Percent Composition & Empirical Formula

Unit: Moles

MA Curriculum Frameworks (2016): HS-PS1-2, HS-PS1-3

Mastery Objective(s): (Students will be able to…)

- Determine the percentage of each element in a compound given its chemical formula.
- Determine the empirical and molecular formulas of a compound from percent composition data.

Success Criteria:

- Percentages are calculated correctly.
- Empirical and molecular formulas are calculated correctly.
- Subscripts in empirical and molecular formulas are whole numbers.
- Ratio of subscripts in empirical formulas is in lowest terms.
- Algebra and rounding to appropriate number of significant figures is correct.

Tier 2 Vocabulary: mole, composition

Language Objectives:

- Accurately describe the process for converting percentages to moles.

Notes:

percent composition: the percentage by mass of each element in a compound.

molecular formula (chemical formula): a formula that gives the numbers and types of atoms in a molecule.

empirical formula: a chemical formula with the subscripts reduced to lowest terms. *E.g.,* the empirical formula for C_2H_4 would be CH_2. The empirical formula for C_8H_{16} would *also* be CH_2. (You may remember that we ***always*** use empirical formulas for ionic compounds.)

formula mass: the mass in grams represented by a chemical formula. Sometimes called molecular mass, formula weight or molecular weight. (This is the same number as the molar mass, but with units of atomic mass units (amu) instead of grams.)

Use this space for summary and/or additional notes:

Determining Percent Composition

To determine the percent by mass of each element in a compound:

1. Determine the atomic mass of the element of interest
2. Determine the formula mass of the entire compound.
3. $\text{percent composition} = \frac{\text{atomic mass of element of interest}}{\text{formula mass of entire compound}} \times 100$

Sample Problem:

Q: What is the percentage of carbon in the compound $C_6H_{12}O_6$?

A: Mass of $C_6 = 6 \times 12.01 = 72.06$

Mass of $C_6H_{12}O_6$:

$C_6 = 6 \times 12.01 = 72.06$
$H_{12} = 12 \times 1.008 = 12.096$
$+ O_6 = 6 \times 16.00 = 96.00$
180.156

$$\frac{\text{mass of } C_6}{\text{mass of } C_6H_{12}O_6} = \frac{72.06}{180.156} = 0.400 \times 100 = 40.0\,\%$$

Determining Empirical and Molecular Formulas

The lowest-terms ratio of the atoms in a chemical formula is the empirical formula.

The ratio of atoms is the same as the ratio of moles, which means you can find the empirical formula of a compound by determining the ratio of moles, and converting that ratio to whole numbers:

1. Find the molar mass (in grams) of each element in the compound.
2. Convert the grams to moles for each element.
3. Convert the number of moles of each element to whole-number subscripts. The easiest way to do this is by dividing them all by whichever number is the smallest.
4. If a subscript is within ±5 % of a whole number after dividing, you can round it off. If a subscript is not within ±5 % of a whole number, multiply ***all*** of the subscripts by the smallest number that would cause ***all*** of the subscripts to be whole numbers (within ±5 %).

Use this space for summary and/or additional notes:

Sample Problem:

A sample of a chemical compound contains 8.56 g of carbon and 1.44 g of hydrogen. What is the empirical formula of this compound?

1. Masses are C: 8.56 g and H: 1.44 g. Write the formula as $C_{8.56\,g}H_{1.44\,g}$
2. Convert grams to moles:

   C: $\frac{8.56\,g}{1}\times\frac{1\,mol}{12.011\,g}=0.713\,mol$

   H: $\frac{1.44\,g}{1}\times\frac{1\,mol}{1.008\,g}=1.429\,mol$

   The formula for this compound is therefore a whole-number ratio that equals $C_{0.713}H_{1.429}$
3. Convert the subscripts to simple whole numbers. The easiest way to do this is to divide them all by the smallest one and see what happens.

   $C_{\frac{0.713}{0.713}}H_{\frac{1.429}{0.713}}=C_1H_{2.004}$
4. Round the empirical formula off. $CH_{2.004}$ becomes CH_2. (You can—*and should*—round, as long as you are within ±5 %.)

Hints:

If the problem gives percentages instead of actual mass, just pretend the percentages are out of 100 g total. *E.g.,* if you had a compound containing 25.3 % nitrogen, you would use 25.3 g of nitrogen in your calculations.

If you have something like $NO_{2.5}$, you can't round 2.5 off to 2 or 3. Instead, you need to multiply both subscripts by 2, which gives you N_2O_5. (This means it's important to be able to recognize decimal equivalents for simple fractions, such as $0.50=\frac{1}{2}$, $0.33=\frac{1}{3}$, $0.25=\frac{1}{4}$, $0.20=\frac{1}{5}$, *etc.*)

Use this space for summary and/or additional notes:

Empirical Formula *vs.* Molecular (actual) Formula

If you know the molar mass of the compound, you can use it to get from the empirical formula to the molecular formula.

For example, suppose you were told that the actual molar mass of the hydrocarbon from the example above is $42.08\frac{g}{mol}$.

The empirical formula mass (*i.e.,* the molar mass of the empirical formula CH_2) is (1 x 12.011) + (2 x 1.008) = 14.027.

The actual molar mass of 42.08 is 3 times as much, *i.e.,* $\frac{42.08}{14.027} = 3.00$.

This means the molecule contains exactly 3 of the empirical formula units, so we need to multiply all of the subscripts by 3 to get the molecular formula:

$CH_2 \times 3 = \boxed{C_3H_6}$.

Use this space for summary and/or additional notes:

Homework Problems

1. A 5.00 g sample of a compound was found to contain 1.93 g carbon, 0.49 g hydrogen and 2.58 g sulfur. What is the empirical formula of the compound?

   Answer: C_2H_8S

2. What is the percentage composition of each element in the compound tetrahydrocannabinol (THC), which has the formula $C_{21}H_{30}O_2$?

   Answers: C: 80.2 %; H: 9.6 %; O: 10.2 %

3. A sample of a compound was found to contain 42.56 g of palladium (Pd) and 0.80 g of hydrogen. If the molar mass of the compound is $2\,216.8\,\frac{g}{mol}$, what is the molecular formula of the compound?

   Answer: Pd_2H_4

4. Find the empirical formula of a compound that contains 30.45% nitrogen and 69.55% oxygen.

   Answer: NO_2

Use this space for summary and/or additional notes:

5. Find the percentage of boron in the compound boron triïodide (BI_3).

   Answer: 2.76 % boron

6. A compound containing only carbon and hydrogen has a molecular mass of 114.26 amu. If one mole of the compound contains 18.17 g of hydrogen, what is its molecular formula?

   Answer: C_8H_{18}

7. Find the molecular formula of a compound that contains 56.36 g of oxygen and 43.64 g of phosphorus. The molecular mass of the compound is 283.9 amu.

   Answer: P_4O_{10}

8. The compound caffeine has a molecular weight of 194.1926 amu. It contains 49.5% carbon, 5.2% hydrogen, 28.9% nitrogen, and 16.5% oxygen. What is its empirical formula? What is its molecular formula?

   Answers: empirical: $C_4H_5N_2O$; molecular: $C_8H_{10}N_4O_2$

Use this space for summary and/or additional notes: