***Chemistry***

**3: Composition of Substances and Solutions**

**3.2: Determining Empirical and Molecular Formulas**

33. Calculate the following to four significant figures:

(a) the percent composition of ammonia, NH3

(b) the percent composition of photographic fixer solution (“hypo”), Na2S2O3

(c) the percent of calcium ion in Ca3(PO4)2

Solution

In each of these exercises asking for the percent composition, divide the molecular weight of the desired element or group of elements (the number of times it/they occur in the formula times the molecular weight of the desired element or elements) by the molecular weight of the compound.

(a) ;

(b) ;

(c) 

35. Determine the percent ammonia, NH3, in Co(NH3)6Cl3, to three significant figures.

Solution



37. Determine the empirical formulas for compounds with the following percent compositions:

(a) 15.8% carbon and 84.2% sulfur

(b) 40.0% carbon, 6.7% hydrogen, and 53.3% oxygen

Solution

(a) The percent of an element in a compound indicates the percent by mass. The mass of an element in a 100.0-g sample of a compound is equal in grams to the percent of that element in the sample; hence, 100.0 g of the sample contains 15.8 g of C and 84.2 g of S. The relative number of moles of C and S atoms in the compound can be obtained by converting grams to moles as shown.

Step 1:



Step 2:



The empirical formula is CS2.

(b) Step 1:



Step 2:



The empirical formula is CH2O.

39. A compound of carbon and hydrogen contains 92.3% C and has a molar mass of 78.1 g/mol. What is its molecular formula?

Solution

To determine the empirical formula, a relationship between percent composition and atom composition must be established. The percent composition of each element in a compound can be found either by dividing its mass by the total mass of compound or by dividing the molar mass of that element as it appears in the formula (atomic mass times the number of times the element appears in the formula) by the formula mass of the compound. From this latter perspective, the percent composition of an element can be converted into a mass by assuming that we start with a 100-g sample. Then, multiplying the percentage times 100 g gives the mass in grams of that component. Division of each mass by its respective atomic mass gives the relative ratio of atoms in the formula. From the numbers so obtained, the whole-number ratio of elements in the compound can be found by dividing each ratio by the number representing the smallest ratio. Generally, this process can be done in two simple steps (a third step is needed if the ratios are not whole numbers).

Step 1: Divide each element’s percentage (converted to grams) by its atomic mass:



This operation established the relative ration of carbon to hydrogen in the formula.

Step 2: To establish a whole-number ratio of carbon to hydrogen, divide each factor by the smallest factor. In this case, both factors are essentially equal; thus the ration of atoms is 1 to 1:



The empirical formula is CH.

Since the molecular mass of the compound is 78.1 amu, some integer times the sum of the mass of 1C and 1H in atomic mass units (12.011 amu + 1.00794 amu = 13.019 amu) must be equal to 78.1 amu. To find this number, divide 78.1 amu by 13.019 amu:



The molecular formula is (CH)6 = C6H6.

41. Determine the empirical and molecular formula for chrysotile asbestos. Chrysotile has the following percent composition: 28.03% Mg, 21.60% Si, 1.16% H, and 49.21% O. The molar mass for chrysotile is 520.8 g/mol.

Solution









(2)(Mg1.5Si1H1.5O4) = Mg3Si2H3O8 (empirical formula), empirical mass of 260.1 g/unit

so (2)(Mg3Si2H3O8) = Mg6Si4H6O16

43. A major textile dye manufacturer developed a new yellow dye. The dye has a percent composition of 75.95% C, 17.72% N, and 6.33% H by mass with a molar mass of about 240 g/mol. Determine the molecular formula of the dye.

Solution

Assume 100.0 g; the percentages of the elements are then the same as their mass in grams. Divide each mass by the molar mass to find the number of moles.

Step 1:



Step 2: Divide each by the smallest number. The answers are 5C, 1N, and 5H. The empirical formula is C5H5N, which has a molar mass of 79.10 g/mol. To find the actual molecular formula, divide 240, the molar mass of the compound, by 79.10 to obtain 3. So the formula is three times the empirical formula, or C15H15N3.

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