- Desferal is a siderophore-based drug that is used in humans to treat iron-overload. One molecule of Desferal (molecular formula: $C_{25}H_{48}O_8N_6$) can bind one Fe^{3+} ion. A patient with an iron-overload disease had an excess of 5.34×10^{-4} M Fe^{3+} in her bloodstream. Assuming the patient had a total blood volume of 4.84 L, what mass of Desferal would be required to complex all of the excess Fe^{3+}? **2**

As one mole of Deferal will complex one mole of Fe^{3+}, the number of moles of Desferal required is:

number of moles = concentration × volume = $(5.34\times10^{-4}) \times 4.84 = 2.58\times10^{-3}$ M

The molar mass of $C_{25}H_{48}O_8N_6$ is:

(25 × 12.01 (C)) + (48 × 1.008 (H)) + (8 × 16.00 (O)) + (6 × 14.01 (N)) = 560.694

Hence, the mass required is:

mass = number of moles × molar mass = $(2.58 \times 10^{-3}) \times (560.694) = 1.45$ g

Answer: **1.45 g**

- Many gases are available for use in compressed gas cylinders, in which they are stored at high pressures. Calculate the mass of oxygen gas that can be stored at 20 °C and 170 atm pressure in a cylinder with a volume of 60.0 L. **2**

Using the ideal gas law, PV = nRT, the number of moles that can be stored is:

$$n = \frac{PV}{RT} = \frac{(170)\times(60.0)}{(0.08206)\times(20+273)} = 424\,\text{mol}$$

As the molar mass of O_2 is (2 × 16.00) = 32.00, this corresponds to a mass of:

mass = number of moles × molar mass = 424 × 32.00 = 13600 g = 13.6 kg

Answer: **13.6 kg**

- If 20.0 mL of a 0.100 M solution of sodium phosphate is mixed with 25.0 mL of a 0.200 M solution of zinc chloride, what mass of zinc phosphate will precipitate from the reaction?

Marks
6

25.0 mL of a 0.200 M solution of $ZnCl_2$ contains:

$n(Zn^{2+}(aq))$ = concentration × volume = $0.200 \times \frac{25}{1000} = 0.00500$ mol

20.0 mL of a 0.100 solution of Na_3PO_4 contains:

$n(PO_4^{3-}) = 0.100 \times \frac{20}{1000} = 0.00200$ mol

The ionic equation for the precipitation reaction is:

$3Zn^{2+}(aq) + 2PO_4^{3-}(aq) \rightarrow Zn_3(PO_4)_2(s)$

As $n(Zn^{2+}(aq) > \frac{3}{2} \times n(PO_4^{3-}(aq))$, PO_4^{3-} which is the limiting reagent. The maximum amount of product depends on $n(PO_4^{3-})$. The amount of zinc phosphate formed is:

$n(Zn_3(PO_4)_2(s) = ½ \times n(PO_4^{3-}(aq)) = ½ \times 0.00200 = 0.00100$ mol

The formula mass of zinc phosphate is:

(3 × 65.39 (Zn)) + 2 × (30.97 (P) + 4 × 16.00 (O)) = 386.11

The mass of this amount of zinc phosphate is therefore:

mass = number of moles × formula mass = 0.00100 × 386.11 = 0.386 g

Answer: **0.386 g**

ANSWER CONTINUES ON THE NEXT PAGE

What is the final concentration of zinc ions in solution after the above reaction?

The number of moles of $Zn^{2+}(aq)$ removed by precipitation = 3 × 0.00100 = 0.00300 mol. The amount remaining is therefore:

$$n(Zn^{2+}(aq)) = 0.00500 - 0.00300 = 0.00200 \text{ mol}$$

The total volume of the solution after mixing is (20.0 + 25.0) = 45.0 mL so the concentration is:

$$[Zn^{2+}(aq)] = \frac{\text{number of moles}}{\text{volume}} = \frac{0.00200}{(45/1000)} = 0.0444 \text{ M}$$

Answer: **0.0444 M**

What is the final concentration of sodium ions in solution after the above reaction?

20.0 mL of a 0.100 solution of Na_3PO_4 contains:

$$n(Na^{+}) = 3 \times 0.100 \times \frac{20}{1000} = 0.00600 \text{ mol}$$

After mixing, this amount is contained in a volume of 45.0 mL so the concentration is:

$$[Na^{+}(aq)] = \frac{\text{number of moles}}{\text{volume}} = \frac{0.00600}{(45/1000)} = 0.133 \text{ M}$$

Answer: **0.133 M**

- Human haemoglobin has a molar weight of 6.45×10^4 g mol^{-1} and contains 3.46 g of iron per kg. Calculate the number of iron atoms in each molecule of haemoglobin.

3

A mole of haemoglobin has a mass of 6.45×10^4 g = 64.5 kg. As each kilogram contains 3.45 g of iron, a mole contains (64.5 × 3.45) = 223 g of iron.

The atomic mass of iron is 55.85 so this mass of iron corresponds to:

$$\textbf{number of moles of iron} = \frac{\textbf{mass}}{\textbf{atomic mass}} = \frac{223}{55.85} = 3.98$$

Answer: **4 iron atoms per molecule**

Marks 3

- If 50 mL of a 0.10 M solution of $AgNO_3$ is mixed with 50 mL of a 0.040 M solution of $BaCl_2$, what mass of AgCl(s) will precipitate from the reaction?

The precipitation reaction, $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$, is a 1:1 reaction of $Ag^+(aq)$ and $Cl^-(aq)$ ions.

Number of moles of Ag^+ = concentration × volume = $0.10 \times \frac{50}{1000}$ = 0.0050 mol

As each mole of $BaCl_2(s)$ gives two moles of $Cl^-(aq)$:

Number of moles of Cl^- = $2 \times 0.040 \times \frac{50}{1000}$ = 0.0040 mol

$Ag^+(aq)$ is present in excess so $Cl^-(aq)$ is the limiting reagent. Hence, 0.0040 mol of AgCl(s) will be formed.

The molar mass of AgCl(s) = (107.87 (Ag)) + (35.45 (Cl)) = 143.32.

The mass of AgCl(s) formed is:

mass = number of moles × molar mass = 0.0040 × 143.32 = 0.57 g

Answer: **0.57 g**

What is the concentration of NO_3^- ions in the final solution from the reaction above?

The number of moles of $NO_3^-(aq)$ is 0.0050 mol. After mixing, the final solution has a volume of (50 + 50) = 100 mL. Hence, the concentration is:

$$[NO_3^-] = \frac{\text{number of moles}}{\text{volume}} = \frac{0.0050}{100/1000} = 0.050\ \text{M}$$

Answer: **0.050 M**

Marks 4

- Solutions of lead(II) nitrate (0.080 M, 60 mL) and potassium iodide (0.080 M, 40 mL) are mixed. What amount (in mol) of $PbI_2(s)$ precipitates?

Lead(II) nitrate and potassium iodide react according to the equation:

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2K(NO_3)(aq)$$

The reaction requires *two* moles of KI for every *one* mole of $Pb(NO_3)_2$. As the same concentrations of the two solutions are used but the volume of KI is smaller, it is this that limits the amount of product. The number of moles of KI used is given by the concentration (in M) × volume (in L):

$$\text{moles of KI} = 0.080 \text{ mol L}^{-1} \times \frac{40}{1000} \text{ L} = 0.0032 \text{ mol}$$

As *one* mole of PbI_2 is made for every *two* moles of KI used, the maximum yield of PbI_2 is one half of the number of moles of KI:

$$\text{moles of } PbI_2 = \tfrac{1}{2} \times 0.0032 \text{ mol} = 0.0016 \text{ mol}$$

Answer: **0.0016 mol**

What is the final concentration of $K^+(aq)$ ions remaining in solution after the reaction?

The number of moles of K^+ is 0.0032 mol. After mixing, the total volume = (60 + 40 mL) = 100 mL or 0.1 L. The concentration is:

concentration = number of moles / volume = (0.0032 mol) / (0.1 L) = 0.032 M

Answer: **0.032 M**

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY

Marks
4

Given that haemoglobin contains 4 Fe atoms per molecule and its concentration in blood is 15 g per 100 mL, calculate the total mass of Fe in the patient's blood *before* being treated with Desferal. (The molar mass of haemoglobin is 6.45×10^4 g mol^{-1}.)

In 5.04 L, the total mass of haemoglobin is $15 \times (5.04 \times 10^3 / 100) = 756$ g. If the molar mass is 6.45×10^4 g mol^{-1}, this corresponds to

moles of haemoglobin = mass / molar mass

$$= (756 \text{ g})/(6.45 \times 10^4 \text{ g mol}^{-1}) = 0.0117 \text{ mol}$$

As haemoglobin contains 4 Fe atoms, the number of moles of Fe is 4×0.0117 mol = 0.0469 mol. There is also 3.2105 mol of free Fe^{3+} present (from 2004-J-3) so the total number of moles of Fe is $(0.0469 + (3.2105 \times 10^{-3}))$ mol = 0.050 mol.

The mass of Fe is given by moles × atomic mass:

mass of Fe = $(0.050 \text{ mol}) \times (55.85 \text{ g mol}^{-1}) = 2.80$ g

ANSWER: **2.80 g**

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Marks
5

- Some micro-organisms thrive under warm, acidic conditions where sulfuric acid is produced as a metabolic by-product from the reaction between sulfur (S), water and oxygen (O_2). Write a balanced equation for this reaction.

$2S(s) + 3O_2(g) + 2H_2O(l) \rightarrow 2H_2SO_4(l)$

Calculate the volume of oxygen that is required to react to completion with 0.0655 g of sulfur at 1.00 atm and 55 °C.

The number of moles of sulfur in 0.0655 g is:

$$\text{number of moles} = \frac{\text{mass (in g)}}{\text{molar mass (in g mol}^{-1})} = \frac{0.0655}{32.07} = 0.002042\ \text{mol}$$

Three **moles of O_2 are required for every** ***two*** **moles of S. Hence the number of moles of O_2 required is:**

$$\text{number of moles} = \frac{3}{2} \times 0.002042 = 0.003064\ \text{mol}$$

The volume of this number of moles of gas at 1.00 atm and 55 °C (= 328 K) is given by the ideal gas law, pV = nRT, so,

$$V = \frac{nRT}{p} = \frac{(0.003064) \times 0.08206 \times 328}{1.00} = 0.0825\ \text{L}$$

(Note the use of R = 0.08206 L atm K^{-1} mol^{-1} as pressure is given in atmospheres provides the answer in litres)

ANSWER: **0.0825 L**

Calculate the pH of the final solution if the reaction is carried out in 20.0 L of water. Assume that the sulfuric acid fully dissociates.

Two **moles of H_2SO_4 is produced from every** ***two*** **moles of S. Therefore, the number of moles of H_2SO_4 is just 0.002042 mol. Every mole of H_2SO_4 produces** ***two*** **moles of H^+. Therefore, the number of moles of H^+ is**

number of moles = 2 × 0.002042 = 0.004084 mol

As the reaction is carried out in 20.0 L of water, the concentration of H^+ is:

$$\text{concentration} = \frac{\text{number of moles (in mol)}}{\text{volume (in L)}} = \frac{0.004084}{20} = 0.0002042\ \text{M}$$

From the definition of pH:

$$\text{pH} = \text{pH} = -\log_{10}[H^+] = -\log_{10}(0.0002042) = 3.69$$

ANSWER: **3.69**

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