

Moles, isotopes and chemical formulas

AP Chemistry · Lesson

Quick answer: A mole is 6.022×10^{23} particles, and its mass in grams is the molar mass M , so $n = m/M$ links mass to amount. Mass spectra give isotope masses and abundances for the average atomic mass. Mole ratios from percent composition or mass data give empirical formulas.

Level: AP Chemistry · **Curriculum:** AP Chem Unit 1

What is a mole and why do chemists use it?

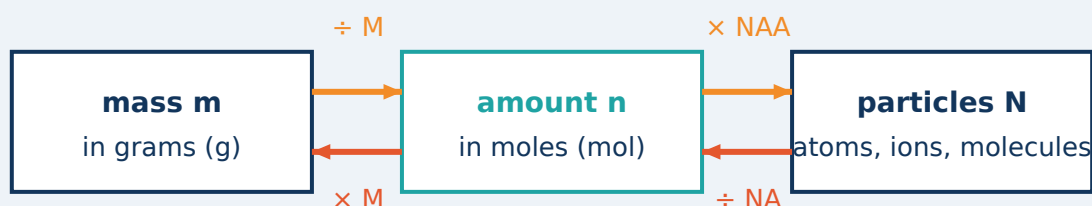
Definition

One mole is the amount of substance that contains 6.022×10^{23} elementary entities, the Avogadro constant N_A . The molar mass M of a substance is the mass of one mole, in g/mol, and equals the formula mass in atomic mass units.

Atoms are far too small to count one by one, so chemists count them in huge, fixed bunches. A mole of carbon-12 atoms has a mass of exactly 12 g, and every other molar mass follows from the atomic masses on the periodic table.

Formula

$n = m/M$ and $N = n \times N_A$, where n is the amount in mol, m the mass in g, M the molar mass in g/mol and N the number of particles.



M = molar mass in g/mol, $N_A = 6.022 \times 10^{23}$ per mol

The mole bridge: moles sit in the middle between mass and number of particles.

Worked example

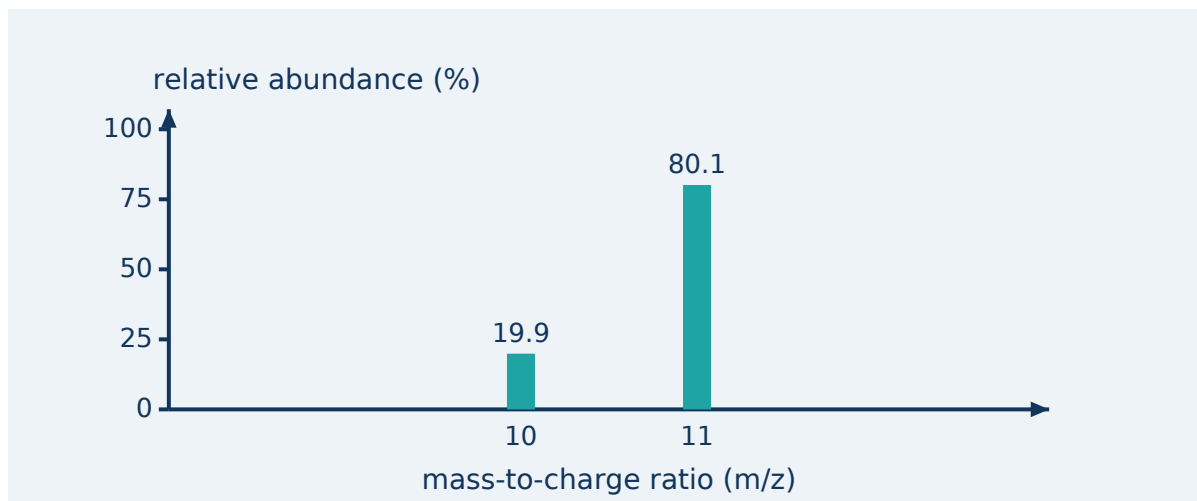
Find the amount and number of formula units in 25.0 g of calcium carbonate, CaCO_3 . $M = 40.078 + 12.011 + 3(15.999) = 100.09$ g/mol. Then $n = 25.0/100.09 = \mathbf{0.250 \text{ mol}}$ and $N = 0.250 \times 6.022 \times 10^{23} = \mathbf{1.50 \times 10^{23} \text{ formula units}}$.

How does a mass spectrum give an average atomic mass?

A mass spectrometer ionises atoms and sorts them by mass-to-charge ratio. For an element, every peak is one isotope. The peak position gives the isotope's mass and its height gives the relative abundance. The average atomic mass is the weighted mean of the isotope masses.

Key law

Average atomic mass = Σ (fractional abundance $\times$ isotope mass). The fractions must add up to 1, or the percentages to 100.



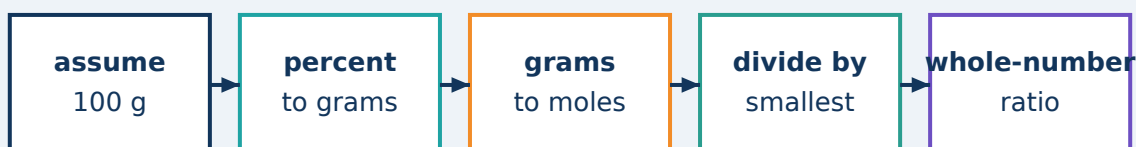
Mass spectrum of boron: two isotopes, so two peaks whose heights give the abundances.

Worked example

Boron has ^{10}B (10.013 u, 19.9 %) and ^{11}B (11.009 u, 80.1 %). Average = $0.199 \times 10.013 + 0.801 \times 11.009 = 1.993 + 8.818 = \mathbf{10.81 \text{ u}}$. The result sits near 11 because the heavier isotope dominates.

How do you find an empirical formula?

The empirical formula is the simplest whole-number ratio of atoms in a compound. The molecular formula is a whole-number multiple of it, found by dividing the true molar mass by the empirical formula mass.



Empirical formula route: always convert to moles before comparing atoms.

Worked example

A liquid is 52.2 % C, 13.0 % H and 34.8 % O by mass. In 100 g: C = $52.2/12.011 = 4.35$ mol, H = $13.0/1.008 = 12.9$ mol, O = $34.8/15.999 = 2.18$ mol. Dividing by 2.18 gives 2.0 : 5.9 : 1.0, which rounds to 2 : 6 : 1. The empirical formula is **C₂H₆O**.

Quantity	Symbol	Unit	Link
Amount of substance	n	mol	$n = m/M$
Molar mass	M	g/mol	$M = m/n$
Number of particles	N	none	$N = n N_A$
Mass percent	%	none	part/whole × 100

How do you work with mixtures?

A mixture holds two or more substances that keep their own properties and can be present in any proportion. A pure substance has fixed composition. To find the composition of a mixture, measure a mass change or product that depends on only one component, convert to moles of that component, then convert back to a mass. Mass percent of a component is its mass divided by the total mass of the mixture, times 100.

Common mistake

Students compare masses of elements instead of moles when finding a formula. Atoms of different elements have different masses, so only mole ratios give atom ratios.

Worked example

Heating 5.00 g of blue crystals of copper(II) sulfate leaves 3.20 g of white solid. The 1.80 g lost is water: $1.80/18.015 = 0.100$ mol. The solid is CuSO₄ (159.61 g/mol): $3.20/159.61 = 0.0200$ mol. The ratio is $0.100/0.0200 = 5$, so the crystals are **CuSO₄·5H₂O**.

Lina's tip

Before any mole problem, write the molar mass first and check the unit g/mol. Then ask: am I going from grams to moles (divide) or moles to grams (multiply)?

Key points to remember

- $n = m/M$ and $N = n \times 6.022 \times 10^{23}$
- Average atomic mass = Σ (fraction × isotope mass)
- Empirical formula: percent to grams, grams to moles, divide by smallest
- Molecular formula = empirical formula × (M / empirical mass)
- Mass percent = (part / whole) × 100

Moles, isotopes and chemical formulas: frequently asked questions

What is a mole in chemistry?

A mole is 6.022×10^{23} particles of a substance. Its mass in grams equals the formula mass in atomic mass units, which is why molar masses are read from the periodic table.

How do you convert grams to moles?

Divide the mass in grams by the molar mass in g/mol: $n = m/M$. Multiply the result by 6.022×10^{23} per mol if you also need the number of particles.

How is average atomic mass found from a mass spectrum?

Multiply each isotope mass by its fractional abundance from the peak height, then add the results. The mean is not a whole number.

What is the difference between empirical and molecular formulas?

The empirical formula gives the simplest whole-number atom ratio. The molecular formula is a whole-number multiple of it that matches the real molar mass.

How do you find the percent of a component in a mixture?

Use a measurement that depends on only one component, convert it to the mass of that component, and divide by the total mass of the mixture. Multiply by 100.