Empirical Formulas & Molecular Formulas

EMPIRICAL FORMULAS

To determine the empirical formula of a compound:

1) Determine the relative weights of the elements that make up the compound, if they have not already been provided.
2) Express these quantities in moles.
3) Divide the number of moles by the minimum number of moles for each element.
4) Create a ratio for the elements in the formula. From this ratio, the empirical formula can often be written.
5) If the ratios are not already whole numbers, multiply each number in the ratio by an integer to remove the denominators.

Example 1: A compound is found to be 53% Aℓ and 47% O. Find its empirical formula.

Solution: Convert the quantities to grams rather than percentages. Assuming a sample weight of 100 g, there would be 53 g of Aℓ and 47 g of O.

Convert these quantities to moles:

$$\text{moles Al} = 53\text{ g Al} \times \frac{1\text{mol Al}}{27.0\text{ g Al}} = 1.96\text{ mol Al}$$

$$\text{moles O} = 47\text{ g O} \times \frac{1\text{mol O}}{16.0\text{ g O}} = 2.94\text{ mol O}$$

Divide these answers by the smallest number of moles:

$$\text{aluminum: } \frac{1.96}{1.96} = 1 \qquad \text{oxygen: } \frac{2.94}{1.96} \approx 1.5$$

This would imply an empirical formula of $Al_1O_{1.5}$, but since chemical formulas do not have fractional subscripts, we must multiply by a whole number to get whole number answers. Since $1.5 = \frac{3}{2}$, we need to multiply by 2.

$$\text{aluminum : oxygen} = 1 : 1.5 = 2 : 3$$

So the empirical formula is Al_2O_3.

MOLECULAR FORMULAS

To determine the molecular formula for a compound:

1) The molecular weight is always a multiple of the empirical formula weight (i.e., M.W. = n × E.F.W.) To determine n, divide the given molecular weight by the empirical formula weight.

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2) Multiply all the subscripts in the empirical formula by the answer to the previous step.

Example 2: If the compound from Example 1 had a molecular weight of 306 g, what would the molecular formula be?

Solution: The empirical formula was $A\ell_2O_3$. The empirical formula weight is $2 \times 27.0\text{ g} + 3 \times 16.0\text{ g} = 102\text{ g}$

The molecular weight is 306 g. 306 ÷ 102 = 3. We multiply the subscripts in the empirical formula by 3 to get the molecular formula $A\ell_6O_9$.

EXERCISES

A. Determine the empirical formula of each compound from its percentage composition by weight:

1) 66.4% Cu, 33.6% S

2) 79.8% Cu, 20.2% S

3) 62.6% Ca, 37.4% C

4) 36.8% N, 63.2% O

5) 38.9% Cℓ, 61.2% O

6) 39.8% K, 27.8% Mn, 32.5% O

7) 32.4% Na, 22.6% S, 45.0% O

8) 52.0% Zn, 9.60% C, 38.4% O

9) 1.90% H, 67.6% Cℓ, 30.5% O

10) 60.0% C 13.3% H, 26.7% O

B. Determine the empirical formula of each compound from the given weights:

1) 7.615 g Ga, 2.622 g O

2) 0.366 g Na, 0.220 g N, 0.752 g O

3) 11.89 g Fe, 5.11 g O

4) 87.3 g Na, 121.5 g S, 91.2 g O

C. Determine the molecular formula of each compound from the empirical formula and the molecular weight:

1) E.F. = NaS_2O_3, mol. wt. = 270.4

2) E.F. = $C_3H_2C\ell$, mol. wt. = 147.0

3) E.F. = $C_2HC\ell$, mol. wt. = 181.4

4) E.F. = Na_2SiO_3, mol. wt. = 732.6

5) E.F. = $NaPO_3$, mol. wt. = 305.9

6) E.F. = NO_2, mol. wt. = 92.0

D. Determine the molecular formula from the percentages by weight and the molecular weight.

1) 65.45% C, 5.45% H, 29.10% O; mol. wt. = 110

2) 40.0% C, 6.7% H, 53.5% O; mol. wt. = 180

3) 7.79% C, 92.21% Cℓ; mol. wt. = 154

4) 10.13% C, 89.87% Cℓ; mol. wt. = 237

5) 25.26% C, 74.74% Cℓ; mol. wt. = 285

6) 11.25% C, 88.75% Cℓ; mol. wt. = 320

SOLUTIONS

A. (1) CuS (2) Cu_2S (3) CaC_2 (4) N_2O_3 (5) $C\ell_2O_7$ (6) K_2MnO_4 (7) Na_2SO_4 (8) $ZnCO_3$ (9) $HC\ell O$ (10) C_3H_8O

B. (1) Ga_2O_3 (2) $NaNO_3$ (3) Fe_2O_3 (4) $Na_2S_2O_3$

C. (1) $Na_2S_4O_6$ (2) $C_6H_4C\ell_2$ (3) $C_6H_3C\ell_3$ (4) $Na_{12}Si_6O_{18}$ (5) $Na_3P_3O_9$ (6) N_2O_4

D. (1) $C_6H_6O_2$ (2) $C_6H_{12}O_6$ (3) $CC\ell_4$ (4) $C_2C\ell_6$ (5) $C_6C\ell_6$ (6) $C_3C\ell_8$