**Quantitative Chemistry Mastery Booklet**

Quantitative Chemistry is how chemists work out how much substance is used and made in a chemical reaction.

**Part 1: Relative formula mass**

Remember that the relative atomic mass of an atom can be found by using the mass numbers of the periodic table. The relative formula mass of a compound is the sum of the relative atomic masses of the atoms involved. It is often given by the symbol Mr

**Worked example 1:**

What is the Mr of CaCO3?

*CaCO3 has one calcium atom, one carbon atom and three oxygen atoms. The relative mass of calcium is 40, carbon is 12 and oxygen is 16. To calculate the total:*

*40 + 12 + (3 x 16) = 100*

**Worked example 2:**

What is the Mr of Ca(OH)2?

*Ca(OH)2 has one atom of calcium, two atoms of oxygen and two atoms of hydrogen (remember that everything in the brackets is multiplied by the little number. To calculate the total:*

*40 + (2 x 16) + (2 x 1) = 74*

1. For each of the compounds below calculate their Mr
	1. CO
	2. MgO
	3. H2O2
	4. SO2
	5. Na2O
	6. Al2O3
	7. Al(OH)3
	8. Mg(NO3)2
	9. CuSO4
	10. K2SO4
	11. Al2(SO4)3
2. *Challenge: for each of the below, establish the chemical formula and calculate the Mr*
	1. Aluminium iodide
	2. Potassium oxide
	3. Sodium nitride
	4. Caesium sulphide
	5. Iron (II) sulphate
	6. Vanadium (V) chloride
	7. Vanadium (V) sulphate
	8. Manganese (VII) nitride

**Part 2: The mole**

We will return to Mr soon. In everyday life, there are some words we can use which represent a number. For example:

A score = 20
A dozen = 12
A baker’s dozen = 13
A gross = 144
A great gross = 1728

These words exist because in different contexts those words are more useful than the numbers they represent. Someone selling eggs will refer to them “by the dozen” as eggs come in containers of six or twelve. So “dozen” is more useful than “twelve.”

1. How many eggs in:
	1. Two dozen
	2. Three dozen
	3. A quarter of a dozen
	4. Four and a half dozen
	5. Two gross
	6. Seven gross
	7. One twelfth of a gross
	8. A score of baker’s dozens

In chemistry, we have a similar word called a “mole.” A “mole” is a word which represents a number just like “dozen” represents “twelve.” A mole represents the number 6.022x1023. This number is called The Avogadro Constant. This number is useful to chemists because when you are talking about atoms or molecules, you are normally referring to an enormous number of them, so it is useful to have a word which can represent enormous numbers.

1. How many atoms are in:
	1. One mole of atoms
	2. Two moles of atoms
	3. Seven moles of atoms
	4. Half a mole of atoms
	5. A dozen moles of atoms
	6. A score of atoms
2. How many:
	1. Electrons are in one mole of electrons?
	2. Protons are in one mole of protons?
	3. Electrons are in two and a half moles of electrons?
3. Sodium has 11 electrons in each atom. How many electrons are in one mole of sodium atoms?
*Answer: one mole of atoms is 6.022x1023. If each atom has 11 electrons then there must be 11 x 6.022x1023 electrons in total which = 6.62x1024*
4. How many electrons are in:
	1. One mole of lithium atoms
	2. Two moles of carbon atoms
	3. One mole of carbon dioxide molecules
	4. Half a mole of methane molecules
5. *Challenge: how many electrons are in seven and a quarter moles of copper (II) chloride?*

**Part 3: moles and Mr**

We can now combine parts 1 and 2. This is because the Mr of a substance represents the **mass** of one mole of that substance.

For example: water has the formula H2O. Each molecule of water has two hydrogen atoms and one oxygen atom. Its Mr is 18. This means that 18 grams of water, contains **one mole** of water molecules.

This leaves us with a formula relating moles, mass and Mr:

$$moles= \frac{mass}{Mr}$$

**Worked example 3**

How many moles are in 30g of CO2?

*The Mr of CO2 is*

*12 + (16x2) = 44*

*Moles = 30/44 =* ***0.68***

**Worked example 4**

*How many moles are in 175g of Na2CO3?*

*Mr = (2 x 23) + 12 + (3 x 16) = 106*

*Moles = 175/106 =* ***1.65***

1. Look back to question 1. For each substance work out how many moles are in 83g.

The equations can be rearranged to:

$mass=moles ×Mr$ and $Mr= \frac{mass}{moles}$

1. What is the mass of:
	1. 5 moles of Cl2
	2. 0.2 moles of Al2O3
	3. 0.01 moles of Ag
	4. 0.002 moles of (NH4)2SO4
	5. 0.3 moles of Na2CO3
2. An experiment was carried out to find the Mr of vitamin C (ascorbic acid). It was found that 1 g contains 0.00568 moles of Vitamin C molecules. Calculate the Mr of vitamin C.

**Part 4: manipulating ratios**

We can use all of the above to make important chemical calculations. But before that, we must understand how to use ratios.

On a youth camp, there must be a ratio of at least one leader to six children. This can be written as a ratio of

1:6

If there are 12 children, there must be at least 2 leaders. This is because in a ratio you can multiply or divide either side to get to a target number. If the target is 12 children, we must multiply 6 by 2. But we must also multiply the other side by 2. This can be represented as

1:6

2: 12

However, this becomes a bit more complicated when we use different numbers. If there are 100 children, how many leaders do we need?

The easiest way to do this is in two steps. First divide the ratio by the original target side (in this case 6). Then multiply by 100 to get to your target of 100:

This shows that if we have 100 children, we need 17 leaders.

This simple method can be applied to any ratio.

1. Using the ratio above, how many leaders are needed for:
	1. 40 children
	2. 81 children
	3. 600 children
	4. 700 children
	5. 87 children
	6. A dozen children
	7. A score of children
	8. A mole of children
2. How many children can be supervised by:
	1. 8 leaders
	2. 51 leaders
	3. 23 leaders
3. A different youth camp has different rules and requires 3 leaders for every 11 children. How many leaders are needed for:
	1. 22 children
	2. 100 children
	3. 230 children
	4. 80 children
4. How many children can be supervised by:
	1. 36 leaders
	2. 45 leaders
	3. 10 leaders
	4. 79 leaders

**Part 5: Balanced equations**

The above becomes relevant when we start to look at balanced equations. Take the equation as an example:

2H2 + O2 → 2H2O

Shown as a diagram:



We can see that two molecules of hydrogen react with one molecule of oxygen to form two molecules of water. This can be expressed as a ratio:

|  |  |  |
| --- | --- | --- |
| H2 | O2 | H2O |
| 2 | 1 | 2 |

Using part 4 we could therefore establish that if we had four molecules of hydrogen and two of oxygen, we would obtain four of water. If I used a dozen hydrogen molecules, I would need half a dozen oxygen molecules and would obtain a dozen water molecules.

|  |  |  |
| --- | --- | --- |
| H2 | O2 | H2O |
| A dozen | Half a dozen | A dozen |

When we do a chemical reaction we do not use such tiny amounts, we use much larger amounts, which we can represent with the mole. If I have **two moles** of hydrogen I would need **one mole** of oxygen and would obtain **two moles of water** as below:#

|  |  |  |
| --- | --- | --- |
| H2 | O2 | H2O |
| Two moles | One mole | Two moles |

If I was starting with 8 moles of hydrogen then it is obvious I would need 4 moles of oxygen. But it is more complicated if we use different numbers. If I started with 13.87 moles of hydrogen, how many moles of oxygen would I need?

|  |  |  |
| --- | --- | --- |
| H2 | O2 | H2O |
| 2 | 1 | 2 |
| 1 | 0.5 |  |
| 13.87 | 6.94 |  |

We can also now predict how much water we would expect to obtain from the reaction:

|  |  |  |
| --- | --- | --- |
| H2 | O2 | H2O |
| 2 | 1 | 2 |
| 1 | 0.5 | 1 |
| 13.87 | 6.94 | 13.87 |

**Worked example 4:**

Hydrogen and nitrogen react together to make ammonia (NH3). Write a balanced symbol equation for this reaction and calculate how much nitrogen would be needed to react with 19.30 moles of hydrogen and how much ammonia would be produced.

*First, we write the equation:*

*H2 + N2 → NH3*

*Then balance:*

*3H2 + N2 → 2NH3*

*Then we calculate our ratio:*

|  |  |  |
| --- | --- | --- |
| H2 | N2 | NH3 |
| 3 | 1 | 2 |
| 1 | 0.33 | 0.67 |
| 19.30 | 6.37 | 12.93 |

*So 6.37 moles of nitrogen would be needed and would produce 12.93 moles of ammonia.*

Guided practice:

1. Methane (CH4) reacts with oxygen to make carbon dioxide and water.
	1. Write a balanced symbol equation for this reaction:
	CH4 + \_\_O2 → CO2 + \_\_H2O
	2. How many moles of oxygen are required to react with 6 moles of methane?

|  |  |  |  |
| --- | --- | --- | --- |
| CH4 | O2 | CO2 | H2O |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

* 1. Use the table to calculate how much water would be produced from 6 moles of methane
1. Ethane (C2H6) also reacts with oxygen to produce carbon dioxide and water.
	1. Write a balanced equation for this reaction.
	2. If 2 moles of ethane are used, how much carbon dioxide is produced?
	3. If 7 moles of ethane are used how much water is produced?
	4. If 19 moles of oxygen is used, how much water is produced?
	5. How many moles of oxygen and ethane would you have to use to generate 43 moles of water?
2. Sulphur reacts with oxygen to make sulphur trioxide as below:
S8 + O2 → SO3
	1. Balance the equation
	2. How many moles of sulphur would be required to produce 12 moles of sulphur trioxide?
	3. A chemist uses 17 moles of sulphur. How much oxygen would they need for a complete reaction?
	4. How much sulphur dioxide would be produced?

**Part 6: moles and masses**

In the questions above you were given a number of moles of one substance (e.g. hydrogen) and asked to work out the moles of another substance (e.g. water). Normally, instead of being given the number of moles you will be given a mass. Using the equation from part 3 you will have to use that mass to calculate the number of moles for yourself.

**Worked example 5:**

A student reacts 45g of lithium with oxygen to make lithium oxide. What mass of lithium oxide is produced?

*Step 1: Construct the symbol equation:*

*4Li + O2 →2Li2O*

*Step 2: work out the moles using moles = mass ÷ Mr*

*45g of lithium, with an Mr of 7*

*Moles = 45 ÷ 7 = 6.43*

*Step 3: manipulate the ratio*

|  |  |  |
| --- | --- | --- |
| Li | O2 | Li2O |
| 4 | 1 | 2 |
| 1 |  | 0.5 |
| 6.43 |  | 3.22 |

*Step 4: work out mass using moles x Mr*

*Moles Li2O = 3.22, Mr of Li2O = 30*

*Mass = 3.22 x 30 =* ***96.60g of Li2O produced.***

Guided example:

Magnesium reacts with oxygen to form magnesium oxide (MgO). Calculate how much magnesium oxide is produced from 13.60g of magnesium.

Step 1: Construct the symbol equation:

\_\_\_Mg + O2 → \_\_\_MgO

Step 2: work out the moles using moles = mass ÷ Mr

13.60g of Mg, Mr of Mg is \_\_\_\_

Step 3: manipulate the ratio

|  |  |  |
| --- | --- | --- |
| Mg | O2 | MgO |
| \_\_\_ | \_\_\_ | \_\_\_ |
| 1 |  |  |
|  |  |  |

Step 4: work out mass using moles x Mr

Answer should come out as: **22.67g**

**Step by step summarised:**

Step 1: Construct the symbol equation
Step 2: work out the moles using moles = mass ÷ MrStep 3: manipulate the ratio
Step 4: work out mass using moles x Mr

1. Li + F2 → LiF
	1. Calculate the amount of lithium fluoride produced from 31g of lithium
	2. Calculate the amount of lithium fluoride produced from 90g of fluorine
	3. How much lithium was used if 87g of lithium fluoride is produced?
2. Ca + O2 → CaO
	1. Calculate the amount of calcium needed to produce 150g of calcium oxide
	2. Calculate the amount of calcium oxide produced from 1kg of calcium (change everything into grams)
	3. Calculate the amount of calcium oxide formed from 0.82g of oxygen
3. P4 + O2 → P2O5
	1. Calculate the amount of product formed from 43g of phosphorous
	2. 21g of oxygen is used. How much product is formed?
	3. How much oxygen would be needed for 90g of product?
4. Al + Cl2 → Al2Cl3
	1. 1.3kg of aluminium is used. How much aluminium chloride is produced?
	2. How much chlorine is required to react with 77g of aluminium?
5. K + H2O → KOH + H2
	1. How much hydrogen is produced from a reaction using 132g of water?
	2. How much potassium is required to produce 0.55g of potassium hydroxide?
6. *Challenge: butane reacts with oxygen in complete combustion to produce carbon dioxide and water. It reacts with oxygen in incomplete combustion to produce carbon monoxide (CO) and water. Use this information to show the difference in the amount of oxygen between the two reactions if in each one we start with 15g of butane.*

**Part 7: Going the other way**

In all of the above, we used a balanced equation to work out masses. We can also go in reverse by using a mass to work out how to balance an equation.

**Worked example 6:**

Sodium nitrate, NaNO3, decomposes to give sodium nitrite, NaNO2, and oxygen gas. When 8.5g of sodium nitrate is used, 6.9g of sodium nitrite and 1.6g of oxygen is produced. Construct and balance an equation for this reaction.

*Step 1: write an unbalanced symbol equation*

*NaNO3 → NaNO2 + O2*

*Even though we could balance this now, the question wants us to use the masses to balance it*

*Step 2: work out Mr of everything in the equation*

*NaNO3 → NaNO2 + O2*

*85 69 32*

*Step 3: work out the number of moles of everything you have using mass ÷ Mr*

*NaNO3 → NaNO2 + O2*

*8.5/85 6.9/69 32/1.6*

*=0.1 =0.1 =0.05*

*Step 4: convert to whole number ratio by dividing by smallest number*

*0.1/0.05 0.1/0.05 0.05/0.05*

*=2 =2 =1*

*Step 5: put these numbers into the equation*

***2****NaNO3 →* ***2****NaNO2 + O2*

*Which you can now see is balanced.*

**Worked example 7:**

Copper reacts with oxygen to form copper oxide, CuO. In an experiment 6.35g of copper reacts with 1.60g of oxygen. Balance an equation for this reaction.

*Step 1: write an unbalanced symbol equation*

*Cu + O2 → CuO*

*Step 2: work out Mr of everything in the equation*

*63.5 32 79.5*

*Step 3: work out the number of moles of everything you have using mass ÷ Mr*

*Cu + O2 → CuO*

*6.35/63.5 1.6/32 9.55/9.5*

*0.1 0.05 0.1*

*Note that we worked out the mass of copper oxide from combining the mass of the reactants – this is the law of conservation of mass.*

*Step 4: convert to whole number ratio by dividing by smallest number*

*0.1/0.05 0.05/0.05 0.1/0.05*

*= 2 =1 =2*

*Step 5: put these numbers into the equation*

*2Cu + O2 → 2CuO*

*Which you can now see is balanced.*

1. Potassium nitrate (KNO3) decomposes on heating to give potassium nitrite (KNO2) and oxygen. When 4.04 g of KNO3 is heated, 3.40 g of KNO2 is produced. Construct a balanced equation for this reaction.
2. Iron(III) oxide (Fe2O3) is reduced by carbon on heating to give iron metal (Fe) and carbon dioxide (CO2). When 480 g of Fe2O3 is heated with carbon, 336 g of Fe and 198 g of CO2 are produced. Construct a balanced equation for this reaction.
3. *Challenge: 0.01 moles of Z are burnt completely in oxygen. The word equation is:
Z + oxygen → carbon dioxide + water
The symbol equation is:
CxHy + O2 → \_\_\_CO2 + \_\_\_H2O (where x and y are unknown numbers*
	1. *1.76g of carbon dioxide and 0.90g of water are produced. Use this information to work out the balancing numbers of CO2 and H2O*
	2. *Use this information to establish x and y*

**Part 8: limiting reactants**

All of the above assumed that we had enough of both reactant to do a perfect reaction with no reactant left over. In reality, one reactant is usually left over at the end and is referred to as an **excess reactant**. The other reactant is all used up and because there isn’t more of it limits the reaction. It is therefore called the **limiting reactant**.

**Worked example 8:**

3 moles of magnesium reacts with 7 moles of oxygen. Which is the limiting reactant?

*Step 1: construct and balance an equation*

*2Mg + O2 → 2MgO*

*Step 2: manipulate the ratio using the number of moles for* ***one of the reactants***

*In this case we will choose magnesium, but it doesn’t really matter so long as you only pick one.*

|  |  |  |
| --- | --- | --- |
| Mg | O2 | MgO |
| 2 | 1 | 2 |
| 1 | 0.5 |  |
| 3 | 1.5 |  |

*This shows us that if we start with 3 moles of magnesium, we only need 1.5 moles of oxygen. In out case we have 7 moles of oxygen.*

*Step 3: Assign the* ***excess*** *and* ***limiting*** *reactants*

*We have a lot more oxygen than we need which means that it is the excess and magnesium is the limiting reactant*

Guided example:

4 moles of aluminium reacts with 3 moles of hydrochloric acid. Which is the limiting reactant?

Step 1: construct and balance an equation

2Al +\_\_\_HCl → \_\_\_\_AlCl3 + 3H2

Step 2: manipulate the ratio using the number of moles for **one of the reactants**

|  |  |  |  |
| --- | --- | --- | --- |
| Al | HCl | AlCl3 | H2 |
| 2 |  |  | 3 |
| 1 |  |  |  |
| 4 |  |  |  |

Step 3: Assign the excess and limiting reactants

In this case, do we have more or less HCl than we need?

1. Nitrogen reacts with hydrogen to form ammonia: N2 + H2 → NH3
	1. Balance the equation
	2. For each of the below conditions, work out what the limiting reactant is:
		1. moles of N2 + 3 moles of H2
		2. 3 moles of N2 + 10 moles of H2
		3. 0.5 moles of N2 + 2.0 moles of H2
	3. For each of the above, work out how many moles of ammonia will be produced
2. Sulphur dioxide reacts with oxygen to make sulphur trioxide.
	1. Construct and balance an equation for this reaction
	2. For each of the below conditions, work out what the limiting reactant is:
		1. 3 moles of SO2 + 3 moles of O2
		2. 3 moles of SO2 + 2 moles of O2
		3. 2.0 moles of SO2 + 0.4 moles of O2

As before, sometimes you will only be provided with masses and will ned to calculate moles for yourself

1. 5.00 g of iron and 5.00 g of sulphur are heated together to form iron (II) sulphide. Which reactant is in excess?
Fe + S → FeS
2. In the Solvay process, ammonia is recovered by the unbalanced equation shown. If 2kg of ammonium chloride and 0.5kg of calcium oxide are used what is the limiting reactant?
NH4Cl + CaO → CaCl2 + H2O + NH3
3. 17g of methane reacts with 20g of oxygen to make carbon dioxide and water.
	1. What is the limiting reactant?
	2. What mass of carbon dioxide would you expect to obtain from this reaction?
4. 28g Aluminium reacts with 49g of fluorine gas to form aluminium fluoride (AlF3).
	1. What is the limiting reactant?
	2. What mass of aluminium fluoride would you expect to obtain from this reaction?
5. In the manufacture of titanium, what mass of titanium can theoretically be formed when 0.5 kg of titanium chloride reacts with 0.1 kg of magnesium?
TiCl4 + 2 Mg → Ti + 2 MgCl2
6. In the manufacture of sulphur troxide, what mass of sulphur trioxide can theoretically be formed when 1 kg of sulphur dioxide reacts with 0.5 kg of oxygen?
7. *Challenge: Hydrazine (N2H4) was used as the rocket fuel for the Apollo missions to the moon. It is by reaction of ammonia with sodium chlorate. What mass of hydrazine is made by reaction of 100 g of ammonia with 100 g of sodium chloriate?
2 NH3 + NaOCl → N2H4 + NaCl + H2O*

**Part 9: concentrations of solution**

The concentration of a solution tells us how much substance there is dissolved in the water. High concentration means lots of substance and low concentration means less. We measure concentration in g/dm3.

A dm3 is a decimetre cubed. This is 1000cm3. To convert from one to the other:

So 1cm3 = 1/1000dm3 = 0.001dm3

1. Convert the below to dm3
	1. 10cm3
	2. 100 cm3
	3. 200 cm3
	4. 0.03 cm3
	5. 730 cm3
	6. 1900 cm3
2. Convert the below to cm3
	1. 1dm3
	2. 10dm3
	3. 70 dm3
	4. 0.8 dm3

**Calculating concentration**

To calculate the concentration we divide the mass by the volume and give units of g/dm3

$$Concentration= \frac{mass}{volume}$$

**Worked example 9**

43g of sodium chloride is dissolved in 500cm3 of water. What is the concentration?

First, change the volume into dm3

500 ÷ 1000 = 0.5dm3

Then, divide the mass by the volume 43/0.5 = **86g/dm3**

1. Calculate the concentration of:
	1. 40g solute in 350cm3
	2. 100g solute in 77cm3
	3. 0.08g solute in 20cm3
	4. 90g solute in 780cm3
2. For each of the below, calculate the concentration in g/dm3. You will need to convert the moles to masses first.
	1. 3 moles HCl in 100cm3 water
	2. 8 moles Na2SO4 in 750cm3 water
	3. 4 moles nitric acid in 300cm3 water
	4. 4 moles nitric acid in 0.83dm3 water

You may also need to rearrange the equation in order to answer questions.

1. Using 83g of solute, how much water is needed to:
	1. Make a 34g/dm-3 solution
	2. Make a 0.1g/dm-3 solution
	3. Make a 83g/dm-3 solution
	4. Make a 79g/dm-3 solution
2. What mass of solute is in:
	1. 25cm3 of a 2.3g/dm3 solution (remember to convert to dm3)
	2. 250cm3 of a 71g/dm3  solution
	3. 2.3dm3 of a 61g/dm3 solution

**Summary question:**

Aluminium hydroxide reacts with sulphuric acid as below

Al(OH)3 + H2SO4 → Al2(SO4)3 + H2O

1. Balance the equation
2. If the sulphuric acid is made by dissolving 6 moles of H2SO4 in 755cm3, what is its concentration?
3. How many moles of aluminium hydroxide are in 35g of it?
4. How many moles of aluminium sulphate are produced from a reaction involving 35g of aluminium hydroxide?
5. What mass of water is produced from a reaction involving 12g of sulphuric acid?
6. 41g of aluminium hydroxide is reacted with 41g of sulphuric acid. Which is in excess and which is limiting?