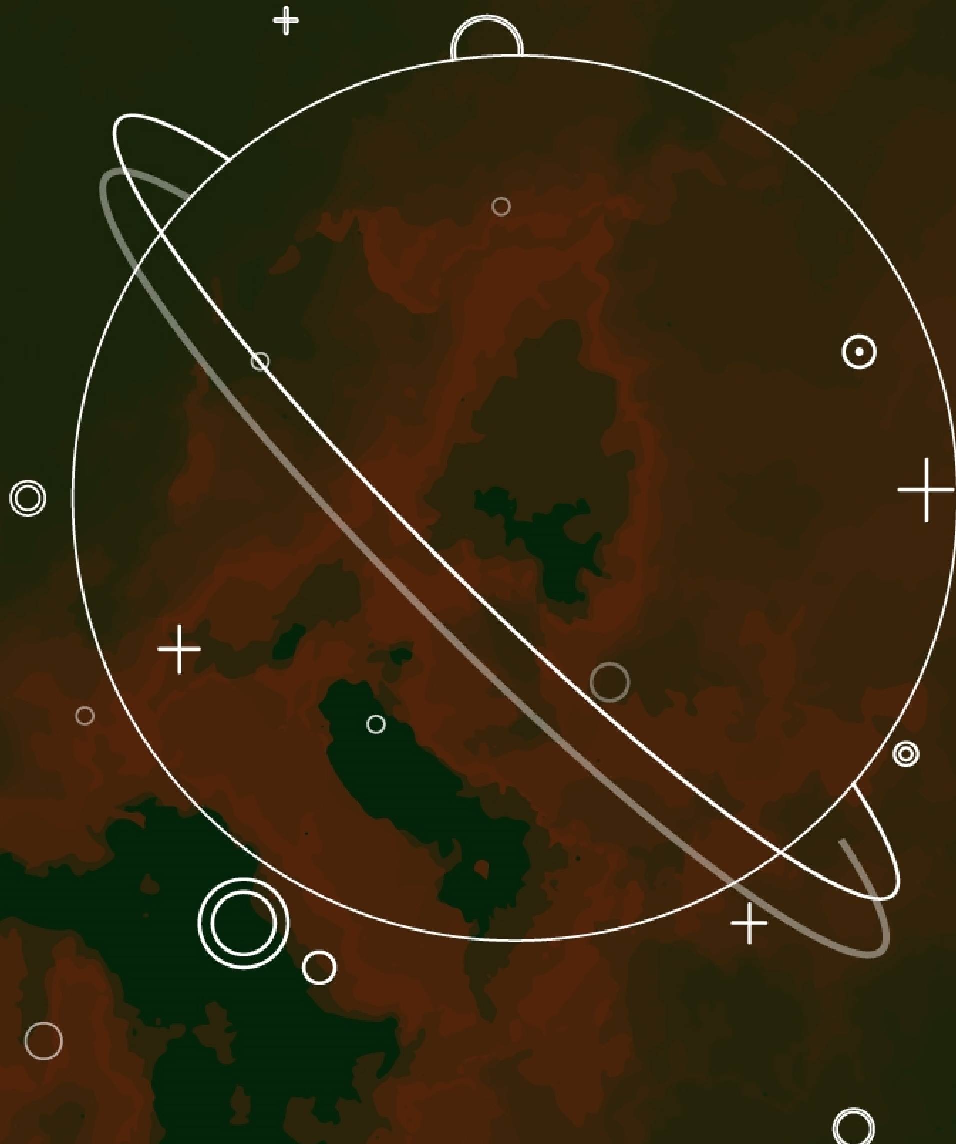

CHAPTER 8

Quantitative Aspects Of Chemical Change

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1 INTRODUCTION

Wherever we look in real life we see the importance of mixing things in precise quantities. Cooking and baking, the medicines you take when sick, the products that you buy, all of these rely on the ingredients being mixed in specific amounts. And even the amount of product formed relies on how much of each ingredient is used. In this chapter we will look at some of these quantities and how they can be calculated.

In grade 10 we learnt about writing chemical equations and about the information that can be obtained from a balanced chemical equation. In this chapter we are going to explore these concepts further and learn more about gases, solutions and reactions. We will explore the concept of theoretical yield in greater detail and learn about limiting reagents.

KEY CONCEPTS

- Ratio and proportion - Physical Sciences, Grade 10, Science skills
- Equations - Mathematics, Grade 10, Equations and inequalities
- Units and unit conversions - Physical Sciences, Grade 10, Science skills

2 GASES AND SOLUTIONS

We will begin by taking a closer look at gases and solutions and work out how to solve problems relating to them.

2.1 Molar volumes of gases

TIP

STP is a temperature of $273\ K$ and a pressure of $101,3\ kPa$. The amount of gas is usually $1\ mol$.

We write down all the values that we know about one mole of gas at STP:

$$p = 101,3\ kPa = 101\ 300\ Pa$$

$$Pa = 1\ mol$$

$$R = 8,31\ J \cdot K^{-1} \cdot mol^{-1}$$

$$T = 273\ K$$

Now we can substitute these values into the ideal gas equation:

$$pV = nRT$$

$$V(101300) = (1)(8,31)(273)$$

$$V(101300) = 2265,9$$

$$= 0,0224m^3$$

$$= 22,4dm^3$$

The volume of 1 mole of gas at STP is $22,4dm^3$.
And if we had any number of moles of gas, not just one mole then we would get:

$$V_g = 22,4n_g$$

TIP

The standard units used for this equation are p in Pa, V in m^3 and T in K. Remember also that $1000\ cm^3 = 1\ dm^3$ and $1000\ dm^3 = 1\ m^3$.

WORKED EXAMPLE 1: MOLAR GAS VOLUME

QUESTION What is the volume of $2,3$ mol of hydrogen gas at STP?

SOLUTION **Step 1: Find the volume**

$$V_g = (22,4)n_g$$

$$= (22,4)(2,3)$$

$$= 51,52\ dm^3$$

2.2 Reactions and gases

Some reactions take place between gases. For these reactions we can work out the volumes of the gases using the fact that volume is proportional to the number of moles.
We can use the following formula:

$$V_A = \frac{a}{b} V_B$$

where:

$$V_A = \text{volume of } A$$
$$V_B = \text{volume of } B$$
$$a = \text{stoichiometric coefficient of } A$$
$$b = \text{stoichiometric coefficient of } B$$

TIP

The number in front of a reactant or a product in a balanced chemical equation is called the stoichiometric coefficient or stoichiometric ratio.

WORKED EXAMPLE 2: VOLUME AND GASES

QUESTION

Hydrogen and oxygen react to form water according to the following equation:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

If $3\ dm^3$ of oxygen is used, what volume of water is produced?

SOLUTION

Step 1: Determine the volume of water produced in the reaction.

We use the equation given above to work out the volume of water needed:

$$V_A = \frac{a}{b} V_B$$
$$V_{H_2O} = \frac{2}{1} V_{O_2}$$
$$= 2(3)$$
$$= 6\ dm^3$$

We can interpret the chemical equation in the worked example above $(2H_2(g) + O_2(g) \rightarrow 2H_2O(g))$ as:

2 moles of hydrogen react with 1 mole of oxygen to produce 2 moles of water. We can also say that 2 volumes of hydrogen react with 1 volume of oxygen to produce 2 volumes of water.

WORKED EXAMPLE 3: GAS PHASE CALCULATIONS

QUESTION

What volume of oxygen at STP is needed for the complete combustion of $3,3\ dm^3$ of propane (C_3H_8)? (Hint: CO_2 and H_2O are the products as in all combustion reactions)

SOLUTION

Step 1: Write a balanced equation for the reaction.

$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

Step 2: Determine the volume of oxygen needed for the reaction.

$$V_A = \frac{a}{b}V_B$$

$$V_{O_2} = \frac{5}{1}V_{C_3H_8}$$

$$= 5 \times 3,3$$

$$= 16,5\ dm^3$$

2.3 Solutions

In grade 10 you learnt how to calculate the molar concentration of a solution. The molar concentration of a solution is the number of moles of solute per litre of solvent $(mol \cdot L^{-1})$. This is more commonly given as moles of solute per cubic decimetre of solution $(mol \cdot dm^{-3})$.

To calculate concentration we use $C = \frac{n}{V}$, where C is the molar concentration, n is the number of moles and V is the volume of the solution.

Calculating molar concentrations is useful to determine how much solute we need to add to a given volume of solvent in order to make a standard solution.

A standard solution is a solution in which the concentration is known to a high degree of precision. When we work with standard solutions we can take the concentration to be constant.

TIP

When you are busy with these calculations, you will need to remember the following:
$1\ dm^3 = 1L = 1000\ mL = 1000\ cm^3$, therefore dividing a volume in cm^3 by $1\ 000$ will give you the equivalent volume in dm^3.

WORKED EXAMPLE 4: CONCENTRATION CALCULATIONS

QUESTION

How much sodium chloride (in g) will one need to prepare $500\ cm^3$ of a standard solution with a concentration of $0,01\ mol \cdot dm^{-3}$?

SOLUTION

Step 1: Convert all quantities into the correct units for this equation.

The volume must be converted to dm^3:

$$V = \frac{500}{1000}$$
$$= 0,5\ dm^3$$

Step 2: Calculate the number of moles of sodium chloride needed.

$$C = \frac{n}{V}$$
$$0,01 = \frac{n}{0,5}$$
$$n = 0,005\ mol$$

Step 3: Convert moles of $NaCl$ to mass.

To find the mass of $NaCl$ we need the molar mass of $NaCl$. We can get this from the periodic table (recall from grade 10 how to calculate the molar mass of a compound).

$$m = nM$$
$$= (0,005)(58)$$
$$= 0,29\ g$$

The mass of sodium chloride needed is $0,29\ g$

We will now look at another use of concentration which is for titration calculations.

2.4 Titrations

A titration is a technique for determining the concentration of an unknown solution. Titrations can be done using many different types of reactions. Acid-base reactions and redox reactions are both commonly used for titrations.

In grade 10 you did a simple acid-base titration. Now we will look at how to calculate the concentration of an unknown solution using an acid-base titration.

TIP

When performing a titration we say that the substance of unknown concentration is **titrated** with the standard solution. A pipette is a measuring device that is used to measure an exact amount of a liquid. If you use a pipette to add liquid to a flask then you would say that the liquid was **pipetted** into a flask.

We can reduce the number of calculations that we have to do in titration calculations by using the following:

$$\frac{C_A V_A}{a} = \frac{C_B V_B}{b}$$

The a and b are the stoichiometric coefficients of compounds A and B respectively.

WORKED EXAMPLE 5: TITRATION CALCULATION

QUESTION Given the equation:

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H2O(l)$$

$25\ cm^3$ of a $0,2\ mol \cdot dm^{-3}$ hydrochloric acid solution was pipetted into a conical flask and titrated with sodium hydroxide. It was found that $15\ cm^3$ of the sodium hydroxide was needed to neutralise the acid. Calculate the concentration of the sodium hydroxide.

SOLUTION

Step 1: Write down all the information you know about the reaction, and make sure that the equation is balanced.

$NaOH\ :\ V = 15\ cm^3$
$HCl\ :\ V = 25\ cm^3; C = 0,2\ mol \cdot dm^{-3}$
The equation is already balanced.

Step 2: Convert the volume to dm^3

$$V_{NaOH} = \frac{15}{1000}$$
$$= 0,015\ dm^3$$

$$V_{HCl} = \frac{25}{1000}$$
$$= 0,025\ dm^3$$

Step 3: Calculate the concentration of the sodium hydroxide

$$\frac{C_A V_A}{a} = \frac{C_B V_B}{b}$$
$$\frac{(0,2)(0,025)}{1} = \frac{C_{NaOH}(0,015)}{1}$$
$$0,005 = (0,015)C_{NaOH}$$
$$C_{NaOH} = 0,33\ mol \cdot dm^{-3}$$

The concentration of the $NaOH$ solution is $0,33\ mol \cdot dm^{-3}$.

WORKED EXAMPLE 6: TITRATION CALCULATION

QUESTION

$4,9\ g$ of sulfuric acid is dissolved in water and the final solution has a volume of $220\ cm^3$. Using an acid-base titration, it was found that $20\ cm^3$ of this solution was able to completely neutralise $10cm^3$ of a sodium hydroxide solution. Calculate the concentration of the sodium hydroxide in mol□dm-3.

SOLUTION

Step 1: Write a balanced equation for the titration reaction.

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$$

Step 2: Calculate the concentration of the sulfuric acid solution.

First convert the volume into dm^3:

$$V = \frac{220}{1000}$$
$$= 0,22\ dm^3$$

$$n = \frac{m}{M}$$
$$= 4,998$$
$$= 0,05\ mol$$

Now we can calculate the concentration of the sulfuric acid:

$$C = \frac{n}{V}$$
$$= \frac{0,05}{0,22}$$
$$= 0,227\ mol \cdot dm^{-3}$$

Step 3: Calculate the concentration of the sodium hydroxide solution.

Remember that only $20\ cm^3$ or $0,02\ dm^3$ of the sulfuric acid solution is used.

$$\frac{C_1V_1}{n_1} = \frac{C_2V_2}{n_2}$$
$$\frac{(0,227)(0,02)}{1} = \frac{C_{NaOH}(0,01)}{2}$$
$$0,00454 = (0,005)C_{NaOH}$$
$$C_{NaOH} = 0,909\ mol \cdot dm^{-3}$$

3 STOICHIOMETRIC CALCULATIONS

In grade 10 you learnt how to write balanced chemical equations and started looking at stoichiometric calculations. By knowing the ratios of substances in a reaction, it is possible to use stoichiometry to calculate the amount of either reactants or products that are involved in the reaction.

The following figure highlights the relation between the balanced chemical equation and the number of moles:

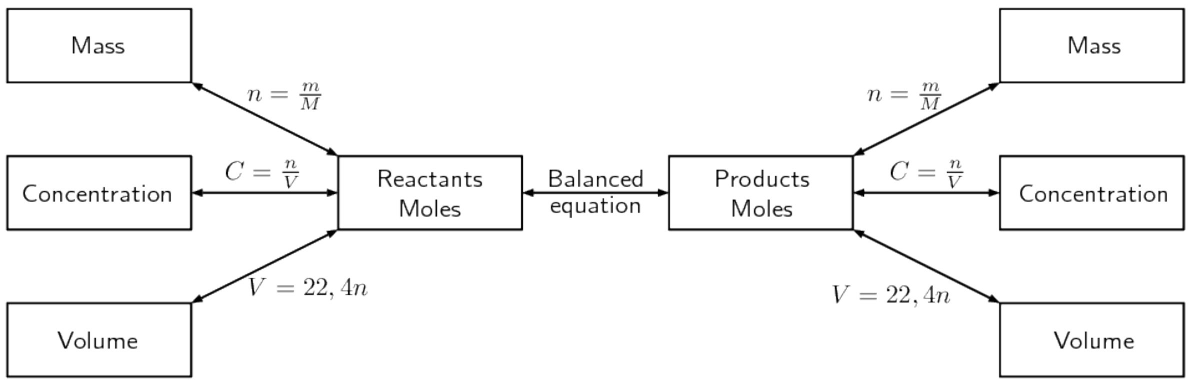

Figure 1: Stoichiometric flow diagram

In grade 10 we explored some of the concepts of stoichiometry. We looked at how to calculate the number of moles of a substance and how to find the molar mass. We also looked at how to find the molecular and empirical formulae of substances. Now we will explore more of these concepts such as limiting reagents, percent purity and percent yield.

3.1 Limiting reagents

ACTIVITY

What is a limiting reagent?

For this activity you will need A4 sheets of paper in white, red, blue, yellow, green and pink. (or you can use several sheets of white paper and colour them using kokis or crayons).

Tear the white sheet into five pieces, the red sheet into ten pieces, the blue sheet into eight pieces, the yellow sheet into seven pieces, the green sheet into nine pieces and the pink piece into four pieces.

1. Stick two red pieces to each white piece. Do you have any red or white pieces left?
2. Stick one yellow piece to each blue piece. Do you have any yellow or blue pieces left?
3. Stick three green pieces to each pink piece. Do you have any green or pink pieces left?

You should find that you had no red or white pieces left. For the blue and yellow pieces you should have one blue piece left. And for the green and pink pieces you should have had one pink piece left.

We say that the pink and blue pieces were in excess while the green and yellow sheets were limiting. In other words you would have had to tear the green and yellow sheets into **more** pieces or you would have had to tear the blue and pink pieces into **less** pieces.

In the above activity we could solve the problem of having too many or too few pieces of paper by simply tearing the pieces of paper into more pieces. In chemistry we also encounter this problem when mixing different substances. Often we will find that we added too much or too little of a particular substance. It is important to know that this happens and to know how much (i.e. the quantities) of different reactants are used in the reaction. This knowledge is used in industrial reactions.

DEFINITION

Limiting reagent A limiting reagent (or reactant) is a reagent that is completely used up in a chemical reaction.

DEFINITION

Excess reagent An excess reagent (or reactant) is a reagent that is not completely used up in a chemical reaction.

WORKED EXAMPLE 7: LIMITING REAGENTS

QUESTION Sulfuric acid (H_2SO_4) reacts with ammonia (NH_3) to produce the fertiliser ammonium sulfate $((NH_4)_2SO_4)$ according to the following equation:
$H_2SO_4(aq) + 2NH_3(g) \rightarrow (NH_4)_2SO_4(aq)$ What is the maximum mass of ammonium sulfate that can be obtained from $2,0$ kg of sulfuric acid and $1,0$ kg of ammonia?

SOLUTIONS

Step 1:Convert the mass of sulfuric acid and ammonia into moles

Moles of sulfuric acid:

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{2000}{98} \\ &= 20,4\ mol \end{aligned}$$

Moles of ammonia:

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{1000}{17} \\ &= 58,8\ mol \end{aligned}$$

Step 2:Use the balanced equation to determine which of the reactants is limiting.

We need to look at how many moles of product we can get from each reactant. Then we compare these two results. The smaller number is the amount of product that we can produce and the reactant that gives the smaller number, is the limiting reagent.
The mole ratio of H_2SO_4 to $(NH_4)_2SO_4$ is 1:1. So the number of moles of $(NH_4)_2SO_4$ that can be produced from the sulfuric acid is:

$$n(NH_4)_2SO_4 = nH_2SO_4 \times \frac{\text{stoichiometric coefficient } (NH_4)_2SO_4}{\text{stoichiometric coefficient } H_2SO_4}$$

$$n(NH_4)_2SO_4 = 20,4\ mol\ H_2SO_4 \times \frac{1\ mol\ (NH_4)_2SO_4}{1\ mol\ H_2SO_4}$$

$$= 20,4\ mol\ (NH4)2SO4$$

WORKED EXAMPLE 7: LIMITING REAGENTS CONTINUES · · ·

QUESTION

The mole ratio of NH_3 to $(NH_4)2_SO_4$ is $2{:}1$. So the number of moles of $(NH_4)_2SO_4$ that can be produced from the ammonia is:

$$n(NH_4)_2SO_4 = nNH_3 \times \frac{\text{stoichiometric coefficient } (NH_4)_2SO_4}{\text{stoichiometric coefficient } NH_3}$$

$$n(NH_4)_2SO_4 = 58,8\ mol\ NH_3 \times \frac{1\ mol\ (NH_4)_2SO_4}{1\ mol\ NH_3}$$

$$= 20,4\ mol\ (NH4)2SO4$$

Since we get less $(NH_4)_2SO_4$from H_2SO_4 than is produced from NH_3, the sulfuric acid is the limiting reactant.

Calculate the maximum mass of ammonium sulfate that can be produced

From the step above we saw that we have $20,4\ mol$ of $(NH_4)_2SO_4$.

The maximum mass of ammonium sulfate that can be produced is calculated as follows:

$$m = nM$$

$$= (20,4)(132)$$

$$= 2692,8\ g$$

$$= 2,6928\ kg$$

The maximum mass of ammonium sulfate that can be produced is $2,69\ kg$.

3.2 Percent yield

The percent yield of a reaction is very important as it tells us how efficient a reaction is. A reaction that has a low percent yield is not very useful in industry. If you are making a new medicine or pesticide and your reaction has a low percent yield then you would search for a different way of doing the reaction. This reduces the amount of (often very expensive) chemicals that you use and reduces waste.

The percent yield can be calculated using:

$$\%yield = \frac{actual\ yield}{theoretical\ yield} \times 100$$

where the actual yield is the amount of product that is produced when you carry out the reaction and the theoretical yield is the amount of product that you calculate for the reaction using stoichiometric methods.

WORKED EXAMPLE 8: PERCENT YIELD

QUESTION

Sulfuric acid (H_2SO_4) reacts with ammonia (NH_3) to produce the fertiliser ammonium sulfate $((NH_4)_2SO_4)$ according to the following equation:

$H_2SO_4(aq) + 2NH_3(g) \rightarrow (NH_4)_2SO_4(aq)$

A factory worker carries out the above reaction (using $2,0\ kg$ of sulfuric acid and $1,0\ kg$ of ammonia) and gets $2,5\ kg$ of ammonium sulfate. What is the percentage yield of the reaction?

SOLUTIONS **Step 1:Determine which is the limiting reagent**

We determined the limiting reagent for this reaction with the same amounts of reactants in the previous worked example, so we will just use the result from there.

Sulfuric acid is the limiting reagent. The number of moles of ammonium sulfate that can be produced is $20,4\ mol$.

Step 2:Calculate the theoretical yield of ammonium sulphate

From the previous worked example we found the maximum mass of ammonium sulfate that could be produced.

The theoretical yield (or maximum mass) of ammonium sulfate that can be produced is $2,69\ kg$.

Calculate the percentage yield

$$\%yield = \frac{actualyield}{theoreticalyield} \times 100$$

$$= \frac{2,5}{2,69} \times 100$$

$$= 92,94\%$$

This reaction has a high percent yield and so would therefore be a useful reaction to use in industry.

3.3 Molecular and empirical formulae

Molecular and empirical formulae were introduced in grade 10. The empirical formula is the simplest formula of a compound (and represents the ratio of atoms of each element in a compound). The molecular formula is the full formula of the compound (and represents the total number of atoms of each element in a compound). You should also recall from grade 10 the percent composition of a substance. This is the percentage by molecular mass that each element contributes to the overall formula. For example water (H_2O) has the following percentage composition: 89% oxygen and 11% hydrogen.

WORKED EXAMPLE 9: EMPIRICAL AND MOLECULAR FORMULA

QUESTION

Vinegar, which is used in our homes, is a dilute form of acetic acid. A sample of acetic acid has the following percentage composition: $39,9\%$ carbon, $6,7\%$ hydrogen and $53,4\%$ oxygen.

1. Determine the empirical formula of acetic acid.
2. Determine the molecular formula of acetic acid if the molar mass of acetic acid is $60,06\ g \cdot mol^{-1}$.

SOLUTIONS

Step 1:Find the mass

In $100\ g$ of acetic acid, there is: $39,9g\ C$, $6,7g\ H$ and $53,4g\ O$.

Step 2:Find the moles

$$n = \frac{m}{M}$$

$$n_C = \frac{39,9}{12} = 3,325\ mol$$
$$n_H = \frac{6,7}{1,01} = 6,6337\ mol$$
$$n_O = \frac{53,4}{16} = 3,3375\ mol$$

Step 2: Find the empirical formula

To find the empirical formula we first note how many moles of each element we have. Then we divide the moles of each element by the smallest of these numbers, to get the ratios of the elements. This ratio is rounded off to the nearest whole number.

C	H	O
$3,325$	$6,6337$	$3,3375$
$\frac{3,325}{3,325}$	$\frac{6,6337}{3,325}$	$\frac{3,3375}{3,325}$
1	2	1

The empirical formula is CH_2O.

Find the molecular formula

The molar mass of acetic acid using the empirical formula (CH_2O) is $30,02\ g \cdot mol^{-1}$. However the question gives the molar mass as $60,06\ g \cdot mol^{-1}$. Therefore the actual number of moles of each element must be double what it is in the empirical formula $\left(\frac{60,06}{30,02} = 2\right)$. The molecular formula is therefore $C_2H_4O_2$ or CH_3COOH

3.4 Percent purity

The final use of stoichiometric calculations that we will look at is to determine the percent purity of a sample. Percent purity is important since when you make a compound you may have a small amount of impurity in the sample and you would need to keep this below a certain level. Or you may need to know how much of a particular ion is dissolved in water to determine if it is below the legally allowed level.

Percent purity can be calculated using:

$$\%purity = \frac{mass\ of\ compound}{mass\ of\ sample} \times 100$$

WORKED EXAMPLE 10: PERCENT PURITY

QUESTION

Shells contain calcium carbonate $(CaCO_3)$ as well as other minerals. Faarah wants to know how much calcium carbonate is in a shell. She finds that the shell weighs $5\ g$. After performing some more experiments she finds that the mass of calcium carbonate and the crucible (a container that is used to heat compounds in) is $3,2\ g$. The mass of the crucible is $0,5\ g$. How much calcium carbonate is in the shell?

SOLUTIONS **Step 1:Write down an equation for percent purity** Percent purity is given by:

$$\%purity = \frac{mass\ of\ compound}{mass\ of\ sample} \times 100$$

Step 2:Find the mass of the product

We are given the mass of the crucible and the mass of the crucible with the product. We need to subtract the mass of the crucible from the mass of the crucible with the product to obtain only the mass of the product.

$$Mass\ product = 3,2\ g - 0,5\ g$$

$$= 2,7\ g$$

Step 3:Calculate the answer.

Substituting the calculated mass into the equation for percent purity gives:

$$\%purity = \frac{mass\ of\ compound}{mass\ of\ sample} \times 100$$

$$= \frac{2,7}{5} \times 100$$

$$= 54\%$$

WORKED EXAMPLE 11: PERCENT PURITY

QUESTION

Limestone is mostly calcium carbonate $(CaCO_3)$. Jake wants to know how much calcium carbonate is in a sample of limestone. He finds that the sample weighs $3,5\ g$. He then adds concentrated hydrochloric acid (HCl) to the sample. The equation for this reaction is:

$$CaCO_3(s) + 2HCl(aq) \rightarrow CO_2(g) + CaCl_2(aq) + H_2O(l)$$

If the mass of calcium chloride produced is $3,6\ g$, what is the percent purity of the limestone sample?

SOLUTIONS

Step 1: Calculate the number of moles of calcium chloride

The number of moles of calcium chloride is:

$$n = \frac{m}{M}$$

$$= \frac{3,6}{111}$$
$$= 0,032\ mol$$

Step 2: Calculate the number of moles of calcium carbonate

The molar ratio of calcium chloride to calcium carbonate is 1:1. Therefore the number of moles of calcium carbonate is $0,032\ mol$.

Step 3: Calculate the mass of calcium carbonate

The mass of calcium carbonate is:

$$m = nM$$

$$= 0,032 \times 100$$

$$= 3,2\ g$$

Step 4: Calculate the percent purity

Substituting the calculated mass into the equation for percent purity gives:

$$\%purity = \frac{mass\ of\ compound}{mass\ of\ sample} \times 100$$
$$= \frac{3,3}{3,5} \times 100$$
$$= 94,29\%$$

4 VOLUME RELATIONSHIPS IN GASEOUS REACTIONS

Using what we have learnt about stoichiometry and about gases we can now apply these principles to reactions involving gases.
We will use explosions as an example.

WORKED EXAMPLE 12: PERCENT PURITY

QUESTION

Ammonium nitrate is used as an explosive in mining. The following reaction occurs when ammonium nitrate is heated:

$$2NH_4NO_3(s) \rightarrow 2N_2(g) + 4H_2O(g) + O_2(g)$$

If $750\ g$ of ammonium nitrate is used, what volume of oxygen gas would we expect to produce (at STP)?
Step 1:Work out the number of moles of ammonium nitrate

The number of moles of ammonium nitrate used is:

$$n = \frac{m}{M}$$

$$= \frac{750}{80}$$

$$= 9,375\ mol$$

Step 2: Work out the amount of oxygen The mole ratio of NH_4NO_3 to O_2 is 2:1. So the number of moles of O_2 is:

$$n_{O_2} = n_{NH_4NO_3} \times \frac{\text{stoichiometric coefficient } O_2}{\text{stoichiometric coefficient } NH_4NO_3}$$

$$= 9,375\ mol NH_4NO_3 \times \frac{1\ mol\ O_2}{2\ mol\ NH_4NO_3}$$

$$= 4,69\ mol$$

Step 3: Work out the volume of oxygen
Recall from earlier in the chapter that we said that one mole of any gas occupies $22,4\ dm^3$ at STP.

$$V = (22,4)n$$

$$= 22,4 \times 4,6875$$

$$= 105\ dm^3$$

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Airbags in cars use a controlled explosion to inflate the bag. When a car hits another car or an object, various sensors trigger the airbag. A chemical reaction then produces a large volume of gas which inflates the airbag.

WORKED EXAMPLE 13: CONTROLLED EXPLOSION

QUESTION

Sodium azide is sometimes used in airbags. When triggered, it has the following reaction:

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

If 55 grams of sodium azide is used, what volume of nitrogen gas would we expect to produce?

Step 1:Work out the number of moles of sodium azide

The number of moles of sodium azide used is:

$$n = \frac{m}{M}$$

$$= \frac{55}{65}$$
$$= 0,85\ mol$$

Step 2: Work out the amount of nitrogen The mole ratio of NaN_3 to N_2 is 2:3. So the number of moles of N_2 is:

$$n_{N_2} = n_{NaN_3} \times \frac{\text{stoichiometric coefficient } N_2}{\text{stoichiometric coefficient } NaN_3}$$

$$= 9,375\ molNH_4NO_3 \times \frac{1\ mol\ O_2}{2\ mol\ NH_4NO_3}$$
$$= 4,69\ mol$$

Step 3: Work out the volume of nitrogen

$$V = (22,4)n$$

$$= 22, \times 1,27$$

$$= 28,4\ dm^3$$

5 CHAPTER SUMMARY

- The volume of **one mole** of gas at STP is $22,4\ dm^3$
- For any number of moles of gas at STP we can use $V_g = 22,4n_g$ to find the volume.
- The volume relationship for two gases in a reaction is given by: $V_A = \frac{a}{b}V_B$.

  where V_A is the volume of gas A, V_B is the gas B, a is the stoichiometric coefficient of gas A and b is the stoichiometric coefficient of gas B.
- The **concentration** of a solution can be calculated using: $C = \frac{n}{V}$ where C is the concentration (in $mol{\cdot}dm^3$), n is the number of moles of solute dissolved in the solution and V is the volume of the solution (in dm^3).
- A **standard solution** is a solution in which the concentration is known to a high degree of precision. For the purposes of calculations, a standard solution can be thought of as one in which the concentration is a set value.
- A **titration** is a technique for determining the concentration of an unknown solution. We can calculate the unknown concentration using:

$$\frac{C_A V_A}{a} = \frac{C_B V_B}{b}$$

- A **limiting reagent** is a reagent that is completely used up in a chemical reaction.
- An **excess reagent** is a reagent that is not completely used up in a chemical reaction.
- **Percent yield** is calculated using:

$$\%yield = \frac{actual\ yield}{theoretical\ yield} \times 100$$

  Where the actual yield is the amount of product that is produced when you carry out the reaction and the theoretical yield is the amount of product that you calculate for the reaction using stoichiometric methods.
- The **empirical formula** is the simplest formula of a compound.
- The **molecular formula** is the full formula of a compound.
- **Percent purity** is calculated using:

$$\%purity = \frac{mass\ of\ compound}{mass\ of\ sample} \times 100$$

Physical Quantities		
Quantity	**Unit name**	**Unit symbol**
Concentration (C)	moles per cubic decimetre	mol.dm^{-3}
Mass (m)	kilogram	kg
Moles (n)	moles	mol
Volume (V)	meters cubed	m^3

Table 2: Units used in **quantitative aspects of chemical change**

6 EXERCISES

6.1 Exercise 1

1. Methane burns in oxygen, forming water and carbon dioxide according to the following equation:

$$CH_4(g) + 2O_2(g) \rightarrow 2H_2O(g) + CO_2(g)$$

If 4 dm^3 of methane is used, what volume of water is produced?

6.2 Exercise 2

1. Acetylene (C_2H_2) burns in oxygen according to the following reaction:

$$2C_2H_2(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O\ (g)$$

If $3,5$ dm^3 of acetylene gas is burnt, what volume of carbon dioxide will be produced?

2. 130 g of magnesium chloride $(MgCl_2)$ is dissolved in 300 mL of water.

   2.1 Calculate the concentration of the solution.

   2.2 What mass of magnesium chloride would need to be added for the concentration to become $6,7$ mol$\cdot$ dm^{-3} ?

6.3 Exercise 3

1. When an electrical current is passed through a sodium chloride solution, sodium hydroxide can be produced according to the following equation:

$$2NaCl(aq) + H_2O(l) \rightarrow Cl_2(g) + H_2(g) + 2NaOH(aq)$$

What is the maximum mass of sodium hydroxide that can be obtained from $4,0$ kg of sodium chloride and $3,0$ kg of water?

6.4 Exercise 4

1. When an electrical current is passed through a sodium chloride solution, sodium hydroxide can be produced according to the following equation:

$$2\text{NaCl} + \text{H}_2\text{O} \rightarrow \text{Cl}_2 + \text{H}_2 + 2\text{NaOH}$$

A chemist carries out the above reaction using $4,0$ kg of sodium chloride and $3,0$ kg of water. The chemist finds that they get $1,8$ kg of sodium hydroxide. What is the percentage yield?

6.5 Exercise 5

1. A sample of oxalic acid has the following percentage composition: $26,7\%$ carbon, $2,2\%$ hydrogen and $71,1\%$ oxygen. Determine the molecular formula of oxalic acid if the molar mass of oxalic acid is 90 g · mol^{-1}.

6.6 Exercise 6

1. Hematite contains iron oxide (Fe_2O_3) as well as other compounds. Thembile wants to know how much iron oxide is in a sample of hematite. He finds that the sample of hematite weighs $6,2$ g. After performing some experiments he finds that the mass of iron oxide and the crucible (a container that is used to heat compounds in) is $4,8$ g. The mass of the crucible is $0,5$ g. How much iron oxide is in the sample of hematite?

6.7 Exercise 7

1. Given the following reaction:

$$3\text{Fe}_2\text{O}_3(\text{s}) + \text{CO}(\text{g}) \rightarrow 2\text{Fe}_2\text{O}_4(\text{s}) + \text{CO}_2(\text{g})$$

If $2,3$ kg of Fe_2O_3 and $1,7$ kg of CO is used, what is the maximum mass of Fe_2O_4 that can be produced?

2. Sodium nitrate decomposes on heating to produce sodium nitrite and oxygen according to the following equation:

$$2\text{NaNO}_3(\text{s}) \rightarrow 2\text{NaNO}_2(\text{s}) + \text{O}_2(\text{g})$$

Nombusa carries out the above reaction using 50 g of sodium nitrate. Nombusa finds that they get 36 g of sodium nitrite. What is the percentage yield?

3. Benzene has the following percentage composition: $92,31\%$ carbon and $7,69\%$ hydrogen Determine the molecular formula of benzene if the molar mass of benzene is 78 g · mol^{-1}.

4. Cuprite is a minor ore of copper. Cuprite is mainly composed of copper(I) oxide (Cu_2O). Jennifer wants to know how much copper oxide is in a sample of cuprite. She has a sample of cuprite that weighs $7,7$ g. She performs some experiments and finds that the mass of iron oxide and crucible (a container that is used to heat compounds in) is $7,4$ g. The mass of the crucible is $0,2$ g. What is the percent purity of the sample of cuprite?

5. A sample containing tin dioxide (SnO_2) is to be tested to see how much tin dioxide it contains. The sample weighs $6,2$ g. Sulfuric acid (H_2SO_4) is added to the sample and tin sulfate $(Sn(SO_4)_2)$ forms. The equation for this reaction is:

$$SnO_2(s) + 2H_2SO_4(aq) \rightarrow Sn(SO_4)_2(s) + 2H_2O(l)$$

If the mass of tin sulfate produced is $4,7$ g, what is the percent purity of the sample?

6.8 Exercise 8

1. What volume of oxygen is needed for the complete combustion of 5 g of magnesium to form magnesium oxide?

2. Annalize is making a mini volcano for her science project. She mixes baking soda (mostly $NaHCO_3$) and vinegar (mostly CH_3COOH) together to make her volcano erupt. The reaction for this equation is:

$$NaHCO_3(s) + CH_3COOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l) + CO_2(g)$$

What volume of carbon dioxide is produced if Annalize uses 50ml of $0,2$ mol · dm^3 acetic acid?

7 ANSWERS FOR EXERCISES

7.1 Exercise 1

1. $V_{H_2O} = 2$ dm^3

7.2 Exercise 2

1. $V_{CO_2} = 7$ dm^3

2.1 $4,56$ mol·dm^3

2.2 $60,95$ g

7.3 Exercise 3

1. $2,74$ kg

7.4 Exercise 4

1. $65,69\%$

7.5 Exercise 5

1. $C_2H_2O_4$

7.6 Exercise 6

1. 69%

7.7 Exercise 7

1. $1,69$ kg
2. $88,69\%$
3. C_6H_6
4. $93,5\%$
5. $48,6\%$

7.8 Exercise 8

1. $2,33$ dm^3
2. $0,224$ dm^3