2015 specification
first exams in 2017

Titrations 'Tricky Topics' Worksheets

for A Level Edexcel Chemistry

Exam skills prep pack

zigzageducation.co.uk

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Contents

Teacher’s Introduction

This activity pack is designed to help your students develop skills both during class and in an extracurricular setting. The content covers titration where it occurs in a range of topics across the A Level course.
The resource contains:

- a student introduction
- 12 worksheets, each of which covers one of the skills outlined below
- exam-style questions
- an appendix – a refresher for GCSE topics relating to titrations

Although each worksheet covers a specific section of the A Level resource, the exercises are primarily skills-focused. These skills are all relevant to the A Level Edexcel examinations and are covered as follows:

1. Titration basics: results and uncertainties
2. Concentrations and dilutions
3. Structured acid–base titration questions
4. Unstructured acid–base titration questions
5. Back titrations
6. Titration curves and choosing indicators
7. Strong acids and bases
8. Weak acids
9. Buffers
10. Structured redox titrations
11. Unstructured redox titrations
12. The most difficult redox titrations

Each worksheet contains a short section of background information, followed by **worked examples** and then **in-depth questions** to test students’ knowledge. The questions are split into **three levels of increasing difficulty**, illustrated using the headings *Prepare your solutions*, *High concentration* and *Drop the base*. You’ll find an answers section at the end of the pack.

The pack also includes **full exam-style questions** which closely replicate the style of questions found in an examination paper.

I hope this resource will be useful to your teaching and will help your students not only to tackle an area of chemistry which many find challenging, but also to gain a deeper, more holistic understanding of the topic.

Student Introduction

Acids

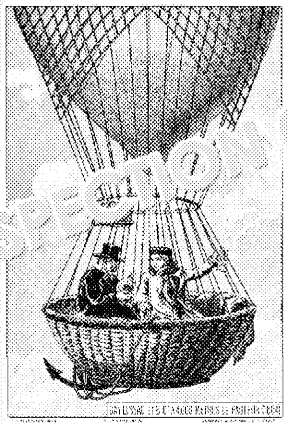
Sour-tasting substances were called 'oxein' by the ancient Greeks. The Greeks didn
responsible for sour tastes were acids. With the Romans, this word became 'acetu
vinegar, which tastes sour due to the presence of ethanoic acid. It was also known
change the colour of litmus, a type of moss, and that they could react with metals.

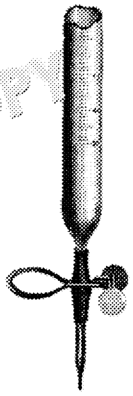
'Acetum' in Latin became 'acid' in English. The word now describes not only the so
acid in vinegar and citric acid in lemons, but also the acids you'd be better off not
sulfuric acid, for example.

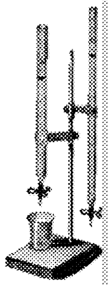
Arrhenius was the first to propose that acids, when dissolved in water, produced s
also noted that alkalis produce solutions of OH⁻ ions, and that acids and alkalis re
water. We still use these definitions today.

Titrations

Titrations were first used in eighteenth-century France. Joseph Louis Gay-Lussac d
side arm, and inexplicably making it so the tap stuck out on the wrong side. Below
another scientist, Biot, in a hot-air balloon in 1814, collecting gases at different alt
improved the burette, adding a clamp and tip at the bottom, and then drawing so
day, the sidearm tap of the burette remains curiously uncomfortable to reach even
chemists.







Purpose of this pack

Titrations are probably among the more difficult practicals you'll do at school. You
the solutions; swirling the flask and operating the tap at the same time always seem
two hands, and even if you do manage to reach the end without your burette com
got to have a pretty good handle on the maths to make it all worth it.

This pack will equip you to deal with the really mathsy stuff, starting at the basics,
exam questions, and everything you need to know in between:

1. Results tables and uncertainties
2. Concentrations and dilutions
3. Structured acid–base titration questions
4. Unstructured acid–base titration questions
5. Back titrations
6. Titration curves and choosing indicators
7. Strong acids and ba
8. Weak acids
9. Buffers
10. Structured redox titr
11. Unstructured redox t
12. The most difficult re

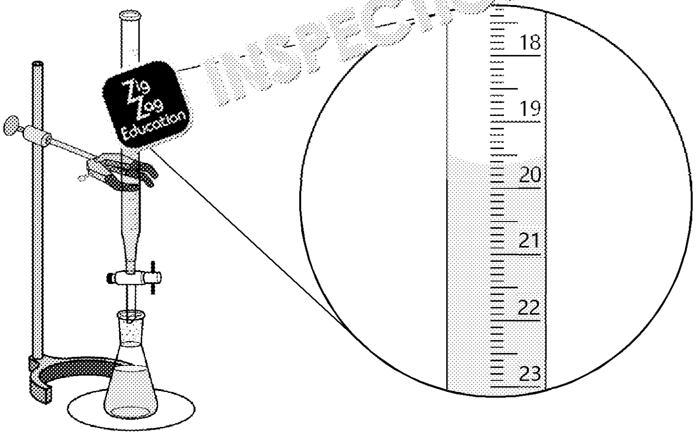
Titration basics: results and unc

Key skills

- Reading a burette
- Completing titration results tables
- Calculating mean titres
- Calculating uncertainties

concordant –
titrations, resu
titre – the res
uncertainty –

Reading the burette



The reading
from the bot
given to 2 d.
This burette
the bottom o
19.60 cm³ an

Results tables

Usually, the first titre will be done very quickly to find a rough result. This result is
not be included in the mean.

After that, the titration is repeated until two concordant results are obtained. This
within 0.1 cm³ of each other.

An average (mean) of concordant results is then taken.

$$\text{mean titre} = \frac{\text{sum of all concordant titres}}{\text{number of concordant titres}}$$

Example table

The experiment is repeated to increase accuracy.

	Rough	1	2	3
Start volume (cm³)	0.00	0.05	0.00	0.00
End volume (cm³)	25.65	23.30	23.50	23.35
Volume of acid (cm³)	25.65	23.25	23.50	23.35

Mea

End volume – Start volume

Titre 2 is **not concordant** with titres 1 and 3, so not included in the mean.

Titres 1 and 3 are **concordant** – they are within 0.10 cm³ of each other.

Uncertainties

Titration results come with a certain amount of **uncertainty**. The main factor in this uncertainty is the uncertainty due to the burette.

The uncertainty of a burette is ± 0.05 cm^3 per reading. There are two readings in a titre; therefore the total uncertainty in a titre is 2 × 0.05 = 0.10 cm^3

A reading involves
temperature.
A measurement re
change (begi
temperature)
end volume).

Occasionally, you might have to factor in the uncertainty from judging an end
There is an additional uncertainty of 0.05 cm^3 in every measurement.

Percentage uncertainties

Percentage uncertainties are a useful way of considering the scale of an uncertain
0.15 cm^3 if including the uncertainty due to the drop) is not very big if the average
more important if the average titre is smaller, such as 8.5 cm^3.
To calculate percentage uncertainty:

$$\% \text{ uncertainty} = \frac{\text{uncertainty}}{\text{value}} \times 100$$

Example

a) Complete the results table.

	Rough	**1**	**2**	**3**
Start volume (cm^3)	0.00	18.15	0.05	17.35
End volume (cm^3)	18.60	36.25	[illegible]	34.80
Volume of acid (cm^3)				

	Rou
Start volume (cm^3)	0.0
End volume (cm^3)	18.6
Volume of acid (cm^3)	18.6

calcu

b) Calculate the mean titre for the results to 2 decimal places.

Mean titre $= \frac{17.40 + 17}{2}$
$= 17.425$
$= 17.43$ ◄

c) Calculate the percentage uncertainty of the mean titre due to the burette readings.

% uncertainty $= \frac{\text{uncertaint}}{\text{value}}$ ◄
$= \frac{0.1}{17.43} \times 1$
$= 0.574$ %

Questions

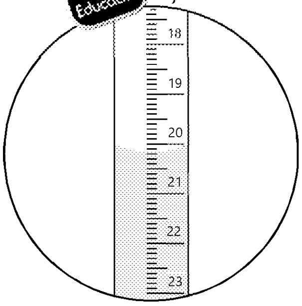
Prepare your solutions

1. Complete the results table below for a titration experiment.

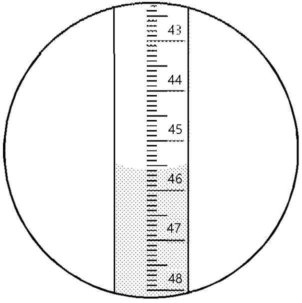
	Rough	1	2	3
Start volume (cm³)	0.00	12.65	[illegible]	0.00
End volume (cm³)	12.65	[illegible]	[illegible]	11.55
Volume of acid (cm³)				

2. What a[illegible] re[illegible] on these burettes?

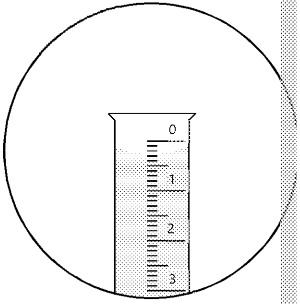
a)



b)



c)



High concentration

3. A titration has the following results:

	Rough	1	2	[illegible]
Start volume (cm³)	0.80	0.20	[illegible]	0.50
End volume (cm³)	17.10	[illegible]	[illegible]	17.35
Volume of acid (cm³)				

Find th[illegible] this titration.

4. Complete the results table below for a titration experiment, and calculate the

	Rough	1	2	3
Start volume (cm³)	0.05	19.50	0.10	19.05
End volume (cm³)	19.50		19.05	38.05
Volume of acid (cm³)		18.90		

Drop the base

5. The table below shows an incomplete set of results for a titration experiment in the mean titre, taking into account the uncertainty due to making readings due to the volume of a drop).

	Rough	1	2	3
Start volume (cm³)	[illegible]	[illegible]	0.40	0.15
End volume (cm³)	[illegible]	43.10	43.05	43.05
Volum[illegible] ac[illegible]				

6. In a titra[illegible] experiment, a student fills the burette with acid. The bure cleaned before this use. Explain how this could affect the mean titre.

Concentrations and diluti

Concentration

Concentrations are used in titrations to calculate the amounts of a substance in a
Concentration can be calculated using:

$$\text{concentration} = \frac{\text{moles}}{\text{volume}} \qquad \text{and has unit}$$

To work out how to make a solution with a specific concentration, you just have to
For example, to make a solution with concentration 0.2 mol dm^{-3} and a volume of

$$\text{moles} = \text{concentration} \times \text{volume} = 0.2 \times \frac{300}{1000} = 0.06$$

Converting units

In titrations you may be given a volume in cm^3 with a concentration in mol dm^{-3}.
from cm^3 to dm^3.

$$1\ dm^3 = 1000\ cm^3 \text{ and } 1\ cm^3 = 0.001\ dm^3$$

To convert a volume from cm^3 to dm^3, **divide** the value by 1000.

e.g. $$20\ cm^3 = \frac{20}{1000}\ dm^3 = 0.020\ dm^3$$

To convert a volume from dm^3 to cm^3, **multiply** the value by 1000.

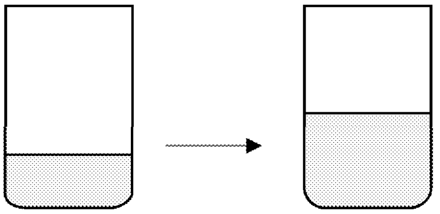
e.g. $$4.0\ dm^3 = 4 \times 1000\ cm^3 = 4000\ cm^3$$

Diluting solutions

Diluting a solution by adding more solvent (e.g. distilled water) decreases its conc
You can calculate the concentration of the diluted solution by dividing the concen
multiplying by the new volume.

$$\text{new concentration} = \frac{\text{old volume}}{\text{new volume}} \times \text{old concent}$$

e.g. A solution with concentration 0.5 mol dm^{-3} is diluted with water from 5 cm^3 t



It's a good idea to
reasonable. In this
would expect the
More specifi
concentratio

$$\text{new concentration} = 0.5 \times \frac{5}{10} = 0.25\ mol\ dm^{-3}$$

For more complex dilutions, you may need to convert the concentrations into the
perform the [illegible] of the calculation, and then convert back into concentration at th

$$\text{concentration} = \frac{\text{moles}}{\text{volume}} \qquad \text{concentration} =$$

Example 1

10 cm³ of a solution with concentration 0.30 mol dm⁻³ is diluted to 0.10 dm³. What is the concentration of the new solution?

$0.1\ dm^3 = 100\ cm^3$

$\text{Concentration} = 0.30 \times \frac{10}{100}$

$= 0.030$ mol d

Example 2

Citric acid has an M_r of 192.1.
0.960 g of citric acid was dissolved in 50.0 cm³ of distilled water. The solution was then poured into a volumetric flask and made up to 250 cm³.
Calculate the concentration of citric acid solution in the volumetric flask in mol dm⁻³.

moles of citric acid $= \frac{0.960}{192.1}$

$= 0.00500$

volume $= \frac{250}{1000}$

$= 0.250$

concentration $= \frac{0.00500}{0.250}$

$= 0.0200$ m

Questions

Prepare your solutions

1. Find the concentration in g dm⁻³ of a solution where 3.00 g is dissolved in 50

2. How many moles are in 200 cm³ of a 0.200 mol dm⁻³ solution?

3. Find the volume required to make a solution with concentration 0.500 mol dm

High concentration

4. A standard solution of HCl is made with concentration 2.00 mol dm⁻³. 25.0 cm solution [illegible] a [illegible] dm³ volumetric flask. Distilled water is used to fill the fla concentration of HCl in the new solution.

5. Calculate the total volume of a solution of concentration 0.0125 mol dm⁻³ pr 0.400 mol dm⁻³ solution with water.

6. In a titration, a 2.00 cm³ sample of Solution A is diluted to 100 cm³. The 100 c using titration, and is found to have a concentration of 0.240 mol dm⁻³. Calcu Solution A.

Drop the base

7. A 200 cm³ solution of KI is made using 3.40 g of solid KI. KI has a relative for concentration of KI in mol dm⁻³.

8. 250 cm³ of an NaCl solution with concentration 1.00 g dm⁻³ is diluted to give extra 0.500 g of NaCl is added. Calculate the concentration of the new solutio

Structured acid–base titration ca

Titration calculations

The purpose of a titration is to find the concentration of a solution. Acid–base titra
reaction between a solution of known concentration and a solution of unknown co

You will need to use the equation: concentration =

And to rearrange it [illegible] moles = concentratio

and volume = $\frac{\text{m}}{\text{concen}}$

You will also need to consider the effects of ratios of reactants in the reaction equa

e.g. $H_3PO_4 + 3NaOH \rightarrow Na_3PO_4 + 3H_2O$

ratio: 1 3 1 3

For this reaction, there is a 1 : 3 ratio of acid (H_3PO_4) to base (NaOH).

Finally, don't forget to convert your answer to the correct units.

Example 1

In a titration experiment, 0.210 mol dm^{-3} NaOH was used to analyse a 25.0 cm^3 solution of HNO_3.

	Rough	1	2	3
Start volume (cm^3)	0.00	0.00	0.00	0.00
End volume (cm^3)	45.80	45.65	[illegible]	[illegible]
Volume of acid (cm^3)	45.80			

The equation for this reaction is:

$NaOH + HNO_3 \rightarrow NaNO_3 + H_2O$

a) Complete the results table above and calculate the mean titre.

b) Calculate the number of moles of NaOH in the mean titre.

c) Find the mass of HNO_3 dissolved in the 25.0 cm^3 solution to an appropriate number of significant figures. (M_r HNO_3 = 63.0)

Example 2

In a titration experiment, a standard solution of H_2SO_4 was used to find the concentration of a solution of NaOH.

$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$

50.0 cm^3 samples of the NaOH solution were titrated against H_2SO_4 with a concentration of 0.200 mol dm^{-3}. The mean titre was [illegible].

a) Find the number of moles of H_2SO_4 in the mean titre.

b) Find the number of moles of NaOH in each sample.

c) Find the concentration in mol dm^{-3} of the NaOH solution to three significant figures.

a)

Start volume (cm^3)
End volume (cm^3)
Volume of acid (cm^3)

mean titre = $\frac{45.65 + 45}{}$

b) mol NaOH = $\frac{4}{1}$

= 0

c) ratio in reaction

mol HNO_3 = 0

mass HNO_3 = 6

= 0.603 g

mol = conc × vol

a) mol H_2SO_4 = 0.

= 0.

b) Ratio in reaction

mol NaOH = 2

= 0.

c) conc NaOH = 0

= 0

Questions

Prepare your solutions

1. In a titration experiment, 0.200 mol dm^{-3} HCl is put into a burette.
   The following results are recorded:

	Rough	1	2	3
Start volume (cm^3)	0.00	[illegible]	0.10	16.15
End volume (cm^3)	[illegible]	[illegible]	16.15	32.25
Volume of acid (cm^3)				

   a) Find the mean titre for this titration.

   b) Calculate the moles of HCl used in the mean titre.

2. In a titration experiment, a solution of H_2SO_4 with a concentration of 0.100 m
   added to a solution of NaOH.

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$$

   The following results are recorded:

	Rough	1	2	3
Start volume (cm^3)	0.00	0.00	23.85	0.00
End volume (cm^3)	24.40	23.85	47.65	23.80
Volume of acid (cm^3)				

   a) Find the mean titre for this titration.

   b) Calculate the moles of H_2SO_4 used in the mean titre.

   c) Calculate the number of moles of NaOH which reacted with the H_2SO_4.

High concentration

3. A student performs a titration experiment between HCl and KOH.

   30.0 cm^3 samples of KOH were titrated with 0.200 mol dm^{-3} HCl. The student
   13.70 cm^3.

   a) Calculate the moles of HCl in the mean titre.

   b) Calculate the moles of KOH in the 30.0 cm^3 samples.

   c) Calculate the concentration of KOH.

4. A student performs a titration experiment between H_2SO_4 and KOH.

   80.0 cm^3 samples of KOH were titrated with H_2SO_4. The H_2SO_4 solution was p
   2.00 mol dm^{-3} solution diluted to 1.00 dm^3. The student calculated the mean

   a) Calculate the concentration of the H_2SO_4 used in the titration.

   b) Calculate the moles of H_2SO_4 in the mean titre.

   c) Calculate the moles of KOH in the 80.0 cm^3 samples.

   d) Calculate the concentration of KOH.

Drop the base

5. A company wants to use calcium hydroxide to pickle cucumbers. To do this, i
that has a concentration of at least 6.00 g dm^{-3}.

A scientist diluted a solution of $Ca(OH)_2$ from 200 cm^3 to 1 dm^3. The scientist
0.206 mol dm^{-3} HCl to titrate 250 cm^3 samples of the solution of $Ca(OH)_2$. The
produced:

	Rough	1	2	3
Start volume (cm^3)	0.05	[illegible]	0.40	0.20
End volume (cm^3)	[illegible]	40.55	40.50	40.50
Volume of acid (cm^3)				

a) Use the results table to find the mean titre.

b) Calculate the moles of $Ca(OH)_2$ in the 250 cm^3 samples to a suitable num

c) Calculate the concentration of $Ca(OH)_2$ in the original 200 cm^3 solution i

d) Determine whether this sample of calcium hydroxide is concentrated eno

6. A titration experiment involves the following reaction of a base, MOH, with H

$$HCl + MOH \rightarrow MCl + H_2O$$

236.4 mg of MOH was dissolved in 200.0 cm^3 of water. 20.0 cm^3 samples of t
100 cm^3 and titrated against 0.245 mol dm^{-3} HCl. The following results table

	Rough	1	2	3
Start volume (cm^3)	0.55	[illegible]	[illegible]	0.40
End volume (cm^3)	[illegible]	[illegible]	17.70	17.65
Volume of acid (cm^3)				

a) Calculate the mean titre and determine the number of moles of HCl in th

b) Calculate the number of moles of MOH in the 20.0 cm^3 samples, and the
compound MOH to an appropriate number of significant figures.

Unstructured acid–base titration c

Titration Calculations

Titration calculations can be used to find out a number of different things, such as:

- the concentration of an unknown solution
- the mass of compound in an unknown substance
- the M_r of a compound / the identity of a compound from a list using M_r

The steps that lead up to answering these questions are usually very similar, and you will need to be able to carry them out comfortably under exam conditions. The steps are labelled on the two examples below.

1. Work out the **equation** for the reaction that happens in the titration.
2. Work out the **moles** in the mean titre.
3. Use the mole **ratio** to work out the moles in the solution being titrated.
4. Work out the moles in the **original** solution, i.e. before it was diluted or samples were taken for titration.
5. **Answer** the question.

You m

Example 1

In a titration experiment, a standard solution of HNO_3 was used to find the concentration of a solution of KOH.

Step 1 (given in question)

$HNO_3 + KOH \rightarrow KNO_3 + H_2O$

20.0 cm^3 samples of the NaOH solution were titrated against H_2SO_4 with a concentration of 0.150 mol dm^{-3}. The mean titre was 18.95 cm^3.

Find the concentration of the NaOH solution to three significant figures.

Step 2

mol HNO_3 = $0.150 \times \frac{18.9}{100}$

= 0.002842 m

Step 3

ratio in reaction HNO_3 : NaO

Step 4

mol KOH = 0.002842

Step 5

conc KOH = 0.002842 ÷

= 0.142 mol d

3 s.f.

Example 2

Compound A is one of the monoprotic carboxylic acids from the list below:

- methanoic acid $HCOOH$
- ethanoic acid CH_3COOH
- propanoic acid CH_3CH_2COOH
- butanoic acid $CH_3CH_2CH_2COOH$

5760 mg of Compound A is mixed with water and made up to 500.0 cm^3. 50.0 cm^3 samples of the solution are titrated against 0.200 mol dm^{-3} NaOH.

The mean titre of NaOH is [illegible] cm^3. Use the results to identify Compound A.

Step 2

moles NaOH = $0.200 \times$

= 0.00655 m

Step 3

monoprotic, so 1 : 1 ratio

n(A) in 25 cm^3 = 0.00655 m

n(A) in 250 cm^3 = 0.00655

= 0.0655

Step 4

M_r A = $\frac{5760}{1000} \div 0.0$

= 87.9

Step 5

Compound A is butanoic ac

Questions

Prepare your solutions

1. 50.0 cm³ samples of NaOH with unknown concentration were titrated agains following results. Calculate the concentration of NaOH.

$$NaOH + HCl \rightarrow NaCl + H_2O$$

	Rough	1	2	3
Start volume (cm³)	[illegible]	18.70	0.65	17.65
End volume (cm³)	[illegible]	35.45	17.65	34.70
Volume of acid (cm³)				

2. 25.0 cm³ samples of KOH with concentration 0.130 mol dm⁻³ were titrated wi results. Calculate the concentration of H_2SO_4.

$$2KOH + H_2SO_4 \rightarrow K_2SO_4 + 2H_2O$$

	Rough	1	2	3
Start volume (cm³)	0.45	0.55	0.00	0.40
End volume (cm³)	32.55	31.50	31.55	31.35
Volume of acid (cm³)				

High concentration

3. 1.37 g of an unknown hydroxide MOH is dissolved in water and made up to titrated against 0.100 mol dm⁻³ H_2SO_4, giving a mean titre of 30.58 cm³. Use hydroxide MOH.

$$2MOH + H_2SO_4 \rightarrow M_2SO_4 + H_2O$$

4. The purity of a solid sample of K_2CO_3 is tested by titration. 9.33 g of the samp water. 25.0 cm³ samples of the solution are titrated with 0.125 mol dm⁻³ HCl.

	Rough	1	2	3
Start volume (cm³)	0.55	0.30	0.05	0.15
End volume (cm³)	41.90	41.10	41.10	41.05
Volume of acid (cm³)				

Write a balanced equation for the reaction between HCl and K_2CO_3, which pr products, and use the results to find the purity of the solid sample.

$$\text{percentage purity} = \frac{\text{mass of } K_2CO_3}{\text{mass of sample}} \times 100$$

Drop the base

5. Two 10 cm³ solutions of KOH, Solution A and Solution B, were mixed together volumetric flask. Solution A has a concentration of [illegible] mol dm⁻³, and Solut concentration. 25.0 cm³ samples of the mixture were titrated with 0.200 mol dr 21.80 cm³. Write the symbol equation for this reaction, and use it to calculate Solution B.

6. A 5.34 g sample contains 2.86 g of $Ba(OH)_2$, an unknown mass of NaOH, and ar impurity. The sample is dissolved in water and made up to 250 cm³ in a volur tested using 0.150 mol dm⁻³ H_2SO_4, giving a mean titre of 28.85 cm³.

$$Ba(OH)_2 + H_2SO_4 \rightarrow BaSO_4 + H_2O$$
$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$$

Find the mass of the unreactive impurity in the sample in g.

'Back' titrations

'Back' titration

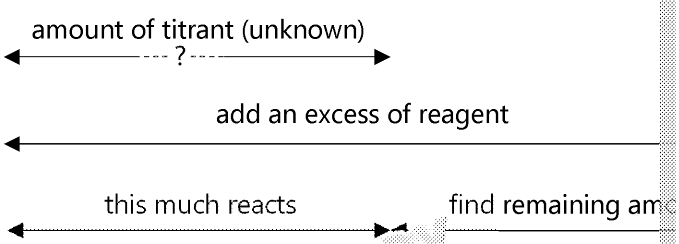
A back titration is a type of titration used to investigate substances which are not very soluble, or when a reaction would be too slow to study using titration. For example, to work out the amount of calcium carbonate in a rock, we cannot use a normal titration because calcium carbonate does not dissolve in water. Instead we would react the calcium carbonate with an excess of acid first, in a back titration.

There are normally two steps to the back titration:

1. An **excess** of acid or alkali is added so that all of the compound being analys
2. The amount of acid/alkali remaining is then found using titration.

The amount of titrant is calculated by:

- finding out how much acid/alkali is remaining and using this value to calcula
- using how much acid/alkali was used up to work out how much of the unkno original solution to react with it



Example 1

A 132 mg solid sample of a carbonate, MCO_3, is added to 50.0 cm^3 of HCl with a concentration of 0.120 mol dm^{-3}. The equation is:

$$MCO_3 + 2HCl \rightarrow MCl_2 + H_2O + CO_2$$

The resulting solution is analysed with 0.100 mol dm^{-3} NaOH, giving a mean titre of 28.68 cm^3.

$$HCl + NaOH \rightarrow NaCl + H_2O$$

Determine the identity of the carbonate.

Step 1: find the moles of H

mol NaOH $= 0.100 \times \frac{28.6}{100}$

$= 0.002868$ m

mol HCl $= 0.002868$

Step 2: calculate the moles

total mol HCl $= 0.120 \times \frac{50}{100}$

$= 0.00600$

mol HCl used $= 0.00600 - 0.$

$= 0.003132$ m

Step 3: calculate the moles

mol MCO_3 $= \frac{0.003132}{2}$

$= 0.001566$ m

Step 4: answer the questio

M_r of MCO_3 $= \frac{132}{1000} \div 0.00$

$= 84.3$

A_r of M $= 84.3 - 12 -$

MCO_3 is $MgCO_3$

Questions

Prepare your solutions

1. A 0.782 g sample of chalk contains $CaCO_3$ and some unreactive impurities. Th solution of 0.100 mol dm^{-3} HCl.

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$$

50.0 cm^3 samples of the resulting solution are titrated with 0.100 mol dm^{-3} KO 17.88 cm^3.

$$HCl + KOH \rightarrow KCl + H_2O$$

a) Calculate the moles of KOH in the mean titre.

b) Calculate the moles of HCl remaining in the 250 cm^3 solution after the C

c) Calculate the moles of HCl which reacted with the $CaCO_3$.

d) Calculate the moles of $CaCO_3$ added to the acid.

e) Calculate the mass of calcium carbonate present in the rock sample.

2. Ammonia is a volatile base and cannot be titrated against directly. A back titr the number of moles of ammonia in a 3.00 dm^3 solution.

A 30.0 cm^3 sample of the 3.00 dm^3 solution reacts with 0.0250 mol of HCl and distilled water.

$$HCl + NH_3 \rightarrow NH_4Cl$$

20.0 cm^3 samples of the resulting solution are titrated against 0.100 mol dm^{-} 32.45 cm^3.

a) Calculate the moles of KOH in the mean titre.

b) From the amount of KOH reacted, calculate the moles of HCl remaining i reaction with NH_3.

c) Calculate the moles of HCl which reacted with the NH_3.

d) Calculate the moles of ammonia in the 3.00 dm^3 solution.

High concentration

3. 1.15 g of a pure solid sample of a hydroxide with the formula $M(OH)_2$ is place H_3PO_4 and diluted to 250 cm^3.

..... $M(OH)_2$ + ... H_3PO_4 → ....+ ..... H

25.0 cm^3 samples of the resulting solution are titrated against KOH with conc

$$H_3PO_4 + 3KOH \rightarrow K_3PO_4 + 3H_2O$$

The following results are produced.

	Rough	1	2	3
Start volume (cm^3)	0.55	0.15	0.05	0.20
End volume (cm^3)	40.00	39.00	38.95	39.00
Volume of acid (cm^3)				

a) Balance the equation for the reaction between $M(OH)_2$ and H_3PO_4.

b) From the mean titre, find the amount in moles of H_3PO_4 in 250 cm^3 after

c) Determine the formula of the salt $M(OH)_2$.

4. A pure solid is thought to be sodium carbonate heptahydrate, $Na_2CO_3{\cdot}7H_2O$ determining the relative formula mass of the salt by reacting the solid sodiu and then titrating the resulting solution with a standard solution of 0.100 mo unreacted acid. Outline, with brief practical details, an experiment to determi the solid, including any calculations you would perform. You are provided wi HNO_3.

$$2HNO_3 + Na_2CO_3{\cdot}7H_2O \rightarrow 2NaNO_3 + CO_2 + 8H_2$$

Drop the [illegible]

5. An insoluble solid salt has the formula $MgCO_3{\cdot}xH_2O$, where x is a whole num finding the relative formula mass of the salt. A crucible is placed on a balance 142.34 g. The salt is placed in the crucible, and the combined mass of the cru This mass of $MgCO_3{\cdot}xH_2O$ is placed in 150.0 cm^3 of 0.240 mol dm^{-3} HCl and

The solution is diluted to 250 cm^3, and 50.0 cm^3 and the samples are titrated giving a mean titre of 20.08 cm^3. Calculate the value of x.

6. A 200 cm^3 solution contains a mixture of $Ba(OH)_2$ and NaOH. 250.0 cm^3 H_2SO 0.200 mol dm^{-3} is added so that H_2SO_4 is in excess of both reagents. The foll

$$2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O($$

$$Ba(OH)_2(aq) + H_2SO_4(aq) \rightarrow BaSO_4(s) + 2H_2O(l)$$

$BaSO_4$ is a precipitate and is removed by filtration. It is dried and weighed to

The remaining solution is made up to 500 cm^3, and 50.0 cm^3 samples are titra find the remaining H_2SO_4, giving a mean titre of 41.30 cm^3.

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$$

Calculate the concentration of NaOH in the 200 cm^3 solution in mol dm^{-3}.

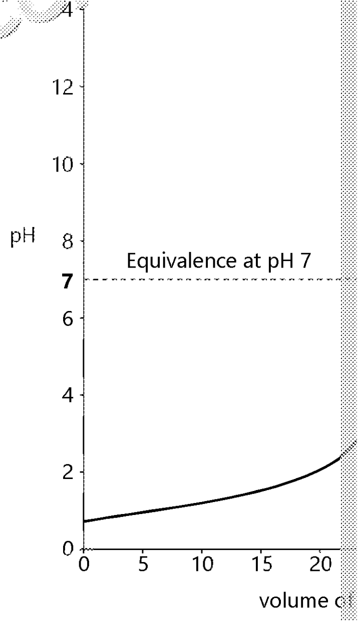
Titration curves / indicato

Titration curves

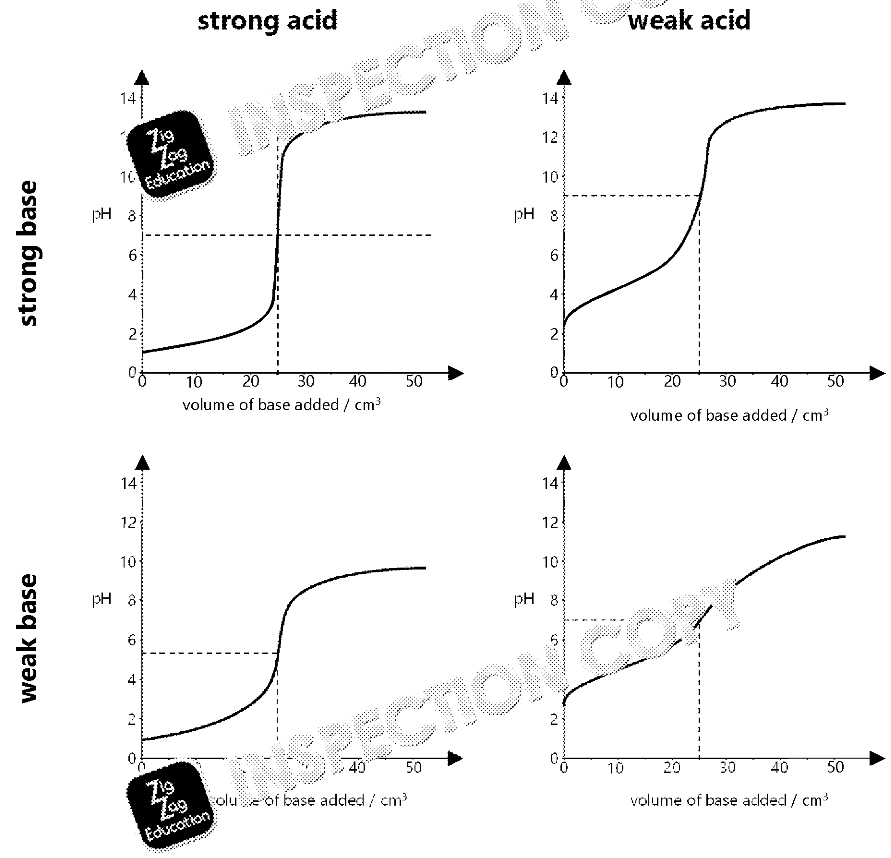
Titration curves show how pH changes as one reagent is added to the other in a n simple neutralisation curve for a titration in which 0.100 mol dm^{-3} NaOH is added t

Key points

- The graph represents the change in pH as NaOH is added to HCl.
- The solution starts acidic (low pH) and becomes more alkaline (high pH).
- At the vertical section, a small volume of NaOH added leads to a large change in pH. This is where the indicator changes colour.
- The equivalence point is the centre of the steep vertical section of the graph.
- For this titration, the acid and base react in a 1 : 1 ratio, and have equal concentration, so the equivalence point occurs when the volumes are equal (25 cm^3).



Strong and weak acids and bases



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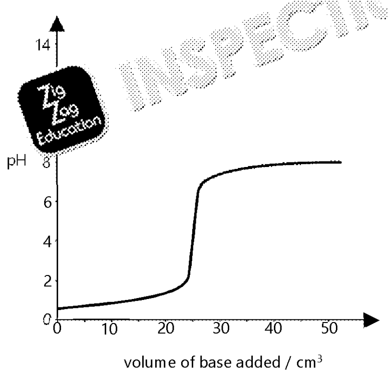
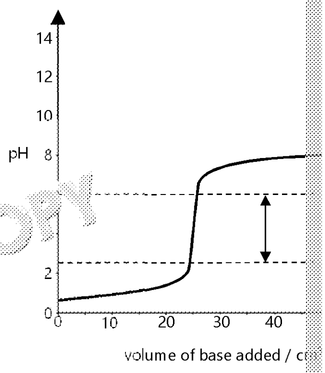
Example 1

Choose a suitable indicator from the list below for the following graph.

Indicator	pH range
methyl orange	3.1–4.4
bromothymol blue	6.0–7.6
phenolphthalein	8.3–10.0





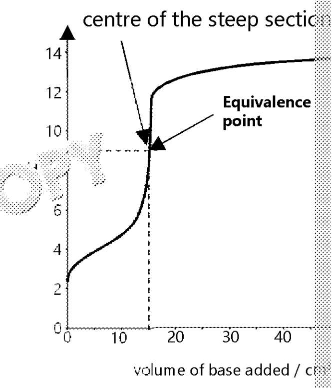
Steep section is from appro

Methyl orange is the only s

Example 2

Draw a pH curve for 0.200 mol dm^{-3} NaOH, a strong base, added to 30 cm^3 0.100 mol dm^{-3} CH_3COOH, a weak acid.

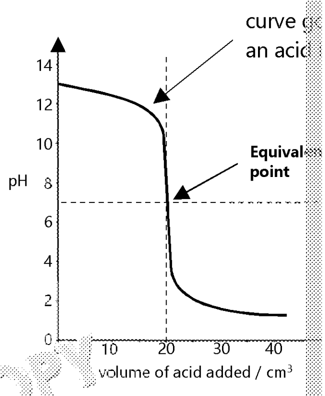
Label the equivalence point.



Example 3

Draw a pH curve for 0.100 mol dm^{-3} HCl, a strong acid, added to 20 cm^3 0.100 mol dm^{-3} NaOH, a strong base.

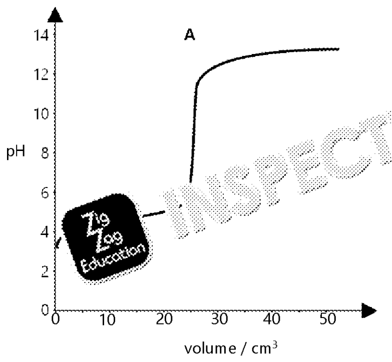
Label the equivalence point.

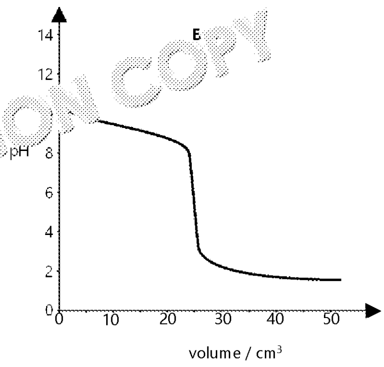


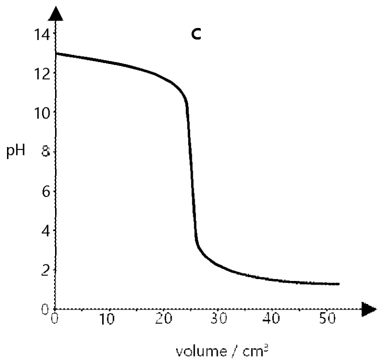
Questions

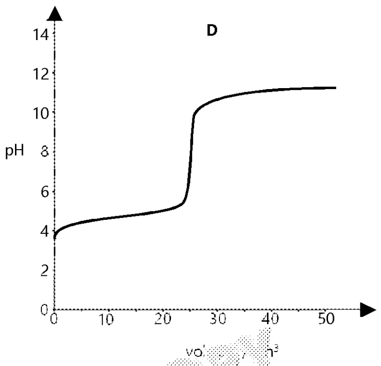
Prepare your solutions

Here are four titration curves. All reagents have a concentration of 0.100 mol dm^{-3}









1. Write the letter of the curve produced by:
   a) adding hydrobromic acid to 25 cm^3 potassium hydroxide
   b) adding ammonia to 25 cm^3 propanoic acid
   c) adding sodium hydroxide to 25 cm^3 ethanoic acid

2. This table shows information about some pH indicators which could be used

Indicator	pH range	Low pH colour
bromothymol blue	6.0–7.6	yellow
phenolphthalein	8.3–10.0	colourless
alizarine yellow	10.1–12.0	yellow
bromocresol green	3.8–5.4	yellow
thymolphthalein	9.3–10.5	colourless

   a) Which indicator(s) could be used to track the titration represented by cu
   b) Which indicator could be used to track the titration represented by curv
   c) Identify the colour change for thymolphthalein during the titration repre

High concentr[illegible]

3. A student tests a solution with a pH meter and finds it has a pH of 8.2. The st phenolphthalein, bromocresol green and thymolphthalein. Assume that none and that the pH of the solution does not change. Use the table above to iden

4. Sketch a titration curve for 50 cm^3 0.100 mol dm^{-3} HCl added to 35 cm^3 0.10

Drop the base

5. Sketch the titration curve for 50 cm^3 0.100 mol dm^{-3} NH_3 added to 10 cm^3 0.2

6. A student is performing a series of titrations of the acids and bases shown in

Acid		Base	
weak	strong	weak	strong
CH_3COOH	HBr	CH_3NH_2	KOH

The following indicators are available:

Indicator	pH range
methyl orange	3.1–4.4
bromothymol blue	6.0–7.6
phenolphthalein	8.3–10.0

For the following titrations, select the indicators which would give a precise e

a) CH_3COOH titrated against KOH

b) CH_3NH_2 titrated against HBr

c) HBr titrated against KOH

Strong acids and bases

Brønsted–Lowry

According to the Brønsted–Lowry theory of acids and bases:

Acid	Base
proton donor	proton accep
$HA \rightleftharpoons H^+ + A^-$	$B + H_2O \rightleftharpoons BH^+ +$

Strong acids

Strong acids are acids which completely ionise in solution. This means we can writ **irreversibly**. The concentration of H^+ ions can be found from the concentration o

- HCl releases one H^+ ion, so $[H^+] = [HCl]$ HCl →
- H_2SO_4 releases two H^+ ions, so $[H^+] = 2 \times [H_2SO_4]$ H_2SO_4

pH

pH is a way of measuring the concentration of H^+ ions.

You can find $[H^+]$ from pH using: $[H^+] = 10^{-pH}$

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

[H⁺] means concentration of H⁺ ions

negative sign

'log to the base 10'

use the 'log' button on your calculator

Strong bases

Bases are in equilibrium. $HA + H_2O \rightleftharpoons BH^+ + OH^-$
To calculate the pH of a base, first find $[H^+]$.
To do this you will have to use K_w, the ionic product of water.

At room temperature: $\boxed{K_w = [H^+] \times [OH^-] = 1.00 \times 10^{-14}}$

To calculate $[H^+]$, rearrange this equation: $[H^+] = \frac{1.00 \times 10^{-14}}{[OH^-]}$

The pH can be calculated in the usual way: $pH = -\log_{10}[H^+]$

Example 1

Find the pH of a solution of H_3PO_4 with concentration 0.00120 mol dm^{-3}.

$[H^+] = 3 \times 0.001$
$= 0.00360$ m
pH $= -\log_{10}(0.0$
$= 2.44$

Example 2

Find the concentration of a solution of HCl with pH 1.3.

conc $= 10^{-1.3}$
$= 0.0501$

Example 3

Find the pH of a solution of NaOH with concentration 0.00670 mol dm^{-3} at room temperature. ($K_w = 1.0 \times 10^{-14}$)

$[OH^-] = 0.00670$ m
$[H^+] = \frac{1.00 \times 10^{-14}}{0.00670}$
$= 1.49 \times 10$
pH $= -\log_{10}(1.4$
$= 11.8$

Questions

Prepare your solutions

1. For the following solutions, convert between pH and concentration.
   a) HCl concentration 0.00100 mol dm^{-3}
   b) HBr pH 2.30
   c) H_2SO_4 concentration 0.000400 mol dm^{-3}

2. Find the pH of the following strong bases using the ionic product of water K
   a) NaOH concentration 0.00160 mol dm^{-3}
   b) KOH concentration 0.000810 mol dm^{-3}
   c) $Ca(OH)_2$ concentration 0.0000451 mol dm^{-3}

High concentration

3. Ammonia, NH_3, is added to water to form a solution for use in a titration. During this step, the following equilibrium occurs:

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

The pH of the solution for titrating is found to be 11.7.

Calculate the concentration of OH^- ions in the solution using the ionic produ $K_w = 1.0 \times 10^{-14}$ $mol^2\ dm^{-6}$.

4. A solution of H_2SO_4 is found by titration to have a concentration of 0.000520 Calculate the concentration of OH^- ions in the solution.

Drop the base

5. In a titration experiment, 500 cm^3 of 0.0100 mol dm^{-3} HCl is added to 150 cm In this step, the following reaction occurs:

$$NaOH + HCl \rightarrow NaCl + H_2O$$

By working out the concentration of either the H^+ ions or the OH^- ions left ov resulting solution.

6. At 10 °C, the ionic product of water is 2.88×10^{-15}.
   a) Use a calculation to show whether pH 7 is acidic, neutral or alkaline at 1
   b) 40.0 cm^3 0.00420 mol dm^{-3} KOH is diluted to 800 cm^3 at 10 °C. Calculate 10 °C to 2 d.p.

Weak acids

Weak acids

Acids are substances that dissociate to form H^+ ions. Whereas strong acids dissoc
dissociate completely. Many organic acids, e.g. carboxylic acids, are weak acids.

$HA \rightarrow H^+ + A^-$ **Strong** $HA \rightleftharpoons$

K_a

Each acid has a quantity called its K_a, which is a way of measuring the strength of
much it dissociates.

For an acid in equilibrium: $HA \rightleftharpoons H^+ + A^-$ K_a can be calculate

When the acid HA dissociates, equal numbers of A^- and H^+ ions are in the solutio

$$[A^-] = [H^+]$$

and so: $K_a = \frac{[H^+]^2}{[HA]}$ which can be

The stronger an acid, the more of it dissociates to form H^+, and, therefore, the hig

pK_a

K_a values are often extremely small or extremely large numbers, so K_a values are c
of **pK_a values** to make them more manageable.

pK_a is calculated as: $pK_a = -\log_{10}(K_a)$

Stronger acids have lower (or even negative) pK_a values.

Example 1

Phenol has a pK_a value of 9.80. Calculate the K_a of phenol.

rear

$K_a = 10^{-pKa}$
$= 10^{-9.8}$
$= 1.6 \text{ x } 10^{-10}$

Example 2

CCl_3COOH has a pK_a value of 0.65. Find the concentration of H^+ ions in a 0.0500 mol dm^{-3} solution of CCl_3COOH.

$CCl_3COOH \rightleftharpoons CCl_3COO^- + H^+$

$K_a = 10^{-pKa}$
$= 10^{-0.65}$
$= 0.224$
$K_a = \frac{[CCl_3COO^-][H^+]}{[CCl_3COOH]}$
$[H^+] = [CH_3COO^-]$, so
$K_a = \frac{[H^+]^2}{[CCl_3COOH]}$
$[H^+] = \sqrt{[CCl_3COOH] \times K_a}$
$= \sqrt{0.05 \times 0.244}$
$= 0.110$ mol dm^{-3}

Example 2

CH_3COOH has a K_a value of 1.58×10^{-5}.

$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$

Calculate the pH of a 0.200 mol dm^{-3} solution of CH_3COOH.

$K_a = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]}$
$[H^+] = [CH_3COO^-]$, so
$K_a = \frac{[H^+]^2}{[CH_3COOH]}$
$[H^+] = \sqrt{[CH_3COOH] \times K_a}$
$= \sqrt{0.2 \times 1.58 \times 10^{-5}}$
$= 1.78$ mol dm^{-3}
$pH = -\log_{10}(1.78)$
$= -0.25$

Questions

Prepare your solutions

1. Convert these values:

   a) $K_a = 1.42 \times 10^{-5}$ to pK_a

   b) $K_a = 4.98 \times 10^{-7}$ to pK_a

   c) $pK_a = 1.03$ to K_a

   d) $pK_a = 3.12$ to K_a

2. HSCN i[illegible]k acid with a pK_a of 1.1.

   a) Write an expression for the K_a of HSCN.

   b) Calculate the pH of 0.0108 mol dm^{-3} HSCN.

High concentration

3. HNO_2 is a weak acid with a pK_a of 3.29.

   A solution of HNO_2 is found to have a concentration of 0.0452 mol dm^{-3}.

   Calculate the concentration of NO_2^- ions in a solution.

4. A 0.0230 mol dm^{-3} solution of phenol, C_6H_5OH, has a pH of 5.79. Calculate th

Drop the base

5. pK_a values are often given fo[illegible]ce dissolved in water. pK_a can also be other solvents, for e[illegible]SO.

   The ta[illegible]ows the pK_a values of ethanoic acid, CH_3COOH, in two solv

pK_a in water	pK_a in DMSO
4.76	12.3

   a) Explain what it means that ethanoic acid has a higher pK_a in DMSO than

   b) What concentration of ethanoic acid in water would have the same pH a ethanoic acid dissolved in DMSO?

6. The pK_a of water, H_2O, can be calculated in the same way as that of any other

   a) Write an expression for the K_a of water.

   b) 1 dm^3 of H_2O contains 1000 g of water. Determine the value of $[H_2O]$ giv formula mass of 18.

   c) Calculate the pK_a of water usin[illegible]ncentration of H_2O along with [H product of water $[H^+][O$[illegible].

Buffers

Buffers

Buffers are solutions which can **minimise** the change in pH when **a small amoun**

Forming buffers

Buffers are formed by combining a weak acid with a salt of [illegible] weak acid. For exa could be formed by adding sodium ethanoate to ethanoic acid.

Sodium ethanoate salt dissociates in solution: $CH_3COONa \rightarrow CH_3$

Ethanoic acid is in equilibrium: $CH_3COOH \rightleftharpoons CH_3O$

How buffers limit pH changes

Buffers minimise pH changes when H^+ or OH^- ions are added through shifts in the base equilibrium:

$$\overset{\xleftarrow{\textbf{add acid}}}{\underset{\xrightarrow{\textbf{add alkali}}}{HA \rightleftharpoons H^+ + A^-}}$$

For the examples of $CH_3COOH\backslash CH_3COO^-$ buffer above:

When H^+ ions are added

- The concentration of H^+ increases.
- The equilibrium $CH_3COOH \rightleftharpoons CH_3OO^- + H^+$ shifts to the left and $[H^+]$ goes back down.
- The pH change is minimised.

When O

- OH^- reacts with H
- The concentratio
- The position of eq $CH_3COOH \rightleftharpoons CH_3$ $[H^+]$ goes back up.
- The pH change is

Buffer calculations

Buffer calculations often involve finding the pH of a buffer solution. It is importan rearrangeme

For this, use the formula: $K_a = \frac{[H^+][A^-]}{[HA]}$

Which rearranges to: $\boxed{[H^+] = K_a \times \frac{[HA]}{[A^-]}}$

Once you have calculated $[H^+]$, you can calculate pH in the usual way, using $-\log_{10}$

Example 1

A 1 dm^3 buffer solution is formed by mixing 400 cm^3 0.175 mol dm^{-3} $CH_2ClCOOH$ (acid) with 600 cm^3 0.200 mol dm^{-3} $CH_2ClCOONa$ (salt).

$CH_2ClCOOH$ has a K_a of 1.380×10^{-3}, calculate the pH of the buffer solution.

First, you need to calculate t and the salt when they have

$$[HA] = \frac{0.175 \times 400}{1000}$$

$$= 0.0700$$

$$[A^-] = \frac{0.200 \times 600}{1000}$$

$$= 0.120$$

$$[H^+] = 1.380 \times 10^{-3} \times \frac{0.070}{0.120}$$

$$= 8.05 \times 10^{-4} \text{ mol dm}$$

$$pH = 3.09 \longleftarrow$$

calc

Example 2

A scientist wants to make a buffer with a pH of 3.60. Calculate the mass of NaNO$_2$ which could be added to a 150 cm^3 0.200 mol dm^{-3} solution of HNO$_2$. HNO$_2$ has a pK$_a$ of 3.29.

The first step is to recognis
from the NaNO$_2$ is A$^-$.

[A$^-$] $= K_a \times \frac{[HA]}{[H^+]}$

K$_a$ $= 10^{-3.29}$

$= 5.129 \times 10^{-4}$

[HA] = 0.200 mol dm

[H$^+$] $= 10^{-3.6}$

$= 2.512 \times 10^{-4}$ m

[A$^-$] $= 5.129 \times 10^{-4} \times$

= 0.408 mol dm

mol A$^-$ $= 0.408 \times \frac{150}{1000}$

= 0.0613 mol

mass HNO$_2$ = 0.0613 × 69

= 4.22 g

mol HNO$_2$ = mol A$^-$

Questions

Prepare your solutions

1. Suggest a salt that could be used to form a buffer with the following weak ac

   a) Methanoic acid, CHOOH

   b) HCN

2. A buffer solution is created by mixing a solution of CF$_3$COOH with CF$_3$COONa the buffer equilibrium. Show how this buffer system minimises changes in pH when
   - a small amount of HCl is added
   - a small amount of NaOH is added

High concentration

3. A 1.00 dm^3 buffer solution is formed by mixing 200 cm^3 of 0.150 mol dm^{-3} H$_2$S HS$^-$.

   H$_2$S has a pK$_a$ of 7.04. Calculate the pH of the buffer solution.

4. A small amount of ammonia, NH$_3$, is added to an excess of hydrofluoric acid, forms a buffer which regulates pH when an acid or an alkali is added.

5. Lactic acid, CH$_3$CH(OH)COOH, has a pK$_a$ of 3.86. A mass of lactic acid is added

   a) Explain why a buffer forms when lactic acid is added to a small amount o

   b) Find the mass of lactic acid needed to create a buffer solution with a pH s[illegible] of [illegible].

Drop the base

6. A buffer is formed between 600 cm^3 of 0.350 mol dm^{-3} C$_5$H$_4$NHCl pK$_a$ 5.25 an solution containing its conjugate base. Find the mass of the conjugate base r buffer system to 5.60.

Structured redox titratio

Redox

Redox reactions occur when one species' oxidation number (also known as oxidation state) increases and another species' oxidation number decreases.

This wo
unders
numbe

An increase in oxidation number is called **oxidation**. A species which causes oxida
A species which has a reduction in oxidation number is **reduced**. Something that
agent.

e.g. $2F$[illegible] $Cu \rightarrow 2FeCl_2 + CuCl_2$

Fe[illegible]es from 3+ → 2+ so is reduced and is, therefore, an oxidising ag

Cu goes from 0 → 2+ so is oxidised and is, therefore, a reducing agent.

Redox titrations

Redox titrations use redox reactions rather than acid–base neutralisations. Becaus
involve a colour change, many redox titrations don't need an indicator.

Whereas equations for neutralisation reactions used in acid–base titrations are us
redox reactions can be quite complex.

Balancing redox equations

Firstly, the individual half-equations must be balanced, and then the equations co

e.g. ① $Fe^{2+} \rightarrow Fe^{3+} + e^-$ This equati

② $MnO_4^- \rightarrow Mn^{2+}$ This equati

- **Step 1: Balance the atoms – use H^+/H_2O (acid) or OH^-/H_2O if you need t**

  $8H^+ +$ [illegible] $\rightarrow Mn^{2+} + 4H_2O$

- **Step 2: Balance the charges.**

  $8H^+ + MnO_4^- + 5e^- \rightarrow Mn^{2+} + 4H_2O$

- **Step 3: Combine the two equations to make a balanced redox equation.**
  Combine the reactions so that the electrons balance on each side:

  $5\times① + ② = 5Fe^{2+} + 8H^+ + MnO_4^- + \cancel{5e^-} \rightarrow 5Fe^{3+} + \cancel{5e^-} + Mn^{2+} + 4H_2O$

  Cancel the electrons (sometimes you will have to cancel other species such a

  $5Fe^{2+} + 8H^+ + MnO_4^- \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$

Example 1

Iodine (I_2) and thiosulfate ($S_2O_3^{2-}$) react together in the following reaction:

$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$$

50.0 cm³ samples of an iodine solution were titrated with 0.120 mol dm⁻³ thiosulfate solution. The mean titre was 26.78 cm³.

a) Calculate the number of moles of thiosulfate used in the mean titre.

b) Calculate the number of moles of iodine required to react with this amount of thiosulfate.

c) Calculate the concentration of iodine in the original solution.

a) mol $S_2O_3^{2-}$ $= \frac{26.78}{1000} \times 0.$

$= 0.00535$

b) mol I_2 $= 0.00535$

$= 0.00267$

c) conc I_2 $= 0.00267$

$= 0.05356$

Example 2

A lump of soluble iron(II) salt was dissolved in 250 cm³ water, and 25.0 cm³ samples were taken and titrated with 0.150 mol dm⁻³ MnO_4^- solution. The titres recorded were 34.55, 34.50 and 34.70 cm³.

$$5Fe^{2+} + 8H^+ + MnO_4^- \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$$

a) Use the concordant titres to calculate the mean volume of MnO_4^- in cm³.

b) Use the mean titre to calculate the moles of MnO_4^- used in the titration.

c) Calculate the moles of Fe^{2+} titrated.

d) Calculate the moles of Fe^{2+} in the original lump of salt.

e) Calculate the total mass of iron in the original Fe^{2+} salt.

a) vol MnO_4^- $= \frac{34.55+34.}{2}$

$= 34.53$ c

b) mol MnO_4^- $= 0.150 \times$

$= 5.180 \times$

c) 1 : 5 ratio MnO_4^- : Fe^{2+}

so mol Fe $= 5 \times 5.1$

$= 0.0259$

d) moles of Fe $= 0.0259$

$= 0.2590$

e) mass Fe $= 0.2590$

$= 1.445$ g

Questions

Prepare your solutions

1. 50.0 cm^3 of an iron(II) solution is titrated with 0.0200 mol dm^{-3} $KMnO_4$ solutio 18.50 cm^3. The reaction is:

$$5Fe^{2+} + 8H^+ + MnO_4^- \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$$

   a) Calculate the number of moles of MnO_4^- used in the titration.

   b) Calculate the number of moles of Fe^{2+} which reacted with MnO_4^-.

   c) Find the concentration of Fe^{2+} ions in the 50.0 cm^3 solution.

2. Iodine (I_2) and thiosulfate ($S_2O_3^{2-}$) react together in the following reaction:

$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$$

   50.0 cm^3 samples of an iodine solution were titrated with 0.120 mol dm^{-3} thio was 26.78 cm^3.

   a) Calculate the number of moles of thiosulfate used in the mean titre.

   b) Calculate the number of moles of iodine required to react with this amo

   c) Calculate the concentration of iodine in the original solution.

High concentration

3. 3.25 g of a soluble iron(II) salt with the formula FeX_2 is dissolved in 1.00 dm^3 titrated with 0.0200 mol dm^{-3} $KMnO_4$, giving a mean titre of 25.65 cm^3.

   The following reaction occurs during the titration:

$$5Fe^{2+} + 8H^+ + MnO_4^- \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$$

   The identity of the ion represented by X in the formula FeX_2 can be determin formula mass of the salt. Determine the identity of the iron(II) salt.

   a) Calculate the number of moles of MnO_4^- used in the titration.

   b) Calculate the number of moles of Fe^{2+} which reacted with MnO_4^-.

   c) Calculate the number of moles of Fe^{2+} ions in the 1.00 dm^3 solution.

   d) Determine the relative formula mass of the iron salt, and so determine t

4. A sample of impure iron with a mass of 6.00 g is reacted with excess nitric ac iron(II) nitrate which is made up to 500 cm^3. 25.0 cm^3 samples of the solution potassium permanganate, giving a mean titre of 23.93 cm^3.

   The following reaction occurs during the titration:

$$5Fe^{2+} + 8H^+ + MnO_4^- \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$$

   a) Calculate the number of moles of MnO_4^- used in the titration.

   b) Calculate the number of moles of Fe^{2+} which reacted with MnO_4^-.

   c) Calculate the number of moles of Fe^{2+} in the original sample.

   d) Calculate the mass of iron in the sample and hence determine the perce

Drop the base

5. A 500 cm³ solution of hydrogen peroxide, H_2O_2, with a concentration of appr analysed using titration methods.

Step 1

8.40 g of potassium iodide is added to the hydrogen peroxide solution and t

$$H_2O_2 + 2H^+ + 2I^- \rightarrow I_2 + 2H_2O$$

Step 2

50.0 cm³ samples of the resulting solution were titrated with a solution of 0.150 giving a mean titre of 26.7[illegible] cm³

The following reaction occurs during the titration:

$$I_2 + 2Na_2S_2O_3 \rightarrow 2NaI + Na_2S_4O_6$$

a) Demonstrate that iodide ions are in excess of hydrogen peroxide in Step

b) From the mean titre, deduce the number of moles of H_2O_2 in a 50.0 cm³

c) Calculate the concentration of H_2O_2 in the original 500 cm³ solution.

6. 6.03 g of a pure soluble iron(II) salt with the formula $FeSO_4 \cdot nH_2O$ was dissolv cm³ samples were taken and titrated with 0.0150 cm³ MnO_4^- solution, giving

The following reaction occurs during the titration:

$$5Fe^{2+} + 8H^+ + MnO_4^- \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$$

a) Calculate the moles of MnO_4^- used in the titration.

b) Calculate the moles of Fe^{2+} titrated.

c) Calculate the moles of Fe^{2+} in the dissolved sample.

d) Calculate the relative formula mass of the salt $FeSO_4 \cdot nH_2O$ and thus det

Unstructured redox titrati

Unstructured calculations

Unstructured redox titration questions can be worth around 4–7 marks. They may
which you haven't seen before.

When performing unstructured redox titration calculations, it can sometimes be h
information you have been given to the answer. Each step of the process will invo
them all together can be difficult without practice.

Here is some advice when attempting unstructured redox titrations:

- Identify what you are **trying to calculate** – this could be:
  - relatively simple – concentration, moles or mass
  - harder – purity, percentage by mass or relative formula mass
  - the most difficult – finding the charge on an ion or finding the formula o
- You might find it helpful to write down all of the values you are given from th
  to work out how all the pieces of information can be used together to find th
- Convert values into the correct units so that you can use them in the equatio
- Make sure that you haven't missed a key step! In complex calculations it's mu
  - ratio in a reaction equation
  - a dilution or where a sample has been taken from a larger volume
  - a volume in cm^3 rather than dm^3

Examples

Example 1

A solution containing iodine is tested using redox titration methods.

50.0 cm^3 samples of an iodine solution require 12.37 cm^3 of 0.0500 mol dm^{-3} thiosulfate ($S_2O_3^{2-}$) solution to reach the end point.

$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$$

Find the concentration of iodine in the solution.

mol $S_2O_3^{2-}$ = 0.05 × $\frac{12.37}{1000}$
= 6.185 × 10

mol I_2 = 6.185 × 10
= 3.0925 × 1

conc I_2 = 3.0925 × 1
= 0.02427 m

Example 2

A 1.00 g iron sample is reacted with dilute sulfuric acid until all of the iron dissolves, to form a 250 cm^3 solution of iron(II) sulfate solution, $FeSO_4$.

25.0 cm^3 samples of the solution are tested by redox titration methods with potassium permanganate, $KMnO_4$, requiring 31.03 cm^3 of 0.00930 mol dm^{-3} permanganate solution to reach the end point.

$$5Fe^{2+} + 8H^+ + MnO_4^- \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$$

Find the purity of iron in the sample.

mol MnO_4^- = 0.00930 ×
= 2.8858 × 1

5 : 1 ratio Fe^{2+} : MnO_4^-
mol Fe^{2+} = 5 × 2.8858
= 0.001443 m

mol Fe^{2+} = 0.001443 ×
= 0.01443 m

mass Fe = 0.01443 ×
= 0.805 g

purity Fe = $\frac{0.805}{1}$ × 100
= 80.5 %

Questions

Prepare your solutions

1. A solution containing iodine is tested using redox titration methods. 50.0 cm
require 24.33 cm^3 of 0.100 mol dm^{-3} thiosulfate ($S_2O_3^{2-}$) solution to reach the

The following reaction occurs during the titration:

$$[illegible]\ 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$$

Find the concentration of the iodine solution.

2. An iron [illegible] reacted with dilute sulfuric acid until all of the iron dissolve
iron(II) [illegible] solution, $FeSO_4$. The solution is made up to 500 cm^3. 20 cm^3 sa
by redox titration methods with potassium permanganate, $KMnO_4$, requiring
permanganate solution to reach the end point.

The following reaction occurs during the titration:

$$5Fe^{2+} + 8H^+ + MnO_4^- \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$$

Find the mass of iron present in the sample.

High concentration

3. A soluble iron(II) salt has the formula FeX_2, where X represents one of Cl^-, Br^-
dissolved in 100 cm^3 water, and 20.0 cm^3 samples are titrated against 0.0500
giving a mean titre of 14.58 cm^3.

The following reaction occurs during the titration:

$$5Fe^{2+} + 8H^+ + MnO_4^- \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$$

Determine the identity of the X ion.

4. 50.0 cm [illegible]ion containing Mn^{3+} reacts with a solid salt containing I^- ions, f
chemist carried out this reaction, forming a 50.0 cm^3 solution of product.

The iodine solution can then be titrated against a solution of thiosulfate, S_2O
during the titration:

$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$$

The solution of thiosulfate is made by dissolving 5.00 g of $Na_2S_2O_3{\bullet}5H_2O$ in 5
thiosulfate is 34.55 cm^3. $Na_2S_2O_3{\bullet}5H_2O$ has a relative formula mass of 248.0.
original Mn^{3+} solution. (You will need to work out the equation for the first re

Drop the base

5. A sample of $Fe(NO_3)_3$ contains soluble, unreactive impurities. 5.64 g of the sa
forming a solution containing Fe^{3+} ions. An excess of tin(II) chloride is added,
The excess Sn^{2+} ions are removed. The solution is made up to 500 cm^3 and 2
against 0.00400 mol dm^{-3} acidified potassium dichromate, $K_2Cr_2O_7$, giving a

$Cr_2O_7^{2-}$ [illegible] oxidise the Fe^{2+} back to Fe^{3+} via the following half-equation:

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$$

Write the balanced equation for the reaction which occurs during the titratio
of iron nitrate in the sample.

6. Cuprite is an ore of copper. 832 mg of cuprite is added to concentrated hydr
formed containing Cu^{2+} ions.

An excess of potassium iodide is added and the following reaction occurs:

$$2Cu^{2+}(aq) + 4I^{-}(aq) \rightarrow 2CuI(s) + I_2(aq)$$

The resulting solution is diluted to 500 cm³, and 25.0 cm³ samples are titrated
thiosulfate, giving a mean titre of 14.55 cm³.

During the titration, the following reaction occurs:

$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^{-} + S_4O_6^{2-}$$

Calculate the percentage by mass of copper in the ore.

The most difficult redox titra

In past papers some of the most difficult redox titration questions have been wort
7-mark questions not uncommon. These questions outline a multistep titration pr
such as the percentage purity, the identity of an ion, or a balanced equation.

These questions are difficult because they require a lot of steps between the initia
The key is to recognise that most of the steps are exactly the same as more struct
can still get most of the marks for doing the same set of steps involving moles, m
you've done many times. To get the final marks, you will need to pay very close at

Top tips:

1. Start by working out the equations for any reactions taking place. This will of
   balanced redox equation.
2. Identify all the quantities you are given in the equation, and what they relate
   short list of what you know can be helpful.
3. Keep an eye out for dilution steps where 'samples' are taken or water is adde
   you would then work out the number of moles or the concentration of the o

Examples

Example 1

A dicarboxylic acid with the formula $(COOH)_2(CH_2)_n$ is analysed using titration methods with potassium permanganate, $KMnO_4$. The formula $(COOH)_2(CH_2)_n$ can be represented as H_2X in equations.

1.38 g of the acid is dissolved in water and made up to 900 cm³. 50 cm³ samples gave a mean [illegible] 26.33 cm³ when titrated against 0.0201 mol dm⁻³ $KMnO_4$.

The half-equation for the oxidation of the acid is:

$$H_2X \rightarrow 2H^+ + X + 2e^-$$

The half-equation for the reduction of permanganate is:

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$

Find the identity of n.

Working out the redox equation:

① $H_2X \rightarrow 2H^+ + X + 2e^-$

② $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2}$

5×① $5H_2X \rightarrow 10H^+ + 5X + 10e^-$

2×② $2MnO_4^- + 16H^+ + 10e^- \rightarrow 2$

$5H_2X + 2MnO_4^- + 16H^+ + 10e^- \rightarrow 10$

$5H_2X + 2MnO_4^- + \underset{6H^+}{\cancel{16H}^+} + \cancel{10e}^- \rightarrow \cancel{10}$

Full eqn: $5H_2X + 2MnO_4^- + 6H^+ \rightarrow 5$

$$\text{mol } MnO_4^- = 0.0201 \times \frac{26.33}{1000} \leftarrow$$
$$= 5.2923 \times 10^{-3} \text{ mol}$$

$$\text{mol } H_2X = \frac{5 \times 5.2923 \times 10^{-3}}{2} \leftarrow$$
$$= 0.01323 \text{ mol}$$

$$\text{r.f.m. } H_2X = \frac{1.38}{0.01323} \leftarrow \text{r.f.m.} = \frac{\text{mass}}{\text{mol}}$$
$$= 104$$

$$\text{r.f.m. } (CH_2)_n = 104 - \underbrace{2\times(12 + 16\times2 +}_{\text{r.f.m. due to }(COOH)_2}$$
$$= 14$$

$$n = 14 \div (12 + 2\times1) \leftarrow n$$
$$= 1$$

Example 2

0.510 g of sodium oxalate, $Na_2C_2O_4$, was titrated against a solution of 0.100 mol dm^{-3} potassium permanganate, $KMnO_4$.

The half-equation for the permanganate ions is:

$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

15.20 cm^3 of the potassium permanganate solution was required to reach the end-point.

Calculate the ratio of MnO_4^- to $C_2O_4^{n-}$ in the overall equation, and hence work out the oxidation state of carbon in the carbon-containing product formed. (You may assume that both carbons end up with the same oxidation state.)

mol MnO_4^- $= 0.1 \times \frac{15.2}{1000}$ ◄

$= 1.52 \times 10^{-3}$ mol

r.f.m. $Na_2C_2O_4$ = 134 ◄ calc
mas

mol $Na_2C_2O_4$ $= \frac{0.51}{134}$

$= 3.8060 \times 10^{-3}$ mol ◄

	$C_2O_4^{2-}$
mol ratio	3.8060×10^{-3}
whole number mol ratio	$\frac{3.8060 \times 10^{-3}}{1.52 \times 10^{-3}}$
	2.5
	5

$C_2O_4^{2-} : MnO_4^- = 5 : 2$ ◄ calculate
masses o

Mn changes oxidation state from +7

in MnO_4^- each O is -2, so Mn mu
be +7 to balance the -1 charge

Using the ratio, 2 × MnO_4^- requires 1
Mn is reduced by 5).

Therefore, each of the 5 $C_2O_4^{2-}$ ions i

Each carbon in $C_2O_4^{2-}$ must, therefore

Carbon's oxidation state in $C_2O_4^{2-}$ is
state at the end must be +4.

Questions

Prepare your solutions

1. 5.68 g of an iron(II) salt is dissolved to form a 500 cm^3 solution. 25.0 cm^3 sam
   solution of 0.0250 mol dm^{-3} dichromate, $Cr_2O_7^{2-}$, giving a mean titre of 18.90
   The half-equations for the reaction are:

   $$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$$

   $$Fe^{2+} \rightarrow Fe^{3+} + e^-$$

   Use the half-equations to write a balanced equation for the redox reaction be
   dichromate ions ($Cr_2O_7^{2-}$). Then, calculate the percentage by mass of iron in t

2. A 0.382 g sample of vanadium metal containing unreactive impurities is react
   V^{2+} ions. 50.0 cm^3 samples of the solution are analysed by redox titration wit
   solution, giving a mean titre of 21.1 cm^3.

   Write a balanced equation for the redox titration calculation, and find the pe
   metal.

   $$V^{2+} + 3H_2O \rightarrow VO_3^- + 6H^+ + 3e^-$$

   $$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$

High concentration

3. A 500 cm^3 solution with an unknown concentration of iron(II) sulfate is left in
   several months, producing solution **A**. Iron(II) sulfate solution can oxidise ove

   $$4FeSO_4 + O_2 + 2H_2O \rightarrow 4Fe(OH)SO_4$$

   Solution **A** is, therefore, a mixture of Fe(II) and Fe(III) ions.
   The following method was used to find the percentage of iron ions which are

   Step 1
   25.0 cm^3 samples of solution **A** are titrated with 0.0200 mol dm^{-3} $KMnO_4$ solu
   23.55 cm^3.

   $$5Fe^{2+} + MnO_4^- + 8H^+ \rightarrow 5Fe^{3+} + Mn^{2+} + H_2O$$

   Step 2
   A 100 cm^3 sample of solution **A** is passed over a reducing agent so that all of
   becomes Fe(II). The solution is then made up to 200 cm^3 with water.

   Step 3
   25.0 cm^3 samples of the solution produced in step 2 are titrated with 0.0200
   a mean titre of 28.93 cm^3.

   Calculate the percentage of iron ions which are Fe^{3+} in solution **A**.

4. An investigation is carried out to determine the reaction occurring when ferra
   by iodide ions.

   Step 1
   0.676 g [illegible] soluble salt barium ferrate(VI) is added to an alkaline solution,
   FeO_4^{2-} ions.

   Step 2
   An excess of acidified potassium iodide, KI, is added to the solution, which re
   an iron species Fe^{n+}, iodine (I_2) and Ba^{2+} ions. The resulting solution is made

Step 3
20.0 cm^3 samples of the resulting solution are titrated with 0.0100 mol dm^{-3} s
$Na_2S_2O_3$, giving a mean titre of 31.55 cm^3. The equation for this redox reactio

$$2S_2O_3^{2-} + I_2 \rightarrow S_4O_6 + 2I^-$$

Determine the identity of the iron species Fe^{n+} and hence determine the bala
reaction between ferrate(VI) (FeO_4^{2-}) and iodide [illegible], where I^- is convertec

Drop the base

5. A bottle of wine is tested for its alcohol concentration by performing the follo

Step 1
100 cm [illegible] is distilled to separate the ethanol, CH_3CH_2OH, from other co
distillate is pipetted into a 500 cm^3 volumetric flask which is made up to the li

Step 2
20.0 cm^3 samples of the distillate are diluted to 100 cm^3, and 25.0 cm^3 of 0.11
solution is added and left to react to completion. Dichromate is in excess for t

$$2Cr_2O_7^{2-} + 3CH_3CH_2OH + 16H^+ \rightarrow 4Cr^{3+} + 3CH_3COOH$$

Step 3
The samples are titrated with 0.109 mol dm^{-3} ammonium iron(II) sulfate soluti
as an indicator, to find the remaining concentration of $Cr_2O_7^{2-}$.

$$Cr_2O_7^{2-} + 6Fe^{2+} + 14H^+ \longrightarrow Cr^{3+} + 6Fe^{3+} + 7H_2O$$

A mean titre of 24.50 cm^3 is recorded for the iron sulfate solution. Calculate t
mol dm^{-3}.

6. **Step 1**
2.00 g [illegible] salt **A** containing molybdenum with the formula Na_2MoO

Step 2
The solution is reacted with hydrochloric acid so that all of the molybdenum
solution is made up to 200 cm^3.

Step 3
50.0 cm^3 samples of the solution of Mo^{5+} are then titrated against 0.103 mol
mean titre of 20.05 cm^3.

$$Ce^{4+} + e^- \rightarrow Ce^{3+}$$

$$Mo^{5+} \longrightarrow Mo^{6+} + e^-$$

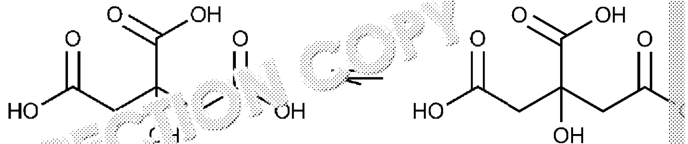
Step 4
A second sample containing 1.50 g of **A** is heated in a crucible, removing the
remaining anhydrous salt has a mass of 1.[illegible]8 [illegible].

Identify the formula of the salt, finding the values of both *x* and *n*.

pH Titrations

1. A fizzy drink company is developing a new soft drink. The drink contains an organi
acid.

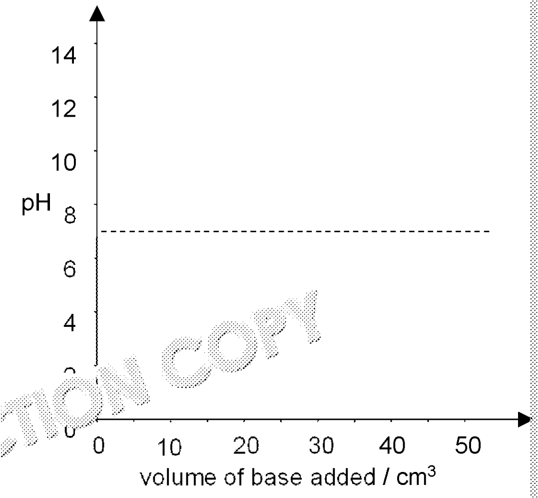
The acid is monoprotic, which means it only ionises once:



A scientist tests a sample of the organic acid which is thought to have a concentra
0.100 mol dm^{-3}

The organic acid is titrated against NaOH, a strong base.

a) Sketch a titration curve that you would expect on the axes when 40.0 cm^3 0.1
25.0 cm^3 of the organic acid with a concentration of exactly 0.100 mol dm^{-3}.



b) The results of the titration are shown below:

	Rough	1	2	
Start volume (cm^3)	0.00	0.10	0.05	0.
End volume (cm^3)	33.35	31.15	31.15	3
Volume of NaOH (cm^3)				

i) Complete the table and calculate the mean titre of NaOH to two decim

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ii) Find the actual concentration of the organic acid.

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c) The organic acid has a pK_a of 3.13.
Find $[OH^-]$ for a 0.150 mol dm^{-3} solution of the organic acid.
$K_w = 1 \times 10^{-14}$ mol^2 dm^{-6}.

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d) The drink manufacturer would like to ensure that the pH of the drink is kept
The scientist proposes making a 1.00 dm^3 buffer solution by adding 500 cm^3
0.100 mol dm^{-3} NaOH.

i) Explain how this buffer controls pH when a small amount of HCl is adde
Include the equation for the buffer system equilibrium and explain how

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ii) What concentration of the organic acid is required to produce a buffer
volumes shown above?

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2. Calcite is a mineral made from calcium carbonate, $CaCO_3$.
A sample of calcite contains a small amount of quartz, made from silicon dioxide, S
The purity of calcium carbonate in calcite can be found by adding an excess of hyd
Calcium carbonate reacts with hydrochloric acid in the following reaction:

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$$

Silicon dioxide does not react with hydrochloric acid.
The amount of unreacted acid can then be determined by titration with sodium hy
Outline a method for an experiment to accurately calculate the purity of calcium c
given 100 cm^3 of 0.150 mol dm^{-3} hydrochloric acid.

Redox Titrations

3. Rose gold is an alloy used to make jewellery. It contains the elements gold and co
A rose gold ring with mass 0.945 g is added to sulfuric acid. The copper dissolves,
not dissolve.

The copper solution is added to an excess of potassium iodide and the following r

$$2CuSO_4(aq) + 4KI(aq) \rightarrow 2CuI(s) + K_2SO_4(aq) + I_2(aq)$$

The solution is filtered to remove the copper iodide, and made up to 250 cm^3 in
Starch is added to 25.0 cm^3 samples, which are titrated with 0.0100 mol dm^{-3} sod
following reaction occurs:

$$I_2 + 2Na_2S_2O_3 \rightarrow Na_2S_4O_6 + 2NaI$$

The average titre is 37.20 cm^3.

a) Write the half-equation for copper in the first reaction.

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b) Suggest why the solid copper iodide is removed by filtration before the titra

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c) State the role of starch in this process.

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d) Determine the percentage by mass of copper in the rose gold ring.

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4. A pure salt with the formula M_2SO_3 contains ions of an unknown metal, M^+.
The salt is tested by redox titration using the following method:

- 1.24 g of the salt is dissolved in water.
- The solution is made up to 200 cm^3.
- 25.0 cm^3 samples are titrated against an acidified solution of 0.0150 mol dm

The end point was reached at 32.8 cm^3.
The half-equations for the reaction are:

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$
$$SO_3^{2-} + H_2O \rightarrow SO_4^{2-} + 2H^+ + 2e^-$$

Construct the full equation for the reaction occurring in the titration between SO
metal, M, is Na^+.

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Appendix: GCSE knowledge re

At GCSE, you will have learnt some very important things about acids, alkalis, titra
an essential foundation for the A Level material you need to know.

If you studied GCSE Chemistry, you will probably already be familiar with some as
will probably know your acids from your alkalis, and know how they react togethe
results tables used in titrations, and you may have used moles to calculate concen
experiment.

The next few pages give a quick summary of the GCSE material to jog your memor
before moving on to the more difficult A Level material. If aren't feeling confident
some time building a strong foundation of knowledge and understanding before
A Level material.

Acids and alkalis

Examples

Acids and alkalis can be dissolved in water to form solutions. Solutions of acids co
alkalis contains OH^- ions.

Here are some examples of acids and alkalis, and the ions they form in solution:

Acids			A
Name	Formula	Ions in solution	Name
Hydrochloric acid	HCl	H^+ and Cl^-	Sodium hydroxide
Sulfuric acid	H_2SO_4	$2H^+$ and SO_4^{2-}	Potassium hydroxide
Phosphoric acid	H_3PO_4	$3H^+$ and PO_4^{3-}	Calcium hydroxide
Ethanoic acid	CH_3COOH	H^+ and CH_3COO^-	Magnesium hydroxide

Neutralisation

When an acid and an alkali are mixed together, a neutralisation reaction occurs, f
water forms when H^+ and OH^- react together:

$$H^+ + OH^- \rightarrow H_2O.$$

This reaction is the general reaction for neutralisation reactions, because it occurs
The salt is formed from the remaining ions in the solution. For example, when HCl
formed is NaCl.

pH

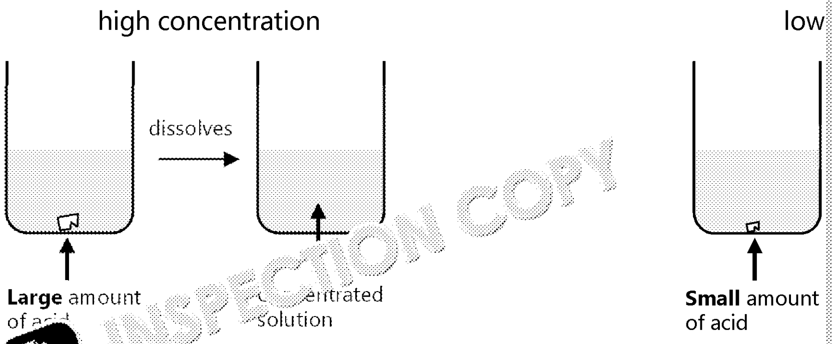
The concentration of H^+ or OH^- ions in a solution determines its pH. pH is a scale,
numbers are more acidic. Here is a pH scale:

Indicators

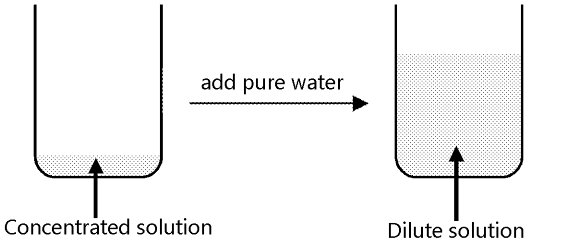
You've probably used universal indicator at school to determine the pH of a soluti
orange in acids, green at neutral and blue or purple in alkalis. There are many kin
one similarity: they change colour depending on the pH.

Concentration of acid

Dissolving more acid in a solution will increase the number of H^+ ions in the solut



A **dilute** acid can be made from a **concentrated** acid by adding more water.



Acidity

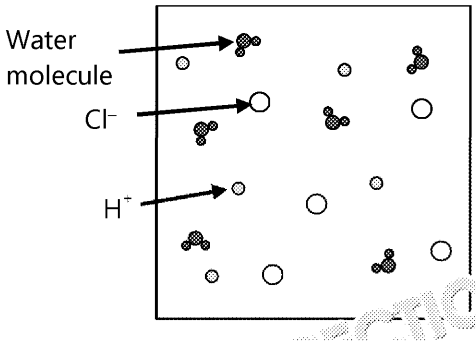
Strong acids ionise more than weak acids. Ionisation is when the ions in the acid 's
For example, when the strong acid HCl dissolves, almost all of the H^+ ions separat

However, when the weak acid CH_3COOH dissolves, most of the H^+ ions remain bo
many free H^+ are in the solution. If the same amount of each acid is dissolved, the
concentration of H^+, and, therefore, a lower pH.

Strong acid

For 100 HCl particles dissolved in solution the result is:

	HCl	→	H^+	+	Cl^-
No. of particles	0		100		100

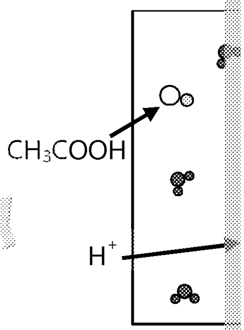


All of the acid is ionised, and there are **many H^+ ions**

W

For 100 C
dissolved i

	CH_3COOH
No. of particles	99



Only som
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Concentrations and mole calculations in reactions

Concentration

The concentration of a solution depends on the amount of the solute and the vol

concentration represents either: the amount (in moles) dissolved in a volume (in dm³ or the mas in a

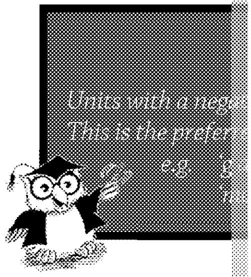
which can be calculated using: conc = $\frac{\text{moles}}{\text{volume}}$

[illegible] ha[illegible] mol dm^{-3}

Example

Dissolving 2 moles of sugar in 4 dm^3 of water:

$$\text{concentration} = \frac{\text{moles}}{\text{volume}} = \frac{2}{4} = 0.5 \text{ mol dm}^{-3}$$



Converting between mol dm^{-3} and g dm^{-3}

You can convert between mol dm^{-3} and g dm^{-3} just as you can convert between mol and g.

You need to use the relative molecular mass of the substance (known as M_r).

$$\text{mol} = \frac{\text{mass}}{M_r} \quad \text{and so} \quad \text{mol dm}^{-3} = \frac{\text{g dm}}{M_r}$$

Example

8 g of sodium hydroxide (NaOH) is dissolved in 2000 cm^3 of water.
NaOH has [illegible] of 40.

The concentration in g dm^{-3} is:

$$\text{concentration} = \frac{\text{grams}}{\text{volume}} = \frac{8}{2} = 4 \text{ g dm}^{-3}$$

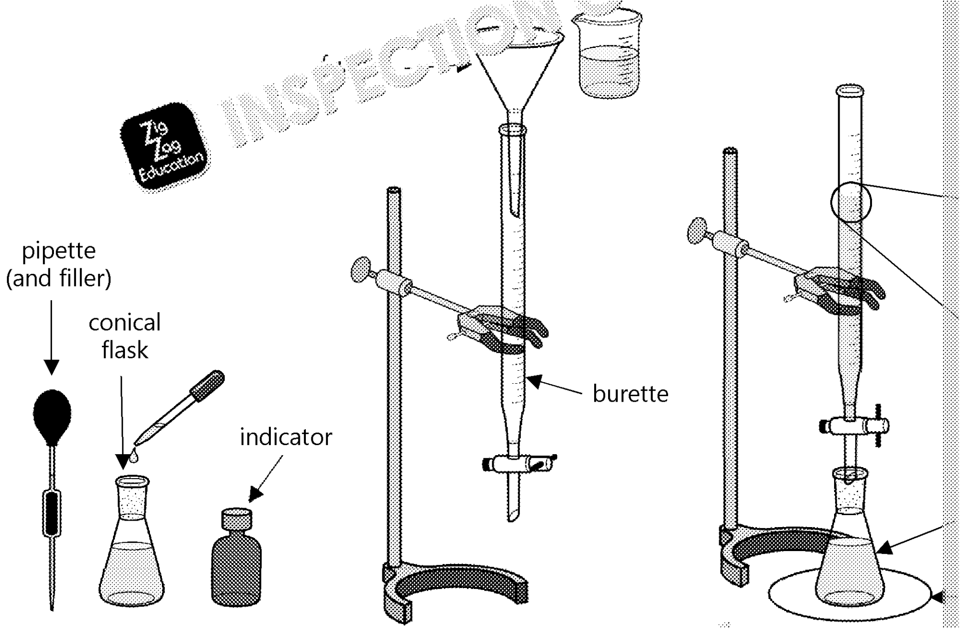
The concentration in mol dm^{-3} is:

$$\frac{4 \text{ g dm}^{-3}}{40} = 0.1 \text{ mol dm}^{-3}$$

Titration method

Titrations can be used to find the concentration of a solution by performing a reac

- An exact volume of the solution with unknown concentration is measured, an
- The solution with known concentration is added to the burette.
- The tap of the burette is opened carefully, and the known solution is added t indicator changes colour, signifying the end point.
- The volume change of the known solution is recorded.
- The experiment is repeated.



Equipment	Purpose
pipette (and filler)	Measuring an accurate volume of the unknown solution to go into the conic
Conical flask	Holds the solution with unknown concentration and the indicator
Indicator	Changes colour and shows that the rea is complete
Funnel	Used to minimise spillage of the soluti known concentration
Burette	A very accurate and precise way of add the solution of known concentration
White tile	A blank background to make it easier t the colour change

Titration calculations

In the following reaction, an acid (HCl) reacts with an alkali (NaOH) to form a salt recognise this as a neutralisation reaction.

$$HCl + NaOH \rightarrow NaCl + H_2O$$

The premise of a titration experiment is that if you know the number of moles o find the number of moles of base.

You will need to use the following equation:

$$\text{concentration} = \frac{\text{moles}}{\text{volume}}$$

Worked example

A solution of NaOH has an unknown concentration. HCl is added to 0.050 dm^3 of the NaOH solution until the indicator changes colour to show that the solution is neutral.

0.020 dm^3 of HCl with a concentration of 1.0 mol dm^{-3} was required to neutralise the NaOH.

This is the reaction:
$HCl + NaOH \rightarrow NaCl + H_2O$

Step 1: find the number of moles of HCl used

moles HCl = concentration × volume

= 1.0 × 0.020

= 0.020 mol

Step 2: find the number of moles of NaOH

ratio of NaOH : HCl = 1 : 1

moles NaOH = 0.020 mol

Step 3: find the concentration of NaOH

conc NaOH $= \frac{\text{moles of NaOH}}{\text{volume}}$ conce

$= \frac{0.020}{0.050}$

= 0.40 mol dm^{-3}

Reduction and oxidation

Oxidation and reduction reactions

At GCSE you will have learnt that in reactions like the following, where substances being oxidised:

$4Li + O_2 \rightarrow 2Li_2O$ Lithium is oxidised

... and that in the opposite of these reactions, where an element loses oxygen

$2Fe_2O_3 \rightarrow 4FeO + O_2$ Iron is reduced

There is also a broader definition for redox reactions, in terms of elements gaining

If an element loses electrons, then it is being oxidised.
If an elemen[illegible] electrons, it is being reduced.

e.g. $Fe^{3+} + e^- \rightarrow Fe^{2+}$ Fe^{3+} is reduced; it **gains** an electron

e.g. $2Br^- \rightarrow Br_2 + 2e^-$ Br^- is oxidised; it **loses** an electron

Quick quiz

1. Which ion is found in all acidic solutions?

2. What is the name of the type of reaction when an acid reacts with a base?

3. Complete all of the gaps in the following word and symbol equation:

   hydrochloric acid + potassium hydroxide → .... +

   HCl .... → .... +

4. On the pH scale, what does 7 represent?

5. Name two methods of measuring pH in a classroom.

6. 3 mol of an acid are dissolved in 9 dm^3 of water.

   Calculate the concentration of this solution in mol dm^{-3}.

7. Name three pieces of practical equipment you might use during a titration.

8. A science teacher makes two solutions of acids:

   Solution 1 contains 1 mol of sulfuric acid, a **strong acid**.

   Solution 2 contains 1 mol of propanoic acid, a **weak acid**.

   Both solutions are made using 500 cm^3 of water.

   Explain why **solution 1** has a higher concentration of hydrogen ions than **sol**

9. a) Write the **balanced** symbol equation for the reaction between H_2SO_4 an

   b) How many moles of water are formed when an excess of H_2SO_4 reacts w

10. Look at the following reaction:

    $$FeO_2 + 2C \rightarrow Fe + CO_2$$

    Identify the elements which are:

    a) reduced

    b) oxidised

    c) neither reduced nor oxidised

Answers

Titration basics: results and uncertainties

1.

	Rough	1	2	3
Start volume (cm^3)	0.00	12.65	24.20	0.00
End volume (cm^3)	12.65	24.20	35.70	11.55
Volume of acid (cm^3)	12.65	11.55	11.50	11.55

2. a) 20.15 cm^3
   b) 45[illegible] cm^3
   c) 0.2[illegible]
   d) 26.80 cm^3

3.

	Rough	1	2	3
Start volume (cm^3)	0.80	0.20	0.55	0.50
End volume (cm^3)	17.10	17.35	17.30	17.35
Volume of acid (cm^3)	16.30	17.15	16.75	16.85

$\frac{16.75 + 16.85}{2}$ = 16.80 [to 2 d.p.]

4.

	Rough	1	2	3
Start volume (cm^3)	0.05	19.50	0.10	19.05
End volume (cm^3)	19.50	38.40	19.05	38.05
Volume of acid (cm^3)	19.45	18.90	18.95	19.00

mean result = $\frac{18.90 + 18.95 + 19.00}{3}$ = 18.95 cm^3 [to 2 d.p.]

5.

	Rough	1	2	3
Start volume (cm^3)	0.00	0.55	0.40	0.15
End volume (cm^3)	43.75	43.10	43.05	43.05
Volume of acid (cm^3)	43.75	42.55	42.65	42.90

Mean titre = $\frac{42.55 + 42.65}{2}$ = 42.60
Percentage uncertainty = $\frac{0.1}{42.60} \times 100$ = 0.23 %

6. Reduces the concentration of the acid / some of the acid is neutralised
   More [acid] is required to reach the end point
   Mean titre is highers

Concentrations and dilution

1. $500 \div 1000 = 0.5\ \text{dm}^3 \quad \frac{3}{0.5} = 6.00\ \text{g dm}^{-3}$

2. $200 \div 1000 = 0.2\ \text{dm}^3 \quad 0.2 \times 0.2 = 0.0400$ moles

3. $\text{vol} = \frac{mol}{conc} = \frac{2.5}{0.5} = 5.00\ \text{dm}^3$

4. $\text{conc} = 2 \times \frac{25}{1000} = 0.100\ \text{mol dm}^{-3}$

5. $10 \times \frac{0.4}{0.0125} = 320\ \text{cm}^3$

6. conc = $0.24 \times \frac{100}{2.}$[illegible] = [illegible]

7. mol KI [illegible] 0.0205 mol

   conc KI = $0.0205 \div \frac{200}{1000} = 0.102\ \text{mol dm}^{-3}$

8. Concentration before NaCl added = $1 \times \frac{250}{1000} = 0.250\ \text{g dm}^{-3}$

   Concentration after NaCl added = $0.25 + 0.5 = 0.750\ \text{g dm}^{-3}$

Structured acid–base titration calculations

1.

	Rough	**1**	**2**	**3**
Start volume (cm³)	0.00	16.20	0.10	16.15
End volume (cm³)	16.20	32.25	16.15	32.25
Volume of acid (cm³)	16.20	16.05	16.05	16.10

a) $\frac{16.05 + 16.05 + 16.10}{3} = 16.07\ \text{cm}^3$

b) $0.2 \times \frac{16.07}{1000} = 3 \times 10^{-3}$ mol

2.

	Rough	**1**	**2**	**3**
Start [illegible] (cm³)	0.00	0.00	23.85	0.00
End volume (cm³)	24.40	23.85	47.65	23.80
Volume of acid (cm³)	24.40	23.85	23.80	23.80

a) $\frac{23.85 + 23.80 + 23.80}{3} = 23.82\ \text{cm}^3$

b) $0.1 \times \frac{23.82}{1000} = 2.382 \times 10^{-3}$ mol

c) $2.382 \times 10^{-3} \times 2 = 4.76 \times 10^{-3}$ mol

3. a) mol HCl $= \frac{13.7}{1000} \times 0.2$

   $= 0.00274\ \text{mol dm}^{-3}$

   b) mol KOH $= 0.00274$ mol [1 : 1 reaction KOH : HCl]

   c) conc KOH $= 0.00274 \div \frac{30}{1000}$

   $= 0.0913\ \text{mol dm}^{-3}$

4. a) conc H_2SO_4 $= 2.00 \times \frac{250}{1000}$

   $= 0.500\ \text{mol dm}^{-3}$

   b) mol H_2SO_4 = [illegible] × [illegible]

   $= 0.0192\ \text{mol dm}^{-3}$

   c) m[illegible] $= 0.0192 \times 2$

   $= 0.0384$ mol [2 : 1 reaction KOH : H_2SO_4]

   d) conc KOH $= 0.0384 \div \frac{80}{1000}$

   $= 0.480\ \text{mol dm}^{-3}$

5. a) Results table:

	Rough	1	2	3
Start volume (cm^3)	0.05	0.40	0.40	0.20
End volume (cm^3)	41.95	40.55	40.50	40.50
Volume of acid (cm^3)	41.90	40.15	40.10	40.30

Mean titre $= \frac{40.15 + 40.10}{2}$

$= 40.13\ cm^3$

b) mol HCl $= \frac{40.13}{1000} \times 0.206$

$= 0.008268\ mol\ dm^{-3}$

mol $Ca(OH)_2$ $= 0.008268 \div 2$

$= 0.0041334$ mol [1 : 2 reaction $Ca(OH)_2$: HCl]

conc $Ca(OH)_2$ $= 0.0041334 \div \frac{250}{1000}$

$= 0.01653\ mol\ dm^{-3}$ [in 250 cm^3 samples]

c) conc $Ca(OH)_2$ $= 0.01653\ mol\ dm^{-3}$ [in 1 dm^3 solution]

conc $Ca(OH)_2$ $= 0.01653 \times \frac{1000}{200}$ [1000/200 is the dilution of 200 cm

$= 0.0827\ mol\ dm^{-3}$ [In 200 cm^3 sample]

d) M_r $Ca(OH)_2$ $= 74.1$

conc $Ca(OH)_2$ $= 74.1 \times 0.0827$

$= 6.13\ g\ dm^{-3}$

Yes (it is above the required concentration)

6. a)

	Rough	1	2	3
Start volume (cm^3)	0.55	0.50	0.85	0.40
End volume (cm^3)	18.15	17.65	17.70	17.65
Volume of acid (cm^3)	18.65	17.15	16.85	17.25

mean titre $= \frac{17.15 + 17.25}{2}$

$= 17.20\ cm^3$

mol HCl $= \frac{17.20}{1000} \times 0.245$

$= 0.004214$ mol

b) mol MOH $= 0.004214$ [1 : 1 ratio HCl : MOH]

mass MOH $= \frac{236.4}{1000}$

$= 0.2364$ g in 200 cm^3

$= 0.02364$ g in 20 cm^3

M_r MOH $= \frac{0.236}{0.004214}$

$= 56.1$ [3 s.f.]

Unstructured acid–base titration calculations

1. Results table:

	Rough	1	2	3
Start volume (cm^3)	0.00	18.70	0.65	17.65
End volume (cm^3)	18.70	35.45	17.65	34.70
Volume of acid (cm^3)	18.70	16.75	17.00	17.05

mean titre = $\frac{17.00 + 17.05}{2}$
= 17.03 cm^3
moles of HCl = 0.150 × [illegible]
= [illegible] mol

1 : 1 rati[illegible] KOH : HCl
moles of KOH = 0.002555 mol

conc KOH = 0.002555 ÷ $\frac{50}{1000}$
= 0.0511 mol dm^{-3}

2. Results table:

	Rough	1	2	3
Start volume (cm^3)	0.45	0.55	0.00	0.40
End volume (cm^3)	32.55	31.50	31.55	31.35
Volume of acid (cm^3)	33.00	30.95	31.55	30.95

mean titre = $\frac{30.95 + 30.95}{2}$
= 30.95 cm^3

moles KOH = 0.130 × $\frac{25.0}{1000}$
= 0.00325 [illegible]

2 : 1 ra[illegible]H : [illegible]
moles [illegible] = $\frac{0.00325}{2}$
= 0.001625
conc H_2SO_4 = 0.001625 ÷ $\frac{30.95}{1000}$
= 0.0525 mol dm^{-3}

3. mol H_2SO_4 = 0.100 × $\frac{30.58}{1000}$
= 0.003058 mol

mol MOH in 25 cm^3 = 0.003058 × 2
= 0.006116 mol
mol MOH in 250 cm^3 = 0.006116 × $\frac{100}{25}$
= 0.02446 mol

M_r MOH = $\frac{mass}{mol}$
= $\frac{1.37}{0.02[illegible]}$
= [illegible]1

MOH is KOH (M[illegible]

4. Balanced equation:
$2HCl + K_2CO_3 \rightarrow 2KCl + CO_2 + H_2O$

	Rough	1	2	3
Start volume (cm^3)	0.55	0.30	0.05	0.15
End volume (cm^3)	41.90	41.10	41.10	41.05
Volume of acid (cm^3)	42.45	40.80	41.05	40.90

mean titre = $\frac{40.80 + 40.90}{2}$
= 40.85 cm^3

mol HCl = $0.125 \times \frac{40.85}{1000}$
= 0.005106 mol

mol K_2CO_3 in 25 cm^3 = $\frac{0.005106}{2}$
= 0.002553 mol

mol K_2CO_3 in 500 cm^3 = $0.002553 \times \frac{500}{25}$
= 0.05106

M_r K_2CO_3 = 138.2
mass K_2CO_3 = 138.2 × 0.05106
= 7.056 g

% purity = $\frac{7.056}{9.33} \times 100$
= 75.6 %

5. $KOH + HNO_3 \rightarrow KNO_3 + H_2O$

mol HNO_3 = $0.200 \times \frac{21.80}{1000}$
= 0.00436 mol

mol KOH in total = 0.00436 mol
mol KOH in A = $0.143 \times \frac{10}{1000}$
= 0.00143 mol

mol KOH in B = mol in total − mol in A
= 0.00436 − 0.00143
= 0.00293 mol
conc B = $0.00293 \div \frac{10}{1000}$
= 0.293 mol dm^{-3}

6. mol H_2SO_4 = $0.150 \times \frac{28.85}{1000}$
= 0.0043275 mol
M_r $Ba(OH)_2$ = 171.7
mol $Ba(OH)_2$ in 250 cm^3 = 2.86 ÷ 171.7
= 0.016657 mol
mol $Ba(OH)_2$ in 25 cm^3 = 0.0016657 mol

mol H_2SO_4 which reacts with NaOH = 0.0043275 − 0.0016657
= 0.0026618 mol
mol NaOH in 25 cm^3 = 0.0026618 × 2
= 0.0053236 mol
mol NaOH in 250 cm^3 = 0.053236 mol
M_r NaOH = 40.0
mass NaOH = 40.0 × 0.053236
= 2.13 g

mass of impurity = 5.34 − (2.86 + 2.13) = 0.35 g

'Back' titrations

1. a) mol KOH = $0.1 \times \frac{17.88}{1000}$
= 0.001788 mol
mol HCl in 50 cm^3 = 0.001788 mol

b) mol HCl in 250 cm^3 (from titration) = $0.001788 \times \frac{250}{50}$
= 0.00894 mol

c) original mol HCl (in stock solution) = $\frac{200}{1000} \times 0.1$
= 0.02 mol
mol HCl reacted = 0.02 − 0.00894
= 0.01106 mol

d) mol $CaCO_3$ = $\frac{0.01106}{2}$
= 0.00553 mol

e M$_r$ $CaCO_3$ = 100.1
mass $CaCO_3$ = 100.1 × 0.00553
= 0.554 g

2. a) mol KOH = $0.100 \times \frac{32.45}{1000}$
= 0.003245 mol

b) mol HCl in 20.0 cm^3 = 0.003245 mol
mol HCl in 100 cm^3 = $0.003245 \times \frac{100}{20}$
= 0.016225 mol

c) mol HCl reacted = 0.0250 − 0.016255
= 0.008745 mol

d) mol NH_3 in 30 cm^3 = 0.008745 mol
mol NH_3 in 3.00 dm^3 = $0.008745 \times (3 \div \frac{30}{1000})$
= 0.875 mol

3. a) $3M(OH)_2 + 2H_3PO_4 \rightarrow M_3(PO_4)_2 + 6H_2O$

b) Results table:

	Rough	**1**	**2**	**3**
Start volume (cm³)	0.55	0.15	0.05	0.20
End volume (cm³)	40.00	39.00	38.95	39.00
Volume of acid (cm³)	39.45	38.85	38.90	38.80

Mean titre = $\frac{38.85 + 38.90 + 38.80}{3}$
= 38.85 cm^3
mol KOH = $\frac{38.85}{1000} \times 0.130$
= 0.0050505 mol
mol H_3PO_4 in 25 cm^3 = $\frac{0.0050505}{3}$
= 0.0016835 mol
mol H_3PO_4 in 250 cm^3 = 0.016835 mol
original mol H_3PO_4 = $\frac{200}{1000} \times 0.15$
= 0.0300
mol H_3PO_4 reacted = 0.03 − 0.016835
= 0.013165 mol
mol $M(OH)_2$ = $0.013165 \times \frac{3}{2}$
= 0.0197475 mol
M$_r$ $M(OH)_2$ = 1.15 ÷ 0.0197475
= 58.2

c) M[illegible] $Mg(OH)_2$

4. *This would be an 8-mark question in an exam. Marks are shown by ✓.*

Part 1: Calculation of solid so that acid is in excess
Recognition that nitric acid must be in excess ✓
mol HNO_3 = $0.150 \times \frac{100}{1000}$ = 0.0150 mol ✓
Ratio from reaction equation is 2 : 1 HNO_3 : Na_2CO_3
so mol Na_2CO_3 is less than 0.0075 mol ($0.0150 \times \frac{1}{2}$) ✓
Mass of Na_2CO_3 weighed out < $0.0075 \times (23\times2 + 12 + 16\times3 + 7\times(16+2))$ = < 1.74

Part 2: Method
Use pipette to measure 100 cm³ of acid AND add weighed solid to acid ✓
Titrate unreacted acid against 0.100 mol dm^{-3} KOH and record titre when indicato

Part 3: Calculation
mol $Na_2CO_3{\cdot}7H_2O$ = $0.0150 - \frac{(\frac{mean\ titre}{2} \times 0.1)}{1000}$ ✓
$M_r = \frac{mass\ of\ sodium\ carbonate\ heptahyrate}{moles\ of\ sodium\ carbonate\ heptahyrate}$ ✓

5. mol NaOH = $0.1 \times \frac{20.08}{1000}$
= 0.002008 mol
mol HCl in 50 cm³ = 0.002008 mol
mol HCl in 250 cm³ = $0.002008 \times \frac{250}{50}$
= 0.01004 mol
original mol HCl = $\frac{150}{1000} \times 0.24$
= 0.0360 mol
mol HCl reacted = 0.0360 – 0.01004
= 0.02596 mol
mol $MgCO_3{\cdot}xH_2O$ = 0.02596 ÷ 2
= 0.01298 mol
mass $MgCO_3{\cdot}xH_2O$ = 144.14 – 142.34
= 1.80 g
M_r $MgCO_3{\cdot}xH_2O$ = $\frac{1.80}{0.01298}$
= 138.7
M_r xH_2O = 138.7 – 84.3
= 54.4
x = 54.4 ÷ 18
= 3
Formula is $MgCO_3{\cdot}3H_2O$

6. mol NaOH = $\frac{41.30}{1000} \times 0.100$
= 0.00413 mol
mol H_2SO_4 in 50 cm³ = 0.00413 ÷ 2
= 0.002065 mol
mol H_2SO_4 in 500 cm³ = 0.02065 mol

M_r $BaSO_4$ = 233.4
mol $BaSO_4$ = $\frac{3.05}{233.4}$
= 0.01307 mol
mol H_2SO_4 reacted with $Ba(OH)_2$ = 0.01307 mol
original mol H_2SO_4 = $\frac{250}{1000} \times 0.200$
= 0.0500 mol
mol H_2SO_4 reacted with NaOH = original mol – remaining mol – mol reacted
= 0.0500 – 0.01307 – 0.02065
= 0.01628 mol
mol NaOH = 0.01628 × 2
= 0.03256 mol
conc NaOH = $0.03256 \div \frac{200}{1000}$
= 0.163 mol dm^{-3}

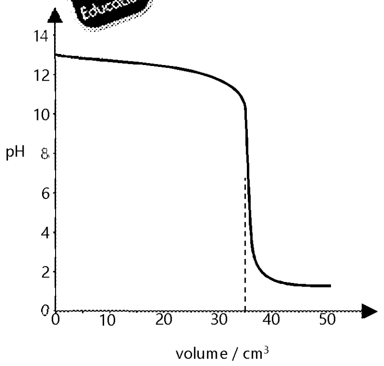
Titration curves / indicators

1. a) C
   b) D
   c) A

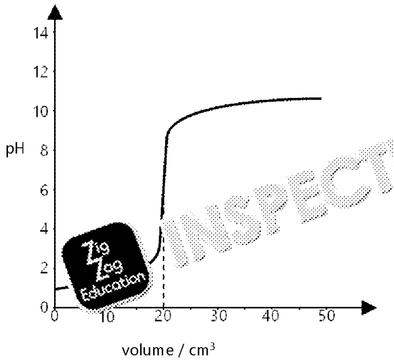
2. a) bromothymol blue
   b) bromocresol green
   c) blue to colourless

3. blue (phenolphthalein and thymolphthalein would both be colourless at this pH;
   giving the solution its colour

4. Graph should be a strong acid–strong base curve with an equivalence point at 35



5. Graph should be a strong acid–weak base curve with an equivalence point at 20



6. a) bromothymol blue and phenolphthalein
   b) methyl orange and bromothymol blue
   c) bromothymol blue

Strong acids and bases

1. a) pH $= -\log_{10}(0.00100) = 3.00$
   b) conc $= 10^{-2.3} = 0.00501$ mol dm^{-3}
   c) pH $= -\log_{10}(2 \times 0.000400) = 3.10$

2. a) $[H^+] = \frac{1.00 \times 10^{-14}}{0.00160}$
   $= 6.25 \times 10^{-13}$ mol dm^{-3}
   pH $= -\log_{10}(6.25 \times 10^{-13})$
   $= 11.2$
   b) $[H^+] = \frac{1.00 \times 10^{-14}}{0.000810}$
   $= 1.23$ [illegible] mol dm^{-3}
   p[illegible]og[illegible].23 $\times 10^{-12})$
   [illegible]9
   c) $[H^+] = \frac{1.00 \times 10^{-14}}{2 \times 0.0000451}$
   $= 1.11 \times 10^{-10}$ mol dm^{-3}
   pH $= -\log_{10}(1.11 \times 10^{-10})$
   $= 9.96$

3. $[H^+] = 10^{-11.7}$
   $= 1.995 \times 10^{-12}$
   $[H^+] \times [OH^-] = 1.00 \times 10^{-14}$
   $[OH^-] = \frac{1.00 \times 10^{-14}}{[H^+]}$
   $= \frac{1.00 \times 10^{-14}}{1.995 \times 10^{-12}}$
   $= 5.01 \times 10^{-3}$ mol dm^{-3}

4. $[H^+] = 2 \times 0.000520$
   $= 1.04 \times 10^{-3}$ mol dm^{-3}
   $[OH^-] = \frac{1.00 \times 10^{-14}}{[H^+]}$
   $= \frac{1.00 \times 10^{-14}}{1.04 \times 10^{-3}}$
   $= 9.62$ [illegible] mol dm^{-3}

5. mol HC[illegible] $= 0.01 \times \frac{500}{1000}$
   $= 5 \times 10^{-3}$ mol
   mol NaOH $= 0.03 \times \frac{150}{1000}$
   $= 4.5 \times 10^{-3}$ mol
   new mol HCl $= 5 \times 10^{-3} - 4.5 \times 10^{-3}$
   $= 5 \times 10^{-4}$ mol
   new conc HCl $= 5 \times 10^{-4} \div \frac{650}{1000}$
   $= 7.692 \times 10^{-4}$ mol dm^{-3}
   pH $= -\log_{10}(7.692 \times 10^{-4})$
   $= 3.11$

6. a) $[H^+] = 10^{-7}$
   $= 1.0 \times 10^{-7}$ mol dm^{-3}
   $[OH^-] = \frac{2.88 \times 10^{-14}}{1.0 \times 10^{-7}}$
   $= 2.88 \times 10^{-8}$ mol dm^{-3}
   $[H^+] > [OH^-]$, so **acidic**
   b) $[OH^-] = 0.00$[illegible]2 [illegible]
   = [illegible]0^{-4} mol dm^{-3}
   [H[illegible] $= \frac{2.88 \times 10^{-15}}{2.1 \times 10^{-4}}$
   $= 1.371 \times 10^{-11}$ mol dm^{-3}
   pH $= -\log_{10}(1.371 \times 10^{-11})$
   $= 10.86$

Weak acids

1. a) $-\log_{10}(1.42 \times 10^{-5}) = 4.85$
   b) $-\log_{10}(4.98 \times 10^{-7}) = 6.30$
   c) $10^{-1.03} = 9.33 \times 10^{-2}$
   d) $10^{-3.12} = 7.59 \times 10^{-4}$

2. a) $K_a = \frac{[H^+][SCN^-]}{[HSCN]}$
   b) $[H^+] = [SCN^-]$
   $K_a = \frac{[H^+]^2}{[HSCN]}$
   $[H^+] = \sqrt{[HSCN] \times K}$
   $= \sqrt{0.010}$[illegible]
   [illegible] 10[illegible] dm^{-3}
   pH [illegible]g$_{10}$(0.1090)
   [illegible] 0.963

3. $K_a = 10^{-3.29}$
   $= 5.129 \times 10^{-4}$
   $= \frac{[H^+][NO_2^-]}{[HNO_2]}$
   $[NO_2^-] = [H^+]$
   $K_a = \frac{[NO_2^-]^2}{[HNO_2]}$
   $[NO_2^-] = \sqrt{[HNO_2] \times K_a}$
   $= \sqrt{0.0452 \times 5.129 \times 10^{-4}}$
   $= 4.81 \times 10^{-3}$ mol dm^{-3}

4. $[H^+] = 10^{-5.79}$
   $= 1.622 \times 10^{-6}$ mol dm^{-3}
   $K_a = \frac{[H^+][C_6H_5O^-]}{[C_6H_5OH]}$
   $[H^+] = [C_6H_5O^-]$
   $K_a = \frac{[H^+]^2}{[C_6H_5OH]}$
   $K_a = \frac{(1.622 \times 10^{-6})^2}{0.0\text{[illegible]}}$
   [illegible] 14[illegible]
   pK$_a$ [illegible]4

5. a) Ethanoic acid dissociates less in DMSO than in water.
   b) $K_a(DMSO) = 10^{-12.3}$
   $= 5.0119 \times 10^{-13}$
   $K_a = \frac{[H^+][CH_3COO^-]}{[CH_3COOH]}$
   $[H^+] = [CH_3COO^-]$
   $K_a = \frac{[H^+]^2}{[CH_3COOH]}$
   $[H^+] = \sqrt{[CH_3COOH] \times K_a}$
   $= \sqrt{0.175 \times 5.0119 \times 10^{-13}}$
   $= 2.962 \times 10^{-7}$ mol dm^{-3}
   $K_a(water) = 10^{-4.76}$
   $= 1.738 \times 10^{-5}$
   $[CH_3COOH] = \frac{[H^+]^2}{K_a}$
   $= \frac{(2.962 \times 10^{-7})^2}{1.738 \times 10^{-5}}$
   = 5.04[illegible]0^{-9} [illegible]dm^{-3}

6. a) K[illegible] = [illegible]/$[H_2O]$
   b) [H$_2$[illegible] $= \frac{1000}{18}$
   $= 55.56$ mol dm^{-3}
   c) $K_a = \frac{10^{-14}}{55.56}$
   $= 1.8 \times 10^{-16}$
   $pK_a = -\log(1.8 \times 10^{-15})$
   $= 15.7$

Buffers

1. a) CHOONa
   b) NaCN$^-$

2. Equilibrium: $CF_3COOH \rightleftharpoons CF_3COO^- + H^+$
   Added HCl: CF_3COO^- reacts / uses up H^+ to form more CF_3COOH
   Equilibrium shifts left
   Added NaOH: H^+ reacts with added OH^- / more CF_3COO^- forms
   Equilibrium shifts right

3. $[H^+] = K_a \times \frac{[HA]}{[A^-]}$
   K_a = [illegible]
   = [illegible] 10^{-8}
   $[HA] = 0.150 \times \frac{200}{1000}$
   = 0.0300 mol dm^{-3}
   $[A^-] = 0.0450 \times \frac{800}{1000}$
   = 0.0360 mol dm^{-3}
   $[H^+] = 9.120 \times 10^{-8} \times \frac{0.0300}{0.0360}$
   = 7.6×10^{-8}
   pH = 7.12

4. HF reacts with NH_3 to form F^- (or NH_4F)
   This means there is a mixture of leftover weak acid (because it was in excess) and its salt
   $HF \rightleftharpoons F^- + H^+$
   When:
   acid added: F^- reacts with added H^+ / more HF forms
   alkali added: H^+ reacts with added OH^- / more [illegible] forms
   Equilibrium shifts left when acid is added, equilibrium shifts right when alkali is ad

5. a) $CH_3CH(OH)COOH$ in excess
   s[illegible] lactic acid reacts with KOH forming $CH_3CH(OH)COOK$ / CH
   b) $[H^+]$ [illegible] $^{-4}$
   = 1×10^{-4} mol dm^{-3}
   $K_a = 10^{-3.86}$
   = 1.3804×10^{-4}
   Assume $[KOH] = CH_3CH(OH)COO^-$
   Assume $[CH_3CH(OH)COOH] = [CH_3CH(OH)COOH] - [KOH]$
   $[H^+] = K_a \times \frac{[CH_3CH(OH)COOH] - [KOH]}{[KOH]}$
   $[CH_3CH(OH)COOH] - [KOH] = [KOH] \times \frac{[H^+]}{K_a}$
   $[CH_3CH(OH)COOH] = [KOH] \times \frac{[H^+]}{K_a} + [KOH]$
   $= 0.05 \times \frac{1 \times 10^{-4}}{1.3804 \times 10^{-4}} + 0.05$
   = 0.08622 mol dm^{-3}
   mol $CH_3CH(OH)COOH$ = $0.08622 \times \frac{400}{1000}$
   = 0.3449 mol
   M_r $CH_3CH(OH)COOH$ = 77.0
   mass $CH_3CH(OH)COOH$ = 2[illegible]

6. Desire
   $[H^+]$ =
   =
   K_a =
   K_a =
   =
   [HA] =
   =
   $[A^-]$ =
   =
   =
   curren
   curren
   additio
   Conjug
   M_r C_5H
   mass C

Structured redox titrations

1. a) mol MnO_4^- = $0.02 \times \frac{18.5}{1000}$
   = 3.7×10^{-4} mol
   b) 1 : 5 ratio
   mol Fe^{2+} = $5 \times 3.7 \times 10^{-4}$
   = 1.85×10^{-3} mol
   c) conc Fe^{2+} = $1.85 \times 10^{-3} \div \frac{50}{1000}$
   = 0.037 mol dm^{-3}

2. a) mol $S_2O_3^{2-}$ = 0.120 × [illegible]
   = [illegible]3 × 10^{-3} mol
   2 [illegible] S[illegible] : I_2
   b) so [illegible] = $\frac{3.2136 \times 10^{-3}}{2}$
   = 1.6068×10^{-3} mol
   c) conc I_2 = $1.6068 \times 10^{-3} \div \frac{50}{1000}$
   = 0.0321 mol dm^{-3}

3. a) mol MnO_4^- = $0.02 \times \frac{25.65}{1000}$
   = 5.13×10^{-4} mol
   b) 1 : 5 ratio
   mol Fe^{2+} = $5.13 \times 10^{-4} \times 5$
   = 0.002565 mol
   c) mol Fe^{2+} = $0.002565 \times \frac{1000}{100}$
   = 0.02565 mol
   d) r.f.m. FeX_2 = 3.25 ÷ 0.02565
   = 126.7
   r.f.m. X = $\frac{126.7-58.8}{2}$
   = 35.5
   X is Cl, so salt is $FeCl_2$

4. a) mol MnO_4^- [illegible] $\frac{[illegible]}{1000}$
   = 9.572×10^{-4} mol
   b) 1 : [illegible]
   mol Fe^{2+} = $5 \times 9.572 \times 10^{-4}$
   = 4.786×10^{-3} mol
   c) mol Fe^{2+} = $4.786 \times 10^{-3} \times \frac{500}{25}$
   = 0.09572 mol
   d) mass Fe = 0.09572 × 55.8
   = 5.34 g
   purity Fe = $\frac{5.34}{6} \times 100$
   = 89 %

5. a) mol KI = $\frac{8.4}{166}$ =
   mol H_2O_2 = ~0.04
   = ~0.02
   mol I^- > 2 × mol H_2O_2
   b) mol $Na_2S_2O_3$ = 0.150
   = 4.017
   2 : 1 ratio $Na_2S_2O_3 : I_2$
   mol I_2 = $\frac{4.017 \times}{3}$
   = 2.008
   mol H_2O_2 = 2.0085 × 1
   c) mol H_2O_2 = 0.020
   conc H_2O_2 = 0.020
   = 0.040

6. a) mol MnO_4^- = 0.015
   = 4.342
   b) 5 : 1 ratio
   mol Fe^{2+} = 5 × 4
   = 0.002
   c) mol Fe^{2+} = 0.021
   d) r.f.m. $FeSO_4 \cdot nH_2O$ =
   =
   n =
   =

Unstructured redox titrations

1. mol $S_2O_3^{2-}$ $= 0.1 \times \frac{24.33}{1000}$
$= 2.433 \times 10^{-3}$ mol
2 : 1 ratio of $S_2O_3^{2-} : I_2$
mol I_2 $= 2.433 \times 10^{-3} \div 2$
$= 1.2165 \times 10^{-3}$ mol
conc I_2 $= 1.2165 \times 10^{-3} \div \frac{50}{1000}$
$= 0.0243$ mol dm^{-3}

2. mol MnO_4^- = [illegible] $\frac{[illegible]}{1000}$
$= 2.2275 \times 10^{-4}$ mol
5 : 1 ra[illegible]$^{2+}$: MnO_4^-
mol Fe^{2}[illegible] cm^3 $= 5 \times 2.2275 \times 10^{-4}$
$= 1.11375 \times 10^{-3}$ mol
mol Fe^{2+} in 500 cm^3 $= 1.11375 \times 10^{-3} \times \frac{500}{20}$
$= 0.02784$ mol
mass Fe in sample $= 0.02784 \times 55.8$
$= 1.55$ g

3. mol MnO_4^- $= 0.050 \times \frac{14.85}{1000}$
$= 7.425 \times 10^{-4}$ mol
5 : 1 ratio of $Fe^{2+} : MnO_4^-$
mol Fe^{2+} in 20 cm^3 $= 5 \times 7.425 \times 10^{-4}$
$= 3.7125 \times 10^{-3}$ mol
mol Fe^{2+} in 100 cm^3 $= 3.7125 \times 10^{-3} \times \frac{100}{20}$
$= 0.01856$ mol
r.f.m. FeX_2 $= 2.74 \div 0.01856$
$= 147.8$
r.f.m. X $= \frac{147.8 - [illegible]}{2}$
[illegible]

X is NO[illegible]

4. mol Na_2[illegible] in solution $= 5 \div 248$
$= 0.02016$ mol
conc of $S_2O_3^{2-}$ in solution $= 0.02016 \div \frac{500}{1000}$
$= 0.04032$ mol dm^{-3}
mol $S_2O_3^{2-}$ in titre $= 0.04032 \times \frac{34.55}{1000}$
$= 1.393 \times 10^{-3}$ mol
mol I_2 $= \frac{1.393 \times 10^{-3}}{2}$
$= 6.966 \times 10^{-4}$ mol
Equation: $2Mn^{3+} + 2I^- \rightarrow 2Mn^{2+} + I_2$

mol Mn^{3+} $= 6.966 \times 10^{-4}$ mol $\times 2 = 1.3932 \times 10^{-3}$ mol
conc I_2 $= 1.3932 \times 10^{-3} \div \frac{50}{1000}$
$= 0.0279$ mol dm^{-3}

5. $Cr_2O_7^{2-} + 6Fe^{2+} + 14H^+$
mol $Cr_2O_7^{2-}$

mol Fe^{2+} (in 25 cm^3)

m[illegible] Fe^{2+} (in 500 cm^3)

mol $Fe(NO_3)_3$
r.f.m. $Fe(NO_3)_3$
mass $Fe(NO_3)_3$

purity $Fe(NO_3)_3$

6. mol $S_2O_3^{2-}$

mol I_2 in 25 cm^3

mol I_2 in 500 cm^3

mol Cu^{2+}

mass Cu^{2+}

[illegible]y mass

The most difficult redox titrations

1. ① $Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$

   ② $Fe^{3+} + e^- \rightarrow Fe^{2+}$

   6×② $6Fe^{2+} \rightarrow 6Fe^{3+} + 6e^-$

   Overall $Cr_2O_7^{2-} + 14H^+ + \cancel{6e^-} + 6Fe^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6Fe^{3+} \cancel{+ 6e^-}$

   $Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6Fe^{3+}$

   mol $Cr_2O_7^{2-}$ $= 0.0250 \times \frac{18.90}{1000}$
   $= 4.725 \times 10^{-4}$ mol
   mol Fe^{2+} in 25 cm³ $= 6 \times 4.725 \times 10^{-4}$
   $= 2.835 \times 10^{-3}$ mol
   mol Fe^{2+} in 500 cm³ $= 2.835 \times 10^{-3} \times \frac{500}{25}$
   $= 0.0567$ mol
   mass Fe $= 0.0567 \times 55.8$
   $= 3.164$ g
   purity Fe $= \frac{3.164}{5.68} \times 100$
   $= 55.7$ %

2. ① $V^{2+} + 3H_2O \rightarrow VO_3^- + 6H^+ + 3e^-$

   ② $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

   5×① $5V^{2+} + 15H_2O \rightarrow 5VO_3^- + 30H^+ + 15e^-$

   3×② $3MnO_4^- + 24H^+ + 15e^- \rightarrow 3Mn^{2+} + 12H_2O$

   $5V^{2+} + \underset{3H_2O}{15\cancel{H_2O}} + 3MnO_4^- + \cancel{24H}^+ + \cancel{15e}^- \rightarrow 5VO_3^- + \underset{6H^+}{\cancel{30H}^+} + \cancel{15e}^- + 3Mn^{2+} + \cancel{12H_2O}$

   Overall $5V^{2+} + 3MnO_4^- + 3H_2O \rightarrow 5VO_3^- + 3Mn^{2+} + 6H^+$

   mol MnO_4^- $= 0.0120 \times \frac{21.1}{1000}$
   $= 2.532 \times 10^{-4}$ mol
   mol V^{2+} in 50 cm³ $= \frac{5}{3} \times 2.532 \times 10^{-4}$
   $= 4.22 \times 10^{-4}$ mol
   mol V^{2+} in 500 cm³ $= 4.22 \times 10^{-4} \times \frac{500}{50}$
   $= 4.22 \times 10^{-3}$ mol
   mass V $= 50.9 \times 4.22 \times 10^{-3}$
   $= 0.2148$ g
   purity $= \frac{0.2148}{0.382} \times 100$
   $= 56.2$ %

3. **Moles of Fe^{2+} in solution A**

   mol MnO_4 $= 0.0200 \times \frac{23.55}{1000}$
   $= 4.71 \times 10^{-4}$ mol
   mol Fe^{2+} in 25 cm³ $= 5 \times 4.71 \times 10^{-4}$
   $= 2.355 \times 10^{-3}$ mol
   mol Fe^{2+} in 500 cm³ $= 2.355 \times 10^{-3} \times \frac{500}{25}$
   $= 0.0471$ mol

   Moles of Fe^{2+} in solution made from solution A

   mol MnO_4 $= 0.0200 \times \frac{28.93}{1000}$
   $= 5.786 \times 10^{-4}$ mol
   mol Fe^{2+} in 25 cm³ $= 5 \times 5.786 \times 10^{-4}$
   $= 2.893 \times 10^{-3}$ mol
   mol Fe^{2+} in 200 cm³ = mol Fe in 200 cm³
   $= 2.893 \times 10^{-3} \times \frac{200}{25}$
   $= 0.02314$ mol
   mol Fe^{2+} and Fe^{3+} in **A** $= 0.02314 \times \frac{500}{100}$
   $= 0.11572$ mol

   % Fe which is Fe^{2+} $= \frac{0.0471}{0.11572} \times 100$
   $= 40.7$ %

4. mol $S_2O_3^{2-}$ $= 0.01 \times \frac{31.55}{1000}$
$= 3.155 \times 10^{-4}$ mol
mol I_2 in 20 cm^3 $= \frac{3.155 \times 10^{-4}}{2}$
$= 1.5775 \times 10^{-4}$ mol
mol I_2 in 500 cm^3 $= \frac{500}{20} \times 1.5775 \times 10^{-4}$
$= 0.003944$ mol

mol $BaFeO_4$ $= 0.676 \div (137.3 + 55.8$ [illegible] $\times 4$[illegible]
$= 2.629 \times 10^{-3}$ [illegible]

	I_2	FeO_4^{2-}
mol ra[illegible]	3.944×10^{-3}	2.629×10^{-3}
whole n[illegible]er mol ratio	$\frac{3.944 \times 10^{-3}}{2.629 \times 10^{-3}}$	$\frac{2.629 \times 10^{-3}}{2.629 \times 10^{-3}}$
	1.5	1
	3	2

ratio $FeO_4^{2-} : I_2 = 3 : 2$

Half-equation I^-: $2I^- \rightarrow I_2 + 2e^-$
FeO_4^{2-} Fe is +6
Fe must be reduced by $2e^- \times \frac{3}{2} = 3e^-$
$FeO_4^{2-} \rightarrow Fe^{3+}$
Half-equation FeO_4^{2-}: $FeO_4^{2-} + 8H^+ \rightarrow Fe^{3+} + 4H_2O$
Full equation: $2FeO_4^{2-} + 16H^+ + 6I^- \rightarrow 2Fe^{3+} + 3I_2 + 8H_2O$

5. mol NH_4FeSO_4 $= 0.109 \times \frac{24.50}{1000}$
$= 2.670$[illegible]
mol $Cr_2O_7^{2-}$ remaining [illegible]
$= 4.451 \times 10^{-4}$ mol
origina[illegible] $= 0.115 \times \frac{25}{1000}$
$= 2.875 \times 10^{-3}$ mol
mol $Cr_2O_7^{2-}$ used up $= 2.875 \times 10^{-3} - 4.451 \times 10^{-4}$
$= 2.4299 \times 10^{-3}$ mol
mol CH_3CH_2OH in sample $= \frac{3}{2} \times 2.4299 \times 10^{-3}$
$= 3.6449 \times 10^{-3}$ mol
mol CH_3CH_2OH in 500 cm^3 $= 3.6449 \times 10^{-3} \times \frac{500}{20}$
$= 0.09112$ mol
conc CH_3CH_2OH in wine $= 0.09112 \div \frac{100}{1000}$
$= 0.911$ mol dm^{-3}

6. Overall equation: $Mo^{5+} + Ce^{4+} \rightarrow Ce^{3+} + Mo^{6+}$

mol Ce^{3+} $= 0.103 \times \frac{20.05}{1000}$
$= 2.0652 \times 10^{-3}$ mol
mol Mo^{5+} in 50.0 cm^3 $= 2.0652 \times 10^{-3}$ mol
mol Mo^{5+} in 200 cm^3 $= 2.0652 \times 10^{-3} \times \frac{200}{50}$
$= 8.26 \times 10^{-3}$ mol
r.f.m. **A** $= 2.00 \div 8.26 \times 10^{-3}$
$= 242.1$

mol **A** in 1.5 g $= 1.5 \div 242.1$
$= 6.196 \times 10^{-3}$ mol

mass H_2O removed $= 1.5 - 1.28$
$= 0.22$ g
mol H_2O removed $= 0.22 \div 18$
$= 0.0122$ mol

	$Na_2MoO_x{\bullet}nH_2O$	H_2O
mol ratio	6.196×10^{-3}	0.0122
whole number mol ratio	$\frac{6.196 \times 10^{-3}}{6.196 \times 10^{-3}}$	$\frac{0.0122}{6.196 \times 10^{-3}}$
	1	2

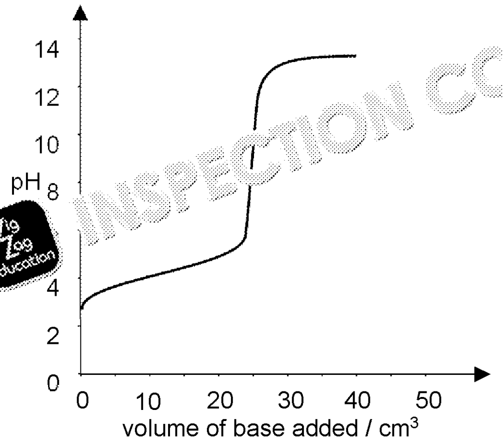
$n = 2$
$Na_2MoO_x{\bullet}2H_2O$

r.f.m. due to $O_x = 242.1 - (2 \times 23 + 95.9 + 2\times(2 + 16))$
$= 64.2$

x $= 64.2 \div 16$
$= 4$

Formula: $Na_2MoO_4{\bullet}2H_2O$

Exam-Style Questions: Answers

<table>
<tr><th>Question</th><th>Marking Guidance</th></tr>
<tr><td>1a</td><td>starts with an upwards curve
ends at 40 cm^3
vertical section at 25 cm^3
 </td></tr>
<tr><td>1bi</td><td>
<table>
<tr><th></th><th>Rough</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Start volume (cm^3)</td><td>0.00</td><td>0.10</td><td>0.05</td><td>0.00</td></tr>
<tr><td>End volume (cm^3)</td><td>33.35</td><td>31.15</td><td>31.15</td><td>31.10</td></tr>
<tr><td>Volume of NaOH (cm^3)</td><td>33.35</td><td>31.05</td><td>31.10</td><td>31.10</td></tr>
</table>
Mean titre $= \frac{31.05 + 31.10 + 31.10}{3}$
$= 31.08$ cm^3</td></tr>
<tr><td>1bii</td><td>mol NaOH $= 0.100 \times \frac{31.08}{1000}$
$= 3.108 \times 10^{-3}$ mol
mol organic acid $= 3.108 \times 10^{-3}$
conc organic acid $= 3.108 \times 10^{-3} \div \frac{25}{1000}$
$= 0.124$ mol dm^{-3}</td></tr>
<tr><td>1c</td><td>K_a = [illegible]
$= 7.41 \times 10^{-4}$
$K_a = \frac{[H^+][A^-]}{[HA]}$
$[H^+] = [A^-]$
$K_a = \frac{[H^+]^2}{[HA]}$
$[H^+] = \sqrt[2]{K_a \times [HA]}$
$= \sqrt[2]{7.41 \times 10^{-4} \times 0.150}$
$= 0.01054$ mol dm^{-3}
$K_w = [H^+] \times [OH^-]$
$[OH^-] = \frac{K_w}{[H^+]}$
$[OH^-] = \frac{1 \times 10^{-14}}{0.01054}$
$= 9.48 \times 10^{-13}$ mol dm^{-3}</td></tr>
</table>

Question	Marking guidance
1di	$H_3C_6H_5O_7 \rightleftharpoons H_2C_6H_5O_7^- + H^+$ $H_2C_6H_5O_7^-$ reacts with HCl / H^+ Equilibrium position shifts left to reduce the concentration of H^+ again / H^+ concentration
1dii	$[H^+] = 10^{-5}$ $= 1 \times 10^{-5}$ mol dm^{-3} $K_a = 7.41 \times 10^{-4}$ $K_a = \frac{[H^+][A^-]}{[HA]}$ assume [NaOH] = [A$^-$] $K_a = \frac{[H^+][NaOH]}{[HA]_{initial} - [NaOH]}$ $[HA]_{initial} - [NaOH] = \frac{[H^+][NaOH]}{K_a}$ $[HA]_{initial} = \frac{[H^+][NaOH]}{K_a} + [NaOH]$ $= \frac{1 \times 10^{-5} \times 0.1}{7.41 \times 10^{-4}} + 0.1$ $= 0.101$ mol dm^{-3}

Question	Marking guidance
2	**Stage 1: Acid is in excess** 'Hydrochloric acid must be in excess.' mol HCl $= 0.150 \times \frac{100}{1000}$ $= 0.015$ mol 2 : 1 ratio HCl : $CaCO_3$ max. mol $CaCO_3$ $= \frac{1}{2} \times 0.015$ $= 7.5 \times 10^{-3}$ mol max. mass $CaCO_3$ $= 7.5 \times 10^{-3} \times (40.1 + 12 + 3 \times 16)$ $= 0.751$ g **Stage 2: Experimental method** Measure 100 cm^3 HCl (with a pipette) and add the mass of calcite weig **conical flask**. Titrate: standard solution / 0.100 mol dm^{-3} / 0.200 mol dm^{-3} NaOH in a and record the volume when the **indicator changes**. **Stage 3: Calculate mol $CaCO_3$** mol NaOH $= \frac{volume\ of\ NaOH\ in\ cm^3}{1000} \times$ [NaOH] **AND** mol HCl $= 7.5 \times 10^{-3}$ – mol NaOH **AND** mol $CaCO_3$ $= \frac{mol\ HCl}{2}$ **Stage 4: Calculate purity** mass $CaCO_3$ $= moles\ CaCO_3 \times 100.1$ **AND** Purity $= \frac{mass\ CaCO_3}{mass\ of\ solid}$

Question	Marking Guidance
3a	$Cu^{2+} + e^- \rightarrow Cu^+$
3b	Because it might react with sodium thiosulfate, causing the result / titre / percentage by mass to be inaccurate
3c	Indicator
3d	mol $Na_2S_2O_3$ $= \frac{37.20}{1000} \times 0.01$ $= 0.0003720$ mol mol I_2 $= \frac{0.0003720}{2}$ $= 0.000186$ mol mol I_2 in 250 cm^3 $= 0.000186 \times \frac{250}{25}$ $= 0.00186$ mol mol Cu in ring $= 0.00186 \times 2$ $= 0.00372$ mol Mass Cu in ring $= 0.00372 \times 63.5$ $= 0.2362$ g % by mass Cu $= \frac{0.2362}{0.945} \times 100$ $= 25.0$ %

Question	Marking Guidance
4	Full equation: $2MnO_4^- + 5SO_3^{2-} + 6H^+ \rightarrow 2Mn^{2+} + 5SO_4^{2-} + 3H_2O$ mol MnO_4^- $= 0.0150 \times \frac{32.8}{1000}$ $= 4.92 \times 10^{-4}$ mol mol SO_3^{2-} $= \frac{5}{2} \times 4.92 \times 10^{-4}$ $= 1.23 \times 10^{-3}$ mol mol SO_3^{2-} in 200 cm^3 $= 1.23 \times 10^{-3} \times \frac{200}{25}$ $= 9.84 \times 10^{-3}$ mol r.f.m. M_2SO_3 $= \frac{1.24}{9.84 \times 10^{-3}}$ $= 126.0$ r.f.m. M $= \frac{126.0 - (32.1 + 3 \times 16)}{2}$ $= 23$ $M^+ = Na^+$

Quick Quiz

1. H^+

2. Neutralisation

3. hydrochloric acid + potassium hydroxide → potassium chloride
   HCl KOH → K[illegible] +

4. Neutral

5. pH meter
   (univers[illegible]ic[illegible]

6. $\frac{3}{9} = 0.33$ [illegible] dm^{-3}

7. Any three from:
   - burette
   - pipette
   - beaker
   - conical flask
   - clamp / clamp stand / retort stand
   - funnel
   - white tile
   - measuring cylinder

8. Strong acids / sulfuric acid / **solution 1** dissociate(s) more easily than weak acids /

9. a) $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$
   b) 0.24 mol

10. a) Fe
    b) C
    c) O