

# Lecture Notes: The Mole Concept

Structured notes on the mole, the Avogadro constant, molar mass, and converting between mass, moles and number of particles.

●○○ Beginner

## Learning objectives

By the end of these notes you should be able to:

1. Explain what a mole is and why chemists use it.
2. State the value of the Avogadro constant and how the mole is defined.
3. Calculate the molar mass of an element or compound from its formula.
4. Convert between mass, amount (moles) and number of particles.
5. Work out the number of moles of atoms of each element in a given amount of a compound.

## 1. Why chemists need a counting unit

Chemical reactions happen between individual atoms, molecules and ions. A balanced equation therefore tells us how many *particles* react. Particles are far too small to count directly, so we need a way to count them by weighing.

Everyday life already uses counting units for large numbers of small things: a *dozen* eggs (12), a *ream* of paper (500 sheets). Chemistry uses the **mole**, a much larger number suited to atoms.

## 2. The mole and the Avogadro constant

- One **mole** (symbol **mol**) of a substance contains  $6.022 \times 10^{23}$  specified particles.
- The particles must always be stated: atoms of Na, molecules of  $\text{H}_2\text{O}$ , formula units of NaCl, ions of  $\text{Cl}^-$ .
- The **Avogadro constant** is  $N_{\text{A}} = 6.022 \times 10^{23} \text{ mol}^{-1}$ .
- The quantity measured in moles is called **amount of substance**, symbol  $n$ .

### 🔍 MORE PRECISELY: The SI definition

Since 2019 the mole has been defined by fixing the Avogadro constant at exactly  $6.022\,140\,76 \times 10^{23} \text{ mol}^{-1}$ . The older definition, the number of atoms in exactly 12 g of carbon-12, still appears in many textbooks. The two agree to far more digits than any calculation in these notes needs.

### 3. Molar mass

The **molar mass**  $M$  of a substance is the mass of one mole of it, in **g/mol**.

**Key fact:** the molar mass in g/mol has the same numerical value as the atomic mass or formula mass in atomic mass units (u).

#### 3.1 Elements

Read the atomic mass from the periodic table:  $M(\text{C}) = 12.01 \text{ g/mol}$ ,  $M(\text{Na}) = 22.99 \text{ g/mol}$ .

For elements that exist as molecules, use the molecular formula:  $M(\text{O}_2) = 2 \times 16.00 = 32.00 \text{ g/mol}$  and  $M(\text{Cl}_2) = 2 \times 35.45 = 70.90 \text{ g/mol}$ .

#### 3.2 Compounds

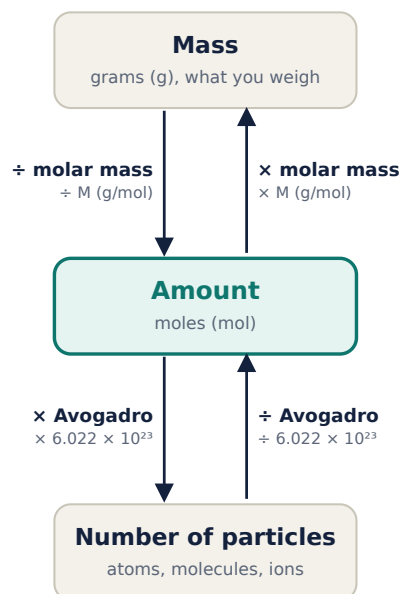
Add the atomic masses of every atom in the formula, multiplying by the subscripts:

| Formula                                       | Calculation                       | Molar mass   |
|-----------------------------------------------|-----------------------------------|--------------|
| H <sub>2</sub> O                              | $2(1.008) + 16.00$                | 18.02 g/mol  |
| NH <sub>3</sub>                               | $14.01 + 3(1.008)$                | 17.03 g/mol  |
| CaCO <sub>3</sub>                             | $40.08 + 12.01 + 3(16.00)$        | 100.09 g/mol |
| C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> | $6(12.01) + 12(1.008) + 6(16.00)$ | 180.16 g/mol |

For ionic compounds such as NaCl there are no molecules, so we speak of the mass of a **formula unit**. The calculation is the same:  $22.99 + 35.45 = 58.44 \text{ g/mol}$ .

### 4. The three-way conversion

Every conversion passes through moles:



Mass  $\rightleftharpoons$  moles  $\rightleftharpoons$  particles.

$$n = \frac{m}{M} \qquad N = n \times N_A$$

### Problem-solving routine

1. Write down what you are given, with units.
2. Find any molar mass you need.
3. Convert to moles first.
4. Convert from moles to what is asked.
5. Check that the units cancel and the answer is sensible.

### 4.1 Mass $\rightarrow$ moles

#### WORKED EXAMPLE: Moles of ammonia

How many moles are in 51.1 g of ammonia,  $\text{NH}_3$ ?

**Step 1**  $M(\text{NH}_3) = 17.03 \text{ g/mol}$

**Step 2**  $n = \frac{51.1 \text{ g}}{17.03 \text{ g/mol}} = 3.00 \text{ mol}$

## 4.2 Moles → mass

### WORKED EXAMPLE: Mass of calcium carbonate

What is the mass of 2.50 mol of calcium carbonate,  $\text{CaCO}_3$ ?

**Step 1**  $M(\text{CaCO}_3) = 100.09 \text{ g/mol}$

**Step 2**  $m = 2.50 \text{ mol} \times 100.09 \text{ g/mol} = 250. \text{ g (that is, } 2.50 \times 10^2 \text{ g)}$

## 4.3 Mass → particles

### WORKED EXAMPLE: Molecules of glucose

How many molecules are in 4.50 g of glucose,  $\text{C}_6\text{H}_{12}\text{O}_6$ ?

**Step 1**  $M = 180.16 \text{ g/mol}$

**Step 2**  $n = \frac{4.50}{180.16} = 0.02498 \text{ mol}$

**Step 3**  $N = 0.02498 \times 6.022 \times 10^{23} = 1.50 \times 10^{22} \text{ molecules}$

## 5. Moles of atoms inside a compound

The subscripts in a formula give the ratio of **moles of atoms** to **moles of compound**.

One mole of glucose,  $\text{C}_6\text{H}_{12}\text{O}_6$ , contains 6 mol of C atoms, 12 mol of H atoms and 6 mol of O atoms.

### WORKED EXAMPLE: Atoms of hydrogen in water

How many hydrogen atoms are in 0.250 mol of water?

**Step 1** Each  $\text{H}_2\text{O}$  contains 2 H atoms, so  $n(\text{H}) = 2 \times 0.250 = 0.500 \text{ mol}$

**Step 2**  $N(\text{H}) = 0.500 \times 6.022 \times 10^{23} = 3.01 \times 10^{23} \text{ atoms}$

### COMMON MISTAKE

Always ask “a mole of what?”. One mole of  $\text{O}_2$  is  $6.022 \times 10^{23}$  molecules but  $1.204 \times 10^{24}$  atoms. Write the formula, then count.

## 6. Significant figures

- Atomic masses from the periodic table usually carry four or more significant figures, so they rarely limit your answer.

- Your answer should normally have the same number of significant figures as the least precise *measured* value given (often a mass).
- Keep extra digits in intermediate steps and round only at the end.

## Summary

### REMEMBER THIS

- $1 \text{ mol} = 6.022 \times 10^{23}$  particles; always state the particles.
- Molar mass (g/mol) has the same number as the atomic or formula mass (u).
- $n = m/M$  and  $N = n \times N_A$ ; convert to moles first.
- Formula subscripts give moles of each kind of atom per mole of compound.

## Key terms

| Term                     | Meaning                                                                                                |
|--------------------------|--------------------------------------------------------------------------------------------------------|
| Mole (mol)               | The SI unit of amount of substance; $6.022 \times 10^{23}$ specified particles                         |
| Amount of substance, $n$ | The quantity measured in moles                                                                         |
| Avogadro constant, $N_A$ | $6.022 \times 10^{23} \text{ mol}^{-1}$                                                                |
| Molar mass, $M$          | Mass of one mole of a substance, in g/mol                                                              |
| Formula unit             | The smallest repeating unit of an ionic compound, e.g. one $\text{Na}^+$ and one $\text{Cl}^-$ in NaCl |