Chemical Equations & Stoichiometry

Chapter Goals

- Balance equations for simple chemical reactions.
- Perform stoichiometry calculations using balanced chemical equations.
- Understand the meaning of the term limiting reactant.
- Calculate the theoretical and percent yield of a chemical reaction.
- Use stoichiometry to analyze a mixture of compounds or to determine the formula of a compound.

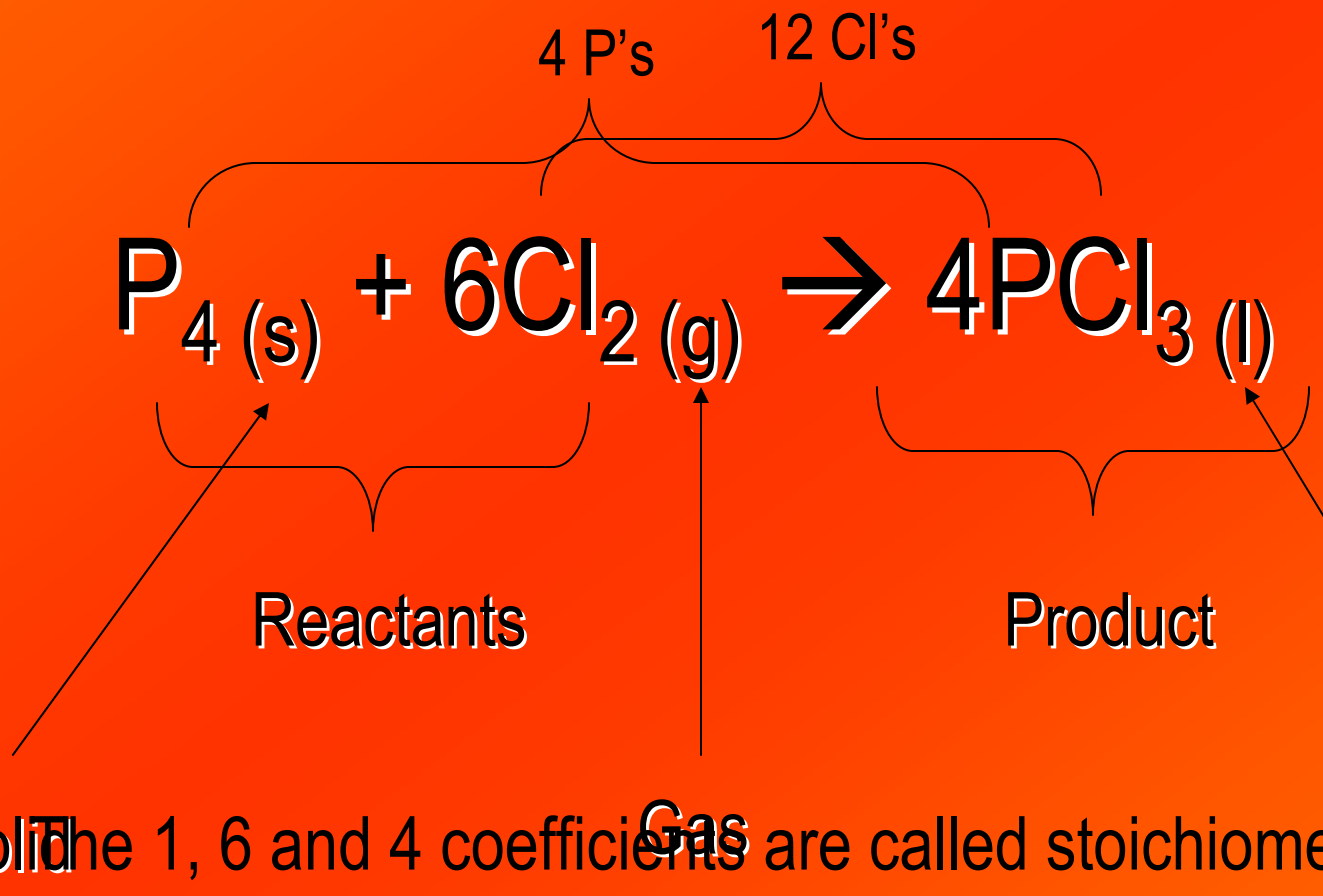
Before We Begin

- Review names of common compounds and ions.
- Know how to convert mass to moles and moles to mass.

Chemical Equations

- A chemical equation is just a way to show what happens in a chemical reaction on paper.
  - Reactants → Products
- States of matter are written as (s), (l), (g) and (aq).
- (aq) stands for an aqueous solution which means that water is the solvent for the solution.
- Law of Conservation of Matter tells us that matter cannot be created or destroyed.
- This means that a chemical equation must be balanced by matter—all atoms must balance.

Chemical Equations



The 1, 6 and 4 coefficients are called stoichiometric coefficients and tell you about the way in which reactants combine and products form.

Check and See

- The reaction of sodium with chlorine is seen below…

- The equation for the reaction is…
  - $2Na_{(s)} + Cl_{2(g)} \rightarrow 2NaCl_{(s)}$
- Name the reactants and products in this reaction and give their states.
- What are the stoichiometric coefficients in this equation?
- If you were to use 8000 atoms of Na, how many molecules of Cl_2 are required to consume the sodium completely?

Balancing Chemical Equations

- Before quantitative information (stoichiometry) can be used a chemical equation MUST be balanced.

Balancing Chemical Equations

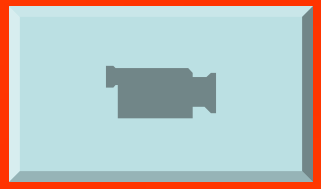
- Let's look at the combustion of propane and balance its equation.
  - $C_3H_{8\,(g)} + O_{2\,(g)} \rightarrow CO_{2\,(g)} + H_2O_{\,(l)}$
- Balance the C atoms adding coefficients only...
  - $\mathbf{C_3}H_{8\,(g)} + O_{2\,(g)} \rightarrow \mathbf{3C}O_{2\,(g)} + H_2O_{\,(l)}$
- Balance the H atoms next…
  - $C_3\mathbf{H_8}_{\,(g)} + O_{2\,(g)} \rightarrow 3CO_{2\,(g)} + \mathbf{4}H_2O_{\,(l)}$
- Finally, balance the O atoms…
  - $C_3H_{8\,(g)} + \mathbf{5}O_{2\,(g)} \rightarrow 3CO_{2\,(g)} + \mathbf{4}H_2O_{\,(l)}$
- Recount all atoms to make sure they are balanced.

Check and See

- Write the balanced equation for the combustion of ammonia (NH_3) to give N_2 and H_2O.
  - $NH_{3\,(g)} + O_{2\,(g)} \rightarrow N_{2\,(g)} + H_2O_{\,(l)}$
  - $\mathbf{2}NH_{3\,(g)} + O_{2\,(g)} \rightarrow \mathbf{N_2}_{\,(g)} + H_2O_{\,(l)}$
  - $\mathbf{2}NH_{\mathbf{3}\,(g)} + O_{2\,(g)} \rightarrow N_{2\,(g)} + \mathbf{3}H_{\mathbf{2}}O_{\,(l)}$
  - $2NH_{3\,(g)} + \mathbf{3/2}\,O_{\mathbf{2}\,(g)} \rightarrow N_{2\,(g)} + \mathbf{3}H_2\mathbf{O}_{\,(l)}$
  - $4NH_{3\,(g)} + 3O_{2\,(g)} \rightarrow 2N_{2\,(g)} + 6H_2O_{\,(l)}$

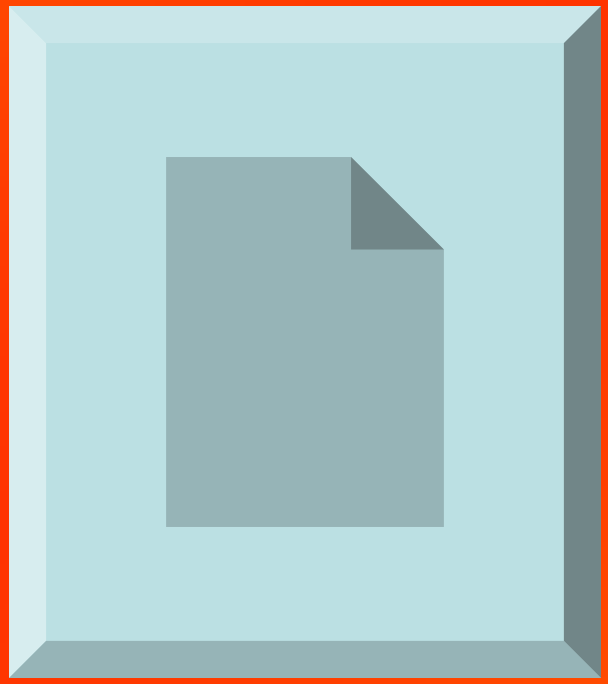
Check and See

- Butane gas, C_4H_{10}, can burn completely in oxygen to give carbon dioxide gas and water vapor. Write a balanced equation for this combustion reaction.



- Write a balanced chemical equation for the complete combustion of liquid tetraethyl lead, $Pb(C_2H_5)_4$. The products of combustion are solid PbO, liquid water and gaseous CO_2.

The Real Deal: Stoichiometry

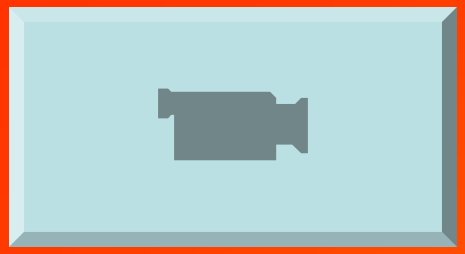


Check and See

- Glucose reacts with oxygen to give CO_2 and H_2O. What mass of oxygen (in grams) is required for complete reaction of 25.0g of glucose? What masses of CO_2 and H_2O (in grams) are formed?
  - Write a balanced chemical equation.
    - $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
  - g gluc. → moles gluc. → moles O_2 → g O_2
    - 26.6g O_2
  - g gluc. → moles gluc. → moles CO_2 → g CO_2
    - 36.6g O_2
  - 51.6g reactant = 36.6g CO_2 + g H_2O
    - 15.0g H_2O

Check and See

- What mass of oxygen is required to completely combust 454g of propane, C_3H_8? What masses of CO_2 and H_2O are produced?
- 1650g O_2, 1360g CO_2, 742g H_2O

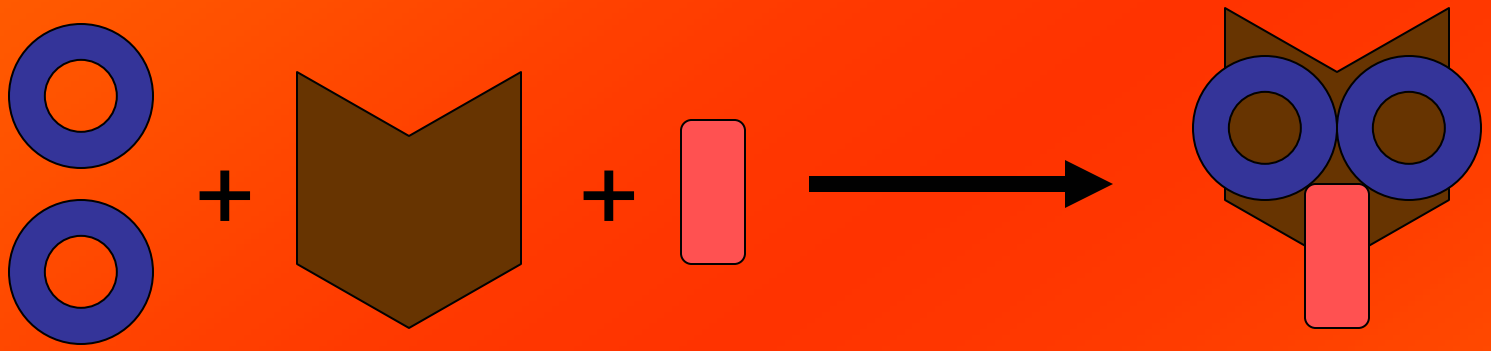


Itty Bitty Practice Problem…

- Suppose 16.04g of benzene, C_6H_6, is combusted…

1. What is the balanced equation for this reaction?
   - $2C_6H_6 + 15O_2 \rightarrow 12CO_2 + 6H_2O$
2. What mass of O_2, in grams, is required for complete combustion of benzene?
   - 49.35g
3. What is the total mass of products expected from 16.04g of benzene?
   - 65.39g

Limiting Reactants



How many goofy owls could you make if you has 100 eyes, 50 heads and 2 tongues?

Only 2! So, the tongues limit the amount of goofy owls that can be made, even though you had enough heads and eyes to make 50!

Limiting Reactants

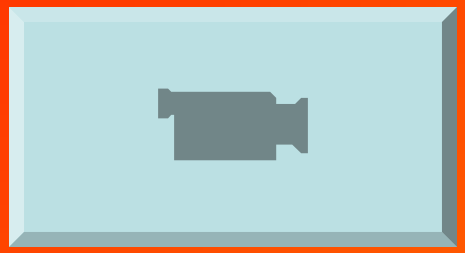
- The limiting reactant is the reactant that "limits" the amount of product that can be made?
- The reactant that doesn't limit the amount of product made is the excess reactant.
- Even though there is still a lot of eyes and heads for our owl, the # of tongues is 0.
- So, we cannot make any more goofy owls.
- This idea also works with reactions.
- For reactions we are looking at the amount of moles to determine the LR.

Limiting Reactants

- The easiest way to determine the maximum amount of product made is to determine the amount of product each reactant could make if it all reacted.
- The reactant that produced the least amount will be the limiting reactant.
- And the amount of product the LR produced is the maximum amount made in the reaction.

Check and See

- The thermite reaction produced iron metal and aluminum oxide from a mixture of powdered aluminum metal and iron (III) oxide.
  - $Fe_2O_{3\,(s)} + 2Al_{\,(s)} \rightarrow 2Fe_{\,(s)} + Al_2O_{3\,(s)}$
- A mixture of 50.0g each of Fe_2O_3 and Al is used. What mass of iron metal can be produced?
  - 35.0g Fe



Check and See

- Methanol, CH_3OH, which is used as a fuel, can be made by the reaction of carbon monoxide and hydrogen.
  - $CO_{(g)} + 2H_{2\,(g)} \rightarrow CH_3OH_{(l)}$
- Suppose 356g of CO is mixed with 65.0g of H_2. What mass of methanol can be produced and what mass of excess reactant remains after the reaction is complete?
  - 407g of CH_3OH produced
  - 14g of H_2 remain

Percent Yield

% Yield = (actual yield / theoretical yield) x 100

What you get in the lab

What stoich “says” you should have gotten

Check and See

- Methanol can decompose into H_2 gas and CO gas by the following reaction…
  - $CH_3OH_{(l)} \rightarrow H_{2\,(g)} + CO_{(g)}$
  - If 125g of methanol is decomposed, what is the theoretical yield of H_2 gas? If only 13.6g of H_2 gas is obtained in the lab, what is the percent yield of the gas?
    - 15.7g H_2
    - 86.6% yield

Chemical Analysis

- Quantitative chemical analysis depends on one or the other of two basic ideas…

1. A substance, present in unknown amount, can be allowed to react with a known quantity of another substance. If the stoich ratio for their reaction is known, the unknown amount can be determined.
   - Titration chemistry in the next chapter will deal with this one.

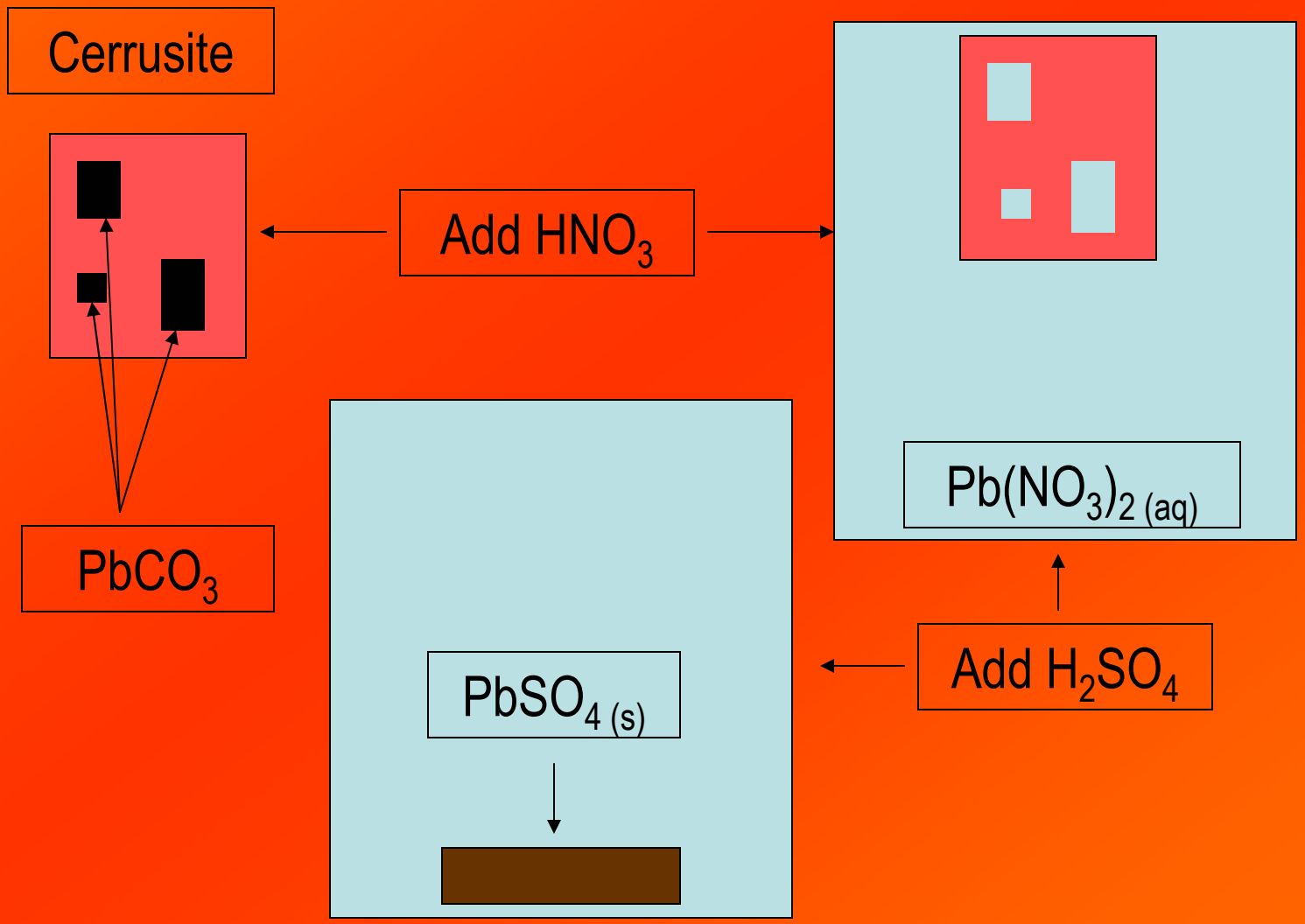
Chemical Analysis

2. A material of unknown composition can be converted to one or more substances of known composition. Those substances can be identified, their amounts determined, and these amounts related to the amount of the original, unknown substance.

Chemical Analysis Ex #2

- Cerrusite, a lead containing mineral, is impure lead (II) carbonate, $PbCO_3$. To analyze a sample of the mineral for its content of $PbCO_3$ a sample is first treated with nitric acid to dissolve the $PbCO_3$.
- $PbCO_{3\,(s)} + 2HNO_{3\,(aq)} \rightarrow Pb(NO_3)_{2\,(aq)} + H_2O_{\,(l)} + CO_{2\,(g)}$
- On adding sulfuric acid, lead sulfate precipitates…
- $Pb(NO_3)_{2\,(aq)} + H_2SO_{4\,(aq)} \rightarrow PbSO_{4\,(s)} + 2HNO_{3\,(aq)}$
- The pure solid lead sulfate is isolated and weighed. Suppose a 0.583g sample of mineral produced 0.628g of $PbSO_4$. What is the mass percent of $PbCO_3$ in the mineral sample?

Chemical Analysis Ex #2



Chemical Analysis Ex #2

- 0.00207 mol $PbSO_4$
- 0.00207 mol $PbCO_3$
- 0.553g $PbCO_3$
- 94.9% of sample is $PbCO_3$

Check Time

- Nickel (II) sulfide occurs naturally as the rare mineral, millerite. One of its occurrences is in meteorites. To analyze a sample containing millerite for the quantity of NiS, the sample is digested in nitric acid to release nickel.
- $NiS_{(s)} + HNO_{3\ (aq)} \rightarrow Ni(NO_3)_{2\ (aq)} + S_{(s)} + 2NO_{2\ (g)} + 2H_2O_{(l)}$
- The aqueous solution of nickel (II) nitrate is then treated with the organic compound dimethylglyoxime (DMG, $C_4H_8N_2O_2$)to give the read solid $Ni(C_4H_7N_2O_2)_2$.
- $Ni(NO_3)_2 + 2\ C_4H_8N_2O_{2\ (aq)} \rightarrow Ni(C_4H_7N_2O_2)_{2\ (s)} + 2HNO_{3\ (aq)}$

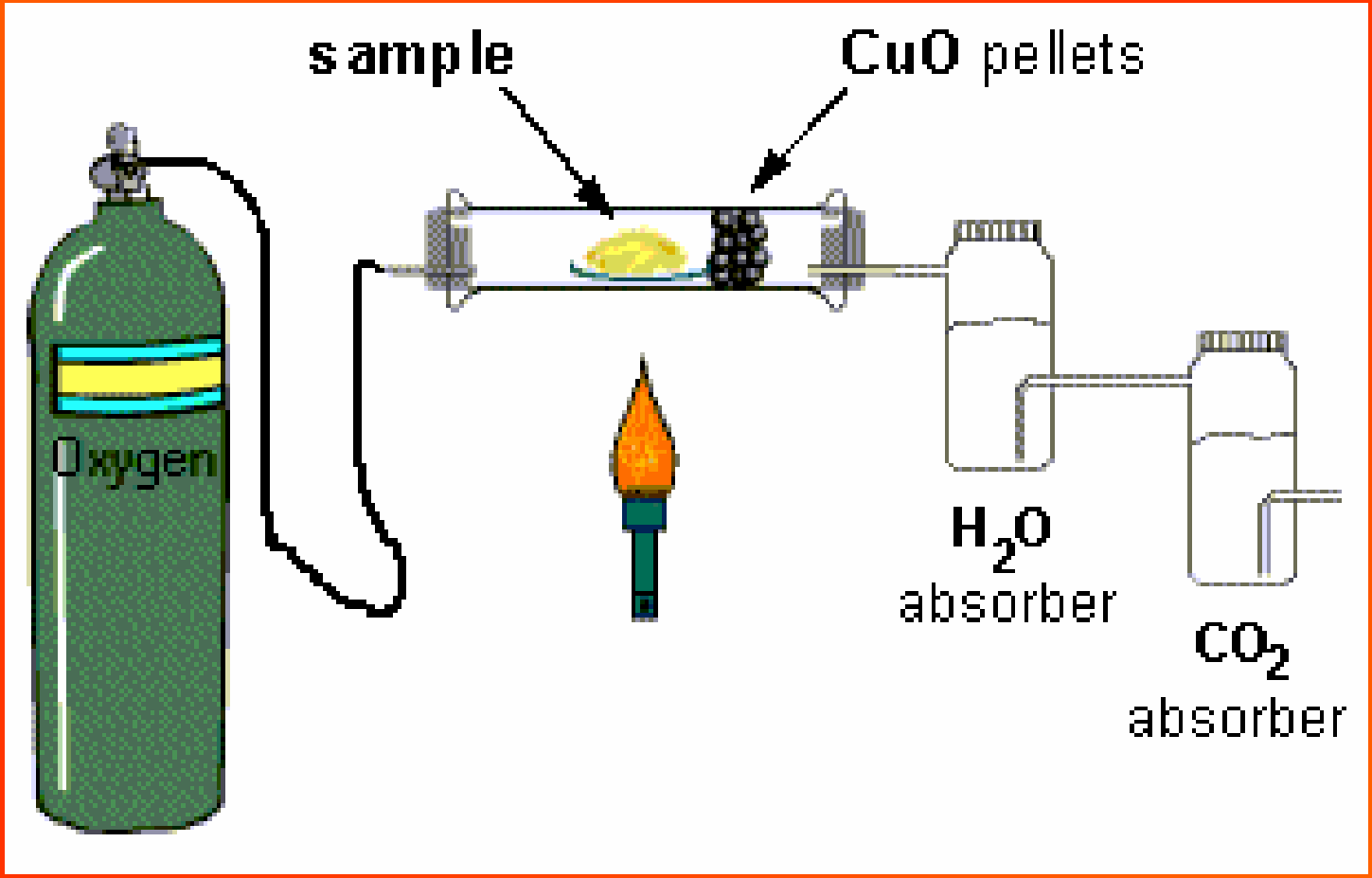
Check Time

- Suppose a 0.468g sample containing millerite produces 0.206g of red, solid $Ni(C_4H_7N_2O_2)_2$. What is the mass percent of NiS in the sample?
  - 7.13×10^{-4} mol $Ni(C_4H_7N_2O_2)_2$
    - 7.13×10^{-4} mol NiS
      - 0.0647g NiS
        - 13.8% NiS in original sample

Combustion Analysis

- The empirical formula of a compound can be determined if the percent composition of the compound is known.
- But where to the percent composition data come from?
  - The main chemical analysis procedure is…
  - The pure unknown compound is decomposed.
  - The products are isolated and the amount is determined.
- The amount of each product is related to the amount of each element in the original compound to give the empirical formula.

Combustion Analysis



Check and See

- When 1.125g of a liquid hydrocarbon, C_xH_y, was burned in the apparatus in the previous slide, 3.447g of CO_2 and 1.647g of H_2O were produced. What is the empirical formula of the hydrocarbon?
  - C_3H_7
- If the molar mass of this compound was determined to by 86.2g/mol, what is the molecular formula of this compound?
  - C_6H_{14}

Check and See

- A 0.523g sample of the unknown compound C_xH_y is burned to give 1.612g of CO_2 and 0.7425g of H_2O. A separate experiment gave a molar mass of this compound to be 114g/mol. Determine the empirical and molecular formulas for the hydrocarbon.
  - C_4H_9
  - C_8H_{18}

Summary

- Do you understand all the parts and meanings of a balanced chemical equation?
- Can you balance a chemical equation?
- Do you understand the principle of the Conservation of Matter and its implication in stoichiometry?
- Can you calculate the mass of one R or P from the mass of another R or P?
- Do you understand the concept of the LR?
- Can you determine the LR of a reaction?
- Can you determine the amount of P formed when dealing with a LR?
- Can you explain the differences between actual, theoretical and percent yield?
- Can you use stoich to analyze a mixture or to find the empirical formula of an unknown compound?