Key Worksheet 6

Mass % Composition, Empirical Formulas, and Molecular Formulas

Mass % Composition: The percent, by mass, of each element in a compound. If the formula of a compound is $A_xB_yC_z$, then the percent composition is given by:

$$\%A = \frac{x(\text{molar mass of A})}{\text{molar mass of } A_xB_yC_z} \times 100\%$$

$$\%B = \frac{y(\text{molar mass of B})}{\text{molar mass of } A_xB_yC_z} \times 100\%$$

$$\%C = \frac{z(\text{molar mass of C})}{\text{molar mass of } A_xB_yC_z} \times 100\%$$

Empirical Formula: The smallest whole number ratio of the elements in a compound.

To calculate the empirical formula when given a mass % composition:

1.) Write each percent as grams.

2.) Convert grams of each element to moles by dividing by that element's molar mass.

3.) Divide the moles of the element with theleast number of moles into the moles of the other elements.

4.) If all resulting numbers are closer than 0.1 to a whole number, round them to those whole numbers. These numbers are the subscripts in the empirical formula.

a.) If any of the resulting numbers are 0.1 or farther away from a whole number, find a whole number such that when multiplied by that number will make it closer than 0.1 to a whole number.

b.) Multiply all resulting ratios by that number over itself. The resulting ratios will give you the empirical formula.

Molecular Formulas: The actual ratio of elements in a compound.

If given the percent composition and the molar mass of the compound, multiply the molar mass of each element by it's percent (divided by 100). The resulting numbers, as whole numbers, are the subscripts for the elements in the molecular formula.

If given the empirical formula and the molecular mass, divide the molecular mass by the empirical mass. Multiply the subscripts in the empirical formula by the resulting whole number to get the subscripts for the molecular formula.

Problems

1.) Calculate the mass percent composition of lysergic acid diethylamide, $C_{20}H_{25}N_3O$.

Molar Mass

$$20\left(12.011\frac{\text{g}}{\text{mol}}\right)+25\left(1.008\frac{\text{g}}{\text{mol}}\right)+3\left(14.007\frac{\text{g}}{\text{mol}}\right)+15.999\frac{\text{g}}{\text{mol}}=323.44_0\frac{\text{g}}{\text{mol}}$$

Percent Composition

$$\%\ \text{C}=\frac{20\left(12.011\frac{\text{g}}{\text{mol}}\right)}{323.44_0\frac{\text{g}}{\text{mol}}}\times 100\%=74.270_3\%$$

$$\%\ \text{H}=\frac{25\left(1.008\frac{\text{g}}{\text{mol}}\right)}{323.44_0\frac{\text{g}}{\text{mol}}}\times 100\%=7.791_1\%$$

$$\%\ \text{N}=\frac{3\left(14.007\frac{\text{g}}{\text{mol}}\right)}{323.44_0\frac{\text{g}}{\text{mol}}}\times 100\%=12.991_8\%$$

$$\%\ \text{O}=\frac{15.999\frac{\text{g}}{\text{mol}}}{323.44_0\frac{\text{g}}{\text{mol}}}\times 100\%=4.9464_8\%$$

% C: 74.270 %

% H: 7.791 %

% N: 12.992 %

% O: 4.9465 %

2.) Calculate the mass percent composition of iron (III) sulfate monohydrate.

$$\text{Fe}_2\left(\text{SO}_4\right)_3\cdot\text{H}_2\text{O}$$

Molar Mass

$$2\left(55.845\frac{\text{g}}{\text{mol}}\right)+3\left(32.066\frac{\text{g}}{\text{mol}}\right)+12\left(15.999\frac{\text{g}}{\text{mol}}\right)+18.015\frac{\text{g}}{\text{mol}}=417.89_1\frac{\text{g}}{\text{mol}}$$

Percent Composition

$$\%\ \text{Fe}=\frac{2\left(55.845\frac{\text{g}}{\text{mol}}\right)}{417.89_1\frac{\text{g}}{\text{mol}}}\times 100\%=26.727_0\%$$

$$\%\ \text{S}=\frac{3\left(32.066\frac{\text{g}}{\text{mol}}\right)}{417.89_1\frac{\text{g}}{\text{mol}}}\times 100\%=23.019_8\%$$

$$\% \text{ O} = \frac{13\left(15.999\frac{\text{g}}{\text{mol}}\right)}{417.89_1\frac{\text{g}}{\text{mol}}} \times 100\% = 49.770_6\%$$

$$\% \text{ H} = \frac{2\left(1.008\frac{\text{g}}{\text{mol}}\right)}{417.89_1\frac{\text{g}}{\text{mol}}} \times 100\% = 0.4824_2\%$$

% Fe: 26.727 %

% S: 23.020 %

% O: 49.771 %

% H: 0.4824 %

3.) Calculate the number of grams of fluorine in 7.228 g of xenon tetrafluoride.

$$XeF_4$$

$$\_\_\_ \text{ g F} = 7.228 \text{ g XeF}_4 \left(\frac{1 \text{ mol XeF}_4}{207.285 \text{ g XeF}_4}\right)\left(\frac{4 \text{ mol F}}{1 \text{ mol XeF}_4}\right)\left(\frac{18.998 \text{ g F}}{1 \text{ mol F}}\right) = 2.649_8 \text{ g F}$$

Grams Fluorine: 2.650 g

4.) Calculate the mass percent of magnesium in the mineral $MgF_2 \cdot (MgSiO_3)_2$.

$$\text{F.W.} = 3\left(24.305\frac{\text{g}}{\text{mol}}\right) + 2\left(18.998\frac{\text{g}}{\text{mol}}\right) + 2\left(28.085\frac{\text{g}}{\text{mol}}\right) + 6\left(15.999\frac{\text{g}}{\text{mol}}\right) = 263.075_0\frac{\text{g}}{\text{mol}}$$

$$\% \text{ Mg} = \frac{3\left(24.305\frac{\text{g}}{\text{mol}}\right)}{263.075_0\frac{\text{g}}{\text{mol}}} \times 100\% = 27.716_4\%$$

$$\% \text{ F} = \frac{2\left(18.998\frac{\text{g}}{\text{mol}}\right)}{263.075_0\frac{\text{g}}{\text{mol}}} \times 100\% = 14.443_0\%$$

$$\% \text{ Si} = \frac{3\left(28.085\frac{\text{g}}{\text{mol}}\right)}{263.075_0\frac{\text{g}}{\text{mol}}} \times 100\% = 21.351_3\%$$

$$\% \text{ O} = \frac{6\left(15.999\frac{\text{g}}{\text{mol}}\right)}{263.075_0\frac{\text{g}}{\text{mol}}} \times 100\% = 36.489_2\%$$

% Mg: 27.716 %

% F: 14.443 %

% Si: 21.351 %

% O: 36.489 %

5.) Krels have 7.22 times the mass of gleps. Gleps have 0.314 the mass of scens. The lightest of these has a mass of 2.171 g. How much total does a collection of 14 krels, 11 gleps, and 9 scens weigh?

The lightest are gleps, which means one glep has a mass of 2.171 g. Krels then have a mass of 7.22(2.171 g) = 15.6_7 g for each glep. We also know one glep = 0.314(mass of 1 scen). Plugging in the mass of a glep we get:

$$2.171\text{g} = 0.314(\text{mass of a scen}) \Rightarrow \text{One scen} = \frac{2.171 \text{ g}}{0.314} = 6.91_4 \text{ g}$$

So the collection will have a mass of:

$$14 \text{ krel } \left(\frac{15.6_7 \text{ g}}{1 \text{ krel}}\right) + 11 \text{ glep } \left(\frac{2.171 \text{ g}}{1 \text{ glep}}\right) + 9 \text{ scen } \left(\frac{6.91_4 \text{ g}}{1 \text{ scen}}\right)$$
$$= 219._4 \text{ g} + 23.88_1 \text{ g} + 62.2_2 \text{ g} = 305._5 \text{ g}$$

Total mass: 306 g

6.) 65.32 g of a compound, that is composed of sodium, oxygen, and sulfur, contains 21.14 g of sodium and 14.75 g of sulfur. What is the empirical formula of this compound?

First find the mass of oxygen in the sample. From the law of conservation of mass, we know that 65.32 g = 21.14 g + 14.75 g + mass of oxygen, or mass of oxygen = 29.43 g.

Now that we know the mass of all elements in this sample, we convert to moles of each by dividing the mass of each element by it's molar mass:

$$\text{mol Na} = \frac{21.14 \text{ g}}{22.990 \frac{\text{g}}{\text{mol}}} = 0.9195_3 \text{ mol Na}$$

$$\text{mol S} = \frac{14.75 \text{ g}}{32.066 \frac{\text{g}}{\text{mol}}} = 0.4599_8 \text{ mol S}$$

$$\text{mol O} = \frac{29.43 \text{ g}}{15.999 \frac{\text{g}}{\text{mol}}} = 1.839_4 \text{ mol O}$$

Because we have the least number of moles of S, we divide that into the others:

$$\frac{0.9195_3 \text{ mol Na}}{0.4599_8 \text{ mol S}} = \frac{1.999_0 \text{ mol Na}}{1 \text{ mol S}} \Rightarrow \frac{2 \text{ mol Na}}{1 \text{ mol S}}$$

$$\frac{1.839_4 \text{ mol O}}{0.4599_8 \text{ mol S}} = \frac{3.998_9 \text{ mol O}}{1 \text{ mol S}} \Rightarrow \frac{4 \text{ mol O}}{1 \text{ mol S}}$$

Since both numbers are closer than 0.01 to a whole number, we can round. That gives us the subscripts in the empirical formula:

$$Na_2SO_4$$

Empirical Formula: Na_2SO_4

7.) A compound is 46.01 % Fe and 53.99 % Si, by mass. Calculate the empirical formula of this compound.

First convert the percents to grams, and find moles of each element:

$$\frac{46.01\text{ g Fe}}{55.845\frac{\text{g}}{\text{mol}}} = 0.8238_8\text{ mol Fe}$$

$$\frac{53.99\text{ g Si}}{28.085\frac{\text{g}}{\text{mol}}} = 1.922_3\text{ mol Si}$$

Next, divide the smallest (Fe) into the other.

$$\frac{1.922_3\text{ mol Si}}{0.8238_8\text{ mol Fe}} = \frac{2.333_3\text{ mol Si}}{1\text{ mol Fe}}$$

Since the result is not less than 0.1 from a whole number, we had to multiply by the smallest whole number that got us closer than 0.1 to a whole number. In this case, we multiplied by 3/3.

$$\frac{2.333_3\text{ mol Si}}{1\text{ mol Fe}}\left(\frac{3}{3}\right) = \frac{6.999_9\text{ mol Si}}{3\text{ mol Fe}} \Rightarrow \frac{7\text{ mol Si}}{3\text{ mol Fe}}$$

This gives us the empirical formula: Fe_3Si_7

Empirical Formula: Fe_3Si_7

8.) A compound that contains only carbon, hydrogen, and oxygen is 45.27% C, 9.499% H, and 45.23% O by mass. Calculate the empirical formula of this compound.

First convert the percents to grams, and find moles of each element:

$$\frac{45.27\text{ g C}}{12.011\frac{\text{g}}{\text{mol}}} = 3.769_0\text{ mol C}$$

$$\frac{9.499\text{ g H}}{1.008\frac{\text{g}}{\text{mol}}} = 9.423_6\text{ mol H}$$

$$\frac{45.23\text{ g O}}{15.999\frac{\text{g}}{\text{mol}}} = 2.827_0\text{ mol O}$$

Next, divide the smallest (O) into the others.

$$\frac{3.769_0\text{ mol C}}{2.827_0\text{ mol O}} = \frac{1.333_2\text{ mol C}}{1\text{ mol O}}\left(\frac{3}{3}\right) = \frac{4\text{ mol C}}{3\text{ mol O}}$$

$$\frac{9.423_6\text{ mol H}}{2.827_0\text{ mol O}} = \frac{3.333_3\text{ mol H}}{1\text{ mol O}}\left(\frac{3}{3}\right) = \frac{10\text{ mol H}}{3\text{ mol O}}$$

Since the results are not less than 0.1 from a whole number, we had to multiply by the smallest whole number that got us closer than 0.1 to a whole number. In this case, we multiplied by 3/3. This gives us the empirical formula: $C_4H_{10}O_3$.

Empirical Formula: $C_4H_{10}O_3$

9.) A compound has the empirical formula PO_2, and a molecular mass of 314.86 g/mol. What is the molecular formula of this compound?

Find the molar mass of the empirical formula. Divide the molecular mass by this, and round to the nearest whole number. Multiply each subscript in the empirical formula by this integer to get the molecular formula.

$$\mathrm{PO_2} = 62.972\frac{\mathrm{g}}{\mathrm{mol}}$$

$$\frac{314.86\frac{\mathrm{g}}{\mathrm{mol}}}{62.972\frac{\mathrm{g}}{\mathrm{mol}}} = 5$$

This gives us the molecular formula: P_5O_{10}

Molecular Formula: P_5O_{10}

10.) A compound has the empirical formula C_3H_6O and a molecular mass of 174.240 g/mol. What is the molecular formula of this compound?

Find the molar mass of the empirical formula. Divide the molecular mass by this, and round to the nearest whole number. Multiply each subscript in the empirical formula by this integer to get the molecular formula.

$$\mathrm{C_3H_6O} = 58.080\frac{\mathrm{g}}{\mathrm{mol}}$$

$$\frac{174.240\frac{\mathrm{g}}{\mathrm{mol}}}{58.080\frac{\mathrm{g}}{\mathrm{mol}}} = 3$$

The molecular formula is $C_9H_{18}O_3$

Molecular Formula: $C_9H_{18}O_3$

11.) A compound is 92.257 % carbon and 7.743 % hydrogen, by mass. The molar mass of this compound is 78.114 g/mol. What are the empirical and molecular formulas of this compound?

$$\left(\frac{92.257\ \mathrm{g\ C}}{100\ \mathrm{g\ Compound}}\right)\left(\frac{78.114\ \mathrm{g\ Compound}}{1\ \mathrm{mol\ Compound}}\right)\left(\frac{1\ \mathrm{mol\ C}}{12.011\ \mathrm{g\ C}}\right) = \frac{6\ \mathrm{mol\ C}}{1\ \mathrm{mol\ Compound}}$$

$$\left(\frac{7.743\ \mathrm{g\ H}}{100\ \mathrm{g\ Compound}}\right)\left(\frac{78.114\ \mathrm{g\ Compound}}{1\ \mathrm{mol\ Compound}}\right)\left(\frac{1\ \mathrm{mol\ H}}{1.008\ \mathrm{g\ H}}\right) = \frac{6\ \mathrm{mol\ H}}{1\ \mathrm{mol\ Compound}}$$

Which gives us the molecular formula: C_6H_6

To get the empirical formula, just divide each subscript by the greatest common divisor, which in this case is 6, giving the empirical formula as CH.

Empirical Formula: CH

Molecular Formula: C_6H_6

12.) A certain sulfur containing amino acid is 33.059% C, 5.551 % H, 11.011 % N, 25.159 % O, and 25.220 % S, by mass. Each molecule of this compound contains two atoms of sulfur. What is the molecular formula of this compound?

First find the empirical formula the normal way:

$$\frac{33.059 \text{ g C}}{12.011\frac{\text{g}}{\text{mol}}} = 2.7523_9 \text{ mol C} \qquad \frac{5.551 \text{ g H}}{1.008\frac{\text{g}}{\text{mol}}} = 5.506_9 \text{ mol H} \qquad \frac{11.011 \text{ g N}}{14.007\frac{\text{g}}{\text{mol}}} = 0.78610_6 \text{ mol N}$$

$$\frac{25.159 \text{ g O}}{15.999\frac{\text{g}}{\text{mol}}} = 1.5725_3 \text{ mol O} \qquad \frac{25.220 \text{ g S}}{32.066\frac{\text{g}}{\text{mol}}} = 0.78650_2 \text{ mol S}$$

$$\frac{2.7523_9 \text{ mol C}}{0.78610_6 \text{ mol N}} = \frac{3.5012_9 \text{ mol C}}{1 \text{ mol N}} \qquad \frac{5.506_9 \text{ mol H}}{0.78610_6 \text{ mol N}} = \frac{7.0053_3 \text{ mol H}}{1 \text{ mol N}}$$

$$\frac{1.5725_3 \text{ mol O}}{0.78610_6 \text{ mol N}} = \frac{2.0004_0 \text{ mol O}}{1 \text{ mol N}} \qquad \frac{0.78650_2 \text{ mol S}}{0.78610_6 \text{ mol N}} = \frac{1.0005_0 \text{ mol S}}{1 \text{ mol N}}$$

Because of the C, we need to multiply each by 2/2. This gives us an empirical formula of $C_7H_{14}N_2S_2O_4$. Since one molecule of this already has 2 atoms of sulfur, this is also the molecular formula.

Molecular Formula: $C_7H_{14}N_2S_2O_4$

13.) A 3.1151 gram sample of a compound containing only cesium and potassium completely decomposes to yield 2.346 g of cesium. What is the empirical formula of this compound?

First find the mass of potassium using the law of conservation of mass:

3.1151 g compound – 2.346 g cesium = 0.770_1 g potassium

Next find moles of each:

$$\frac{2.345 \text{ g Cs}}{132.905\frac{\text{g}}{\text{mol}}} = 0.01764_4 \text{ mol Cs} \qquad \frac{0.770_1 \text{ g K}}{39.098\frac{\text{g}}{\text{mol}}} = 0.0196_9 \text{ mol K}$$

Now divide moles of K by moles Cs:

$$\frac{0.0196_9 \text{ mol K}}{0.01764_4 \text{ mol Cs}} = \frac{1.11_6 \text{ mol K}}{1 \text{ mol Cs}}$$

Since this is more than 0.1 from a whole number, we need to multiply this ration by a whole number over itself that will give us a whole number ration (within 0.1). 9 is the smallest whole number that will do this.

$$\frac{1.11_6 \text{ mol K}}{1 \text{ mol Cs}}\left(\frac{9}{9}\right) = \frac{10 \text{ mol K}}{9 \text{ mol Cs}} \Rightarrow \mathrm{Cs_9K_{10}}$$

Empirical Formula: Cs_9K_{10}

14.) Oxygen forms a binary compound (compound A) with a certain metal that is 13.38 % oxygen by mass. When this compound is heated gently some of the oxygen is driven off and the new compound (compound B) is 9.334 % oxygen by mass. When this new compound is heated up very strongly more oxygen is driven off and the new compound (compound C) is 7.168 % oxygen by mass. Given that the empirical formula of compound A is MO_2, where "M" stands for the metal, calculate the molar mass of the metal, the identity of the metal, and the empirical formulas of compounds B and C.

We know there is one mol of the metal per 2 moles of oxygen in compound A. For exactly 100 g of compound A, we also know there is 100 g MO_2 – 13.38 g O = 86.62 g M.

Now we can find moles of O in compound A. We then know moles of M, since it is æ that of the moles of O. Knowing moles of M and grams of M, we can find it's molar mass and identity:

$$\frac{13.38 \text{ g O}}{15.999\frac{\text{g}}{\text{mol}}} = 0.8363_0 \text{ moles O}$$

$$\text{moles M} = (0.8363_0 \text{ mol O})\left(\frac{1 \text{ mol M}}{2 \text{ mol O}}\right) = 0.4181_5 \text{ mol M}$$

$$\text{Molar Mass M} = \frac{86.62 \text{ g}}{0.4181_5 \text{ mol}} = 207.1_4\frac{\text{g}}{\text{mol}}$$

This is lead, Pb, whose actual molar mass is 207.2 g/mol. Now we can find the empirical formulas of B & C the normal way.

In compound B there are 100 g compound – 9.334 g O = 90.666 g Pb in exactly 100 g of the compound.

In compound C there are 100 g compound – 7.168 g O = 92.832 g Pb in exactly 100 g of the compound.

Compound B

$$\frac{9.334 \text{ g O}}{15.999\frac{\text{g}}{\text{mol}}} = 0.5834_1 \text{ mol O} \qquad \frac{90.666 \text{ g Pb}}{207.2\frac{\text{g}}{\text{mol}}} = 0.4375_7 \text{ mol Pb}$$

$$\frac{0.5834_1 \text{ mol O}}{0.4375_7 \text{ mol Pb}} = \frac{1.333_2 \text{ mol O}}{1 \text{ mol Pb}}\left(\frac{3}{3}\right) = \frac{4 \text{ mol O}}{3 \text{ mol Pb}} \Rightarrow Pb_3O_4$$

Compound C

$$\frac{7.168 \text{ g O}}{15.999\frac{\text{g}}{\text{mol}}} = 0.4480_2 \text{ mol O} \qquad \frac{92.832 \text{ g Pb}}{207.2\frac{\text{g}}{\text{mol}}} = 0.4480_3 \text{ mol Pb}$$

$$\frac{0.4480_2 \text{ mol O}}{0.4480_3 \text{ mol Pb}} = \frac{1 \text{ mol O}}{1 \text{ mol Pb}} \Rightarrow PbO$$

Molar Mass of Metal: 207.2 g/mol

Identity of Metal: Pb

Empirical Formula Compound B: Pb_3O_4

Empirical Formula Compound C: PbO