**Relative Atomic Mass**

Atomic mass or mass number is equal to the number of protons and neutrons in the nucleus of an atom.

However we have seen that there are lots of elements which have different isotopes.

If we were to pick out a jar of such an element, we would have a mixture of atoms of different isotopes and yet we would still need to know how many atoms were contained in a specific mass of something. Therefore we need to know the average mass of the atoms in our sample.

It is also necessary that we define what 1 mass unit is. We will make this equivalent to 1/12th of the mass of carbon-12, which has a mass of 12. [This is more useful than saying it is equal to the mass of a hydrogen or choosing another element.]

**Definition: The relative atomic mass of an element is the weighted average of the masses of the isotopes where a carbon-12 atom has a mass of exactly 12.**

**Relative atomic mass is given the symbol A*r***

**Calculating the average mass of the isotopes of an element, A*r***

Relative atomic masses are not always whole numbers. The relative atomic mass of chloride is 35.5 this is because chlorine is a mixture of two isotopes: chlorine-35 and chlorine-37. On average, out of every four atoms, three are chlorine-35 and one is chlorine-37.

The average relative atomic mass of chlorine = $\frac{\left(3 x 35\right)+(1 x 37)}{4}$ = 35.5

This question could also be given to you in percentage terms. In which case 75% of our atoms are chlorine-35 and 25% are chlorine-37.

The average relative atomic mass of chlorine = $\frac{\left(75 x 35\right)+(25 x 37)}{100}$ = 35.5

Double check your answer: it should be somewhere in between the masses of the individual isotopes.

At GCSE these values are usually quoted to the nearest whole number, unless they fall exactly between as above.

**In all the questions below, find the relative atomic mass of the relevant element:**

1) In 100 atoms of gallium, 60 atoms are gallium-69 and 40 atoms are gallium-71

2) Antimony consists of 57% antimony-121 and 43% antimony-123.

3) In a sample of neon, 9 of neon atoms are neon-20 and one atom is neon-22.

4) From a sample of 123 typical atoms of boron, 23 of these would be Boron-10 and 100 would be Boron-11.

**Extension questions – above GCSE**

5) Zirconium has five isotopes, listed below. Calculate the average relative atomic mass to one decimal place.

zirconium-90 51.5% zirconium-91 11.2% zirconium-92 17.1%

zirconium-94 17.4% zirconium-96 2.8%

5) Germanium has five isotopes, listed below. Calculate the average relative atomic mass to one decimal place. NB these are not percentages.

Germanium-70 56.4 germanium-72 75.1 germanium-73 21.4

Germanium-74 100 germanium-76 21.1

**Calculating the relative atomic mass for a molecule or compound, M*r***

If the mass of a hydrogen atom is 1, and the mass of oxygen is 16, then what is the mass of a water molecule H2O?

To find the relative formula mass of a compound, you add up the relative atomic masses of every atom found inside it. Remember that if you have two hydrogen atoms, as above, then you will need to count the mass of hydrogen twice.

Have a go at the practice questions below, set your answers out neatly on lined paper.

|  |  |  |
| --- | --- | --- |
| 1. P4
2. I2
3. Cl2
4. H2
5. SO2
6. CuSO4
7. C2H6
8. KBr
9. H2SO4
 | 1. NH4NO3
2. FeBr3
3. Ne
4. CsI
5. CO2
6. H2O
7. CaCl2
8. CaCO3
9. HCl
 | 1. HNO3
2. C2H5OH, ethanol

Extension1. Ca(NO3)2
2. Al2(SO4)3
3. (NH4)2SO4
4. CuSO4.5H2O
5. Na2CO3.10H2O
 |

Questions

1. Which atom has approximately twice the mass of a sulphur atom?
2. How heavy is a calcium atom compared to a bromine atom?
3. Oxygen can be found as ozone, O3. What is the M*r* of ozone?

Extension

1. Calcium carbonate reacts with hydrochloric acid to produce a salt of calcium chloride, water and carbon dioxide. Write out a word and balanced symbol equation to show this. Use the masses you calculated above for each of those chemicals, to show that there is conservation of mass within this reaction.

**The Mole - What is the point of moles?**

**Defining a mole**

**A mole of substance is the amount of that substance that contains the same number of stated “things” as there are atoms in 12 g of carbon-12.**

**The mole**

The unit for amount of substance is called the mole, shown as mol. One mole of atoms, ions or molecules is around 6 × 1023 (6 followed by 23 zeroes). This is the same number as the number of carbon atoms in 12 g of carbon.

**Molar mass**

The molar mass of a substance is its relative formula mass in grams. The unit for molar mass is g/mol. For example:

the Mr of water is 18, so its molar mass is 18 g/mol or the mass of 1 mole of water is 18g

the Mr of calcium hydroxide is 74, so its molar mass is 74 g/mol or the mass of 1 mole of calcium hydroxide is 74g

Remember: work out the relative formula mass of the substance in the question first, then give this number as g/mol for its molar mass.

**Avagadro**

The number 6 x 1023 is called Avagadro’s number. This is how many things are in a mole.

**Calculating the number of moles of something**

If the Mr of CaCO3 is 100, as you found in a previous question, then we can say that 100g of CaCO3 = 1 mole of CaCO3. What about if we have 10g? We have a tenth of the amount of 1 mole, i.e. 0.1 moles.

We can say:

This is really useful when we come to work out whether we have enough of a chemical for a reaction or not.

You need to learn and be able to rearrange this equation.

**Questions**

Example 1: How many moles are in 7.4 grams of calcium hydroxide?

Example 2: What is the mass of 2 moles of neon?

**Practice**

Answer the questions below.

What is the mass of the following?

1. 0.1 moles of P4
2. 2 moles of I2
3. 0.05 moles of Cl2
4. 6 moles of H2
5. 80 moles of SO2
6. 0.01 moles of CuSO4
7. 3 moles of C2H6
8. 0.5 moles of KBr
9. 1 mole of H2SO4

How many moles are in the following?

1. 8 g of NH4NO3
2. 3 g of FeBr3
3. 5 g of Ne
4. 520g of CsI
5. 0.44g of CO2
6. 180ml of H2O
7. 22.2g CaCl2
8. 0.1g CaCO3
9. 0.73g of HCl

**Reacting amounts in chemical equations**

We can work out how many moles of a chemical is reacting and then use this to work out the number of moles of the other chemicals it is reacting with, and therefore we can find the masses of the chemicals it is reacting with so we can weigh out the right amount for our reaction.

**Example 1**

In the thermit reaction, what mass of aluminium powder is needed to react with 8.0g of iron (III) oxide?

Steps:

(1) Write out the balanced equation and set it out across the full width of the page

(2) Which chemical do you know two things about? (Usually mass and A*r* or M*r* as you can work these out yourself). Find the A*r* or M*r* of this chemical, and the one the question is asking you about.

(3) Find moles of that chemical using the equation

$$moles= \frac{mass in grams}{Ar or Mr in g/mol}$$

(4) Use the balanced equation to work out how many moles you must need of the chemical you are interested in.

(5) Go up the table by using the moles you have found to work out the mass using the equation

$$mass in grams=moles x Ar or Mr in g/mol$$

(6) Always make sure you say what it is you are finding – never just write numbers on the page without any explanation of what they mean.

Equation: 2Al + Fe2O3 → Al2O3 + 2Fe

Write masses: *x* g 8.0g

Find A*r* or M*r* 27 160

Find moles: 0.1 = $\frac{8.0}{160}$

 = 0.05

Ratio from equation: 2 x 0.05 1 x 0.05 2 x 0.05

Answer

**Example 2**

What mass of ethanol is formed when 4.5g of glucose is fermented?

Equation: C6H12O6 → 2C2H5OH + 2CO2

Write masses:

Find A*r* or M*r*:

Find moles:

Ratio from equation:

**Example 3**

What mass of magnesium sulphate crystals, MgSO4.7H2O can be made from 14.0g of magnesium carbonate and an excess of dilute sulphuric acid?

Note: when a chemical is in excess, this means there is more than enough for the reaction to be carried out. It means you can be confident all of your chemical is able to react. It also means you cannot work out how many moles you have of this chemical.

Equation: MgCO3 + H2SO4 → MgSO4.7H2O + CO2 + H2O

Write masses: excess

Find A*r* or M*r*:

Find moles:

Ratio from equation:

**Questions**

In these questions, the balanced equation has been given to you so step 1 has been done for you. Set your work out neatly on lined paper.

1) How much magnesium must be burned in oxygen to make 4.0g of magnesium oxide?

 2Mg + O2 → 2MgO

2) What mass of calcium oxide is formed when 25g of calcium carbonate is decomposed by heat?

 CaCO3 → CaO + CO2

3) In the blast furnace, iron (III) oxide is reduced to iron by carbon monoxide:

 Fe2O3 + 3CO → 2Fe + 3CO2

 (a) What mass of carbon monoxide is needed to reduce 16 tonnes of iron(III) oxides?

 (b) What mass of iron is obtained from the reduction of 16 tonnes of the oxide?

4) What mass of coke is consumed in a blast furnace in the production of 2.8 tonnes of carbon monoxide?

 2C + O2 → 2CO

In the following questions, you are given the formulae but you have to write the balanced equation in step 1.

5) What is the loss in mass when 1.25g of blue copper (II) sulphate crystals, CuSO4.5H2O is heated and decomposed to anhydrous copper(II) sulphate, CuSO4?

6) What mass of ammonia, NH3, is formed when 12g of hydrogen, H2, combines with nitrogen N2?

7) Lead(II) oxide, PbO, reacts with hydrogen to form lead and steam, H2O. Calculate the mass of lead formed when 446g of lead(II) oxide is reduced in this way.

8) What mass of sulphur is needed to react with 8.0g copper to form copper(I) sulphide, Cu2S?

**Limiting Reactants and Reacting Masses**

The reactant that gets used up first in a reaction is called the limiting reactant. This is the reactant that is NOT in excess. Therefore the amounts of product formed in a chemical reaction are determined by the limiting reactant.

**Method**

A + 2B → C + D

1. First find the number of moles of chemical A and B using the masses given to you in the equation and the RAMS.
2. Then take the number of moles of A, and use the ratios from the balanced equation to predict how much of B it would actually react with in a perfect reaction.
3. Now compare this to the number of moles of B you found in Step 1.
	1. If you have more moles of B than your ratio says you need, then B is in excess and A is the limiting reactant.
	2. If you have fewer moles of B than your ratio says you need, then B the limiting reactant and A is in excess.
4. Use the moles of the limiting reactant to calculate how many moles of product you will form, and hence the mass of it. Ignore the amount of the substance which is in excess.

**Worked example**

1. Cu + 2AgNO3 → 2Ag + Cu(NO3)2

How many grams of Ag will be produced from 19.0g of Cu and 125g of AgNO3?

Find Moles of copper = 19.0/63.5 = 0.299 moles

Find Moles of silver nitrate = 125/170 = 0.735 moles

Use equation to help you work out the moles of silver nitrate I should need = 0.299 x 2 = 0.598

Compare: We actually have more than this, we have 0.735 moles. Therefore silver nitrate is in excess and copper is the limiting reactant.

Using the limiting reactant:

Amount of silver is 2 x moles of copper, (from the balanced equation) = 0.598 moles.

Therefore Mass of silver = moles x RAMS = 0.598 x 108 = 64.6g (3sf)

**Examples**

1. C3H8 + 5O2 → 3CO2 + 4H2O

How many grams of CO2 will be produced from 39.0g of propane and 11.0g of oxygen?

1. NaCl + AgNO3 → AgCl + NaNO3

How many grams of AgCl will be produced from 5.00g of NaCl and 103g of AgNO3

1. Mg(OH)2 + 2HCl → MgCl2 + 2H2O

How many grams of MgCl2 will be produced from 12.0g of Mg(OH)2 and 42.0g HCl

1. Mg(OH)2 + 2HCl → MgCl2 + 2H2O

How many grams of MgCl2 will be produced from 16.0g of Mg(OH)2 and 11.0g HCl

**Continued**

1. 4Fe + 3O2 → 2Fe2O3

How many grams of Fe2O3 will be produced from 10.0g of Fe and 7g of O2

1. Zn + 2HCl → ZnCl2 + H2

How many grams of ZnCl2 will be produced from 26.0g of Zn and 42.0g of HCl

1. 2Na + Cl2 → 2NaCl

How many grams of NaCl will be produced from 33.0g of Na and 34.0g of Cl2?

1. Zn + CuCl2 → ZnCl2 + Cu

How many grams of ZnCl2 will be produced from 7.0g of Zn and 8.0g of CuCl2

1. CH4 + 2O2 → CO2 + 2H2O

How many grams of CO2 will be produced from 12.0g of methane and 133.0g of oxygen?

**Percentage yield**

Not all reactions produce as much of the desired product as they should.

There are a number of reasons why this might happen. Read the page in the book and list the reasons given below.

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In the following questions below, not all of the substances has formed.

Calculate the percentage yield of the reaction, using the equation:

$$Percentage yield= \frac{amount of product produced}{maximum amount of product possible} x 100$$

**Questions**

These questions relate to your previous worksheet. Answer on this sheet. Make your answer clear by underlining it.

1) In a reaction, 2.4g of magnesium reacted and should have produced 4.0g of magnesium oxide. Only 3.2g of magnesium oxide was produced. What is the percentage yield of the magnesium oxide?

 2Mg + O2 → 2MgO

2) In a reaction, 25g of calcium carbonate was decomposed by heat and 14 grams of calcium oxide should have been produced? However only 12g was produced. What was the percentage yield?

 CaCO3 → CaO + CO2

3) In the blast furnace, iron (III) oxide is reduced to iron by carbon monoxide:

16 tonnes of iron(III) oxide was reacted and 11.2 tons of iron should have been produced.

However only 5 tonnes of iron was produced. What was the percentage yield of iron?

 Fe2O3 + 3CO → 2Fe + 3CO2

4) In a reaction, 1.25g of blue copper (II) sulphate crystals, CuSO4.5H2O were heated and decomposed to form anhydrous copper(II) sulphate, CuSO4. The mass of copper sulphate should have been 0.8g grams. And the mass of water formed should have been 0.45g. The actual mass loss of water was only 0.40g. What was the percentage yield of water?

 CuSO4.5H2O → CuSO4 + H2O

5) In a reaction, 68 grams of ammonia, NH3, should have formed when 12g of hydrogen, H2, combined with nitrogen N2. However only 8g of ammonia was produced. What was the percentage yield of ammonia?

 N2 + 3H2 ↔ 2NH3

6) Lead(II) oxide, PbO, reacts with hydrogen to form lead and steam, H2O. 446g of lead(II) oxide was reacting and 414g of lead should have been produced. However the mass of lead produced was 300g. What was the percentage yield of lead?

 PbO + H2 → Pb + H2O

7) In a reaction to produce methane, it should have been possible to produce 3.25 tonnes. However only 2.75 tonnes was produced. What was the percentage yield?

8) In a reaction to produce sodium chloride from a reaction, it was found that 0.585 grams should have been produced from the reacting amounts. However only 0.4 grams was found to be present. What was the percentage yield?

9) In a reaction to produce dry crystals of magnesium sulphate from a solution of magnesium sulphate, the final step in the method included heating the magnesium sulphate in an evaporating basin until most of the water had evaporated and then leaving it to crystalise. It was expected that 8.3 grams of magnesium sulphate was going to be produced. The mass of the crystals in the basin was found to be 9.6g. Find the percentage yield.

What is unusual about this result?

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Try to explain what might have happened to produce this result by reading the final step in the method.

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**Percentage of an element in a compound**

This is not listed in your specification but these questions does appear from time to time, and they give you the equation. It is considered a generic maths skill.

**To calculate the percentage of an element in a compound:**

$$Percentage of an element= \frac{total mass of the element in the compound}{total mass of the whole compound} x 100$$

Find the percentage of the element listed in the compounds below:

Use your answer to the relevant previous worksheet to help you answer the questions.

|  |  |  |
| --- | --- | --- |
| 1. Phosphorous in P4
2. Iodine in I2
3. Chlorine in Cl2
4. Hydrogen in H2
5. Sulfur in SO2
6. Copper in CuSO4
7. Carbon in C2H6
8. Potassium in KBr
9. Sulfur in H2SO4
 | 1. Nitrogen in NH4NO3
2. Iron in FeBr3
3. Neon in Ne
4. Iodine in CsI
5. Carbon in CO2
6. Hydrogen in H2O
7. Calcium in CaCl2
8. Calcium in CaCO3
9. Hydrogen in HCl
 | 1. Nitrogen in HNO3
2. Carbon in C2H5OH, ethanol

Extension1. Calcium in Ca(NO3)2
2. Aluminium in Al2(SO4)3
3. Nitrogen in (NH4)2SO4
4. Copper in CuSO4.5H2O
5. Sodium in Na2CO3.10H2O
 |

Questions

1. Which out of water and hydrogen chloride has the highest percentage of hydrogen?
2. Which out of calcium chloride, calcium carbonate and calcium nitrate has the highest percentage of calcium?
3. Which out of ammonium nitrate and ammonium sulphate has the highest percentage of nitrogen?
4. On the basis of your answer to Q3, which of the two compounds would you recommend as a fertiliser designed to deliver the maximum amount of nitrogen to a soil?

**Concentration Calculation Notes**

The concentration of a solution tells us how much of something is dissolved in a specific volume of solvent (usually water). Concentrations are measured in many different units.

The two main units used by chemists are:

1. g per cm3 or g per dm3 , also written g/cm3 or g/dm3 or even g cm-3 and g dm-3 (where g = grams)
2. Moles per dm3 or mol/dm3 or moldm-3 or M

You need to be able to find the concentration in g/dm3 using the following equation. Recall that 1 dm3 is 1000cm3

$$concentration \left(g dm^{-3}\right)= \frac{amount of solute(g)}{volume of solution (dm^{3})}$$

And also

$$concentration \left(g dm^{-3}\right)= \frac{amount of solute(g)}{volume of solution (cm^{3})} x 1000$$

You can increase the concentration of a solution by:

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**In the following questions, calculate the concentration of the solution in g/dm3**

1. 4g of sodium hydroxide is dissolved into 1000cm3 of water
2. 120g of potassium hydroxide is dissolved into 3dm3 of water
3. 4.25g of silvernitrate is dissolved into 250cm3 of water
4. 20.75g of potassium iodide is dissolved into 100cm3 of water
5. 600g of calcium nitrate is dissolved into 5dm3 of water

**In the following questions, calculate the mass of solute present in the quantity of solution described**

1. 1000cm3 of a solution of 2.5g/dm3
2. 250cm3 of a solution of 1.24g/dm3
3. 1.5 dm3 of a solution of 3.6g/dm3
4. 12cm3 of a solution of 6g/dm3
5. 225cm3 of a solution of 110g/dm3

**What volume of the solution is required below to have the desired mass of solute?**

1. 4g of solute from a 2 g/dm3 solution
2. 25g of solute from a 10 g/dm3 solution
3. 600g of solute from a 12g/dm3 solution
4. 0.1g of solute from a 10g/dm3 solution
5. 15g of solute from a 25g/dm3 solution

