TOPIC: 1.3 ELEMENTAL COMPOSITION OF PURE SUBSTANCES

ENDURING UNDERSTANDING:	
SPQ-2	Chemical Formulas identify substances by their unique combination of atoms
LEARNING OBJECTIVE:	
SPQ-2.A	Explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance
ESSENTIAL KNOWLEDGE:	
SPQ-2.A.1	Some pure substances are composed of individual molecules, while others consist of atoms or ions held together in fixed proportions as described by a formula unit.
SPQ-2.A.2	According to the law of definite proportions, the ratio of the masses of the constituent elements in any pure sample of that compound is always the same.
SPQ-2.A.3	The chemical formula that lists the lowest whole number ratio of atoms of the elements in a compound is the empirical formula.
EQUATION(S):	
	N/A

NOTES:

A pure substance is one with constant composition; a pure substance can either be an element or a compound

When dealing with compounds you can assume it follows the law of definite proportion, which states compounds with the same elements in the same proportion are the SAME compound.

Following the law of definite proportion, you can find the percent composition which is the percent by mass of each element that makes up a compound.
To calculate the percent composition, you divide the mass of each element in a compound by the total molar mass of the substance.

In compounds, the **empirical formula** represents the simplest ratio of one element to another in a compound. The **molecular formula** represents the actual formula for the substance.

An example is glucose which has the molecular formula $C_6H_{12}O_6$ but the empirical formula is CH_2O.

To determine the empirical and molecular formula.

1. Determine the *empirical formula* for the compound when given percent of each element
   a. Assume you are given a 100g sample so you can change percent to grams
   b. For each element take grams / molar mass to get moles of each element
   c. Divide each mole value by the lowest of the values
   d. If you are within 0.1 of a whole number round to the whole number, if you are not you must multiply by a factor that gives you whole numbers for all.
   e. The values you found are the subscripts for each element
2. Determine *molecular formula* (can only determine if given molar mass of substance)
   a. Find mass of empirical formula
   b. Molar mass/ empirical formula mass to find factor
   c. Multiply all subscripts in the empirical formula by the value

I DO:

A certain sugar used in treating patients with low blood sugar has the following chemical composition: 40 carbon, 6.70 % hydrogen, and 53.3 percent oxygen. What is the empirical formula?

40.0 % C → 40.0 g C (1 mol/12.011 g C) = 3.33 moles C / 3.33 moles = 1

6.70% H → 6.70 g H (1 mol/1.01 g H) = 6.63 moles H / 3.33 moles = 2

53.3 % O → 53.3 g O (1 mol/16.0 g O) = 3.33 moles O /3.33 moles = 1

CH_2O

The molar mass of the compound is 180 grams/mole. What is the molecular formula of this compound?

C = 1 x 12.01 = 12.01

H = 2 x 1.01 = 2.02

O = 1 x 16.00 = 16.00

30.03 g/mole (30.03 g/mol) *x = 180 g/mol

X = 6 $C_6H_{12}O_6$

WE DO:

a. A compound is found to contain 56.5% carbon, 7.11% hydrogen, and 36.4% phosphorus. Find the empirical formula. C_4H_6P

56.5% C → 56.5 g C = 4.70 mol C/1.18 = 4

7.11% H → 7.11 g H = 7.03 mol H/1.18 = 6

36.4% P → 36.4 g P = 1.18 mol P/1.18 = 1

b. If the compound has a molar mass of 170.14 g/mol, what is its molecular formula?

85.06X = 170.14 ⇒ X = 2 $C_8H_{12}P_2$

SCAN ME

YOU DO:

1. The most abundant molecule found in the human body is 88.810% oxygen and 11.190% hydrogen. Calculate the empirical formula for this substance.

88.81% O → 88.81 g O = 5.55 mol O/5.55 = 1 H_2O

11.19% H → 11.19 g H = 11.10 mol H/5.55 = 2

2. Arginine is one of the amino acids; it is used in the biosynthesis of proteins. Analysis revealed that a sample of arginine was 41.368 % carbon, 8.101% hydrogen, 32.162 % nitrogen and 18.369% oxygen.
   a. What is the empirical formula of arginine?

41.368% C → 41.368 g C = 3.44 mol C 1.5 18.369 g O → 1.15 mol O 0.5

8.101% H → 8.101 g H = 8.04 mol H → 3.5

32.162% N → 32.162 g N = 2.30 mol N → 1 $C_3H_7N_2O$

   b. The molecular weight of arginine is 174.204 grams/mole. What is the molecular formula?

87.106X = 174.204 $C_6H_{14}N_4O_2$

X = 2

3. The empirical and molecular formulas of urea are the same. 90 % of the world's urea is used for fertilizer. If the percentage composition of the elements in urea are 19.999% carbon, 6.713% hydrogen, 46.646% nitrogen and 26.641% oxygen.

1.67 mol C → 1 1.67 mol O → 1 CH_4N_2O

6.66 mol H → 4

3.33 mol N → 2

4. A compound containing phosphorus and oxygen is a powerful desiccant. The compound is 43.642% phosphorus and 56.358% oxygen.

Calculate the empirical formula for this compound.

1.41 mol P → 1 → 2 P_2O_5
3.52 mol O → 2.5 → 5

b. The molar mass of this compound is 283.889044 g/mol, determine the molecular formula.

141.94X = 283.889044 P_4O_{10}
X = 2

5. Emeralds are composed of 4 different elements in a fixed proportion. They are composed of 5.030 % beryllium, 10.040 % Aluminum, 31.351% Silicon and 53.579% oxygen. The empirical and molecular formula are the same.
   a. Calculate the empirical formula.

0.56 mol Be → 1.5 $Al_2Be_3O_{18}Si_6$
0.37 mol Al → 1
1.12 mol Si → 3
3.35 mol O → 9

   b. Calculate the molar mass.

537.53 g/mol

6. Iron can form three different oxides, FeO, Fe_2O_3 and Fe_3O_4. A sample of iron oxide was analyzed and was found to contain 69.943% iron with the rest of the mass from oxygen. Determine the empirical formula to determine the identity of the iron oxide.

1.25 mol Fe → 1 Fe_2O_3
1.88 mol O → 1.5

7. Serotonin is a chemical that nerve cells produce from an essential amino acid called tryptophan. Tryptophan must enter our body through a balanced diet, and is commonly found in nuts, cheese and red meat. Serotonin is considered to be a natural mood stabilizer as it helps with sleeping, eating and digestion. A sample of serotonin was found to be 6.864% hydrogen, 68.159% carbon, 15.897% nitrogen and 9.079% oxygen. Calculate the empirical formula for serotonin.

6.81 mol H → 12 $C_{10}H_{12}N_2O$
5.68 mol C → 10
1.13 mol N → 2
0.57 mol O → 1

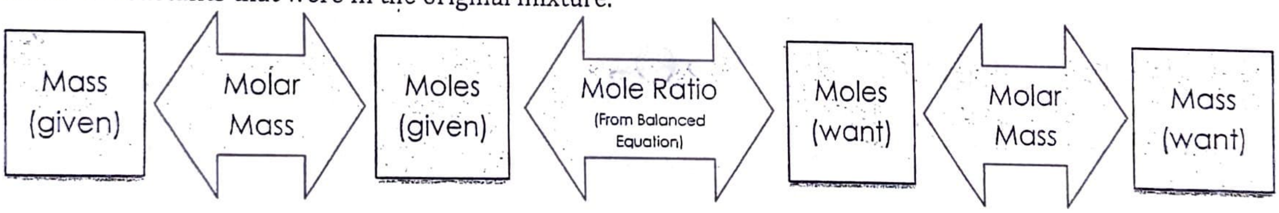
TOPIC: 1.4 COMPOSITION OF MIXTURES

ENDURING UNDERSTANDING:	
SPQ-2	Chemical formulas identify substances by their unique combination of atoms
LEARNING OBJECTIVE:	
SPQ-2.B	Explain the quantitative relationship between the elemental composition by mass and the composition of substances in a mixture.
ESSENTIAL KNOWLEDGE:	
SPQ-2.B.1	While pure substances contain molecules or formula units of a single type, mixtures contain molecules or formula units of two or more types, whose relative proportions can vary.
SPQ-2.B.2	Elemental analysis can be used to determine the relative numbers of atoms in a substance and to determine its purity.
EQUATION(S):	
	N/A

NOTES:

When two or more pure substances (elements and compounds) are combined they form a mixture. In mixtures the composition can vary. The mixture can be analyzed in order to determine the mass composition of each substance in that mixture.

You can use stoichiometry (mole ratios) to convert the masses of the products from the analysis to find the amounts of reactants that were in the original mixture.



The mass percentage of a substance in the mixture can be calculated:

$$\frac{\text{Mass of Substance}}{\text{Total Mass of Mixture}} \times 100 = \text{Mass Percentage}$$

Elemental Analysis to determine the composition of a mixture can be qualitative (identify the different elements present) or quantitative (identify the amounts of elements present.) Elemental analysis is a part of analytical chemistry.

Some examples of elemental analysis include:

- CHNX - Used by organic chemists to identify the mass fractions of carbon, hydrogen, nitrogen and other atoms such as halogens or sulfur. One form of this is <u>combustion analysis</u>. All of the carbon in a sample is converted into carbon dioxide, all of the hydrogen is converted into water, nitrogen is converted into nitrogen monoxide or nitrogen dioxide and sulfur (for example) is converted into sulfur dioxide.
- Spectroscopy
  - Optical – light is passed through a colored solution and the amount of light absorbed or transmitted is measured to determine the concentration of the solution (3.13 Beer-Lambert Law)
  - Mass – The charge to mass ratio is measured by atomizing then ionizing a sample, then accelerating the sample between charged plates and measuring the deflection of the sample. Greater deflection is found in smaller masses or larger charges. (1.2 Mass Spectroscopy)
  - Photoelectron – The energy to remove electrons from atoms is measured and can be translated into the electron configuration (arrangement) for an element. (1.7 Photoelectron Spectroscopy)

…m metal reacts with the air and forms a thin, corrosion resistant coating of aluminum oxide, Al_2O_3, …ing to the following unbalanced equation.

$$Al_{(s)} + O_{2\,(g)} \rightarrow Al_2O_{3\,(s)}$$

…ample of a mixture of aluminum and aluminum oxide weighing 120.91 grams were analyzed and the total mass …f aluminum in the sample was found to be 120.32 grams of aluminum.

a) Balance the equation provided.
b) What mass of oxygen was in the sample?
c) What mass of aluminum oxide was in the mixture?
d) What is the mass percent of aluminum oxide in the aluminum and aluminum oxide mixture?

a) $4\,Al + 3\,O_2 \rightarrow 2\,Al_2O_3$

b) 120.91 g − 120.32 = 0.59 g Oxygen

c) $0.59 \text{ grams } O_2 \times \frac{1 \text{ mole } O_2}{32.0 \text{ g } O_2} \times \frac{2 \text{ moles } Al_2O_3}{3 \text{ moles } O_2} \times \frac{101.948 \text{ g } Al_2O_3}{1 \text{ mole } Al_2O_3} = 1.3 \text{ g } Al_2O_3$

d) $\frac{1.3 \text{ g } Al_2O_3}{120.91 \text{ g Mixture}} \times 100 = 1.1\%$

WE DO:

The main component of egg shells is the compound calcium carbonate, $CaCO_3$. If you react egg shells with acetic acid, HCH_3COO, from vinegar the following reaction will take place.

$$CaCO_{3\,(s)} + 2\,HCH_3COO_{(aq)} \rightarrow H_2O_{(l)} + CO_{2\,(g)} + Ca(CH_3COO)_{2\,(aq)}$$

If 4.421 grams of carbon dioxide, CO_2, was produced from 10.57 grams of egg shells, what percentage of the mass of the egg shells was calcium carbonate?

SCAN ME

$4.421 \cancel{\text{g } CO_2} \times \frac{\cancel{1 \text{ mol } CO_2}}{44.01 \cancel{\text{g } CO_2}} \times \frac{\cancel{1 \text{ mol } CaCO_3}}{\cancel{1 \text{ mol } CO_2}} \times \frac{100.09 \text{ g } CaCO_3}{\cancel{1 \text{ mol } CaCO_3}} = \frac{10.054 \text{ g } CaCO_3}{10.57 \text{ g egg shells}} = 95.12\%$

YOU DO:

1) A 15.0 gram sample of sodium hydrogen carbonate, $NaHCO_3$, was contaminated with an impurity. In order to determine the purity of the sample, it was heated to decompose the material according to the following reaction:

15.0 g $NaHCO_3$ 6.35 g Na_2CO_3

$2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$

If 6.35 grams of sodium carbonate, Na_2CO_3, were recovered, what percentage (by mass) of the sample was sodium hydrogen carbonate, $NaHCO_3$?

$6.35 \cancel{\text{g } Na_2CO_3} \times \frac{\cancel{1 \text{ mol } Na_2CO_3}}{105.99 \cancel{\text{g } Na_2CO_3}} \times \frac{2 \cancel{\text{ mol } NaHCO_3}}{\cancel{1 \text{ mol } Na_2CO_3}} \times \frac{84.008 \text{ g } NaHCO_3}{1 \cancel{\text{ mol } NaHCO_3}} = 10.07 \text{ g } NaHCO_3 \quad 67.1\%$

2) Devise a method to separate a mixture of sand, salt and iron filings.

Use a magnet to separate iron filings from the mixture. Dissolve the sand and salt in water and filter the sand. Boil the water and salt and the salt will be separated through evaporation.

3) A sample of brass weighing 1.203 grams was analyzed. Brass is an alloy composed of copper, Cu, and zinc, Zn. The zinc in the alloy was reacted with 35.123 grams of hydrochloric acid, HCl, in excess, according to the following balanced equation:

$$Zn_{(s)} + 2\ HCl_{(aq)} \rightarrow H_{2\,(g)} + ZnCl_{2\,(aq)}$$

After all of the zinc reacted the mass of the remaining solution weighed 36.309 grams.

a) What mass of hydrogen gas was produced?
b) What mass of zinc reacted?
c) What was the percentage of zinc (by mass) in the alloy?

a) 0.97 g H
b) 16.96 g Zn
c)

4) A sample of sodium bromide, NaBr, has a mass percentage of sodium of 22.34%.
a) If the sample of sodium bromide were contaminated with sodium chloride, NaCl, would the mass percentage of Na in the sample be higher or lower than the pure sample? Justify your claim.
b) If the sample of sodium bromide were contaminated with sodium iodide, NaI, would the mass percentage of Na in the sample be higher or lower than the pure sample? Justify your claim.

5) A mixture consisting only of lithium chloride, LiCl, lithium carbonate, Li_2CO_3, and lithium nitrate, $LiNO_3$, was analyzed. The elemental analysis of the mixture revealed the following:

Element	% composition
Li	14.19 %
Cl	10.56 %
C	6.198 %
O	59.06%
N	10.01 %

Calculate the mass percentage of each compound in the mixture.

6) A sample of a mixture containing an unknown hydrocarbon and some nitrogen dioxide, NO_2, had a total mass of 31.25 grams. The mixture was analyzed using combustion analysis, producing 78.44 g of carbon dioxide, CO_2, and 32.12 g of water, H_2O. 31.25 g Sample 78.44 g CO_2 32.12 g H_2O

a) Calculate the empirical formula of the hydrocarbon.

$$78.44\,\cancel{g\,CO_2} \times \frac{\cancel{1\,mol\,CO_2}}{44.01\,\cancel{g\,CO_2}} \times \frac{1\,mol\,C}{\cancel{1\,mol\,CO_2}} = 1.78\,mol\,C \quad CH_2$$

b) The molar mass of the compound was found to be 252.48 g/mol. What is the molecular formula of the hydrocarbon?

$14.026X = 252.48 \Rightarrow X = 18 \quad C_{18}H_{36}$

c) What percentage (by mass) of the original sample was the hydrocarbon?

80%