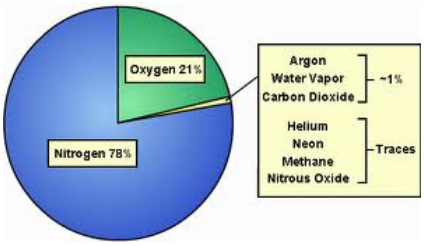
3.5 – 3.7: Percent Composition, Empirical Formulas



Our Atmosphere's Composition

Percent Composition

Unknown compounds are identified by <u>percent composition</u>: each element (by mass) adds a particular amount to the overall sample mass.

By <u>sample</u>, one could be using a full mole of sample, or a differently sized quantity of analyte. The Law of Definite Proportions is useful here.

To find the % composition of any element in a compound:

$$\%\,Element_{(mass)} = \frac{Mass\ of\ Element\ in\ Sample}{Total\ Mass\ of\ Sample} \cdot 100\%$$

Use this for EACH element in your compound.

1. HCN Example

Find the percent mass of the elements in hydrocyanic acid, HCN.

1: Determine molar mass of HCN:

$$1\,mol\,H \cdot \frac{1.01\,g\,H}{1\,mol\,H} = 1.01\,g\,H$$

$$1\,mol\,C \cdot \frac{12.01\,g}{1\,mol\,C} = 12.01\,g\,C$$

$$1\,mol\,N \cdot \frac{14.01\,g}{1\,mol\,N} = 14.01\,g\,N$$

$$= 27.03\,g\,/\,mol\,HCN$$

1. Example

Apply the formula for each element:

$$\%\,Hydrogen = \frac{1.01\,g\,H}{27.03\,g\,HCN} \cdot 100\% = 3.74\%$$

$$\%\,Carbon = \frac{12.01\,g\,C}{27.03\,g\,HCN} \cdot 100\% = 44.43\%$$

$$\%\,Nitrogen = \frac{14.01\,g\,N}{27.03\,g\,HCN} \cdot 100\% = 51.83\%$$

The total should be 100.00 %.

Empirical Formula (E. F.)

A chemical formula with the <u>smallest whole number ratio</u> of elements.

If a compound's percent composition is known, its E. F. can be calculated.

2. What is the E. F. of glucose ($C_6H_{12}O_6$)? CH_2O.

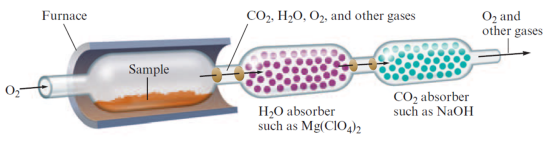
3. What the E. F. of Teflon, C_2F_4? CF_2

Mystery Compounds!

How are the formulas of unknown compounds determined?

The percent composition must be determined through analytical methods, then a mathematical process is used to figure out the empirical formula.

Ex: Hydrocarbons are burned in oxygen, and their products are separated and analyzed.



4. Guided E.F. Process

What's the empirical formula for a gaseous compound with 40.05% sulfur and 59.95% oxygen?

Candidates are SO, SO_2, SO_3, S_2O, and S_2O_2.

Step 1: Assume you have 100 grams, so:

40.05 grams S

59.95 grams O

4. Guided Example Process

Step 2: Convert mass to moles for all elements.

Sulfur: $40.05\,g\,S \bullet \frac{1\,mol\,S}{32.07\,g\,S} = 1.249\,mol\,S$

Oxygen: $59.95\,g\,O \bullet \frac{1\,mol\,O}{16.00\,g\,O} = 3.747\,mol\,O$

Mole ratio sulfur : oxygen is 1.249 : 3.747

Possible formula: $S_{1.249}O_{3.747}$

4. Guided Example Process

Step 3: Divide both molar values by the SMALLEST to get whole numbers.

S → $\frac{1.249\,mol\,S}{1.249} = 1\,mol\,S$

O → $\frac{3.747\,mol\,O}{1.249} = 3\,mol\,O$

Thus, the empirical formula is SO_3.

Possible Last Step

Possible Step 4: If values are not whole numbers (within 0.05), find a small multiplier that makes them so.

5. A compound's ratio winds up as follows:
C: 1.32 H: 3.0 O: 1.0

Find a multiplier that will yield a formula with small whole numbers. What is the formula?
Multiply by 3: $C_4H_9O_3$

Do the same for the following ratio:
C: 2.24 H: 6.49 O: 1.0

Multiply by 4: $C_9H_{26}O_4$.

Molecular Formula Process

Finding the E. F. of a compound doesn't always yield the compound's molecular (actual) formula.

Step 1: You **must** have the molar mass of the compound; then calculate E. F, and E. F. mass of it.

Step 2: Divide molar mass by the E. F. mass. This tells the number of times the E. F. is repeated in the molecule.

Step 3: Multiply the E. F. by this value: this gives the molecular formula.

6. Mystery Organic Compound

A compound contains only C, H and O.
Combustion of 10.68 g of the compound yields 16.01 g of CO_2 and 4.37 g of H_2O.
What is its empirical, and molecular formulas?
The molar mass of the compound is 176.10 g/mol.

6. Mystery Organic Compound: Strategy

What a mess! How will you approach this situation?

In the problem, you are given an initial compound mass, as well as product masses. You must determine the masses of elements in the products using a % composition approach.

Then, you can determine the % composition of the mystery compound, and use the process to find empirical formula.

6. Mystery Organic Compound - Product Analysis

Carbon in CO_2: Molar Mass = 44.01 g/mol

% C in CO_2 = $\frac{12.01\,g\,C}{44.01\,g\,CO_2} \bullet 100\% = 27.29\%\,C$

g C in CO_2 = $16.01\,g\,CO_2 \bullet 27.29\%\,C = \boxed{4.37\,g\,C}$

Hydrogen in H_2O: Molar Mass = 18.02 g/mol

% H in H_2O = $\frac{2.02\,g\,H}{18.02\,g\,H_2O} \bullet 100\% = 11.21\%\,H$

g H in H_2O = $4.37\,g\,H_2O \bullet 11.21\%\,H = \boxed{0.49\,g\,H}$

Oxygen (difference calculation):

10.68 g compound - 4.37g C - 0.49g H = 5.82g O

6. Mystery Organic Compound - % Composition of Mystery Compound

We can now find % composition of the elements in the mystery compound (MC), and use the process to figure out the empirical formula.

$$\%\,C = \frac{4.37\,g\,C}{10.68\,g\,MC} \bullet 100\% = 40.92\%\,C$$

$$\%\,H = \frac{0.49\,g\,H}{10.68\,g\,MC} \bullet 100\% = 4.59\%\,H$$

$$\%\,O = \frac{5.82\,g\,O}{10.68\,g\,MC} \bullet 100\% = 54.49\%\,O$$

6. Mystery Organic Compound - Empirical Formula Process

Percent to grams to moles to empirical formula:

Carbon: 40.92%

$40.92\,g\,C \bullet \frac{1\,mol\,C}{12.01\,g\,C} = 3.34\,mol\,C$ → 1 mol C

Hydrogen: 4.59%

$4.59\,g\,H \bullet \frac{1\,mol\,H}{1.01\,g\,H} = 4.54\,mol\,H$ → ÷3.34 → 1.35 mol H

Oxygen: 54.48%

$54.48\,g\,O \bullet \frac{1\,mol\,O}{16.00\,g\,O} = 3.41\,mol\,O$ → 1.02 mol O

What multiplier can we use to modify our ratio?

3: $C_3H_4O_3$.

7. Mystery Organic Compound - Molecular Formula Process

Dividing the molar mass of the molecular formula by the empirical formula mass should give a whole number representing the number of times the empirical formula is repeated in the molecule.

Empirical formula mass ($C_3H_4O_3$): 88.07g/mol.

Comparison: $\frac{176.10\,g/mol}{88.07\,g/mol} = 2.0$

Thus, the molecular formula is $C_6H_8O_6$.

Homework

Read 3.8 - 3.9

3.5 - 3.7 Problems in your Booklet
Due: Next Class.