Volume of HCl(aq):

$$V = 35.3\ \cancel{\text{mL}} \times 1 \times 10^{-3}\ \text{L}/\cancel{\text{mL}}$$
$$= 0.0353\ \text{L}$$

Amount in moles, n, of NaOH(aq):

$$n_{\text{NaOH}} = cV$$
$$= 1.50\ \text{mol}/\cancel{\text{L}} \times 0.0500\ \cancel{\text{L}}$$
$$= 0.0750\ \text{mol}$$

Amount in moles, n, of HCl(aq):

$$\frac{1\ \text{mol NaOH}}{1\ \text{mol HCl}} = \frac{0.0750\ \text{mol NaOH}}{n_{\text{HCl}}}$$
$$n_{\text{HCl}} = \frac{0.0750\ \cancel{\text{mol NaOH}} \times 1\ \text{mol HCl}}{1\ \cancel{\text{mol NaOH}}}$$
$$= 0.0750\ \text{mol}$$

Concentration of HCl(aq):

$$c = \frac{n}{V}$$
$$= \frac{0.0750\ \text{mol}}{0.0353\ \text{L}}$$
$$= 2.12\ \text{mol/L}$$

The concentration of HCl(aq) is 2.12 mol/L.

Check Your Solution

For the mole ratio of 1:1 between NaOH(aq) and HCl(aq), it is reasonable that the HCl(aq) would have a slightly higher concentration than NaOH(aq) since slightly less HCl(aq) was used in the titration. The answer correctly shows three significant digits.

2. Practice Problem (page 466)

What volume of 0.400 mol/L sodium hydroxide, NaOH(aq), is needed to neutralize 26.8 mL of 0.504 mol/L sulfuric acid, H_2SO_4(aq), completely? **Hint:** Sulfuric acid loses two hydrogen ions during this neutralization reaction.

What Is Required?

You need to find the volume of a sodium hydroxide solution.

What Is Given?
You know the volume and concentration of the $H_2SO_4(aq)$: $V = 26.8$ mL; $c = 0.504$ mol/L
You know the concentration of the NaOH(aq): $c = 0.400$ mol/L

Plan Your Strategy
Write the balanced chemical equation for the reaction.
Convert the volume of $H_2SO_4(aq)$ from millilitres to litres: 1 mL = 1×10^{-3} L
Calculate the amount in moles of $H_2SO_4(aq)$ using the relationship $n = cV$.
Use the mole ratio in the balanced equation to calculate the amount in moles of NaOH(aq).
Calculate the volume of NaOH(aq) using the relationship $V = \frac{n}{c}$.

Act on Your Strategy
Balanced chemical equation:

	$2NaOH(aq)$ +	$H_2SO_4(aq)$ →	$Na_2SO_4(aq)$ +	$2H_2O(\ell)$
Mole ratio:	2 moles	1 mole	1 mole	1 mole

Volume of $H_2SO_4(aq)$:

$$V = 26.8\ \cancel{mL} \times 1 \times 10^{-3}\ L/\cancel{mL}$$
$$= 0.0268\ L$$

Amount in moles, n, of $H_2SO_4(aq)$:

$$n_{H_2SO_4} = cV$$
$$= 0.504\ mol/\cancel{L} \times 0.0268\ \cancel{L}$$
$$= 0.0135\ mol$$

Amount in moles, n, of NaOH(aq):

$$\frac{2\ mol\ NaOH}{1\ mol\ H_2SO_4} = \frac{n_{NaOH}}{0.0135\ mol\ H_2SO_4}$$
$$n_{NaOH} = \frac{2\ mol\ NaOH \times 0.0135\ \cancel{mol\ H_2SO_4}}{1\ \cancel{mol\ H_2SO_4}}$$
$$= 0.0270\ mol$$

Volume of NaOH(aq):

$$V = \frac{n}{c}$$
$$= \frac{0.0270\ mol}{0.400\ mol/L}$$
$$= 0.0675\ L$$

The volume of NaOH(aq) is 0.0675 L.

Check Your Solution
Since the mole ratio between NaOH(aq) and H_2SO_4(aq) is 2:1, the volume of NaOH required will be $\frac{2}{1}$ times more than the volume of H_2SO_4(aq). Since the concentration of NaOH(aq) is less than that of H_2SO_4(aq), the volume of NaOH(aq) required will be $\frac{0.5}{0.4}$ more than the volume of H_2SO_4(aq).
The volume, V, of NaOH(aq) required can be estimated:

$$V \approx \text{volume of } H_2SO_4(aq) \times \text{concentration factor} \times \text{mole ratio factor}$$
$$\approx 0.027\text{ L} \times \frac{0.5}{0.4} \times \frac{2}{1} = 0.067\text{ L}$$

The calculated answer of 0.0675 L seems reasonable and correctly shows three significant digits.

3. **Practice Problem (page 466)**
A 25.00 mL sample of a nitric acid solution, HNO_3(aq), is neutralized by 18.55 mL of a 0.1750 mol/L sodium hydroxide solution, NaOH(aq). What is the concentration of the nitric acid solution?

What Is Required?
You need to find the concentration in moles per litre of a nitric acid solution.

What Is Given?
You know the volume and concentration of the NaOH(aq): $V = 18.55$ mL; $c = 0.1750$ mol/L
You know the volume of the HNO_3(aq): $V = 25.00$ mL

Plan Your Strategy
Write the balanced chemical equation for the reaction.
Convert the volumes of the reactants to litres: 1 mL = 1×10^{-3} L
Calculate the amount in moles of NaOH(aq) using the relationship $n = cV$.
Use the mole ratio in the balanced equation to calculate the amount in moles of HNO_3(aq).
Calculate the concentration of HNO_3(aq) using the relationship $c = \frac{n}{V}$.

4. Practice Problem (page 466)

What volume of 1.25 mol/L hydrobromic acid, HBr(aq), will neutralize 75.0 mL of 0.895 mol/L magnesium hydroxide, $Mg(OH)_2(aq)$?

What Is Required?

You need to find the volume of a hydrobromic acid solution.

What Is Given?

You know the volume and concentration of the $Mg(OH)_2(aq)$: $V = 75.0$ mL; $c = 0.895$ mol/L

You know the concentration of the HBr(aq): $c = 1.25$ mol/L

Plan Your Strategy

Write the balanced chemical equation for the reaction.

Convert the volume of $Mg(OH)_2(aq)$ to litres: 1 mL = 1×10^{-3} L

Calculate the amount in moles of $Mg(OH)_2(aq)$ using the relationship $n = cV$.

Use the mole ratio in the balanced equation to calculate the amount in moles of HBr(aq).

Calculate the volume of HBr(aq) using the relationship $V = \frac{n}{c}$.

Act on Your Strategy

Balanced chemical equation:

$$2HBr(aq) + Mg(OH)_2(aq) \rightarrow MgBr_2(aq) + 2H_2O(\ell)$$

Mole ratio: 2 moles 1 mole 1 mole 2 moles

Volume of $Mg(OH)_2(aq)$:

$$V = 75.0\ \cancel{mL} \times 1 \times 10^{-3}\ L/\cancel{mL}$$
$$= 0.0750\ L$$

Amount in moles, n, of $Mg(OH)_2(aq)$:

$$n_{Mg(OH)_2} = cV$$
$$= 0.895\ mol/\cancel{L} \times 0.0750\ \cancel{L}$$
$$= 0.067125\ mol$$

Amount in moles, n, of HBr(aq):

$$\frac{2\ mol\ HBr}{1\ mol\ Mg(OH)_2} = \frac{n_{HBr}}{0.067125\ mol\ Mg(OH)_2}$$

$$n_{HBr} = \frac{2\ mol\ HBr \times 0.067125\ \cancel{mol\ Mg(OH)_2}}{1\ \cancel{mol\ Mg(OH)_2}}$$

$$= 0.13425\ mol$$

Volume of HBr(aq):

$$V = \frac{n}{c}$$
$$= \frac{0.13425\ \cancel{\text{mol}}}{1.25\ \cancel{\text{mol}}/\text{L}}$$
$$= 0.1074\ \text{L}$$
$$= 0.107\ \text{L}$$

The volume of HBr(aq) is 0.107 L.

Check Your Solution

Since the mole ratio between $Mg(OH)_2(aq)$ and HBr(aq) is 1:2, the volume of HBr required will be $\frac{2}{1}$ times more than the volume of $Mg(OH)_2(aq)$. Since the concentration of HBr is more than that of $Mg(OH)_2(aq)$, the volume of HBr will be about $\frac{0.9}{1.25}$ the volume of $Mg(OH)_2(aq)$.

The volume, V, of HBr(aq) can be estimated:

$$V \approx \text{volume } Mg(OH)_2(aq) \times \text{concentration ratio factor} \times \text{mole ratio factor}$$
$$\approx 0.0750\ \text{L} \times \frac{0.9}{1.25} \times \frac{2}{1} = 0.108\ \text{L}$$

The calculated answer of 0.107 L seems reasonable and correctly shows three significant digits.

5. Practice Problem (page 466)

A solution of sodium hydroxide was prepared by dissolving 4.0 g of sodium hydroxide, NaOH(s), in 250 mL of water. It was found that 20.0 mL of the sodium hydroxide solution neutralizes 25.0 mL of vinegar. Determine the concentration of acetic acid, $CH_3COOH(aq)$, in the sample of vinegar. Assume that acetic acid is the only acidic substance in the vinegar.

What Is Required?

You need to find the concentration in moles per litre of acetic acid in a vinegar solution.

What Is Given?

You know the mass of the NaOH(s): 4.0 g
You know the volume of the NaOH(aq) stock solution: 250 mL
You know the volume of the NaOH(aq) used in the neutralization = 20.0 mL
You know the volume of the vinegar containing $CH_3COOH(aq)$: 25.0 mL

6. Practice Problem (page 466)

Phosphoric acid, $H_3PO_4(aq)$, is a triprotic acid. If 15.0 mL of phosphoric acid completely neutralizes 38.5 mL of 0.150 mol/L sodium hydroxide, NaOH(aq), what is the concentration of the phosphoric acid?

What Is Required?

You need to find the concentration in moles per litre of a phosphoric acid solution.

What Is Given?

You know the volume and concentration of the NaOH(aq): $V = 38.5$ mL; $c = 0.105$ mol/L

You know the volume of the $H_3PO_4(aq)$: $V = 15.0$ mL

Plan Your Strategy

Write the balanced chemical equation for the reaction.

Convert the volumes of the reactants from millilitres to litres: 1 mL = 1×10^{-3} L

Calculate the amount in moles of NaOH(aq) using the relationship $n = cV$.

Use the mole ratio in the balanced equation to calculate the amount in moles of $H_3PO_4(aq)$.

Calculate the concentration of $H_3PO_4(aq)$ using the relationship $c = \frac{n}{V}$.

Act on Your Strategy

Balanced chemical equation:

	$3NaOH(aq)$	$+ H_3PO_4(aq)$	$\rightarrow Na_3PO_4(aq)$	$+ 3H_2O(\ell)$
Mole ratio:	3 moles	1 mole	1 mole	3 moles

Volume of NaOH(aq):

$$V = 38.5\ \cancel{mL} \times 1 \times 10^{-3}\ L/\cancel{mL}$$
$$= 0.0385\ L$$

Volume of $H_3PO_4(aq)$:

$$V = 15.00\ \cancel{mL} \times 1 \times 10^{-3}\ L/\cancel{mL}$$
$$= 0.01500\ L$$

Amount in moles, n, of NaOH(aq):

$$n_{NaOH} = cV$$
$$= 0.150\ mol/\cancel{L} \times 0.0385\ \cancel{L}$$
$$= 0.005775\ mol$$

Amount in moles, n, of $H_3PO_4(aq)$:

$$\frac{1 \text{ mol } H_3PO_4}{3 \text{ mol NaOH}} = \frac{n_{H_3PO_4}}{0.005775 \text{ mol NaOH}}$$

$$n_{H_3PO_4} = \frac{1 \text{ mol } H_3PO_4 \times 0.005775 \cancel{\text{mol NaOH}}}{3 \cancel{\text{mol NaOH}}}$$

$$= 0.001925 \text{ mol}$$

Concentration of $H_3PO_4(aq)$:

$$c = \frac{n}{V}$$

$$= \frac{0.001925 \text{ mol}}{0.0150 \text{ L}}$$

$$= 0.1283 \text{ mol/L}$$

$$= 0.128 \text{ mol/L}$$

The concentration of $H_3PO_4(aq)$ is 0.128 mol/L.

Check Your Solution

Since the mole ratio between NaOH(aq) and $H_3PO_4(aq)$ is 3:1, the concentration of $H_3PO_4(aq)$ will be $\frac{1}{3}$ the concentration of NaOH(aq). Since the volume of NaOH used is about $\frac{40}{15}$ more than the volume of $H_3PO_4(aq)$, the concentration of the $H_3PO_4(aq)$ should be $\frac{40}{15}$ greater than the concentration of NaOH(aq).

The concentration, c, of $H_3PO_4(aq)$ can be estimated:

$$c \approx \text{concentration of NaOH(aq)} \times \text{volume factor} \times \text{mole ratio factor}$$

$$\approx 0.15 \text{ mol/L} \times \frac{40}{15} \times \frac{1}{3} = 0.13 \text{ mol/L}$$

This estimate is in the range of the calculated answer. The calculated answer of 0.128 mol/L seems reasonable and correctly shows three significant digits.

Amount in moles, n, of $H^+(aq)$:

$$\frac{1 \text{ mol } H^+}{1 \text{ mol NaOH}} = \frac{n_{H^+}}{2.0 \times 10^{-5} \text{ mol NaOH}}$$

$$n_{H^+} = \frac{1 \text{ mol } H^+ \times 2.0 \times 10^{-5} \cancel{\text{mol NaOH}}}{1 \cancel{\text{mol NaOH}}}$$

$$= 2.0 \times 10^{-5} \text{ mol}$$

Concentration of $H^+(aq)$:

$$c = \frac{n}{V}$$

$$= \frac{2.0 \times 10^{-5} \text{ mol}}{0.100 \text{ L}}$$

$$= 2 \times 10^{-4} \text{ mol/L}$$

The concentration of $H^+(aq)$ is 2×10^{-4} mol/L.

Check Your Solution

The mole ratio between NaOH(aq) and $H^+(aq)$ is 1:1, and the volume of acid solution used is about 10 times more than the volume of NaOH(aq) used. The concentration of the acid would be expected to be about $\frac{1}{10}$ the concentration of the NaOH(aq). The answer seems reasonable and has one significant digit.

8. Practice Problem (page 466)

Citric acid, $H_3C_6H_5O_7(aq)$, is a weak triprotic acid that occurs naturally in many fruits and vegetables, especially the citrus fruits from which it gets its name. What volume of 0.165 mol/L sodium hydroxide, NaOH(aq), will completely react with 40.0 mL of 0.120 mol/L citric acid? For this calculation, assume that all the hydrogen ions are released by the citric acid.

What Is Required?

You need to find the volume of a sodium hydroxide solution.

What Is Given?

You know the volume and concentration of the $H_3C_6H_5O_7(aq)$: $V = 40.0$ mL; $c = 0.120$ mol/L

You know the concentration of the NaOH(aq): $c = 0.165$ mol/L

Plan Your Strategy

Write the balanced chemical equation for the reaction.

Convert the volume of $H_3C_6H_5O_7(aq)$ from millilitres to litres: 1 mL = 1×10^{-3} L

Calculate the amount in moles of $H_3C_6H_5O_7(aq)$ using the relationship $n = cV$.

Use the mole ratio in the balanced equation to calculate the amount in moles of NaOH(aq).

Calculate the volume of NaOH(aq) using the relationship $V = \frac{n}{c}$.

Act on Your Strategy

Balanced chemical equation:

	$3NaOH(aq)$ +	$H_3C_6H_5O_7(aq)$ →	$Na_3C_6H_5O_7(aq)$ +	$3H_2O(\ell)$
Mole ratio:	3 moles	1 mole	1 mole	3 moles

Volume of $H_3C_6H_5O_7(aq)$:

$$V = 40.0\ \cancel{mL} \times 1 \times 10^{-3}\ L/\cancel{mL}$$
$$= 0.0400\ L$$

Amount in moles, n, of $H_3C_6H_5O_7(aq)$:

$$n_{H_3C_6H_5O_7} = cV$$
$$= 0.120\ mol/\cancel{L} \times 0.0400\ \cancel{L}$$
$$= 4.80 \times 10^{-3}\ mol$$

Amount in moles, n, of NaOH(aq):

$$\frac{3\ mol\ NaOH}{1\ mol\ H_3C_6H_5O_7} = \frac{n_{NaOH}}{4.80 \times 10^{-3}\ mol\ H_3C_6H_5O_7}$$
$$n_{NaOH} = \frac{3\ mol\ NaOH \times 4.80 \times 10^{-3}\ \cancel{mol\ H_3C_6H_5O_7}}{1\ \cancel{mol\ H_3C_6H_5O_7}}$$
$$= 1.44 \times 10^{-2}\ mol$$

Volume of NaOH(aq):

$$V = \frac{n}{c}$$
$$= \frac{1.44 \times 10^{-2}\ \cancel{mol}}{0.165\ \cancel{mol}/L}$$
$$= 8.7272 \times 10^{-2}\ L$$
$$= 8.73 \times 10^{-2}\ L$$

The volume of NaOH(aq) is 8.73×10^{-2} L.

Check Your Solution

Estimating the answer, the volume of NaOH(aq) will be $\frac{0.12}{0.16}$ less than the volume of citric acid because the ratio of the concentrations of NaOH(aq) to $H_3C_6H_5O_7$(aq) is $\frac{0.12}{0.16}$. The volume of NaOH(aq) will be $\frac{3}{1}$ times greater than the volume of $H_3C_6H_5O_7$(aq) because of the 3:1 mole ratio between NaOH(aq) and $H_3C_6H_5O_7$(aq).

The volume, V, of NaOH(aq) can be estimated:

$V \approx$ volume of $H_3C_6H_5O_7$(aq) × concentration ratio factor × mole ratio factor

$$\approx 0.04\text{ L} \times \frac{0.12}{0.16} \times \frac{3}{1} = 0.09\text{ L}$$

The calculated answer of 8.73×10^{-2} L seems reasonable and has three significant digits.

9. Practice Problem (page 466)

Phosphoric acid, H_3PO_4(aq), is a weak triprotic acid. When phosphoric acid reacts with a base, different salts can be prepared, depending on how many hydrogen ions are replaced by cations.

For example, potassium hydrogen phosphate, K_2HPO_4 (aq), can be prepared in an aqueous solution by adding just enough potassium hydroxide, KOH(aq), to replace two hydrogen ions:

$H_3PO_4(aq) + 2KOH(aq) \rightarrow K_2HPO_4(aq) + 2H_2O(\ell)$

What volume of 0.185 mol/L potassium hydroxide should be added to 80.0 mL of 0.137 mol/L phosphoric acid, H_3PO_4(aq), to form a solution of potassium hydrogen phosphate?

What Is Required?

You need to find the volume of a potassium hydroxide solution required to produce potassium hydrogen phosphate.

What Is Given?

You know the volume and concentration of the H_3PO_4(aq): $V = 80.0$ mL; $c = 0.137$ mol/L

You know the concentration of the KOH(aq): $c = 0.185$ mol/L

You know the balanced chemical equation for the reaction.

Plan Your Strategy

Convert the given volume of H_3PO_4(aq) from millilitres to litres: 1 mL = 1×10^{-3} L

Calculate the amount in moles of H_3PO_4(aq) using the relationship $n = cV$.

Check Your Solution

Estimating the answer, the volume of KOH(aq) will be $\frac{2}{1}$ times that of phosphoric acid because the mole ratio between KOH(aq) and H_3PO_4(aq) is 2:1. The volume will be approximately $\frac{0.14}{0.18}$ the volume of phosphoric acid because the ratio of the concentrations of H_3PO_4(aq) to KOH(aq) is 0.14:0.18.

The volume, V, of KOH(aq) can be estimated:

$V \approx$ volume of H_3PO_4(aq) × concentration factor × mole ratio factor

$$\approx 0.080 \text{ L} \times \frac{0.14}{0.18} \times \frac{2}{1} = 0.12 \text{ L}$$

The calculated answer of 0.118 L seems reasonable and has three significant digits.

10. Practice Problem (page 466)

What volume of 0.150 mol/L calcium hydroxide, $Ca(OH)_2$(aq), is needed to completely neutralize 20 mL of 0.185 mol/L sulfuric acid, H_2SO_4(aq)?

What Is Required?

You need to find the volume of a calcium hydroxide solution.

What Is Given?

You know the volume and concentration of the H_2SO_4(aq) : $V = 20$ mL; $c = 0.185$ mol/L

You know the concentration of the $Ca(OH)_2$(aq): $c = 0.150$ mol/L

Plan Your Strategy

Write the balanced chemical equation for the reaction.

Convert the given volumes of H_2SO_4(aq) and $Ca(OH)_2$(aq) from millilitres to litres: 1 mL = 1×10^{-3} L

Calculate the amount in moles of H_2SO_4(aq) using the relationship $n = cV$.

Use the mole ratio in the balanced equation to calculate the amount in moles of $Ca(OH)_2$(aq).

Calculate the volume of $Ca(OH)_2$(aq) using the relationship $V = \frac{n}{c}$.

Act on Your Strategy

Balanced chemical equation:

	H_2SO_4(aq)	+ $Ca(OH)_2$ (aq)	→ $CaSO_4$(s)	+ $2H_2O$(ℓ)
Mole ratio:	1 mole	1 mole		

Volume of H_2SO_4(aq):

$$V = 20\ \cancel{mL} \times 1 \times 10^{-3}\ L/\cancel{mL}$$
$$= 0.020\ L$$

Amount in moles, n, of H_2SO_4(aq):

$$n_{H_2SO_4} = cV$$
$$= 0.185\ mol/\cancel{L} \times 0.020\ \cancel{L}$$
$$= 0.3.70 \times 10^{-3}\ mol$$

Amount in moles, n, of $Ca(OH)_2$(aq):

$$\frac{1\ mol\ Ca(OH)_2}{1\ mol\ H_2SO_4} = \frac{n_{Ca(OH)_2}}{3.70 \times 10^{-3}\ mol\ H_2SO_4}$$
$$n_{Ca(OH)_2} = \frac{1\ mol\ Ca(OH)_2 \times 3.70 \times 10^{-3}\ \cancel{mol\ H_2SO_4}}{1\ \cancel{mol\ H_2SO_4}}$$
$$= 3.7 \times 10^{-3}\ mol$$

Volume of $Ca(OH)_2$ (aq):

$$V = \frac{n}{c}$$
$$= \frac{3.70 \times 10^{-3}\ \cancel{mol}}{0.150\ \cancel{mol}/L}$$
$$= 2.466 \times 10^{-2}\ L$$
$$= 2.5 \times 10^{-2}\ L$$

The volume of $Ca(OH)_2$ (aq) is 2.5×10^{-2} L.

Check Your Solution

The mole ratio between H_2SO_4(aq) and $Ca(OH)_2$ (aq) is 1:1. Since the concentrations are almost the same, the volumes used in this neutralization reaction should be about the same. The answer seems reasonable and has two significant digits.