

Titration Calculations

Mark Scheme



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Section 1: Determining an unknown concentration

1. For each of the following questions determine the concentration giving each answer to 3 significant figures.

a) 25.0 cm³ of 0.300 mol/dm³ barium hydroxide solution reacted with 21.3 cm³ of Nitric acid.

Step 1: Convert any volumes given in cm³ to dm³. Volume of Ba(OH) ₂ = 25.0 ÷ 1000 = 0.0250 dm ³ Volume of HNO ₃ = 21.3 ÷ 1000 = 0.0213 dm ³	
Step 2: Calculate the moles of barium hydroxide, Ba(OH)₂. moles = concentration × volume (dm ³) moles of Ba(OH) ₂ = 0.300 × 0.0250 = 0.0075 mol	1 mark
Step 3: Use the balanced equation to find the moles of nitric acid, HNO₃. The ratio of Ba(OH) ₂ to HNO ₃ is 1 : 2. moles of HNO ₃ = moles of Ba(OH) ₂ × 2 moles of HNO ₃ = 0.0075 × 2 = 0.015 mol	1 mark
Step 4: Calculate the concentration of nitric acid, HNO₃. concentration = moles ÷ volume (dm ³) concentration of HNO ₃ = 0.015 ÷ 0.0213 = 0.70422... mol/dm ³ Concentration = 0.704 mol/dm³ (to 3 significant figures)	1 mark
	Total: 3 marks

b) 22.0 cm³ of 0.20 mol/dm³ sodium hydroxide reacted with 27 cm³ of a solution of ethanoic acid.

Calculate the concentration of the ethanoic acid in mol/dm³.

Step 1: Convert any volumes given in cm³ to dm³. Volume of NaOH = 22.0 ÷ 1000 = 0.0220 dm ³ Volume of CH ₃ COOH = 27 ÷ 1000 = 0.027 dm ³	
Step 2: Calculate the moles of sodium hydroxide, NaOH. moles of NaOH = 0.20 × 0.0220 = 0.0044 mol	1 mark
Step 3: Use the balanced equation to find the moles of ethanoic acid, CH₃COOH. The ratio of CH ₃ COOH to NaOH is 1 : 1. moles of CH ₃ COOH = 0.0044 mol	1 mark
Step 4: Calculate the concentration of ethanoic acid, CH₃COOH. concentration of CH ₃ COOH = 0.0044 ÷ 0.027 = 0.16296... mol/dm ³ Concentration = 0.163 mol/dm³ (to 3 significant figures)	1 mark
	Total: 3 marks

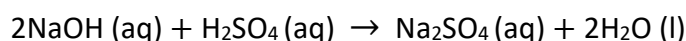
- c) 25 cm³ of sodium hydroxide solution reacted with 22.2 cm³ of 0.500 mol/dm³ hydrochloric acid.

Calculate the concentration of the sodium hydroxide solution in mol/dm³.

Step 1: Convert any volumes given in cm³ to dm³. Volume of NaOH = $25 \div 1000 = 0.025 \text{ dm}^3$ Volume of HCl = $22.2 \div 1000 = 0.0222 \text{ dm}^3$	
Step 2: Calculate the moles of hydrochloric acid, HCl. moles = concentration $\times$ volume (dm ³) moles of HCl = $0.500 \times 0.0222 = 0.0111 \text{ mol}$	1 mark
Step 3: Use the balanced equation to find the moles of sodium hydroxide, NaOH. The ratio of NaOH to HCl is 1 : 1. moles of NaOH = moles of HCl moles of NaOH = 0.0111 mol	1 mark
Step 4: Calculate the concentration of sodium hydroxide, NaOH. concentration = moles $\div$ volume (dm ³) concentration of NaOH = $0.0111 \div 0.025 = 0.444 \text{ mol/dm}^3$ Concentration = 0.444 mol/dm³	1 mark
	Total: 3 marks

- d) 20 cm³ of sodium hydroxide solution reacted with 25.0 cm³ of 0.200 mol/dm³ sulphuric acid.

Calculate the concentration of the sodium hydroxide solution in mol/dm³.



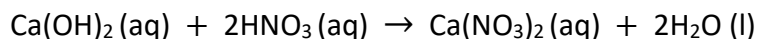
Step 1: Convert any volumes given in cm³ to dm³. Volume of NaOH = $20 \div 1000 = 0.020 \text{ dm}^3$ Volume of H ₂ SO ₄ = $25.0 \div 1000 = 0.0250 \text{ dm}^3$	
Step 2: Calculate the moles of sulfuric acid, H₂SO₄. moles = concentration $\times$ volume (dm ³) moles of H ₂ SO ₄ = $0.200 \times 0.0250 = 0.005 \text{ mol}$	1 mark
Step 3: Use the balanced equation to find the moles of sodium hydroxide, NaOH. The ratio of NaOH to H ₂ SO ₄ is 2 : 1. moles of NaOH = moles of H ₂ SO ₄ $\times$ 2 moles of NaOH = $0.005 \times 2 = 0.010 \text{ mol}$	1 mark
Step 4: Calculate the concentration of sodium hydroxide, NaOH. concentration = moles $\div$ volume (dm ³) concentration of NaOH = $0.010 \div 0.020 = 0.5 \text{ mol/dm}^3$ Concentration = 0.500 mol/dm³ (to 3 significant figures)	1 mark
	Total: 3 marks

(Total for Question 1 is 12 marks)

2. For each of following questions determine the missing concentration.

- a) 25.0 cm³ of 0.150 mol/dm³ calcium hydroxide solution reacted with 30.6 cm³ nitric acid.

Calculate the concentration of the nitric acid in mol/dm³.



Step 1: Convert any volumes given in cm³ to dm³. Volume of Ca(OH) ₂ = 25.0 ÷ 1000 = 0.0250 dm ³ Volume of HNO ₃ = 30.6 ÷ 1000 = 0.0306 dm ³	
Step 2: Calculate the moles of calcium hydroxide, Ca(OH)₂. moles = concentration × volume (dm ³) moles of Ca(OH) ₂ = 0.150 × 0.0250 = 0.00375 mol	1 mark
Step 3: Use the balanced equation to find the moles of nitric acid, HNO₃. The ratio of Ca(OH) ₂ to HNO ₃ is 1 : 2. moles of HNO ₃ = moles of Ca(OH) ₂ × 2 moles of HNO ₃ = 0.00375 × 2 = 0.0075 mol	1 mark
Step 4: Calculate the concentration of nitric acid, HNO₃. concentration = moles ÷ volume (dm ³) concentration of HNO ₃ = 0.0075 ÷ 0.0306 = 0.24509... mol/dm ³ Concentration = 0.245 mol/dm³ (to 3 significant figures)	1 mark
	Total: 3 marks

- b) 22.5 cm³ of sodium hydroxide solution reacted with 26.0 cm³ of 0.100 mol/dm³ hydrochloric acid.

Calculate the concentration of the sodium hydroxide solution in mol/dm³.

Step 1: Convert any volumes given in cm³ to dm³. Volume of NaOH = 22.5 ÷ 1000 = 0.0225 dm ³ Volume of HCl = 26.0 ÷ 1000 = 0.0260 dm ³	
Step 2: Calculate the moles of hydrochloric acid, HCl. moles = concentration × volume (dm ³) moles of HCl = 0.100 × 0.0260 = 0.00260 mol	1 mark
Step 3: Use the balanced equation to find the moles of sodium hydroxide, NaOH. The ratio of NaOH to HCl is 1 : 1. moles of NaOH = moles of HCl moles of NaOH = 0.00260 mol	1 mark
Step 4: Calculate the concentration of sodium hydroxide, NaOH. concentration = moles ÷ volume (dm ³) concentration of NaOH = 0.00260 ÷ 0.0225 = 0.11555... mol/dm ³ Concentration = 0.116 mol/dm³ (to 3 significant figures)	1 mark
	Total: 3 marks

- c) A solution is made by dissolving calcium chloride in water. 11.1 g of calcium chloride are dissolved in water. The volume of the solution is made up to 500 cm³.

Calculate the concentration in mol/dm³ of calcium chloride, CaCl₂ in this solution.

Step 1: Calculate the moles of calcium chloride, CaCl₂. First, find the relative formula mass (Mr) of CaCl ₂ . Mr of CaCl ₂ = 40 + (2 × 35.5) = 111 moles = mass ÷ Mr moles of CaCl ₂ = 11.1 ÷ 111 = 0.1 mol	1 mark
Step 2: Convert the volume from cm³ to dm³. Volume = 500 ÷ 1000 = 0.5 dm ³	1 mark
Step 3: Calculate the concentration of the calcium chloride, CaCl₂, solution. concentration = moles ÷ volume (dm ³) concentration of CaCl ₂ = 0.1 ÷ 0.5 = 0.2 mol/dm ³ Concentration = 0.200 mol/dm ³	1 mark
Total: 3 marks	

- d) 25 cm³ of sodium hydroxide solution reacted with 23.2 cm³ of 0.1 mol/dm³ hydrochloric acid.

Calculate the concentration of this sodium hydroxide solution, NaOH, in mol/dm³.

Step 1: Convert any volumes given in cm³ to dm³. Volume of NaOH = 25 ÷ 1000 = 0.025 dm ³ Volume of HCl = 23.2 ÷ 1000 = 0.0232 dm ³	
Step 2: Calculate the moles of hydrochloric acid, HCl. moles = concentration × volume (dm ³) moles of HCl = 0.1 × 0.0232 = 0.00232 mol	1 mark
Step 3: Use the balanced equation to find the moles of sodium hydroxide, NaOH. The ratio of NaOH to HCl is 1 : 1. moles of NaOH = moles of HCl moles of NaOH = 0.00232 mol	1 mark
Step 4: Calculate the concentration of sodium hydroxide, NaOH. concentration = moles ÷ volume (dm ³) concentration of NaOH = 0.00232 ÷ 0.025 = 0.0928 mol/dm ³ Concentration = 0.0928 mol/dm ³	1 mark
Total: 3 marks	

(Total for Question 2 is 12 marks)

3. A student needed to determine the concentration of a sample of limewater, calcium hydroxide solution, Ca(OH)_2 .

The student used a pipette to measure out 25.0 cm^3 of the limewater into a conical flask, adding a few drops of phenolphthalein indicator. They then titrated this against nitric acid (HNO_3) from a burette. The indicator turned from pink to colourless at the end point.

The concentration of the nitric acid was 12.6 g/dm^3 .

The student's titration results are shown in the table below.

Titration Number	Final burette reading (cm^3)	Initial burette reading (cm^3)	Volume of HNO_3 added (cm^3)
1	25.50	0.00	25.50
2	24.60	0.10	24.50
3	49.70	25.10	24.60
4	24.95	0.80	24.15

Calculate the concentration of the calcium hydroxide (Ca(OH)_2) solution in mol/dm^3 .

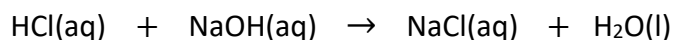
Relative atomic masses: H = 1; N = 14; O = 16

Step 1: Calculate the concentration of nitric acid (HNO_3) in mol/dm^3. First, find the relative formula mass (Mr) of HNO_3 . $\text{Mr of } \text{HNO}_3 = 1 + 14 + (3 \times 16) = 63$ $\text{concentration (mol/dm}^3\text{)} = \text{concentration (g/dm}^3\text{)} \div \text{Mr}$	1 mark
$\text{concentration of } \text{HNO}_3 = 12.6 \div 63 = 0.200 \text{ mol/dm}^3$	1 mark
Step 2: Determine the mean volume of HNO_3 added from concordant results. Concordant results are Titration 2 (24.50 cm^3) and Titration 3 (24.60 cm^3). $\text{Mean volume} = (24.50 + 24.60) \div 2 = 24.55 \text{ cm}^3$	1 mark
Step 3: Calculate the moles of nitric acid (HNO_3) used. First, convert the mean volume from cm^3 to dm^3 : $\text{Volume} = 24.55 \div 1000 = 0.02455 \text{ dm}^3$ $\text{moles} = \text{concentration} \times \text{volume (dm}^3\text{)}$ $\text{moles of } \text{HNO}_3 = 0.200 \times 0.02455 = 0.00491 \text{ mol}$	1 mark
Step 4: Use the balanced equation to find the moles of calcium hydroxide, Ca(OH)_2. The ratio of Ca(OH)_2 to HNO_3 is 1 : 2. $\text{moles of } \text{Ca(OH)}_2 = \text{moles of } \text{HNO}_3 \div 2$ $\text{moles of } \text{Ca(OH)}_2 = 0.00491 \div 2 = 0.002455 \text{ mol}$	1 mark
Step 5: Calculate the concentration of the calcium hydroxide, Ca(OH)_2, solution. First, convert the volume of Ca(OH)_2 from cm^3 to dm^3 : $\text{Volume} = 25.0 \div 1000 = 0.0250 \text{ dm}^3$ $\text{concentration} = \text{moles} \div \text{volume (dm}^3\text{)}$ $\text{concentration of } \text{Ca(OH)}_2 = 0.002455 \div 0.0250 = 0.0982 \text{ mol/dm}^3$ Concentration = 0.0982 mol/dm^3 (to 3 significant figures)	1 mark
	Total: 6 marks

(Total for Question 3 is 6 marks)

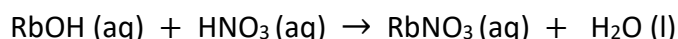
Section 2: Determining an unknown volume

4. For each of the following questions determine the volume giving each answer to **3 significant figures**.
- a) Find the volume of 1.0 mol/dm^3 hydrochloric acid that reacts with 23.5 cm^3 of 1.25 mol/dm^3 sodium hydroxide.



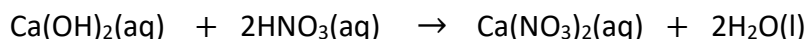
Step 1: Convert the known volume from cm^3 to dm^3. Volume of NaOH = $23.5 \div 1000 = 0.0235 \text{ dm}^3$	
Step 2: Calculate the moles of sodium hydroxide, NaOH. moles = concentration $\times$ volume (dm^3) moles of NaOH = $1.25 \times 0.0235 = 0.029375 \text{ mol}$	1 mark
Step 3: Use the balanced equation to find the moles of hydrochloric acid, HCl. The ratio of HCl to NaOH is 1 : 1. moles of HCl = moles of NaOH moles of HCl = 0.029375 mol	1 mark
Step 4: Calculate the volume of hydrochloric acid, HCl. volume (dm^3) = moles $\div$ concentration volume of HCl = $0.029375 \div 1.0 = 0.029375 \text{ dm}^3$ Convert volume to cm^3 : $0.029375 \times 1000 = 29.375 \text{ cm}^3$ Volume = 29.4 cm^3 (to 3 significant figures)	1 mark
	Total: 3 marks

- b) What volume of 0.2 mol/dm^3 rubidium hydroxide reacts with 18.0 cm^3 of 0.320 mol/dm^3 nitric acid?



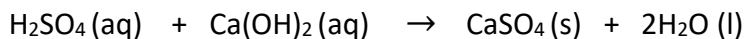
Step 1: Convert the known volume from cm^3 to dm^3. Volume of HNO_3 = $18.0 \div 1000 = 0.0180 \text{ dm}^3$	
Step 2: Calculate the moles of nitric acid, HNO_3. moles = concentration $\times$ volume (dm^3) moles of HNO_3 = $0.320 \times 0.0180 = 0.00576 \text{ mol}$	1 mark
Step 3: Use the balanced equation to find the moles of rubidium hydroxide, RbOH. The ratio of RbOH to HNO_3 is 1:1. moles of RbOH = moles of HNO_3 moles of RbOH = 0.00576 mol	1 mark
Step 4: Calculate the volume of rubidium hydroxide, RbOH. volume (dm^3) = moles $\div$ concentration volume of RbOH = $0.00576 \div 0.2 = 0.0288 \text{ dm}^3$ Convert volume to cm^3 : $0.0288 \times 1000 = 28.8 \text{ cm}^3$ Volume = 28.8 cm^3	1 mark
	Total: 3 marks

- c) What volume of 0.520 mol/dm³ calcium hydroxide neutralises 28.0 cm³ of 0.20 mol/dm³ nitric acid?



Step 1: Convert the known volume from cm³ to dm³. Volume of HNO ₃ = 28.0 ÷ 1000 = 0.0280 dm ³	
Step 2: Calculate the moles of nitric acid, HNO₃. moles = concentration × volume (dm ³) moles of HNO ₃ = 0.20 × 0.0280 = 0.0056 mol	1 mark
Step 3: Use the balanced equation to find the moles of calcium hydroxide, Ca(OH)₂. The ratio of Ca(OH) ₂ to HNO ₃ is 1 : 2. moles of Ca(OH) ₂ = moles of HNO ₃ ÷ 2 moles of Ca(OH) ₂ = 0.0056 ÷ 2 = 0.0028 mol	1 mark
Step 4: Calculate the volume of calcium hydroxide, Ca(OH)₂. volume (dm ³) = moles ÷ concentration volume of Ca(OH) ₂ = 0.0028 ÷ 0.520 = 0.0053846 dm ³ Convert volume to cm ³ : 0.0053846 × 1000 = 5.3846 cm ³ Volume = 5.38 cm ³ (to 3 significant figures)	1 mark
	Total: 3 marks

- d) What volume of 0.450 mol/dm³ calcium hydroxide neutralises 26.0 cm³ of 0.150 mol/dm³ sulfuric acid?



Step 1: Convert the known volume from cm³ to dm³. Volume of H ₂ SO ₄ = 26.0 ÷ 1000 = 0.0260 dm ³	
Step 2: Calculate the moles of sulfuric acid, H₂SO₄. moles = concentration × volume (dm ³) moles of H ₂ SO ₄ = 0.150 × 0.0260 = 0.00390 mol	1 mark
Step 3: Use the balanced equation to find the moles of calcium hydroxide, Ca(OH)₂. The ratio of H ₂ SO ₄ to Ca(OH) ₂ is 1 : 1. moles of Ca(OH) ₂ = moles of H ₂ SO ₄ moles of Ca(OH) ₂ = 0.00390 mol	1 mark
Step 4: Calculate the volume of calcium hydroxide, Ca(OH)₂. volume (dm ³) = moles ÷ concentration volume of Ca(OH) ₂ = 0.00390 ÷ 0.450 = 0.008666 dm ³ Convert volume to cm ³ : 0.008666 × 1000 = 8.666 cm ³ Volume = 8.67 cm ³ (to 3 significant figures)	1 mark
	Total: 3 marks

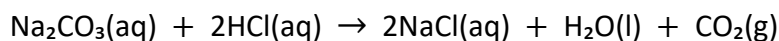
(Total for Question 4 is 12 marks)

5. A student was given a sample of sodium carbonate solution (Na_2CO_3) of a known concentration, but with an unknown volume.

To determine its volume, the student titrated it with hydrochloric acid (HCl) of concentration 0.200 mol/dm^3 .

The student placed the unknown volume of sodium carbonate solution in a conical flask with a few drops of methyl orange indicator. The hydrochloric acid was added from a burette.

The **balanced** chemical equation for the reaction is:



The student's titration results are shown in the table below.

Titration Number	Final burette reading (cm^3)	Initial burette reading (cm^3)	Volume of HCl added (cm^3)
1	21.50	0.00	21.50
2	42.30	21.50	20.80
3	23.70	2.50	21.20
4	44.60	23.80	20.80

The concentration of the sodium carbonate (Na_2CO_3) solution was 0.125 mol/dm^3 .

Using the student's results, calculate the unknown volume of the sodium carbonate solution that was in the conical flask. Give your answer in cm^3 to 3 significant figures.

Step 1: Determine the mean volume of HCl added from concordant results. Concordant results are Titration 2 (20.80 cm^3) and Titration 4 (20.80 cm^3). Mean volume = $(20.80 + 20.80) \div 2 = 20.80 \text{ cm}^3$	1 mark
Step 2: Calculate the moles of hydrochloric acid (HCl) used. First, convert the mean volume from cm^3 to dm^3 : Volume = $20.80 \div 1000 = 0.0208 \text{ dm}^3$ moles = concentration $\times$ volume (dm^3) moles of HCl = $0.200 \times 0.0208 = 0.00416 \text{ mol}$	1 mark
Step 3: Use the balanced equation to find the moles of sodium carbonate (Na_2CO_3). The ratio of Na_2CO_3 to HCl is 1 : 2. moles of Na_2CO_3 = moles of HCl $\div$ 2 moles of Na_2CO_3 = $0.00416 \div 2 = 0.00208 \text{ mol}$	2 marks
Step 4: Calculate the unknown volume of the sodium carbonate (Na_2CO_3) solution. volume (dm^3) = moles $\div$ concentration volume of Na_2CO_3 = $0.00208 \div 0.125 = 0.01664 \text{ dm}^3$	1 mark
Convert volume to cm^3 : $0.01664 \times 1000 = 16.64 \text{ cm}^3$ Volume = 16.6 cm^3 (to 3 significant figures)	1 mark
Total: 6 marks	

(Total for Question 5 is 6 marks)

6. A laboratory technician prepared a stock solution of sulfuric acid (H_2SO_4) by dissolving a quantity of pure acid in a large beaker of water.

To determine this unknown volume, the technician first had to find the concentration of their acid. They did this by titrating it against a standard solution of sodium hydroxide (NaOH) with a known concentration of 10.0 g/dm^3 .

Titration Number	Final burette reading (cm^3)	Initial burette reading (cm^3)	Volume of H_2SO_4 added (cm^3)
1	22.50	0.00	22.50
2	44.50	22.50	22.00
3	21.90	0.00	21.90
4	37.50	15.50	22.00

Using the information and the technician's **concordant** volumes, calculate the original volume of the sulfuric acid stock solution. Relative atomic masses: $\text{H} = 1$; $\text{O} = 16$; $\text{Na} = 23$

Step 1: Calculate the concentration of sodium hydroxide (NaOH) in mol/dm^3. First, find the relative formula mass (M_r) of NaOH. M_r of $\text{NaOH} = 23 + 16 + 1 = 40$ concentration (mol/dm^3) = concentration (g/dm^3) $\div$ M_r concentration of $\text{NaOH} = 10.0 \div 40 = 0.250 \text{ mol/dm}^3$	1 mark
Step 2: Calculate the moles of sodium hydroxide (NaOH) used in the titration. First, convert the volume of NaOH from cm^3 to dm^3: Volume = $25.0 \div 1000 = 0.0250 \text{ dm}^3$ moles = concentration $\times$ volume (dm^3) moles of $\text{NaOH} = 0.250 \times 0.0250 = 0.00625 \text{ mol}$	1 mark
Step 3: Determine the mean volume of H_2SO_4 added from concordant results. Concordant results are Titrations 2 (22.00 cm^3), 3 (21.90 cm^3), and 4 (22.00 cm^3). Mean volume = $(22.00 + 21.90 + 22.00) \div 3 = 21.97 \text{ cm}^3$ (or 21.966)	1 mark
Step 4: Use the balanced equation to find the moles of sulfuric acid (H_2SO_4). The ratio of H_2SO_4 to NaOH is 1 : 2. moles of $\text{H}_2\text{SO}_4 = \text{moles of NaOH} \div 2$ moles of $\text{H}_2\text{SO}_4 = 0.00625 \div 2 = 0.003125 \text{ mol}$	1 mark
Step 5: Calculate the concentration of the sulfuric acid (H_2SO_4) solution. First, convert the mean volume of H_2SO_4 from cm^3 to dm^3: Volume = $21.966 \div 1000 = 0.021966 \text{ dm}^3$ concentration = moles $\div$ volume (dm^3) concentration of $\text{H}_2\text{SO}_4 = 0.003125 \div 0.021966 = 0.14226 \text{ mol/dm}^3$	1 mark
Step 6: Calculate the original volume of the sulfuric acid stock solution. The original solution contained 0.110 moles of H_2SO_4. volume (dm^3) = moles $\div$ concentration Original volume = $0.110 \div 0.14226 = 0.7732 \text{ dm}^3$ Volume = 0.773 dm^3 (to 3 significant figures)	1 mark
Total: 6 marks	

(Total for Question 6 is 6 marks)