Chem Factsheet

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How To Answer Questions on Titration Calculations

Titration calculations are one of the most unpopular calculation types with many A-level students. This Factsheet aims to supply a method for these calculations which will allow students to tackle them confidently, even when the context is unfamiliar.

Before starting this Factsheet, you should review the formulae connecting moles with masses, volumes and concentrations (Factsheets 2, 3 and 7).

Approaching calculations

The commonest comment from students is 'I didn't know where to start on it!'. The key point in overcoming this is to recognise that despite their appearances, all titration calculations involve the same processes, and once you recognise this you will succeed in solving them.

Success in titration calculations not only requires the manipulation of numbers - familiarity with reactions and an ability to write balanced chemical equations are also vital.

Exam Hint: *Few marks will be gained from calculations from an incorrect chemical equation. Take time checking your equations are balanced.*

The Method

1. Read the question and produce your own flowchart of the information given. Decide whether any parts are not relevant to the calculation.
2. From the equation(s) (either given in the question or the ones you have to write for yourself) write down the ratio of reacting amounts needed
3. **Remember** the following equations:

$$\text{moles} = \frac{g}{A_r \text{ or } M_r}$$

$$\text{moles} = \frac{cm^3 \times M}{1000}$$

$$\text{percentage purity} = \frac{\text{mass of pure substance} \times 100}{\text{mass of impure sample}}$$

4. Look at the flowchart and decide where, and to what, you can apply the equations in step 3 above. Look for something you know two pieces of informaton about that occur in the same equation - for example, both moles and cm^3, or both mass (g) and M_r.
5. Work back through the flowchart to the answer asked for in the question.

Understanding how step 4 works is the key to overcoming the "where do I start?" problem. If you know two pieces of information about the same thing - for example, the volume and concentration of a solution - then you can use one of the equations listed in step 3 - you cannot get anywhere with only one piece of information!

Example 1.

A fertiliser contains ammonium sulphate and potassium sulphate. When 0.50g of the fertiliser was warmed with sodium hydroxide solution, ammonia gas was evolved. The ammonia required $15.0cm^3$ of 0.2 M hydrochloric acid to neutralise it. What is the percentage by mass of ammonium sulphate in the fertiliser?

Method

1. Produce the flowchart:

$(NH_4)_2SO_4/K_2SO_4$ (0.50g) $\xrightarrow{NaOH}$ NH_3 + $15.0cm^3$ 0.2 M HCl

2. The equations are:

$(NH_4)_2SO_4 + 2NaOH \rightarrow 2NH_3 + Na_2SO_4 + 2H_2O$

Ratio 2 NH_3 : 1 $(NH_4)_2SO_4$

$NH_3 + HCl \rightarrow NH_4Cl$

Ratio 1 NH_3 : 1 HCl

4. We know cm^3 and M for HCl. So we start at the end of the flowchart we can use:

$\text{moles} = \frac{cm^3 \times M}{1000}$ on the HCl amounts,

So moles HCl $= \frac{15 \times 0.2}{1000} = 0.003$

5. Working backwards:

If we know the moles of HCl then the moles NH_3 is the same (1:1)

So moles NH_3 = 0.003

We know 2 NH_3 : 1 $(NH_4)_2SO_4$

So if we half the NH_3 moles we get the moles of $(NH_4)_2SO_4$

So moles $(NH_4)_2SO_4$ = 0.003/2 = 0.0015

The question asks about % by mass, so we need this answer as a mass. So we need to change moles to grams i.e.

$\text{moles} = \frac{g}{M_r}$

To use this, we need $M_r((NH_4)_2SO_4) = (18 \times 2) + 32 + (4 \times 16) = 132$

So mass $(NH_4)_2SO_4$ = moles × M_r

= 0.0015 × 132

= 0.198g

So percentage $(NH_4)_2SO_4 = \frac{g \times 100}{0.50}$

$= \frac{0.198 \times 100}{0.50}$

= 39.6%

Before you go on to the next example you should make sure you understand:

- how the flowchart was produced
- why the calculation started with HCl,
- the process of working back to $(NH_4)_2SO_4$ via the ratios from the equations

Example 2.

A piece of iron wire of mass 2.3g was reacted with heated dilute sulphuric acid until it had all reacted and dissolved. After cooling the solution, it was made up to 250cm^3 in a volumetric flask. The solution contained only Fe^{2+} ions, not Fe^{3+} ions. 25.0 cm^3 of the iron solution was acidified and titrated with a 0.015 moldm^{-3} solution of potassium dichromate (VI) of which 30.0cm^3 was required.

The reaction is:

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

Calculate the percentage of iron in the wire.

Method

1. The flowchart is,

$$\underbrace{\text{Wire}}_{2.3g} \xrightarrow{H_2SO_4} Fe^{2+} \rightarrow 250cm^3\ Fe^{2+} \rightarrow 25cm^3\ Fe^{2+} + 30.0cm^3\ 0.015\ \text{M}\ Cr_2O_7^{2-}$$

2. From the equation, $6\ Fe^{2+} : 1\ Cr_2O_7^{2-}$
4. We know cm^3 and M for $Cr_2O_7^{2-}$ So we can use moles $= \frac{cm^3}{1000} \times M$ on the $Cr_2O_7^{2-}$ in the flowchart to find its moles

   Moles $Cr_2O_7^{2-} = \frac{30 \times 0.015}{1000} = 0.00045$

5. $6 \times Cr_2O_7^{2-} \rightarrow$ moles Fe^{2+} in 25cm^3

   So moles Fe^{2+} in 25cm^3 $= 0.00045 \times 6$
   $= 0.0027$

   Moles Fe^{2+} in 25cm^3 $\times 10 \rightarrow$ moles Fe^{2+} in 250cm^3

   So moles Fe^{2+} in 250cm^3 $= 10 \times 0.0027 = 0.027$

   $1\ Fe^{2+} \rightarrow 1\ Fe$

   So moles Fe = 0.027

   We need mass of Fe, since question is about % purity.

   So use moles $= \frac{g}{A_r}$

   So mass of Fe $= A_r \times$ moles
   $= 56 \times 0.027 = 1.512g$

   Now find % purity

   Percentage Fe $= \frac{1.512 \times 100}{2.3} =$ **65.74%**

Example 3

In an experiment to find the value of n in $(NH_4)_2SO_4.FeSO_4.nH_2O$, 16.98g of the salt were dissolved in a mixture of water and dilute sulphuric acid. The solution was made up to 250cm^3 in a volumetric flask. 25.0cm^3 of this solution was titrated with potassium manganate(VII) of concentration 0.030 mol dm^{-3}. 22.5cm^3 of this solution was required.

The reaction is:

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

What is the value of n in the salt?

This solution is written out only in minimum detail. Construction of the flowchart is left as an exercise for the student.

$5\ Fe^{2+} : 1\ MnO_4^-$

Moles $MnO_4^- = \frac{22.5 \times 0.003}{1000} = 0.000675$

Moles Fe^{2+}in 25cm^3 $= 0.000675 \times 5$
$= 0.003375$

Moles Fe^{2+} in 250cm^3 $= 0.003375 \times 10 = 0.03375$

$1\ Fe^{2+} : 1\ (NH_4)_2\ SO_4.FeSO_4.nH_2O$

Moles $(NH_4)_2\ SO_4.FeSO_4.nH_2O = 0.03375$

So $0.03375 = 16.98/ M_r$

So $M_r = 16.98/0.03375 = 503.1$

$(18 \times 2) + 32 + (4 \times 16) + 56 + 32 + (4 \times 16) + 18n = 503.1$

284 + 18n	=	503.1
18n	=	503.1 – 284 = 219.1
n	=	219.1/18 = 12.17

But n must be a whole number

So n = 12

Practice Questions

1. A marble chip of mass 5.0g required 40cm^3 of 1.5 mol dm^{-3} hydrochloric acid to react with all the calcium carbonate it contained. What is the percentage of calcium carbonate in the marble chip?

2. 13.73g of sodium carbonate crystals were dissolved in 1 dm^3 of water. 25cm^3 of the solution were neutralised by 24cm^3 of 0.10 mol dm^{-3} hydrochloric acid. What is the value of n in the formula $Na_2CO_3 . nH_2O$ for sodium carbonate crystals?

3. A piece of iron wire weighs 2.8g. it is dissolved in acid and converted to Fe^{2+} ions. The solution reacts with 40cm^3 of 0.2M potassium dichromate (VI) solution. The reaction is:

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

   What is the percentage of iron in the sample of wire?

4. A 0.50g sample of potassium(V) iodate, KIO_3 is dissolved in water and made up to 250cm^3. A 25.0cm^3 sample of this solution is added to an excess of potassium iodide in sulphuric acid solution. The reaction is:

   $$IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$$

   The iodine formed requires 20.0cm^3 of sodium thiosulphate solution for titration. The reaction is:

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

   What is the concentration of the sodium thiosulphate solution?

Answers

1. **60%**
   moles HCl = 0.06; moles $CaCO_3$ = 0.03;
   Mass $CaCO_3 = 100 \times 0.03 = 3g$

2. **n = 10**
   moles HCl = 0.0024 moles Na_2CO_3 (in 1 dm^3) = 0.048
   $M_r = 3.73/0.048 = 286$ $Na_2CO_3 = 106$, so n = (286 – 106)/18 = 10

3. **96%**
   moles $Cr_2O_7^{2-} = 0.008$; moles $Fe^{2+} = 6 \times 0.008$
   mass Fe $= 0.048 \times 56 = 2.688g$
   % = $2.688 \times 100/2.8$

4. **0.072 mol dm^{-3}**
   moles KIO_3 in 250cm^3 $= 0.5/M_r = 0.5/214 = 0.00234$
   moles KIO_3 in 25cm^3 $= 0.00234 /10 = 0.000234$
   mole $I_2 = 0.000234 \times 3$
   moles $Na_2S_2O_3 = 0.000234 \times 2 = 0.00144$
   $M = 0.00144 \times 1000/20$

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