Mass Relationships in Chemical Reactions

Chapter 3

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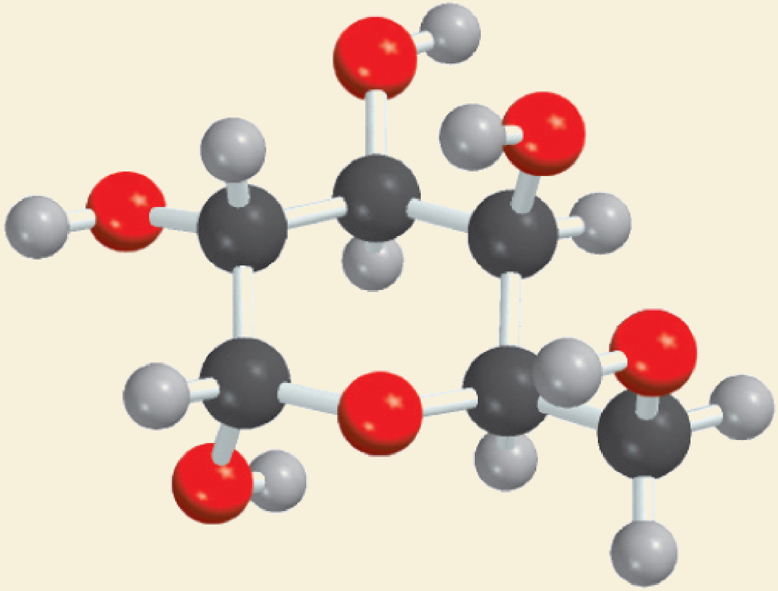
Example 3.13

The food we eat is degraded, or broken down, in our bodies to provide energy for growth and function. A general overall equation for this very complex process represents the degradation of glucose ($C_6H_{12}O_6$) to carbon dioxide (CO_2) and water (H_2O):



$C_6H_{12}O_6$

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

If 856 g of $C_6H_{12}O_6$ is consumed by a person over a certain period, what is the mass of CO_2 produced?

End 9/6 W
9 am class

Example 3.13 (1)

Strategy

Looking at the balanced equation, how do we compare the amounts of $C_6H_{12}O_6$ and CO_2?

We can compare them based on the *mole ratio* from the balanced equation. Starting with grams of $C_6H_{12}O_6$, how do we convert to moles of $C_6H_{12}O_6$?

Once moles of CO_2 are determined using the mole ratio from the balanced equation, how do we convert to grams of CO_2?

Example 3.13 (2)

Solution We follow the preceding steps and Figure 3.8.

Step 1: The balanced equation is given in the problem.

Step 2: To convert grams of $C_6H_{12}O_6$ to moles of $C_6H_{12}O_6$, we write

$$856 \cancel{\text{g } C_6H_{12}O_6} \times \frac{1 \text{ mol } C_6H_{12}O_6}{180.2 \cancel{\text{g } C_6H_{12}O_6}} = 4.750 \text{ mol } C_6H_{12}O_6$$

Step 3: From the mole ratio, we see that

$$1 \text{ mol } C_6H_{12}O_6 \triangleq 6 \text{ mol } CO_2.$$

Therefore, the number of moles of CO_2 formed is

$$4.750 \cancel{\text{mol } C_6H_{12}O_6} \times \frac{6 \text{ mol } CO_2}{1 \cancel{\text{mol } C_6H_{12}O_6}} = 28.50 \text{ mol } CO_2$$

Example 3.13 (3)

Step 4: Finally, the number of grams of CO_2 formed is given by

$$28.50 \text{ mol } CO_2 \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 1.25 \times 10^3 \text{ g } CO_2$$

After some practice, we can combine the conversion steps

$$\text{grams of } C_6H_{12}O_6 \rightarrow \text{moles of } C_6H_{12}O_6 \rightarrow \text{moles of } CO_2 \rightarrow \text{grams of } CO_2$$

into one equation:

$$\text{mass of } CO_2 = 856 \cancel{\text{g } C_6H_{12}O_6} \times \frac{1 \cancel{\text{mol } C_6H_{12}O_6}}{180.2 \cancel{\text{g } C_6H_{12}O_6}} \times \frac{6 \cancel{\text{mol } CO_2}}{1 \cancel{\text{mol } C_6H_{12}O_6}} \times \frac{44.01 \text{ g } CO_2}{1 \cancel{\text{mol } CO_2}}$$

$$= 1.25 \times 10^3 \text{g } CO_2$$

Example 3.13 (4)

Check Does the answer seem reasonable?

Should the mass of CO_2 produced be larger than the mass of $C_6H_{12}O_6$ reacted, even though the molar mass of CO_2 is considerably less than the molar mass of $C_6H_{12}O_6$?

What is the mole ratio between CO_2 and $C_6H_{12}O_6$?

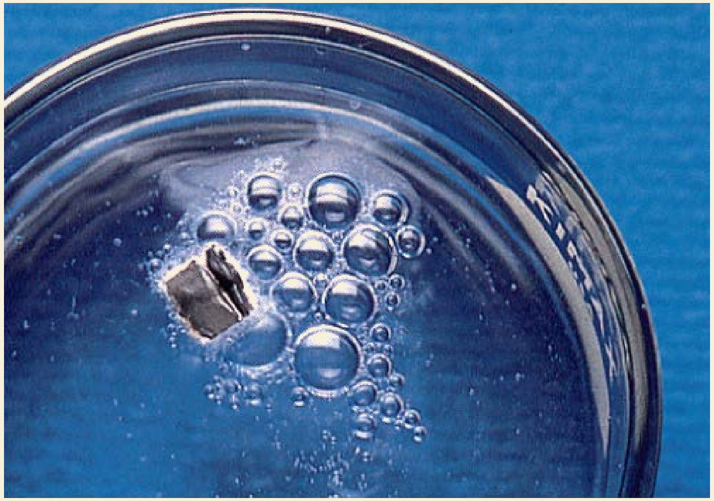
Example 3.14

All alkali metals react with water to produce hydrogen gas and the corresponding alkali metal hydroxide.

A typical reaction is that between lithium and water:

$$2\mathrm{Li}(s) + 2\mathrm{H_2O}(l) \rightarrow 2\mathrm{LiOH}(aq) + \mathrm{H_2}(g)$$

How many grams of Li are needed to produce 9.89 g of H_2?



Lithium reacting with water to produce hydrogen gas.

Example 3.14 (1)

Strategy The question asks for number of grams of reactant (Li) to form a specific amount of product (H_2). Therefore, we need to reverse the steps shown in Figure 3.8. From the equation we see that $2 \text{ mol Li} \triangleq 1 \text{ mol } H_2$.

Example 3.14 (2)

Solution The conversion steps are

$$\text{grams of H}_2 \rightarrow \text{moles of H}_2 \rightarrow \text{moles of Li} \rightarrow \text{grams of Li}$$

Combining these steps into one equation, we write

$$9.89 \text{ g H}_2 \times \frac{1 \text{ mol H}_2}{2.016 \text{ g H}_2} \times \frac{2 \text{ mol Li}}{1 \text{ mol H}_2} \times \frac{6.941 \text{ g Li}}{1 \text{ mol Li}} = 68.1 \text{ g Li}$$

Check There are roughly 5 moles of H_2 in 9.89 g H_2, so we need 10 moles of Li. From the approximate molar mass of Li (7 g), does the answer seem reasonable?

End 10 am class 9/6/17

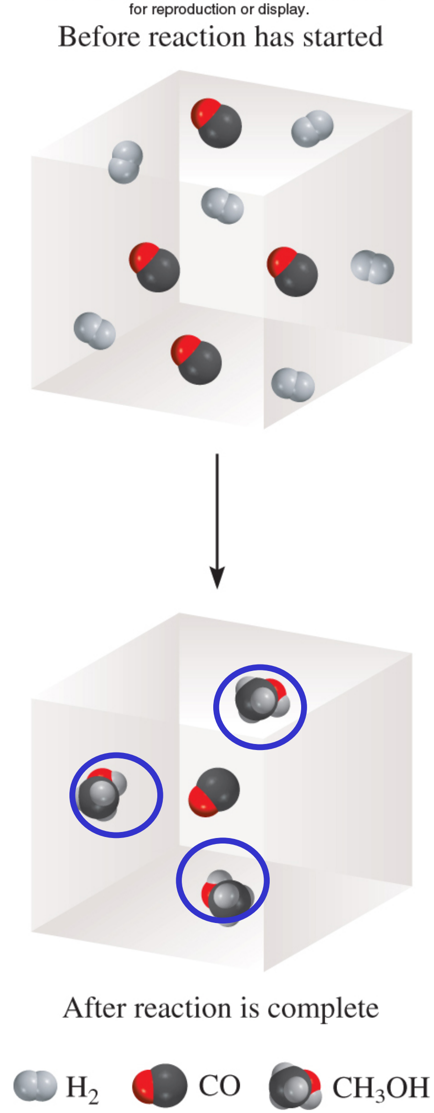
Limiting Reagent:

Reactant used up first in the reaction.

$$CO + 2H_2 \rightarrow CH_3OH$$

H_2 is the limiting reagent

CO is the excess reagent



Stoichiometric Calculations

2 bread slices + 1 salami slices $\rightarrow$ 1 salami sandwich

What is the theoretical yield of salami sandwiches from 4 bread slices and 3 salami slices ? Which is the limiting reagent ?

(a) salami sandwiches (b) bread slices (c) salami slices (d) b & c

$$4 \text{ bread} \times \frac{1 \text{ sandwich}}{2 \text{ bread}} = 2 \text{ sandwiches}$$

bread is Limiting Reagent

$$3 \text{ salami} \times \frac{1 \text{ sandwich}}{1 \text{ salami}} = 3 \text{ sandwiches}$$

Theoretical Yield is 2 sandwiches.

Example 3.15

Urea [$(NH_2)_2CO$] is prepared by reacting ammonia with carbon dioxide:

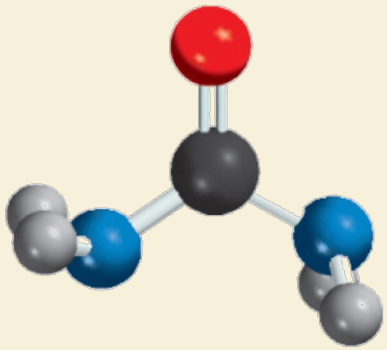
$$2NH_3(g) + CO_2(g) \rightarrow (NH_2)_2CO(aq) + H_2O(l)$$

In one process, 637.2 g of NH_3 are treated with 1142 g of CO_2.

a) Which of the two reactants is the limiting reagent?

b) Calculate the mass of $(NH_2)_2CO$ formed.

c) How much excess reagent (in grams) is left at the end of the reaction?



$(NH_2)_2CO$

Example 3.15 (1)

(a) Strategy The reactant that produces fewer moles of product is the limiting reagent because it limits the amount of product that can be formed.

How do we convert from the amount of reactant to amount of product?

Perform this calculation for each reactant, then compare the moles of product, $(NH_2)_2CO$, formed by the given amounts of NH_3 and CO_2 to determine which reactant is the limiting reagent.

Example 3.15 (2)

Solution We carry out two separate calculations. First, starting with 637.2 g of NH_3, we calculate the number of moles of $(NH_2)_2CO$ that could be produced if all the NH_3 reacted according to the following conversions:

$$\text{grams of } NH_3 \rightarrow \text{moles of } NH_3 \rightarrow \text{moles of } (NH_2)_2CO$$

Combining these conversions in one step, we write

$$\text{moles of}(NH_2)_2CO = 637.2 \, \cancel{\text{g } NH_3} \times \frac{1 \, \cancel{\text{mol } NH_3}}{17.03 \, \cancel{\text{g } NH_3}} \times \frac{1 \text{ mol}(NH_2)_2CO}{2 \, \cancel{\text{mol } NH_3}}$$

$$= 18.71 \text{ mol } (NH_2)_2CO$$

Example 3.15 (3)

Second, for 1142 g of CO_2, the conversions are

$$\text{grams of } CO_2 \rightarrow \text{moles of } CO_2 \rightarrow \text{moles of } (NH_2)_2CO$$

The number of moles of $(NH_2)_2CO$ that could be produced if all the CO_2 reacted is

$$\text{moles of } (NH_2)_2CO = 1142 \cancel{\text{g } CO_2} \times \frac{1 \cancel{\text{mol } CO_2}}{44.01 \cancel{\text{g } CO_2}} \times \frac{1 \text{ mol } (NH_2)_2CO}{1 \cancel{\text{mol } CO_2}}$$

$$= 25.95 \text{ mol } (NH_2)_2CO$$

It follows, therefore, that NH_3 must be the limiting reagent because it produces a smaller amount of $(NH_2)_2CO$.

Example 3.15 (4)

(b) Strategy We determined the moles of $(NH_2)_2CO$ produced in part (a), using NH_3 as the limiting reagent. How do we convert from moles to grams?

Solution The molar mass of $(NH_2)_2CO$ is 60.06 g. We use this as a conversion factor to convert from moles of $(NH_2)_2CO$ to grams of $(NH_2)_2CO$:

$$\text{mass of } (\text{NH}_2)_2\text{CO} = 18.71\ \cancel{\text{mol } (\text{NH}_2)_2\text{CO}} \times \frac{60.06\ \text{g } (\text{NH}_2)_2\text{CO}}{\cancel{1\ \text{mol } (\text{NH}_2)_2\text{CO}}}$$

$$= 1124\ \text{g } (\text{NH}_2)_2\text{CO}$$

Check Does your answer seem reasonable? 18.71 moles of product are formed. What is the mass of 1 mole of $(NH_2)_2CO$?

Example 3.15 (5)

(c) Strategy Working backward, we can determine the amount of CO_2 that reacted to produce 18.71 moles of $(NH_2)_2CO$. The amount of CO_2 left over is the difference between the initial amount and the amount reacted.

Solution Starting with 18.71 moles of $(NH_2)_2CO$, we can determine the mass of CO_2 that reacted using the mole ratio from the balanced equation and the molar mass of CO_2. The conversion steps are

$$\text{moles of } (NH_2)_2CO \rightarrow \text{moles of } CO_2 \rightarrow \text{grams of } CO_2$$

Example 3.15 (6)

Combining these conversions in one step, we write

$$\text{mass of } CO_2 \text{ reacted} = 18.71 \; \cancel{\text{mol (NH}_2\text{)}_2\text{CO}} \times \frac{1 \; \cancel{\text{mol CO}_2}}{1 \text{ mol } \cancel{\text{(NH}_2\text{)}_2\text{CO}}} \times \frac{44.01 \text{ g CO}_2}{1 \; \cancel{\text{mol CO}_2}}$$

$$= 823.4 \text{ g CO}_2$$

The amount of CO_2 remaining (in excess) is the difference between the initial amount (1142 g) and the amount reacted (823.4 g):

$$\text{mass of } CO_2 \text{ remaining} = 1142 \text{ g} - 823.4 \text{ g} = 319 \text{ g}$$

Example 3.16

The reaction between alcohols and halogen compounds to form ethers is important in organic chemistry, as illustrated here for the reaction between methanol (CH_3OH) and methyl bromide (CH_3Br) to form dimethylether (CH_3OCH_3), which is a useful precursor to other organic compounds and an aerosol propellant.

$$\mathrm{CH_3OH + CH_3Br + LiC_4H_9 \rightarrow CH_3OCH_3 + LiBr + C_4H_{10}}$$

This reaction is carried out in a dry (water-free) organic solvent, and the butyl lithium (LiC_4H_9) serves to remove a hydrogen ion from CH_3OH. Butyl lithium will also react with any residual water in the solvent, so the reaction is typically carried out with 2.5 molar equivalents of that reagent. How many grams of CH_3Br and LiC_4H_9 will be needed to carry out the preceding reaction with 10.0 g of CH_3OH?

End 9/8F 9am class