Marks
8

- One of the causes of acid rain is a reaction occurring in the upper atmosphere between gaseous NO_2 and water to produce nitric acid and gaseous NO. Write a balanced chemical equation for this reaction.

$3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(aq) + NO(g)$

As part of their school project on acid rain, some high school students collected a sample of rain (220 mL) and measured the pH value of the solution, reporting the value as pH = 3.9. Assuming that the rain sample does not contain any acids other than nitric acid, calculate the volume of gaseous NO_2 that would have been consumed in the upper atmosphere (where temperature = –56 °C and pressure = 11.6 kPa) to produce the sample of rain collected by the students.

By definition,

$pH = -\log_{10}[H^+]$ or $[H^+] = 10^{-pH}$

pH = 3.9 therefore corresponds to $[H^+] = 10^{-3.9}$ M.

The number of moles of H^+ in the sample of 220 mL is,

number of moles = volume (in L) × molarity (in mol L^{-1})
$= 0.220 \text{ L} \times 10^{-3.9} \text{ M} = 2.8 \times 10^{-5}$ mol

As nitric acid is a strong acid, this is also the number of moles of nitric acid present. From the chemical equation, *two* moles of nitric acid are produced from every *three* moles of NO_2. Therefore, the number of moles of NO_2 used is:

number of moles $= \frac{3}{2} \times 2.8 \times 10^{-5}$ mol $= 4.2 \times 10^{-5}$ mol

The volume of this number of moles of gas at 11.6 kPa and –56 °C (= 217 K) is given by the ideal gas law:

$$pV = nRT$$

so,

$$V = \frac{nRT}{P} = \frac{(4.2\times10^{-5}\text{ mol})(8.314\text{ J}^{-1}\text{ K}^{-1}\text{ mol}^{-1})(217\text{ K})}{11.6\times10^{3}\text{ Pa}}$$
$$= 6.5 \times 10^{-6}\text{ m}^3 = 6.5 \times 10^{-3}\text{ L}$$

(Note the use of $R = 8.314$ J K^{-1} mol^{-1} as pressure is given in Pascal provides the answer in m^3)

ANSWER: **6.5×10^{-3} L**

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 g) × (5.04 × 10^3 mL / 100 mL) = 756 g. If the molar mass is 6.45 × 10^4 g mol^{-1}, this corresponds to

moles of haemoglobin = mass / molar mass

= (756 g) / (6.45 × 10^4 g mol^{-1}) = 0.0117 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 × 10^{-3}) mol) = 0.050 mol.

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

mass of Fe = (0.050 mol) × (55.85 g mol^{-1}) = 2.80 g

ANSWER: **2.8 g**

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY

- 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:

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

Answer: **4 iron atoms per molecule**

	Marks
• 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?	**3**

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

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

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

Number of moles of Cl^- = 2 × 0.040 × $\frac{50}{1000}$ = 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:

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

Answer: **0.050 mol**

- 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 = $(5.34 \times 10^{-4}) \times 4.84 = 2.58 \times 10^{-3}$ 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**

Marks 6

- 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?

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

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

20.0 mL of a 0.100 solution of Na_3PO_4 contains:

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

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:

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

The formula mass of zinc phosphate is:

$$(3 \times 65.39 \text{ (Zn)}) + 2 \times (30.97 \text{ (P)} + 4 \times 16.00 \text{ (O)}) = 386.11$$

The mass of this amount of zinc phosphate is therefore:

$$\text{mass} = \text{number of moles} \times \text{formula mass} = 0.00100 \times 386.11 = 0.386 \text{ g}$$

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 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**