Chem Factsheet

www.curriculumpress.co.uk Number 57

Answering Questions on Redox Titrations I

To succeed with this topic you need to:
- Know and understand how to do AS titration calculations (Factsheets No. 7 ('Moles and Volumetric Analysis') and No. 23 ('How to Answer Questions on Titration Calculations'))
  Understand the whole concept of Redox Equilibria (Factsheet No.37, No.45, and No.50).
- Understand the basics of redox titrations (Factsheet No.51)

After working through this Factsheet you will have
- met more examples of redox titrations
- seen the 'method' being used on a range of examples

You may be given a problem that looks very different from ones you have seen before. The way to deal with it is to remember the following method:

(1) Write the **EQUATION** for the titration reaction (you may need to combine half equations using numbers of e^- to write the full equation).

(2) Write down the **REACTING RATIO** from the balanced equation.

(3) Identify which of the reactants you can find the **NUMBER OF MOLES** of using

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

(4) Combine answers from (2) + (3) to find the **NUMBER OF MOLES OF THE OTHER REACTANT.**

(5) Look at the question – **WHAT DO YOU NEED TO FIND?** This will dictate which equation to use next i.e.

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

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

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

Summary - you could remember the 5 stages as
EQ → RR → Moles → 'other moles' → Q → A
(1) (2) (3) (4) (5) (6)

***Exam Hint** - there are some equations e.g. iodine/sodium thiosulphate and some half equations e.g. MnO_4^- reduced to Mn^{2+} that **YOU NEED TO LEARN!** In this Factsheet you will be given them – you may not be given them in A2 examination papers!*

In the following examples the questions are underlined at key places so the method can be explained e.g. U2 = the second underlined section. Underlining key points is often helpful in examination questions – and not just for the topic we are dealing with now - as it helps you focus your attention on the key facts and figures.

Before you start – remember this topic requires problem solving - so the method is a way of thinking, not just a recipe sheet. It's worth taking your time to make sure you really are happy with what is going on.

Example 1
Ammonium iron(II) sulphate crystals have the formula:
$(NH_4)_2Fe(SO_4)_2 \cdot x\ H_2O$. (U1)

In an experiment to find the value of x, 4.25 g (U2) of crystals were dissolved in water and dilute sulphuric acid and made up to 250 cm^3. (U3)
A 25.0 cm^3 (U4) portion of the solution was titrated against 0.015 mol dm^{-3} (U5) potassium manganate(VII) solution of which 11.3 cm^3 (U6) was needed.

The equation is: $MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$
Only the iron(II) from the crystals react with potassium manganate (VII).

What is the value for x?

Method	**Answer**
(1) + (2) I've been given the EQUATION so I need the REACTING RATIO from it.	$1\ MnO_4^- \equiv 5\ Fe^{2+}$
(3) What can I find the 'moles of ? U5 and U6 will work for MnO_4^- in Moles $= \frac{cm^3}{1000} \times M$	moles of $MnO_4^- = \frac{11.3}{1000} \times 0.015 = 1.695 \times 10^{-4}$
(4) If I combine answers (2) + (3) I can work out the moles of Fe^{2+} in 25.0cm^3 (U4)	Moles $Fe^{2+} = 1.695 \times 10^{-4} \times 5 = 8.475 \times 10^{-4}$
(5) The question is about x. What have moles of Fe^{2+} got to do with it? I have to look at the crystal (U1) formula. It seems that there is one Fe^{2+} in the formula – so number of moles of crystals is no. of moles of Fe^{2+}. Must use the 250cm^3 (U3) so I will scale up by 10.	Moles 'crystal' $= 8.475 \times 10^{-4}$ in 25.0cm^3 Moles in 250cm^3 $= 8.475 \times 10^{-4} \times 10 = 8.475 \times 10^{-3}$
(6) Where now? I have used all the data except the 4.25g (U2) in 250cm^3. To find x I need the M_r value – I can add up all the other parts and find x!	Moles $= \frac{g}{M_r}$ $M_r = \frac{g}{\text{moles}}$ $M_r = \frac{4.25}{8.475 \times 10^{-3}} = 501.5$

CHECK Seems o.k. – I've gone back over and checked the 'number work'. Double checked (4) – it is ×5 not divide by 5 (common error)

$(NH_4)_2Fe(SO_4)_2 = 284$
$H_2O = 18$
so $284 + 18x = 501.5$
$x = \frac{501.5 - 284}{18} = 12.08$
$x = 12.08$ $x = 12$
(must be a whole number in a formula)

Example 2 (U1)

2.05g of potassium dichromate (VI), $K_2Cr_2O_7$, is dissolved in water and made up to 250cm³. (U2)

(U3) 25.0 cm³ of this solution is mixed with an excess of acidified potassium iodide solution and iodine is formed by the reaction,

$$Cr_2O_7^{2-} + 6I^- + 14H^+ \rightarrow 2Cr^{3+} + 3I_2 + 7H_2O \qquad \text{equation [1]}$$

The iodine produced is titrated with sodium thiosulphate solution and 21.5cm³ is needed. (U4)

$$2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2I^- \qquad \text{equation [2]}$$

What is the concentration of the sodium thiosulphate solution? (U5)

Before we start on the example, think about this– on the face of it the 'method' seems not easy to use e.g. two equations involved, and there are no 'mol dm³' given so what calculation equation can we use?

It's important to take the time to work through the "thinking process" explained in the method, to help you deal with this type of demanding question in the exam

Method	Answer
(1) + (2) I should be looking at the equation first but there are two! However, I_2 is in both so I have nothing to lose by putting both reacting ratios down – I may need them.	$Cr\ O_7^{2-} \rightarrow 3I_2$ $2\ S_2O_3^{2-} \equiv 1I_2$
(3) Where are the 'moles'? There are no 'mol dm⁻³ so how can I use any of my calculation equations?	$M_r(K_2Cr_2O_7) = 294$
Let's go for moles from grams (U1)	$\text{Moles} = \frac{\text{grams}}{M_r} = \frac{2.05}{294} = 6.97 \times 10^{-3}$
This is in 250cm³ so I must go the 25cm³ for the moles I need to use later. (U2)	$\text{Moles } Cr_2O_7^{2-} = \frac{6.97 \times 10^{-3}}{10} = 6.97 \times 10^{-4}$
(4) I need to combine (2) + (3) to find the 'other moles'. I have a problem here – what 'other moles'? All the information seems to ignore 'I_2' – why? Let's revisit (1) + (2) – I need to sort out 'reacting ratios' – I need only one of them. 'I_2' seems to be a bridge between $Cr_2O_7^{2-}$ and $S_2I_3^{2-}$ so let's go that way for 'reacting ratios'	If $2S_2O_3^{2-} \equiv 1I_2$ then $3I_2 \equiv 6S_2O_3^{2-}$ so $6S_2O_3^{2-} \equiv 1Cr_2O_7^{2-}$ (6:1)
I can use the answer from (3) to get the 'other moles' of $S_2O_3^{2-}$	$S_2O_3^{2-} = 6.97 \times 10^{-3} \times 6$ $= 4.182 \times 10^{-3}$
(5) What does the question want? (U4) 'Concentration' of $S_2O_3^{2-}$ - so I need the equation involving M.	$\text{Moles} = \frac{\text{cm}^3}{1000} \times M$
What do I know about $S_2O_3^{2-}$ so far? I have moles (4.182×10^{-3}) **and** a volume (21.50 cm³) so from my calculation equations I only have one with these in i.e. $\text{moles} = \frac{\text{volume(cm}^3) \times \text{M(mol dm}^{-3})}{1000}$	$4.182 \times 10^{-3} = \frac{21.50}{1000} \times M$ $\text{so } M = \frac{4.182 \times 10^{-3} \times 1000}{21.5}$ $= 0.195 \text{ mol dm}^{-3}$
(6) IS THIS THE ANSWER? It seems O.K. – I have followed the 'method' and I have checked the mathematics using the calculator. HOWEVER – have I checked the 6:1 ratio which is the commonest error – should I divide or multiply? Seems O.K.	ANSWER - 0.195 mol dm⁻³

***Exam Hint** - it is quite common to need to use a "bridging" substance, as in the example above. The bridging substance will be a **product** in the first reaction that takes place and a **reactant** in the second reaction.*

Although you can work with one equation at a time, and actually work out the moles of the bridging substance, this is not a very efficient way of doing the calculation - it will waste time in the exam - and it may lead to rounding errors due to re-entering rounded data.

Practice Questions

1. 2.50g of iodine was dissolved in potassium iodide solution and made up to 250 cm^3 with water.

   25.0 cm^3 of the iodine solution was titrated against sodium thiosulphate solution of which 22.0 cm^3 was required.

   The equation is: $2S_2O_3^{2-} + I_2 \rightarrow 2I^- + S_4O_6^{2-}$

   What is the concentration of the sodium thiosulphate solution?
   (A_r of I = 127)

2. 1.1g of potassium dichromate (VI) was dissolved in water and made up to 250cm^3. A 25.0cm^3 portion of this solution was added to an excess of potassium iodide solution and dilute sulphuric acid, and the iodine released was titrated with sodium thiosulphate solution, of which 22.0cm^3 was needed.

   The equations involved are:

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

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

   What is the concentration of the thiosulphate solution?
   (M_r of $K_2Cr_2O_7$ = 294)

3. 6.74g of an unknown iron (II) salt was dissolved in a mixture of water and dilute sulphuric acid and made up to 250cm^3. 25.0cm^3 of this solution was titrated against 0.04 mol dm^{-3} potassium dichromate (VI) solution and 23.60cm^3 was needed.

   The equations are:

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

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

   Calculate the percentage by mass of iron in the unknown iron (II) salt.
   (A_r of Fe = 56)

Answers

1. $2S_2O_3^{2-} \equiv I_2$

   M_r of $I_2 = 2 \times 127 = 254$

   Moles of I_2 in 250cm^3 $= \frac{2.50}{254} = 0.00984$

   Moles I_2 in 25.0cm^3 $= \frac{0.00984}{10} \equiv 0.000984$

   Moles $Na_2S_2O_3 = 0.000984 \times 2$
   $= 0.00197$

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

   so $0.00197 = \frac{22.0}{1000} \times M$

   so $M = \frac{0.00197 \times 100}{22.0} = \underline{0.0895}$ mol dm^{-3}

2. $Cr_2O_7^{2-} \equiv 3I_2$

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

   so $Cr_2O_3^{2-} \equiv 6S_2O_3^{2-}$

   Moles $K_2Cr_2O_7$ in 250cm^3 $= \frac{1.1}{294} = 0.00374$

   Moles $K_2Cr_2O_7$ in 25.0cm^3 $= \frac{0.00374}{10} = 0.000374$

   Moles $S_2O_3^{2-} = 0.000374 \times 6$
   $= 0.00224$

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

   $0.00224 = \frac{22.0}{1000} \times M$

   so $M = \frac{0.00224 \times 1000}{22.0} = \underline{0.102}$ mol dm^{-3}

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

   $6Fe^{2+} \equiv 1\ Cr_2O_7^{2-}$

   Moles $Cr_2O_7^{2-}$ in 25.0cm^3 $= \frac{23.60}{1000} \times 0.04$
   $= 0.000944$

   Moles $Cr_2O_7^{2-}$ in 250cm^3 = 0.00944

   Moles Fe^{2+} in 250cm^3 = $0.00944 \times 6 = 0.05664$

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

   $0.05644 = \frac{g}{56}$

   mass Fe $= 0.05664 \times 56 = 3.172$g

   % iron $= \frac{3.172}{6.74} \times 100 = \underline{47.06}$ %

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***