

# STOICHIOMETRY

## Honors Chemistry

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Stoichiometry is the calculation of quantities in chemical reactions.

You can imagine chemical equations as the recipe for baking cookies:

200 chocolate chips + 1cup milk + 2cup flour + 4cup sugar → 12 cookies

The recipe tells you how many ingredients to mix together to make a certain number of cookies.

**Ex.** If I want to bake 48 cookies, how many chocolate chips would I need to buy at the store?

x chocolate chips = 48 cookies x (200 cc/ 12 cookies)  
= 800 chocolate chips

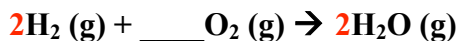
How many cups of milk do I need? How many cups of sugar?

x cups of milk = 48 cookies x (1 cup of milk/ 12 cookies)  
= 4 cups of milk

x cups of sugar = 48 cookies x (4 cups of sugar/ 12 cookies)  
= 16 cups of sugar



### Interpreting Chemical Equations:



What are the reactants? H<sub>2</sub> and O<sub>2</sub>. This corresponds with ingredients from the cookie analogy.

What are the products? water. This corresponds with # cookies from the cookie analogy.

What are the smaller numbers called? subscripts

What are the larger numbers called? coefficients

Why do we have to balance chemical equations? Law of Conservation of Mass

The coefficients tell us the number of moles of reactants and products just as they tell us about the amount of ingredients and products in the cookie analogy.

Convert the equation  $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$  into words:

Hydrogen gas reacts with oxygen gas and produces water.

What is the ratio of hydrogen to oxygen? 2:1

What is the ratio of hydrogen to water? 2:2

Ex.  $2\text{H}_2\text{S}(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{SO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$

Convert the equation into words:

$\text{H}_2\text{S}$  reacts with oxygen gas and produces  $\text{SO}_2$  and water.

What is the ratio of  $\text{H}_2\text{S}$  to  $\text{H}_2\text{O}$ ? 2:2

What is the ratio of  $\text{O}_2$  to  $\text{SO}_2$ ? 3:2

Why do we care about these coefficient ratios?

## MOLE:MOLE CALCULATIONS

COMPOUND A

COMPOUND B



Ex. Write out the conversion from moles of A to moles of B

$2\text{A} + 3\text{B} \rightarrow 4\text{C}$ —If I have 1.5 mol of A  $\rightarrow$  x mol B =  $1.5 \text{ mol A} \times (3 \text{ mol B} / 2 \text{ mol A}) = 2.25 \text{ mol B}$

### Examples of Mole:Mole Calculations with Real Chemical Equations:

1. Given the formula  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$ , how many moles of ammonia are produced when 0.60 mol of nitrogen reacts with hydrogen?

$$x \text{ mol NH}_3 = .60 \text{ mol N}_2 \times (2 \text{ mol NH}_3 / 1 \text{ mol N}_2)$$

$$= 1.2 \text{ mol NH}_3$$

2a. Based on the equation,  $4\text{Al}(\text{s}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{Al}_2\text{O}_3(\text{s})$ , which represents the formation of aluminum oxide, write the six mole ratios that can be derived from this equation.

$$4 \text{ mol Al} / 2 \text{ mol O}_2; 4 \text{ mol Al} / 2 \text{ mol Al}_2\text{O}_3; 3 \text{ mol O}_2 / 2 \text{ mol Al}_2\text{O}_3;$$

$$2 \text{ mol O}_2 / 4 \text{ mol Al}; 2 \text{ mol Al}_2\text{O}_3 / 4 \text{ mol Al}; 2 \text{ mol Al}_2\text{O}_3 / 3 \text{ mol O}_2$$

b. How many moles of aluminum are needed to form 3.7 mol  $\text{Al}_2\text{O}_3$ ?

$$= 7.4 \text{ mol}$$

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

$$= 11.1 \text{ mol}$$

d. How many moles of  $\text{Al}_2\text{O}_3$  are formed when 0.78 mol  $\text{O}_2$  reacts with aluminum?

$$=.52 \text{ mol}$$

# MASS:MASS CALCULATIONS

COMPOUND A

COMPOUND B



(Right before the left hand side arrow should be grams of A and right above the left hand side arrow should be 1mol/ Molecular Mass)

(Right above the right hand side arrow should be Molecular Mass/ 1 mol and right after the arrow should be grams of B)

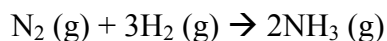
Ex. Write out the conversion from grams of A to grams of B

X grams of B = x grams of A x (1 mol A / MM of A) x (Mol B / Mol A Ratio) x (MM of B / 1 mol B)

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## Examples of Mass:Mass Calculations with Real Equations:

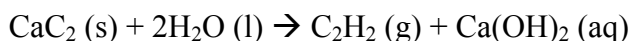
1. Calculate the number of grams of  $\text{NH}_3$  produced by the reaction of 5.40 g of hydrogen with an excess of nitrogen. The balanced equation is



Xg  $\text{NH}_3$  = 5.4 g  $\text{H}_2$  x (1 mol / 2 g) x (2 mol  $\text{NH}_3$  / 3 mol  $\text{H}_2$ ) x (17 g / 1 mol)

=**30.6 g of  $\text{NH}_3$**

2. Acetylene gas ( $\text{C}_2\text{H}_2$ ) is produced by adding water to calcium carbide ( $\text{CaC}_2$ )



a. How many grams of acetylene are produced by adding water to 5.00 g  $\text{CaC}_2$ .

=**2.03 g**

b. How many moles of  $\text{CaC}_2$  are needed to react completely with 49.0 g  $\text{H}_2\text{O}$ ?

= 1.36 mol

## VOLUME:VOLUME CALCULATIONS

COMPOUND A

COMPOUND B



(Right before the left hand side arrow should be volume of A)

(Right after the arrow should be volume of B)

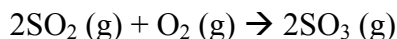
Ex. Write out the conversion from liters of A to liters of B

Volume A  $\rightarrow$  Mol A  $\rightarrow$  Mol B  $\rightarrow$  Volume B

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### Examples of Volume:Volume Calculations with Real Equations:

1. Assuming STP, how many liters of oxygen are needed to produce 19.8 L  $\text{SO}_3$  according to this balanced equation?



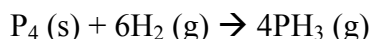
$$x \text{ L O}_2 = 19.8 \text{ L SO}_3 \times (1 \text{ mol SO}_3 / 22.4\text{L}) \times (1 \text{ mol O}_2 / 2 \text{ mol SO}_3) \times (22.4 \text{ L} / 1 \text{ mol O}_2)$$

= 9.9 L  $\text{O}_2$

2. The equation for the combustion of carbon monoxide is  $2\text{CO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g})$ . How many liters of oxygen are required to burn 3.86 L of carbon monoxide?

= 1.93 L

3. Phosphorus and hydrogen can be combined to form phosphine ( $\text{PH}_3$ ).

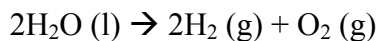


How many liters of phosphine are formed when 0.42 L of hydrogen reacts with phosphorus?

= .28 L

## MIX OF PROBLEM TYPES

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



**=4.88 x 10<sup>23</sup> molecules**

2. How many molecules of oxygen are produced by the decomposition of 6.54 g of potassium chlorate (KClO<sub>3</sub>)?

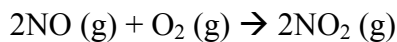


**=4.82 x 10<sup>22</sup> molecules**

3. The last step in the production of nitric acid is the reaction of nitrogen dioxide with water.  $3\text{NO}_2 (\text{g}) + \text{H}_2\text{O} (\text{l}) \rightarrow 2\text{HNO}_3 (\text{aq}) + \text{NO} (\text{g})$ . How many grams of nitrogen dioxide must react with water to produce  $5.00 \times 10^{22}$  molecules of nitrogen monoxide?

**=11.46 g**

4. Nitrogen monoxide and oxygen gas combine to form brown gas nitrogen dioxide. How many milliliters of nitrogen dioxide are produced when 3.4 mL of oxygen reacts with an excess of nitrogen monoxide? Assume conditions of STP.



**xmL NO<sub>2</sub>=3.4 mL x (1L/1000mL) x (1mol O<sub>2</sub>/22.4L) x (2mol NO<sub>2</sub>/1mol O<sub>2</sub>) x (22.4L/1mol) x (1000mL/1L)**

**=6.8mL**

5. Consider the equation  $\text{CS}_2 (\text{l}) + 3\text{O}_2 (\text{g}) \rightarrow \text{CO}_2 (\text{g}) + 2\text{SO}_2 (\text{g})$ :

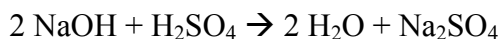
a. Calculate the volume of sulfur dioxide produced when 27.9 mL  $\text{O}_2$  reacts with carbon disulfide.

**=.0186L**

b. How many deciliters of carbon dioxide are produced when 0.38 L  $\text{SO}_2$  is formed?

**= 1.9 dL**

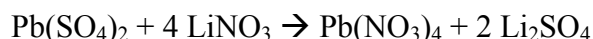
6. Using the following equation:



How many grams of sodium sulfate will be formed if you start with 200 grams of sodium hydroxide and you have an excess of sulfuric acid?

**=355 g**

7. Using the following equation:



How many grams of lithium nitrate will be needed to make 250 grams of lithium sulfate, assuming that you have an adequate amount of lead (IV) sulfate to do the reaction?

**=313 grams**

8. The incandescent white of a fireworks display is caused by the reaction of phosphorous with  $\text{O}_2$  to give  $\text{P}_4\text{O}_{10}$ .

a. Write the balanced chemical equation for the reaction.



b. How many grams of  $\text{O}_2$  are needed to combine with 6.85g of P?

**= 8.8 g**

c. How many grams of  $\text{P}_4\text{O}_{10}$  can be made from 8.00g of  $\text{O}_2$ ?

**=14.2 g**

d. How many grams of P are needed to make 7.46g P<sub>4</sub>O<sub>10</sub>?  
= 4.74 g

9. In *dilute* nitric acid, HNO<sub>3</sub>, copper metal dissolves according to the following equation: 3Cu(s) + 8HNO<sub>3</sub>(aq) → 3Cu(NO<sub>3</sub>)<sub>2</sub>(aq) + 2NO(g) + 4H<sub>2</sub>O(aq)  
How many grams of HNO<sub>3</sub> are needed to dissolve 11.45g of Cu?  
=30.3 g

10. Lithium hydroxide reacts with hydrobromic acid to produce lithium bromide and water. If you start with ten grams of lithium hydroxide, how many grams of lithium bromide will be produced?  
LiOH + HBr → LiBr + H<sub>2</sub>O  
=36.25 g

11. Ethylene (C<sub>2</sub>H<sub>4</sub>) reacts with oxygen gas to produce carbon dioxide and water. If you start with 45 grams of ethylene, how many grams of carbon dioxide will be produced?  
C<sub>2</sub>H<sub>4</sub> + 3O<sub>2</sub> → 2CO<sub>2</sub> + 2H<sub>2</sub>O  
=141.4 g



## LIMITING REAGENT

When we bake our chocolate chip cookies, if we have plenty of flour, sugar, and milk, but not of chocolate chips, the number of \_\_\_cookies\_\_\_ that we can bake is limited by the number of chocolate chips we have.

Therefore, we say that chocolate chips are the \_\_\_limiting reagent\_\_\_ while the other ingredients are the \_\_\_excess reagents\_\_\_.

**Ex.** Recipe: 20 chocolate chips, .25 cup of water, .25 cup of flour, 1 tbsp of sugar → 6 cookies.

If I have 20 chocolate chips, 1 cup of water, flour, and sugar, what is the limiting reagent? **Chocolate Chips**

If I have .1 cup of water, 20 chocolate chips, and 1 cup of flour and sugar, what is the limiting reagent? How many cookies can I make?

$$\begin{aligned} X \text{ cookies} &= .1 \text{ cup of water} \times (6 \text{ cookies}/.25 \text{ cup of water}) \\ &= \mathbf{2.4 \text{ cookies}} \end{aligned}$$

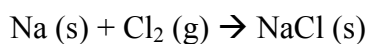
### Definitions:

\_\_\_limiting reagent\_\_\_ limits or determines the amount of product that can be formed in a reaction.

\_\_\_excess reagent\_\_\_ the reactant that is not completely used up in a reaction.

**THE AMOUNT OF PRODUCT CAN BE DETERMINED FROM THE GIVEN AMOUNT OF \_\_\_limiting reagent\_\_\_.**

**Ex.** Sodium chloride can be prepared by the reaction of sodium metal with chlorine gas.



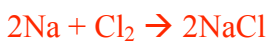
Suppose that 6.70 mol Na reacts with 3.20 mol Cl<sub>2</sub>.

a. How many moles of NaCl are produced?

Step 1: Determine whether this is a limiting reagent problem

This is a limiting reagent problem because there are two quantities given to you for the amount of reactant being used. As a result, you must decide which is the limiting reagent.

Step 2: Write a balanced chemical equation



Step 3: Convert mass of reactants to moles of products

$$\text{Na: } X \text{ mol NaCl} = 6.7 \text{ mol Na} \times (2 \text{ mol NaCl} / 2 \text{ mol Na})$$

$$= 6.7 \text{ mol NaCl}$$

$$\text{Cl}_2: X \text{ mol NaCl} = 3.2 \text{ mol Cl}_2 \times (2 \text{ mol NaCl} / 1 \text{ mol Cl}_2)$$

$$= 6.4 \text{ mol NaCl}$$

Step 4: Identify the limiting and excess reactants.

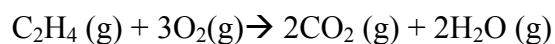
Therefore, since Cl<sub>2</sub> produces fewer moles of NaCl, we say that it is the limiting reagent. It limits the number of moles of NaCl that will be produced.

Step 5: Answer the question.

6.4 moles of NaCl are produced.

**Practice Problems:**

1. The equation for the complete combustion of ethene (C<sub>2</sub>H<sub>4</sub>) is



If 2.70 mol C<sub>2</sub>H<sub>4</sub> is reacted with 6.30 mol O<sub>2</sub>:

a. Identify the limiting reagent.

$$\text{C}_2\text{H}_4\text{- } X \text{ mol H}_2\text{O} = 2.70 \text{ mol C}_2\text{H}_4 \times (2 \text{ mol H}_2\text{O} / 1 \text{ mol C}_2\text{H}_4) = 5.4 \text{ mol}$$

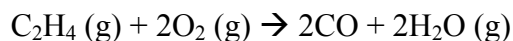
$$\text{O}_2\text{- } X \text{ mol H}_2\text{O} = 6.3 \text{ mol O}_2 \times (2 \text{ mol H}_2\text{O} / 3 \text{ mol O}_2) = 4.2 \text{ mol}$$

Therefore, O<sub>2</sub> is your limiting reagent.

b. Calculate the moles of water produced.

$$4.2 \text{ mol of H}_2\text{O}$$

2. The equation for the incomplete combustion of ethene (C<sub>2</sub>H<sub>4</sub>) is



If 2.70 mol C<sub>2</sub>H<sub>4</sub> is reacted with 6.30 mol O<sub>2</sub>:

a. Identify the limiting reagent.



b. Calculate the moles of water produced.

$$5.4 \text{ moles of water}$$

3a. If  $2\text{Cu} (\text{s}) + \text{S} (\text{s}) \rightarrow \text{Cu}_2\text{S} (\text{s})$ , what is the limiting reagent when 80.0 g Cu reacts with 25.0 g S?

$$\text{Cu} \rightarrow x \text{ mol of Cu}_2\text{S} = 80 \text{ g Cu} \times (1 \text{ mol Cu} / 63.5 \text{ g}) \times (1 \text{ mol Cu}_2\text{S} / 2 \text{ mol Cu}) = .63 \text{ mol}$$

$$\text{S} \rightarrow x \text{ mol of Cu}_2\text{S} = 25 \text{ g S} \times (1 \text{ mol S} / 32 \text{ g}) \times (1 \text{ mol Cu}_2\text{S} / 1 \text{ mol S}) = .78 \text{ mol}$$

Therefore, Cu is the limiting reagent.

b. What is the maximum number of grams of Cu<sub>2</sub>S that can be formed?

$$X \text{ g} = .63 \text{ mol of Cu}_2\text{S} \times (159 \text{ g} / \text{mol}) = \mathbf{100.2 \text{ g}}$$

4. Hydrogen gas can be produced in the laboratory by the reaction of magnesium metal with hydrochloric acid.



a. Identify the limiting reagent when 6.00 g HCl reacts with 5.00 g Mg.

HCl is limiting.

b. How many grams of hydrogen can be produced when 6.00 g HCl is added to 5.00 g Mg?

HCl will produce .082 mol of H<sub>2</sub>. Convert that to grams and you get .164 g.

5. Acetylene (C<sub>2</sub>H<sub>2</sub>) will burn in the presence of oxygen:



How many grams of water can be produced by the reaction of 2.40 mol C<sub>2</sub>H<sub>2</sub> with 7.4 mol O<sub>2</sub>?

C<sub>2</sub>H<sub>2</sub> is the limiting reagent. As a result, only 2.40 mol of water are produced which means that 43.2 g of water are produced.

## PERCENT YIELD:

When an equation is used to calculate the amount of product that will form during a reaction, the theoretical yield is obtained. This is the maximum amount of product that can 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.

Therefore the Percent Yield =  $\text{Actual Yield} / \text{Theoretical Yield} \times 100$

It tells us: What percent of our expected amount of product was actually produced. If it is >100% this really doesn't make sense and means that some serious error happened in the experiment. Normally, our percent yield is <100% which means that not as much product was actually produced as what was originally predicted.

### Practice Problems:

1. Calcium carbonate is decomposed by heating, as shown below:



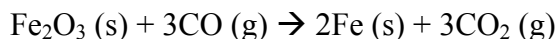
a. What is the theoretical yield of CaO if 24.8 g CaCO<sub>3</sub> is heated?

$$\begin{aligned} X \text{ g CaO} &= 24.8 \text{ g CaCO}_3 \times (1 \text{ mol} / 100 \text{ g}) \times (1 \text{ mol CaO} / 1 \text{ mol CaCO}_3) \times (56 \text{ g} / 1 \text{ mol}) \\ &= \mathbf{13.89 \text{ g}} \end{aligned}$$

b. What is the percent yield if 13.1 g CaO is produced?

$$\begin{aligned} \% \text{ yield} &= \text{Actual Yield} / \text{Theoretical Yield} \\ &= 13.1 / 13.89 \times 100 \\ &= \mathbf{94.3\% \text{ yield.}} \end{aligned}$$

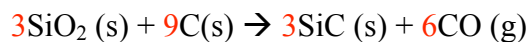
2. When 84.8 g of iron (III) oxide reacts with an excess of carbon monoxide, 54.3 g of iron is produced:



What is the percent yield of this reaction?

$$\mathbf{91.48\%}$$

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



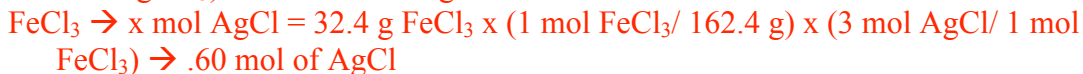
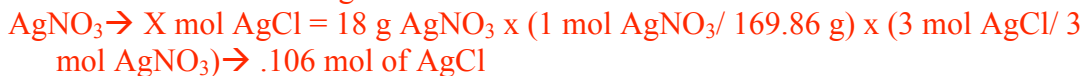
What is the percent yield of this reaction? **83.7 %**

## Review Problems:

- The reaction of powdered aluminum and iron(II)oxide,  
$$2\text{Al}(\text{s}) + \text{Fe}_2\text{O}_3(\text{s}) \rightarrow \text{Al}_2\text{O}_3(\text{s}) + 2\text{Fe}(\text{l})$$
produces so much heat the iron that forms is molten. Because of this, railroads use the reaction to provide molten steel to weld steel rails together when laying track. Suppose that in one batch of reactants 4.20mol Al was mixed with 1.75mol  $\text{Fe}_2\text{O}_3$ .
  - Which reactant, if either, was the limiting reactant?  
 **$\text{Fe}_2\text{O}_3$  is the limiting reactant.**
  - Calculate the mass of iron (in grams) that can be formed from this mixture of reactants.  
**279.5 g**
- Silver nitrate,  $\text{AgNO}_3$ , reacts with iron(III) chloride,  $\text{FeCl}_3$ , to give silver chloride,  $\text{AgCl}$ , and iron(III) nitrate,  $\text{Fe}(\text{NO}_3)_3$ . A solution containing 18.0g  $\text{AgNO}_3$  was mixed with a solution containing 32.4g  $\text{FeCl}_3$ . How many grams of which reactant *remains* after the reaction is over?

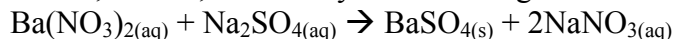


Now find which is limiting:



Now answer the question. If  $\text{AgNO}_3$  is your limiting reagent, That means only .106 mol of  $\text{AgCl}$  were used. As a result, we can determine the number of grams of  $\text{FeCl}_3$  that were used and then find the amount that was left over. Therefore, lets first use .106mol of  $\text{AgCl}$  to find out how much of our excess reagent was actually used.  $X \text{ g of FeCl}_3 = .106 \text{ mol AgCl} \times (1 \text{ mol FeCl}_3 / 3 \text{ mol AgCl}) \times (162.4 \text{ g} / 1 \text{ mol FeCl}_3) \rightarrow 5.74 \text{ grams of FeCl}_3$  were actually used. Since you start with 32.4 g, then by calculating  $32.4 - 5.74$ , you will find the amount of reactant that remains after the reaction is over: **26.7 g**

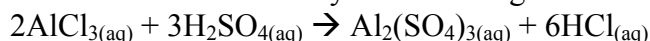
3. Barium sulfate, BaSO<sub>4</sub>, is made by the following reaction:



An experiment was begun with 75.00g of Ba(NO<sub>3</sub>)<sub>2</sub> and an excess of Na<sub>2</sub>SO<sub>4</sub>. After collecting and drying the product, 63.45g BaSO<sub>4</sub> was obtained. Calculate the theoretical yield and percent yield of BaSO<sub>4</sub>.

**94.8%**

4. Aluminum sulfate can be made by the following reaction:



It is quite soluble in water, so to isolate it the solution has to be evaporated to dryness. This drives off the volatile HCl, but the residual solid has to be treated to a little over 200°C to drive off all the water. In one experiment, 25.0g of AlCl<sub>3</sub> was mixed with 30.0g H<sub>2</sub>SO<sub>4</sub>. Eventually, 28.46g of pure Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> was isolated. Calculate the percent yield.

Must first find the theoretical yield which is .094 mol or 32.148g of Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>.

Now find percent yield= **88.5%**

5. Given the equation:  $2\text{HCl} + \text{Na}_2\text{SO}_4 \rightarrow 2\text{NaCl} + \text{H}_2\text{SO}_4$

If you start with 20 grams of hydrochloric acid, how many grams of sulfuric acid will be produced? **26.85 g**

6. Propane (C<sub>3</sub>H<sub>8</sub>) is the fuel used in most gas grills. It burns according to the balanced equation:  $\text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 4\text{H}_2\text{O} + 3\text{CO}_2$ . If you burn 215 g of propane, how many grams of H<sub>2</sub>O will be produced?

**351.82g**

7. The combustion of acetylene gas is represented by this equation:



- a. How many grams of CO<sub>2</sub> and grams of H<sub>2</sub>O are produced when 52.0 g C<sub>2</sub>H<sub>2</sub> burns?

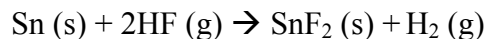
**176 g CO<sub>2</sub>**

**36 g H<sub>2</sub>O**

b. How many grams of oxygen are required to burn 52.0 g C<sub>2</sub>H<sub>2</sub>?

160g

8. Tin (II) Fluoride, formerly found in many kinds of toothpaste, is formed in this reaction:



a. How many liters of HF are needed to produce 9.40 L H<sub>2</sub> at STP?

18.8 L

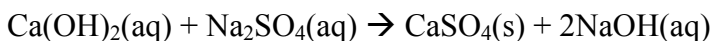
b. How many molecules of H<sub>2</sub> are produced by the reaction of tin with 20.0 L HF at STP?

$2.69 \times 10^{23}$  molecules

c. How many grams of SnF<sub>2</sub> can be made by reacting  $7.42 \times 10^{24}$  molecules of HF with tin?

965.7 g

9. 3.64 g of calcium hydroxide react with excess sodium sulfate in aqueous solution to produce solid sulfate and aqueous sodium hydroxide. How many moles of calcium atoms are reacting here?



A. 0.00982 mol

B. 0.0246 mol

C. 0.0266 mol

D. 0.0491 mol

E. 0.0909 mol

10. A 0.250 M solution of AgNO<sub>3</sub> is to be prepared. What mass of solid AgNO<sub>3</sub> do you need in order to prepare 50.0 mL of this solution?

A. 2.12 g

B. 4.98 g

C. 6.66 g

D. 9.87 g

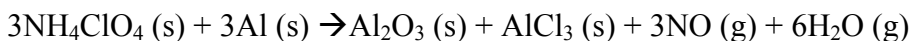


E. 12.5 g

11. Which compound has the highest percent by mass of nitrogen?

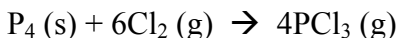
- A.  $(\text{CH}_3)_3\text{N}(\text{l})$
- B.  $\text{N}_2\text{O}_4(\text{l})$
- C.  $\text{HNO}_3(\text{g})$
- D.  $\text{NO}_2(\text{g})$
- E.  $\text{N}_2(\text{g})$

12. If one mole of the rocket fuel ammonium perchlorate,  $\text{NH}_4\text{ClO}_4(\text{s})$  is allowed to react with excess Al so all of the  $\text{NH}_4\text{ClO}_4$  is consumed, how many molecules of water will be produced?



- A.  $3.61 \times 10^{23}$
- B.  $1.00 \times 10^{23}$
- C.  $6.02 \times 10^{23}$
- D.  $1.20 \times 10^{24}$
- E.  $3.01 \times 10^{24}$

13. How many grams of potassium cyanide,  $\text{PCl}_3$ , is produced from 93.0 grams of  $\text{P}_4(\text{s})$  and 213 g of  $\text{Cl}_2(\text{g})$ , assuming the reaction goes to completion? The balanced equation for the reaction is:



- A. 277 g
- B. 416 g
- C. 213 g
- D. 104 g
- E. 69.3 g

14. How many grams of  $\text{K}_2\text{Cr}_2\text{O}_7$  (molar mass = 294 g/mol) are required to prepare 200 mL of a 0.100 M solution?

- A. 2.94
- B. 4.82
- C. 5.88
- D. 2.94
- E. 58.8

15. How many moles of  $\text{Al}_2\text{O}_3$  are formed when a mixture of 0.36 moles Al and 0.36 moles  $\text{O}_2$  is ignited?

- A. 0.12
- B. 0.18
- C. 0.28
- D. 0.46
- E. 0.72

16. What is the total number of atoms contained in 2.00 moles of nickel?

- A. 58.9
- B. 118
- C.  $6.02 \times 10^{23}$
- D.  $1.2 \times 10^{24}$
- E.  $2.4 \times 10^{24}$