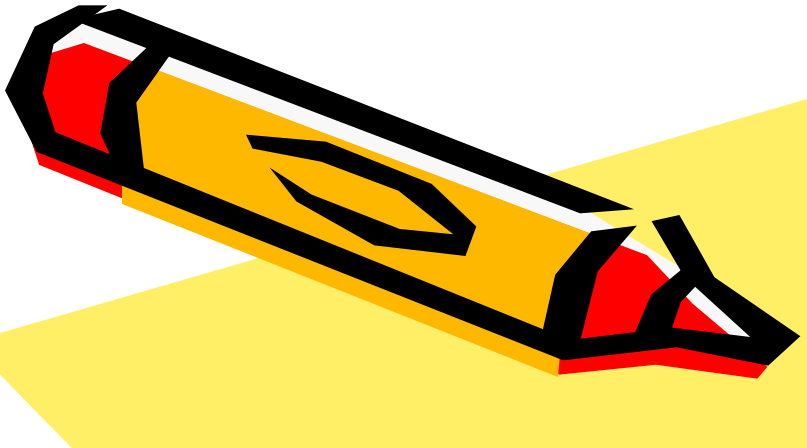


Chapter 12: Stoichiometry

12.1 The Arithmetic of Equations

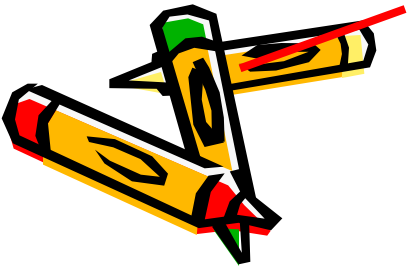
Example

- At a sandwich shop, the sandwich requires 2 pieces of bread, 3 slices of meat and 1 slice of cheese. You need to make 50 sandwiches. How much of each do you need?

Proportional Relationships

2 1/4 c. flour
1 tsp. baking soda
1 tsp. salt
1 c. butter
3/4 c. sugar
3/4 c. brown sugar
1 tsp vanilla extract
2 eggs
2 c. chocolate chips
Makes 5 dozen cookies.

- I have 5 eggs. How many cookies can I make?



Using Balanced Chemical Equations

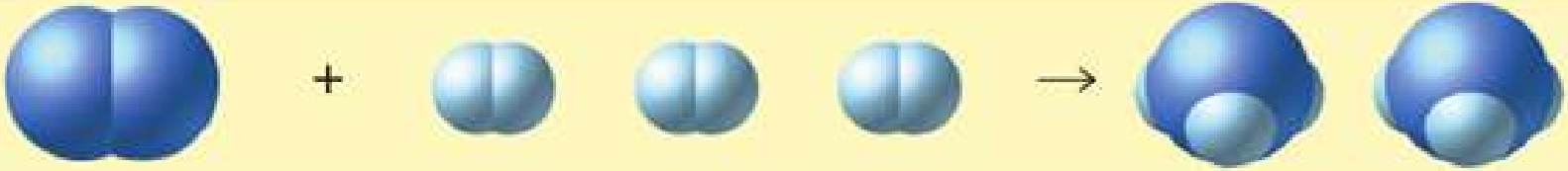
- Chemists use balanced chemical equations as a basis to calculate how much reactant is needed or product is formed in a reaction.
  - **The calculation of quantities in chemical reactions is a subject of chemistry called** stoichiometry.

Interpreting Chemical Equations

- A balanced chemical equation can be interpreted in terms of different quantities.

$$N_2(g) + 3H_2(g) \longrightarrow 2\,NH_3(g)$$

molecules, or moles; mass; and volume.

$N_2(g)$	+	$3H_2(g)$	→	$2NH_3(g)$
				
2 atoms N	+	6 atoms H	→	2 atoms N and 6 atoms H
1 molecule N_2	+	3 molecules H_2	→	2 molecules NH_3
10 molecules N_2	+	30 molecules H_2	→	20 molecules NH_3
$1 \times \left(\begin{matrix}6.02 \times 10^{23} \\ \text{molecules } N_2\end{matrix}\right)$	+	$3 \times \left(\begin{matrix}6.02 \times 10^{23} \\ \text{molecules } H_2\end{matrix}\right)$	→	$2 \times \left(\begin{matrix}6.02 \times 10^{23} \\ \text{molecules } NH_3\end{matrix}\right)$
1 mol N_2	+	3 mol H_2	→	2 mol NH_3
28 g N_2	+	3 × 2 g H_2	→	2 × 17 g NH_3
		34 g reactants	→	34 g products
Assume STP 22.4 L	+	22.4 L, 22.4 L, 22.4 L	→	22.4 L, 22.4 L
22.4 L N_2		67.2 L H_2		44.8 L NH_3

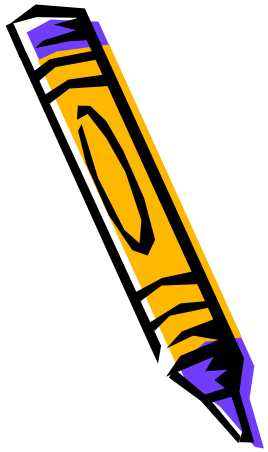
Example: Balance and state in terms of molecules and moles

- $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$

Practice

- 1) $NO + H_2 \rightarrow N_2 + H_2O$
- 2) $SiH_4 + NH_3 \rightarrow Si_3N_4 + H_2$
- 3) $H_2 + O_2 \rightarrow H_2O$

Mass Conservation in Chemical Reactions



- Mass and atoms are conserved in every chemical reaction.

Conceptual Problem 12.1

Interpreting a Balanced Chemical Equation

Hydrogen sulfide, which smells like rotten eggs, is found in volcanic gases. The balanced equation for the burning of hydrogen sulfide is:

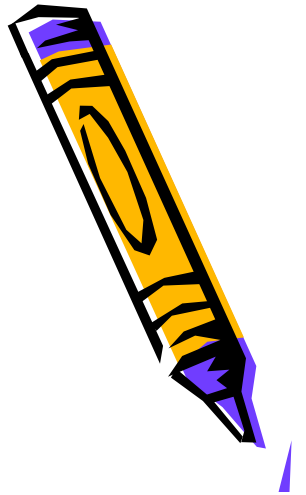
$$2H_2S(g) + 3O_2(g) \longrightarrow 2SO_2(g) + 2H_2O(g)$$

Interpret this equation in terms of

a. numbers of representative particles and moles.

b. masses of reactants and products.

for Conceptual Problem 12.1



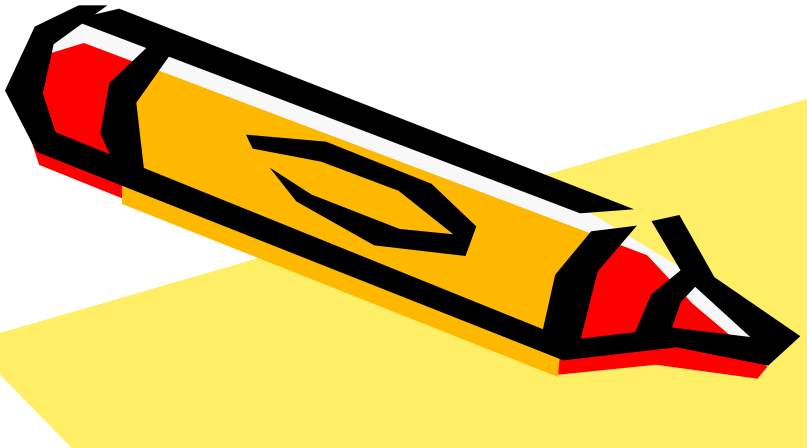
4. Balance the following equation.

$$C_2H_2(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$$

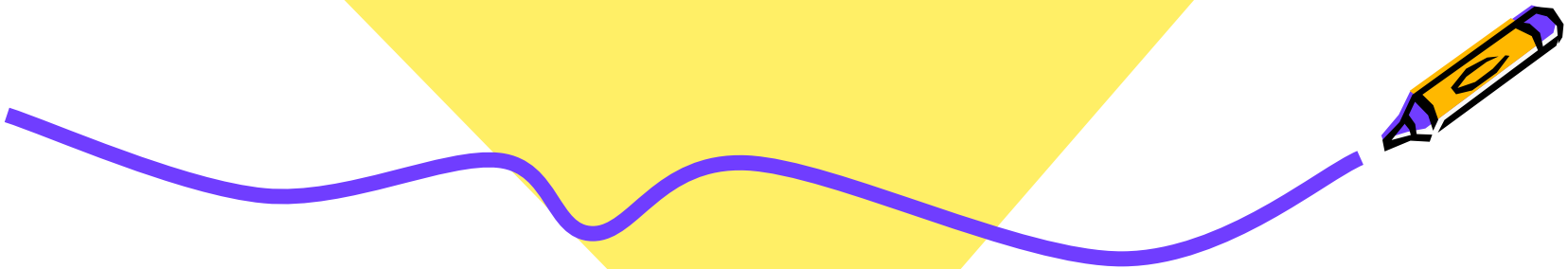
Interpret the balanced equation in terms of relative numbers of moles, volumes of gas at STP, and masses of reactants and products.

Writing Activity

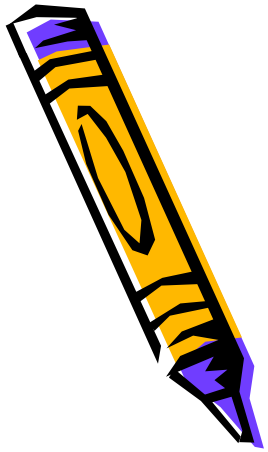
- **Explanatory Paragraph**
  - Explain this statement: "Mass and atoms are conserved in every chemical reaction, but moles are not necessarily conserved."



12.2 Chemical Calculations



Writing and Using Mole Ratios



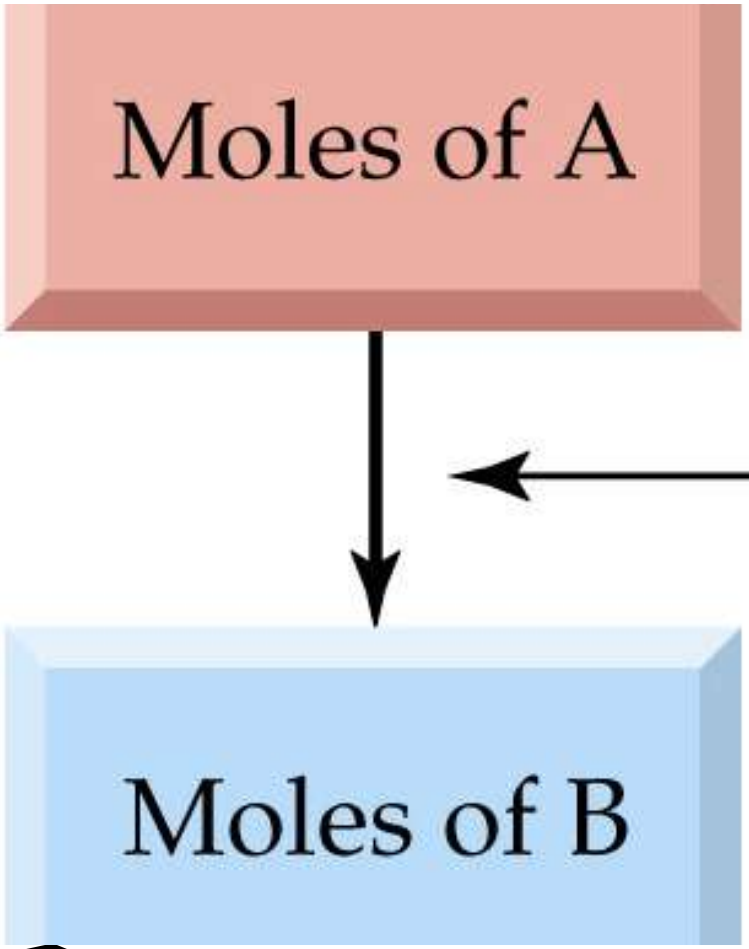
- Mole-Mole Calculations
  - A **mole ratio** is a conversion factor derived from the coefficients of a balanced chemical equation interpreted in terms of moles.

Mole-Mole Conversions

- 1) Balance Equation
- 2) Mole Ratio Step

Moles given x $\frac{\text{moles solve}}{\text{moles given}}$ = moles solve

Mole - Mole



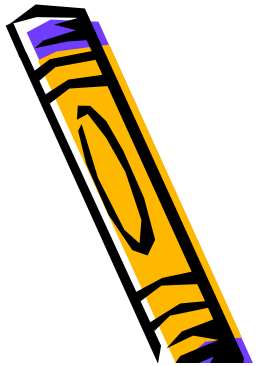
Use coefficients in the balanced equation to find mole ratios

Sample Problem 12.2

Calculating Moles of a Product

How many moles of ammonia are produced when 0.60 mol of nitrogen reacts with hydrogen?

for Sample Problem 12.2



12. According to the equation in Problem 11 $4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$

a. How many moles of oxygen are required to react completely with 14.8 mol Al?

b. How many moles of Al_2O_3 are formed when 0.78 mol O_2 reacts with aluminum?

Practice

- 1) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
  - How many mol of O_2 are required to react with 7.4 mol methane?
  - How many mol of CO_2 are produced by 2.6 mol O_2?

Practice

- 2) Calculate the number of moles of O_2 required to react with 4.30 mol propane:

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

Mole-Mass Conversions

- 1) Balance Equation
- 2) Mole ratio
- 3) Convert moles solve to grams of solve (multiply by molar mass of solve)

Example

- Determine the mass of sodium chloride produced when 1.25 mol chlorine gas reacts with sodium

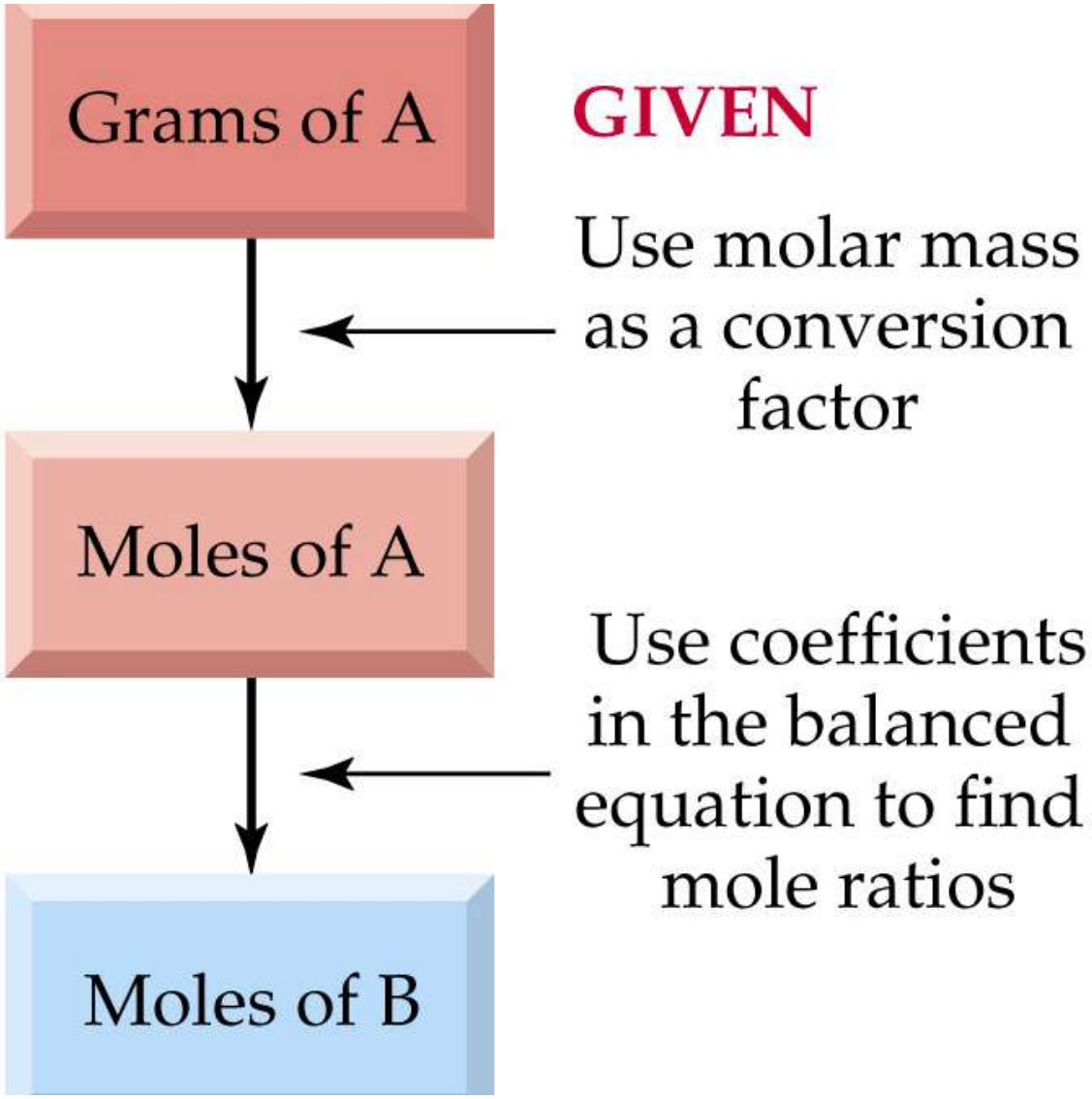
Practice

- 1) $TiO_2 + C + 2Cl_2 \rightarrow TiCl_4 + CO_2$
  - If you begin with 1.25 mol TiO_2, what mass of Cl_2 gas is needed?

Practice

- 2) Sodium chloride is decomposed into its elements sodium and chlorine. How many grams of chlorine gas can be obtained from 2.50 mol NaCl?

Grams *A* to Moles B



Example

- If you began the reaction with 2.00 g of Al_2O_3, how many moles of O_2 will you end up with?

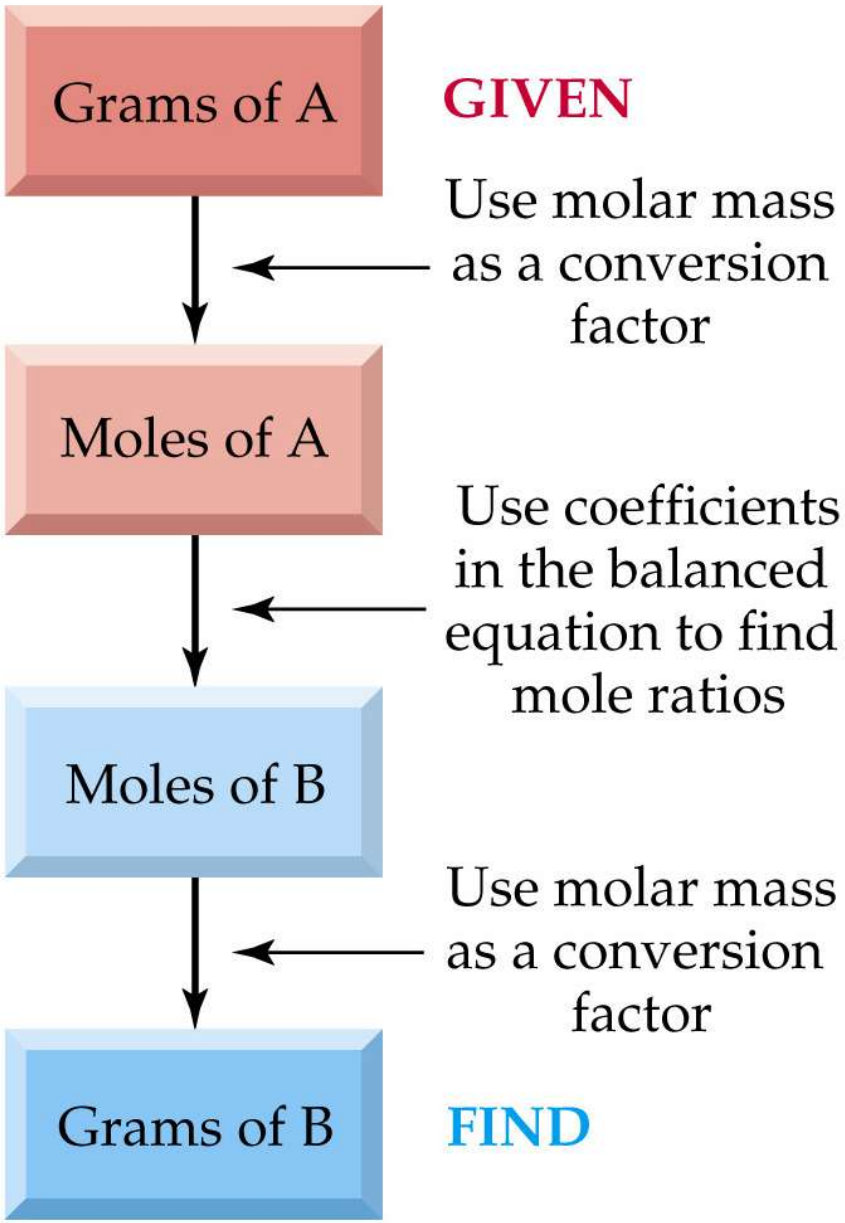
Example

- If the reaction ended with 23.7 mol Al, how many grams of O_2 would it also end with?

Mass-Mass Conversion

- 1) Balance
- 2) Convert mass given to moles (divide by molar mass of given)
- 3) Mole ratio
- 4) Convert moles solve to mass of solve (multiply by molar mass of solve)

Grams *A* to Grams B

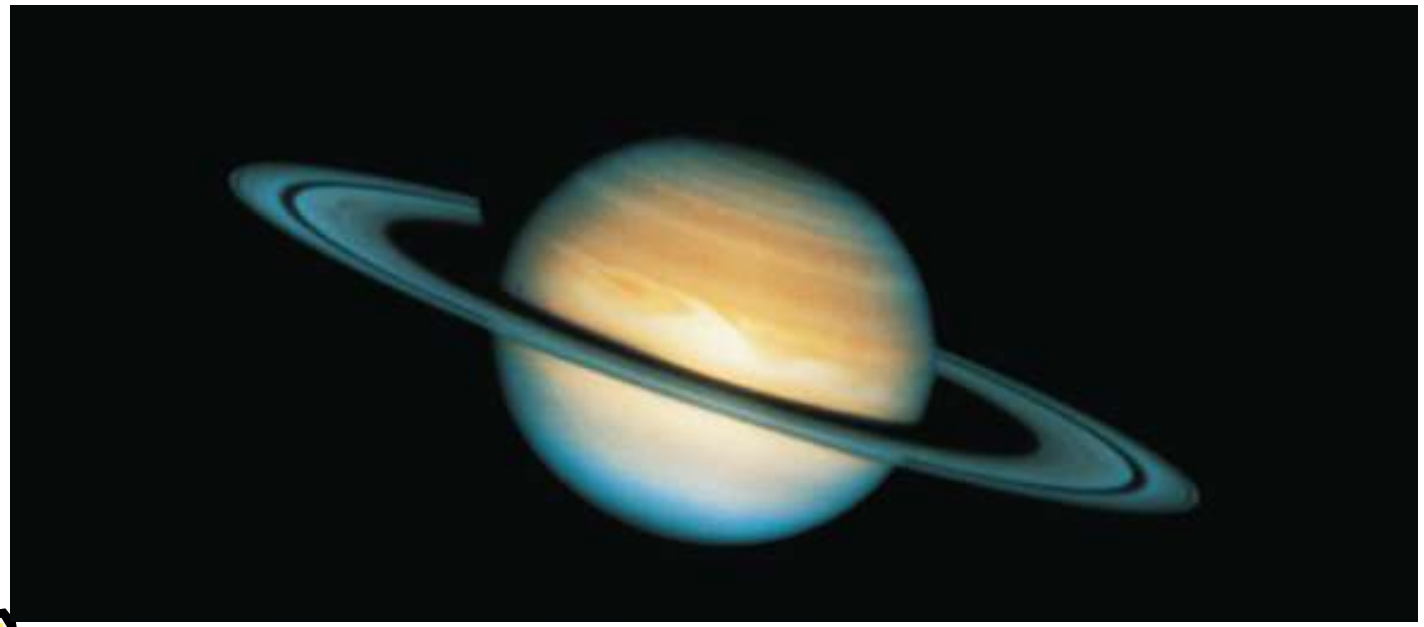


Sample Problem 12.3

Calculating the Mass of a Product

Calculate the number of grams of NH_3 produced by the reaction of 5.40 g of hydrogen with an excess of nitrogen. The balanced equation is

$$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$$



for Sample Problem 12.3

13. Acetylene gas (C_2H_2) is produced by adding water to calcium carbide (CaC_2).

$$CaC_2(s) + 2H_2O(l) \longrightarrow C_2H_2(g) + Ca(OH)_2(aq)$$

How many grams of acetylene are produced by adding water to 5.00 g CaC_2?

Practice

- 1) $2Al + 3I_2 \rightarrow 2AlI_3$
  - Calculate the mass if I_2 needed to react with 35.0 g Al

Practice

- 2) $2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$
  - Calculate the mass of CO_2 to react with 10.0 g NaOH
  - Calculate the mass of Na_2CO_3 produced when 10.0 g NaOH reacts with excess CO_2

Other Stoichiometric Calculations

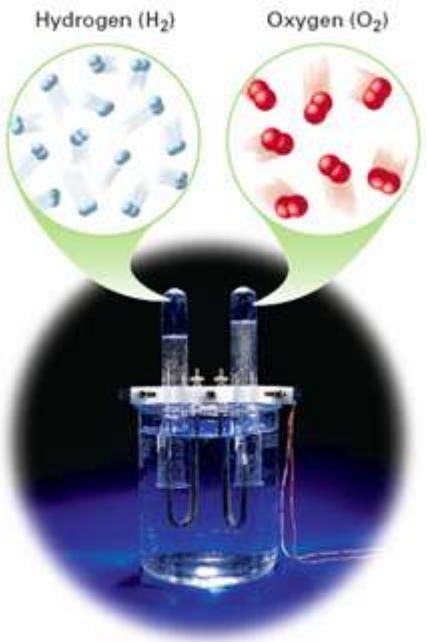
- In a typical stoichiometric problem, the given quantity is first converted to moles. Then the mole ratio from the balanced equation is used to calculate the number of moles of the wanted substance. Finally, the moles are converted to any other unit of measurement related to the unit mole, as the problem requires.

Sample Problem 12.4

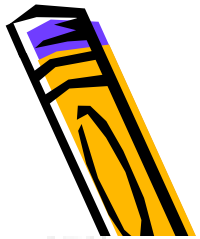
Calculating Molecules of a Product

How many molecules of oxygen are produced when 29.2 g of water is decomposed by electrolysis according to this balanced equation?

$$2H_2O(l) \xrightarrow{\text{electricity}} 2H_2(g) + O_2(g)$$



for Sample Problem 12.4



15. How many molecules of oxygen are produced by the decomposition of 6.54 g of potassium chlorate ($KClO_3$)?

$$2KClO_3(s) \longrightarrow 2KCl(s) + 3O_2(g)$$

Sample Problem 12.5

Volume-Volume Stoichiometric Calculations

Nitrogen monoxide and oxygen gas combine to form the brown gas nitrogen dioxide, which contributes to photochemical smog. How many liters of nitrogen dioxide are produced when 34 L of oxygen reacts with an excess of nitrogen monoxide? Assume conditions of STP.

$$2NO(g) + O_2(g) \longrightarrow 2NO_2(g)$$

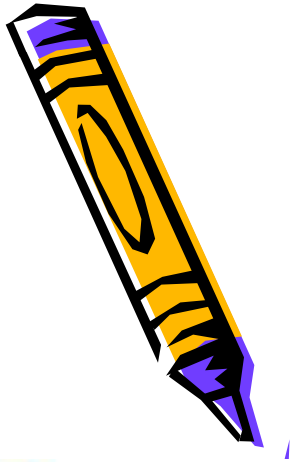
for Sample Problem 12.5

18. Phosphorus and hydrogen can be combined to form phosphine (PH_3).

$$P_4(s) + 6H_2(g) \longrightarrow 4PH_3(g)$$

How many liters of phosphine are formed when 0.42 L of hydrogen reacts with phosphorus?

Sample Problem 12.6

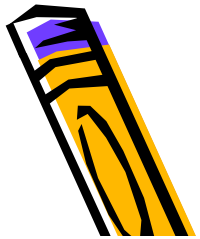


Finding the Volume of a Gas Needed for a Reaction

Assuming STP, how many milliliters of oxygen are needed to produce 20.4 mL SO_3 according to this balanced equation?

$$2SO_2(g) + O_2(g) \longrightarrow 2SO_3(g)$$

for Sample Problem 12.6



Consider this equation:

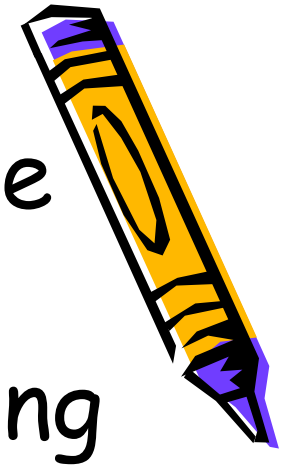
$$CS_2(l) + 3O_2(g) \longrightarrow CO_2(g) + 2SO_2(g)$$

19. Calculate the volume of sulfur dioxide produced when 27.9 mL O_2 reacts with carbon disulfide.

$$2KClO_3 \rightarrow 2KCl + 3O_2$$

- How many molecules of O_2 are formed from 5.45 g $KClO_3$?
- How many liters of O_2 are made when 9.83 g of KCl are formed?

12.2 Section Quiz.



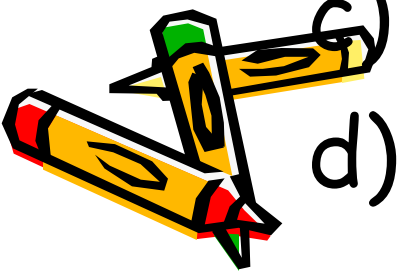
- 1. How many moles of water are produced when 2.5 mol of O_2 react according to the following equation?
  - $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

a) 2.0

b) 2.5

c) 3.0

d) 4.0



12.2 Section Quiz

– 2. Given $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$ what volume of H_2 is required to react with 3.00 L of N_2, and what volume of NH_3 is produced at 200°C?

a) H_2 = 9.00 L, NH_3 = 6.00 L

b) H_2 = 3.00 L, NH_3 = 3.00 L

c) H_2 = 3.00 L, NH_3 = 6.00 L

d) H_2 = 1.00 L, NH_3 = 1.50 L

12.2 Section Quiz

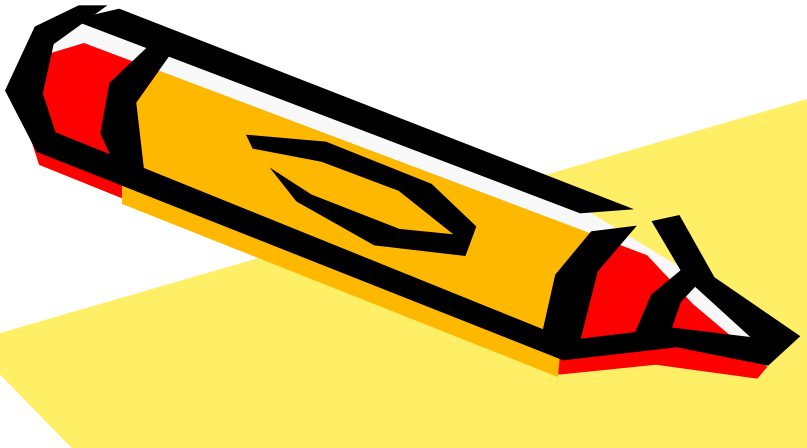
– 3. Automotive airbags inflate using this reaction: $2NaN_3 \rightarrow 2Na + 3N_2$. How many grams of sodium azide are required to form 5.00 g of nitrogen gas?

a) 11.61 g

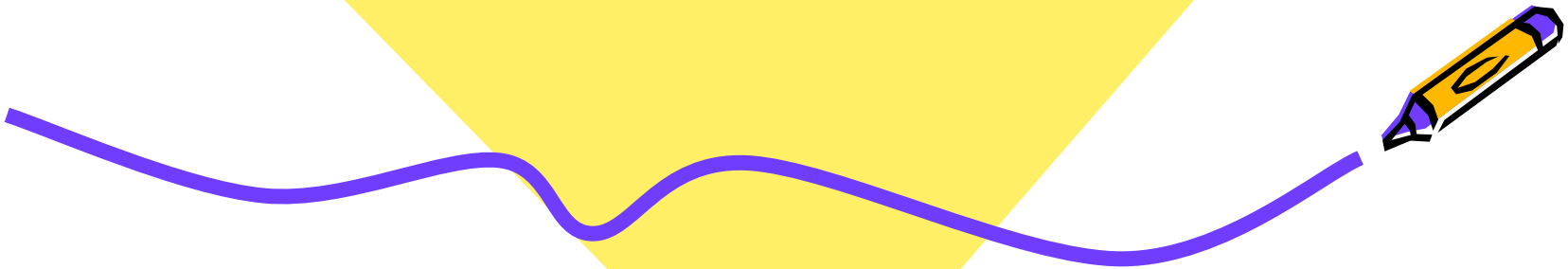
b) 17.41 g

c) 7.74 g

d) 1.36 g



12.3 Limiting Reactant and Percent Yield



What does limiting mean?

A sandwich consists of two slices of bread, 3 slices of meat, and one slice of cheese.

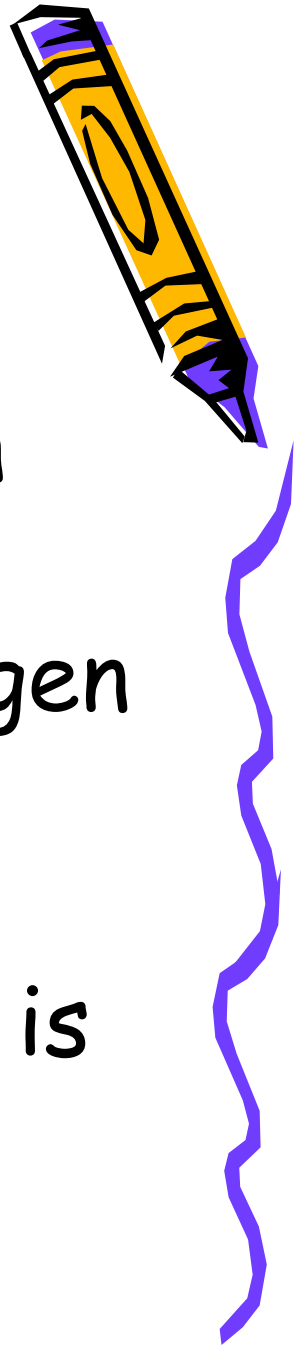
For each of the following amounts, determine the number of sandwiches that can be made and what is left over:

- 6 bread, 10 meat, 4 cheese slices
- 10 bread, 6 meat, 8 cheese slices
- 25 bread, 15 meat, 12 cheese slices

Limiting and Excess Reagents

- In a chemical reaction, an insufficient quantity of any of the reactants will limit the amount of product that forms.
  - The **limiting reagent** is the reagent that determines the amount of product that can be formed by a reaction.

Limiting and Excess Reagents



- In the reaction of nitrogen and hydrogen, hydrogen is the limiting reagent. Nitrogen is the reagent that is not completely used up in the reaction. The reagent that is not used up is called the **excess reagent**.

Sample Problem 12.7

Determining the Limiting Reagent in a Reaction

Copper reacts with sulfur to form copper(I) sulfide according to the following balanced equation.

$$2Cu(s) + S(s) \longrightarrow Cu_2S(s)$$

What is the limiting reagent when 80.0 g Cu reacts with 25.0 g S?

for Sample Problem 12.7

25. The equation for the complete combustion of ethene (C_2H_4) is

$$C_2H_4(g) + 3O_2(g) \longrightarrow 2CO_2(g) + 2H_2O(g)$$

If 2.70 mol C_2H_4 is reacted with 6.30 mol O_2, identify the limiting reagent.

Sample Problem 12.8

Using a Limiting Reagent to Find the Quantity of a Product

What is the maximum number of grams of Cu_2S that can be formed when 80.0 g Cu reacts with 25.0 g S?

$$2Cu(s) + S(s) \longrightarrow Cu_2S(s)$$

for Sample Problem 12.8

28. The heat from an acetylene torch is produced by burning acetylene (C_2H_2) in oxygen.

$$2C_2H_2(g) + 5O_2(g) \longrightarrow 4CO_2(g) + 2H_2O(g)$$

How many grams of water can be produced by the reaction of 2.40 mol C_2H_2 with 7.40 mol O_2?

Example

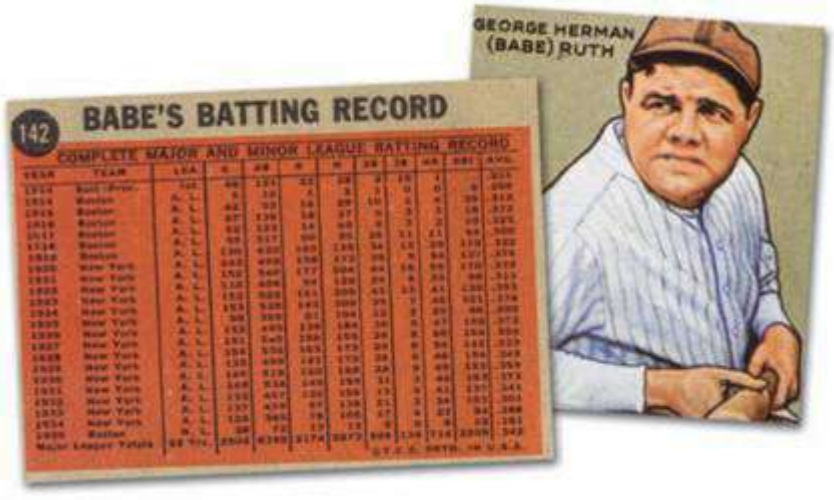
- $2Al + 3Cl_2 \rightarrow 2AlCl_3$
  - 10 g of Al react with 35 g Cl_2, what mass of $AlCl_3$ is produced?
  - What mass of which reactant is left after the reaction?

Practice

- 1) $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
  - If 5.0 g Fe_2O_3 reacts with 5.0 g CO, what mass of iron will be produced?
  - What mass of CO_2 will be produced?

Percent Yield

- The percent yield is a measure of the efficiency of a reaction carried out in the laboratory.
- **A batting average is actually a percent yield.**



Percent Yield

- The **theoretical yield** is the maximum amount of product that could be formed from given amounts of reactants.
  - In contrast, the amount of product that actually forms when the reaction is carried out in the laboratory is called the **actual yield**.

Percent Yield

- The **percent yield** is the ratio of the actual yield to the theoretical yield expressed as a percent.

$$\text{Percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

Sample Problem 12.9

Calculating the Theoretical Yield of a Reaction

Calcium carbonate, which is found in seashells, is decomposed by heating. The balanced equation for this reaction is:

$$CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$$

What is the theoretical yield of CaO if 24.8 g $CaCO_3$ is heated?

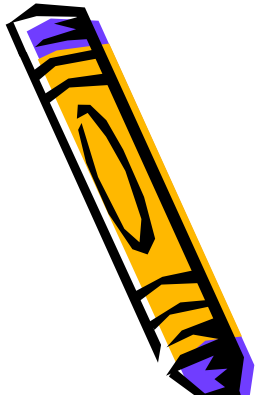
for Sample Problem 12.9

29. When 84.8 g of iron(III) oxide reacts with an excess of carbon monoxide, iron is produced.

$$Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(s) + 3CO_2(g)$$

What is the theoretical yield of iron?

Sample Problem 12.10



Calculating the Percent Yield of a Reaction

What is the percent yield if 13.1 g CaO is actually produced when 24.8 g $CaCO_3$ is heated?

$$CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$$

for Sample Problem 12.10

31. If 50.0 g of silicon dioxide is heated with an excess of carbon, 27.9 g of silicon carbide is produced.

$$SiO_2(s) + 3C(s) \longrightarrow SiC(s) + 2CO(g)$$

What is the percent yield of this reaction?

Practice

- 1) $Al(OH)_3 + 3HCl \rightarrow AlCl_3 + 3H_2O$
  - If 14 g of $Al(OH)_3$ is present, determine the theoretical yield of $AlCl_3$.
  - If the actual yield is 22.0 g, what is the percent yield?

Practice

- 2) $2NH_3 + CO_2 \rightarrow CN_2H_4O + H_2O$
  - 100 g of ammonia reacts with 100 g carbon dioxide and 120 g of urea is produced. Determine the percent yield.

12.3 Section Quiz.

– 1. In the reaction $3NO_2 + H_2O \rightarrow 2HNO_3 + NO$, how many grams of HNO_3 can form when 1.00 g of NO_2 and 2.25 g of H_2O are allowed to react?

a) 0.913 g

b) 0.667 g

c) 15.7 g

d) 1.37 g

12.3 Section Quiz.

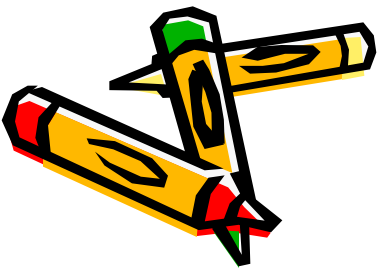
– 2. How many grams of H_2O can be formed from 24.0 g O_2 and 6.00 g H_2?

a) 30.0 g

b) 27.0 g

c) 54.0 g

d) 13.5 g



12.3 Section Quiz.

- 3.Octane burns according to the following equation.
- $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$
- What is the percent yield if 14.6 g of CO_2 are produced when 5.00 g of C_8H_{18} are burned?

a) 106%

b) 94.8%

c) 34.2%

d) 62.5%