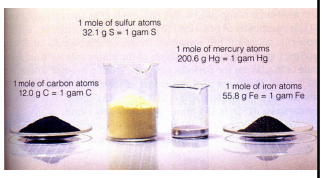
Chapter 3

Stoichiometry

University Chemistry

Molar mass and the mole

- one mole is defined as the number of carbon atoms in exactly 12.000000 grams of pure 12C.
- From the sugar example, a mole of $C_{12}H_{22}O_{11}$ would have a mass of 342.299 grams.
- This quantity is known as the **molar mass**, a term that is often used in place of the terms *atomic mass* or *molecular mass*.



Determine the molar mass of NaOH?

NaOH contains one Na atom + one oxygen atom + one hydrogen atom

Molar mass = 1 x mass of Na atom + 1 x mass of O atom + 1 x mass of H atom

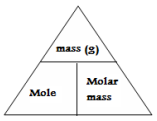
The masses of the elements can be obtained from the periodic table.

= 1 x 22.99 + 1 x 16.00 + 1 x 1.008 = 39.99 g

Molar mass of NaOH = 39.99 g

Number of moles

- **To determine the number of moles use the following formula or triangles:**



$$number\ of\ moles = \frac{mass\,(g)}{molar\ mass\,(g/mole)}$$

How many moles are there in 22.99 g of sodium?

$$\text{number of moles} = \frac{\text{mass (g)}}{\text{molar mass (g/mole)}} = \frac{22.99\,\text{g}}{22.99\,\text{g/mole (from the periodic table)}}$$

number of moles = 1 mole.

How many moles are there in 1 g of chlorine?

$$\text{number of moles} = \frac{\text{mass (g)}}{\text{molar mass (g/mole)}} = \frac{1\,\text{g}}{35.45\,\text{g/mole (from the periodic table)}}$$

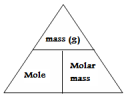
number of moles = 0.028 mole.

How many grams are there in 0.10 mole of CH_4?

First calculate the molar mass of CH_4

Molar mass of CH_4 = 1 x mass of C atom + 4 x mass of H atoms
= 1 x 12.01 + 4 x 1.008 = 16.02 g / mole

Then use the formula:



mass of CH_4 = number of moles × molar mass of CH_4
= 0.10 mole x16.02 g/ mole = 1.602 g

Which one is the lightest in mass: one mole of hydrogen, one mole of sodium, one mole of iron, one mole of sulfur?

One mole for an element contains the atomic mass of the element.
Atomic mass of H = 1.008 g / mole, Atomic mass of Na = 22.99 g / mole,
Atomic mass of Fe = 55.85 g / mole, Atomic mass of S = 32.07 g / mole.

The lightest one is one mole of hydrogen
The heaviest one mole is the iron.

• Avogadro's number and the mole

1 mole of anything contains the Avogadro 's Number (N_A) of this thing

Avogadro 's Number (NA) = *6.02214 x 10^{23}*

1 mole of particles= 6.02214 x 1023 particles for any substance

1 mole of shoes= 6.02214 x 1023 shoes

1 mole of cars = 6.02214 x 1023 car

1 mole of carbon atoms= 6.02214 x 1023 carbon atoms

1 mole of water molecules = 6.02214 x 1023 water molecules

Number of particles = number of moles x Avogadro's number

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To calculate the number of particles (atoms, molecules, shoes….etc) use the following formula:

Number of particles = number of moles x Avogadro's number

Calculate the number of atoms in 2 mole of hydrogen?

Number of hydrogen atoms =
2 moles of H x 6.02214 x 10^{23} H atom / mole

Number of hydrogen atoms = 1.20 x 10^{24} H atom

Calculate the number of atoms in 6.46 grams of helium (He)?

$$\text{number of moles} = \frac{\text{mass (g)}}{\text{molar mass (g/mole)}} = \frac{6.46\,\text{g}}{4.003\,\text{g/mole (from the periodic table)}}$$

number of moles = 1.61 mole.

Number of He atoms = number of moles × Avogadro's number
= 1.61 moles of He x 6.02214 x 10^{23} He atom / mole
= 9.66 x 10^{23} He atom

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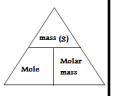
Caffeine is a stimulant drug and it is found in coffee, tea and beans. Its molecular formula is $C_8H_{10}N_4O_2$. Calculate the number of oxygen atoms in 19.40 grams of caffeine.

Molar mass of caffeine = 8 x C + 10 x H + 4 x N + 2 x O
= 8 x 12 + 10 x 1 + 4 x 14 + 2 x 16 = 194 g / mole

$$\text{number of moles} = \frac{\text{mass (g)}}{\text{molar mass (g/mole)}} = \frac{19.40\,\text{g}}{194\,\text{g/mole (from the periodic table)}}$$



number of moles = 0.10 mole

Total number of $C_8H_{10}N_4O_2$ molecules= number of moles x N_A
= 0.10 moles x 6.022 x 10^{23} molecules / mole

Total number of $C_8H_{10}N_4O_2$ molecules = 6.022 x 10^{22} molecules

$$\text{Number of oxygen atoms} = \frac{\text{number of oxygen atoms}}{\text{molecules}} \times \text{total number of molecules}$$

$$\text{Number of oxygen atoms} = \frac{2\ \text{oxygen atoms}}{\text{molecules}} \times 6.022 \times 10^{22}\ \text{molecules}$$

Number of oxygen atoms = 1.20 x 10^{23} oxygen atoms

Number of carbon atoms = 4.8 x 10^{23} carbon atoms
Number of hydrogen atoms = 6.022 x 10^{23} hydrogen atoms
Number of nitrogen atoms = 2.40 x 10^{23} nitrogen atoms

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Chemical Reactions

It is process in which one or more pure substances are converted into one or more different pure substance.

All chemical reactions involve a change in substances and a change in energy.

Neither matter nor energy is created or destroyed in a chemical reaction, only changed.

Chemical equation

- When a chemical reaction occurs, it can be described by an equation.
- This shows the chemicals that react (***reactants***) on the left-hand side, and the chemicals that they produce (***products***) on the right-hand side.

Reactants → **Reaction conditions** → **Products**

Reaction between hydrogen gas and oxygen gas to produce liquid water

hydrogen gas + oxygen gas → liquid water

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

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Balancing chemical equations

- first write the correct formula for both reactants and products and then **balance** all of the atoms on the left side of the reaction with the atoms on the right side.

Write the chemical equation which represents the burning of glucose in presence of oxygen gas which produces carbon dioxide and water.

To answer this question, follow the following steps:

1. ***Identify the reactants and the products and put an arrow in between.***

glucose + oxygen gas ⟶ carbon dioxide + water

2. Try to figure out the correct formula for the reactants and products,

Glucose is $C_6H_{12}O_6$, oxygen gas is O_2, carbon dioxide is CO_2, and water is H_2O.

$$C_6H_{12}O_6 + O_2 \longrightarrow CO_2 + H_2O$$

3.Count the number of each atom at both sides of the equation:

$$C_6H_{12}O_6 + O_2 \longrightarrow CO_2 + H_2O$$

(6 C + 12 H + 6 O) + (2 O) ⟶ (1C + 2 O) + (2H + 1 O)

Total: (6 C + 12 H + 8 O) ⟶ (1C + 2H + 3 O)

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Balance C first, then H, and finally O:

At the left side there are 6 C atoms and at the right side there are 1 C atom, so multiply CO_2 by 6 (x 6)

$$C_6H_{12}O_6 + O_2 \longrightarrow 6\ CO_2 + H_2O$$

At the left side there are 12 H atoms and at the right side there are 2 H atom, so multiply H_2O by 6 (x 6)

$$C_6H_{12}O_6 + O_2 \longrightarrow 6\ CO_2 + 6H_2O$$

At the left side there are 8 O atoms and at the right side there are 18 O atom, so multiply O_2 by 6 (x 6)

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6\ CO_2 + 6H_2O$$

Recount all atoms again,

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6\ CO_2 + 6H_2O$$

(6 C + 12 H + 6 O) + (12 O) (6C + 12 O) + (12H + 6 O)

Total: (6 C + 12 H + 18 O) (6 C + 12 H + 18 O)

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Amount of reactants and products problems

$$aA \longrightarrow bB$$

In this type of problems, you are given the mass (#moles) of the reactant and you calculate the mass (#moles) of the product.

You can use the following formula to calculate the #moles of B:

$$\text{number of moles of (B)} = \text{number of moles of (A)} \times \left(\frac{b}{a}\right)$$

You can use the following formula to calculate the mass of B:

$$\text{mass of (B)} = \left(\frac{\text{mass of (A)}}{\text{Molar mass of (A)}}\right) \times \left(\frac{b}{a}\right) \times \text{Molar mass of (B)}$$

How many grams of water are produced when 7.00 grams of oxygen react with an excess of hydrogen according to the reaction shown below?

$2H_2(g) + O_2(g) \text{ ----> } 2H_2O(g)$

✓The "excess" reactant has nothing to do with the problem.

✓Identify which is the "given" and which is the unknown.

$2H_2(g) + O_2(g) \text{ ----> } 2H_2O(g)$

10 g ?

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- Use the formula:

$$\text{mass of } (H_2O) = \left(\frac{\text{mass of } O_2}{\text{Molar mass of } O_2}\right) \times \left(\frac{2(H_2O)}{1(O_2)}\right) \times \text{Molar mass of } (H_2O)$$

$$\text{mass of } (H_2O) = \left(\frac{7.0\,g}{32\,g/mole}\right) \times \left(\frac{2(H_2O)}{1(O_2)}\right) \times 18\,g/mole$$

Mass of H_2O = 7.89 g

Calculate the number of moles of CO_2 resulted from the reaction of 3.5 moles of C_2H_6 with excess oxygen according to the equation

$$2\ C_2H_6 + 7\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$$

•Use the formula:

$$\text{number of moles of } (CO_2) = \text{number of moles of } (C_2H_6) \times \left(\frac{4(C_2H_6)}{2(CO_2)}\right)$$

$$\text{number of moles of } (CO_2) = 3.5\,\text{moles of } (C_2H_6) \times \left(\frac{4(C_2H_6)}{2(CO_2)}\right)$$

Number of moles of CO_2 = 7.0 moles

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Calculate the mass of chlorine that reacts with 4.770 g of hydrogen to form hydrogen chloride according the following equation:

$H_2 + Cl_2 \rightarrow 2\ HCl$

•Use the formula:

$$\text{mass of}(Cl_2) = \left(\frac{\text{mass of } H_2}{\text{Molar mass of } H_2}\right) x \left(\frac{1(H_2)}{1(Cl_2)}\right) x \text{ Molar mass of}(Cl_2)$$

$$\text{mass of}(Cl_2) = \left(\frac{4.770\text{g of } H_2}{2.0\text{g/mole}}\right) x \left(\frac{1(H_2)}{1(Cl_2)}\right) x\ 71.0\text{g/mole}$$

Mass of Cl_2 = 169.3 g

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