2.3 DETERMINING CHEMICAL FORMULAS

TRY THIS ACTIVITY: WHAT MAKES POPCORN POP?

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Type of popcorn kernel	Initial mass (g)	Final mass (g)	Change in mass (g)	Percentage water (%)	Percentage of popped corn (%)
whole	18.16	16.30	1.86	10.2	~90
split crosswise	15.34	13.90	1.45	9.45	~20
split lengthwise	15.04	13.54	1.50	9.97	<1

(a) In general, the results seem to confirm that popcorn pops because the moisture inside the large part (endosperm) of the seed vaporizes, builds up the internal pressure, and suddenly breaks the hard outer coating (pericarp). The evidence of the popping percentage of the whole seeds versus the lengthwise-split seeds clearly illustrates this. The results for the crosswise-split seeds are inconclusive, perhaps because this splitting will, in some cases, include some of the endosperm and, in other cases, be restricted only to the bottom, germinating part of the seed.

PRACTICE

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Understanding Concepts

1. H = 2.20%
   C = 26.7%
   O = 71.1%

$$m_H = \frac{2.20}{100} \times 100\ \text{g}$$
$$m_H = 2.20\ \text{g}$$

$$m_C = \frac{26.7}{100} \times 100\ \text{g}$$
$$m_C = 26.7\ \text{g}$$

$$m_O = \frac{71.1}{100} \times 100\ \text{g}$$
$$m_O = 71.1\ \text{g}$$

$$n_H = 2.20\ \cancel{\text{g H}} \times \frac{1\ \text{mol H}}{1.01\ \cancel{\text{g H}}}$$
$$n_H = 2.18\ \text{mol H}$$

$$n_C = 26.7\ \cancel{\text{g C}} \times \frac{1\ \text{mol C}}{12.01\ \cancel{\text{g C}}}$$
$$n_C = 2.22\ \text{mol C}$$

$$n_O = 71.1\ \cancel{g\ O} \times \frac{1\ mol\ O}{16.00\ \cancel{g\ O}}$$

$$n_O = 4.44\ mol\ O$$

$$n_H : n_C : n_O = 2.18 : 2.22 : 4.44$$
$$= \frac{2.18}{2.18} : \frac{2.22}{2.18} : \frac{4.44}{2.18}$$
$$= 1.00 : 1.02 : 2.04$$
$$n_H : n_C : n_O = 1 : 1 : 2$$

The empirical formula of this compound is HCO_2.

2. Al = 35.9%
   S = 64.1%

$$m_{Al} = \frac{35.9}{100} \times 100\ g$$
$$m_{Al} = 35.9\ g\ Al$$

$$m_S = \frac{64.1}{100} \times 100\ g$$
$$m_S = 64.1\ g\ S$$

$$n_{Al} = 35.9\ \cancel{g\ Al} \times \frac{1\ mol\ Al}{26.98\ \cancel{g\ Al}}$$
$$n_{Al} = 1.33\ mol\ Al$$

$$n_S = 64.1\ \cancel{g\ S} \times \frac{1\ mol\ S}{32.06\ \cancel{g\ S}}$$
$$n_S = 2.00\ mol\ S$$

$$n_{Al} : n_S = 1.33 : 2.00$$
$$= \frac{1.33}{1.33} : \frac{2.00}{1.33}$$
$$= 1.00 : 1.50$$
$$= 2(1.00) : 2(1.50)$$
$$n_{Al} : n_S = 2.00 : 3.00$$
$$n_{Al} : n_S = 2 : 3$$

The empirical formula of the compound is Al_2S_3.

PRACTICE

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Understanding Concepts

3. C = 68.54%
   H = 8.63%
   O = 22.83%
   $M_{compound}$ = 140.20 g/mol

$$m_C = \frac{68.54}{100} \times 100 \text{ g}$$
$$m_C = 68.54 \text{ g}$$

$$m_H = \frac{8.63}{100} \times 100 \text{ g}$$
$$m_H = 8.63 \text{ g}$$

$$m_O = \frac{22.83}{100} \times 100 \text{ g}$$
$$m_O = 22.83 \text{ g}$$

$$n_C = 68.54 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}}$$
$$n_C = 5.707 \text{ mol C}$$

$$n_H = 8.63 \text{ g C} \times \frac{1 \text{ mol C}}{1.01 \text{ g C}}$$
$$n_H = 8.54 \text{ mol C}$$

$$n_O = 22.83 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}}$$
$$n_O = 1.427 \text{ mol O}$$

$$\begin{aligned} n_C : n_H : n_O &= 5.707 : 8.54 : 1.427 \\ &= \frac{5.707}{1.427} : \frac{8.54}{1.427} : \frac{1.427}{1.427} \\ &= 3.999 : 5.98 : 1.00 \\ n_C : n_H : n_O &= 4 : 6 : 1 \end{aligned}$$

The empirical formula of the compound is C_4H_6O.

$$M_{C_4H_6O} = 4(12.01 \text{ g/mol}) + 6(1.01 \text{ g/mol}) + 1(16.00 \text{ g/mol})$$
$$M_{C_4H_6O} = 70.10 \text{ g/mol}_{C_4H_6O}$$

$$\frac{M_{\text{compound}}}{M_{C_4H_6O}} = \frac{140.20 \text{ g/mol}}{70.10 \text{ g/mol}}$$
$$\frac{M_{\text{compound}}}{M_{C_4H_6O}} = 2$$

molecular formula = 2(empirical formula)
$= 2(C_4H_6O)$
molecular formula = $C_8H_{12}O_2$

The molecular formula of the compound is $C_8H_{12}O_2$.

4. C = 76.5%
H = 12.2%
O = 11.3%
$M_{compound}$ = 706.3 g/mol

$$m_C = \frac{76.5}{100} \times 100 \text{ g}$$
$$m_C = 76.5 \text{ g}$$

$$m_H = \frac{12.2}{100} \times 100 \text{ g}$$
$$m_H = 12.2 \text{ g}$$

$$m_O = \frac{11.3}{100} \times 100 \text{ g}$$
$$m_O = 11.3 \text{ g}$$

$$n_C = 76.5 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}}$$
$$n_C = 6.37 \text{ mol C}$$

$$n_H = 12.2 \text{ g H} \times \frac{1 \text{ mol H}}{1.01 \text{ g H}}$$
$$n_H = 12.1 \text{ mol H}$$

$$n_O = 11.3 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}}$$
$$n_O = 0.706 \text{ mol O}$$

$$n_C : n_H : n_O = 6.37 : 12.1 : 0.706$$
$$= \frac{6.37}{0.706} : \frac{12.1}{0.706} : \frac{0.706}{0.706}$$
$$= 9.02 : 17.1 : 1.00$$
$$n_C : n_H : n_O = 9 : 17 : 1$$

The empirical formula of the compound is $C_9H_{17}O$.

$$M_{C_9H_{17}O} = 9(12.01 \text{ g/mol}) + 17(1.01 \text{ g/mol}) + 1(16.00 \text{ g/mol})$$
$$M_{C_9H_{17}O} = 141.26 \text{ g/mol } C_9H_{17}O$$
$$\frac{M_{compound}}{M_{C_9H_{17}O}} = \frac{706.3 \text{ g/mol}}{141.26 \text{ g/mol}}$$
$$\frac{M_{compound}}{M_{C_9H_{17}O}} = 5$$

$$\text{molecular formula} = 5(\text{empirical formula})$$
$$= 5(C_9H_{17}O)$$
$$\text{molecular formula} = C_{45}H_{85}O_5$$

The molecular formula of the fat is $C_{45}H_{85}O_5$.

5. K = 26.65%
Cr = 35.33%
O = 38.02%
M_{compound} = 294.20 g/mol

$$m_K = \frac{26.65}{100} \times 100 \text{ g}$$
$$m_K = 26.65 \text{ g}$$

$$m_{Cr} = \frac{35.33}{100} \times 100 \text{ g}$$
$$m_{Cr} = 35.33 \text{ g}$$

$$m_O = \frac{38.02}{100} \times 100 \text{ g}$$
$$m_O = 38.02 \text{ g}$$

$$n_K = 26.65 \text{ g K} \times \frac{1 \text{ mol K}}{39.10 \text{ g K}}$$
$$n_K = 0.6816 \text{ mol K}$$

$$n_{Cr} = 35.33 \text{ g Cr} \times \frac{1 \text{ mol Cr}}{52.00 \text{ g Cr}}$$
$$n_{Cr} = 0.6794 \text{ mol Cr}$$

$$n_O = 38.02 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}}$$
$$n_O = 2.376 \text{ mol O}$$

$$n_K : n_{Cr} : n_O = 0.6816 : 0.6794 : 2.376$$
$$= \frac{0.6816}{0.6794} : \frac{0.6794}{0.6794} : \frac{2.376}{0.6794}$$
$$= 1.003 : 1.000 : 3.497$$
$$n_C : n_H : n_O = 1 : 1 : 3.5$$

Multiply the ratio by 2 to obtain whole numbers.

$$n_C : n_H : n_O = 2(1) : 2(1) : 2(3.5)$$
$$n_C : n_H : n_O = 2 : 2 : 7$$

The empirical formula of the compound is $K_2Cr_2O_7$.

$$M_{K_2Cr_2O_7} = 2(39.10 \text{ g/mol}) + 2(52.00 \text{ g/mol}) + 7(16.00 \text{ g/mol})$$
$$M_{K_2Cr_2O_7} = 294.20 \text{ g/mol } K_2Cr_2O_7$$

$$\frac{M_{\text{substance}}}{M_{K_2Cr_2O_7}} = \frac{294.20\ \cancel{\text{g/mol}}}{294.20\ \cancel{\text{g/mol}}}$$

$$\frac{M_{\text{substance}}}{M_{K_2Cr_2O_7}} = 1$$

$$\text{molecular formula} = 1(\text{empirical formula})$$
$$= 1(K_2Cr_2O_7)$$
$$\text{molecular formula} = K_2Cr_2O_7$$

The molecular formula of the substance is $K_2Cr_2O_7$.

6. C = 74.0%
H = 8.7%
N = 17.3%
M_{nicotine} = 162.26 g/mol

$$m_C = \frac{74.0}{100} \times 100\ \text{g}$$
$$m_C = 74.0\ \text{g}$$

$$m_H = \frac{8.7}{100} \times 100\ \text{g}$$
$$m_H = 8.7\ \text{g}$$

$$m_N = \frac{17.3}{100} \times 100\ \text{g}$$
$$m_N = 17.3\ \text{g}$$

$$n_C = 74.0\ \cancel{\text{g C}} \times \frac{1\ \text{mol C}}{12.01\ \cancel{\text{g C}}}$$
$$n_C = 6.16\ \text{mol C}$$

$$n_H = 8.7\ \cancel{\text{g H}} \times \frac{1\ \text{mol H}}{1.01\ \cancel{\text{g H}}}$$
$$n_H = 8.6\ \text{mol H}$$

$$n_N = 17.3\ \cancel{\text{g N}} \times \frac{1\ \text{mol N}}{14.01\ \cancel{\text{g N}}}$$
$$n_N = 1.23\ \text{mol N}$$
$$n_C : n_H : n_N = 6.16 : 8.6 : 1.23$$
$$= \frac{6.16}{1.23} : \frac{8.6}{1.23} : \frac{1.23}{1.23}$$
$$= 5.01 : 7.0 : 1.00$$
$$n_C : n_H : n_N = 5 : 7 : 1$$

The empirical formula of the compound is C_5H_7N.

$$M_{C_5H_7N} = 5(12.01\ \text{g/mol}) + 7(1.01\ \text{g/mol}) + 1(14.01\ \text{g/mol})$$

$$M_{C_5H_7N} = 81.13\ \text{g/mol}\ C_5H_7N$$

$$\frac{M_{\text{nicotine}}}{M_{C_5H_7N}} = \frac{162.26\ \cancel{\text{g/mol}}}{81.13\ \cancel{\text{g/mol}}}$$

$$\frac{M_{\text{nicotine}}}{M_{C_5H_7N}} = 2$$

$$\text{molecular formula} = 2(\text{empirical formula})$$

$$= 2(C_5H_7N)$$

$$\text{molecular formula} = C_{10}H_{14}N_2$$

The molecular formula of the compound is $C_{10}H_{14}N_2$.

PRACTICE

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Understanding Concepts

7. (a) $m_C = 12.01$ u
$m_H = 1.01$ u
$m_O = 16.00$ u

$$m_{C_6H_8O_6} = 6(m_C) + 8(m_H) + 6(m_O)$$

$$= 6(12.01\ \text{u}) + 8(1.01\ \text{u}) + 6(16.00\ \text{u})$$

$$= 72.06\ \text{u} + 8.08\ \text{u} + 96.00\ \text{u}$$

$$m_{C_6H_8O_6} = 176.14\ \text{u}$$

$$\%\ \text{C} = \frac{72.06\ \cancel{\text{u}}}{176.14\ \cancel{\text{u}}} \times 100\%$$

$$\%\ \text{C} = 40.91\%$$

$$\%\ \text{H} = \frac{8.08\ \cancel{\text{u}}}{176.14\ \cancel{\text{u}}} \times 100\%$$

$$\%\ \text{H} = 4.59\%$$

$$\%\ \text{O} = \frac{96.00\ \cancel{\text{u}}}{176.14\ \cancel{\text{u}}} \times 100\%$$

$$\%\ \text{O} = 54.50\%$$

The percentage composition by mass of $C_6H_8O_6$ is 40.91% carbon, 4.59% hydrogen, and 54.50% oxygen.

(b) $m_{Al} = 26.98$ u
$m_O = 16.00$ u

$$m_{Al_2O_3} = 2(m_{Al}) + 3(m_O)$$

$$= 2(26.98\ \text{u}) + 3(16.00\ \text{u})$$

$$= 53.96\ \text{u} + 48.00\ \text{u}$$

$$m_{Al_2O_3} = 101.96\ \text{u}$$

$$\% \text{ Al} = \frac{53.96 \text{ u}}{101.96 \text{ u}} \times 100\%$$

$$\% \text{ Al} = 52.92\%$$

$$\% \text{ O} = \frac{48.00 \text{ u}}{101.96 \text{ u}} \times 100\%$$

$$\% \text{ O} = 47.08\%$$

The percentage composition by mass of aluminum oxide is 52.92% aluminum and 47.08% oxygen.

(c) $m_{Zn} = 65.38$ u
$m_{N} = 14.01$ u
$m_{O} = 16.00$ u

$$\begin{aligned} m_{Zn(NO_3)_2} &= m_{Zn} + 2(m_N) + 6(m_O) \\ &= 65.38 \text{ u} + 2(14.01 \text{ u}) + 6(16.00 \text{ u}) \\ &= 65.38 \text{ u} + 28.02 \text{ u} + 96.00 \text{ u} \\ m_{Zn(NO_3)_2} &= 189.4 \text{ u} \end{aligned}$$

$$\% \text{ Zn} = \frac{65.38 \text{ u}}{189.4 \text{ u}} \times 100\%$$

$$\% \text{ Zn} = 34.52\%$$

$$\% \text{ N} = \frac{28.02 \text{ u}}{189.4 \text{ u}} \times 100\%$$

$$\% \text{ N} = 14.79\%$$

$$\% \text{ O} = \frac{96.00 \text{ u}}{189.4 \text{ u}} \times 100\%$$

$$\% \text{ O} = 50.69\%$$

The percentage composition by mass of zinc nitrate is 34.52% zinc, 14.79% nitrogen, and 50.69% oxygen.

SECTION 2.3 QUESTIONS

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Understanding Concepts

1. The law of constant composition states that compounds contain the same ratio of elements by mass, regardless of their source.
2. (a) A small sample of a compound is placed in the mass spectrometer where it is vapourized, ionized, and possibly broken into a number of fragments. The resulting charged fragments are accelerated by an electric field and deflected by a magnetic field. The amount of deflection of the fragments is used to calculate the molar mass of the original compound.
   (b) A combustion analyzer is used to determine the percentages of carbon, hydrogen, oxygen, and possibly nitrogen in a compound containing these elements. An accurately known mass of the compound is burned in a stream of pure oxygen gas to form water and carbon dioxide gas. The resulting water and carbon dioxide are trapped in water and carbon dioxide absorbers. Using the mass of water and carbon dioxide absorbed by the traps, and the mass of the original sample, the percentage composition of the original compound may be calculated.
3. (a) You need to know the percentage composition of a compound to determine the empirical formula.
   (b) You need to know the molar mass of a compound (in addition to its empirical formula) to determine the molecular formula of a compound.

4. (a) CH_2O
   (b) NH_3
   (c) CH
5. K = 26.6%
   Cr = 35.4%
   O = 38.1%

$$m_K = \frac{26.6}{100} \times 100 \text{ g}$$
$$m_K = 26.6 \text{ g}$$

$$m_{Cr} = \frac{35.4}{100} \times 100 \text{ g}$$
$$m_{Cr} = 35.4 \text{ g}$$

$$m_O = \frac{38.1}{100} \times 100 \text{ g}$$
$$m_O = 38.1 \text{ g}$$

$$n_K = 26.6 \text{ g K} \times \frac{1 \text{ mol K}}{39.10 \text{ g K}}$$
$$n_K = 0.680 \text{ mol K}$$

$$n_{Cr} = 35.4 \text{ g Cr} \times \frac{1 \text{ mol Cr}}{52.00 \text{ g Cr}}$$
$$n_{Cr} = 0.681 \text{ mol Cr}$$

$$n_O = 38.1 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}}$$
$$n_O = 2.38 \text{ mol O}$$

$$n_K : n_{Cr} : n_O = 0.680 : 0.681 : 2.30$$
$$= \frac{0.680}{0.680} : \frac{0.681}{0.680} : \frac{2.38}{0.680}$$
$$n_K : n_{Cr} : n_O = 1 : 1 : 3.5$$

Multiply the ratio by 2 to obtain whole numbers.

$$n_K : n_{Cr} : n_O = 2(1 : 1 : 3.5)$$
$$n_K : n_{Cr} : n_O = 2 : 2 : 7$$

The empirical formula of the compound is $K_2Cr_2O_7$.

6. (a) C = 40.87%
   H = 3.72%
   N = 8.67%
   O = 24.77%
   Cl = 21.98%

$$m_C = \frac{40.87}{100} \times 100 \text{ g}$$
$$m_C = 40.87 \text{ g}$$

$$m_H = \frac{3.72}{100} \times 100 \text{ g}$$
$$m_H = 3.72 \text{ g}$$

$$m_N = \frac{8.67}{100} \times 100 \text{ g}$$
$$m_N = 8.67 \text{ g}$$

$$m_O = \frac{24.77}{100} \times 100 \text{ g}$$
$$m_O = 24.77 \text{ g}$$

$$m_{Cl} = \frac{21.98}{100} \times 100 \text{ g}$$
$$m_{Cl} = 21.98 \text{ g}$$

$$n_C = 40.87 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}}$$
$$n_C = 3.403 \text{ mol C}$$

$$n_H = 3.72 \text{ g H} \times \frac{1 \text{ mol H}}{1.01 \text{ g H}}$$
$$n_H = 3.68 \text{ mol H}$$

$$n_N = 8.67 \text{ g N} \times \frac{1 \text{ mol N}}{14.01 \text{ g N}}$$
$$n_N = 0.619 \text{ mol N}$$

$$n_O = 24.77 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}}$$
$$n_O = 1.548 \text{ mol O}$$

$$n_{Cl} = 21.98 \text{ g Cl} \times \frac{1 \text{ mol Cl}}{35.45 \text{ g Cl}}$$
$$n_{Cl} = 0.6200 \text{ mol Cl}$$

$$\begin{aligned} n_C : n_H : n_N : n_O : n_{Cl} &= 3.403 : 3.68 : 0.619 : 1.548 : 0.6200 \\ &= \frac{3.403}{0.619} : \frac{3.68}{0.619} : \frac{0.619}{0.619} : \frac{1.548}{0.619} : \frac{0.6200}{0.619} \\ &= 5.498 : 5.95 : 1.00 : 2.501 : 1.002 \\ n_C : n_H : n_N : n_O : n_{Cl} &= 5.5 : 6 : 1 : 2.5 : 1 \end{aligned}$$

Multiply the ratio by 2 to obtain whole numbers.

$n_C : n_H : n_N : n_O : n_{Cl} = 2(5.5) : 2(6) : 2(1) : 2(2.5) : 2(1)$

$n_C : n_H : n_N : n_O : n_{Cl} = 11 : 12 : 2 : 5 : 2$

The empirical formula of chloromycetin is $C_{11}H_{12}N_2O_5Cl_2$.

(b) C = 41.86%
H = 4.65%
N = 16.28%
O = 18.60%
S = 18.60%

$$m_C = \frac{41.86}{100} \times 100 \text{ g}$$
$$m_C = 41.86 \text{ g}$$

$$m_H = \frac{4.65}{100} \times 100 \text{ g}$$
$$m_H = 4.65 \text{ g}$$

$$m_N = \frac{16.28}{100} \times 100 \text{ g}$$
$$m_N = 16.28 \text{ g}$$

$$m_O = \frac{18.60}{100} \times 100 \text{ g}$$
$$m_O = 18.60 \text{ g}$$

$$m_S = \frac{18.60}{100} \times 100 \text{ g}$$
$$m_S = 18.60 \text{ g}$$

$$n_C = 41.86 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}}$$
$$n_C = 3.485 \text{ mol C}$$

$$n_H = 4.65 \text{ g H} \times \frac{1 \text{ mol H}}{1.01 \text{ g H}}$$
$$n_H = 4.60 \text{ mol H}$$

$$n_N = 16.28 \text{ g N} \times \frac{1 \text{ mol N}}{14.01 \text{ g N}}$$
$$n_N = 1.162 \text{ mol N}$$

$$n_O = 18.60 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}}$$
$$n_O = 1.163 \text{ mol O}$$

$$n_S = 18.60 \cancel{\text{ g S}} \times \frac{1 \text{ mol S}}{32.06 \cancel{\text{ g S}}}$$

$$n_S = 0.5802 \text{ mol S}$$

$$n_C : n_H : n_N : n_O : n_S = 3.485 : 4.60 : 1.162 : 1.163 : 0.5802$$

$$= \frac{3.485}{0.5802} : \frac{4.60}{0.5802} : \frac{1.162}{0.5802} : \frac{1.163}{0.5802} : \frac{0.5802}{0.5802}$$

$$= 6.007 : 7.93 : 2.00 : 2.00 : 1.00$$

$$n_C : n_H : n_N : n_O : n_S = 6 : 8 : 2 : 2 : 1$$

The empirical formula of sulfanilamide is $C_6H_8N_2O_2S$.

7. (a) $m_H = 1.01$ u

$m_O = 16.00$ u

$$m_{H_2O} = 2(m_H) + m_O$$

$$= 2(1.01 \text{ u}) + 16.00 \text{ u}$$

$$= 2.02 \text{ u} + 16.00 \text{ u}$$

$$m_{H_2O} = 18.02 \text{ u}$$

$$\% \text{ H} = \frac{2.02 \cancel{\text{ u}}}{18.02 \cancel{\text{ u}}} \times 100\%$$

$$\% \text{ H} = 11.21\%$$

$$\% \text{ O} = \frac{16.00 \cancel{\text{ u}}}{18.02 \cancel{\text{ u}}} \times 100\%$$

$$\% \text{ O} = 88.79\%$$

The percentage composition by mass of water is 11.21% hydrogen and 88.79% oxygen.

(b) $m_{Ca} = 40.08$ u

$m_O = 16.00$ u

$m_H = 1.01$ u

$$m_{Ca(OH)_2} = m_{Ca} + 2(m_O) + 2(m_H)$$

$$= 40.08 \text{ u} + 2(16.00 \text{ u}) + 2(1.01 \text{ u})$$

$$= 40.08 \text{ u} + 32.00 \text{ u} + 2.02 \text{ u}$$

$$m_{Ca(OH)_2} = 74.10 \text{ u}$$

$$\% \text{ Ca} = \frac{40.08 \cancel{\text{ u}}}{74.10 \cancel{\text{ u}}} \times 100\%$$

$$\% \text{ Ca} = 54.09\%$$

$$\% \text{ O} = \frac{32.00 \cancel{\text{ u}}}{74.10 \cancel{\text{ u}}} \times 100\%$$

$$\% \text{ O} = 43.18\%$$

$$\% \text{ H} = \frac{2.02 \cancel{\text{u}}}{74.10 \cancel{\text{u}}} \times 100\%$$

$$\% \text{ H} = 2.73\%$$

The percentage composition by mass of calcium hydroxide is 54.09% calcium, 43.18% oxygen, and 2.73% hydrogen.

Applying Inquiry Skills

8. Na = 21.9%
C = 45.7%
H = 1.9%
O = 30.5%
$M_{\text{compound}} = 210$ g/mol

$$m_{\text{Na}} = \frac{21.9}{100} \times 100\,\text{g}$$
$$m_{\text{Na}} = 21.9\ \text{g}$$

$$m_{\text{C}} = \frac{45.7}{100} \times 100\text{g}$$
$$m_{\text{C}} = 45.7\ \text{g}$$

$$m_{\text{H}} = \frac{1.9}{100} \times 100\ \text{g}$$
$$m_{\text{H}} = 1.9\ \text{g}$$

$$m_{\text{O}} = \frac{30.5}{100} \times 100\ \text{g}$$
$$m_{\text{O}} = 30.5\,\text{g}$$

$$n_{\text{Na}} = 21.9\ \cancel{\text{g Na}} \times \frac{1\ \text{mol Na}}{22.99\ \cancel{\text{g Na}}}$$
$$n_{\text{Na}} = 0.953\ \text{mol Na}$$

$$n_{\text{C}} = 45.7\ \cancel{\text{g C}} \times \frac{1\ \text{mol C}}{12.01\ \cancel{\text{g C}}}$$
$$n_{\text{C}} = 3.81\,\text{mol C}$$

$$n_{\text{H}} = 1.9\ \cancel{\text{g H}} \times \frac{1\,\text{mol H}}{1.01\ \cancel{\text{g H}}}$$
$$n_{\text{H}} = 1.88\ \text{mol H}$$

$$n_{\text{O}} = 30.5\ \cancel{\text{g O}} \times \frac{1\,\text{mol O}}{16.00\ \cancel{\text{g O}}}$$
$$n_{\text{O}} = 1.91\,\text{mol O}$$

$$n_{Na} : n_C : n_H : n_O = 0.953 : 3.81 : 1.88 : 1.91$$
$$= \frac{0.953}{0.953} : \frac{3.81}{0.953} : \frac{1.88}{0.953} : \frac{1.91}{0.953}$$
$$= 1.00 : 4.00 : 1.97 : 2.00$$
$$n_{Na} : n_C : n_H : n_O = 1 : 4 : 2 : 2$$

The empirical formula of the compound is $NaC_4H_2O_2$.

$$M_{NaC_4H_2O_2} = 1(22.99\ g/mol) + 4(12.01\ g/mol) + 2(1.01\ g/mol) + 2(16.00\ g/mol)$$
$$M_{NaC_4H_2O_2} = 105.05\ g/mol\ NaC_4H_2O_2$$
$$\frac{M_{compound}}{M_{NaC_4H_2O_2}} = \frac{210\ \cancel{g/mol}}{105.05\ \cancel{g/mol}}$$
$$\frac{M_{compound}}{M_{NaC_4H_2O_2}} = 2$$
$$\text{molecular formula} = 2(\text{empirical formula})$$
$$= 2(NaC_4H_2O_2)$$
$$\text{molecular formula} = Na_2C_8H_4O_4$$

The molecular formula of the compound is $Na_2C_8H_4O_4$.

9. C = 49.38%
H = 3.55%
O = 9.40%
S = 37.67%
$M_{compound}$ = 170.2 g/mol

$$m_C = \frac{49.38}{100} \times 100\ g$$
$$m_C = 49.38\ g$$

$$m_H = \frac{3.55}{100} \times 100\ g$$
$$m_H = 3.55\ g$$

$$m_O = \frac{9.40}{100} \times 100\ g$$
$$m_O = 9.40\ g$$

$$m_S = \frac{37.67}{100} \times 100\ g$$
$$m_S = 37.67\ g$$

$$n_C = 49.38\ \cancel{g\ C} \times \frac{1\ mol\ C}{12.01\ \cancel{g\ C}}$$
$$n_C = 4.112\ mol\ C$$

$$n_H = 3.55\ \cancel{g\ H} \times \frac{1\ \text{mol H}}{1.01\ \cancel{g\ H}}$$

$$n_H = 3.51\ \text{mol H}$$

$$n_O = 9.40\ \cancel{g\ O} \times \frac{1\ \text{mol O}}{16.00\ \cancel{g\ O}}$$

$$n_O = 0.588\ \text{mol O}$$

$$n_S = 37.67\ \cancel{g\ S} \times \frac{1\ \text{mol S}}{32.06\ \cancel{g\ S}}$$

$$n_S = 1.175\ \text{mol S}$$

$$n_C : n_H : n_O : n_S = 4.112 : 3.51 : 0.588 : 1.175$$

$$= \frac{4.112}{0.588} : \frac{3.51}{0.588} : \frac{0.588}{0.588} : \frac{1.175}{0.588}$$

$$= 6.99 : 5.97 : 1.00 : 2.00$$

$$n_C : n_H : n_O : n_S = 7 : 6 : 1 : 2$$

The empirical formula is $C_7H_6OS_2$.

$$M_{C_7H_6OS_2} = 7(12.01\ \text{g/mol}) + 6(1.01\ \text{g/mol}) + 1(16.00\ \text{g/mol/}) + 2(32.06\ \text{g/mol})$$

$$M_{C_7H_6OS_2} = 170.25\ \text{g/mol}\ C_7H_6OS_2$$

$$\frac{M_{\text{compound}}}{M_{C_7H_6OS_2}} = \frac{170.2\ \cancel{\text{g/mol}}}{170.25\ \cancel{\text{g/mol}}}$$

$$\frac{M_{\text{compound}}}{M_{C_7H_6OS_2}} = 0.9997 \approx 1$$

$$\text{molecular formula} = 1(\text{empirical formula})$$

$$= 1(C_7H_6OS_2)$$

$$\text{molecular formula} = C_7H_6OS_2$$

The molecular formula of the newly discovered compound is $C_7H_6OS_2$.