



## Titration Calculations: Revision Summary

To succeed with this topic you need to know and understand the material covered so far in Factsheets No. 7 (Moles and Volumetric Analysis), No.23 (How to Answer Questions on Titration Calculations), No.51 ('Redox Equilibria (IV) : Redox Titrations') No.57: Answering questions on Redox Titrations 1)

The purpose of this Factsheet is to bring together all the different types of titration calculations under various categories.

By now you should be competent in titration calculations. If you can now recognise a calculation problem as belonging to a particular category it will help you to get into the problem more quickly.

You should regard this Factsheet as a **summary** of all the four Factsheets listed above. We will re-visit the basic equations and terms, and then put in the categories.

### TERMS USED

**Volumetric analysis** - this is another way of saying TITRATION i.e. adding reacting solutions together to find the exact point (the end-point) when the two solutions have completely reacted together.

**Standard Solution** - a solution made by dissolving an **accurate** amount of solid in, usually, water. The volume is usually 250cm<sup>3</sup> so you can **always** calculate g dm<sup>-3</sup>. If the  $M_r$  is known, you can calculate mol dm<sup>-3</sup>.

**Titre** - the final volume added from the burette in the titration. When a series of titrations are done, then titres in good agreement (concordant) are averaged to give the volume used in calculations – the **AVERAGE TITRE**.

**Acid/Base Titration** - as it says! An acidic solution reacting with a basic solution (neutralisation).

**Redox Titration** - the two half equations are combined to give the balanced chemical equation (using the 'electron balancing method'). One of the half equations is a reduction process (electron gain) and the other an oxidation process (loss of electrons)

### EQUATIONS USED IN CALCULATIONS

$$\text{moles} = \frac{\text{grams}}{A_r/M_r}$$

$$\text{moles} = \frac{\text{volume (cm}^3\text{)}}{1000} \times M \text{ (mol dm}^{-3}\text{)}$$

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

$$\text{percentage by mass} = \frac{\text{mass of element}}{\text{mass of compound}} \times 100$$

### CATEGORIES OF TITRATION CALCULATIONS

- categories 1, 2, 3, 4 and 5 use examples from both redox and acid/base titrations.
- category 6 is usually only acid/base titration type.

Type	Example
1. Finding concentration of a solution	A standard solution is made and used to find the concentration of the other solution in the titration.
2. Finding the <b>formula mass</b> ( $M_r$ ) of a compound	A standard solution is made of the compound. It is titrated with the other solution and its concentration, mol dm <sup>-3</sup> , found.  Using: moles = $\frac{g}{M_r}$ the value of $M_r$ is found.
3. Finding the <b>percentage purity</b> of a sample of impure compounds	A standard solution of the impure solid is made. Titration with the other solution enables you to find the mass of the pure solid and hence the percentage purity.
4. Finding the <b>formula</b> of a compound	Exactly the same as (2) above, but the $M_r$ value is used to find, for example, 'the x in Na <sub>2</sub> CO <sub>3</sub> · xH <sub>2</sub> O'
5. Finding the <b>percentage mass</b> of an element in a compound	The method is the same as for (4) above, but you find the mass of the element and hence the percentage of it in the compound.
6. Using the ' <b>back titration</b> ' method	Usually a solid is reacted with an excess of acid. The acid left after the reaction is found by titrating with a base. It is therefore possible to find how much acid reacted with the solid and so more about the solid itself.

The examples on the next page review how to tackle each of these types of calculation - these include a mixture of acid-base and redox titrations. The key approach is to make sure you understand what is going on at each stage, rather than try to remember the method "parrot fashion".

**Exam Hint** - make sure you are confident rearranging the various equations used in these calculations. Factsheet 56 (Maths for Chemists 1) gives some assistance on calculations involving percentages, and a later Factsheet will review rearrangement of formulae.

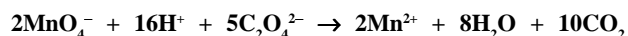
## Worked Examples

## 1. Finding Concentration

0.95g of ethanedioic acid crystals,  $\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ , was dissolved in  $250\text{cm}^3$  of water. A  $25.0\text{cm}^3$  sample of solution required  $33.0\text{cm}^3$  of potassium manganate (VII) solution in a titration.

What is the concentration of the manganate (VII) solution?

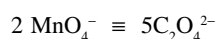
The equation is,



$$M_r \text{ of acid crystals} = 2 + 24 + 64 + 36 = 126$$

$$\text{Moles of acid crystals in } 250\text{cm}^3 = \frac{0.95}{126} = 0.00754$$

$$\text{Moles of acid crystals in } 25\text{cm}^3 = \frac{0.00754}{10} = 0.000754$$



$$\text{Moles MnO}_4^- = 0.000754 \times \frac{2}{5} = 0.000302$$

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

$$0.000302 = \frac{33.0}{1000} \times M$$

$$\text{so } M = \frac{0.000302 \times 1000}{33} = 0.0092 \text{ mol dm}^{-3}$$

## 2. Finding a formula mass

5.2g of compound X was dissolved in  $250\text{cm}^3$  of water. A  $25.0\text{cm}^3$  portion of the solution required  $20.0\text{cm}^3$  of a  $0.20 \text{ mol dm}^{-3}$  of potassium dichromate (VI) solution in a titration. The reacting ratio is:  $5 \equiv 1\text{Cr}_2\text{O}_7^{2-}$

What is the formula mass,  $M_r$ , of X?

$$\text{Moles Cr}_2\text{O}_7^{2-} = \frac{20.0}{1000} \times 0.20 = 0.004$$

$$\text{Moles X in } 25.0\text{cm}^3 = 5 \times 0.004 = 0.02$$

$$\text{Moles X in } 250\text{cm}^3 = 0.02 \times 10 = 0.2$$

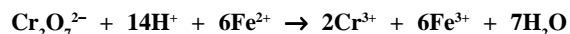
$$\text{Moles} = \frac{g}{M_r}$$

$$\text{so } M_r = \frac{g}{\text{moles}} = \frac{5.2}{0.2} = 26$$

## 3. Finding Percentage Purity

A piece of iron wire has a mass of 0.62g. It is dissolved in acid, then reduced from  $\text{Fe}^{3+}$  to  $\text{Fe}^{2+}$ . The whole solution was titrated with  $0.04 \text{ mol dm}^{-3}$  potassium dichromate (VI) solution of which  $42.5\text{cm}^3$  was required.

The equation is:



What is the percentage purity of the iron wire?

$$\text{Moles Cr}_2\text{O}_7^{2-} = \frac{42.5}{1000} \times 0.04 = 0.0017$$

$$\text{Moles Fe}^{2+} = 0.0017 \times 6 = 0.0102$$

$$\text{Moles} = \frac{g}{A_r} \quad A_r \text{ of Fe} = 6$$

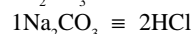
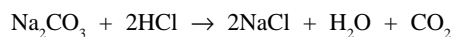
$$\text{so mass} = 0.0102 \times 56 = 0.5712\text{g}$$

$$\text{Percentage purity} = \frac{0.5712}{0.62} \times 100 = 92.13\%$$

## 4. Finding the Formula of a Compound

Sodium carbonate crystals ( $13.91\text{g}$ ) were dissolved in water and made up to  $1.0 \text{ dm}^3$ . A  $25.0\text{cm}^3$  portion of the solution was neutralised by  $24.4\text{cm}^3$  of  $0.10 \text{ mol dm}^{-3}$  hydrochloric acid solution.

What is  $x$  in  $\text{Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O}$ ?



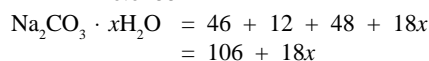
$$\text{Moles HCl in } 25.0\text{cm}^3 = \frac{24.4}{1000} \times 0.1 = 0.00244$$

$$\text{Moles of HCl in } 1 \text{ dm}^3 = 0.00244 \times \frac{1000}{40} = 0.0976$$

$$\text{Moles of sodium carbonate} = \frac{0.0976}{2} = 0.0488$$

$$\text{Moles} = \frac{g}{M_r} \quad 0.0488 = \frac{13.91}{M_r}$$

$$\text{so } M_r = \frac{13.91}{0.0488} = 285.04$$



$$285.04 = 106 + 18x$$

$$\text{so } 18x = 285.04 - 106 = 179.04$$

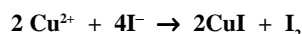
$$x = \frac{179.04}{18} = 10$$

i.e.  $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$

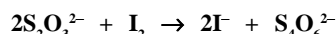
## 5. Finding Percentage Mass

Brass is a mixture of copper and zinc. It dissolves in nitric acid to form  $\text{Cu}^{2+}$  and  $\text{Zn}^{2+}$  ions. The  $\text{Cu}^{2+}$  ions can be found by using iodide and sodium thiosulphate. The zinc ions do not react in the process.

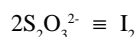
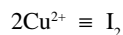
2.0g of a sample of brass was dissolved in nitric acid and after treating the solution formed to remove other materials excess potassium iodide was added.



The iodine reacted with  $20.0\text{cm}^3$  of  $1 \text{ mol dm}^{-3}$  sodium thiosulphate solution,



What is the percentage by mass of copper in the brass sample?



$$\text{so } \text{Cu}^{2+} \equiv \text{S}_2\text{O}_3^{2-}$$

$$\text{Moles S}_2\text{O}_3^{2-} = \frac{20.0}{1000} \times 1 = 0.02$$

$$\text{Moles Cu}^{2+} = 0.02 \quad A_r \text{ of Cu} = 63.5$$

$$\text{Moles} = \frac{g}{A_r}$$

$$\text{so Mass} = 0.02 \times 63.5 = 1.27\text{g}$$

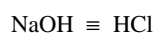
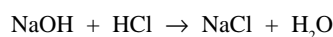
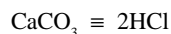
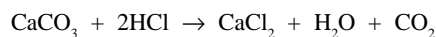
$$\text{Percentage purity} = \frac{1.27}{2.0} \times 100 = 63.5\%$$

## 6. Using a 'Back Titration' Method

0.80g of impure chalk was reacted with 100cm<sup>3</sup> of 1 mol dm<sup>-3</sup> hydrochloric acid (an excess). The mixture was filtered into a volumetric flask and made-up to 250cm<sup>3</sup>.

A 25.0cm<sup>3</sup> portion of the solution required 8.5cm<sup>3</sup> of 1 mol dm<sup>-3</sup> sodium hydroxide solution for neutralisation.

What is the percentage of calcium carbonate in the impure chalk?



$$\text{Moles NaOH in } 25.0\text{cm}^3 = \frac{8.50}{1000} \times 1 = 0.0085$$

$$\text{Moles HCl in } 25.0\text{cm}^3 = 0.0085$$

$$\text{Moles HCl in } 250\text{cm}^3 = 0.085 \text{ (the excess after the reaction)}$$

$$\text{Moles of HCl used initially} = \frac{100}{1000} \times 1 = 0.1$$

$$\text{Moles HCl used in the chalk} = 0.1 - 0.085 = 0.015$$

$$\text{Moles CaCO}_3 = \frac{0.015}{2} = 0.0075$$

$$M_r \text{ of CaCO}_3 = 40 + 12 + 48 = 100$$

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

$$\text{so } 0.0075 = \frac{g}{100}$$

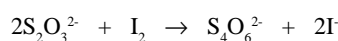
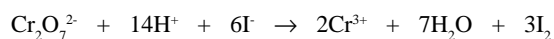
$$\text{so mass} = 0.75\text{g}$$

$$\text{Percentage} = \frac{0.75}{0.80} \times 100 = 93.75\%$$

## Practice Questions

1. In a titration with methyl orange as the indicator, 25.0 cm<sup>3</sup> of sodium hydroxide solution required 27.85 cm<sup>3</sup> of 0.0487 mol dm<sup>-3</sup> sulphuric acid to produce a colour change. Calculate the concentration of the sodium hydroxide solution.

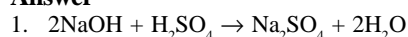
2. 25.0 cm<sup>3</sup> of potassium dichromate(VI) solution were acidified and treated with excess KI(aq). The liberated iodine was titrated with 24.4 cm<sup>3</sup> of 0.102 mol dm<sup>-3</sup> Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>(aq). Calculate the concentration of the K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>(aq).



3. 1.33 g of hydrated ethanedioic acid, H<sub>2</sub>C<sub>2</sub>O<sub>4</sub>·nH<sub>2</sub>O, were dissolved in distilled water and the solution made up to 250 cm<sup>3</sup> in a graduated flask. 25.0 cm<sup>3</sup> of this solution were titrated by 21.1 cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> NaOH(aq). How many molecules of water of crystallisation are there in the hydrated ethanedioic acid?  
A<sub>r</sub>: H = 1; C = 12; O = 16.

4. 0.414 g of an ammonium salt were boiled with 10.0 cm<sup>3</sup> of 1.04 dm<sup>-3</sup> aqueous sodium hydroxide until no more ammonia was evolved. Afterwards the solution was titrated with 0.101 dm<sup>-3</sup> hydrochloric acid, 26.25 cm<sup>3</sup> of which were needed to reach an end-point with methyl orange. Calculate the percentage of ammonia in the ammonium salt. A<sub>r</sub>: H = 1; N = 14.

## Answer

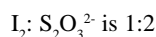
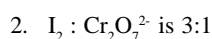


$$\text{NaOH: H}_2\text{SO}_4 \text{ is } 2:1$$

$$\text{Moles H}_2\text{SO}_4 = 0.02785 \times 0.0487$$

$$\text{Moles NaOH} = 2 \times 0.02785 \times 0.0487$$

$$\text{Concentration NaOH} = 2 \times 0.02785 \times \frac{0.0487}{0.025} = 0.109 \text{ mol dm}^{-3}$$

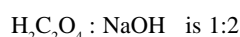
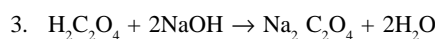


$$\text{So Cr}_2\text{O}_7^{2-} : \text{S}_2\text{O}_3^{2-} \text{ is } 1:6$$

$$\text{Moles S}_2\text{O}_3^{2-} \text{ used} = 0.0244 \times 0.102$$

$$\text{Moles of Cr}_2\text{O}_7^{2-} = 0.0244 \times \frac{0.102}{6}$$

$$\text{Concentration of Cr}_2\text{O}_7^{2-} = \frac{0.0244 \times 0.102}{6 \times 0.0250} = 0.0166 \text{ mol dm}^{-3}$$



$$\text{Moles NaOH} = 0.0211 \times 0.1$$

$$\text{Moles H}_2\text{C}_2\text{O}_4 = 0.0211 \times \frac{0.1}{2} \text{ in } 25\text{cm}^3$$

$$\text{Moles H}_2\text{C}_2\text{O}_4 = 0.0211 \times 0.1 \times \frac{10}{2} = 0.01055 \text{ in } 250\text{cm}^3$$

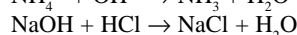
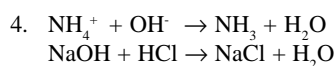
$$\text{So } 1.33\text{g of H}_2\text{C}_2\text{O}_4 \cdot n\text{H}_2\text{O} \text{ is } 0.01055 \text{ moles}$$

$$\text{So } M_r = \frac{1.33}{0.01055} = 126$$

$$\text{So } (2 \times 1) + (2 \times 12) + (4 \times 16) + 18n = 126$$

$$90 + 18n = 126$$

$$n = 2$$



$$\text{Moles HCl} = 0.101 \times 0.02625$$

$$\text{Moles NaOH reacting with HCl} = 0.101 \times 0.02625$$

$$\text{Moles NaOH originally added to ammonium salt} = 1.04 \times 0.01$$

$$\text{So moles NaOH reacting with ammonium salt} = (1.04 \times 0.01) - (0.101 \times 0.02625)$$

$$\text{So moles NH}_4^+ = (1.04 \times 0.01) - (0.101 \times 0.02625) = 0.00774875$$

$$\text{So mass NH}_3 = 0.00774875 \times 17$$

$$\text{So \% by mass of NH}_3 = 0.00774875 \times 17 \times 100 / 0.414 = 31.8\%$$

**Acknowledgements:** This Factsheet was researched and written by Sam Goodman. Curriculum Press, Bank House, 105 King Street, Wellington, Shropshire, TF1 1NU. ChemistryFactsheets may be copied free of charge by teaching staff or students, provided that their school is a registered subscriber. No part of these Factsheets may be reproduced, stored in a retrieval system, or transmitted, in any other form or by any other means, without the prior permission of the publisher. ISSN 1351-5136