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.

$$\%\ \textbf{compostion of an element} = \frac{\textit{total mass of}\ \textbf{element}\ \textit{in compound}}{\textit{total mass of}\ \textbf{compound}} \times 100$$

not on formula Chart

Guided Practice

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

$\%\ Cu = \frac{2(63.55)}{159.16} \times 100 = \boxed{79.86\%\ Cu}$ $\quad Cu^{+1}\ S^{2-} = Cu_2S$

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

2. Find the mass percentage of water in sodium carbonate decahydrate, $Na_2CO_3 \bullet 10H_2O$, which has a molar mass of 286.15 g/mol.

$\%\ H_2O = \frac{10(18.02)}{286.15} \times 100 = \boxed{62.96\ \%H_2O}$

3. 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?

$\frac{1.0\ g\ H}{5.0\ g\ N} = \frac{2.5\ g\ H}{x}$ $\quad x = 2.5 \times 5 = \boxed{12.5\ g\ N_2}$

4. 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

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

$1.2 \times 10^{16} \times 1 \times 10^{-1}$ or $(1.2 \times 10^{16}) \times 0.1$ $= \boxed{1.2 \times 10^{15}\ kg}$

5. For a 150 g sample of glucose, $C_6H_{12}O_6$, 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.) 120 g

$\frac{60\ g\ C}{150\ g\ C_6H_{12}O_6} = \frac{x}{300\ g}$ $\quad x = \frac{60(\cancel{300}^{2})}{\cancel{150}} = \boxed{120\ g}$

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!

1. 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?

P: 43.67 g / 30.97 g/mol = 1.41 mol

O: 56.33 g / 16.00 g/mol = 3.52 mol

↑ 100 − 43.67

÷ 1.41

= 1

≈ 2.5

× 2

= 2

= 5

$P_{1.41}O_{3.52}$ → $P_1O_{2.5}$ → P_2O_5

diphosphorus pentoxide

Need two things:
1.) empirical formula
2.) molecular mass (always given)

How to Determine the Molecular Formula

FW → same as molar mass

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?

$FW(H_2O) = 18.016\ g/mol$

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

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: $57.14\ g / 12.01\ g/mol = 4.76\ mol$ → $\div 0.680 = 7$ → $\times 2 = 14$

H: $6.16\ g / 1.008\ g/mol = 6.11\ mol$ → $\div 0.680 \approx 9$ → $\times 2 = 18$

N: $9.52\ g / 14.01\ g/mol = 0.680\ mol$ → $\div 0.680 = 1$ → $\times 2 = 2$

O: $27.18\ g / 16.00\ g/mol = 1.70\ mol$ → $\div 0.680 = 2.5$ → $\times 2 = 5$

$C_{14}H_{18}N_2O_5$

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

$$\frac{294.30}{294.304} = 1 \Rightarrow \boxed{C_{14}H_{18}N_2O_5}$$

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: $87.4\ g / 14.01\ g/mol = 6.24\ mol$ → $\div 6.24 = 1$

H: $12.6\ g / 1.008\ g/mol = 12.5\ mol$ → $\div 6.24 = 2$

NH_2 ← empirical formula

$FW(NH_2) = 16.026\ g/mol$

$$\frac{32.06}{16.026} = 2 \times NH_2 = \boxed{N_2H_4}$$

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

$16\,g\,O \times \frac{1\,mol\,O}{16\,g\,O} \times \underbrace{\frac{1\,mol\,X}{2\,mol\,O}}_{b/c\ XO_2} = 0.5\,mol\,X \Rightarrow \frac{24.0\,g}{0.5\,mol} = 48\,g/mol$

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

$10.0\,mol\,Ag \times \frac{107.87\,g}{1\,mol\,Ag} = 1,078.7\,g \Rightarrow \frac{1,078.7\,g}{x} = 0.523 \Rightarrow x \approx \frac{1,000}{0.5} = 2,000$

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

Si: $14.0/28 = 0.5$ → $\div 0.5$ → $= 1$

O: $32.0/16 = 2$ → $\div 0.5$ → $= 4$

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 $MgSO_4$.] ↓ % Ca

   d. The sample is a mixture of $CaSO_4$ and $Ca(BrO_3)_2$.] ↓ % 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
   c. 8.0×10^{23} H atoms
   (b.) 2.4×10^{24} H atoms
   d. 6.1×10^{23} H atoms

$FW(CH) \approx 13$

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

$52\,g \times \frac{1\,mol}{104\,g} \times \frac{8\,mol\,H}{1\,mol\,C_8H_8} \times \frac{6E23\ atoms\ H}{1\,mol\,H} = 24E23$

$= 2.4E24$

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

N: $7.48/14 \approx 0.5$ $= 1$

H: $1.08/1.008 = 1$ $\div 0.5$ $= 2$

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

$115 \times 0.7 \approx 70\,g\,Au \times \frac{1\,mol\,Au}{196.97\,g\,Au} \approx \frac{70}{200} = \frac{35}{100} = 0.35$

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.