Chem Factsheet

January 2001 Number 07

Moles and Volumetric Analysis

To succeed with this topic, you need to be able to:
- Do basic moles and formulae calculations (see Factsheet No. 2 - Moles and Formulae)
- Use equations to calculate reacting amounts (see Factsheet No 3 - Moles and Equations).

After working through this Factsheet, you will understand:
- How moles are related to the term 'concentration' for solutions.
- The use of equations in calculating reacting volumes of solutions.
- The concept of 'percentage purity' when used in volumetric analysis (.i.e. titration)

> ***Exam Hint:*** *Many candidates find volumetric analysis calculations frightening, and complain of not knowing where to start on the problems. To avoid being in this situation, you need to:*
> - *ensure you learn the equation linking moles, volume and concentration, and can rearrange it as necessary.*
> - *practise examples frequently, so you do not forget how to do it, working carefully through each step in the method.*

Chemicals in solution
The amount of a chemical in a certain volume of solvent is called its **concentration**.

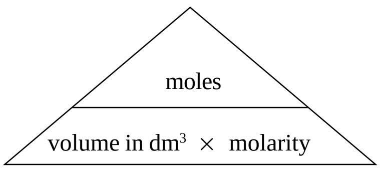
> *The concentration of a solution is the number of moles of the substance in 1 litre (= 1 dm^3 or 1000 cm^3).*
> ***Concentration in mol dm^{-3} is also called molarity.***
> *It is measured in mol dm^{-3}, which can also be written as M.*
> *For example, 2 moles in 1000cm^3 is a concentration of 2mol dm^{-3} or 2M*

Calculations on Concentrations
The equation used is:-

> moles = volume in dm^3 × molarity

NB. The volume **must be in dm^3.** If you are given a volume in cm^3, **divide by 1000 to change it to dm^3. before you start!**

As with many other equations in Chemistry, a "triangle" may help with rearranging this equation (see box).

> **Triangle for concentration formula**
>
> 
>
>
> Cover up the thing in the triangle you want to find. Then, what you can see tells you the calculation to do. For example, if you want to find molarity, cover it up and you are left with moles/ volume

This equation can be used to find the moles, volume or molarity (M) as shown below.

eg 1. How many moles of NaOH are there in 250cm^3 of a 0.1M solution?

First change the volume to dm^3: 250cm^3 = 0.25dm^3
Now use the formula: moles = volume in dm^3 × molarity
= 0.25× 0.1
= 0.025 moles

eg 2. What is the concentration in mol dm^{-3} of 0.5 moles of sodium chloride dissolved in 2 dm^3 ?

The volume is already in dm^3.
Formula: molarity = moles÷ volume
= 0.5÷ 2
= 0.25 mol dm^{-3}

eg 3. What volume of water should 1.5 moles NaCl be dissolved in to produce a 0.5M solution?

Formula: volume = moles ÷ molarity
= 1.5 ÷ 0.5
= 3 dm^3

Questions involving Mass
Questions will often require you to find or use masses in molarity calculations. The rule is simple:
- If you are **given** a mass, change it to moles at the start, using moles = mass ÷ M_r
- If you have to **find** a mass, find moles first, then change to mass, using mass = moles × M_r

eg 1. What mass of NaOH is present in 50cm^3 of a 2M solution?
(A_r values Na: 23 O:16 H:1)

We are asked to find a mass, so we first aim to find moles of NaOH.
We change the volume to dm^3: 50cm^3 = 0.05dm^3
Now use moles = volume × molarity
= 0.05 × 2 = 0.1 moles
Now we find mass:
M_r = 23 + 16 + 1 = 40.
mass = moles × M_r
= 0.1 × 40 = 4 g.

eg 2. What is the concentration in mol dm^{-3} of 49 g H_2SO_4 dissolved in 50 cm^3? (A_r values S:32 O:16 H:1)

We are given a mass, so we change it into moles first:
M_r = 2 + 32 + 64 = 98.
moles = mass ÷ M_r
= 49 ÷ 98 = 0.5
Change the volume to dm^3: 50cm^3 = 0.05dm^3
Now use molarity = moles ÷ volume
= 0.5÷ 0.05 = 10M

eg 3. What volume of water must 5.85g NaCl be dissolved in to produce a 0.2M solution? (A_r values Na:23 Cl:35.5)

We are given a mass, so we change it into moles first:
M_r = 23 + 35.5 = 58.5
moles = mass ÷ M_r
= 5.85 ÷ 58.5 = 0.1
Now use volume = moles ÷ molarity
= 0.1÷ 0.2 = 0.5 dm^3

All the work from now on depends on you being competent at these types of calculation! You should stop now and attempt questions 1-6 at the end of the Factsheet before carrying on - until you can answer them all with no errors, there is no point in attempting the harder work.

Volumetric Analysis Calculations (Titration Calculations)

In this section we will cover the type of volumetric calculations needed for AS level, and we begin with the method that you need to learn and use. However, before you start, make sure you are happy with the work in Factsheet 3 - Moles and Equations.

Step 1. Write the **balanced** equation for the reaction.(If you are not given it in the question).

Step 2. From the equation, find the mole ratio for the substances involved in the question.

Step 3. Convert any masses you are given into moles, and any volumes into dm^3

Step 4. Study the information in the question, and find the substance for which you are given **two pieces of information** (eg the volume and the concentration)

Step 5. For the substance in step 4, find its number of moles.

Step 6. Use the mole ratio (step 2) to work out the moles of the substance you are asked about.

Step 7. Go back to the question - **what have you got to find?** Use the information in step 6, together with the right equation, to find the mass or molarity or volume.

Worked examples using this method

The following three examples show you the method

eg 1. 25cm^3 of 0.1M NaOH reacts with 25cm^3 of H_2SO_4. What is the molarity of the acid?

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

Step 2. $NaOH:H_2SO_4$ is 2:1

Step 3. no masses involved.
25cm^3 is 0.025 dm^3

Step 4. We're given volume and molarity for NaOH

Step 5. moles of NaOH= molarity × volume in dm^3
= 0.1 × 0.025 = 0.0025 moles

Step 6. moles of H_2SO_4 = moles of NaOH ÷ 2 = 0.00125

Step 7. We need molarity.
Use molarity = moles ÷ volume in dm^3
= 0.00125 ÷ 0.025 = 0.05M

eg 2. What volume of 0.02M $KMnO_4$ solution is needed to react with 50cm^3 of 0.2M Fe^{2+}? The equation for the reaction is:
$MnO_4^-(aq) + 5Fe^{2+}(aq) + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 5Fe^{3+}(aq) + 4H_2O(l)$

Step 1. equation given

Step 2. MnO_4^- : Fe^{2+} is 1:5

Step 3. no masses involved.
50cm^3 is 0.05 dm^3

Step 4. We're given both volume and molarity for Fe^{2+}

Step 5. moles of Fe^{2+} = molarity × volume in dm^3
= 0.2 × 0.05 = 0.01 moles

Step 6. moles of MnO_4^- = moles of Fe^{2+} ÷ 5 = 0.002 moles

Step 7. We need volume.
Use volume = moles ÷ molarity
= 0.002 ÷ 0.02 = 0.1 dm^3

Tip: If in step 6 of the above examples you would have been unsure whether to multiply or divide, remember: the substance with the larger number in front of it in the equation has the higher number of moles.

eg 3. What is the concentration of a hydrochloric acid solution if 50cm^3 if it reacts exactly with 10g of calcium carbonate?
(A_r values Ca:40 O:16 C:12)

Step 1. $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$

Step 2. $CaCO_3$: HCl is 1:2

Step 3. M_r for $CaCO_3$ is 40 + 12 + 48 = 100
moles of $CaCO_3$ = mass ÷ M_r
= 10 ÷ 100 = 0.1 moles
50cm^3 is 0.05 dm^3

Step 4,5 not applicable

Step 6. moles of HCl = moles of $CaCO_3$ × 2 = 0.2 moles

Step 7. We need molarity.
Use molarity = moles ÷ volume in dm^3
= 0.2 ÷ 0.05 = 4M

Exam Hint: *From these worked examples you will have seen how crucial the 'reacting ratio' is to obtaining the correct final answer.* ***However -*** *In the examination if you write an incorrect equation, so getting an incorrect ratio, you will* ***only lose 1 mark*** *if the rest of your steps are correct.* ***This is why it is vitally important that you show every step in your calculation!***

Equations

You are expected to know how to write equations for the following:

acid + alkali → a salt + water
acid + base → a salt + water
NB: alkalis and bases are metal oxides or hydroxides and ammonia

acid + carbonate → a salt + water + carbon dioxide
acid + metal → a salt + hydrogen

Other reaction equations will probably be given in the question.

Before you go on to the next section, you need to make sure you can use the basic method confidently and accurately. You should do question 7 at the end of the Factsheet before carrying on!

Percentage Purity

At AS Level the questions relate to solids which are 'impure'. This means the chemical is present and reacts but some of the solid is not the chemical so does not react.

The object of the calculation is to find the amount of pure chemical, which is put into the equation.

$$\text{percentage purity} = \frac{\text{mass of pure chemical (g)}}{\text{mass of starting material}} \times 100$$

The 'method' is slightly different and you should refer to the original method above as you look at each step.

Percentage Purity Method

Step 1. Write the **balanced** equation for the reaction. (If you are not given it in the question).

Step 2. From the equation, find the mole ratio for the substances involved in the question.

Step 3. Convert any volumes you are given into dm^3

Step 4. Find the substance for which you are given volume & molarity

Step 5. For the substance in step 4, find its number of moles.

Step 6. Use the mole ratio to work out the moles of **pure chemical**

Step 7. Turn step 6 moles into mass

Step 8. Use step 7 answer and the impure mass from the question to find percentage purity, using the equation above.

Now let's see how this works on a question:

eg. 2.00g of impure NaOH is titrated with 0.5M HCl, and $50cm^3$ of the acid is used up in neutralising the sodium hydroxide.
What is the percentage purity of the original sodium hydroxide sample?
(A_r values Na: 23 O:16 H:1)

Step 1. $HCl + NaOH \rightarrow NaCl + H_2O$

Step 2. HCl : NaOH is 1:1

Step 3. $50cm^3$ is $0.05 dm^3$

Step 4. We're given both for HCl

Step 5. moles of HCl = molarity × volume in dm^3
= 0.5 × 0.05 = 0.025 moles

Step 6. moles of pure NaOH = 0.025

Step 7. M_r for NaOH = 23 + 16 + 1 = 40
So mass of NaOH = moles × M_r
= 0.025 × 40 = 1g

Step 8. % purity = $\frac{1}{2} \times 100 = 50\%$

Question 8 will give you some practice at percentage purity calculations.

Practice Questions

1. Calculate the number of moles present in each of the following:-
a) $500cm^3$ of 2M NaOH b) $25cm^3$ of 1M H_2SO_4
c) $100cm^3$ of 0.5M KOH d) $2dm^3$ of 0.25M HCl
e) $30cm^3$ of 0.3M KOH f) $200cm^3$ of 0.1M HNO_3

2. Calculate the concentration of each of the following:-
a) 2 moles in 2 dm^3 b) 0.2 moles in 1 dm^3
c) 0.1 mole in $100cm^3$ d) 1 mole in $10cm^3$
e) 0.25 moles in $250cm^3$ f) 5 moles in 2 dm^3

3. What volume of liquid would be needed to produce the required concentration in each case?
a) 2 moles to make 1 mol dm^{-3} b) 0.1 moles to make 1 mol dm^{-3}
c) 5 moles to make 0.5 mol dm^{-3} d) 0.2 moles to make 2 mol dm^{-3}

4. Calculate the mass present in each of the following:-
a) $500cm^3$ of NaOH b) $1.5dm^3$ of 2M KOH
c) $100cm^3$ of 1M H_2SO_4 d) $250cm^3$ of 0.1M HNO_3

5. What is the concentration of each of the following?
a) 3.65g HCl in $500cm^3$ b) 4.0g NaOH in $100cm^3$
c) 63g HNO_3 in $250cm^3$ d) 0.98g H_2SO_4 in $10cm^3$

6. What volume of liquid must each of the following masses be dissolved in to produce the required concentration?
a) 4g NaOH to make 1M b) 0.56g KOH to make 0.1M
c) 49g H_2SO_4 to make 0.05M d) 5.85g NaCl to make 0.2M

7. a) $25cm^3$ of 0.2M NaOH reacts with $50cm^3$ of HCl.
What is the molarity of the acid?
b) $50cm^3$ of 1M H_2SO_4 reacts with $50cm^3$ of KOH solution
What is the molarity of the KOH solution?
c) $20cm^3$ of 2M HNO_3 reacts with $10cm^3$ of NaOH solution
What is the concentration of the NaOH solution?
d) $100cm^3$ of 0.1M HCl reacts with $50cm^3$ of $Ca(OH)_2$ solution.
What is the molarity of the $Ca(OH)_2$ solution?
e) $30cm^3$ of 0.01M $AgNO_3$ solution reacts with $10cm^3$ of $AlCl_3$ solution.
$3AgNO_3 + AlCl_3 \rightarrow 3AgCl + Al(NO_3)_2$
What is the molarity of the $AlCl_3$ solution?
f) The reaction between NaOH and H_3PO_4 is:
$NaOH + H_3PO_4 \rightarrow NaH_2PO_4 + H_2O$
What volume of 0.4M H_3PO_4 will react with $100cm^3$ of 0.1M NaOH solution?
g) Barium chloride reacts with sulphuric acid according to the following equation: $BaCl_2 + H_2SO_4 \rightarrow BaSO_4 + 2HCl$
What volume of 0.02M $BaCl_2$ solution will react with $40cm^3$ of 0.05M H_2SO_4 ?
h) What volume of 0.02M $KMnO_4$ solution will react with $20cm^3$ of 0.1M Fe^{2+}(aq)? The reaction is:-
$MnO_4^-(aq) + 5Fe^{2+}(aq) + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 5Fe^{3+}(aq) + 4H_2O(l)$

8. a) 2.50g of impure NaOH reacts with $25cm^3$ of 2M HNO_3
What is the percentage purity of the NaOH?
b) 2.50g of impure iron reacts with $40cm^3$ of 1M H_2SO_4 according to the equation: $Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$
What is the percentage purity of the iron?
c) $50cm^3$ of 0.1M HCl reacts with 1.00g of impure calcium carbonate, $CaCO_3$. What is the percentage purity of the calcium carbonate?

Answers

1. a) 1 b) 0.025 c) 0.05 d) 0.5 e) 0.009 f) 0.05
2. a) 1 b) 0.2 c) 1 d) 100 e) 1 f) 2.5
3. a) $2000cm^3$ b) $100cm^3$ c) $10,000cm^3$ d) $100cm^3$
4. a) 20g b) 168g c) 9.8g d) 1.57g
5. a) 0.2M b) 1M c) 4M d) 1M
6. a) $100cm^3$ b) $100cm^3$ c) $10,000cm^3$ d) $500cm^3$
7. a) 0.1M b) 2M c) 4M d) 0.1M e) 0.01M f) $25cm^3$ g) $25cm^3$ h) $20cm^3$
8. a) 80% b) 89% c) 50%

Acknowledgements;
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