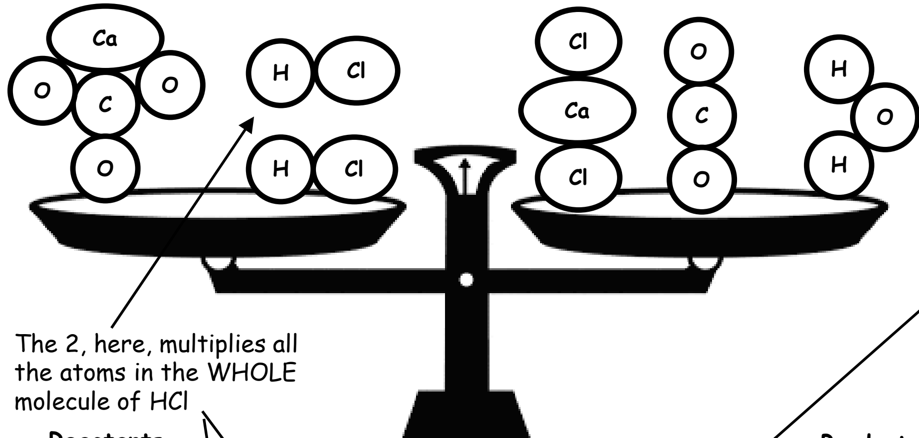
CONSERVATION of MASS (from C1)
The law of conservation of mass states that the total amount of substance in a chemical reaction does not change during the reaction. Another way of saying this is the total mass of **reactants** is the same as the total mass of the **products**

A balanced chemical equation represents this in a different way: it uses symbols and molecular formulae to show the same balance. The numbers of each type of atom at the start and the finish are the same.



The 2, here, multiplies all the atoms in the WHOLE molecule of HCl

Reactants **Products**

$$CaCO_{3(aq)} + 2\ HCl_{(aq)} \rightarrow CaCl_{2(aq)} + CO_{2\ (g)} + H_2O_{(l)}$$

M_r = 40+12+16+16+16 = **100**

M_r = 1 + 35.5 = **36.5**

But there are 2 of them!

M_r = 40+35.5+35.5 = **111**

M_r = 12+16+16 = **44**

M_r = 16+1+1 = **18**

OH NO! THE LAW IS WRONG!
Sometimes it can appear that the law of conservation of mass is wrong! It can appear that the mass of substance has either increased or decreased.
This occurs in OPEN-SYSTEMS where (usually) a gas is allowed to escape or is used in the reaction.

In this reaction one of the products, CO_2, is a gas and can escape the reaction.

If I weigh the products it will appear that the mass has decreased.

BUT if I could catch and weigh the CO_2 and add it on, I would find the mass does balance! Phew!

RELATIVE masses, A_r and M_r
We cannot actually weigh atoms and molecules because they are TOO SMALL. However we can use RELATIVE masses to help us.

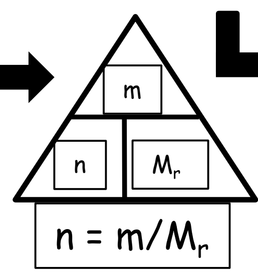
Each atom of an element has a RELATIVE ATOMIC MASS, A_r
This is how heavy the atom is compared to a single carbon atom. We assume a carbon atom has a relative mass of exactly 12.
Everything else is compared to this.

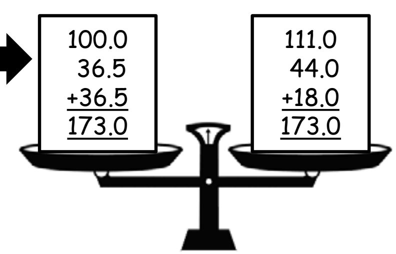
Symbols on the periodic table tell us how heavy each element is:

← Atomic Mass A_r

In molecules we can add up the relative masses of EVERY ATOM to give the FORMULA MASS, M_r

MOLES 1 **(Higher)**
A MOLE is a numerical term, much like the words PAIR or DOZEN. It relates to a fixed number of something.
This fixed number is called the AVOGADRO NUMBER, 6.02×10^{23}
A MOLE of a substance will have a mass equal to its formula mass: e.g. if I have 6.02×10^{23} molecules of calcium carbonate, $CaCO_3$, it will have a mass of 100.0 g. There is a direct relationship between the number of **moles, n,** the **mass of substance, m** and the **formula mass of the same substance, M_r**

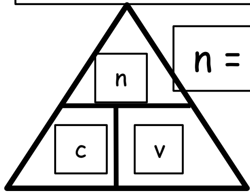




A useful check of your maths is to add up the formula masses for ALL reactants and compare to the total formula masses for ALL products. They MUST be the SAME!

MOLES 2 (Higher)
The equation shows **RATIOS of moles** of substance. I can read this as 1 mole of $CaCO_3$ reacts with 2 moles of HCl.
If I start with 2 moles of $CaCO_3$, I will use 4 moles of HCl....and if I start with a ¼ mole of $CaCO_3$, I will need ½ mole of HCl.

MOLES 3 (Higher)
There are other tricks I can do knowing about moles.
1) LIMITING reagents
If I have LESS of one substance than expected for an equation it will stop the reaction once it has run out. It will **LIMIT** the reaction.
e.g. If I start with only 50 g of $CaCO_3$ in this reaction, instead of 100 g, it will only use up half the amount of HCl, even if I have more HCl present.
2) Working out MOLE ratios for equations
I can work backwards from masses to give the RATIOS by turning masses into moles, using $n = m/M_r$ then simplifying the ratio of moles.



$n = cv$

Reactants | Products

$$CaCO_{3(aq)} + 2\,HCl_{(aq)} \rightarrow CaCl_{2(aq)} + CO_{2\,(g)} + H_2O_{(l)}$$

M_r =100 | M_r =36.5 | M_r =111 | M_r =44 | M_r = 18

CONCENTRATIONS of solutions

When a substance is dissolved in a solvent to produce a solution we can calculate the strength of the solution. The substance dissolved is called the solute and the amount of the solute per volume is called the CONCENTRATION.

Concentration, c (g/dm^3)= mass(g)/volume (dm^3)

If I dissolve 11.1 g of $CaCl_2$ in 1 dm^3 of water, the concentration c = 11.1/1 = 11.1 g/dm^3.
However if I dissolve 11.1 g of $CaCl_2$ in 0.25 dm^3, the concentration c = 11.1/0.25 = 44.4 g/dm^3
If the volume is given in different units make sure to convert it into dm^3 first:
11.1 g $CaCl_2$ dissolved in 200 cm^3 becomes (convert it into dm^3) 200/1000 dm^3 = 0.20 dm^3
And concentration c = 11.1/0.20 = 55.5 g/dm^3

Concentrations HIGHER TIER ONLY

Concentrations can also be given in units of moles per dm^3, written mol/dm^3 or mol dm^{-3}

First convert mass into number of moles (using n = m/M_r) then concentration c (mol/dm^3) = number of moles (n) /volume (dm^3)

e.g. If I dissolve 11.1 g of $CaCl_2$ in 1 dm^3 of water..
The number of moles of $CaCl_2$ = 11.1/111 = 0.1 moles…
And the concentration c = 0.10/1 = 0.10 mol/dm^3.

As a final example: 55.5 g $CaCl_2$ dissolved in 2500 cm^3 of water:
Number of moles n = m/M_r = 55.5/111 = 0.5 mols
Volume = 2500 cm^3 = 2500/1000 = 2.5 dm^3
Concentration = 0.5/2.5 = 0.20 mol/dm^3

CALCULATING theoretical YIELDS

Method 1:
Simple scaling of the formula masses
The equation reads as "100 g of $CaCO_3$ will react to produce 111g of $CaCl_2$"
If I start with half as much $CaCO_3$, I would expect half as much $CaCl_2$.
If I start with ***x*** g of $CaCO_3$, I should produce $\frac{x}{100}$ x 111g of $CaCl_2$

CALCULATING theoretical YIELDS

Method 2:
Using moles. This is MORE important when the numbers in front of the reactant and product are NOT the same.

a) Calculate the number of moles n of your reactant using n = m/M_r
b) Use the ratio of the numbers in front of the reactant and product to calculate the number of moles of product
c) Use the equation m = n x M_r to calculate the expected mass of product…the **theoretical yield**

e.g. How much $CaCl_2$ is produced if I start with 18.25 g of HCl?

Step a) Number of moles of HCl = 18.25/36.5 = 0.5
Step b) from the equation the ratio of HCl: $CaCl_2$ is 2:1….so there is half the number of moles of $CaCl_2$ compared to HCl…..n = 0.25 moles
Step c) Mass of $CaCl_2$ = n x M_r = 0.25 x 111 = 27.8 g
CHALLENGE! In this example the HCl is likely to be given as a solution with a concentration and a volume used e.g. 250 cm^3 of 1.0 mol/dm^3 solution…you will need to use your knowledge of concentrations to calculate the number of moles of HCl, then do steps b and c… n = c x v = 1.0 x 0.25 = 0.25 moles

CHEMICAL YIELDS

The efficiency of a reaction can be calculated as a **CHEMICAL YIELD**, which represents the amount of product actually produced in a reaction compared to the amount that should have been produced…this is called the **theoretical yield/amount.**

$$\text{Chemical yield} = \frac{\text{amount produced}}{\text{theoretical amount}} \times 100$$

E.g. In the reaction above I start with 100 g of $CaCO_3$….this **SHOULD** produce 111 g of $CaCl_2$…however, it only makes 93.7 g of $CaCl_2$…what is the yield?

$$\text{Yield} = \frac{93.7}{111.0} \times 100 = 84\ \%$$

ATOM ECONOMY (atom utilization)

The efficiency of a reaction can be calculated in a different way using ATOM ECONOMY. This compares the M_r of USEFUL product as a percentage of the overall M_r of ALL the reactants:

$$\text{Atom economy} = \frac{\text{Mr useful product}}{\text{Mr ALL reactants}} \times 100$$

In the example above, if we designate the $CaCl_2$ as 'useful' and the H_2O and CO_2 as 'waste', the atom economy would be: $\frac{111}{100+36.5+36.5}$ x 100 = 64 %

VOLUMES of GASES HIGHER TIER ONLY

The final calculation we need allows us to convert VOLUMES OF GASES into a number of moles.

$$\text{Number of moles} = \frac{\text{volume of gas given}}{\text{molar gas volume}}$$

The molar gas volume is the volume of any gas at standard conditions of 20°C and 1 atmosphere pressure. It is a fixed value of 24 dm^3.
In the reaction above 100 g (1 mole) of $CaCO_3$ produces **1 mole** of CO_2 what volume of CO_2 is this?

Volume of gas = n x molar volume = **1** x 24 = 24 dm^3