H^+\,(aq)}$$

→ At equilibrium
$[\mathrm{BrCH_2COO^-\,(aq)}] = [\mathrm{H^+\,(aq)}] = 9.18 \times 10^{-3}\ \mathrm{mol\ L^{-1}}$ as the are formed in a $1:1$.

♦♦ Mean mark 27%.
COMMENT: Students who identified the acid conc in the organic solvent often succeeded in this question.

$$K_a = \frac{[\mathrm{H^+}][\mathrm{BrCH_2COO^-}]}{[\mathrm{BrCH_2COOH}]_{\mathrm{eq}}}$$

$$[\mathrm{BrCH_2COOH}]_{\mathrm{eq}} = \frac{[\mathrm{H^+}][\mathrm{BrCH_2COO^-}]}{K_a}$$

$$= \frac{(9.18 \times 10^{-3})^2}{1.29 \times 10^{-3}}$$

$$= 0.06533\ \mathrm{mol\ L^{-1}}$$

$$[\mathrm{BrCH_2COOH}]_{\mathrm{total}} = [\mathrm{BrCH_2COOH\,(aq)}]_{\mathrm{eq}} + [\mathrm{BrCH_2COO^-\,(aq)}] + [\mathrm{BrCH_2COOH(octan\text{-}1\text{-}ol)}]_{\mathrm{eq}}$$

$$[\mathrm{BrCH_2COOH(octan\text{-}1\text{-}ol)}]_{\mathrm{eq}} = 0.1000 - 0.06533 - 9.18 \times 10^{-3} = 0.02549\ \mathrm{mol\ L^{-1}}$$

→ Since the volume of the aqueous solution of bromoacetic acid and octane is the same, the concentration values between the water and octane solutions can be added/subtracted in one equation and mole calculations are not required.

$$K_{eq} = \frac{[\mathrm{BrCH_2COOH(octan\text{-}1\text{-}ol)}]_{\mathrm{eq}}}{[\mathrm{BrCH_2COOH\,(aq)}]_{\mathrm{eq}}} = \frac{0.02549}{0.06533} = 0.390\ (3\ \text{sig. fig.})$$