4 The Mole and Chemical Formulas

A tablespoon of water holds about 5×10^{23} molecules. Counting them at one per second would take roughly a million times the age of the universe. So chemists do not count; they weigh, the way a bank weighs a bag of coins instead of counting it. The mole is the conversion between the mass you can measure and the number you cannot. The mock exam gives this chapter 8 of its 70 questions.

4.1 The Mole and Avogadro's Number

Atoms are far too small to count one at a time, so chemists count them by weighing. A hardware store sells screws by the pound and never counts them, because the weight of one screw turns a total weight into a count. A chemist does the same with atoms, using a counting unit large enough to weigh on a balance.

Mole
An amount of substance. One mole holds 6.022×10^{23} particles.

That unit is the **mole**. One mole is 6.022×10^{23} particles, a number called **Avogadro's number**, N_A. A mole is a count, like a dozen, and it applies to anything: atoms, molecules, ions, or marbles.

Particle
Whatever the formula names: atoms for Cu, molecules for H_2O, formula units for NaCl.

The size of the mole is chosen so that the mass of one mole of an element, in grams, has the same number as the mass of one atom in **atomic mass units**. The atomic mass unit, u, is one twelfth of the mass of a carbon-12 atom. The average carbon atom is 12.01 u, so one mole of carbon atoms is 12.01 g. This is why the atomic masses on the periodic table also serve as molar masses in g/mol.

Name the particle before you count. One mole of O_2 is 6.022×10^{23} molecules, and that is 1.204×10^{24} atoms, because each molecule holds two atoms.

One mole of	contains
Cu	6.022×10^{23} Cu atoms
O_2	6.022×10^{23} O_2 molecules, or 1.204×10^{24} O atoms
NaCl	6.022×10^{23} formula units: the same number of Na^+ ions and of Cl^- ions

RULE One mole is 6.022×10^{23} particles, and its mass in grams is the molar mass.

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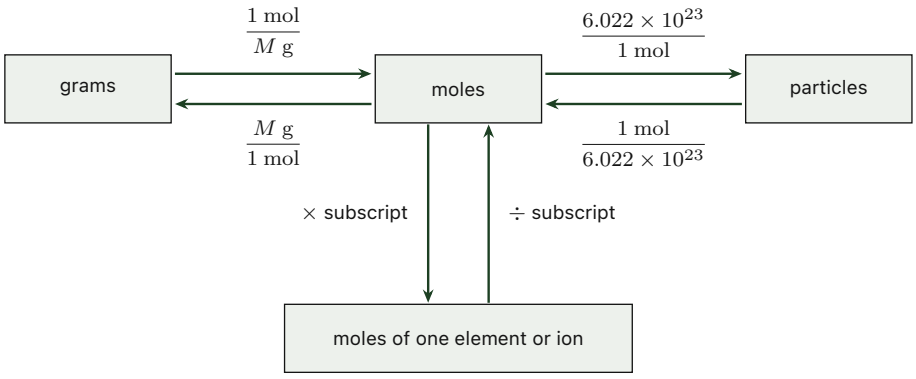
4.2 Molar Mass and the Conversion Map

Molar mass
The mass of one mole, in g/mol. Symbol M.

Every mass measurement is a measurement of a huge number of particles. **Molar mass** links the two. For a compound, add the atomic masses of every atom in the formula. A subscript multiplies the symbol before it, and a subscript after a closing parenthesis multiplies everything inside. For $Ca(OH)_2$:

$$M = 40.08 + 2(16.00) + 2(1.008) = 74.10\ \text{g/mol}.$$

Every conversion in this chapter passes through moles. Grams cannot be counted directly, and particles cannot be weighed directly. Moles connect them. The molar mass factor changes with the substance. Avogadro's number never changes.



EXAMPLE 4.1

How many molecules are in $5.00\,\text{g}$ of ethanol, C_2H_6O?

What is asked A count of molecules, from a mass.

Molar mass $M = 2(12.01) + 6(1.008) + 16.00 = 46.07$ g/mol

Grams to moles $5.00\,\text{g} \times \dfrac{1\ \text{mol}}{46.07\ \text{g}} = 0.1085$ mol

Moles to molecules $0.1085\ \text{mol} \times 6.022 \times 10^{23} = 6.54 \times 10^{22}$ molecules

Check Under half a mole of molecules, so the count is under 3×10^{23}.

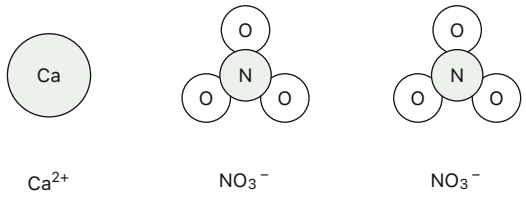
Answer 6.54×10^{22} **molecules**

4.3 Formulas as Mole Ratios

Formula unit
The smallest repeating group of an ionic compound, such as $CaCl_2$.

A formula states how many of each part are in one unit of the substance. Each **formula unit** of $Ca(NO_3)_2$ is made of one Ca^{2+} ion and two NO_3^- ions, and together those ions hold 1 Ca, 2 N and 6 O. A mole of formula units is a mole of those groups, so the same numbers count moles: 1 mol Ca, 2 mol N, 6 mol O. The subscripts are mole ratios.

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Ca^{2+} NO_3^- NO_3^-

One formula unit: 1 Ca, 2 N, 6 O. That is 9 atoms and 3 ions.

One mole: 1 mol Ca, 2 mol N, 6 mol O.

An ionic compound gives ions. Each formula unit of $Ca(NO_3)_2$ gives one Ca^{2+} and two NO_3^-, three ions in all. Most misses here come from counting atoms when the question asks for ions, or the reverse.

Ion count
A polyatomic ion is one ion that holds several atoms. Say which you are counting.

RULE Moles of X equal moles of compound times the number of X in one formula unit.

EXAMPLE 4.2

How many sulfate ions are in $12.0\,\text{g}$ of $Fe_2(SO_4)_3$?

What is asked Sulfate ions, not atoms.

Molar mass $M = 2(55.85) + 3(32.06) + 12(16.00) = 399.88$ g/mol

Moles of compound $12.0/399.88 = 0.03001$ mol $Fe_2(SO_4)_3$

Mole ratio Three SO_4^{2-} per formula unit: $0.03001 \times 3 = 0.09003$ mol

To ions $0.09003 \times 6.022 \times 10^{23} = 5.42 \times 10^{22}$ ions

Check One formula unit has 17 atoms ($2+3+12$) but only 3 sulfate ions, so the ion count is 3 times the formula-unit count, not 17 times.

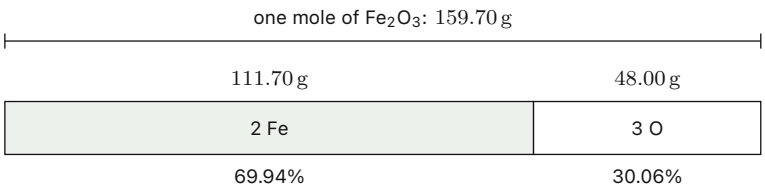
Answer 5.42×10^{22} **sulfate ions**

4.4 Percent Composition

Mass percent does not depend on sample size, so use one mole as the sample. In one mole, an element's mass is its subscript times its atomic mass, and the whole is the molar mass.

Mass percent
The share of a compound's mass that comes from one element.

$$\%\text{ of element} = \frac{(\text{subscript}) \times (\text{atomic mass})}{M\text{ of compound}} \times 100$$



The mass of an element in a sample is its mass percent, as a fraction, times the mass of the sample.

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PRACTICE SET 4A 12 questions · 18 minutes · calculator

1. Each sample has a mass of $2.00\,\text{g}$. Which sample contains the greatest number of atoms?

(A) He **(B)** CH_4 **(C)** H_2O **(D)** N_2

2. A flask holds $1.00\,\text{mol}$ of O_2. A second flask holds $1.00\,\text{mol}$ of O_3. Which quantity is the same for both flasks?

(A) Total mass
(B) Number of oxygen atoms
(C) Number of electrons
(D) Number of molecules

3. What is the molar mass of $Al_2(SO_4)_3$?

(A) $342.14\,\text{g/mol}$
(B) $315.16\,\text{g/mol}$
(C) $214.14\,\text{g/mol}$
(D) $150.02\,\text{g/mol}$

4. What is the mass of one atom of zinc?

(A) $65.38\,\text{g}$
(B) $9.21 \times 10^{21}\,\text{g}$
(C) $1.09 \times 10^{-22}\,\text{g}$
(D) $3.94 \times 10^{25}\,\text{g}$

5. How many moles of $NaHCO_3$ are in $12.5\,\text{g}$?

(A) $0.240\,\text{mol}$
(B) $0.149\,\text{mol}$
(C) $6.72\,\text{mol}$
(D) $1.05 \times 10^{3}\,\text{mol}$

6. Which sample contains the same number of molecules as $8.00\,\text{g}$ of CH_4?

(A) $8.00\,\text{g}$ of O_2
(B) $14.0\,\text{g}$ of N_2
(C) $8.00\,\text{g}$ of N_2
(D) $14.0\,\text{g}$ of CO_2

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