Chapter 1

Stoichiometry

1. Determine molar masses for the following:

a) $C_{22}H_{10}O_2$ (22 mol C)(12.011 g·mol^{-1}) + (10 mol H)(1.008 g·mol^{-1}) + (2 mol O)(15.999 g·mol^{-1}) = 306.320 g·mol^{-1}

b) $Ca(NO_3)_2$ (1 mol Ca)(40.078 g·mol^{-1}) + (2 mol N)(14.007 g·mol^{-1}) + (6 mol O)(15.999 g·mol^{-1}) = 164.086 g·mol^{-1}

c) P_2O_5 (2 mol P)(30.974 g·mol^{-1}) + (5 mol O)(15.999 g·mol^{-1}) = 141.943 g·mol^{-1}

d) $Al_2(CO_3)_3$ (2 mol Al)(26.982 g·mol^{-1}) + (3 mol C)(12.011 g·mol^{-1}) + (9 mol O)(15.999 g·mol^{-1}) = 233.988 g·mol^{-1}

3. Determine mass of each of the following:

a) 0.694 mol $C_{22}H_{10}O_2$ (0.694 mol)(306.320 g·mol^{-1}) = 213 g

b) 2.84 mol $Ca(NO_3)_2$ (2.84 mol)(164.086 g·mol^{-1}) = 466 g

c) 0.00652 mol P_2O_5 (0.00652 mol)(141.943 g·mol^{-1}) = 0.925 g

d) 8.44 mol $Al_2(CO_3)_3$ (8.44 mol)(233.988 g·mol^{-1}) = 1.97x10^3 g = 1.97 kg

5. Determine mass of each of the following:

a) $2.24x10^{20}$ molecules of CO_2

$$2.24\times10^{20}\text{ molecules}\times\frac{1\text{ mol CO}_2}{6.02\times10^{23}\text{ molecules}}\times\frac{44.01\text{ g CO}_2}{1\text{ mol CO}_2} = 0.0164\text{ g}$$

b) $2.24x10^{24}$ molecules of H_2

$$2.24\times10^{24}\text{ molecules}\times\frac{1\text{ mol H}_2}{6.02\times10^{23}\text{ molecules}}\times\frac{2.016\text{ g H}_2}{1\text{ mol H}_2} = 7.53\text{ g}$$

c) 12 C atoms

$$12\text{ C atoms}\times\frac{1\text{ mol C}}{6.02\times10^{23}\text{ C atoms}}\times\frac{12.011\text{ g C}}{1\text{ mol C}} = 2.39\times10^{-22}\text{ g}$$

d) $8.66x10^{18}$ Pt atoms

$$8.66\times10^{18}\text{ Pt atoms}\times\frac{1\text{ mol Pt}}{6.02\times10^{23}\text{ Pt atoms}}\times\frac{195\text{ g Pt}}{1\text{ mol Pt}} = 2.81\times10^{-3}\text{ g} = 2.81\text{ mg}$$

7. How many moles of people are on earth if world population is 6.3 billion ($6.3x10^9$) people?

$$6.3\times10^{9}\text{ people}\times\frac{1\text{ mol people}}{6.02\times10^{23}\text{ people}} = 1.0\times10^{-14}\text{ mol people}$$

9. A bottle contains 12.6 g of $(NH_4)_3PO_4$.

a) **How many moles of $(NH_4)_3PO_4$ does it contain?**

$$12.6\text{ g (NH}_4)_3\text{PO}_4\times\frac{1\text{ mol (NH}_4)_3\text{PO}_4}{149.1\text{ g (NH}_4)_3\text{PO}_4} = 0.0845\text{ mol} = 84.5\text{ mmol}$$

b) **How many oxygen atoms does it contain?**

$$0.0845\text{ mol (NH}_4)_3\text{PO}_4\times\frac{4\text{ mol O atoms}}{1\text{ mol (NH}_4)_3\text{PO}_4}\times\frac{6.02\times10^{23}\text{ O atoms}}{1\text{ mol O atoms}} = 2.03\times10^{23}\text{ O atoms}$$

c) **What mass of nitrogen atoms does it contain?**

$$0.0845\text{ mol (NH}_4)_3\text{PO}_4\times\frac{3\text{ mol N}}{1\text{ mol (NH}_4)_3\text{PO}_4}\times\frac{14.007\text{ g N}}{1\text{ mol N}} = 3.55\text{ g N}$$

d) **How many moles of H does it contain?**

$$0.0845\text{ mol (NH}_4)_3\text{PO}_4\times\frac{12\text{ mol H atoms}}{1\text{ mol (NH}_4)_3\text{PO}_4} = 1.01\text{ mol H atoms}$$

11. What is the simplest formula of each of the following compounds?

a) $C_{22}H_{10}O_2$	b) C_3H_6O	c) C_6H_6	d) $C_3H_6O_3$
$C_{11}H_5O$	C_3H_6O	CH	CH_2O

13. What is the elemental composition of each of the molecules in Exercise 11? Express your answer as percents?

a) $C_{22}H_{10}O_2$

First calculate the molar mass (M_m) of the molecule.

$$\begin{array}{llcl} M_m(C_{22}H_{10}O_2) = & 22 \times (12.011 \text{g / mol C}) & = & 264.24 \text{ g C} \\ & 10 \times (1.008 \text{ g / mol H}) & = & 10.08 \text{ g H} \\ + & 2 \times (15.999 \text{ g / mol O}) & = & \underline{31.998 \text{ g O}} \\ & & & 306.32 \text{ g / mol } C_{22}H_{10}O_2 \end{array}$$

The fraction of each element's contribution will be that element's mass in the compound over the molar mass of the compound. Multiplying this fraction by 100 gives the percent.

$$\frac{264.24 \text{ g C}}{306.32 \text{ g } C_{22}H_{10}O_2} \times 100\% = 86.263\% \text{ C} \qquad \frac{10.08 \text{ g H}}{306.32 \text{ g } C_{22}H_{10}O_2} \times 100\% = 3.291\% \text{ H}$$

$$\frac{31.998 \text{ g O}}{306.32 \text{ g } C_{22}H_{10}O_2} \times 100\% = 10.446\% \text{ O}$$

Parts b, c, & d are solved in the same way.

b) C_3H_6O **$M_m(C_3H_6O)$ = 58.080 g/mol**

C: 36.033 g C / 58.080 g C_3H_6O x 100% = 62.040% C

H: 6.048 g H / 58.080 g C_3H_6O x 100% = 10.41% H

O: 15.999 g O / 58.080 g C_3H_6O x 100% = 27.546% O

c) C_6H_6 **$M_m(C_6H_6)$ = 78.114 g/mol**

C: 72.066 g C / 78.114 g C_6H_6 x 100% = 92.257%

H: 6.048 g H / 78.114 g C_6H_6 x 100% = 7.743% H

d) $C_3H_6O_3$ **$M_m(C_3H_6O_3)$ = 90.078 g/mol**

C: 36.033 g C / 90.078 g $C_3H_6O_3$ x 100% = 40.002% C

H: 6.048 g H / 90.078 g $C_3H_6O_3$ x 100% = 6.714% H

O: 47.997 g O / 90.078 g $C_3H_6O_3$ x 100% = 53.284% O

15. How many moles of magnesium are present in a sample of each of the following that contains 3.0 moles of oxygen atoms?

a) $MgSO_4$ $$3.0 \text{ moles O} \times \frac{1.0 \text{ moles Mg}}{4.0 \text{ moles O}} = 0.75 \text{ moles Mg}$$

b) $MgSO_3$ $$3.0 \text{ moles O} \times \frac{1.0 \text{ moles Mg}}{3.0 \text{ moles O}} = 1.0 \text{ moles Mg}$$

c) $Mg_3(PO_4)_2$ $$3.0 \text{ moles O} \times \frac{3.0 \text{ moles Mg}}{8.0 \text{ moles O}} = 1.1 \text{ moles Mg}$$

d) $Mg(ClO_3)_2$ $$3.0 \text{ moles O} \times \frac{1.0 \text{ moles Mg}}{6.0 \text{ moles O}} = 0.50 \text{ moles Mg}$$

17. What mass of Al is in a sample of $Al_2(SO_4)_3$ that contains 3.2 grams of S?

$$3.2 \text{ g S} \times \frac{1 \text{ mol S}}{32.066 \text{ g S}} \times \frac{2 \text{ moles Al}}{3 \text{ moles S}} \times \frac{26.982 \text{ g Al}}{1 \text{ mol Al}} = 1.8 \text{ g Al}$$

19. Caffeine has the molecular formula $C_8H_{10}N_4O_2$. What mass of caffeine contains 5.0 mg of nitrogen?

Use the factor label method to convert 5.0 mg N to mg of caffeine.

$$5.0 \text{ mg N} \times \frac{1 \text{ mmol N}}{14.007 \text{ mg N}} \times \frac{1 \text{ mmol } C_8H_{10}N_4O_2}{4 \text{ mmol N}} \times \frac{194.19 \text{ mg } C_8H_{10}N_4O_2}{\text{mmol } C_8H_{10}N_4O_2} = 17 \text{ mg } C_8H_{10}N_4O_2$$

Note that you do not have to convert the mass to grams. Multiplying the numerator and denominator of any ratio by the same number does not change the value of the ratio, so, as long as both the numerator and the denominator are multiplied by 'm', the ratio is unchanged. Thus, molar mass also has units of mg/mmol.

21. What mass of Na_2CO_3 contains 2.1×10^{22} oxygen atoms?

$$2.1\times10^{22}\text{ atoms O}\times\frac{1\text{ mol O}}{6.022\times10^{23}\text{ atoms O}}\times\frac{1\text{ mol Na}_2\text{CO}_3}{3\text{ mol O}}\times\frac{105.989\text{ g Na}_2\text{CO}_3}{1\text{ mol Na}_2\text{CO}_3\text{l}} = 1.2\text{ g Na}_2\text{CO}_3$$

23. What mass of KCl was in a solution if all of the chloride in the solution was precipitated as 1.68 g of $PbCl_2$?

$$1.68\text{ g PbCl}_2\times\frac{1\text{ mol PbCl}_2}{278.106\text{ g PbCl}_2}\times\frac{2\text{ mol Cl}}{1\text{ mol PbCl}_2}\times\frac{74.551\text{ g KCl}}{1\text{ mol KCl}} = 0.901\text{ g KCl}$$

25. What is the simplest formula of a compound in which 0.362 mol X is combined with 1.267 mol Y? How many moles of X are present in 6.336 mol of the compound?

Divide each of the number of moles by the smaller. $X = \frac{0.362}{0.362} = 1$ and $Y = \frac{1.267}{0.362} = 3.5$

Multiply each ratio by 2 to eliminate the fraction in 3.5: X =2 and Y = 7. The formula is X_2O_7.

$$6.336\text{ mol }X_2Y_7\times\frac{2\text{ mol X}}{1\text{ mol }X_2Y_7} = 12.67\text{ mol X}$$

27. What is the simplest formula of a hydrocarbon that is 81.71 % C?

Assume 100 g of material, then the mass of C in the sample is its percent, and the mass of H is 100 - mass of C. Next, divide each mass by the molar mass to obtain moles

$$81.71\text{ g C}\times\frac{1\text{ mol C}}{12.011\text{ g C}} = 6.80\text{ mol C};\quad 18.29\text{ g H}\times\frac{1\text{ mol H}}{1.008\text{ g H}} = 18.14\text{ mol H}$$

Divide each by smaller number of mole: 1.00 mol C/mol C and $\frac{18.14}{6.80} = 2.67$ mol H/mol C

Multiply each ratio by 3 to eliminate the fraction in 2.67: $C = 1\times3 = 3$ and $H = 2.67\times3 = 8$

Simplest formula is C_3H_8.

29. Ibuprofen (Advil or Motrin), is an anti-inflammatory agent that is 75.69% C, 8.80% H and 15.51% O. What is the simplest formula of ibuprofen?

Assume 100 g of material, then the percentages translate to 75.69 g C, 8.80 g H and 15.51 g O. Divide each mass by the molar mass to obtain moles.

C: $75.69\text{g C}\times\frac{1\text{ mol C}}{12.011\text{ g C}} = 6.302\text{ mol C}$ H: $8.80\text{g H}\times\frac{1\text{ mol H}}{1.008\text{ g H}} = 8.73\text{ mol H}$

O: $15.51\text{g O}\times\frac{1\text{ mol O}}{15.999\text{ g O}} = 0.9694\text{ mol O}$

Divide each of the number of moles by the smallest number (0.9694 mol O) to obtain mole ratios.

C: $\frac{6.302}{0.9694} = 6.5$ H: $\frac{8.73}{0.9694} = 9.0$ O: $\frac{0.9694}{0.9694} = 1.0$

Multiply each ratio by two to convert 6.5 to an integer: C: 6.50 x 2 = 13; H: 9.00 x 2 = 18; O: 1.00 x 2 = 2

There are 13 mol C and 18 mol H for every 2 mol O, so the empirical (simplest) of ibuprofen is $C_{13}H_{18}O_2$

31. The sugar arabinose, found in ripe fruits, is 40.00% C, 6.71% H and 53.29% O and has a molar mass of 150. g/mol. What is the molecular formula for this compound?

Assume 100 g of arabinose, then the percentages translate to 40.00 g C, 6.71 g H and 53.29 g of O. Divide each element's mass by its molar mass to obtain moles.

C: $40.00\text{ g C}\times\frac{1\text{ mol C}}{12.011\text{ g C}} = 3.330\text{ mol C}$ H: $6.71\text{ g H}\times\frac{1\text{ mol H}}{1.008\text{ g H}} = 6.66\text{ mol H}$

O: $53.29\text{ g O}\times\frac{1\text{ mol O}}{15.999\text{ g O}} = 3.331\text{ mol O}$

Divide each by the smallest one (3.330 mol C) to obtain mole ratios.

C: $\frac{3.330}{3.330} = 1.0$ mol C/mol C H: $\frac{6.66}{3.330} = 2.0$ mol H/mol C O: $\frac{3.331}{3.330} = 1.0$ mol O/mol C

Each ratio is a whole number, so the empirical formula is CH_2O.

The molecular formula is $(CH_2O)_n$, where n can be found by dividing the molar mass of the molecular formula (150) by that of the empirical formula (30).

$n = \frac{150 \text{ g/mol}}{30 \text{ g/mol}} = 5$ Hence, arabinose = $(CH_2O)_5 = C_5H_{10}O_5$

33. Burning 1.346 g of chromium in air results in 1.967 g of an oxide. What is the simplest formula of the oxide of chromium?

Get the mass of O by difference: mass of O = sample mass – Cr mass = 1.967 – 1.346 = 0.621 g O

Next, determine the number of moles of each element

$1.346 \text{ g Cr} \times \frac{1 \text{ mol Cr}}{51.996 \text{ g Cr}} = 0.02589 \text{ mol Cr}$ $0.621 \text{ g O} \times \frac{1 \text{ mol O}}{15.999 \text{ g O}} = 0.03881 \text{ mol O}$

Divide the larger by the smaller to obtain the mole ratio: $\frac{0.03881 \text{ mol O}}{0.02589 \text{ mol Cr}} = \frac{1.499 \text{ mol O}}{\text{mol Cr}} = \frac{3 \text{ mol O}}{2 \text{ mol Cr}}$

The simplest formula for the oxide of chromium is Cr_2O_3.

35. A 2.500-g sample of an oxide of lead produces 0.376 g of water when reduced with hydrogen. What is the simplest formula of this lead oxide? Assume all of the oxygen in the oxide is converted to water.

Both the moles and mass of oxygen are required in this problem. The moles for the formula and the mass to determine the mass of lead in the sample. Thus, we determine them separately. The number of moles is determined from the amount of water that is produced.

$0.376 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.015 \text{ g } H_2O} \times \frac{1 \text{ mol O}}{1 \text{ mol } H_2O} = 0.0209 \text{ mol O}$

Convert the moles of O to mass, in order to determine mass of Pb: $0.0209 \text{ mol O} \times \frac{15.999 \text{ g O}}{1 \text{ mol O}} = 0.334 \text{ g O}$

Next, determine the mass of lead by difference: 2.500 g sample - 0.334 g O = 2.166 g Pb

The number of moles of lead in the lead oxide sample is then determined to be

$2.166 \text{ g Pb} \times \frac{1 \text{ mol Pb}}{207.2 \text{ g Pb}} = 0.01045 \text{ mol Pb}$.

Finally, find the ratio of moles of oxygen to moles of lead

$\frac{0.0209 \text{ mol O}}{0.01045 \text{ mol Pb}} = 2$. The simplest formula for the lead oxide is PbO_2

37. A 0.540-g sample of Anavenol, a compound containing C, H, and O that is used as an anesthetic in veterinary surgeries, is analyzed by combustion. What is its empirical formula if the combustion produces 0.310 g of H_2O and 1.515 g of CO_2. If its molar mass is 188.22 g/mol, what is the molecular formula for Anavenol?

Determine the number of moles of C and H from the amount of CO_2 and H_20.

$1.515 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.009 \text{ g } CO_2} \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.03443 \text{ mol C}$

$0.310 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.015 \text{ g } H_2O} \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.0344 \text{ mol H}$

Determine the elemental masses, in order to obtain the mass of oxygen by difference.

Mass of C = (0.03443 mol C)(12.011 g/mol) = 0.4135 g C

Mass of H = (0.0344 mol H)(1.008 H g/mol) = 0.0347 g H

Mass of O = 0.540 g Anavenol - 0.414 g of C - 0.034 g H = 0.092 g O = 0.0057 mol O

Divide all mole components by the smallest (0.00565 mol O).

C: $\frac{0.0344}{0.0057} = 6.0$ mol C/mol O; H: $\frac{0.0344}{0.0057} = 6.0$ mol H/mol O; O: $\frac{0.0057}{0.0057} = 1.0$ mol O/mol O

Therefore, the simplest formula for Anavenol is C_6H_6O (M_m = 94.113 g/mol).

The molecular formula is $(C_6H_6O)_n$, where $n = \frac{188.22 \text{ g/mol}}{94.113 \text{ g/mol}} = 1.9999 = 2.0$

The molecular formula is $(C_6H_6O)_2 = C_{12}H_{12}O_2$

39. $KClO_x$ produces KCl and O_2 upon heating. What is the value of x if a 22.6-g sample produces 7.07 L of O_2 at 0.956 atm and 25 °C?

First determine the mass of oxygen.

$$n = \frac{PV}{RT} = \frac{0.956 \text{ atm } 7.07 \text{ L}}{0.0821 \text{ L}\cdot\text{atm}\cdot\text{K}^{-1}\cdot\text{mol}^{-1} \text{ 298 K}} = 0.276 \text{ mol } O_2$$

$$0.276 \text{ mol } O_2 \times \frac{2 \text{ mol O}}{1 \text{ mol } O_2} \times \frac{15.99 \text{ g O}}{1 \text{ mol O}} = 8.83 \text{ g O}$$

Determine the amount and moles of KCl.

22.6 g $KClO_x$ - 8.83 g O_2 = 13.8 g KCl left, which is $13.8 \text{ g KCl} \times \frac{1 \text{ mol KCl}}{74.54 \text{ g KCl}} = 0.185 \text{ mol KCl}$

Finally, determine the ratio of O to KCl: $x = \frac{0.552 \text{ mol O}}{0.185 \text{ mol KCl}} = 3$

There are 3 moles of oxygen for each mole of KCl, therefore the compound is $KClO_3$.

41. Heating a 27.7-mg sample of $MnSO_4\cdot xH_2O$ results in 15.1 mg of anhydrous $MnSO_4$. What is value of x?

$$15.1 \text{ mg } MnSO_4 \ \frac{1 \text{ mmol } MnSO_4}{150.97 \text{ mg } MnSO_4} = 0.100 \text{ mmol } MnSO_4$$

27.7 mg $MnSO_4\cdot xH_2O$ - 15.1 mg $MnSO_4$ = 12.6 mg H_2O $\qquad$ $12.6 \text{ mg } H_2O \ \frac{1 \text{mmol } H_2O}{18.006 \text{ mg } H_2O} = 0.700 \text{ mmol } H_2O$

$x = \frac{0.700 \text{ mmol } H_2O}{0.100 \text{ mmol } MnSO_4} = 7$ $\qquad$ The original sample is $MnSO_4\cdot 7H_2O$

43. Balance the equations by inspection:

a) $Al_2S_3 + 6H_2O \rightarrow 2\,Al(OH)_3 + 3\,H_2S$

b) $Fe_3O_4 + 4H_2 \rightarrow 3Fe + 4H_2O$

c) $2Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2$

d) $2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$

e) $3KOH + H_3PO_4 \rightarrow K_3PO_4 + 3H_2O$

f) $4Ag + 2H_2S + O_2 \rightarrow 2Ag_2S + 2H_2O$

45. Balance the equations by inspection:

a) $2FeS_2 + 7O_2 \rightarrow 2FeSO_4 + 2SO_3$

b) $2S_2Cl_2 + 2H_2O \rightarrow SO_2 + 4HCl + 3S$

c) $V_2O_5 + 3C + 6Cl_2 \rightarrow 2VOCl_3 + 3COCl_2$

d) $2NH_3 + 2O_2 \rightarrow N_2O + 3H_2O$

e) $4BF_3 + 3NaBH_4 \rightarrow 3NaBF_4 + 2B_2H_6$

f) $Al_4C_3 + 12HCl \rightarrow 3CH_4 + 4AlCl_3$

47. A mixture of 3.0 mol of CS_2 and 2.0 mol of O_2 reacts according to the equation: $CS_2 + 3O_2 \rightarrow CO_2 + 2SO_2$

a) What is the limiting reactant?

First, find the number of mols produced of a product.

$3.0 \text{ mol } CS_2 \times \frac{2 \text{ mol } SO_2}{1 \text{ mol } CS_2} = 6.0 \text{ mol } SO_2$; $\qquad$ $2.0 \text{ mol } O_2 \times \frac{2 \text{ mol } SO_2}{3 \text{ mol } O_2} = 1.3 \text{ mol } SO_2$

Fewer moles of SO_2 are formed from 2.0 mol O_2, so O_2 is the limiting reactant is O_2.

b) How many moles of SO_2 are produced? As shown above, 1.3 mol SO_2 could be formed.

c) How many moles of which reactant are unreacted?

The number of moles of CS_2 that react is: $2.0 \text{ mol } O_2 \times \frac{1 \text{ mol } CS_2}{3 \text{ mol } SO_2} = 0.67 \text{ mol } CS_2$ used

The number of moles unreacted = 3.0 mol CS_2 added – 0.67 mol CS_2 used = 2.3 mol CS_2 unreacted.

d) If 72 g of SO_2 are actually isolated, what is the percent yield?

The theoretical yield of SO_2 is: $2.0 \text{ mol } O_2 \times \frac{2 \text{ mol } SO_2}{3 \text{ mol } O_2} \times \frac{64.058 \text{ g } SO_2}{1 \text{ mol } SO_2} = 85 \text{ g } SO_2$

The percent yield is: $\text{Percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\% = \frac{72 \text{ g } SO_2}{85 \text{ g } SO_2} \times 100\% = 85\%$

49. Consider the reaction $N_2O_4 + 2N_2H_4 \rightarrow 3N_2 + 4H_2O$

a) How many moles of N_2 are formed by reaction of 5.0 g of N_2H_4?

$$5.0\text{ g } N_2H_4 \times \frac{1\text{ mol } N_2H_4}{32.0456\text{ g } N_2H_4} \times \frac{3\text{ mol } N_2}{2\text{ mol } N_2H_4} = 0.23\text{ mol } N_2$$

b) What mass of N_2O_4 would be required for Part a?

$$5.0\text{ g } N_2H_4 \times \frac{1\text{ mol } N_2H_4}{32.0456\text{ g } N_2H_4} \times \frac{1\text{mol } N_2O_4}{1\text{ mol } N_2H_4} \times \frac{92.01\text{ g } N_2O_4}{1\text{ mol } N_2O_4} = 7.2\text{ g } N_2O_4$$

c) What is the percent yield if 4.8 g of water is produced?

First, determine the theoretical yield of water.

$$5.0\text{ g } N_2H_4 \times \frac{1\text{ mol } N_2H_4}{32.0\text{ g } N_2H_4} \times \frac{4\text{ mol } H_2O}{2\text{ mol } N_2H_4} \times \frac{18.0\text{ g } H_2O}{1\text{ mol } H_2O} = 5.6\text{ g } H_2O\text{ ;} \quad \%\text{ yield} = \frac{4.8\text{ g } H_2O\text{ produced}}{5.6\text{ g } H_2O\text{ theoretical}} \times 100\% = 86\%\text{ yield}$$

51. What mass of HCl is produced by the reaction of 23.6 g of PCl_3 and water? The other product is H_3PO_3.

The balanced equation is $PCl_3 + 3H_2O \rightarrow 3HCl + H_3PO_3$

$$23.6\text{ g } PCl_3 \times \frac{1\text{ mol } PCl_3}{137.32\text{ g } PCl_3} \times \frac{3\text{ mol HCl}}{1\text{ mol } PCl_3} \times \frac{36.458\text{ g HCl}}{1\text{ mol HCl}} = 18.8\text{ g HCl}$$

53. Consider the following reaction that occurs at 1000 ^oC: $4NH_3(g) + 3O_2(g) \rightarrow 2N_2(g) + 6H_2O(g)$.

A mixture of 2.72 atm of NH_3 and 3.80 atm of O_2 reacts to completion. Determine the pressures of all gases remaining when the reaction is complete. What is the total pressure inside the vessel at the beginning and end of the reaction? Why are the total pressures different?

$P \propto n$, so the reaction table can be expressed in atm instead of moles. The total pressure is the sum of the partial pressures. NH_3 is the limiting reactant, so the reaction table has the following form.

	$4NH_3(g)$	$+ 3O_2(g)$	$\rightarrow 2N_2(g)$	$+ 6H_2O(g)$	total pressure
Initial	2.65	3.80	0.00	0.00	6.45 atm
Δ	-2.65	-1.99	+1.33	+3.98	+0.67 atm
Final	0.00	1.81	1.33	3.98	7.12 atm

The final pressure is 7.12 atm, which is 0.67 atm greater than the initial pressure, 6.45 atm. This is because 8 moles of product gas are formed from 7 moles of reactant gas. This increase in the number of moles results in an increase in pressure in accordance with the ideal gas equation.

55. Construct the reaction table for the reaction of 7.0 g of N_2 and 6.0 g of H_2 to form ammonia. What mass of ammonia forms and what mass of the excess reactant remains after reaction?

The first step is to write a balanced equation: $N_2 + 3H_2 \rightarrow 2NH_3$

Then determine moles: $7.0\text{ g } N_2 \times \frac{1\text{ mol } N_2}{28.01\text{ g } N_2} = 0.25\text{ mol } N_2$; $\quad 6.0\text{ g } H_2 \times \frac{1\text{ mol } H_2}{2.02\text{ g } H_2} = 3.0\text{ mol } H_2$

	N_2	$+ 3H_2$	$\rightarrow 2NH_3$
Initial	0.25	3.0	0.0
Δ	-0.25	-0.75	+0.50
Final	0.0	2.2	0.50

$0.50\text{ mol } NH_3 \times \frac{17.04\text{ g } NH_3}{1.0\text{ mol } NH_3} = 8.5\text{ g } NH_3$; $\quad 2.2\text{ mol } H_2 \times \frac{2.02\text{ g } H_2}{1.0\text{ mol } H_2} = 4.5\text{ g } H_2$

Note mass is conserved at 13 g. This is a good check of your calculations.

57. Construct a reaction table for the reaction of 0.200 mol of iron(III) oxide and 0.270 mol of carbon to produce elemental iron and carbon dioxide. What is the percent yield 19.4 g of iron are produced?

Carbon is the limiting reactant, so all calculations are based on 0.270 mol C.

	$2Fe_2O_3$	$+ 3C$	$\rightarrow 3CO_2$	$+ 4Fe$	
initial	0.200	0.270	0.00	0.00	mol
Δ	-0.180	-0.270	+0.270	+0.360	mol
Final	0.020	0.00	0.270	0.360	mol

Theoretical yield of iron: $0.360\text{ mol Fe} \times \frac{55.85\text{ g Fe}}{\text{mol Fe}} = 20.1\text{ g Fe}$, so percent yield = $\frac{19.4}{20.1} \times 100\% = 96.5\%$

59. The most common acid in acid rain is sulfuric acid (H_2SO_4). When sulfuric acid reacts with sodium hydroxide (NaOH), sodium sulfate is formed along with water. The reaction is

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$$

A 10.0-L sample of rain water was treated with a 0.200-g tablet of NaOH. When the reaction was complete, 0.0018 moles of NaOH remained unreacted.

a) What was the limiting reagent in this reaction?

0.0018 mol NaOH is left unreacted, so NaOH is in excess. Thus, H_2SO_4 is the limiting reagent.

b) How many grams of H_2SO_4 were in the 10.0-L sample of rain water?

Determine the initial number of moles of NaOH

$$0.200 \text{ g NaOH} \times \frac{1 \text{ mol NaOH}}{39.997 \text{ g NaOH}} = 0.005 \text{ moles NaOH}$$

The number of moles of NaOH that reacted is the difference between the initial and final moles.

0.005 moles NaOH – 0.0018 = 0.0032 mols NaOH

Finally, convert mols of NaOH to grams of H_2SO_4:

$$0.0032 \text{ mols NaOH} \times \frac{1 \text{ mol } H_2SO_4}{2 \text{ mol NaOH}} \times \frac{98.072\text{g } H_2SO_4}{1 \text{ mol } H_2SO_4} = 0.16 \text{ g } H_2SO_4$$

c) How many moles of H_2SO_4 were present in each liter of rainwater?

Calculate the number of moles for the 10.0 L sample:

$$0.0032 \text{ mols NaOH} \times \frac{1 \text{ mol } H_2SO_4}{2 \text{ mol NaOH}} = 0.0016 \text{ mols } H_2SO_4$$

Divide by the total volume of 10.0 L of rainwater to get the number of moles in one liter of rainwater.

$$\frac{0.0016 \text{ mols } H_2SO_4}{10.0 \text{ L}} = 0.00016 \text{ mols } H_2SO_4/\text{L}$$

61. It is desired to remove the lead from a solution containing 6.41 g of $Pb(NO_3)_2$ by adding KCl and precipitating $PbCl_2$. What mass of KCl should be added if a 15.0% excess is required? What mass of $PbCl_2$ would form?

The first step is to write a balanced equation.

$Pb(NO_3)_2 + 2KCl \rightarrow PbCl_2 + 2KNO_3$

$$6.41 \text{ g } Pb(NO_3)_2 \times \frac{1\text{mol } Pb(NO_3)_2}{331.21 \text{ g } Pb(NO_3)_2} \times \frac{2 \text{ mol KCl}}{1 \text{ mol } Pb(NO_3)_2} \times \frac{74.55 \text{ g KCl}}{1 \text{ mol KCl}} = 2.89 \text{ g KCl}$$

$$\text{For a 15\% excess, 2.89 g KCl theoretical} \times \frac{115 \text{ g KCl required}}{100 \text{ g KCl theoretical}} = 3.32 \text{ g KCl required}$$

The mass of $PbCl_2$ that would form can be calculated the same as above.

$$6.41 \text{ g } Pb(NO_3)_2 \times \frac{1\text{mol } Pb(NO_3)_2}{331.21 \text{ g } Pb(NO_3)_2} \times \frac{1 \text{ mol } PbCl_2}{1 \text{ mol } Pb(NO_3)_2} \times \frac{278.11 \text{ g } PbCl_2}{1 \text{ mol } PbCl_2} = 5.38 \text{ g } PbCl_2$$

63. Consider the reaction of 27.8 g of FeS_2 with O_2 to produce Fe_2O_3 and SO_2.

a) What mass of oxygen would be required for a 20% excess?

The balanced equation is $4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$

$$27.8 \text{ g Fe } S_2 \times \frac{1 \text{ mol } FeS_2}{119.98 \text{ g } FeS_2} \times \frac{11\text{mol } O_2}{4 \text{ mol } FeS_2} \times \frac{32.00 \text{ g } O_2}{1 \text{ mol } O_2} = 20.4 \text{ g } O_2$$

$$\text{For a 20\% excess, 20.4 g } O_2 \text{ theoretical} \times \frac{120 \text{ g } O_2 \text{ required}}{100 \text{ g } O_2 \text{ theoretical}} = 24.5 \text{ g } O_2$$

b) What is the theoretical yield of Fe_2O_3?

The above calculation can be used to find moles of FeS_2, so starting from 0.232 mol FeS_2, the calculation follows

$$0.232 \text{ mol } FeS_2 \times \frac{2 \text{ mol } Fe_2O_3}{4 \text{ molFeS}_2} \times \frac{159.69 \text{ g } Fe_2O_3}{1 \text{ mol } Fe_2O_3} = 18.5 \text{ g } Fe_2O_3$$

c) What mass of SO_2 would form if the actual yield is 94.2%?

$0.232 \text{ mol } FeS_2 \times \frac{8 \text{ mol } SO_2}{4 \text{ mol } FeS_2} \times \frac{64.06 \text{ g } SO_2}{1 \text{ mol } SO_2}$ = 29.7 g theoretically, so 29.7 x 0.942 = 28.0 g SO_2 would form

65. What element forms an oxide X_2O_3 that is 88.39% X by mass?

We identify element X by its atomic mass. To get the atomic mass, we realize that 100 g of compound contains 88.39 g X and (100.00 – 88.39) = 11.61 g O. We use the factor label method to obtain g X/mol X from the initial ratio of the masses of the elements.

$$\frac{88.39 \text{ g X}}{11.61 \text{ g O}} \times \frac{16.00 \text{ g O}}{\text{mole O}} \times \frac{3 \text{ mol O}}{2 \text{ mol X}} = 182.7 \text{ g X/mol X} \Rightarrow \text{X is tungsten}$$

67. Aspartame, $C_{14}H_{18}N_2O_5$, is the active ingredient in Nutrasweet.

a) What is the elemental composition of aspartame expressed as percents?

$M_m(C_{14}H_{18}N_2O_5)$ = 294.3 g/mol

C: 168.15 g C / 294.3 g $C_{14}H_{18}N_2O_5$ x 100% = 57.14% C

H: 18.14 g H / 294.3 g $C_{14}H_{18}N_2O_5$ x 100% = 6.165% H

N: 28.014 g N / 294.3 g $C_{14}H_{18}N_2O_5$ x 100% = 9.519% N

O: 79.995 g O / 294.3 g $C_{14}H_{18}N_2O_5$ x 100% = 27.18% O

b) What is the mass of a sample of aspartame that contains 2.6 mg of carbon?

$$2.6 \text{ mg C} \times \frac{1 \text{ mmol C}}{12.011 \text{ mg C}} \times \frac{1 \text{ mmol } C_{14}H_{18}N_2O_5}{14 \text{ mmol C}} \times \frac{294.3 \text{ mg } C_{14}H_{18}N_2O_5}{1 \text{ mmol } C_{14}H_{18}N_2O_5} = 4.6 \text{ mg } C_{14}H_{18}N_2O_5$$

Alternatively, we can use the fact that the compound is 57.14% carbon,

$$2.6 \text{ mg C} \times \frac{100 \text{ mg } C_{14}H_{18}N_2O_5}{57.14 \text{ mg C}} = 4.6 \text{ mg } C_{14}H_{18}N_2O_5$$

c) A tablet of Equal has a mass of 0.088 g and the "sweetness of one teaspoon of sugar." A teaspoon of sugar ($C_{12}H_{22}O_{11}$) has a mass of 4.8 g. Assume the Equal tablet is 30% aspartame and estimate the relative "sweetness" of a molecule of aspartame and a molecule of sugar.

First, solve for moles of sugar in 1 tsp. of sugar.

$$1 \text{ tsp } C_{12}H_{22}O_{11} \times \frac{4.8 \text{ g } C_{12}H_{22}O_{11}}{1 \text{ tsp } C_{12}H_{22}O_{11}} \times \frac{1 \text{ mol } C_{12}H_{22}O_{11}}{342.3 \text{ g } C_{12}H_{22}O_{11}} = 0.014 \text{ mol } C_{12}H_{22}O_{11}$$

Next, solve for moles of aspartame that have the same sweetness as 1 tsp. of sugar.

$$1 \text{ tsp } C_{12}H_{22}O_{11} \times \frac{0.088 \text{ g } \textit{Equal}}{1 \text{ tsp } C_{12}H_{22}O_{11}} \times \frac{30 \text{ g } C_{14}H_{18}N_2O_5}{100 \text{ g Equal}} \times \frac{1 \text{ mol } C_{14}H_{18}N_2O_5}{294.3 \text{ g } C_{14}H_{18}N_2O_5} = 9.0 \times 10^{-5} \text{ mol } C_{14}H_{18}N_2O_5$$

Finally, make the ratio of moles of sugar to moles of Aspartame.

$$\text{Relative Sweetness} = \frac{0.014 \text{ mol sugar}}{9.0 \times 10^{-5} \text{ mol Aspartame}} = 160$$, so Aspartame is 160 times sweeter than sugar.

69. Cisplatin, $Pt(NH_3)_2Cl_2$, a compound used in chemotherapy for cancer patients, is synthesized by reacting ammonia with tetrachloroplatinate, K_2PtCl_4, to form the product and potassium chloride.

a) What is the maximum mass of cisplatin that can be formed by the reaction of 60.0 g of K_2PtCl_4 and 40.0 g of ammonia?

First write the balanced equation: $2\ NH_3 + K_2PtCl_4 \rightarrow Pt(NH_3)_2Cl_2 + 2\ KCl$

Next, determine the limiting reactant by calculating the mass of cisplatin that could be produced from each reactant. Note the problem could be done by determining the number of moles instead.

First, for 40.0 g of ammonia

$$40.0 \text{ g } NH_3 \times \frac{1 \text{ mol } NH_3}{17.03 \text{ g } NH_3} \times \frac{1 \text{ mol } Pt(NH_3)_2Cl_2}{2 \text{ mol } NH_3} \times \frac{300.06 \text{ g } Pt(NH_3)_2Cl_2}{1 \text{ mol } Pt(NH_3)_2Cl_2} = 352 \text{ g } Pt(NH_3)_2Cl_2$$

Next, for 60.0 g of potassium tetrachloroplatinate

$$60.0 \text{ g } K_2PtCl_4 \times \frac{1 \text{ mol } K_2PtCl_4}{415.1 \text{ g } K_2PtCl_4} \times \frac{1 \text{ mol } Pt(NH_3)_2Cl_2}{1 \text{ mol } K_2PtCl_4} \times \frac{300.06 \text{ g } Pt(NH_3)_2Cl_2}{1 \text{ mol } Pt(NH_3)_2Cl_2} = 43.4 \text{ g } Pt(NH_3)_2Cl_2$$

The theoretical yield is the smaller amount: 43.4g $Pt(NH_3)_2Cl_2$

b) What is the percent yield if 35.0 g are obtained experimentally?

The actual yield of cisplatin is 35.0 g so the percent yield is $\frac{35.0\text{ g}}{43.4\text{ g}}\times 100\% = 80.6\%$

71. A 5.00 g-sample of a mixture of NaCl and $BaCl_2$ was dissolved in water, then a solution of Na_2SO_4 was added to precipitate $BaSO_4$. What percent of the mass of the original mixture was $BaCl_2$ if the mass of $BaSO_4$ was 2.78g?

$$2.78\text{ g }BaSO_4 \times \frac{1\text{ mol }BaSO_4}{233.37\text{ g }BaSO_4} = 0.012\text{ mol }BaSO_4$$

$$0.012\text{ mol }BaSO_4 \times \frac{1\text{ mol }BaCl_2}{1\text{ mol }BaSO_4} \times \frac{208.33\text{ g }BaCl_2}{1\text{ mol }BaCl_2} = \frac{2.49996\text{ g }BaCl_2}{5\text{ g sample}} = 49.6\%\ BaCl_2$$

73. Chlorophyll contains 2.72% magnesium. If there is one magnesium per chlorophyll molecule, what is the molar mass of chlorophyll?

We are asked for the molar mass of chlorophyll, which can be found by dividing the number of moles in a sample by the mass of the sample. A 100-g sample of chlorophyll contains 2.72 g magnesium. Then the problem is simply to convert 2.72 g of magnesium to the number of moles of chlorophyll using the stoichiometric ratio of 1 mol Mg per mole chlorophyll.

$$2.72\text{ g Mg} \times \frac{1\text{ mol Mg}}{24.305\text{ g Mg}} \times \frac{1\text{ mol chlorophyll}}{1\text{ mol Mg}} = 0.112\text{ mol chlorophyll}$$

The 0.112 mol of chlorophyll has a mass of 100 g, so the molar mass is

$$\frac{100\text{ g chlorophyll}}{0.112\text{ mol chlorophyll}} = 893\text{ g/mol chlorophyll}$$

75. A mixture of NH_4Cl and NH_4Br is 27.4% NH_4Cl by mass. What mass of the mixture contains 0.200 mol NH_4^{1+} ions?

$$\frac{27.4\text{g }NH_4Cl}{100\text{ g mixture}} \times \frac{1\text{ mol }NH_4Cl}{53.4\text{ g }NH_4Cl} \times \frac{1\text{ mol }NH_4^{1+}}{1\text{ mol }NH_4Cl} = \frac{0.5135\text{ mol }NH_4^{1+}}{100\text{ g mixture}}\quad \text{from }NH_4Cl$$

$$\frac{72.6\ NH_4Br}{100\text{ g mixture}} \times \frac{1\text{ mol }NH_4Br}{97.914\text{ g }NH_4Br} \times \frac{1\text{ mol }NH_4^{1+}}{1\text{ mol }NH_4Br} = \frac{0.7415\text{ mol }NH_4^{1+}}{100\text{ g mixture}}\quad \text{from }NH_4Br$$

$$\frac{0.5135\text{ mol }NH_4^{1+}}{100\text{ g mixture}} + \frac{0.7415\text{ mol }NH_4^{1+}}{100\text{ g mixture}} = \frac{1.2540\text{ mol }NH_4^{1+}}{100\text{ g mixture}}\quad \text{total}$$

$$0.200\text{ mol }NH_4^{1+} \times \frac{100\text{ g mixture}}{1.2540\text{ mol }NH_4^{1+}} = 16.0\text{ g mixture}$$

77. A metal (M) reacts with acid according to the following equation: $2M + 6HCl \rightarrow 2MCl_3 + 3H_2$. What is the metal if reaction of 0.305 g of M produces 161mL of H_2 measured at 23°C and 753 torr?

The number of moles of hydrogen generated is

$$n = \frac{PV}{RT} = \frac{\left(\frac{753}{760}\text{ atm}\right)(0.161\text{ L})}{(0.0821\text{ L}\cdot\text{atm}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(296\text{ K})} = 0.00656\text{ mol }H_2$$

Use the stoichiometry of the reaction to convert to moles of M

$$0.00656\text{ mol }H_2 \times \frac{2\text{ mol M}}{3\text{ mol }H_2} = 0.00438\text{ mol M}$$

$$M_m = \frac{\text{mass of M}}{\text{moles of M}} = \frac{0.305\text{ g M}}{0.00438\text{ mol M}} = 69.6\text{ g/mol} \Rightarrow \text{ the metal is Gallium}$$

79. Epsom salts have the formula $MgSO_4{\cdot}xH_2O$. What is the value of x if drying a 3.268-g sample results in 1.596 g of anhydrous $MgSO_4$?

Proceed as in Example 1.5.

$$x = \frac{\text{mol }H_2O}{\text{mol }MgSO_4} = \frac{(3.268 - 1.596)\text{ g }H_2O \times \frac{1\text{ mol }H_2O}{18.015\text{ g }H_2O}}{1.596\text{ g }MgSO_4 \times \frac{1\text{ mol }MgSO_4}{120.367\text{ g }MgSO_4}} = \frac{0.09281\text{ mol }H_2O}{0.01326\text{ mol }MgSO_4} = 7\text{ mol }H_2O/\text{mol }MgSO_4$$

81. Sodium nitride (Na_3N) is prepared by reacting nitrogen gas with sodium. How many liters of nitrogen measured at 765 torr and 27.5 °C are required for the complete reaction of 7.22 g of Na?

The balanced chemical equation: $6Na + N_2 \rightarrow 2Na_3N$

$$7.22 \text{ g Na} \times \frac{1 \text{ mol Na}}{22.99 \text{ g Na}} \times \frac{1 \text{ mol } N_2}{6 \text{ mol Na}} = 0.0523 \text{ mol } N_2$$

$$V = \frac{nRT}{P} = \frac{(0.0523 \text{ mol})(0.0821 \text{ L} \cdot \text{atm} \cdot \text{K}^{-1} \cdot \text{mol}^{-1})(273.15+27.5)\text{K}}{(765/760 \text{ atm})} = 1.28 \text{ L}$$

How many grams of sodium nitride would be produced?

$$7.22 \text{ g Na} \times \frac{1 \text{ mol Na}}{22.99 \text{ g Na}} \times \frac{2 \text{ mol } Na_3N}{6 \text{ mol Na}} \times \frac{82.98 \text{ g } Na_3N}{1 \text{ mol } Na_3N} = 8.69 \text{ g } Na_3N$$

83. How many carbon atoms are present in a 2.0 carat diamond? 1 carat = 0.200g.

$$2.0 \text{ carat} \times \frac{0.200 \text{ g C}}{1 \text{ carat}} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} \times \frac{6.02 \times 10^{23} \text{ C atoms}}{1 \text{ mol C}} = 2.0 \times 10^{22} \text{ C atoms}$$

85. A mixture of KBr and $MgBr_2$, which has a mass of 6.81 g, is dissolved in water. An excess of $AgNO_3$ is then added to the solution to precipitate all of the bromide as AgBr. What are the mass percents of K and Mg in the mixture if 13.24 g of AgBr precipitate?

There are two unknowns (masses of KBr and and $MgBr_2$) and two equations (total mass of mixture and mass of AgBr). Solve the two equations in two unknowns. Molar masses: KBr = 119 g/mol; $MgBr_2$ = 184 g/mol. If x = moles of KBr and y = moles of $MgBr_2$ then the total mass of mixture is 119x + 184y = 6.81 g (Eq 1)

Moles of Br in the AgBr: $13.24 \text{ g AgBr} \times \frac{1 \text{ mol AgBr}}{187.77 \text{ g AgBr}} \times \frac{1 \text{ mol Br}}{1 \text{ mol AgBr}} = 0.07051 \text{ mol Br}$

The total moles of Br can be expressed in terms of the Br in x moles of KBr and y moles of $MgBr_2$ as

x + 2y = 0.07051 mol Br or x = 0.07051 – 2y (Eq 2), which is substituted into Eq 1 to yield Eq 3

119(0.07501 – 2y) +184y = 6.81 or 1.58 = 54 y (Eq 3), so y = 1.58/54 = 0.0293 mol $MgBr_2$

mass of Mg = (0.0293 mol)(24.305 g/mol) = 0.712 g Mg; $\%Mg = \frac{0.712 \text{ g Mg}}{6.81 \text{ g mixture}} \times 100\% = 10.5\% \text{ Mg}$

x = 0.07051 – 2(0.0293) = 0.0119 mol KBr, so mass of K = (0.0119 mol)(39.098 g/mol) = 0.465 g K

$\%K = \frac{0.465 \text{ g K}}{6.81 \text{ g mixture}} \times 100\% = 6.83\% \text{ K}$

87. Vanillin, which is the primary ingredient in vanilla flavoring, contains C, H, and O. What is its empirical formula if the combustion of 0.6427 g of vanillin produces 0.3043 g of H_2O and 1.487 g of CO_2?

Convert the masses of H2O and CO2 into moles of H and C. Use the moles to determine masses so the mass of O can be determined by difference.

$$0.3043 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.03377 \text{ mol H, which is } 0.03377 \text{ mol H} \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 0.03404 \text{ g H}$$

$$1.487 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2} \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.03379 \text{ mol C, which is } 0.03379 \text{ mol C} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 0.4058 \text{ g C}$$

mass of O = 0.6427 g vanillim – 0.0340 g H – 0.4058 g C = 0.2029 g O

$0.2029 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 0.01268 \text{ mol O}$. Get ratio of mol C (or H) to mol O:

$\frac{0.03378 \text{ mol C \& H}}{0.2029 \text{ mol O}} = \frac{2.66 \text{ mol C \& H}}{1 \text{ mol O}}$ multiply numerator and denominator by 3 to eliminate decimal (0.66) and obtain an 8/3 ratio. The empirical formula of vanillin is $C_8H_8O_3$

If the molar mass of vanillin is found to be near 150 g/mol, what is its molecular formula?

The molar mass of the empirical unit is 8(12) + 8(1) + 3(16) = 152 g/mol, so there is only one empirical unit in the molecule. The molecular formula is also $C_8H_8O_3$

89. Analysis of a compound shows that it is 17.71% N, 40.55% S, and 40.46% O by mass. It is also known to contain H. What is its empirical formula? If its molar mass is close to 240 g/mol, what is it molecular formula?

% H = 100.00 – 17.71 – 40.55 – 40.46 = 1.28%. Assume percents are masses and determine moles of each element.

$$\frac{17.71}{14.007} = 1.264 \text{ mol N}; \quad \frac{40.55}{32.066} = 1.264 \text{ mol S}; \quad \frac{40.46}{15.999} = 2.529 \text{ mol O}; \quad \frac{1.28}{1.0079} = 1.27 \text{ mol H}$$

The empirical formula is $NHSO_2$, which has a molar mass of 14 + 1+ 32 + 32 = 79. 240/79 ~ 3, so the molecular formula is $N_3H_3S_3O_6$, which is a trimer so the formula is often written as $(NHSO_2)_3$

91. Construct a reaction table for the reaction of 12.0 g N_2 with 18.0 g O_2 to produce N_2O_5. How many g of N_2O_5 are produced and what is the mass of the excess reactant if the reaction goes 100% to completion.

$$\frac{12.0 \text{ g } N_2}{28.0 \text{ g/mol}} = 0.429 \text{ mol } N_2; \quad \frac{0.429}{2} = 0.214$$

$$\frac{21.0 \text{ g } O_2}{32.0 \text{ g/mol}} = 0.656 \text{ mol } O_2; \quad \frac{0.656}{5} = 0.131$$

O_2 is limiting reactant because its number of moles divided by its coefficient is smaller.

N_2 reacting: $0.656 \text{ mol } O_2 \times \frac{2 \text{ mol } N_2}{5 \text{ mol } O_2} = 0.262 \text{ mol } N_2$ reacts

N_2O_5 produced: $0.656 \text{ mol } O_2 \times \frac{2 \text{ mol } N_2O_5}{5 \text{ mol } O_2} = 0.262 \text{ mol } N_2O_5$ produced

	$2N_2$	+	$5O_2$	$\rightarrow$	$2N_2O_5$	
initial	0.426		0.656		0	mol
Δ	-0.262		-0.656		+0.262	mol
final	0.164		0		0.262	mol

$$0.164 \text{ mol } N_2 \times \frac{28.0 \text{ g } N_2}{1 \text{ mol } N_2} = 4.59 \text{ g } N_2 \text{ remain}$$

$$0.262 \text{ mol } N_2O_5 \times \frac{108 \text{ g } N_2O_5}{1 \text{ mol } N_2O_5} = 28.3 \text{ g } N_2O_5 \text{ produced}$$