

Using equations to find masses and yields

Chemistry grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Lesson

Quick answer: Reacting masses come from a balanced equation. Convert the known mass to moles with $n = m \div M$, use the mole ratio to find the moles of the other substance, then convert back to grams. The limiting reactant sets the product, and percentage yield compares actual with theoretical mass.

Level: Chemistry grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · **Curriculum:** HS-PS1-7, GCSE C3

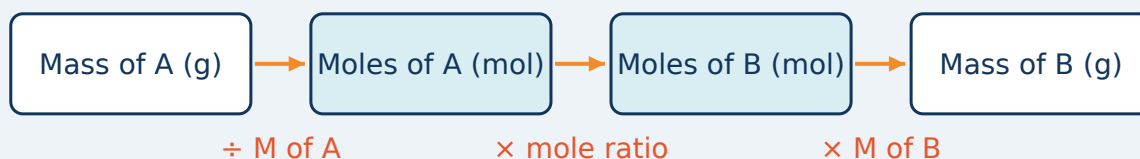
How do you use a balanced equation to find reacting masses?

A balanced equation is a recipe written in moles. The big numbers in front of the formulae give the **mole ratio** in which substances react and form. Chemists never compare masses directly, because a mole of one substance has a different mass from a mole of another. So they convert the mass to moles, use the ratio, then convert back to a mass.

Formula

$$n = m \div M$$

n = amount of substance (mol), m = mass (g), M = molar mass (g/mol), numerically equal to the relative formula mass.



Mass in grams cannot be compared directly: always go through moles.

The four-step route from the mass of one substance to the mass of another.

Worked example

Aarav burns 6.0 g of magnesium ribbon: $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$. Calculate the mass of magnesium oxide formed (Ar: Mg = 24, O = 16).

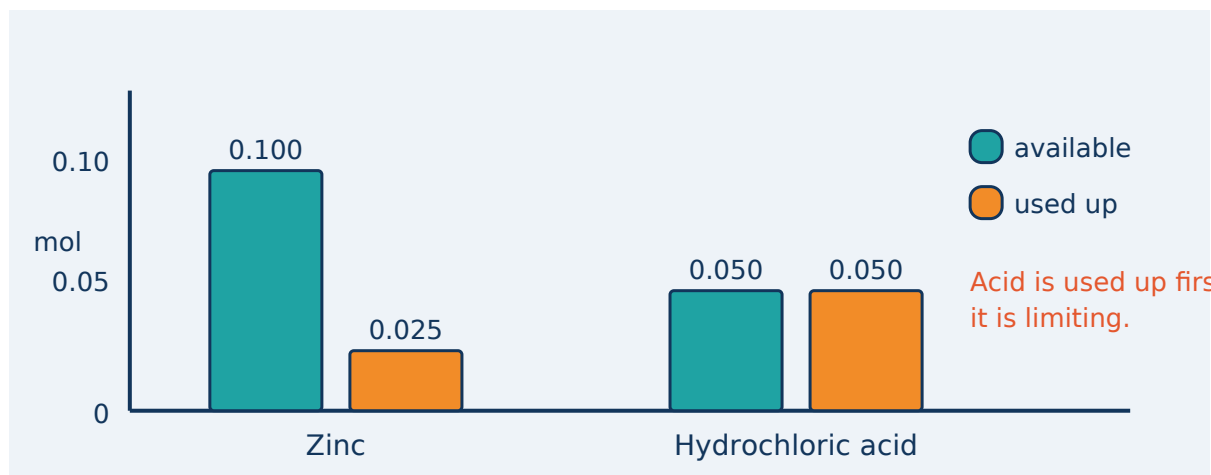
$n(\text{Mg}) = 6.0 \div 24 = 0.25$ mol. The ratio Mg : MgO is 2 : 2, so $n(\text{MgO}) = 0.25$ mol. $M(\text{MgO}) = 24 + 16 = 40$ g/mol, so $m = 0.25 \times 40 = \mathbf{10\text{ g}}$.

What is a limiting reactant?

Definition

The **limiting reactant** is the reactant that is completely used up first. It decides how much product can form. A reactant that is left over at the end is **in excess**.

To find it, work out the moles of each reactant, then divide by its coefficient in the equation. The smallest answer belongs to the limiting reactant. A fire needs fuel and oxygen in the same way: whichever runs out first stops the burning.



Zinc is in excess; the acid runs out first, so it limits the product.

Worked example

Wanjiru adds 6.5 g of zinc to 50 cm³ of 1.0 mol/dm³ hydrochloric acid: $\text{Zn} + 2\text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2$. Find the mass of hydrogen (Ar: Zn = 65, H = 1).

$n(\text{Zn}) = 6.5 \div 65 = 0.10$ mol. $n(\text{HCl}) = 1.0 \times 0.050 = 0.050$ mol. Zinc would need $2 \times 0.10 = 0.20$ mol of HCl, so the acid is limiting. $n(\text{H}_2) = 0.050 \div 2 = 0.025$ mol, and $m = 0.025 \times 2 = \mathbf{0.050 \text{ g}}$.

How do you calculate percentage yield?

The **theoretical yield** is the mass of product the equation predicts. The **actual yield** is what you really collect. Some product is lost on filter paper, some reactant forms other substances, and some reactions do not go to completion, so the actual yield is almost always smaller.

Formula

$$\text{percentage yield} = (\text{actual yield} \div \text{theoretical yield}) \times 100$$

Both yields must use the same unit, usually grams.

Worked example

Heating 25.0 g of calcium carbonate: $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$. Chidi collects 11.2 g of calcium oxide (Ar: Ca = 40, C = 12, O = 16).

$n(\text{CaCO}_3) = 25.0 \div 100 = 0.250 \text{ mol}$, so $n(\text{CaO}) = 0.250 \text{ mol}$ and the theoretical yield is $0.250 \times 56 = 14.0 \text{ g}$. Percentage yield = $11.2 \div 14.0 \times 100 = \mathbf{80\%}$.

Common mistake

Do not divide the actual yield by the mass of the *reactant*. Compare the actual mass of product only with the theoretical mass of the *same* product.

How do you calculate concentration in mol/dm³?

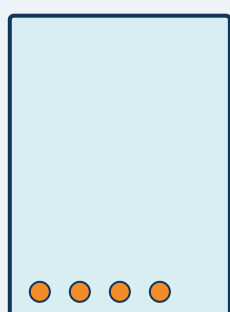
Concentration tells you how many moles are dissolved in each cubic decimetre ($1 \text{ dm}^3 = 1000 \text{ cm}^3$) of solution. A solution that is twice as concentrated holds twice as many particles in the same volume.

Formula

$$c = n \div V \text{ and } n = c \times V$$

c = concentration (mol/dm³), n = amount (mol), V = volume (dm³ = cm³ ÷ 1000). In g/dm³: concentration = mass ÷ volume.

Each orange dot stands for 0.05 mol of dissolved solute



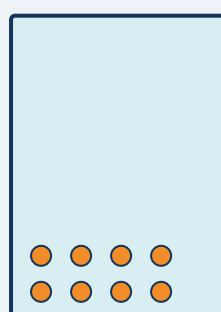
1.0 dm³, 4 dots

0.20 mol/dm³



0.5 dm³, 4 dots

0.40 mol/dm³



1.0 dm³, 8 dots

0.40 mol/dm³

Concentration rises when you add more solute or use less solution.

Quantity	Unit	How to get it
Amount	mol	$m \div M$
Volume	dm ³	$\text{cm}^3 \div 1000$
Concentration	mol/dm ³	$n \div V$
Mass concentration	g/dm ³	$c \times M$

Worked example

Kofi dissolves 4.0 g of sodium hydroxide in water and makes the volume up to 250 cm³ (Ar: Na = 23, O = 16, H = 1).

$n = 4.0 \div 40 = 0.10 \text{ mol}$. $V = 0.250 \text{ dm}^3$. $c = 0.10 \div 0.250 = \mathbf{0.40 \text{ mol/dm}^3}$, which is 0.40

$$\times 40 = 16 \text{ g/dm}^3.$$

Lina's tip

Write the amount in moles under every formula in the equation before you calculate anything. Then you can see the ratio, the limiting reactant and the target at a glance.

Key points to remember

- $n = m \div M$, with M in g/mol
- The coefficients give the mole ratio, not the mass ratio
- Limiting reactant: smallest (moles $\div$ coefficient)
- Percentage yield = actual $\div$ theoretical $\times 100$
- $c = n \div V$, with V in dm^3 ($\text{cm}^3 \div 1000$)

Using equations to find masses and yields: frequently asked questions

What is a mole ratio?

A mole ratio is the proportion of the coefficients in a balanced equation. In $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$, magnesium, oxygen and magnesium oxide react and form in the ratio 2 : 1 : 2.

How do I find the limiting reactant?

Convert each reactant to moles and divide by its coefficient. The reactant with the smallest value runs out first and is limiting. All product calculations then use its moles.

Why can percentage yield never be above 100%?

The theoretical yield is the most product the reactants can form. If you measure more than 100%, the product is probably wet, impure or contaminated by another substance.

How do I convert cm^3 to dm^3 ?

Divide by 1000. For example, 25.0 cm^3 is 0.0250 dm^3 . Concentration in mol/dm^3 is only correct when the volume is in dm^3 .

How do I change g/dm^3 into mol/dm^3 ?

Divide the mass concentration by the molar mass. A solution of 16 g/dm^3 sodium hydroxide, with $M = 40 \text{ g/mol}$, is 0.40 mol/dm^3 .