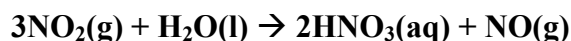


Marks
8

- 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.



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 $\text{pH} = 3.9$. 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,

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

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

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

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

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:

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

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,

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

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

ANSWER: $6.5 \times 10^{-3} \text{ L}$

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 $6.45 \times 10^4 \text{ g mol}^{-1}$.)

Marks
4

In 5.04 L, the total mass of haemoglobin is $(15 \text{ g}) \times (5.04 \times 10^3 \text{ mL} / 100 \text{ mL}) = 756 \text{ g}$. If the molar mass is $6.45 \times 10^4 \text{ g mol}^{-1}$, 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 $4 \times 0.0117 \text{ mol} = 0.0469 \text{ mol}$. There is also 3.2105 mol of free Fe^{3+} present (from 2004-J-3) so the total number of moles of Fe is $(0.0469 + (3.2105 \times 10^{-3}) \text{ mol}) = 0.050 \text{ mol}$.

The mass of Fe is given by moles \times atomic mass:

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

ANSWER: 2.8 g

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY

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

A mole of haemoglobin has a mass of $6.45 \times 10^4 \text{ g} = 64.5 \text{ kg}$. As each kilogram contains 3.45 g of iron, a mole contains $(64.5 \times 3.45) = 223 \text{ g}$ of iron.

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

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

Answer: 4 iron atoms per molecule

- 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 $\text{AgCl}(s)$ will precipitate from the reaction?

Marks
3

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

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

As each mole of $\text{BaCl}_2(s)$ gives two moles of $\text{Cl}^-(\text{aq})$:

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

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

The molar mass of $\text{AgCl}(s) = (107.87 (\text{Ag})) + (35.45 (\text{Cl})) = 143.32$.

The mass of $\text{AgCl}(s)$ formed is:

$$\text{mass} = \text{number of moles} \times \text{molar mass} = 0.0040 \times 143.32 = 0.57 \text{ g}$$

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 $\text{NO}_3^-(\text{aq})$ is 0.0050 mol. After mixing, the final solution has a volume of $(50 + 50) = 100 \text{ mL}$. Hence, the concentration is:

$$[\text{NO}_3^-] = \frac{\text{number of moles}}{\text{volume}} = \frac{0.0050}{100/1000} = 0.050 \text{ mol}$$

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 $5.34 \times 10^{-4} M Fe^{3+}$ 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+} ?

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

$$\text{number of moles} = \text{concentration} \times \text{volume} = (5.34 \times 10^{-4}) \times 4.84 = 2.58 \times 10^{-3} M$$

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

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

Hence, the mass required is:

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

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.

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 $(2 \times 16.00) = 32.00$, this corresponds to a mass of:

$$\text{mass} = \text{number of moles} \times \text{molar mass} = 424 \times 32.00 = 13600 \text{ g} = 13.6 \text{ kg}$$

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?

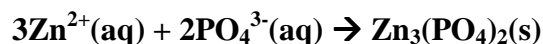
25.0 mL of a 0.200 M solution of ZnCl₂ contains:

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

20.0 mL of a 0.100 solution of Na₃PO₄ contains:

$$n(\text{PO}_4^{3-}) = 0.100 \times \frac{20}{1000} = 0.00200 \text{ mol}$$

The ionic equation for the precipitation reaction is:



As $n(\text{Zn}^{2+}(\text{aq})) > \frac{3}{2} \times n(\text{PO}_4^{3-}(\text{aq}))$, PO_4^{3-} which is the limiting reagent. The maximum amount of product depends on $n(\text{PO}_4^{3-})$. The amount of zinc phosphate formed is:

$$n(\text{Zn}_3(\text{PO}_4)_2(\text{s})) = \frac{1}{2} \times n(\text{PO}_4^{3-}(\text{aq})) = \frac{1}{2} \times 0.00200 = 0.00100 \text{ mol}$$

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 $\text{Zn}^{2+}(\text{aq})$ removed by precipitation = $3 \times 0.00100 = 0.00300$ mol. The amount remaining is therefore:

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

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

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

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:

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

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

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

Answer: **0.133 M**