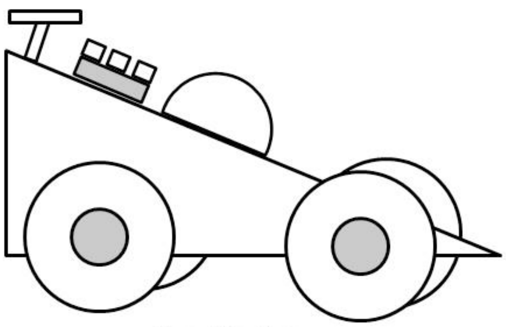
Limiting Reactants

How do you know if there will be enough of each chemical to make your desired product?

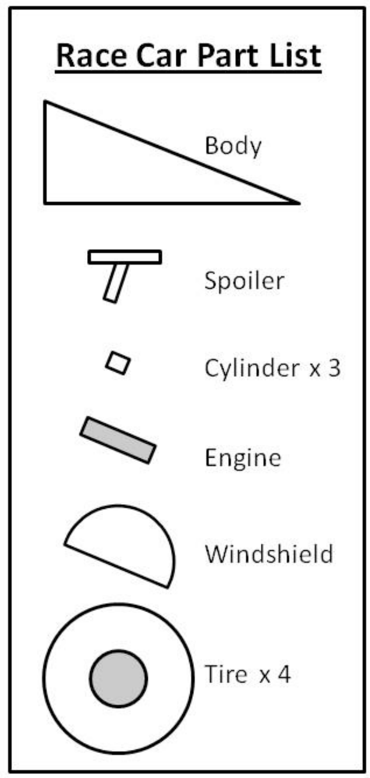
Why?

If a factory runs out of tires while manufacturing a car, all production stops. No more cars can be fully built without ordering more tires. Similar things happen in chemical reactions. When given fixed amounts of reactants to work with in a chemical reaction, one of the reactants is used up first and 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 components needed has been used up.

Model 1



Race Car Toy



1. Answer the following questions about the race car toy represented in Model 1.

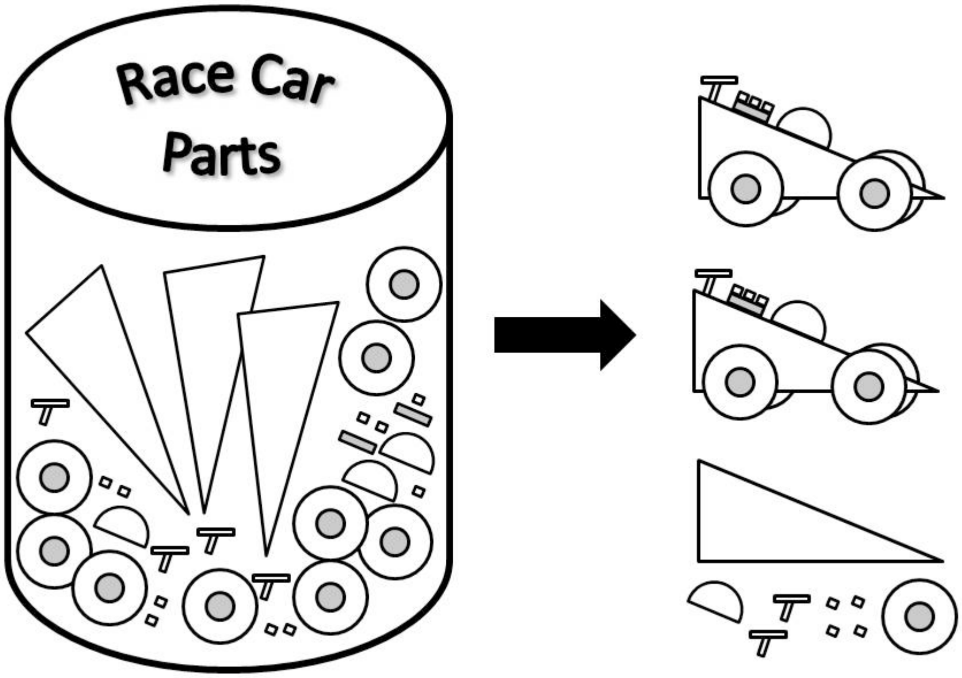
   a. How many <u>bodies</u> are needed to make one race car?

   b. How many <u>cylinders</u> are needed to make one race car?

   c. How many <u>tires</u> are needed to make one race car?

   d. How many <u>engines</u> are needed to make one race car?

Model 2



2. Remembering the race car from Model 1, answer the following questions about making race car toys in Model 2.

   a. How many bodies are in the "Race Car Parts" container?

   b. How many cylinders are in the "Race Car Parts" container?

   c. How many tires are in the "Race Car Parts" container?

   d. How many engines are in the "Race Car Parts" container?

3. According to Model 2, how many complete race cars can be made from the parts in the "Race Car Parts" container?

4. What car parts were extra or in excess when building the cars from the parts in the "Race Car Parts" container?

5. What car part(s) ran out or was used up completely when building the cars from the parts in the "Race Car Parts" container? Explain how you came to this conclusion.

6. What part(s) prevented more cars from being built from the parts in the "Race Car Parts" container? Explain how you came to this conclusion.

STOP

7. Suppose you have almost enough race car parts to build 100 cars, except that you have only 5 engines and 12 cylinders.

    a. If you start building cars, which component (engines or cylinders) would limit the number of cars that could be made? Explain how you came to this conclusion. Show any math you did.

    b. How many complete cars could you build?

    c. The number of complete cars you predicted that could be built is called the **theoretical yield**. **Theoretical yield** is defined as the maximum amount of product produced during ideal conditions in a chemical reaction. It is what we mathematically think will be produced. What is the theoretical yield of cars in this scenario?

    d. Instead of producing your theoretical yield while building cars, you actually produced less. What might have happened for you to build fewer cars than expected?

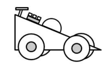
8. You are planning activities for a younger sibling's birthday party. You decide that each of the 10 partygoers will build a toy race car to take home. You have almost enough toy race car parts to build 100 cars, except you only have 10 car bodies and 46 tires.

    a. Which component is the limiting reactant? Explain how you came to this conclusion. Show any math you did.

    b. Do you relax or do you run to the toy store to buy more car pieces? Why?

9. Look back your answers in the previous two questions with your group. Is the component with the smallest number of pieces always the one that limits production? Explain your group's reasoning.

Model 3

Race Car Toy Information 		
Car Part	**Mass of Part (grams)**	**Number Required to make 1 Car**
Body	4.0 g	1
Cylinder	0.1 g	3
Tire	2.0 g	4
Engine	1.5 g	1

10. Consider the new information in Model 3 about the toy race car presented originally in Model 1.

    a. What is the mass of one tire?

    b. What is the mass of one cylinder?

11. Suppose that you have 100.0 g of tires and 100.0 g of cylinders.

    a. How many tires do you have in 100.0 g? (Fractions or broken pieces, if present, should not be counted.) Explain how you came to this conclusion. Show any math you did.

    b. How many cylinders do you have in 100.0 g? (Fractions or broken pieces, if present, should not be counted.) Explain how you came to this conclusion. Show any math you did.

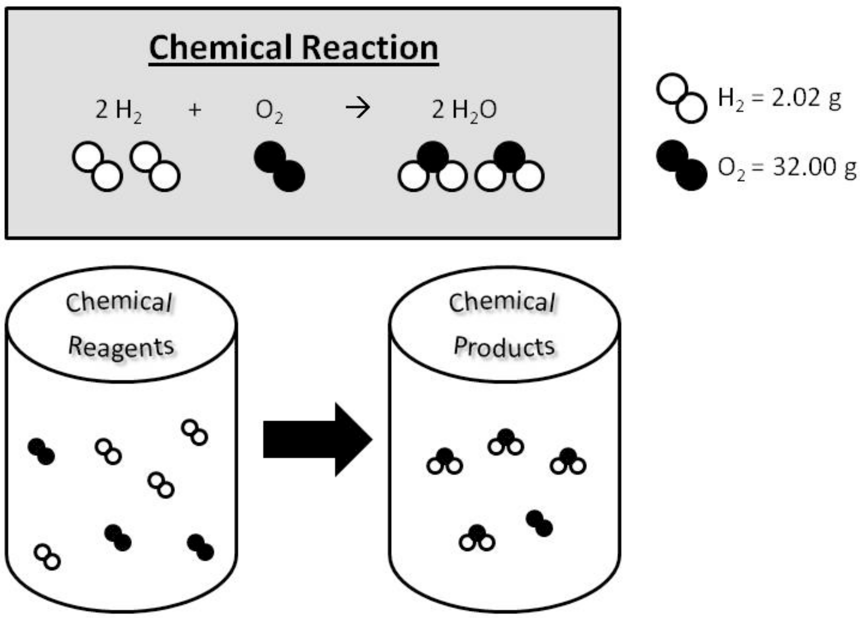
    c. You were given the same mass of tires and cylinders. Why do you have a different number of parts between the two?

    d. How many cars could you build, assuming that you have more than enough of all the other required car components? Explain how you came to this conclusion. Show any math you did.

    e. Which component (tires or cylinders) will limit the production of cars in this situation?

12. Look back at the previous question. Does having equal masses of components mean that every piece will be used up at the exact same time? Explain why or why not. Share your thoughts with your group and record the group consensus below.

Model 4



13. Consider the chemical reaction in Model 4 in which 2 moles of hydrogen gas (H_2) react with 1 mole of oxygen gas (O_2) to produce 2 moles of water vapor (H_2O).

   a. How many hydrogen (H_2) molecules are in the chemical reagent container?

   b. How many oxygen (O_2) molecules are in the chemical reagent container?

   c. How many water (H_2O) molecules are produced from the molecules found in the chemical reagent container?

   d. Every one mole of oxygen produces how many moles of water? What is the ratio of oxygen to water?

   e. Every two moles of hydrogen produces how many moles of water? What is the ratio of hydrogen to water?

14. When looking at the two containers in Model 4, which substance (O_2 or H_2) limits the production of water? How did you determine this?

15. a) The title of this activity is "Limiting Reactant". Take a minute to individually propose a definition of Limiting Reactant.

b) Share your definitions in the group, and reach a consensus for your definition.

16. You react 100.0 g of O_2 and 50.0 g of H_2 in a container and produce water. Use the reaction given in Model 4 to answer the following questions.

a. How many moles of oxygen are in 100.0 g? Explain how you determined your answer.

b. How many moles of water could be made from 100.0 g of oxygen and excess hydrogen?

c. How many moles of hydrogen are in 50.0 g? Explain how you determined your answer.

d. How many moles of water could be made from 50.0 g of hydrogen and excess oxygen?

e. Which reactant is the limiting reactant in this scenario? Why?

f. Reacting 100.0 g of O_2 and 50.0 g of H_2 will produce how many moles of water? Explain.

g. What is the theoretical yield of water in this scenario? Report your answer in moles of water.

h. What might have happened during this chemical reaction that prevented it from producing the theoretical yield of water in lab? In other words, why might your water production be lower than expected?

Extension Questions

17. Consider the scenario in Problem 16. If a water molecule's mass is 18.02 g, what would be the mass of water produced from 100.0 g of O_2 and 50.0 g of H_2? Explain how you determined your answer.

Read This!

Percent yield represents the percent of product produced in a laboratory setting. Not all chemicals react and collide as we theoretically think they should. What we predict on paper is usually higher than what actually happens in lab. Use the following equation to determine percent yield:

$$\%\ yield = \frac{actual\ yield}{theoretical\ yield} \times 100$$

"Actual" means what was measured in lab and "theoretical" means what was predicted through mathematical analysis on paper.

18. Consider the scenario in Problem 16 and your answer to Problem 17. In Problem 17 you predicted the mass of water produced when 100.0 g of O_2 and 50.0 g of H_2 react. This is the theoretical yield. While performing this experiment in lab you only produced 104.0 g of water. Use the equation in the "Read This!" box to find your percent yield. Show all work.

19. Could a percent yield ever be higher than 100%? Explain your rationale.

Teacher Resources

Learning Objectives:

1. Students should be able to define a limiting reactant and identify it conceptually and mathematically.
2. Students should be able to understand that the reactant present initially in the lesser amount is not always the limiting reactant.
3. Students should be able to understand that when given equal amount of two reactants, a limiting reactant could still exist.

Prerequisites:

1. Students should be familiar with the periodic table and the element symbols
2. Students should know basics of chemical formulas, chemical structures, chemical reactions, mole conversions, and mole ratios.

Assessment Questions:

1. Consider the following chemical reaction: $3H_2 + N_2 \rightarrow 2\ NH_3$. If you are given 6 molecules of H_2 and 4 molecules of N_2, what is the limiting reactant?
   a) H_2
   b) N_2
   c) NH_3
   d) None of the above

2. Consider the following chemical reaction: $2KCl + 3O_2 \rightarrow 2KClO_3$. KCl = 74.5 g/mol and O_2 = 32.0 g/mol. If you are given 100.0 g of KCl and 100.0 g of O_2, what is the limiting reactant?
   a) $KClO_3$
   b) KCl
   c) O_2
   d) None of the above

3. Explain what a limiting reactant is and what it is not.

Assessment Target Responses:

1. b) N_2
2. b) KCl
3. A limiting reactant is a reactant that limits the production of a product because it is used up in the reaction before other reactants. A limiting reactant is not found in excess at the end of the reaction and cannot be identified solely by the initial amounts of reactants given.

Teacher Tips:

- The objectives of this lesson focus on two misconceptions that students have about limiting reactants (see the learning objectives above). These misconceptions result from finding easier trends to follow when completing a problem.
- If you would like to make Model 2 more hands on, you may cut out the paper car parts. Instead of showing them Model 2, give each group a bag full of the cut out car parts and ask them to build as many cars as possible. They may then continue answering the questions. You may do something similar with small LEGO® cars.
- In Model 2, the teacher may just provide the picture of the car parts only (instead of the car parts and possible cars made). The instructor can then ask the students to draw all complete and incomplete cars to make it more engaging.
- When groups share to the entire class (during the stop signs) make sure groups talk about their math process as well as their conceptual reasoning. This will help make the transition to limiting reagent book problems easier.

Target Responses

1. Answer the following questions about the race car toy represented in Model 1.

    a. How many bodies are needed to make one race car? *1 body*
    b. How many cylinders are needed to make one race car? *3 cylinders*
    c. How many tires are needed to make one race car? *4 tires*
    d. How many engines are needed to make one race car? *1 engine*

2. Remembering the race car from Model 1, answer the following questions about making race car toys in Model 2.

    a. How many bodies are in the "Race Car Parts" container? *3 bodies*
    b. How many cylinders are in the "Race Car Parts" container? *10 cylinders*
    c. How many tires are in the "Race Car Parts" container? *9 tires*
    d. How many engines are in the "Race Car Parts" container? *2 engines*

3. According to Model 2, how many complete race cars can be made from the parts in the "Race Car Parts" container? *2 complete cars*

4. What car parts were extra or in excess when building the cars from the parts in the "Race Car Parts" container? *A body, 2 spoilers, 4 cylinders, 1 windshield (and one tire is also shown)*

5. What car part(s) ran out or was used up completely when building the cars from the parts in the "Race Car Parts" container? Explain how you came to this conclusion.
    The engines were used up completely because there were only enough to build the two cars and not more.

6. What part(s) prevented more cars from being built from the parts in the "Race Car Parts" container? Explain how you came to this conclusion.
    The engine (and students may also mention the tires) prevented the completion of any more cars.

7. Suppose you have almost enough race car parts to build 100 cars, except that you have only 5 engines and 12 cylinders.

a. If you start building cars, which component (engines or cylinders) would limit the number of cars that could be made? Explain how you came to this conclusion. Show any math you did.

Cylinders would be the limiting reagent. 5 engines can make 5 cars because I only need 1 engine per car. I can make only 2 cars with 12 cylinders because I need 6 cylinders per car. I took 12/6 = 2.

b. How many complete cars could you build? *2 cars*

c. The number of complete cars you predicted that could be built is called the **theoretical yield**. **Theoretical yield** is defined as the maximum amount of product produced during ideal conditions in a chemical reaction. It is what we mathematically think will be produced. What is the theoretical yield of cars in this scenario? *2 cars*

d. Instead of producing your theoretical yield while building cars, you actually produced less. What might have happened for you to build fewer cars than expected?

(Answers will vary) Broken pieces or lost pieces.

8. You are planning activities for a younger sibling's birthday party. You decide that each of the 10 partygoers will build a toy race car to take home. You have almost enough toy race car parts to build 100 cars, except you only have 10 car bodies and 46 tires.

a. Which component is the limiting reactant? Explain how you came to this conclusion. Show any math you did. *Car bodies. 10 car bodies can make 10 cars because you need 1 body per car. 46 tires can make about 11 cars because you need 4 tires per car. 46/4 = 11.5. Since I will run out of tires before 11 cars are made, car body is the limiting reagent.*

b. Do you relax or do you run to the toy store to buy more car pieces? Why?

Relax because you have enough for 10 kids.

9. Look back your answers in the previous two questions with your group. Is the component with the smallest number of pieces always the one that limits production? Explain your group's reasoning.

No it is not. Limiting reagents not only depend on initial numbers, but amount needed to make the product or car.

10. Consider the new information in Model 3 about the toy race car presented originally in Model 1.

a. What is the mass of one tire? *2.0 g*

b. What is the mass of one cylinder? *0.1 g*

11. Suppose that you have 100.0 g of tires and 100.0 g of cylinders.

a. How many tires do you have in 100.0 g? (Fractions or broken pieces, if present, should not be counted.) Explain how you came to this conclusion. Show any math you did.

50 tires because each tire weighs 2.0 g so 100/2.0 = 50

b. How many cylinders do you have in 100.0 g? (Fractions or broken pieces, if present, should not be counted.) Explain how you came to this conclusion. Show any math you did.

1000 cylinders because each cylinder is 0.1 g so 100/0.1 = 1000

c. You were given the same mass of tires and cylinders. Why do you have a different number of parts between the two?

There are more cylinders than tires because each cylinder weighs less than a tire and therefore you need more cylinders to take up the same amount of mass as a tire.

d. How many cars could you build, assuming that you have more than enough of all the other required car components? Explain how you came to this conclusion. Show any math you did.

You can make 12 cars and will run out of tires after that point. You can make 12 complete cars with the tires because 50/4 = 12.5. You can make 333 complete cars with the cylinders because 1000/3 = 333.3.

e. Which component (tires or cylinders) will limit the production of cars in this situation?

Tires

12. Look back at the previous question. Does having equal masses of components mean that every piece will be used up at the exact same time? Explain why or why not. Share your thoughts with your group and record the group consensus below.

No because each car part has a different mass. Two parts would be used up at the same time only if they had the same initial masses, individual masses, and are used in the same ratio to produce the product.

13. Consider the chemical reaction in Model 4 in which 2 hydrogen (H_2) molecules react with 1 oxygen (O_2) molecule to produce 2 water (H_2O) molecules.

a. 4 molecules
b. 3 molecules
c. 4 molecules
d. 2 moles; 1:2
e. 2 moles; 2:2 or 1:1

14. When looking at the two containers in Model 4, which substance (O_2 or H_2) limits the production of water? How did you determine this?

Hydrogen because there was extra oxygen left in the container.

15. a) The title of this activity is "Limiting Reactant". Take a minute to individually propose a definition of Limiting Reactant. *(Answers will vary)*

The limiting reactant is the reactant that is used up completely in a reaction. When it runs out, the reaction stops.

16. You react 100.0 g of O_2 and 50.0 g of H_2 in a container and produce water. Use the reaction given in Model 4 to answer the following questions.

a. 3.125 moles of oxygen. $100.0g \div 32.00g/mol = 3.125mol$

b. *6.250 moles of water. 3.125mol × 2 H_2O/1 O_2 = 6.250 mol*
c. *24.8 moles of hydrogen. 50.0g÷2.02g/mol = 24.8mol*
d. *24.8 moles of water. 1:1 ratio.*
e. *Oxygen because it will run out when the smaller amount of water is made..*
f. *6.250 moles of water because I will run out of oxygen before the hydrogen is used up.*
g. *6.250 moles of water*
h. *(Answers will vary) The reaction was not complete. Concentration of reactant molecules became so low that they did not ever collide and react. Leaking of reactant gases out of the container. Not enough time was allowed for reaction to finish.*

Extension Questions

17. Consider the scenario in Problem 16. If a water molecule's mass is 18.02 g, what would be the mass of water produced from 100.0 g of O_2 and 50.0 g of H_2? Explain how you determined your answer.
    6.25 mol water × 18.02 g/mol = 113 g water

18. Consider the scenario in Problem 16 and your answer to Problem 17. In Problem 17 you predicted the mass of water produced when 100.0 g of O_2 and 50.0 g of H_2 react. This is the theoretical yield. While performing this experiment in lab you only produced 104.0 g of water. Use the equation in the "Read This!" box to find your percent yield. Show all work.
    104.0 g ÷ 113 g water × 100 = 92.0 %

19. Could a percent yield ever be higher than 100%? Explain your rationale.
    Yes, if there were contaminants that entered into the reaction in lab.