Unit 7 Chemical Quantities

<u>mole</u> - amount of pure substance that contains as many particles (atoms or molecules) as there are atoms in exactly 12 g of ^{12}C isotope or the **<u>gram atomic mass</u>** of Carbon. Particles are

atoms for elements = gram atomic mass
molecules for molecular compounds = gram molecular mass
formula units for ionic compounds = gram formula mass

Molar mass = mass of 1 mol of an element

One mole of any gas at Standard Temperature and Pressure has a volume of 22.4 liters; STP is 1 atmospheric pressure and 0°C or 273K.

One mole contains Avogadro's number of particles = 6.022×10^{23} or 602 sextillion.

<u>CHANGING MASS TO NUMBER OF MOLES</u>

If you find the mass of a sample of dextrose ($C_6H_{12}O_6$) to be 90.0 g, how many moles of dextrose do you have?

We find the Molar mass of dextrose the same way as we would find its molecular mass. We look up the masses of each atom on the periodic table, multiply by the number of atoms present and add the total.

Carbon	= 12.0 g	x 6 atoms	=	72.0 g
Hydrogen	= 1.0 g	x 12 atoms	=	12.0 g
Oxygen	= 16.0 g	x 6 atoms	=	96.0 g
molar mass of $C_6H_{12}O_6$			=	180.0 g *or* 1.80×10^2 g

Now use the formula:

$$\frac{\text{mass of sample}}{\text{molar mass of substance}} = \text{number of moles}$$

Given: The mass of the sample is 90.0 g and the molar mass of the substance is 180 g/mol.

$$moles\ of\ dextrose = \frac{90\,g}{} \times \frac{1\,mole\ C_6H_{12}O_6}{180\,g} = 0.5\ moles\ C_6H_{12}O_6$$

Answer: 0.5 moles $C_6H_{12}O_6$

CHANGING NUMBER OF MOLES TO MASS

$$\text{number of moles} \times \text{molar mass of substance} = \text{mass of sample}$$

A certain laboratory procedure requires the use of 0.100 moles of magnesium. How many grams of magnesium would you mass out on the balance?

From the periodic table we get the molar mass of magnesium as 24.3 g.

Given: The number of moles of the substance = 0.100 mol
molar mass of the substance = 24.3 g/mol

$$0.1\,mol\ \ Mg \times \frac{24.3\,g}{mol} = 2.43\,g\ Mg$$

Answer = 2.43 g of magnesium

CHANGING NUMBER OF MOLES TO NUMBER OF PARTICLES

One mole is always Avogadro's number, 6.02×10^{23}, so multiply the number of moles by Avogadro's number.

How many molecules of carbon dioxide are found in 2.50 moles of CO_2?

Use this formula:

$$\text{number of moles} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mole}} = \text{total number of particles}$$

Given: Number of moles = 2.50 mol

$$\frac{2.50\ \text{mol}}{} \times \frac{6.02\ x\ 10^{23}\ \text{molecules}}{\text{mol}} = 1.51\ x\ 10^{24}\ \text{molecules}$$

Answer = 1.51×10^{24} molecules of CO_2

CHANGING NUMBER OF PARTICLES TO NUMBER OF MOLES

$$\text{number of particles} \times \frac{1\ \text{mole}}{6.02 \times 10^{23}\ \text{particles}} = \text{number of moles}$$

How many moles of O_2 are represented by 7.45×10^{24} molecules of O_2?
Given: The total number of particles = 7.45×10^{24} molecules of O_2

$$7.45 \times 10^{24}\ \text{molecules} \times \frac{1\ \text{mole}}{6.02 \times 10^{23}\ \text{molecules}} = 12.4\ \text{moles}$$

Answer = 12.4 moles of O_2

CHANGING NUMBER OF PARTICLES TO MASS

This is a two-step problem. The first step is to change the number of particles to number of moles, the second step is to change the number of moles into mass.

What would be the mass of 3.75×10^{21} atoms of iron?
First, change the number of atoms to moles:

$$\frac{3.75 \times 10^{21}\ \text{atoms Fe}}{} \times \frac{1\ \text{mole}}{6.02 \times 10^{23}\ \text{atoms}} = 6.23 \times 10^{-3}\ \text{moles Fe}$$

Answer to step one = 6.23×10^{-3} moles of iron.
Next, change number of moles to mass using the equation:

$$\frac{6.23 x 10^{-3}\ moles\ Fe}{} x \frac{55.8\ g\ Fe}{1\ mole\ Fe} = 0.348\ g\ Fe$$

Final Answer: Mass of the iron = 0.348 g

CHANGING MASS TO A NUMBER OF PARTICLES

This is a two-step operation. First we would change the mass to number of moles. Then we would change number of moles to number of particles.

How many water molecules would be found in a 54.0 gram sample of water?

First, convert the mass of water to moles, i.e. find the molar mass of 54.0g of H_2O:

$$\frac{54.0\text{ g }H_2O}{} \text{X} \frac{1\text{ mol }H_2O}{18.0\text{ g }H_2O} = 3.00\text{ moles }H_2O$$

Next, change the number of moles H_2O to number of particles H_2O.

$$\frac{3.00\ mol\ H_2O}{} X \frac{6.02\,x\,10^{23}\ molecules}{1 mol} = 1.81\,x\,10^{24}\ molecules\ H_2O$$

Answer = 1.81 x 10^{24} molecules of water.

Molar volume- volume of 1 mole of a gas at STP is 22.4L. Density (in g/L) can also be used to convert volume to mass.

CONVERTING MOLES OF A GAS TO VOLUME

What is the volume, in liters, of 0.60 mol SO_2 gas at STP in significant figures?

Given: 0.60 mol SO_2 and 1 mole of gas at STP = 22.4 liters

$$\frac{0.60\,\text{mol SO}_2}{} \text{X} \frac{22.4\,\text{L SO}_2}{1\,\text{mol SO}_2} = 13.44\,\text{L SO}_2$$

Answer= Volume of Sulfur Dioxide is 13 liters (in 2 significant figures).

CONVERTING DENSITY OF A GAS TO MASS

The density of a gaseous compound containing carbon and oxygen is 1.964g/L at STP. What is the molar mass of this gas in significant figures?

Given: density of gas is 1.964g/L and 1 mole of gas @STP =22.4 L

$$\frac{1.964\,\text{g}}{\text{L}} \text{X} \frac{22.4\,\text{L}}{1\,\text{mol}} = \frac{43.994\,\text{g}}{\text{mol}}$$

Answer= molar mass is 43.99 g/mol in 4 significant figures

CONVERTING MASS OF A GAS TO DENSITY

What is the density of O_2 gas at STP in significant figures?

Given: 1 mol O_2 and 1 mole of gas at STP = 22.4 liters

$$\frac{32.0\text{g O}_2}{1\text{mole O}_2} \text{X} \frac{1\text{ mole}}{22.4\text{L}} = 1.428\text{g}/\text{L}\ \ \text{O}_2$$

Answer = Density of O_2 is 1.43 g/L (in 3 significant figures).

Percent Composition and Chemical Formulas

$$\%\text{ element} = \frac{\text{mass element}}{\text{total mass}} \text{x}100$$

Percent composition- percent by mass of each element in a compound.
Empirical formula- lowest whole number (mole) ratio of elements (atoms) in a compound.

CO_2 is a molecular and empirical formula

$C_1H_2O_1$ is an empirical formula for glucose, $C_6H_{12}O_6$

Molecular formula- actual number of elements (atoms) in a compound.

Example 1: An 8.20g piece of magnesium combines completely with 5.40g of oxygen to form a compound. What is the percent composition of this compound?
Given: 8.20g Mg and 5.40g O and total mass is 13.60g

$$\%\text{ Mg} = \frac{8.20\text{g}}{13.60\text{g}} \text{x}100 = 60.3\%\text{ Mg}$$

$$\%\text{O} = \frac{5.40\text{g}}{13.60\text{g}} \text{x}100 = 39.7\%\text{ O}$$

Answer: This compound contains 60.3% magnesium and 39.7% oxygen.

Example 2: Calculate the mass of carbon in 82g of propane (C_3H_8)
Given: 82g of propane, and the molar mass of propane is 44g.

$$\text{mass of C} = 82g\ C_3H_8 \text{x} \frac{36\text{ g C}}{44\text{ g }C_3H_8} = 67.1\text{ g C}$$

Answer: For 82g of propane, there is 67.1g of carbon. Because

$$\%\text{C} = \frac{\text{mass C}}{\text{mass }C_3H_8}\text{x}100 = \frac{36\text{g C}}{44\text{g }C_3H_8}\text{x}100 \text{ or } 81.8\%$$

Example 3: What is the empirical formula of a compound that is 25.9% nitrogen and 74.1% oxygen?

Convert to moles and find smallest whole-number (mole) ratio of atoms for each element.

$$25.9\,\text{g N} \times \frac{1\,\text{mol N}}{14.0\,\text{g N}} = 1.85\,\text{mol N}$$

$$74.1\,\text{g O} \times \frac{1\,\text{mol O}}{16.0\,\text{g O}} = 4.63\,\text{mol O}$$

The empirical formula must be smallest whole number (mole) ratio.
Take the mole ratio and divide the largest number by the smallest to reduce it.

$$\frac{4.63\,\text{mole O}}{1.85\,\text{mol N}} = \frac{2.5\,\text{mol O}}{1\,\text{mole N}}$$

The empirical formula would be

$$\mathbf{N_1O_{2.50}}$$

but that formula is not made up of only whole numbers. The formula must be the smallest whole number ratio, so the formula is doubled to make

$$\mathbf{N_2O_5}$$

Another empirical formula problem

What is the molecular formula of methyl butanoate if the molecular weight is 102 grams and it contains 31.4% oxygen, 58.8% carbon, and 9.8% hydrogen ?

Step 1: Convert to moles.

$$\frac{31.4\text{g O}}{} \times \frac{1 \text{ mole O}}{16 \text{ g O}} = 1.9625 \text{ mol O}$$

$$\frac{58.8\text{g C}}{} \times \frac{1 \text{ mole C}}{12 \text{ g C}} = 4.9 \text{ mol C}$$

$$\frac{9.8 \text{ g H}}{} \times \frac{1 \text{ mole H}}{1 \text{ g H}} = 9.8 \text{ mol H}$$

Step 2: Use the mole ratios for each element.

$$\frac{4.9}{1.9625} = 2.49 \text{ C} \qquad \frac{9.8}{1.9625} = 4.99 \text{ H} \qquad \frac{1.9625}{1.9625} = 1 \text{ O}$$

Step 3: Find whole numbers for the formula.

For every molecule of methyl butanoate, there are 5 hydrogens, 2.5 carbons and one oxygen or $C_{2.49}H_{4.99}O_1$

But we need whole numbers in the subscripts. Multiplying by 2 will do that:

$C_{2.49}$ becomes C_5 $\qquad$ $H_{4.99}$ becomes H_{10} $\qquad$ O_1 becomes O_2

Molecular Weight of $C_5H_{10}O_2$ is:

C $\quad 5 \times 12\text{g} = 60\text{g}$ $\qquad$ H $\quad 10 \times 1\text{g} = 10\text{g}$ $\qquad$ O $\quad 2 \times 16\text{g} = 32\text{g}$

Total = 102 g/mol (correct molecular weight)