4.2: The mole

Avogadro's number and mole

The Avogadro's number

The Avogadro's number is equal to $6.02214076 \times 10^{23}$ exact.

Just like the dozen is equal to 12, the Avogadro's number $6.02214076 \times 10^{32}$ is exact by definition, but usually, 6.022×10^{23} is used in calculations with 4 significant figures.

Mole (mol)

The mole is a SI unit of the amount of a substance that is equal to $6.02214076 \times 10^{23}$ particles of the substance.

The particle of a substance are usually atoms, ions, or molecules. For example, $6.02214076 \times 10^{23}$ atoms of ${}^{12}_{6}\mathrm{C}$ isotope is one mole of ${}^{12}_{6}\mathrm{C}$. The number $6.02214076 \times 10^{32}$ is exact by definition, but usually, 6.022×10^{23} is used with 4 significant figures.

One mole of a substance is equal to one Avogadro's number of atoms, molecules, or formula units of the substance. i.e.,

$$1 \text{ Avogadro's number of particles } = 1 \text{ mol} = 6.022 \times 10^{23} \text{ particles}$$

, where particles are atoms, molecules, or formula units in chemistry.

The equality between Avogadro's number and mole gives two conversion factor:

$$\frac{6.022 \times 10^{23} \text{ particles}}{1 \text{ mol}} \quad \text{and} \quad \frac{1 \text{ mol}}{6.022 \times 10^{23} \text{ particles}}$$

, where the first factor is used to convert a number of moles to a number of particles and the second for a number of particles to number moles conversions, as explained in the following examples.

Example 4.2.1

How many aspirin ($C_9H_8O_4$ molecules are in 0.0139 mol of aspirin?

Solution

Step 1. Write the given quantity and the desired quantity.

Given: 0.0139 mol ($C_9H_8O_4$, Desired: ? molecules of ($C_9H_8O_4$

Step 2. Write the two conversion factors from equality between the given and the desired quantity.

$$\frac{6.022 \times 10^{23} \text{ particles}}{1 \text{ mol}} \quad \text{and} \quad \frac{1 \text{ mol}}{6.022 \times 10^{23} \text{ particles}}$$

Step 3. Multiply the given quantity with the conversion factor that cancels the given unit and leaves the desired unit in the answer.

$$0.0139 \;\; \text{mol } \cancel{C_9H_8O_4} \times \frac{6.022 \times 10^{23} \text{ molecules } C_9H_8O_4}{1 \;\; \text{mol } \cancel{C_9H_8O_4}} = 8.37 \times 10^{21} \text{ molecules } C_9H_8O_4$$

Example 4.2.2

How many moles of aspirin (($C_9H_8O_4$) are in 9.50×10^{25} molecules of aspirin?

Solution

Step 1. Write the given quantity and the desired quantity.

Given: 9.50 x 10^{25} molecules of aspirin, Desired: ? mol of aspirin

Step 2. Write the two conversion factors from equality between the given and the desired quantity.

$$\frac{6.022\times 10^{23}\text{ particles}}{1\text{ mol}}\quad\text{and}\quad\frac{1\text{ mol}}{6.022\times 10^{23}\text{ particles}}$$

Step 3. Multiply the given quantity with the conversion factor that cancels the given unit and leaves the desired unit in the answer.

$$9.50\times 10^{25}\ \cancel{\text{molecules } C_9H_8O_4}\times\frac{1\text{ mol } C_9H_8O_4}{6.022\times 10^{23}\ \cancel{\text{molecules } C_9H_8O_4}}=158\text{ mol } C_9H_8O_4$$

Moles of elements in a mole of a compound

Moles of an element in a mole of a compound is equivalent to atoms of the element in a molecule or formula unit of the compound. For example in 1 mole of glucose ($C_6H_{12}O_6$) there are 6 moles of carbon, 12 moles of hydrogen, and 6 moles of oxygen. Each of these equalities between a mole of a substance and the moles of the element in it gives two conversion factors for the calculations.

✔ Example 4.2.3

How many moles of hydrogen are in 3.0 moles of glucose ($C_6H_{12}O_6$)?

Solution

Step 1. Write the given quantity and the desired quantity.

Given: 3.0 moles of ($C_6H_{12}O_6$), Desired: ? mol of H

Step 2. Write the two conversion factors from equality between the given and the desired quantity.

$$\frac{12\ mol\ H}{1\ mol\ C_6H_{12}O_6}\quad\text{and}\quad\frac{12\ mol\ \mathrm{C_6H_{12}O_6}}{1\ mol\ H}$$

Step 3. Multiply the given quantity with the conversion factor that cancels the given unit and leaves the desired unit in the answer.

$$3.0\ \cancel{\text{mol } C_6H_{12}O_6}\times\frac{12\text{ mol H}}{1\ \cancel{\text{mol } C_6H_{12}O_6}}=36\ mol\ H$$

✔ Example 4.2.4

Calculate the moles of oxygen are in 0.50 mole of $Ca(NO_3)_2$?

Solution

Step 1. Write the given quantity and the desired quantity.

Given: 0.50 moles of $Ca(NO_3)_2$, Desired: ? mol of O

Step 2. Write the two conversion factors from equality between the given and the desired quantity. Note that NO_3^- is polyatomic ion that has three oxygen atoms in it. There are two NO_3^- in the formula unit as shown by subscript 2 outside the bracket enclosing the polyatomic anion (\ce{NO3^-}\). So, the equality is:

1 mole $Ca(NO_3)_2$ = 6 mole O,

and the two conversion factors from the equality are:

$$\frac{1\ mol\ \mathrm{Ca(NO_3)_2}}{6\ mol\ O}\quad\text{and}\quad\frac{6\ mol\ O}{1\ mol\ \mathrm{Ca(NO_3)_2}}$$

Step 3. Multiply the given quantity with the conversion factor that cancels the given unit and leaves the desired unit in the answer.

$$0.50\ mol\ \cancel{\mathrm{Ca(NO_3)_2}} \times \frac{6\ mol\ O}{1\ mol\ \cancel{\mathrm{Ca(NO_3)_2}}} = 3.0\ mol\ O$$

Molar mass

The mass of one mole of a substance, in $\frac{g}{mol}$, is called the molar mass.

Recall that one mole = 1 Avogadro's number, i.e., 6.022×10^{23} atoms, molecules, or formula units of a substance. Fig. 4.2.1 helps in visualizing the molar masses of aluminum, copper, and carbon. The molar mass of an element or a compound is a reasonable quantity to be measured on an analytical balance commonly available in laboratories, while the mass of an individual atom or molecule is too small to be easily measured. That is why the mole is commonly used in stoichiometric calculations.

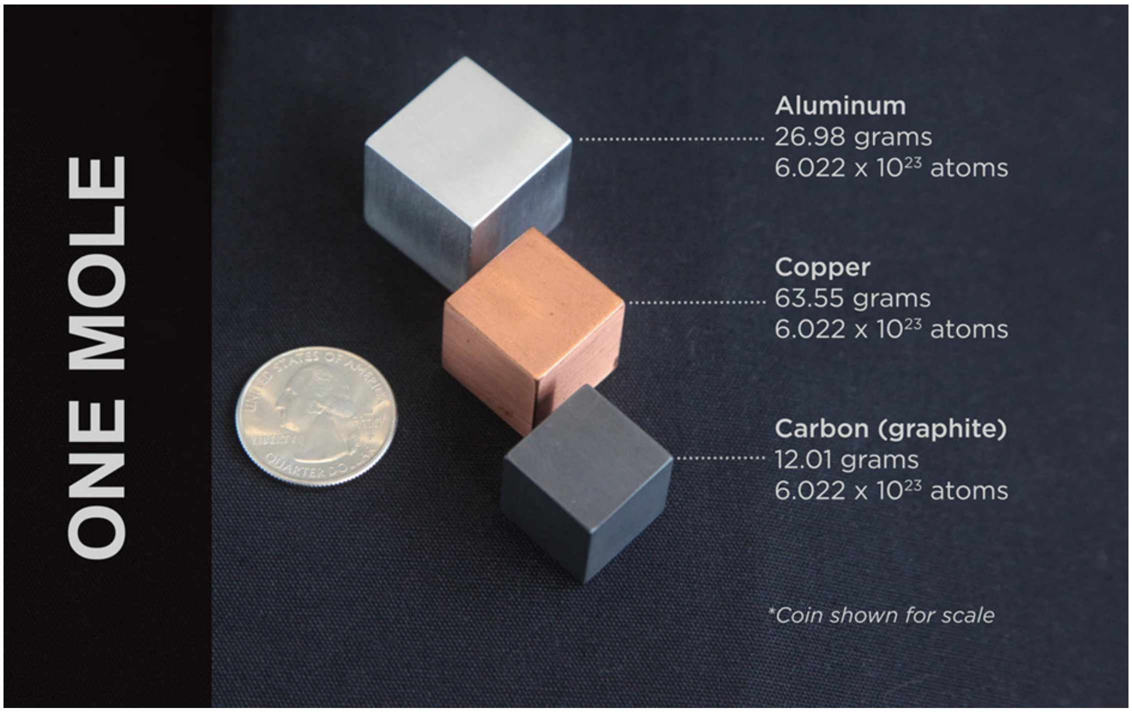

Figure 4.2.1: A mole of aluminum, copper, and carbon visualized. Source: photo: R. Press/NIST; graphic design: N. Hanacek/NIST

The molar mass of atoms of an element

The atomic mass listed in the periodic table is the molar mass of atoms of the element in $\frac{g}{mol}$. For example, the atomic mass of H listed in the periodic table is 1.008, so the molar mass of H is 1.008 $\frac{g}{mol}$. Similarly, the atomic mass of O listed in the periodic table is 15.999, and the molar mass of O is 15.999 $\frac{g}{mol}$.

The molar mass of molecules of an element

The molar mass of molecules of an element is the sum of atomic mass of atoms in the molecule expressed in $\frac{g}{mol}$. For example, the molar mass of H_2 is 1.008 $\frac{g}{mol}$ + 1.008 $\frac{g}{mol}$ = 2.016 $\frac{g}{mol}$.

The molar mass of a compound

The molar mass of a compound is the sum of the atomic masses of all the atoms in the molecular formula or formula unit of the compound. For example, the molar mass of water (H_2O) is the sum of the molar mass of two hydrogen atoms + the molar mass of one oxygen atom, i.e., 2x1.008 $\frac{g}{mol}$ H + 15.999 $\frac{g}{mol}$ O = 18.02 $\frac{g}{mol}$ H_2O. In other words, to calculate the molar mass of a compound, take the atomic masses of the constituent elements from a periodic table, multiply them with the number of atoms of the element in the formula of the compound, and then add these numbers, as explained in the following examples. Note that the unit $\frac{g}{mol}$ can also be written as: $g.mol^{-1}$.

Example 4.2.5

Calculate the molar mass of NaOH?

Solution

Step 1. Find the atomic masses of the constituent elements from the periodic table.

Na = 22.990 g.mol^{-1}, O = 15.999 g.mol^{-1}, H = 1.008 g.mol^{-1}.

Step 2. Multiply the atomic masses with the number of atoms in the fourmula.

1x22.990 g.mol^{-1} Na, 1x15.999 g.mol^{-1}O, 1x1.008 g.mol^{-1} H.

Step 3. Add all the numbers from step 2.

1x22.990 g.mol^{-1} Na + 1x15.999 g.mol^{-1}O + 1x1.008 g.mol^{-1} H = 39.997 g.mol^{-1} NaOH

Example 4.2.6

Calculate the molar mass of $Ca(NO_3)_2$?

Solution

Step 1. Find the atomic masses of the constituent elements from the periodic table.

Ca = 40.078 g.mol^{-1}, N = 14.007 g.mol^{-1}, O = 15.999 g.mol^{-1}.

Step 2. Multiply the atomic masses with the number of atoms in the formula. (Note that there are two NO_3 units in $(NO_3)_2$?, To get the total number of atoms, multiply the subscript outside the bracket with the subscript to the element symbol inside the bracket to get the total number of atoms. That is, there are 1x2 = 2 N and 3x2 = 6 O in this compound.

1x40.078 g.mol^{-1} Ca, 2x14.007 g.mol^{-1} N, 6x15.999 g.mol^{-1} O.

Step 3. Add all the numbers from step 2.

1x40.078 g.mol^{-1} Ca + 2x14.007 g.mol^{-1}N + 6x15.999 g.mol^{-1} O = 164.008 g.mol^{-1} $Ca(NO_3)_2$.

Conversion from grams to moles and moles to grams of a substance

The molar mass in $\frac{g}{mol}$ is a conversion factor converting the amount of a substance in moles to the mass of the substance in grams. Reciprocal of the molar mass in $\frac{mol}{g}$ is a conversion factor converting the mass of a substance in grams to the amount of the substance in moles. The conversions are explained in the following examples.

Example 4.2.7

How many grams of water are in 2.50 moles of water?

Solution

Step 1. Write the given quantity and the desired quantity.

Given: 2.50 moles H_2O, Desired: ? g H_2O

Step 2. Calculate the molar mass of the substance.

2x1.008 g.mol^{-1} H + 15.999 g.mol^{-1} O = 18.02 g.mol^{-1} H_2O.

Step 3. Write the molar mass of the substance, and it's reciprocal as the two conversion factors.

$$\frac{18.02\ g\ \mathrm{H_2O}}{1\ \mathrm{mol\ H_2O}} \quad \text{and} \quad \frac{1\ \mathrm{mol\ H_2O}}{18.02\ g\ \mathrm{H_2O}}$$

Step 4. Multiply the given quantity with the conversion factor that cancels the given unit and leaves the desired unit in the answer.

$$2.50 \ \text{mol } \cancel{H_2O} \times \frac{18.02 \text{ g } H_2O}{1 \ \text{mol } \cancel{H_2O}} = 45.1 \text{ g } H_2O$$

Example 4.2.8

How many moles are present in 2.50 g of aspirin? (Aspirin $C_9H_8O_4$, molar mass 180.2 g.mol^{-1})

Solution

Step 1. Write the given quantity and the desired quantity.

Given: 2.50 g $C_9H_8O_4$, Molar mass of $C_9H_8O_4$ = 180 g.mol^{-1}, Desired: ? g H_2O

Step 2. Calculate the molar mass of the substance.: given 180.2 g.mol^{-1}

Step 3. Write the molar mass of the substance, and it's reciprocal as the two conversion factors.

$$\frac{180 \ g \ C_9H_8O_4}{1 \ mol \ C_9H_8O_4} \quad \text{and} \quad \frac{1 \ mol \ C_9H_8O_4}{180 \ g \ C_9H_8O_4}$$

Step 4. Multiply the given quantity with the conversion factor that cancels the given unit and leaves the desired unit in the answer.

$$2.5 \ \ g \ \cancel{C_9H_8O_4} \times \frac{1 \ mol \ C_9H_8O_4}{180 \ \ g \ \cancel{C_9H_8O_4}} = 0.0193 \ mol \ C_9H_8O_4$$

Example 4.2.9

How many moles of NaOH are in 10.0 g of NaOH?

Solution

Step 1. Write the given quantity and the desired quantity.

Given: 10.0 g NaOH, Desired: ?mol NaOH

Step 2. Calculate the molar mass of the substance.

22.99 g.mol^{-1} Na + 16.00 g.mol^{-1} O + 1.01 g.mol^{-1} H = 40.00 g.mol^{-1} NaOH.

Step 3. Write the molar mass of the substance and it's reciprocal as the two conversion factors.

$$\frac{40.00 \ g \ NaOH}{1 \ mol \ NaOH} \quad \text{and} \quad \frac{1 \ mol \ NaOH}{40.00 \ g \ NaOH}$$

Step 4. Multiply the given quantity with the conversion factor that cancels the given unit and leaves the desired unit in the answer.

$$10.0 \ \ g \ \cancel{NaOH} \times \frac{1 \ mol \ NaOH}{40.00 \ \ g \ \cancel{NaOH}} = 0.250 \text{ mol NaOH}$$

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