Chem Factsheet

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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 $250cm^3$ so you can **always** calculate g dm^{-3}. If the M_r is known, you can calculate mol dm^{-3}.

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

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

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

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

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

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 **formula mass** (**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^{-3}, formed. Using: moles = $\frac{g}{M_r}$ the value of M_r is found.
3. Finding the **percentage purity** 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 **formula** of a compound	Exactly the same as (2) above, but the M_r value is used to find, for example, 'the x in $Na_2CO_3 \cdot xH_2O$'
5. Finding the **percentage mass** 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 **'back titration'** 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 rearrangment of formulae.*

Worked Examples

1. ***Finding Concentration***

0.95g of ethonedioic acid crystals, $H_2C_2O_4 . 2H_2O$, was dissolved in 250cm^3 of water. A 25.0cm^3 sample of solution required 33.0cm^3 of potassium manganate (VII) solution in a titration.

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

The equation is,

$$2MnO_4^- + 16H^+ + 5C_2O_4^{2-} \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$$

M_r of acid crystals $= 2 + 24 + 64 + 36 = 126$

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

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

$2\ MnO_4^- \equiv 5C_2O_4^{2-}$

Moles $MnO_4^- = 0.000754 \times \frac{2}{5} = 0.000302$

Moles $= \frac{Vcm^3}{1000} \times M$

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

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

2. ***Finding a formula mass***

5.2g of compound X was dissolved in 250cm^3 of water. A 25.0cm^3 portion of the solution required 20.0cm^3 of a 0.20 mol dm^{-3} of potassium dichromate (VI) solution in a titration. The reacting ratio is: $5 \equiv 1Cr_2O_7^{2-}$

What is the formula mass, M_r, of X ?

Moles $Cr_2O_7^{2-} = \frac{20.0}{1000} \times 0.20 = 0.004$

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

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

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

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

3. ***Finding Percentage Purity***

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

The equation is:

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

What is the percentage purity of the iron wire?

Moles $Cr_2O_7^{2-} = \frac{42.5}{1000} \times 0.04 = 0.0017$

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

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

so mass $= 0.0102 \times 56 = 0.5712g$

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

4. ***Finding the Formula of a Compound***

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

What is x in $Na_2CO_3 . x\ H_2O$?

$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$

$1Na_2CO_3 \equiv 2HCl$

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

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

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

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

so Mr $= \frac{13.91}{0.0488} = 285.04$

$Na_2CO_3 \cdot xH_2O = 46 + 12 + 48 + 18x$

$= 106 + 18x$

$285.04 = 106 + 18x$

so $18x = 285.04 - 106 = 179.04$

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

i.e. $Na_2CO_3 \cdot 10H_2O$

5. ***Finding Percentage Mass***

Brass is a mixture of copper and zinc. It dissolves in nitric acid to form Cu^{2+} and Zn^{2+} ions. The 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.

$$2\ Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$$

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

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

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

$2Cu^{2+} \equiv I_2$

$2S_2O_3^{2-} \equiv I_2$

so $Cu^{2+} \equiv S_2O_3^{2-}$

Moles $S_2O_3^{2-} = \frac{20.0}{1000} \times 1 = 0.02$

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

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

so Mass $= 0.02 \times 63.5 = 1.27g$

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

6. Using a 'Back Titration' Method

0.80g of impure chalk was reacted with 100cm³ of 1 mol dm⁻³ hydrochloric acid (an excess). The mixture was filtered into a volumetric flask and made-up to 250cm³.

A 25.0cm³ portion of the solution required 8.5cm³ of 1 mol dm⁻³ sodium hydroxide solution for neutralisation.

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

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

$CaCO_3 \equiv 2HCl$

$NaOH + HCl \rightarrow NaCl + H_2O$

$NaOH \equiv HCl$

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

Moles HCl in $25.0cm^3 = 0.0086$

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

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

Moles HCl used in the chalk $= 0.1 - 0.085 = 0.015$

Moles $CaCO_3 = \frac{0.015}{2} = 0.0075$

M_r of $CaCO_3 = 40 + 12 + 48 = 100$

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

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

so mass $= 0.75g$

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

Practice Questions

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

2. 25.0 cm^3 of potassium dichromate(VI) solution were acidified and treated with excess KI(aq). The liberated iodine was titrated with 24.4 cm^3 of 0.102 mol dm^{-3} $Na_2S_2O_3$(aq). Calculate the concentration of the $K_2Cr_2O_7$(aq).

   $Cr_2O_7^{2-} + 14H^+ + 6I^- \rightarrow 2Cr^{3+} + 7H_2O + 3I_2$

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

3. 1.33 g of hydrated ethanedioic acid, $H_2C_2O_4.nH_2O$, were dissolved in distilled water and the solution made up to 250 cm^3 in a graduated flask. 25.0 cm^3 of this solution were titrated by 21.1 cm^3 of 0.100 mol dm^{-3} NaOH(aq). How many molecules of water of crystallisation are there in the hydrated ethanedioic acid?
   A_r: H = 1; C = 12; O = 16.

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

Answer

1. $2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$

   NaOH: H_2SO_4 is 2:1

   Moles $H_2SO_4 = 0.02785 \times 0.0487$

   Moles NaOH $= 2 \times 0.02785 \times 0.0487$

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

2. $I_2 : Cr_2O_7^{2-}$ is 3:1

   $I_2 : S_2O_3^{2-}$ is 1:2

   So $Cr_2O_7^{2-} : S_2O_3^{2-}$ is 1: 6

   Moles $S_2O_3^{2-}$ used $= 0.0244 \times 0.102$

   Moles of $Cr_2O_7^{2-} = 0.0244 \times \frac{0.102}{6}$

   Concentration of $Cr_2O_7^{2-} = \frac{0.0244 \times 0.102}{6 \times 0.0250}$
   $= 0.0166$ mol dm^{-3}

3. $H_2C_2O_4 + 2NaOH \rightarrow Na_2C_2O_4 + 2H_2O$

   $H_2C_2O_4$: NaOH is 1:2

   Moles NaOH $= 0.0211 \times 0.1$

   Moles $H_2C_2O_4 = 0.0211 \times \frac{0.1}{2}$ in $25cm^3$

   Moles $H_2C_2O_4 = 0.0211 \times 0.1 \times \frac{10}{2} = 0.01055$ in $250cm^3$

   So 1.33g of $H_2C_2O_4.nH_2O$ is 0.01055 moles

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

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

   $90 + 18n = 126$

   $n = 2$

4. $NH_4^+ + OH^- \rightarrow NH_3 + H_2O$
   $NaOH + HCl \rightarrow NaCl + H_2O$

   Moles HCl $= 0.101 \times 0.02625$
   Moles NaOH reacting with HCl $= 0.101 \times 0.02625$

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

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

   So moles $NH_4^+ = (1.04 \times 0.01) - (0.101 \times 0.02625) = 0.00774875$

   So mass $NH_3 = 0.00774875 \times 17$

   So % by mass of $NH_3 = 0.00774875 \times 17 \times 100/0.414$
   $= 31.8\%$

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