3.13 In a formula this complicated, it is easy to count the atoms incorrectly, so rewrite the formula by gathering atoms of the same kind together: Ca$_5$(PO$_4$)$_3$(OH) = Ca$_5$(P$_3$O$_{12}$)(OH) = Ca$_5$P$_3$O$_{13}$H

Formula mass of Ca$_5$P$_3$O$_{13}$H = 5(40.08) + 3(30.97) + 13(16.00) + (1.008) = 502.32 amu

\[
\% \text{ Ca} = \frac{5 \times 40.08 \text{ amu}}{502.32 \text{ amu}} \times 100 = 39.89\%
\]

\[
\% \text{ P} = \frac{3 \times 30.97 \text{ amu}}{502.32 \text{ amu}} \times 100 = 18.50\%
\]

\[
\% \text{ O} = \frac{13 \times 16.00 \text{ amu}}{502.32 \text{ amu}} \times 100 = 41.41\%
\]

\[
\% \text{ H} = \frac{1 \times 1.008 \text{ amu}}{502.32 \text{ amu}} \times 100 = 0.20\%
\]

Check: 39.89 + 18.50 + 41.41 + 0.20 = 100.0

Note that in problems such as this, rounding error may result in the final sum of percentages not being exactly equal to 100.

3.38 a. We write:

\[
? \text{ g/Ag atom} = \frac{107.9 \text{ g Ag}}{1 \text{ mol Ag}} \times \frac{1 \text{ mol Ag}}{6.022 \times 10^{23} \text{ Ag atoms}} = 1.792 \times 10^{-22} \text{ g/Ag atom}
\]

b. Follow same method as part (a).

\[
? \text{ g/K atom} = \frac{39.10 \text{ g K}}{1 \text{ mol K}} \times \frac{1 \text{ mol K}}{6.022 \times 10^{23} \text{ K atoms}} = 6.493 \times 10^{-23} \text{ g/K atom}
\]

Strategy: Should the mass of a single atom of Ag or K be a very small mass?
Let's complete these three conversions in one step to determine the number of C atoms.

grams of glucose $\rightarrow$ moles of glucose $\rightarrow$ number of glucose molecules $\rightarrow$
number of carbon atoms

\[
1.50 \text{ g glucose} \times \frac{1 \text{ mol glucose}}{180.2 \text{ g glucose}} \times \frac{6.022 \times 10^{23} \text{ molecules glucose}}{1 \text{ mol glucose}} \times \frac{6 \text{ C atoms}}{1 \text{ molecule glucose}}
\]

\[= 3.01 \times 10^{22} \text{ C atoms}\]

The ratio of H atoms to C atoms in glucose is 2:1. Therefore, there are twice as many H atoms in glucose as C atoms, so the number of H atoms = \(2(3.01 \times 10^{22} \text{ atoms}) = 6.02 \times 10^{22} \text{ H atoms}\).

The ratio of O atoms to C atoms in glucose is 1:1. Therefore, there are the same number of O atoms in glucose as C atoms, so the number of O atoms = \(3.01 \times 10^{22} \text{ O atoms}\).

Think Should 1.50 g of glucose contain fewer than Avogadro's number of C, H, and O atoms?
In each case, assume 100 g of compound.

a.

\[ 2.1 \text{ g H} \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 2.08 \text{ mol H} \]

\[ 65.3 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 4.081 \text{ mol O} \]

\[ 32.6 \text{ g S} \times \frac{1 \text{ mol S}}{32.07 \text{ g S}} = 1.017 \text{ mol S} \]

This gives the formula \( \text{H}_2\text{O}_4\text{S}_{1.017}\text{O}_{4.081} \). Dividing by 1.017 gives the empirical formula, \( \text{H}_2\text{SO}_4 \).

b.

\[ 20.2 \text{ g Al} \times \frac{1 \text{ mol Al}}{26.98 \text{ g Al}} = 0.7487 \text{ mol Al} \]

\[ 79.8 \text{ g Cl} \times \frac{1 \text{ mol Cl}}{35.45 \text{ g Cl}} = 2.251 \text{ mol Cl} \]

This gives the formula, \( \text{Al}_{0.7487}\text{Cl}_{2.251} \). Dividing by 0.7487 gives the empirical formula, \( \text{AlCl}_3 \).

\[ \text{mol C} = 7.86 \text{ g CO}_2 \times \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} \times \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} = 0.1786 \text{ mol C} \]

\[ \text{mol H} = 2.14 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} = 0.2375 \text{ mol H} \]

\[ \text{mass O} = \text{mass Sample} - (\text{mass C} + \text{mass H}) = 2.856 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.1785 \text{ mol O} \]

Molar ratios: \( \text{C} : \text{H} : \text{O} = 0.1786 : 0.2375 : 0.1785 = \frac{0.1786}{0.1785} : \frac{0.2375}{0.1785} : \frac{0.1785}{0.1785} = 1.00 : 1.33 : 1.00 \)

Multiplying all three numbers by 3 give the empirical formula \( \text{C}_6\text{H}_8\text{O}_6 \), which has an empirical formula weight of 88.06 g. The molecular formula is \( \text{C}_6\text{H}_8\text{O}_6 \).
Starting with the 5.0 moles of $C_4H_{10}$, we can use the mole ratio from the balanced equation to calculate the moles of $CO_2$ formed.

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(l)$$

$$? \text{ mol } CO_2 = 5.0 \text{ mol } C_4H_{10} \times \frac{8 \text{ mol } CO_2}{2 \text{ mol } C_4H_{10}} = 20 \text{ mol } CO_2 = 2.0 \times 10^1 \text{ mol } CO_2$$

This is a limiting reactant problem. Let's calculate the moles of $Cl_2$ produced assuming complete reaction for each reactant.

$$0.86 \text{ mol } MnO_2 \times \frac{1 \text{ mol } Cl_2}{1 \text{ mol } MnO_2} = 0.86 \text{ mol } Cl_2$$

$$48.2 \text{ g } HCl \times \frac{1 \text{ mol } HCl}{36.458 \text{ g } HCl} \times \frac{1 \text{ mol } Cl_2}{4 \text{ mol } HCl} = 0.3305 \text{ mol } Cl_2$$

$HCl$ is the limiting reactant; it limits the amount of product produced. It will be used up first. The amount of product produced is 0.3305 mole $Cl_2$. Let's convert this to grams.

$$? \text{ g } Cl_2 = 0.3305 \text{ mol } Cl_2 \times \frac{70.90 \text{ g } Cl_2}{1 \text{ mol } Cl_2} = 23.4 \text{ g } Cl_2$$