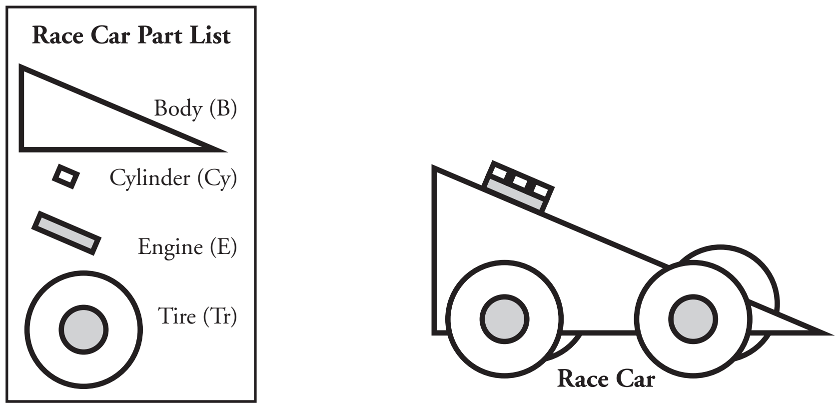
Limiting and Excess Reactants

Is there enough of each chemical reactant to make a desired amount of product?

Why?

If a factory runs out of tires while manufacturing cars, production stops. No more cars can be fully built without ordering more tires. A similar thing happens in a chemical reaction. If there are fixed amounts of reactants to work with in a chemical reaction, one of the reactants may be used up first. This prevents the production of more products. In this activity, you will look at several situations where the process or reaction is stopped because one of the required components has been used up.

Model 1 – Assembling a Race Car



1. How many of each part are needed to construct 1 complete race car?

Body (B)	Cylinder (Cy)	Engine (E)	Tire (Tr)
1	*3*	*1*	*4*

2. How many of each part would be needed to construct 3 complete race cars? Show your work.

Body (B)	Cylinder (Cy)	Engine (E)	Tire (Tr)
$3 \text{ cars}\left(\frac{1 \text{ B}}{1 \text{ car}}\right) = 3 \text{ B}$	$3 \text{ cars}\left(\frac{3 \text{ Cy}}{1 \text{ car}}\right) = 9 \text{ Cy}$	$3 \text{ cars}\left(\frac{1 \text{ E}}{1 \text{ car}}\right) = 3 \text{ E}$	$3 \text{ cars}\left(\frac{4 \text{ Tr}}{1 \text{ car}}\right) = 12 \text{ Tr}$

3. Assuming that you have 15 cylinders and an unlimited supply of the remaining parts:

   a. How many complete race cars can you make? Show your work.

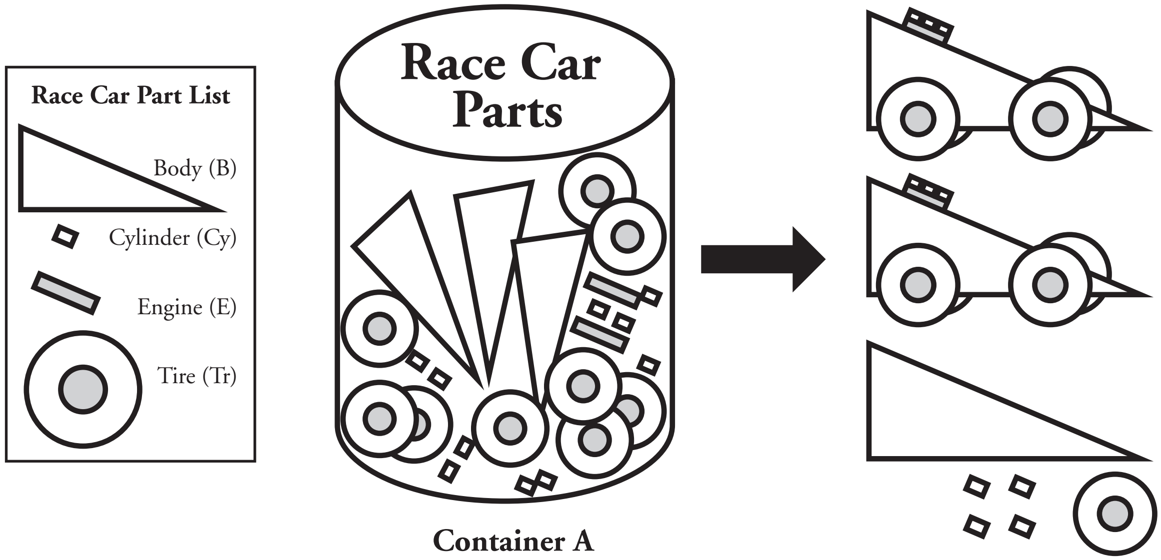
   $$15 \text{ Cy}\left(\frac{1 \text{ car}}{3 \text{ Cy}}\right) = 5 \text{ cars}$$

   b. How many of each remaining part would be needed to make this number of cars? Show your work.

   $$5 \text{ cars}\left(\frac{1 \text{ B}}{1 \text{ car}}\right) = 5 \text{ B} \qquad 5 \text{ cars}\left(\frac{1 \text{ E}}{1 \text{ car}}\right) = 5 \text{ E} \qquad 5 \text{ cars}\left(\frac{4 \text{ Tr}}{1 \text{ car}}\right) = 20 \text{ Tr}$$

STOP

Model 2 – Manufacturing Race Cars



4. Count the number of each Race Car Part present in Container A of Model 2.

Body (B)	Cylinder (Cy)	Engine (E)	Tire (Tr)
3	*10*	*2*	*9*

5. Complete Model 2 by drawing the maximum number of cars that can be made from the parts in Container A. Show any excess parts remaining also.

   There will be two cars, plus one extra body, four extra cylinders, and one extra tire.

6. A student says "I can see that we have three car bodies in Container A, so we should be able to build three complete race cars." Explain why this student is incorrect in this case.

   Not all the body parts can be used because there are only two engines. The engines run out before the third car can be built.

7. Suppose you have a very large number (dozens or hundreds) of tires and bodies, but you only have 5 engines and 12 cylinders.

   a. How many complete cars can you build? Show your work.

   $12\ Cy\left(\frac{1\ car}{3\ Cy}\right) = 4\ cars$ $\qquad$ $5\ E\left(\frac{1\ car}{1\ E}\right) = 5\ cars$

   You can only build four cars.

   b. Which part (engines or cylinders) limits the number of cars that you can make?

   Cylinders limit the number of cars you can make.

8. Fill in the table below with the maximum number of complete race cars that can be built from each container of parts (A–E), and indicate which part limits the number of cars that can be built. Divide the work evenly among group members. Space is provided below the table for each group member to show their work. Have each group member describe to the group how they determined the maximum number of complete cars for their container. Container A from Model 2 is already completed as an example.

   1 B + 3 Cy + 4 Tr + 1 E = 1 car

Container	Bodies	Cylinders	Tires	Engines	Max. Number of Completed Cars	Limiting Part
A	3	10	9	2	2	Engines
B	50	12	50	5	*4*	*Cylinders*
C	16	16	16	16	*4*	*Tires*
D	4	9	16	6	*3*	*Cylinders*
E	20	36	40	24	*10*	*Tires*

9. The Zippy Race Car Company builds toy race cars by the thousands. They do not count individual car parts. Instead they measure their parts in "oodles" (a large number of things).

   a. Assuming the inventory in their warehouse below, how many race cars could the Zippy Race Car Company build? Show your work.

Body (B)	Cylinder (Cy)	Engine (E)	Tire (Tr)
4 oodles	5 oodles	8 oodles	8 oodles
4 oodles B $\left(\frac{1\ car}{1\ B}\right)$	*5 oodles Cy* $\left(\frac{1\ car}{3\ Cy}\right)$	*8 oodles Tr* $\left(\frac{1\ car}{4\ Tr}\right)$	*8 oodles E* $\left(\frac{1\ car}{1\ E}\right)$
= *4 oddles cars*	= *1.6 oddles cars*	= *2 oddles cars*	= *8 oddles cars*

   They can make 1.6 oodles of cars.

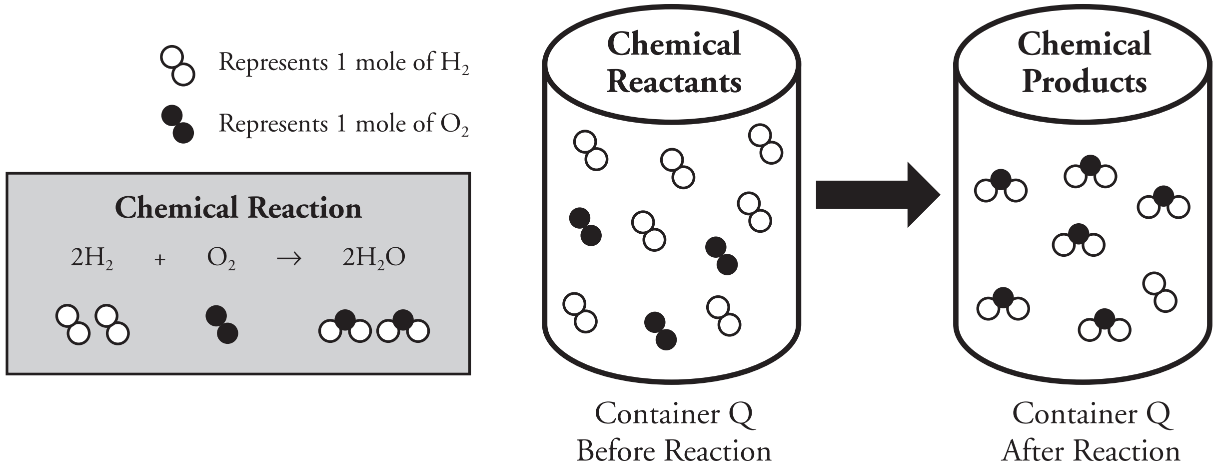
   b. Explain why it is not necessary to know the number of parts in an "oodle" to solve the problem in part *a*.

   All calculations are ratios, so the actual number in an "oodle" doesn't matter.

10. Look back at the answers to Questions 8 and 9. Is the component with the smallest number of parts always the one that limits production? Explain your group's reasoning.

   No—if several parts of one component are needed per car, it could be a component that is present in a larger amount that is limiting.

Model 3 – Assembling Water Molecules



11. Refer to the chemical reaction in Model 3.

    a. How many moles of water molecules are produced if one mole of oxygen molecules completely reacts?

    2 moles

    b. How many moles of hydrogen molecules are needed to react with one mole of oxygen molecules?

    2 moles

12. Complete Model 3 by drawing the maximum moles of water molecules that could be produced from the reactants shown, and draw any remaining moles of reactants in the container after reaction as well.

    a. Which reactant (oxygen or hydrogen) limited the production of water in Container Q?

    Oxygen.

    b. Which reactant (oxygen or hydrogen) was present in excess and remained after the production of water was complete?

    Hydrogen.

13. Fill in the table below with the maximum moles of water that can be produced in each container (Q–U). Indicate which reactant limits the quantity of water produced—this is the **limiting reactant**. Also show how much of the other reactant—the **reactant in excess**—will be left over. Divide the work evenly among group members. Space is provided below the table for each group member to show their work. Have each group member describe to the group how they determined the maximum number of moles of water produced and the moles of reactant in excess. Container Q from Model 3 is already completed as an example.

$2H_2 + O_2 \rightarrow 2H_2O$

Container	Moles of Hydrogen	Moles of Oxygen	Max. Moles of Water Produced	Limiting Reactant	Reactant in Excess
Q	7	3	6	O_2	1 mole H_2
R	8	3	*6*	*O_2*	*2 moles H_2*
S	10	5	*10*	*None*	*None*
T	5	5	*5*	*H_2*	*2.5 moles O_2*
U	8	6	*8*	*H_2*	*2 moles O_2*

14. Look back at Questions 12 and 13. Is the reactant with the smaller number of moles always the limiting reactant? Explain your group's reasoning.

No. If a reaction requires several moles of a reactant, that reactant could still limit the reaction even though there may be a larger initial supply of it.

15. Below are two examples of mathematical calculations that could be performed to find the limiting reactant for Container U in Question 13.

$8 \text{ mol } H_2 \left(\frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2}\right) = 8 \text{ mol } H_2O$ $6 \text{ mol } O_2 \left(\frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2}\right) = 12 \text{ mol } H_2O$ Hydrogen makes the lesser amount of product, so it is the limiting reactant.	$8 \text{ mol } H_2 \left(\frac{1 \text{ mol } O_2}{2 \text{ mol } H_2}\right) = 4 \text{ mol } O_2$ needed There are 6 moles of O_2 present, which is more than enough, so H_2 must be the limiting reactant.

a. Do both calculations give the same answer to the problem?

Yes.

b. Which method was used most by your group members in Question 13?

Answers will vary.

c. Which method seems "easier," and why?

Answers will vary.

d. Did your group use any other method(s) of solving this problem that were scientifically and mathematically correct? If so, explain the method.

Answers will vary.

One common method is to divide the available moles of a reactant by the coefficient in the balanced equation, i.e., to calculate the "mole number" of times the reaction can occur before that reactant runs out. The reactant that gives the lower answer is limiting.

Extension Questions

16. Consider the synthesis of water as shown in Model 3. A container is filled with 10.0 g of H_2 and 5.0 g of O_2.

   a. Which reactant (hydrogen or oxygen) is the limiting reactant in this case? Show your work. *Hint:* Notice that you are given reactant quantities in mass units here, not moles.

   $$10.0\ g\ H_2\left(\frac{1\ mol\ H_2}{2.0\ g\ H_2}\right)\left(\frac{2\ mol\ H_2O}{2\ mol\ H_2}\right) = 5.0\ mol\ H_2O$$

   $$5.0\ g\ O_2\left(\frac{1\ mol\ O_2}{32.0\ g\ O_2}\right)\left(\frac{2\ mol\ H_2O}{1\ mol\ O_2}\right) = 0.31\ mol\ H_2O \quad \textit{Oxygen is limiting.}$$

   b. What mass of water can be produced? Show your work.

   $$0.31\ mol\ H_2O\left(\frac{18.0\ g\ H_2O}{1\ mol\ H_2O}\right) = 5.6\ g\ H_2O$$

   c. Which reactant is present in excess, and what mass of that reactant remains after the reaction is complete? Show your work.

   $$0.31\ mol\ g\ H_2O\left(\frac{2\ mol\ H_2}{2\ mol\ H_2O}\right)\left(\frac{2.0\ g\ H_2O}{1\ mol\ H_2O}\right) = 0.62\ g\ H_2\ used$$

   $$10.0\ g\ H_2\ initially - 0.62\ g\ H_2\ used = 9.38\ g\ H_2\ remaining$$

Teacher Resources – Limiting and Excess Reactants

Learning Objectives

1. Define the terms "limiting reactant" and "excess reactant."
2. Identify the limiting reactant and excess reactant in a given situation.
3. Calculate the moles of product formed and the moles of excess reactant remaining in a limiting reactant problem.

Prerequisite

1. Students should be able to do simple stoichiometry conversions (moles of A to moles of B).

Assessment Questions

1. Consider the following chemical reaction: $3H_2 + N_2 \rightarrow 2NH_3$. If you are given 6 molecules of H_2 and 4 molecules of N_2, what is the limiting reactant?

   a. H_2 *c.* NH_3

   b. N_2 *d.* None of the above.

2. Consider the following chemical reaction: $2KCl + 3O_2 \rightarrow 2KClO_3$. If you are given 100.0 moles of KCl and 100.0 moles of O_2, what is the limiting reactant?

   a. $KClO_3$ *c.* O_2

   b. KCl *d.* None of the above.

3. Explain what a limiting reactant is to a student who has been absent from this class for a few days.

Assessment Target Responses

1. *a.*
2. *c.*
3. *A limiting reactant is a reactant that stops the production of a product because the reactant is used up in the reaction before the other reactants. There will be no limiting reactant remaining in excess at the end of the reaction. The limiting reactant cannot be identified solely by the initial amounts of reactants given. You have to consider the mole ratio.*

Teacher Tips

- The objectives of this lesson focus on two misconceptions that students have about limiting reactants. One misconception is that if a reactant is present in a smaller quantity, it must automatically be the limiting reactant. Likewise, students think that if equal quantities of two different reactants are mixed, there must be no limiting reactant. These misconceptions are common, and it takes time for students to understand that the key to determining limiting reactants is the required mole ratio of reactants from a balanced equation. Using the race car analogy and constructing it from loose parts in a quantitative way in Model 2 helps students build this important understanding.

- As students work through both the race car models and the production of water questions, emphasize that it is important to show mathematically how they obtain their answers. Students may use proportions or dimensional analysis. This will give them something to refer back to when the problems get more complex.
- Model 2 can be adapted into a more "hands on" activity by cutting out the paper car parts. Instead of showing the students Model 2, give each group a bag full of the cut-out car parts and ask students to build as many cars as possible. They may then continue answering the questions. You may also do something similar with small LEGO® cars.

Notes