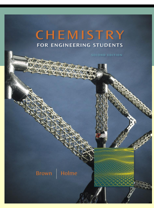

BROOKS/COLE CENGAGE Learning

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Chapter 4
Stoichiometry

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Warning!!

- These slides contains visual aids for learning BUT they are NOT the actual lecture notes!
- Failure to attend to lectures most probably result in failing the lecture!
- So I strongly recommend that you attend to the classes. Take a pen, a notebook and WRITE!

Chapter Objectives

- Describe the chemical composition of gasoline.
- Write balanced chemical equations for the combustion of fuels.
- Calculate the amount of product expected from a chemical reaction, given the amounts of reactants used.
- Calculate the amounts of reactants needed in a chemical reaction to produce a specified amount of product.

Chapter Objectives

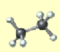
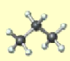
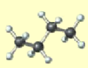
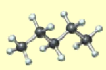
- Identify a limiting reagent and calculate the amount of product formed from a nonstoichiometric mixture of reactants.
- Calculate the percentage yield of a chemical reaction.
- Identify at least two common additives in gasoline and explain why they are used.

Gasoline and Other Fuels

- Gasoline is a very complex mixture of compounds, but contains predominantly alkanes.
  - Alkanes are hydrocarbons where the carbon atoms are linked together with single bonds.
  - Hydrocarbons are compounds composed only of hydrogen and carbon.

Alkanes

Table 4.1
The first five alkanes

Compound	Formula	Structure
Methane	CH_4	
Ethane	C_2H_6	
Propane	C_3H_8	
Butane	C_4H_{10}	
Pentane	C_5H_{12}	

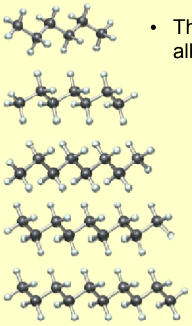
- Alkanes have the general formula C_nH_{2n+2} where n is an integer.
- The five smallest straight chain alkanes.

Alkanes

Table 4.1

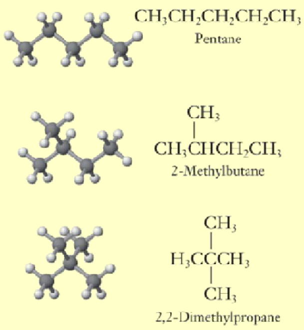
The first ten alkanes

Compound	Formula
Hexane	C_6H_{14}
Heptane	C_7H_{16}
Octane	C_8H_{18}
Nonane	C_9H_{20}
Decane	$C_{10}H_{22}$



- The next five straight chain alkanes

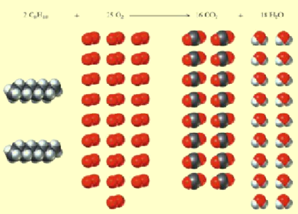
Isomers



Structural isomers of pentane, C_5H_{12}

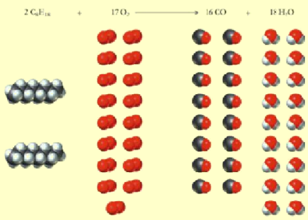
- Isomers are compounds that have the same chemical formula but are connected differently.
  - Three isomers of pentane, C_5H_{12}.
    - One straight chain
    - Two branched chains

Octane: Complete Combustion



- Octane is used as a simplified model for gasoline.
  - Complete combustion of octane with excess oxygen produces carbon dioxide and water.
- The stoichiometric ratio between octane and oxygen is 2:25.
- The stoichiometric ratio between carbon dioxide and water is 16:18.

Octane: Incomplete Combustion



- Incomplete combustion occurs when the amount of oxygen is limited.
  - The products are carbon monoxide and water.
- The stoichiometric ratio between octane and oxygen is 2:17.
- The stoichiometric ratio between carbon monoxide and water is 16:18.

Octane: Combustion

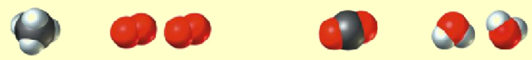
- Complete and incomplete combustion both occur with the relative amounts of each determined by:
  - Ratio of fuel to oxygen
  - Engine temperature
  - Engine tuning
- Engineers help control these factors to maximize fuel efficiency.

Fundamentals of Stoichiometry

- Stoichiometry is a term used to describe quantitative relationships in chemistry.
  - "How much?" of a product is produced or reactant is consumed.
  - Balanced chemical equation needed.
  - Conversion between mass or volume to number of moles frequently needed.

Ratios from a Balanced Chemical Equation

$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(\ell)$$



- Mole ratios are obtained from the coefficients in the balanced chemical reaction.
  - 1 mol CH_4 : 2 mol O_2 : 1 mol CO_2 : 2 mol H_2O
- These ratios can be used in solving problems:

$$\frac{1 \text{ mol } CH_4}{2 \text{ mol } O_2} \text{ or } \frac{2 \text{ mol } H_2O}{1 \text{ mol } CH_4}$$

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Example Problem 4.1

- In the combustion of methane, how many moles of O_2 are required if 6.75 mol of CH_4 is to be completely consumed?

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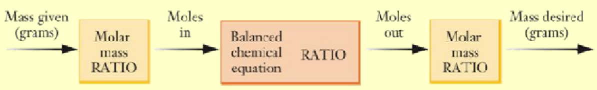
Ratios from a Balanced Chemical Equation

- This flow diagram illustrates the various steps involved in solving a typical reaction stoichiometry problem.
  - No different than unit conversion
  - Usually more than one conversion is necessary
  - Write all quantities with their complete units



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Example Problem 4.2

- How many grams of water can be produced if sufficient hydrogen reacts with 26.0 g of oxygen?

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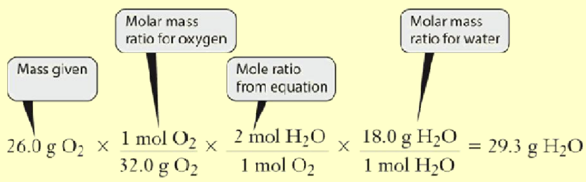
Ratios from a Balanced Chemical Equation



- Solution to Problem 4.2 using the stoichiometry problem flow diagram, Figure 4.3.

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Example Problem 4.3

- If we have 153 g of S_8 and an excess of phosphorus, what mass of P_4S_3 can be produced in the reaction shown?

$$8P_4 + 3S_8 \rightarrow 8P_4S_3$$

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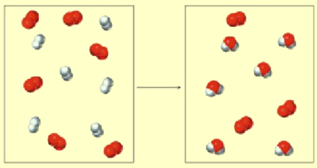
Limiting Reactants

- In many chemical reactions, one reactant is often exhausted before the other reactants. This reactant is the limiting reactant.
  - Limiting reactant is determined using stoichiometry.
  - The limiting reactant limits the quantity of product produced.

Limiting Reactants

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$$



- Reaction between 6 H_2 and 6 O_2 will produce 6 H_2O.
  - 6 H_2 can produce 6 H_2O.
  - 6 O_2 can produce 12 H_2O.
  - H_2 is limiting reactant.
  - 3 O_2 left over.

Limiting Reactants

- In many cases, we manipulate the amounts of reactants to ensure that one specific compound is the limiting reactant.
  - For example, a more expensive or scarce reagent is usually chosen to be the limiting reagent.
- Other times, it is best to have a stoichiometric mixture (equal ratio of moles) to prevent waste.
  - For example, rocket fuel is designed so that no mass is left over, which would add unnecessary weight to the rocket.

Example Problem 4.4

- A solution of hydrochloric acid contains 5.22 g of HCl. When it is allowed to react with 3.25 g of solid K_2CO_3, the products are KCl, CO_2, and H_2O. Which reactant is in excess?

Example Problem 4.5

- If 28.2 g of P_4 is allowed to react with 18.3 g of S_8, which is the limiting reactant?

$$8P_4 + 3S_8 \rightarrow 8P_4S_3$$

Example Problem 4.6

- If 45.0 kg of methanol is allowed to react with 70.0 kg of isobutene, what is the maximum mass (theoretical yield) of MTBE that can be obtained?

$$\underset{\text{Methanol}}{CH_3OH} + \underset{\text{Isobutene}}{(CH_3)_2C{=}CH_2} \rightarrow \underset{\text{MTBE}}{(CH_3)_3COCH_3}$$

Example Problem 4.7

- The solid fuel rockets of the space shuttle are based on the following reaction between ammonium perchlorate and aluminum:

$$3NH_4ClO_4(s) + 3Al(s) \rightarrow Al_2O_3(s) + AlCl_3(g) + 3NO(g) + 6H_2O(g)$$

- If either reactant is in excess, unnecessary mass will be added to the shuttle, so a stoichiometric mixture is desired. What mass of each reactant should be used for every kilogram of the fuel mixture?

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Theoretical Yield

- The maximum mass of a product that can be obtained in a reaction is determined by the limiting reactant.
  - Determine which reactant is the limiting reactant.
  - Calculate the mass of product that can be made from the limiting reactant. This mass is the theoretical yield.
  - In stoichiometric mixtures, however, both reactants are consumed completely, so either could be considered the limiting reactant.

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Theoretical and Percent Yields

- Many factors determine the amount of desired product actually produced in a reaction.
  - Temperature of the reaction
  - The possibility of side reactions
  - Further reaction of the product
  - Time

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Theoretical and Percentage Yields

$$\text{Percentage Yield} = \left(\frac{\text{actual yield}}{\text{theoretical yield}}\right) \times 100\%$$

- Reaction efficiency is measured with percentage yield.
  - The mass of product obtained is the actual yield.
  - The ideal mass of product obtained from calculation is the theoretical yield.

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Example Problem 4.8

- In a laboratory experiment, a student heats 42.0 g of $NaHCO_3$ and determines that 22.3 g of Na_2CO_3 is formed. What is the percentage yield of this reaction?

$$2NaHCO_3(s) \xrightarrow{\text{heat}} Na_2CO_3(s) + CO_2(g) + H_2O(g)$$

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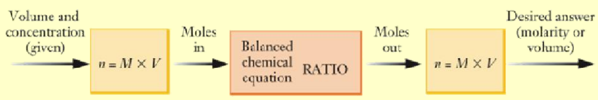
Solution Stoichiometry



- For reactions occurring in solution, the concentration and volume of reactants and products are often used instead of mass to solve solution stoichiometry problems.
  - n = number of moles; M = mol/L; V = L

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Example Problem 4.9

- If 750.0 mL of 0.806 M NaClO is mixed with excess ammonia, how many moles of hydrazine can be formed?

$$NaClO(aq) + 2NH_3(aq) \rightarrow N_2H_4(aq) + NaCl(aq) + H_2O(l)$$

- If the final volume of the resulting solution is 1.25 L, what will be the molarity of hydrazine?

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Solution Stoichiometry

- A titration is a common laboratory technique that uses solution stoichiometry.
  - A solution-phase reaction is carried out under controlled conditions so that the amount of one reactant can be determined with high precision.
  - An indicator is a dye added to a titration to indicate when the reaction is complete.

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Solution Stoichiometry

1. A solution of one of the reactants (A) is added to a burette.
2. The burette is positioned above a flask containing the second reactant (B).
3. The burette is used to add A to the flask in a controlled manner; volume is determined from initial and final burette readings.
4. The reaction is complete when the indicator changes color.

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Example Problem 4.10

- If 24.75 mL of 0.503 M NaOH solution is used to titrate a 15.00 mL sample of sulfuric acid, H_2SO_4, what is the concentration of the acid?

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Alternative Fuels and Fuel Additives

- Fuel additives are added to gasoline to improve engine performance, reduce undesirable engine emissions, and reduce dependence on imported petroleum products.
  - Some additives, oxygenates , increase the oxygen content of gasoline and gasoline containing them is called an oxygenated fuel.
    - Ensure more complete combustion by reducing emitted carbon monoxide, hydrocarbons, and soot.
  - Gasoline containing at least 2% oxygen by weight is call reformulated gasoline (RFG), which is mandatory in some areas with severe pollution.

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Alternative Fuels and Fuel Additives

- Additives improve engine performance by improving the octane rating.
  - Higher octane rating delivers better performance and has lower “knocking”.
  - Knock is the result of premature cylinder ignition when gasoline-air mixture is compressed.

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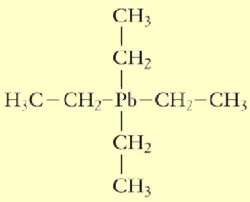
Alternative Fuels and Fuel Additives



Tetraethyl lead

- Tetraethyl lead, used until the 1970s, increased octane rating.
  - Poisoned the surfaces of catalytic converters.
  - Discontinued due to the toxicity of lead.

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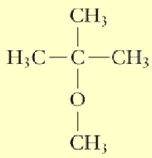
Alternative Fuels and Fuel Additives



MTBE

- MTBE, methyl tert-butyl ether, is an oxygenate.
  - As much as 15% MTBE can be used in gasoline.
  - Possible health concerns have led to it being banned in some areas.

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Alternative Fuels and Fuel Additives

- Ethanol is another oxygenate.
  - Produced from crops such as corn, barley, and wheat.
  - Gasoline containing 10% ethanol can be burned in modern automobiles.
  - Gasoline containing 85% ethanol can be burned in specially designed engines. At this concentration, it is considered an alternative fuel rather than an oxygenate.

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