

# **Module 3: Representing Amounts of Substances**

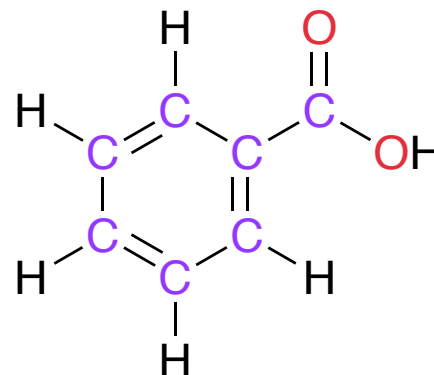
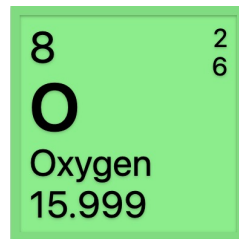
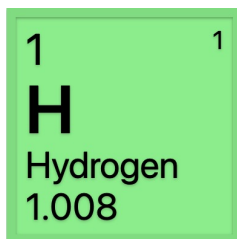
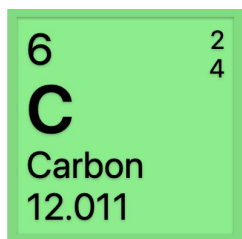
## The Mole and Molar Mass

Fundamentals of Chemistry Open Course

1. Explain the significance of Avogadro's number and why the value  $6.022 \times 10^{23} \text{ mol}^{-1}$  is a convenient definition of the mole.
2. Use average atomic masses to calculate the molar mass of a substance with given chemical formula.
3. Apply molar mass to determine amount of substance from mass and *vice versa*.
4. Define mass density and molar volume; apply them in calculations.
5. Visualize liquid solutions at the submicroscopic level; identify the components of a solution.
6. Define concentration and recognize common units of concentration.
7. Define molarity and apply it to calculate amount of solute from volume of a solution and *vice versa*.
8. Recognize quantities in the ideal gas law and their associated units.
9. Apply the ideal gas law to calculate the amount of a gas from pressure, volume, and temperature.

# How Much Does a Molecule Weigh?

- The **atomic mass unit (u, amu)** is defined as one twelfth the mass of a carbon-12 atom.
  - One carbon-12 atom weighs 12.00 u; other isotopic masses are measured with respect to this standard.
  - One atomic mass unit is equivalent to  $1.661 \times 10^{-24}$  g.
- **Average atomic masses** on the periodic table are averages of all known isotopes of an element, weighted by their relative abundance.
- Macroscopic samples of chemical substances, which contain a *very* large number of atoms, always reflect average atomic masses.
- The **formula mass** of a substance is the sum of the average atomic masses of all atoms in the chemical formula.

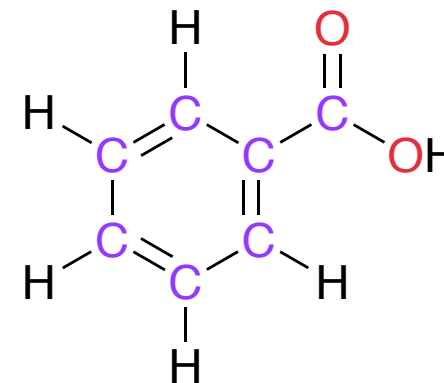


**benzoic acid**  
 $\text{C}_7\text{H}_6\text{O}_2$

$$\begin{aligned} &7(12.011 \text{ u}) \\ &+ 6(1.008 \text{ u}) \\ &+ 2(15.999 \text{ u}) = 123.123 \text{ u} \end{aligned}$$

- If we know the mass of a compound and the mass of one of the particles in the sample, we can use proportional reasoning to determine the *number* of particles in the sample.

**Example.** How many molecules are in a sample of benzoic acid weighing 5.00 grams?

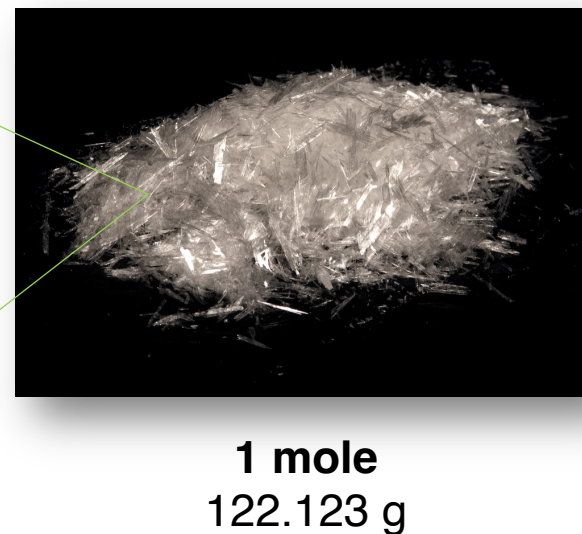
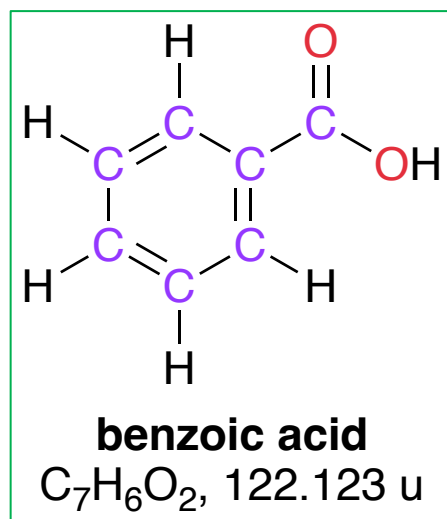


**benzoic acid**  
 $\text{C}_7\text{H}_6\text{O}_2$ , 122.123 u

- Macroscopic samples of compounds contain *huge* numbers of molecules.  
[We need a very large counting unit for molecules.](#)

# The Mole and Avogadro's Number

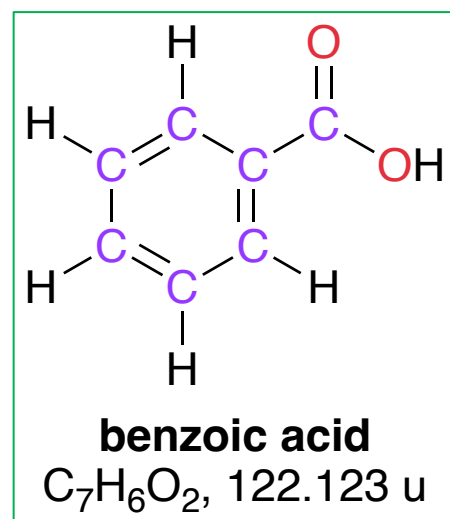
- The **mole (mol)** is the number of particles in a substance with a mass in grams equal numerically to the mass of a single particle in atomic mass units. **This is a highly convenient definition!**
- For example, 1 mole of benzoic acid has a mass of 122.123 grams.



- The mole is just a counting unit—a representation of a count of atoms, molecules, ions, photons, reactions, etc. Number of particles in a substance (measured in moles) is referred to formally as **amount of substance**.
- Using the mole, we can easily keep track of numbers of particles using macroscopic masses in grams.

# The Mole and Avogadro's Number

- One mole corresponds to a fixed number of particles: **Avogadro's number  $N_A$** .
- The number of particles in 1 mole is equal to the mass of 1 mole of a substance in grams divided by the formula mass *in grams*. For example, using benzoic acid,



**1 mole**  
122.123 g

$$N_A = \frac{122.123 \text{ g}}{122.123 \text{ u} \left( \frac{1.661 \times 10^{-24} \text{ g}}{1 \text{ u}} \right)} = 6.022 \times 10^{23}$$

- Thanks to the definition of the mole, Avogadro's number is the same for all substances.

- Avogadro's number has units of “[anything] per mole,” often represented as  $\text{mol}^{-1}$  or  $/\text{mol}$ .

$$N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$$

- The objects to which a count refers are typically clear from the context: molecules for a molecular compound, formula units for an ionic compound, reaction occurrences for thermodynamic quantities, etc.
- However, when working with mole units, including a chemical formula after “mol” is **strongly advised**. This formula answers the vital question: “moles of *what*?”
- Avogadro's number is used to “convert” from an absolute count to units of moles and *vice versa*.

- The mole is significantly more convenient than an absolute count when working with macroscopic substances or reactions.

**Example.** We previously calculated the absolute count of molecules in a 5.00-gram sample of benzoic acid. What is this count in units of moles?

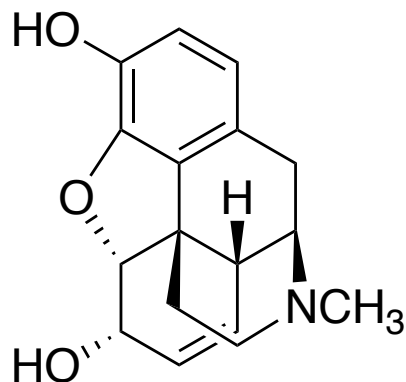
**Example.** What is the absolute count of formula units in 2.50 mol  $\text{CaCO}_3$ ?



# Molar Mass: How Much Does a Mole Weigh?

- From the definition of the mole, it follows that the **molar mass** of any substance in grams (for 1 mole) is numerically equal to the formula mass of the substance in atomic mass units (for 1 particle).
- Thus, we can apply our known method for calculating formula mass to determine molar mass as well.
  - Average atomic masses on the periodic table are also molar masses (just a change of units).
  - The molar mass of a substance is the sum of the molar masses of all atoms in its chemical formula.
- Molar mass has units of grams per mole (g/mol or g mol<sup>-1</sup>).

**Example.** What is the molar mass of morphine, which has the molecular formula C<sub>17</sub>H<sub>19</sub>NO<sub>3</sub>?



**morphine**  
C<sub>17</sub>H<sub>19</sub>NO<sub>3</sub>

- Can the mole and Avogadro's number be defined with respect to a mass unit other than the gram?
- What about substances dissolved in solutions and other substances that we can't weigh?  
How do we count particles of these substances?
- How are moles used in planning and carrying out chemical reactions?