

Percent Composition by Mass

Percent Composition: the percent by mass of each element in a compound.

- According to the law of Definite Proportions, a given chemical compound always contains the exact same elements in the exact same ratio by mass.

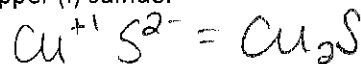
$$\% \text{ composition of an element} = \frac{\text{total mass of element in compound}}{\text{total mass of compound}} \times 100$$

not on formula chart

Guided Practice

- Find the percentage composition of each element in the compound copper (I) sulfide.

$$\% \text{ Cu} = \frac{2(63.55)}{159.16} \times 100 = \boxed{79.80\% \text{ Cu}}$$



$$\% \text{ S} = \frac{32.06}{159.16} \times 100 = \boxed{20.14\% \text{ S}}$$

- Find the mass percentage of water in sodium carbonate decahydrate, $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$, which has a molar mass of 286.15 g/mol.

$$\% \text{ H}_2\text{O} = \frac{10(18.02)}{286.15} \times 100 = \boxed{62.96\% \text{ H}_2\text{O}}$$

- When ammonia, NH_3 , is formed, 1.0 gram of hydrogen reacts with about 5.0 grams of nitrogen. How much nitrogen would be needed to react with 2.5 grams of hydrogen in the production of ammonia?

$$\frac{1.0 \text{ g H}}{5.0 \text{ g N}} = \frac{2.5 \text{ g H}}{x} \quad x = 2.5 \times 5 = \boxed{12.5 \text{ g N}_2}$$

- Lake Superior is the largest lake in North America and contains about 1.2×10^{16} kg of water. What mass of hydrogen is contained in Lake Superior?

a. 6.0×10^{15} kg

c. 1.3×10^{15} kg

b. 1.1×10^{16} kg

d. 1.2×10^{16} kg

$$\% \text{ H} = \frac{2(1)}{18} \times 100 \approx \frac{2}{20} \times 100 = 10\%$$

$$1.2 \times 10^{16} \times 1 \times 10^{-1} = \boxed{1.2 \times 10^{15} \text{ kg}}$$

- For a 150 g sample of glucose, $\text{C}_6\text{H}_{12}\text{O}_6$, there is 60 g of carbon. How many grams of carbon are there for a 300 g sample of glucose?

a. 30 g

c. 90 g

b. 60 g

d. $\boxed{120 \text{ g}}$

$$\frac{60 \text{ g C}}{150 \text{ g C}_6\text{H}_{12}\text{O}_6} = \frac{x}{300 \text{ g}}$$

$$x = \frac{60(300)}{150} = \boxed{120 \text{ g}}$$

Empirical and Molecular Formulas

Empirical Formula: the symbols for the elements combined in a compound, with subscripts showing the smallest whole-number mole ratio of the different atoms in the compound.

Molecular Formula: the actual formula of a compound which shows the total number of each atom in the molecule.

*** It is possible for the empirical formula and the molecular formula to be the same! ***

Molecular	Simplify by dividing	Empirical
$C_6H_{12}O_6$	6	CH_2O
P_4O_{10}	2	P_2O_5
$C_9H_3O_3N_{12}$	3	C_3HON_4
$NaCl$	1	$NaCl$

Steps for the Calculation of Empirical Formula

Step 1: Convert % composition to a mass composition by assuming 100 g of sample.

Step 2: Convert the mass into moles. **DO NOT ROUND!! Keep at least 3 #.**

Step 3: Divide by each number of moles by the smallest number of moles calculated in step #2.

Step 4: If not a whole number, multiply to get rid of the decimal (see chart on right) and use those whole numbers as subscripts in compound.

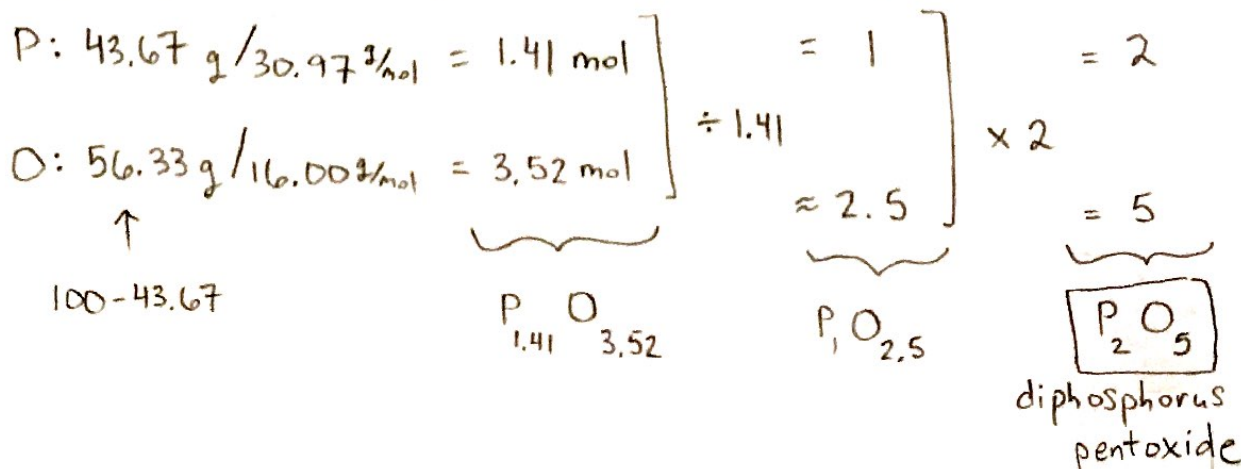
Fractional Subscript	Multiply by This
0.20	5
0.25	4
0.33	3
0.40	5
0.50	2
0.66	3
0.75	4
0.80	5

The Empirical Song! (sung with the melody from Twinkle, Twinkle Little Star)

Percent to mass and mass to mole,
Divide by small then multiply til whole.
That's how you find the empirical
Smallest whole-number ratio.

Let's Practice!

- Analysis of a sample of a compound known to contain only phosphorus and oxygen indicates that it contains 43.67% phosphorus by mass. What is the empirical formula and name of this compound?



How to Determine the Molecular Formula

FW \rightarrow Same as molar mass

Need two things:

- 1.) empirical formula
- 2.) molecular mass (always given)

Step 1: Find the mass (formula weight) of the empirical formula.

Step 2: Take the molecular mass and divide it by empirical mass (this will always give you a whole number).

Step 3: Multiply the whole # by the empirical formula's subscripts to determine the molecular formula.

Let's Practice!

2. What is the molecular formula for a compound with the empirical formula H_2O and a molecular mass of 54 g/mol?

$$FW(H_2O) = 18.016 \text{ g/mol}$$

$$\frac{FW(\text{molec.})}{FW(\text{emp.})} = \frac{54}{18.016} \approx 3 \times H_2O = \boxed{H_6O_3}$$

3. A sample of NutraSweet is 57.14% C, 6.16% H, 9.52% N, and 27.18% O. Calculate the empirical formula of NutraSweet and find the molecular formula. (The molar mass of NutraSweet is 294.30 g/mol)

$$C: 57.14 \text{ g} / 12.01 \text{ g/mol} = 4.76 \text{ mol}$$

$$H: 6.16 \text{ g} / 1.008 \text{ g/mol} = 6.11 \text{ mol}$$

$$N: 9.52 \text{ g} / 14.01 \text{ g/mol} = 0.680 \text{ mol}$$

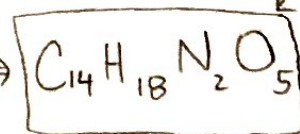
$$O: 27.18 \text{ g} / 16.00 \text{ g/mol} = 1.70 \text{ mol}$$

$$\left. \begin{array}{l} = 7 \\ \approx 9 \\ = 1 \\ = 2.5 \end{array} \right\} \div 0.680 \left\{ \begin{array}{l} = 14 \\ = 18 \\ = 2 \\ = 5 \end{array} \right. \times 2$$



$$FW(C_{14}H_{18}N_2O_5) = 294.304 \text{ g/mol}$$

$$\frac{294.30}{294.304} = 1$$



empirical and molecular!

4. The analysis of a rocket fuel sample showed that it contained 87.4% nitrogen and 12.6% hydrogen by weight. Mass spectral analysis showed the fuel to have a molar mass of 32.06 g/mol. What is the molecular formula of the fuel?

$$N: 87.4 \text{ g} / 14.01 \text{ g/mol} = 6.24 \text{ mol}$$

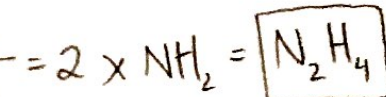
$$H: 12.6 \text{ g} / 1.008 \text{ g/mol} = 12.5 \text{ mol}$$

$$\left. \begin{array}{l} = 1 \\ = 2 \end{array} \right\} \div 6.24$$

empirical formula NH_2

$$FW(NH_2) = 16.026 \text{ g/mol}$$

$$\frac{32.06}{16.026} = 2$$



Multiple Choice Practice: Tasty and Delicious

1. An element X combines with oxygen to form a compound of formula XO_2 . If 24.0 g of element X combine with exactly 16.0 g of O to form this compound, what is the atomic weight of element X?

(a) 48.0 amu b. 24.0 amu c. 16.0 amu d. 12.0 amu

$$16 \text{ g O} \times \frac{1 \text{ mol O}}{16 \text{ g O}} \times \frac{1 \text{ mol X}}{2 \text{ mol O}} = 0.5 \text{ mol X} \quad \left. \vphantom{\frac{1 \text{ mol X}}{2 \text{ mol O}}} \right\} \frac{24.0 \text{ g}}{0.5 \text{ mol}} = 48 \text{ g/mol}$$

b/c XO_2

2. A new ore contains 52.3% silver by mass. How many grams of the ore are needed to obtain 10.0 moles of silver?

(a) 2,060 g b. 1,080 g c. 564 g d. 10.0 g

$$10.0 \text{ mol Ag} \times \frac{107.87 \text{ g}}{1 \text{ mol Ag}} = 1,078.7 \text{ g} \quad \left. \vphantom{\frac{1,078.7 \text{ g}}{x}} \right\} \frac{1,078.7 \text{ g}}{x} = 0.523 \Rightarrow x \approx \frac{1,000}{0.5} = 2,000$$

3. A compound is made up of entirely silicon and oxygen atoms. If there are 14.0 g Si and 32.0 g O present, what is the empirical formula of the compound?

a. SiO_2 (b) SiO_4 c. Si_2O d. Si_2O_3

$$\begin{array}{l} Si: 14.0/28 = 0.5 \\ O: 32.0/16 = 2 \end{array} \quad \left. \vphantom{\begin{array}{l} Si: 14.0/28 = 0.5 \\ O: 32.0/16 = 2 \end{array}} \right\} \div 0.5 \quad \begin{array}{l} = 1 \\ = 4 \end{array}$$

4. A chemist suspects that a given sample of $CaSO_4$ is impure. Upon testing, the chemist finds that the sample contains 31.6% calcium, but pure $CaSO_4$ is 29.4% calcium by mass. Which of the following might account for the measured percent mass of the sample?

a. The sample is composed entirely of $CaSO_4$.] no change to % Ca

(b) The sample is a mixture of $CaSO_4$ and $CaCO_3$. $FW(CO_3^{2-}) < FW(SO_4^{2-})$

c. The sample is a mixture of $CaSO_4$ and $MgSO_4$.] \downarrow % Ca

d. The sample is a mixture of $CaSO_4$ and $Ca(BrO_3)_2$.] \downarrow % Ca

5. Styrene has the empirical formula CH with a molar mass of 104.13 g/mol. Approximately how many hydrogen atoms are present in a 52 g sample of styrene?

- a. 5.0×10^{22} H atoms
 (b) 2.4×10^{24} H atoms
 c. 8.0×10^{23} H atoms
 d. 6.1×10^{23} H atoms

$$FW(CH) \approx 13$$

$$\frac{104}{13} \approx 8 \times CH = C_8H_8$$

$$\left. \begin{array}{l} 52 \text{ g} \\ 104 \text{ g} \\ 2 \text{ } C_8H_8 \end{array} \right\} \times \frac{1 \text{ mol}}{104 \text{ g}} \times \frac{8 \text{ mol H}}{1 \text{ mol } C_8H_8} \times \frac{6.023 \text{ atoms H}}{1 \text{ mol H}} = 24 \text{ E } 23 = 2.4 \text{ E } 24$$

6. What is the empirical formula for a compound that contains 7.48 g N and 1.08 g H?

- a. N_2H
 (b) NH_2
 c. NH
 d. NH_5

$$\begin{array}{l} N: 7.48 / 14 \approx 0.5 \\ H: 1.08 / 1.008 = 1 \end{array} \left. \vphantom{\begin{array}{l} N \\ H \end{array}} \right\} \div 0.5 = \begin{array}{l} 1 \\ 2 \end{array}$$

7. If the compound in #6 has a molecular mass of 32.05 g/mol, what is its molecular formula?

- a. N_2H_2
 b. N_4H_2
 c. N_2H_{10}
 (d) N_2H_4

$$FW(NH_2) \approx 16$$

$$32 / 16 = 2 \times NH_2$$

8. An Olympic medal contains 71.5% of gold by mass. How much gold could be extracted from a medal that weighs 115 g?

- (a) 0.417 mol
 b. 0.817 mol
 c. 2.43 mol
 d. 4.86 mol

$$115 \times 0.715 \approx 81 \text{ g Au} \times \frac{1 \text{ mol Au}}{196.97 \text{ g Au}} \approx \frac{81}{200} = \frac{35}{100} = 0.35$$

9. Two different samples are analyzed. Sample A contains 2.8 g of N and 1.6 g of O. Sample B contains 14.0 g of N and 8.0 g of O. Which of the following statements is true?

- a. Sample A and B are the same compound because they contain the same types of atoms.
 (b) Sample A and B are the same compound because their mass ratios indicate they both contain the same ratio of atoms within the molecule.
 c. Sample A and B are different compounds because they contain different numbers of atoms indicating a different ratio of atoms within the molecule.
 d. Sample A and B are different compounds because their molar masses are different.