**Answer Key to Problem Set on Empirical Formulas**

General comments: Always use at least the same number of significant figures for the molar masses of the elements as are given for the elemental composition. For example, if you are given 43.89% C, then use at least 12.01g/mol for the molar mass of carbon. Using fewer significant figures (12 g/mol or 12.0 g/mol, in this case) could actually lead to the incorrect formula. On the other hand, when determining the multiple for converting the empirical formula to a molecular formula, whole number molar masses are typically sufficient.

 When given the elemental percent composition, it is convenient to assume 100 grams of the substance. Doing so allows you to have a reference point in that the percentage of the element becomes the mass. For example, if the elemental composition of a compound is 54.3 %A and 45.7 %B, assuming 100 grams allows you to start with 54.3 g of A and 45.7 g of B.

**1 a.** Assume exactly 100 grams of aspirin. As a result, 60.00% C becomes 60.00 g C, 4.48% H becomes 4.48 g H and 35.53% O becomes 35.53 g O. Convert each of these masses to moles:
$$60.00 g C x \frac{1 mol C}{12.01 g C} = 4.996 mol C$$

$$4.48 g H x \frac{1 mol H}{1.008 g H} = 4.44 mol H$$

$$35.53 g O x \frac{1 mol O}{16.00 g O} = 2.221 mol O$$

Divide through by the smallest moles to find the ratio of C:H:O :

$$\frac{4.006 mol C}{2.221 mol O} : \frac{4.44 mol H}{2.221 mol O} : \frac{2.221 mol O}{2.221 mol O}$$

 2.250 : 2.00 : 1.000

The ratio does not work out to a whole numbers, so since 2.25 is 2 ¼, which is 9/4, multiply the entire ratio by 4:

 2.250 x 4 = 9 C 2.00 x 4 = 8 H 1.000 x 4 = 4 O

The empirical formula is thus: **C9H8O4.** The empirical formula is the simplest possible formula for a compound.

**1 b.** The molecular formula is either the same as, or a multiple of the empirical formula. To find the multiple, one must compare the molar mass (MM) of the actual compound to the empirical formula weight (EFW). It is not necessary to use many significant figures to find this multiple.

Calculate the EFW: 9(12 g C/mol C) + 8(1 g H/mol H) + 4(16 g O/mol O) = 180 g/mol

The molar mass of aspirin is given to be 180 g/mol

Determine the multiple:
$$\frac{MM}{EFW} = \frac{180 g/mol}{180 g/mol} = 1$$

Since the multiple is “1”, the empirical formula is identical to the molecular formula: **C9H8O4**.

**2 a.** Assume exactly 100 g of para-dichlorobenzene. As a result, 49.02% C becomes 29.02 g C, 2.74 % H becomes 2.74 g H and 48.24% Cl becomes 48.24 g Cl. Convert each of the masses to moles:

$$49.02 g C x \frac{1 mol C}{12.01 g C} = 4.082 mol C$$

$$2.74 g H \frac{1 mol H}{1.008 g H} = 2.72 mol H$$

$$48.24 g Cl \frac{1 mol Cl}{35.45 g Cl} = 1.361 mol Cl$$

Divide through by the smallest moles to find the ratio of C:H:Cl :

$$\frac{4.082 mol C}{1.361 mol Cl} : \frac{2.72 mol H}{1.361 mol Cl} : \frac{1.361 mol Cl}{1.361 mol Cl}$$

 3.00 : 2.00 : 1.00

The empirical formula of para-dichlorobenzene is **C3H2Cl**. This is the simplest formula for the compound.

**2 b.** The molecular formula is either the same as, or a multiple of the empirical formula. To find the multiple, one must compare the molar mass (MM) of the actual compound to the empirical formula weight (EFW). It is not necessary to use many significant figures to find this multiple.

Calculate the EFW: 3(12 g/mol) + 2(1 g/mol) + 1(35.5 g/mol) = 73.5 g/mol

The molar mass of para-dichlorobenzene is given to be 147 g/mol.

Determine the multiple:
$$\frac{147 g/mol}{73.5 g/mol} = 2$$

The molecular formula is found by multiplying the subscripts of the empirical formula by the multiple of 2:

C3 x 2H2 x 2Cl1 x 2 = **C6H4Cl2**

**3 a.** Assume exactly 100 g of PABA. Thus, 61.31% C becomes 61.31 g C, 5.15% H becomes 5.15 g H, 10.21 g N becomes 10.21 g N and 23.33% O becomes 23.33 g O. Convert each of these masses to moles:

$$61.31 g C x \frac{1 mol C}{12.01 g C} = 5.105 mol C$$

$$5.15 g H x \frac{1 mol H}{1.008 g H} = 5.109 mol H$$

$$10.21 g N x \frac{1 mol N}{14.01 g N} = 0.7288 mol N$$

$$23.33 g O x \frac{1 mol O}{16.00 g O} = 1.458 mol O$$

Divide through by the smallest moles to find the ratio of C:H:N:O :

$$\frac{5.105 mol C}{0.7288 mol N} : \frac{5.109 mol H}{0.7288 mol N} : \frac{0.7288 mol N}{0.7288 mol N} : \frac{1.458 mol O}{0.7288 mol N}$$

 7.00 : 7.01 : 1.00 : 2.00

The empirical formula of PABA is **C7H7NO2**. This is the simplest formula for the compound.

**3 b.** compound.

**2 b.** The molecular formula is either the same as, or a multiple of the empirical formula. To find the multiple, one must compare the molar mass (MM) of the actual compound to the empirical formula weight (EFW). It is not necessary to use many significant figures to find this multiple.

Calculate the EFW of PABA: 7(12 g/mol) + 7(1 g/mol) + 1(14 g/mol) + 2(16 g/mol) = 137 g/mol

The molar mass of PABA is given to be 137 g/mol.

Determine the multiple:
$$\frac{MM}{EFW} = \frac{137 g/mol}{137 g/mol} = 1$$

The molecular formula for PABA is the same as the empirical formula: **C7H7NO2.**

**4 a.** Assume exactly 100 grams of potassium ferricyanide. As result, 35.62 % K becomes 35.62 g K, 16.96 %Fe becomes 16.96 g Fe, 21.89 %C becomes 21.89 g C and 25.53 %N becomes 25.53 g N. Convert each of these masses to moles:

$$35.62 g K x \frac{1 mol K}{39.10 g K} = 0.9110 mol K$$

$$16.96 g Fe x \frac{1 mol Fe}{55.85 g Fe} = 0.3056 mol Fe$$

$$21.89 g C x \frac{1 mol C}{12.01 g C} = 1.823 mol C$$

$$25.53 g N x \frac{1 mol N}{14.01 g N} = 1.823 mol N$$

Divide through by the smallest moles to find the ratio of K:Fe:C:N :

$$\frac{0.9110 mol K}{0.3056 mol Fe} : \frac{.3056 mol Fe}{.3056 mol Fe} : \frac{1.823 mol C}{.3056 mol Fe} : \frac{1.823 mol N}{.3056 mol Fe}$$

 3.000 : 1.000 : 6.000 : 6.000

The empirical formula for potassium ferricyanide is **K3FeC6N6.** This is the simplest formula for this compound.

**4 b.** The molecular formula is either the same as, or a multiple of the empirical formula. To find the multiple, one must compare the molar mass (MM) of the actual compound to the empirical formula weight (EFW). It is not necessary to use many significant figures to find this multiple.

Calculate the EFW for potassium ferricyanide:

3(39 g/mol) + 1(55.85 g/mol) + 6(12 g/mol) + 6(14 g/mol) = 329 g/mol

The molar mass of potassium ferricyanide is given to be 329 g/mol.

Determine the multiple:
$$\frac{MM}{EFW} = \frac{329 g/mol}{329 g/mol} = 1$$

The molecular formula is the same as the empirical formula: **K3FeC6N6**

**5 a.** Assume exactly 100 g of lindane. As a result, 24.78 %C becomes 24.78 g C, 2.08 %H becomes 2.08 g H and 73.14% Cl becomes 73.14 g Cl. Convert each of these masses to moles:

$$24.78 g C x \frac{1 mol C}{12.01 g C} = 2.063 mol C$$

$$2.08 g H x \frac{1 mol H}{1.08 g H} = 2.063 mol H$$

$$73.14 g Cl x \frac{1 mol Cl}{35.45 g Cl} = 2.063 mol Cl$$

Divide through by the smallest moles to find the ratio of C:H:Cl :

$$\frac{2.063 mol C}{2.063 mol C} : \frac{2.063 mol H}{2.063 mol C} : \frac{2.063 mol Cl}{2.063 mol C}$$

 1.000 : 1.000 : 1.000

The empirical formula for lindane is **CHCl**. This is the simplest formula for the compound.

**5 b.** The molecular formula is either the same as, or a multiple of the empirical formula. To find the multiple, one must compare the molar mass (MM) of the actual compound to the empirical formula weight (EFW). It is not necessary to use many significant figures to find this multiple.

Calculate the EFW: 1(12 g/mol) + 1(1 g/mol) + 1(35.5 g/mol) = 48.5 g/mol

The molar mass of lindane is given to be 290 g/mol.

Determine the multiple:
$$\frac{MM}{EFW} = \frac{290 g/mol}{28.5 g/mol} = 6$$

The molecular formula of lindane is found by multiplying the subscripts of the empirical formula by the multiple of 6:

C1 x 6H1 x 6Cl1 x 6 = **C6H6Cl6**