CHEMISTRY
Stage 6

Module 5: Equilibrium and Acid Reactions
Solution Equilibria

Teacher: Samantha Wong

Exam Equivalent Time: 112.5 minutes *(based on allocation of 1.5 minutes per mark)*

Questions

1. CHEMISTRY, M5 2019 HSC 3 MC

Which of the following metal carbonates has the highest molar solubility?

A. Calcium carbonate

B. Copper(II) carbonate

C. Iron(II) carbonate

D. Lead(II) carbonate

2. CHEMISTRY, M5 2023 HSC 4 MC

Sodium chloride dissolves in water according to the following equation.

$$NaCl(s) \rightleftharpoons Na^{+}(aq) + Cl^{-}(aq)$$

A saturated solution of $NaCl$ in water contains sodium and chloride ions at the following concentrations.

Ion	*Concentration* $(mol\ L^{-1})$
Na^{+}	6.13
Cl^{-}	6.13

What is the K_{sp} of sodium chloride?

A. 2.65×10^{-2}

B. 8.16×10^{-2}

C. 12.26

D. 37.6

3. CHEMISTRY, M5 2024 HSC 2 MC

Aboriginal and Torres Strait Islander Peoples have used leaching in flowing water over several days to prepare various foods from plants that can be toxic to humans.

What was the reason for this?

A. To react with toxins

B. To dissolve low solubility toxins

C. To prevent the food from decomposing

D. To break down compounds that are difficult to digest

4. CHEMISTRY, M5 2020 HSC 11 MC

Equal volumes of two 0.04 mol L $^{-1}$ solutions were mixed together.

Which pair of solutions would give the greatest mass of precipitate?

A. $Ba(OH)_2$ and $MgCl_2$

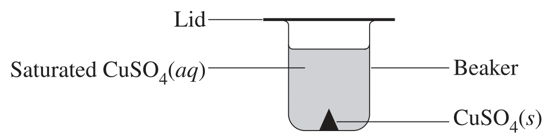
B. $Ba(OH)_2$ and $MgSO_4$

C. $Ba(OH)_2$ and $NaCl$

D. $Ba(OH)_2$ and Na_2SO_4

5. CHEMISTRY, M5 2020 HSC 17 MC

The following apparatus was set up in a temperature-controlled laboratory.



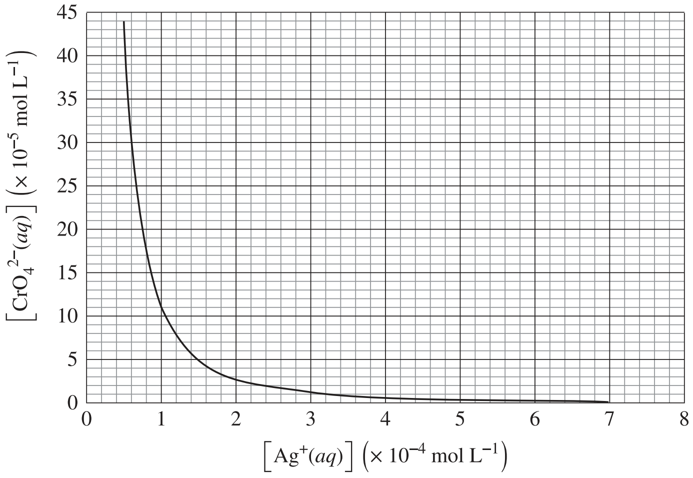
Excess solid sodium hydroxide is added to the beaker.

Which row of the table correctly identifies the change in the $CuSO_4(s)$ mass and the colour of the solution after several days?

	Solid $CuSO_4$ mass	*Colour of solution*
A.	No change	No change
B.	No change	Blue colour fades
C.	Decreases	Blue colour intensifies
D.	Decreases	Blue colour fades

6. CHEMISTRY, M5 2020 HSC 20 MC

The graph shows the concentration of silver and chromate ions which can exist in a saturated solution of silver chromate.



Based on the information provided, what is the K_{sp} for silver chromate?

A. 1.1×10^{-8}

B. 2.2×10^{-8}

C. 1.1×10^{-12}

D. 4.4×10^{-12}

7. CHEMISTRY, M5 2022 HSC 19 MC

What is the molar solubility of iron(II) hydroxide?

A. 2.3×10^{-6} mol L^{-1}

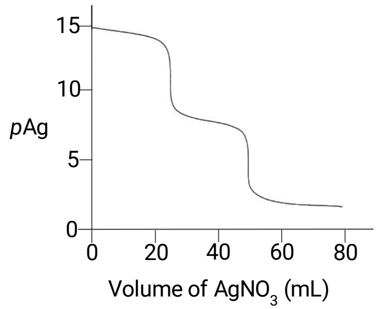
B. 2.9×10^{-6} mol L^{-1}

C. 3.7×10^{-6} mol L^{-1}

D. 4.9×10^{-9} mol L^{-1}

8. CHEMISTRY, M5 2023 HSC 16 MC

A solution contains potassium iodide and potassium chloride. It was analysed by performing a precipitation titration using silver nitrate. The titration curve for this reaction is shown, where $p\,\mathrm{Ag} = -\log_{10}[\mathrm{Ag}^+]$.



Why is this a valid and correct procedure for quantifying the amount of each anion present in the mixture?

A. $AgCl$ would precipitate out first, followed by AgI.

B. AgI would precipitate out first, followed by $AgCl$.

C. Both AgI and $AgCl$ precipitate out of the solution together.

D. Neither $AgCl$ nor AgI would precipitate out of the solution.

9. CHEMISTRY, M5 2023 HSC 17 MC

What mass of lead(II) iodide (MM = 461 g mol^{-1}) will dissolve in 375 mL of water?

A. 0.233 g

B. 0.293 g

C. 0.369 g

D. 0.621 g

10. CHEMISTRY, M5 2024 HSC 11 MC

Which is the correct expression for calculating the solubility (in mol L^{-1}) of lead(II) iodide in a 0.1 mol L^{-1} solution of NaI at 25°C?

A. $\dfrac{9.8 \times 10^{-9}}{2 \times 0.1}$

B. $\dfrac{9.8 \times 10^{-9}}{(2 \times 0.1)^2}$

C. $\dfrac{9.8 \times 10^{-9}}{0.1}$

D. $\dfrac{9.8 \times 10^{-9}}{(0.1)^2}$

11. CHEMISTRY, M5 EQ-Bank 15 MC

What will happen when sulfuric acid is added to a saturated solution of sparingly soluble calcium sulfate?

A. The concentration of calcium and sulfate ions will increase over time due to the presence of H^+ ions.

B. The concentration of calcium and sulfate ions will decrease over time due to the presence of H^+ ions.

C. The concentration of calcium and sulfate ions will increase over time due to the presence of SO_4^{2-} ions.

D. The concentration of calcium and sulfate ions will decrease over time due to the presence of SO_4^{2-} ions.

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12. CHEMISTRY, M5 2019 HSC 18 MC

Consider the following equilibrium.

$HF\,(aq) + CF_3COO^-\,(aq) \rightleftharpoons F^-\,(aq) + CF_3COOH\,(aq) \qquad K_{eq} = 3.80 \times 10^{-4}$

Which row of the table correctly identifies the strongest acid and the strongest base in this system?

	Strongest acid	Strongest base
A.	$CF_3OOH\,(aq)$	$F^-\,(aq)$
B.	$CF_3OOH\,(aq)$	$CF_3OO^-\,(aq)$
C.	$HF\,(aq)$	$F^-\,(aq)$
D.	$HF\,(aq)$	$CF_3OO^-\,(aq)$

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13. CHEMISTRY, M5 2022 HSC 17 MC

A 2.0 g sample of silver carbonate (MM = 275.81 g mol $^{-1}$) was added to 100.0 mL of water in a beaker. The solubility of silver carbonate at this temperature is 1.2×10^{-4} mol L $^{-1}$. It was then diluted by adding another 100.0 mL of water.

What is the ratio of the concentration of silver ions in solution before and after dilution?

A. $1:1$

B. $1:2$

C. $2:1$

D. $4:1$

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14. 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)***

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15. 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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16. CHEMISTRY, M5 EQ-Bank 26

The diagrams represent equipment used in an investigation to determine the chloride ion concentration in a water sample.

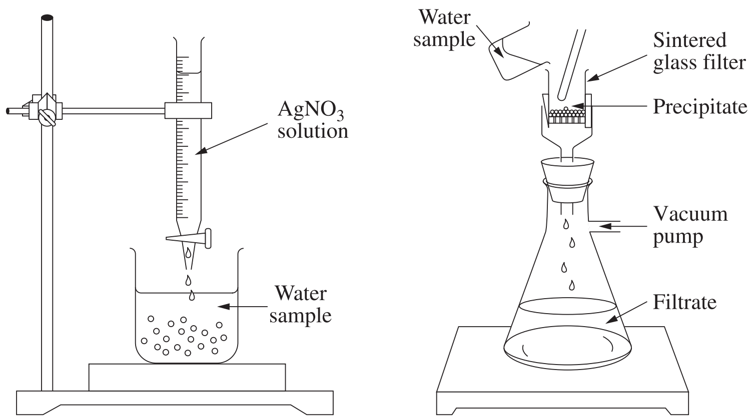

Figure 1 Figure 2

Describe how the chloride ion concentration in a water sample can be determined using the equipment in the diagrams. Include a relevant chemical equation. ***(3 marks)***

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17. CHEMISTRY, M5 EQ-Bank 28

A 100 mL saturated solution of calcium hydroxide at 25°C contains 0.173 g of calcium hydroxide.

a. Calculate the solubility product (K_{sp}) of this salt at 25°C. ***(3 marks)***

b. Explain why the undissolved solid is not included in the expression for the solubility product constant. ***(1 marks)***

18. CHEMISTRY, M5 EQ-Bank 29

The information in the table shows how the solubility of lead chloride is affected by temperature.

Temperature (°C)	*Solubility* (g/100 g water)
0	0.25
20	0.35
40	0.55
60	0.90
80	1.75
100	3.20

Using a graph, calculate the solubility product (K_{sp}) of the dissolution of lead chloride at 50°C. Include a fully labelled graph and a relevant chemical equation in your answer ***(6 marks)***

19. CHEMISTRY, M5 2020 HSC 35

In aqueous solution, iodide ions (I^-) react rapidly with iodine (I_2) to form triiodide ions 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)***

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20. CHEMISTRY, M5 2021 HSC 27

An experiment is carried out to determine the K_{sp} value for lithium phosphate $(\mathrm{Li_3PO_4})$.

Five samples of $\mathrm{Li^+}$ ion solution were prepared, and a different solution of $\mathrm{PO_4}^{3-}$ was added to each of them. Columns 2 and 3 of the table show the values before any reaction occurs.

Sample	$[\mathrm{Li^+}]$ (mol L^{-1})	$[\mathrm{PO_4}^{3-}]$ (mol L^{-1})	*Observation*
1	0.15	0.00010	No precipitate
2	0.15	0.0010	No precipitate
3	0.15	0.010	No precipitate
4	0.15	0.10	White precipitate
5	0.15	1.00	Heavy white precipitate

a. Calculate the range within which the K_{sp} value of lithium phosphate lies. ***(4 marks)***

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b. Justify ONE way in which the procedure of this investigation could be improved to increase the accuracy of the calculated result. ***(2 marks)***

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21. CHEMISTRY, M5 2022 HSC 31

Silver ions form the following complex with ammonia solution.

$$Ag^{+}(aq) + 2\,NH_3(aq) \rightleftharpoons [Ag(NH_3)_2]^{+}(aq)$$

The equilibrium constant is 1.6×10^7 at 25°C.

a. In order to determine the free Ag^{+} concentration in an aqueous ammonia solution, a student carried out a precipitation titration with $NaI\,(aq)$ as the titrant.

Evaluate the suitability of this method. *(3 marks)*

b. If 0.010% of the total silver ions in solution are present as $Ag^{+}(aq)$ at equilibrium, calculate the equilibrium concentration of aqueous ammonia in this solution. *(4 marks)*

22. CHEMISTRY, M5 2022 HSC 35

A precipitate of strontium hydroxide $\mathrm{Sr(OH)_2}$, (MM = 121.63 g mol $^{-1}$) was produced when 80.0 mL of 1.50 mol L $^{-1}$ strontium nitrate solution was mixed with 80.0 mL of 0.855 mol L $^{-1}$ sodium hydroxide solution. The mass of the dried precipitate was 3.93 g.

What is the K_{sp} of strontium hydroxide? ***(5 marks)***

23. CHEMISTRY, M5 2023 HSC 34

When 125 mL of a magnesium nitrate solution is mixed with 175 mL of a 1.50 mol L^{-1} sodium fluoride solution, 0.6231 g of magnesium fluoride (MM = 62.31 g mol^{-1}) precipitates. The K_{sp} of magnesium fluoride is 5.16×10^{-11}.

Calculate the equilibrium concentration of magnesium ions in this solution. ***(5 marks)***

24. CHEMISTRY, M5 2024 HSC 32

Calculate the concentration of cadmium ions in a saturated solution of cadmium(II) phosphate, $Cd_3(PO_4)_2,\ K_{sp} = 2.53 \times 10^{-33}$. ***(4 marks)***

25. CHEMISTRY, M8 2019 HSC 29

Stormwater from a mine site has been found to be contaminated with copper(II) and lead(II) ions. The required discharge limit is 1.0 mg L^{-1} for each metal ion. Treatment of the stormwater with $Ca(OH)_2$ solid to remove the metal ions is recommended.

a. Explain the recommended treatment with reference to solubility. Include a relevant chemical equation. ***(2 marks)***

b. Explain why atomic absorption spectroscopy can be used to determine the concentrations of Cu^{2+} and Pb^{2+} ions in a solution containing both species. ***(2 marks)***

c. The data below were obtained after treatment of the stormwater.

Data from atomic absorption spectroscopy

Concentration ($\times 10^{-5}$ mol L^{-1})	*Absorbance*	
Cu^{2+} or Pb^{2+}	Cu^{2+}	Pb^{2+}
0.0	0.000	0.000
1.0	0.140	0.090
2.0	0.310	0.180
4.0	0.520	0.390
6.0	0.840	0.530
Water sample before treatment	0.820	0.440
Water sample after treatment	0.040	0.080

To what extent is the treatment effective in meeting the required discharge limit of 1.0 mg L^{-1} for each metal ion? Support your conclusion with calibration curves and calculations. ***(7 marks)***

Worked Solutions

1. CHEMISTRY, M5 2019 HSC 3 MC

→ Calcium carbonate has the greatest solubility product among the listed metal carbonates.

→ Since all of these metal carbonates release the same amount of ions in solutions, their solubility products can be directly compared to determine which substance is most soluble.

$\Rightarrow A$

2. CHEMISTRY, M5 2023 HSC 4 MC

$NaCl(s) \rightleftharpoons Na^+(aq) + Cl^-(aq)$

$K_{sp} = \dfrac{[Na^+][Cl^-]}{[NaCl]}$

Since NaCl is a solid, its concentration is assumed to be 1

$K_{sp} = 6.13 \times 6.13$

$= 37.6$

$\Rightarrow D$

3. CHEMISTRY, M5 2024 HSC 2 MC

→ The toxins form a equilibrium system: $\text{toxins}(s) \rightleftharpoons \text{toxins}(aq)$

→ As the water flows away, the concentration of aqueous toxins decreases which shifts the equilibrium system to the right, causing more low solubility toxins to break down.

$\Rightarrow B$

4. CHEMISTRY, M5 2020 HSC 11 MC

$Ba(OH)_2(aq) + MgSO_4(aq) \longrightarrow BaSO_4(s) + Mg(OH)_2(s)$

→ Reaction B produces 2 molecules of precipitate

→ Reactions A and D produce 1 molecule of precipitate each

→ Reaction C does not produce a precipitate.

$\Rightarrow B$

Worked Solutions

5. CHEMISTRY, M5 2020 HSC 17 MC

$CuSO_4\,(s) \rightleftharpoons Cu^{2+}\,(aq) + SO_4{}^{2-}\,(aq)$

→ The addition of $NaOH$ to the solution would result in a precipitate $Cu(OH)_2$ and thus decreases the amount of Cu^{2+} ions.

♦♦ Mean mark 35%.

→ According to Le Chatlelier's Principle, the system would shift right in an attempt to counteract the change and increase $[Cu^{2+}]$, thereby decreasing the mass of the precipitate.

→ The blue colour will fade since the $[Cu^{2+}]$ in the final solution is less.

$\Rightarrow D$

6. CHEMISTRY, M5 2020 HSC 20 MC

When $[Ag^+] = 1 \times 10^{-4}\ \text{mol L}^{-1}$,

$CrO_4{}^{2-} = 11 \times\ 10^{-5}\ \text{mol L}^{-1}$

♦ Mean mark 43%.

$$\begin{aligned} K_{sp} &= [Ag^+]^2[CrO_4{}^{2-}] \\ &= (1 \times 10^{-4})^2(11 \times 10^{-5}) \\ &= 1.1 \times 10^{-12}\ \text{mol L}^{-1} \end{aligned}$$

$\Rightarrow C$

7. CHEMISTRY, M5 2022 HSC 19 MC

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

Solids are not included in the K_{sp} expression

♦ Mean mark 45%.

	Fe^{2+}	OH^-
Initial	0	0
Change	$+x$	$+2x$
Equilibrium	x	$2x$

$$K_{sp} = [Fe^{2+}][OH^-]^2$$

$$4.87 \times 10^{-17} = x \times (2x)^2$$

$$4.87 \times 10^{-17} = 4x^3$$

$$\therefore x = \sqrt[3]{\frac{4.87 \times 10^{-17}}{4}}$$

$$= 2.30 \times 10^{-6}\ \text{mol L}^{-1}$$

$\Rightarrow A$

8. CHEMISTRY, M5 2023 HSC 16 MC

→ This procedure is only correct and valid if the ions precipitated out at different times.

♦ Mean mark 41%.

→ Therefore AgI would precipitate out first as it is less soluble than $AgCl$.

$\Rightarrow B$

9. CHEMISTRY, M5 2023 HSC 17 MC

→ $PbI_2 \rightleftharpoons Pb^{2+} + 2I^-$ $\quad K_{sp} = 9.8 \times 10^{-9}$ (from data sheet)

$$\begin{aligned} K_{sp} &= [Pb^{2+}][2I^-]^2 \\ 9.8 \times 10^{-9} &= [x][2x]^2 \\ x^3 &= \frac{9.8 \times 10^{-9}}{4} \\ x &= 0.001348\ \text{mol L}^{-1} \end{aligned}$$

Mass in 1 L $= 0.001348 \times 461 = 0.62147$ g

Mass in 375 mL $= 0.62147 \times 0.375 = 0.233$ g

$\Rightarrow A$

10. CHEMISTRY, M5 2024 HSC 11 MC

$PbI_2\,(s) \rightleftharpoons Pb^{2+}\,(aq) + 2I^-\,(aq)$

♦ Mean mark 55%.

→ Let the solubility of $PbI_2 = x\ \text{mol L}^{-1}$

Concentration (mol/L)	PbI_2	Pb^{2+}	$2I^-$
Initial	–	0	0.1
Change	–	$+x$	$+2x$
Equilibrium	–	x	$0.1 + 2x$

→ As x is very small, assume $0.1 + 2x \approx 0.1$

$$K_{sp} = [Pb^{2+}][I^-]^2 = 9.8 \times 10^{-9}$$

$$K_{sp} = 0.1^2 \times x = 9.8 \times 10^{-9}$$

$$\therefore x = \frac{9.8 \times 10^{-9}}{0.1^2}$$

$\Rightarrow D$

11. CHEMISTRY, M5 EQ-Bank 15 MC

→ The saturated solution of calcium sulfate is originally at equilibrium

$$\mathrm{CaSO_4\,(s)} \rightleftharpoons \mathrm{Ca^{2+}\,(aq)} + \mathrm{SO_4{}^{2-}\,(aq)}$$

→ The addition of sulfuric acid increases the concentration of $\mathrm{SO_4{}^{2-}}$ (sulfate) ions in solution.

→ By Le Chatelier's principle, the above equilibrium will shift left to counteract this, decreasing the concentration of calcium and sulfate ions over time.

$\Rightarrow D$

12. CHEMISTRY, M5 2019 HSC 18 MC

♦♦♦ Mean mark 23%.

→ The small size of K_{eq} means that there is a higher concentration of reactants than products at equilibrium.

→ This shifts the equilibrium towards the reactants, which means that the reverse reaction is more likely to occur.

→ Because $\mathrm{F^-}$ is more likely to accept a proton than $\mathrm{CF_3COO^-}$, it is a stronger base.

→ On the other hand, $\mathrm{CF_3COO^-}$ is more likely to donate a proton than HF, making it the stronger acid.

$\Rightarrow A$

13. CHEMISTRY, M5 2022 HSC 17 MC

♦♦♦ Mean mark 15%.

The maximum moles of $\mathrm{Ag_2CO_3}$ that can be dissolved in 100.0 mL is:

$$\begin{aligned} \mathrm{n(Ag_2CO_3)_{max}} &= 1.2 \times 10^{-4} \times 0.1000 \\ &= 1.2 \times 10^{-5}\ \mathrm{mol} \end{aligned}$$

The number of moles of silver carbonate added to the water is:

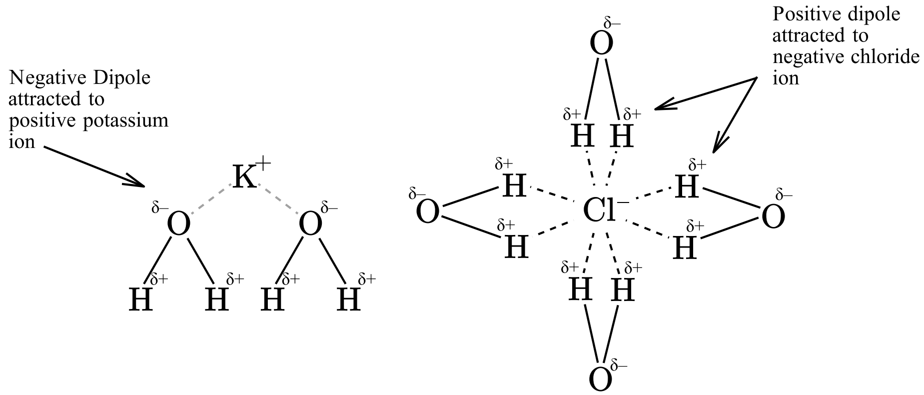
$$\begin{aligned} \mathrm{n(Ag_2CO_3)} &= \frac{\mathrm{m}}{\mathrm{MM}} \\ &= \frac{2.0}{275.81} \\ &= 7.2514 \times 10^{-3}\ \mathrm{mol} \end{aligned}$$

→ Thus, the moles of $\mathrm{Ag_2CO_3}$ added is more than the maximum moles of $\mathrm{Ag_2CO_3}$ able to be dissolved. i.e. the solution would be saturated before and after dilution.

→ As a result, the solution would have the same $\mathrm{Ag_2CO_3}$ concentration before and after, thus, the ratio is 1:1.

$\Rightarrow A$

14. 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.

15. CHEMISTRY, M5 EQ-Bank 24

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

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

Let $x = [\mathrm{Ag^+}]$

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

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

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

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

16. CHEMISTRY, M5 EQ-Bank 26

→ When the silver nitrate solution is added, chloride ions present in the water sample will precipitate with the added silver ions described by the following equation:

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

→ Adding excess silver nitrate ensures all chloride ions precipitate out.

→ The filtering apparatus is used to filter solid silver chloride. This solid is then dried to constant mass and weighed.

→ Using the molar mass of silver chloride, the number of moles of solid silver chloride produced is calculated. Silver chloride contains silver ions and chloride ions in a 1:1 molar ratio and using this ratio, the moles of chloride present is calculated.

→ The result represents the same number of moles of chloride in the original water sample. Using the volume of the water sample, its chloride ion concentration is calculated.

17. CHEMISTRY, M5 EQ-Bank 28

a. $CaOH_2 (s) \rightleftharpoons Ca^{2+} (aq) + 2\,OH^- (aq)$

$\text{Solubility} = 0.173\,g/100\,mL = 1.73\,g/L$

$$n = \frac{m}{MM} = \frac{1.73}{74.093} = 0.00233\,mol$$

$[Ca^{2+}] = 0.0233\,mol\,L^{-1}$

$\text{Mole ratio } Ca^{2+} : OH^- = 1:2$

$K_{sp} = [Ca^{2+}][OH^-]^2$

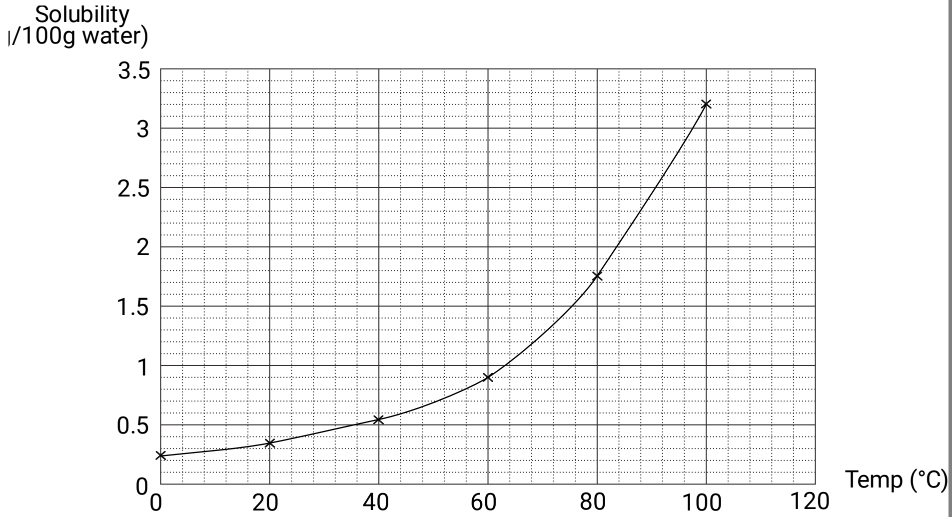
$[OH^-] = 2 \times 0.0233 = 0.0466\,mol\,L^{-1}$

$$\begin{aligned} K_{sp} &= [Ca^{2+}][OH^-]^2 \\ &= 0.0233 \times (0.0466)^2 \\ &= 5.06 \times 10^{-5} \end{aligned}$$

b. → $[CaOH_2 (s)]$ is constant throughout the reaction.

→ Since it does not change, it is not included in the equilibrium expression.

18. CHEMISTRY, M5 EQ-Bank 29



$PbCl_2 (s) \rightleftharpoons Pb^{2+} (aq) + 2\,Cl^- (aq)$

Using the graph:

$\text{Solubility } (50^\circ) = 0.7\,g/100\,g \text{ water} = 7\,g/L$

Converting to $mol\,L^{-1}$:

$MM(PbCl_2) = 207.2 + 2 \times 35.45 = 278.1$

$$n = \frac{m}{MM} = \frac{7}{278.1} = 0.0252\,mol\,L^{-1}$$

$[Pb^{2+} (aq)] = 0.0252\,mol\,L^{-1}$

$\text{Mole ratio } Pb^{2+} : Cl^- = 1:2$

$\Rightarrow [Cl^-] = 2 \times 0.0252 = 0.0504\,mol\,L^{-1}$

$$\begin{aligned} K_{sp} &= [Pb^{2+}][Cl^-]^2 \\ &= 0.0252 \times (0.0504)^2 \\ &= 6.4 \times 10^{-5} \end{aligned}$$

19. CHEMISTRY, M5 2020 HSC 35

Mean mark 55%.

$$A = [I_3^-]_{eq} \times 2.76 \times 10^4$$
$$0.745 = [I_3^-]_{eq} \times 2.76 \times 10^4$$
$$[I_3^-]_{eq} = 2.70 \times 10^{-5} \text{ mol L}^{-1}$$

$$[I^-]_{initial} = 4\,[I_2]_{eq} + 3\,[I_3^-]_{eq}$$
$$7.00 \times 10^{-4} = 4[I_2]_{eq} + (3 \times 2.70 \times 10^{-5})$$
$$[I_2]_{eq} = \frac{7.00 \times 10^{-4} - (3 \times 2.70 \times 10^{-5})}{4}$$
$$= 1.55 \times 10^{-4} \text{ mol L}^{-1}$$

$$[I^-]_{eq} = 2[I_2]_{eq} = 2 \times (1.55 \times 10^{-4}) = 3.10 \times 10^{-4} \text{ mol L}^{-1}$$

$$K_{eq} = \frac{[I_3^-]_{eq}}{[I^-]_{eq} \times [I_2]_{eq}}$$
$$= \frac{2.70 \times 10^{-5}}{3.10 \times 10^{-4} \times 1.55 \times 10^{-4}}$$
$$= 564$$

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20. CHEMISTRY, M5 2021 HSC 27

a. $Li_3PO_4\,(s) \leftrightharpoons 3\,Li^+\,(aq) + PO_4^{3-}\,(aq)$

♦ Mean mark (a) 50%.

$K_{sp} = [Li^+]^3\,[PO_4^{3-}]$

To calculate the range, we compare the point just before no precipitation occurs to the point when the precipitation first occurs.

Sample 3:

$K_{sp} = [Li^+]^3\,[PO_4^{3-}] = (0.15)^3 \times 0.010 = 3.375 \times 10^{-5}$

Sample 4:

$K_{sp} = (0.15)^3 \times 0.10 = 3.375 \times 10^{-4}$

Therefore the K_{sp} is between the range of 3.4×10^{-5} and 3.4×10^{-4}

b. Answers could include one of the following.

Mean mark (b) 52%.

→ Add more solutions of PO_4^{3-} ions between the concentrations of 0.010 mol L^{-1} and 0.10 mol L^{-1}, thus increasing the accuracy of the estimated SI value.

→ Form a precipitate titration by titrating the Li^+ ions against a PO_4^{3-} ion solution until a precipitate is formed. This would allow the experimental value to be closer to the correct SI value for lithium phosphate, and in turn increase the accuracy of the calculated results.

21. CHEMISTRY, M5 2022 HSC 31

a. The method is not suitable.

♦ Mean mark (a) 40%.

→ Adding NaI would cause the I^- ions to precipitate with the Ag^+ ions to form AgI

$$AgI(s) \rightleftharpoons Ag^+(aq) + I^-(aq)$$

→ As a result, this would decrease $[Ag^+]$, and disturb the equilibrium.

→ According to Le Chatelier's Principle, the equilibrium will shift to the right in an attempt to counteract the change and increase $[Ag^+]$.

$$Ag^+(aq) + 2\,NH_3(aq) \rightleftharpoons [Ag(NH_3)_2]^+(aq)$$

→ As a result, $[Ag(NH_3)_2]^+$ would shift to the left and increase $[Ag^+]$.

b.

♦ Mean mark (b) 40%.

$$K_{eq} = \frac{[[Ag(NH_3)_2]^+]}{[Ag^+][NH_3]^2}$$

$$[[Ag(NH_3)_2]^+] = \frac{99.99}{0.010} \times [Ag^+] \quad \ldots (1)$$

Substitute (1) into K_{eq}:

$$1.6 \times 10^7 = \frac{(99.99\,\%) \times [Ag^+]}{(0.010\,\%) \times [Ag^+][NH_3]^2}$$

$$= \frac{99.99\,\%}{0.010\,\%\,[NH_3]^2}$$

$$[NH_3]^2 = \frac{99.99\,\%}{1.6 \times 10^7 \times 0.010\,\%}$$

$$[NH_3] = \sqrt{\frac{99.99\,\%}{1.6 \times 10^7 \times 0.010\,\%}}$$

$$= 0.025 \text{ mol L}^{-1}$$

Therefore, the concentration of NH_3 at equilibrium is 0.025 mol L^{-1}.

22. CHEMISTRY, M5 2022 HSC 35

♦ Mean mark 43%

$$Sr(NO_3)_2(aq) + 2\,NaOH(aq) \longrightarrow Sr(OH)_2(s) + 2\,NaNO_3(aq)$$

$$n(Sr(NO_3)_2) = c \times V = 1.50 \times 0.0800 = 0.120 \text{ mol}$$

$$n(NaOH) = 0.855 \times 0.0800 = 0.0684 \text{ mol}$$

$$NaOH = \text{limiting reagent}, \quad Sr(NO_3)_2 = \text{excess reagent}$$

$$n(Sr(OH)_2) \text{ produced} = \frac{1}{2} \times 0.0684 = 0.0342 \text{ mol}$$

Thus, 0.0342 moles of $Sr(OH)_2$ can be produced in solution.

$$n(Sr(OH)_2) \text{ precipitate} = \frac{m}{MM} = \frac{3.93}{121.63} = 0.0323111 \text{ mol}$$

$$n(Sr(OH)_2) \text{ in solution} = n(Sr(OH)_2) \text{ produced} - n(Sr(OH)_2) \text{ precipitate} = 0.0342 - 0.0323111 = 0.0018889 \text{ mol}$$

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

$$n(Sr(NO_3)_2)_{init} = 0.120 - \frac{1}{2} \times 0.0684 = 0.0858 \text{ mol}$$

	Sr^{2+}	OH^-
Initial	0.0858	0
Change	+0.0018889	+2 × 0.0018889
Equilibrium	0.0877	0.00378

$$V(\text{total}) = 0.08 + 0.08 = 0.16 \text{ L}$$

$$[Sr^{2+}] = \frac{n}{V} = \frac{0.0877}{0.16} = 0.548 \text{ mol L}^{-1}$$

$$[OH^-] = \frac{0.00378}{0.16} = 0.0236 \text{ mol L}^-1$$

$$K_{sp} = [Sr^{2+}][OH^-]^2 = 0.548 \times (0.02362)^2 = 3.06 \times 10^{-4}$$

23. CHEMISTRY, M5 2023 HSC 34

♦ Mean mark 45%.

$$MgF_2\,(s) \rightleftharpoons Mg^{2+}\,(aq) + 2\,F^-\,(aq)$$

$$n(MgF_2) = \frac{m}{MM} = \frac{0.6231}{62.31} = 1.000 \times 10^{-2}\ mol$$

$$n(F^-)_{init} = c \times V = 1.50 \times 0.175 = 0.263\ mol$$

$$n(F^-)_{after} = 0.263 - 2 \times 1.00 \times 10^{-2} = 0.243\ mol$$

$$[F^-]_{after} = \frac{n}{V} = \frac{0.243}{0.300} = 0.808\ mol\ L^{-1}$$

$$K_{sp} = [Mg^{2+}][F^-]^2$$

Since K_{sp} is small $\Rightarrow$ assume $[F^-]_{eq} = 0.808\ mol\ L^{-1}$

$$[Mg^{2+}]_{eq} = \frac{5.16 \times 10^{-11}}{0.808^2} = 7.90 \times 10^{-11}\ mol\ L^{-1}$$

24. CHEMISTRY, M5 2024 HSC 32

♦ Mean mark 55%.

$$Cd_3(PO_4)_2\,(s) \rightleftharpoons 3\,Cd^{2+}\,(aq) + 2\,PO_4{}^{3-}\,(aq)$$

$$\Rightarrow K_{sp} = [Cd^{2+}]^3[PO_4{}^{3-}]^2 = 2.53 \times 10^{-33}$$

→ Let the molar solubility of $Cd_3(PO_4)_2$ be x mol L^{-1}

→ $[Cd^{2+}] = 3x,\ \ [PO_4{}^{3-}] = 2x$

$$\begin{aligned}[Cd^{2+}]^3[PO_4{}^{3-}]^2 &= 2.53 \times 10^{-33}\\ (3x)^3 \times (2x)^2 &= 2.53 \times 10^{-33}\\ 108x^5 &= 2.53 \times 10^{-33}\\ x &= \sqrt[5]{\frac{2.53 \times 10^{-33}}{108}}\\ &= 1.11856 \times 10^{-7}\end{aligned}$$

→

$[Cd^{2+}] = 3 \times 1.1186 \times 10^{-7} = 3.56 \times 10^{-7}\ mol\ L^{-1}$ (3 sig.fig)

25. CHEMISTRY, M8 2019 HSC 29

a. Recommended Treatment:

♦ Mean mark (a) 46%.

→ Calcium hydroxide is a slightly soluble compound, while copper(II) hydroxide and lead(II) hydroxide are very insoluble in water.

→ When these compounds are added to water, the metal ions tend to precipitate out of solution.

→ For example, the addition of solid calcium hydroxide to water produces calcium ions Ca^{2+} and hydroxide ions OH^-, which can then react with lead(II) ions (Pb^{2+}) and copper(II) ions Cu^{2+} to form precipitates of lead(II hydroxide and copper(II) hydroxide, respectively.

→ These reactions are represented by the equations:

$$Pb^{2+} + 2\,OH^- \longrightarrow Pb(OH)_2, \quad Cu^{2+} + 2\,OH^- \longrightarrow Cu(OH)_2$$

b. Atomic absorption spectroscopy (AAS):

♦♦ Mean mark (b) 32%.

→ Can be used for determining the concentration of metal ions in a sample by measuring the absorbance of light at specific wavelengths that are characteristic of each metal.

→ AAS uses light wavelengths that correspond to atomic absorption by the element of interest, and since each element has unique wavelengths that are absorbed, the concentration of that element can be selectively measured in the presence of other species.

→ As a result, AAS can be used to independently measure the concentrations of different metal ions, such as lead(II) ions and copper(II) ions in a sample containing both types.

c. Concentrations of ions:

Sample	$Cu^{2+} \times 10^{-5}$ mol L^{-1}	$Pb^{2+} \times 10^{-5}$ mol L^{-1}
Water (pre-treatment)	5.95	4.75
Water (post-treatment)	0.25	0.85

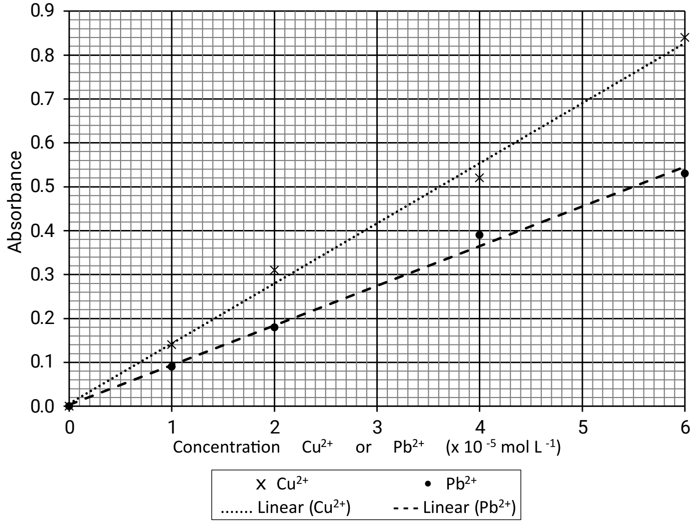
→ Concentrations of copper and lead have been significantly reduced.

♦ Mean mark (c) 53%.

→ Convert concentrations to compare with standard:

$$\begin{aligned}Cu^{2+}:\quad & 5.95 \times 10^{-5} \times 63.55 \times 1000 = 3.78\ mg\ L^{-1}\\ & 0.25 \times 10^{-5} \times 63.55 \times 1000 = 0.16\ mg\ L^{-1}\end{aligned}$$

$$\begin{aligned}Pb^{2+}:\quad & 4.75 \times 10^{-5} \times 207.2 \times 1000 = 9.84\ mg\ L^{-1}\\ & 0.85 \times 10^{-5} \times 207.2 \times 1000 = 1.76\ mg\ L^{-1}\end{aligned}$$



Conclusion:

→ The concentration of copper ions has been reduced to a level that is lower than the discharge limit (0.16 < 1.0) but the lead ion concentration has not (1.76 > 1.0).

→ The treatment has only been partially successful.