

limiting reagent the reactant that is completely consumed in a chemical reaction; the reactant that determines how much product will be formed

excess reagent a reactant that is still present after the reaction is complete

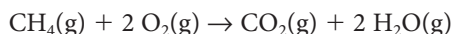


Figure 1 When you light a Bunsen burner, you start with an orange flame then adjust the air intake to get a hot, blue flame.

In Section 7.2, you saw that when exactly stoichiometric amounts of reactants are combined, all the reactants are used up. This produces the maximum possible amount of product. However, in practice this rarely occurs. Carefully measuring stoichiometric amounts of each reactant is tedious and often impractical. Usually, one of the reactants is used up first. The reactant that is completely used up is called the **limiting reagent**. When this reactant runs out, the reaction stops. Some of the other reactants are left over. The **excess reagent** is the substance that is present in a larger quantity than is required. Some of the excess reagent is left over after the reaction. There can only be one limiting reagent in a reaction but there could be more than one excess reagent.

Limiting and Excess Reagents

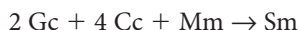
Lighting a Bunsen burner is a familiar activity in which limiting and excess reagents are involved. When you light a Bunsen burner, you adjust the barrel to limit the rate at which oxygen reaches the fuel. This is because an air/fuel mixture that is rich in fuel is easier to ignite than a “lean” mixture. However, once the burner is lit and you are ready to use it, you have to make another adjustment: you open the barrel to allow more air to enter the burner. Most of the natural gas burned in a Bunsen burner is methane, CH_4 . The chemical equation for the complete combustion of methane is



The clean blue flame of a Bunsen burner is evidence of complete combustion (**Figure 1**). This occurs only when plenty of oxygen is available. Under these conditions, methane is the limiting reagent while oxygen is the excess reagent.

An Analogy for Limiting and Excess Reagents

We can return to the s'more analogy from Section 7.1 to practise the concepts of limiting and excess reagents. If you recall, the process of making a s'more was described by the “equation”



Two crackers combine with four chocolate chips and one marshmallow to make one s'more. When exact stoichiometric amounts of the “reactants” are combined, all the reactants are used up and a whole number of s'mores is produced. However, when non-stoichiometric amounts are available, such as in **Figure 2**, some reactants are in excess. The number of s'mores that can be produced is limited by the number of marshmallows.

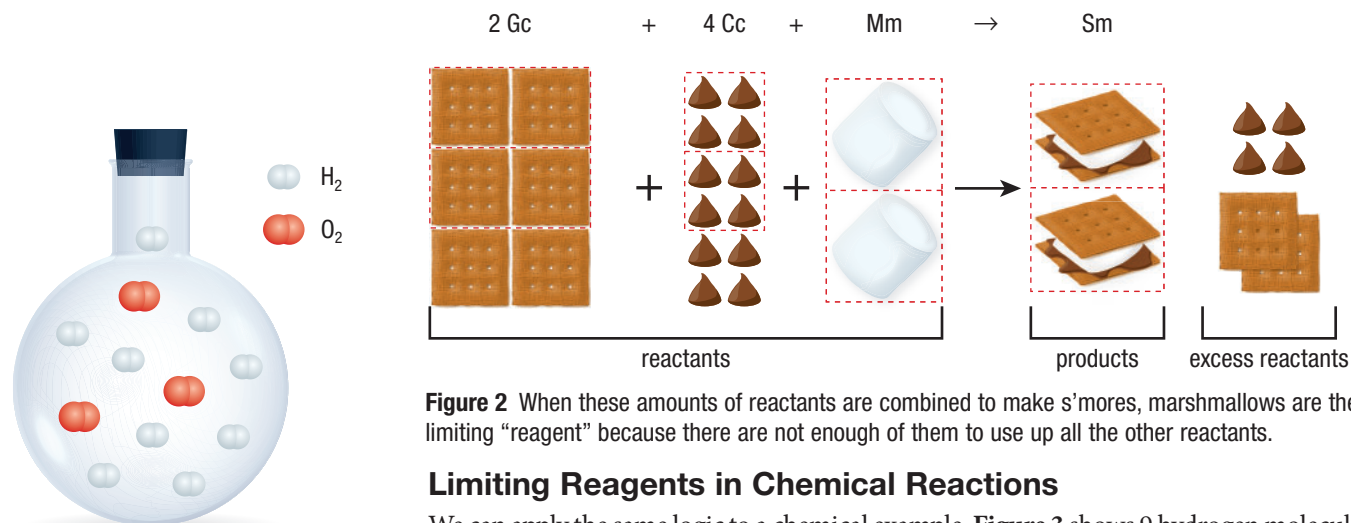


Figure 2 When these amounts of reactants are combined to make s'mores, marshmallows are the limiting “reagent” because there are not enough of them to use up all the other reactants.

Limiting Reagents in Chemical Reactions

We can apply the same logic to a chemical example. **Figure 3** shows 9 hydrogen molecules and 3 oxygen molecules in a flask. What happens when a spark ignites the mixture?

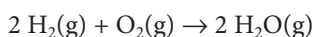


Figure 3 A flask containing 3 oxygen molecules and 9 hydrogen molecules

In **Figure 4**, the molecules are grouped together so that it is easier to see which molecules result in the formation of water molecules. Since the ratio of hydrogen to oxygen in the balanced equation is 2:1, only 6 hydrogen molecules are required to react with the 3 oxygen molecules to form 6 water molecules. As a result, 3 hydrogen molecules are left over. Oxygen, in this case, is the limiting reagent and hydrogen is in excess.

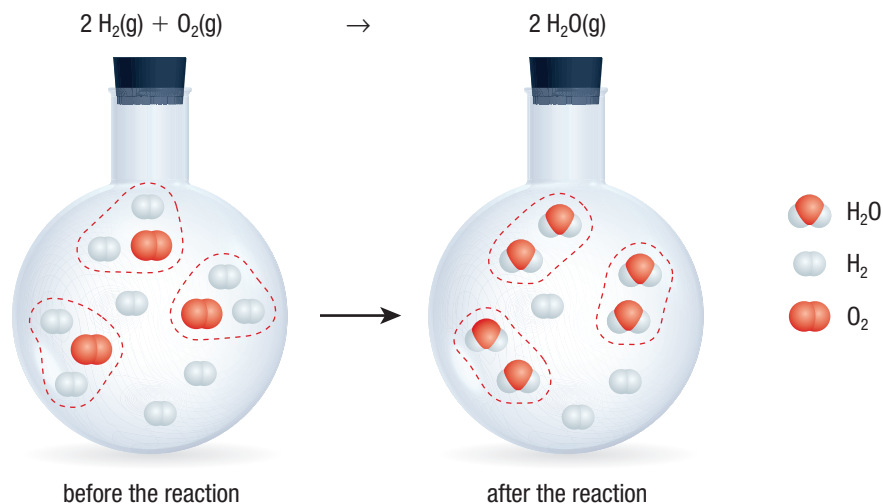


Figure 4 The synthesis of water from its elements. The limiting reagent, oxygen, is completely used up in the reaction. Some hydrogen, the excess reagent, remains after the reaction is complete.

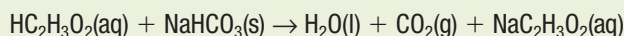
Mini Investigation

Balloon Stoichiometry

Skills: Predicting, Planning, Controlling Variables, Performing, Observing, Analyzing, Communicating

SKILLS
HANDBOOK A1, A2.4

Sodium hydrogen carbonate (baking soda) reacts with ethanoic acid (in vinegar) in a 1:1 ratio:



In this experiment, you will explore the quantitative relationships between the two reagents to see which determines the amount of carbon dioxide gas produced.

Equipment and Materials: chemical safety goggles; lab apron; 4 medium-sized balloons; permanent marker; 4 plastic 500 mL bottles; funnel; teaspoon; sodium hydrogen carbonate (baking soda); ethanoic acid solution (vinegar)

- Put on your safety goggles and lab apron.
- Stretch the balloons a few times to ensure that they are flexible. Also check that they do not have any holes or tears.
- Label the four bottles 1, 4, 7, and 10.
- Using the dry funnel, add 1 level teaspoon (tsp) of sodium hydrogen carbonate to each balloon.
- Add 1 tsp of ethanoic acid solution to the first bottle, 4 tsp to the second bottle, 7 tsp to the third bottle, and 10 tsp to the fourth bottle.
- Use your finger to wet the mouth of each balloon with tap water. This will help to maintain a good seal.
- Carefully stretch a balloon over the mouth of each bottle. Be careful not to allow the sodium hydrogen carbonate to fall into the bottle (**Figure 5(a)**).

- Raise the balloon on Bottle 1 so that its contents fall into the bottle (**Figure 5(b)**). Swirl to mix. Repeat with the other balloons. Record your observations.

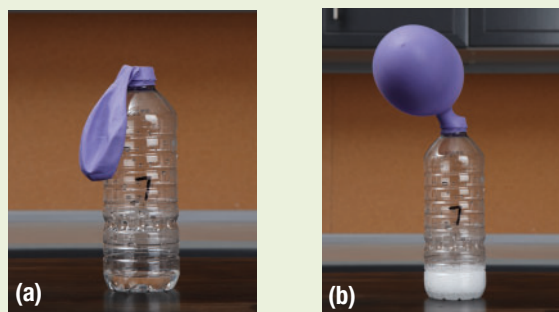


Figure 5 (a) Step 7 (b) Raising the balloon causes the baking soda to fall into the vinegar. Carbon dioxide from the resulting reaction inflates the balloon.

- Compare the sizes of the balloons after they have inflated. T/I
- If two or more of your balloons were equally large, explain why. Refer to the quantities of reactants in your explanation. T/I
- Based on your observations, predict the limiting and excess reagents in each bottle. Test your prediction by planning and conducting a chemical test on the contents of the bottles after the fizzing has stopped. Your test should involve only the materials provided in this investigation. T/I

UNIT TASK BOOKMARK

In the Unit Task (page 352) you will use a technique similar to the one used in the Mini Investigation on page 327. Look for the similarities in the two investigations as you figure out the quantity of limiting reagent in the Unit Task.

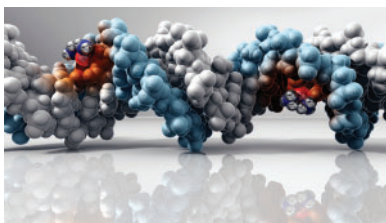


Figure 6 Cisplatin (in centre of DNA strands) is an important drug used to treat various types of cancer. Cisplatin works by binding to the DNA of the cancer cell, preventing the cell from replicating.

CAREER LINK

Pharmaceutical development engineers play a crucial role in planning how new medicines will be produced. To find out about this career,



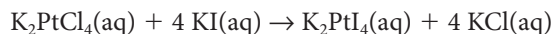
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Applications of Limiting Reagents

Why should we be concerned about limiting reagents? Companies that want to reduce both their costs and their impact on the environment pay attention to this decision. Chemical cleanup crews consider the proportions of reactants in their work. Also, anyone who burns hydrocarbons as a heat source should pay attention to the ratio of fuel to air during combustion.

REDUCING COSTS

Companies often choose the most expensive reactant to be the limiting reagent while a large excess of the least expensive reactant is available. This strategy helps ensure that none of the more expensive chemical is left over and wasted. Cisplatin, for example, is an important drug used in chemotherapy treatments for various types of cancer (**Figure 6**). The process to make cisplatin involves four chemical reactions. In the first reaction, a compound called potassium tetrachloroplatinate(II), K_2PtCl_4 , is added to a solution containing a large excess of potassium iodide:



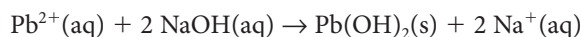
If you own platinum jewellery, you are well aware that platinum metal is expensive. Platinum compounds are even more expensive. Potassium iodide, in comparison, is cheap. Using a large excess of potassium iodide helps to ensure that all the potassium tetrachloroplatinate(II) is used up and converted into product. A large excess also increases the likelihood that all 4 chlorine atoms in the platinum compound are replaced by iodine. Once the limiting reagent is completely used up, the reaction stops. In this step of the cisplatin production process, $K_2PtCl_4(aq)$ is the limiting reagent while $KI(aq)$ is the excess reagent. 

REDUCING ENVIRONMENTAL IMPACT

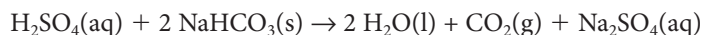
Controlling the limiting and excess reagents can make a manufacturing process greener. You already know that metal smelting is a major source of sulfur dioxide, a pollutant that reacts in the atmosphere to cause acid rain. In Chapter 5 you learned that flash smelting involves burning ore concentrate in a large excess of oxygen. The oxygen reacts with sulfur, forming sulfur dioxide. Because there is an excess of oxygen, sulfur is the limiting reagent. All of the sulfur is converted to sulfur dioxide. It is economically feasible to collect the sulfur dioxide gas and convert it into useful products such as sulfuric acid.

ENVIRONMENTAL CLEANUP

Strategies used to clean up or neutralize pollutants in the environment can involve limiting and excess reagents. Consider, for example, the treatment of water contaminated with dissolved toxic metal ions from a mining operation. One way to remove the metal ions is to precipitate them as metal hydroxides. This can be done by adding a large excess of a base such as sodium hydroxide. The metal hydroxide precipitates are then filtered out of the solution. In the following example, toxic lead ions are the limiting reagent while the added hydroxide is the excess reagent:



Spills of concentrated acids or bases can be neutralized by adding a slight excess of sodium hydrogen carbonate (baking soda). Using an excess of baking soda ensures that the spilled compound is completely consumed in the neutralization reaction. The following equation shows the neutralization of sulfuric acid:



A more basic substance such as sodium hydroxide could also be used to neutralize an acid spill. However, a stoichiometric amount of base must be used. The use of too much base would make the resulting mixture basic and therefore corrosive. This could affect the environment just as badly as the original spill.

IMPROVING FUEL EFFICIENCY

We usually want the most possible energy from our home furnaces, car engines, and Bunsen burners. Complete combustion releases more energy, per mole of fuel, than does incomplete combustion. We therefore want our fuels to undergo complete combustion, rather than the less efficient incomplete combustion. To ensure complete combustion, we have to be sure that enough oxygen (usually in air) is supplied. Oxygen must be present in excess for complete combustion to occur.

Complete Combustion of Different Fuels


Different fuels react in different stoichiometric ratios. For example, some barbecues burn methane (natural gas) while others burn propane. Which requires more oxygen for each mole of fuel? **Table 1** shows the equations for the complete combustion of three common fuels. Note that the amount of oxygen required per mole of fuel increases as the size of the hydrocarbon molecule increases. The combustion of a mole of propane requires more than twice the amount of oxygen required for the combustion of a mole of methane. 

Table 1 Fuel Combustion Comparison

Fuel	Chemical equation for complete combustion
methane	$\text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g})$
propane	$\text{C}_3\text{H}_8(\text{g}) + 5 \text{O}_2(\text{g}) \rightarrow 3 \text{CO}_2(\text{g}) + 4 \text{H}_2\text{O}(\text{g})$
heptane (in gasoline)	$\text{C}_7\text{H}_{16}(\text{l}) + 11 \text{O}_2(\text{g}) \rightarrow 7 \text{CO}_2(\text{g}) + 8 \text{H}_2\text{O}(\text{g})$

Suppose you had a Bunsen burner designed for complete combustion of methane. What do you think would happen if the same burner were attached to a propane tank without adjusting its air/fuel ratio? The burner would likely produce a dirty orange flame, because there is insufficient oxygen for the complete combustion of propane. The reaction would change to incomplete combustion. This is one reason why devices that burn fuels, such as barbecues and vehicles, are designed for a specific fuel. As a result, a natural gas barbecue, for example, cannot be used to burn propane.

7.3 Summary

- The limiting reagent is the reactant that runs out in a chemical reaction.
- The amount of product in a chemical reaction is determined by the amount of limiting reagent.
- Excess reagents are reactants that remain after the reaction is complete.
- Controlling the limiting and excess reagents in a chemical reaction has important consumer, health, and environmental applications.

WEB LINK

Fuel efficiency researchers have to consider the ratios of various fuels to oxygen. Their aim is to obtain the maximum desired product (usually energy) from the combustion reaction. To learn more about this career,



GO TO NELSON SCIENCE

UNIT TASK BOOKMARK

You will use the concept of limiting and excess reagents as you perform the Unit Task on page 352.

7.3 Questions

- Use an analogy of making sandwiches to illustrate the difference between limiting and excess reagents. Devise your own list of ingredients and ratios. K/U A
- Figure 7** shows a flask containing nitrogen and hydrogen. When the temperature of the flask is raised, these elements combine to form ammonia:

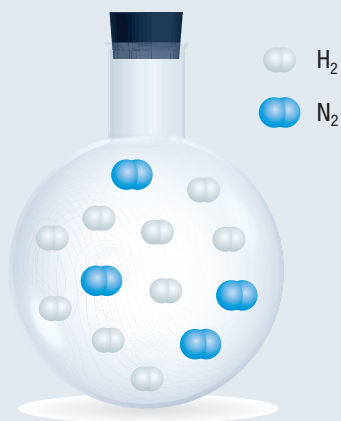


Figure 7 Nitrogen and hydrogen molecules about to react to form ammonia, NH_3

- Identify the limiting and excess reagents in the flask.
 - What is the maximum number of ammonia molecules that can be made?
 - How many molecules of excess reagent remain?
- Figure 8** shows the results of an experiment in which different masses of magnesium were combined with identical volumes of hydrochloric acid. Hydrogen gas, produced by the reaction, inflated the balloons in each trial of the experiment. K/U T/I C

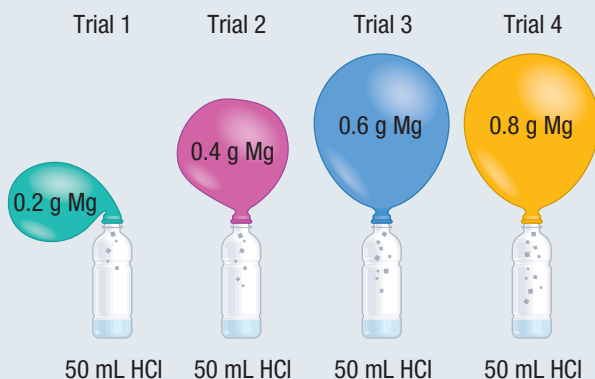
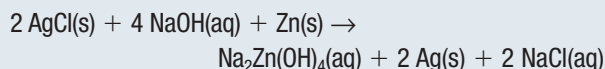


Figure 8 The four bottles contain the same quantities of hydrochloric acid but different quantities of magnesium metal.

- Write a chemical equation for the reaction.
- Classify the reaction.
- Identify the limiting and excess reagents for each trial of the experiment. Explain your answers.

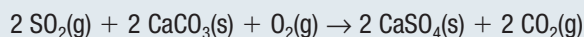
- Use the concepts of limiting and excess reagents to explain the following observations: K/U A
 - The best way to extinguish a grease fire in a pot is to cover it with the lid.
 - A sodium sulfide solution precipitates all the iron ions from a sample of contaminated groundwater.

- Silver is expensive. One way to recover silver from waste silver chloride produced in an investigation is to react it with zinc metal in a basic solution:



Choose the limiting and excess reagents in this process so that all of the silver is extracted from the silver chloride. Justify your choices. K/U T/I

- Sulfur dioxide can be scrubbed from smokestack emissions with the following reaction:



Based on this chemical equation, which reagent(s) should be the excess reagent(s) so that the most sulfur dioxide is scrubbed from the emissions? K/U T/I A

- Gold can be extracted from ore containing gold(III) sulfide by passing hydrogen gas through the ore:

$$\text{Au}_2\text{S}_3(\text{s}) + 3 \text{H}_2(\text{g}) \rightarrow 3 \text{H}_2\text{S}(\text{g}) + 2 \text{Au}(\text{s})$$
 - Identify the limiting and excess reagents if 5 mol gold(III) sulfide is combined with 13 mol hydrogen.
 - Based on the chemical equation, which reagent should be the limiting reagent in order for this process to be most profitable? Justify your choice. K/U T/I A
- A complex system of sensors and computer equipment helps modern automobiles to burn fuel as efficiently as possible. Research the role played by an automobile's oxygen sensor in maintaining engine efficiency. Summarize your findings as a brief web article for new car owners. T/I C A
- A medical treatment called chelation is used to remove toxic dissolved metals, such as lead, from the body. Research the role of a chemical called EDTA in chelation therapy. T/I A
- Both diesel and gasoline are common fuels for road vehicles. Which is better for the environment? Research this complex question to identify some of the factors that a motorist should bear in mind when trying to make a "green" decision. T/I A

