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): 1
   - Cylinder (Cy): 3
   - Engine (E): 1
   - Tire (Tr): 4

2. How many of each part would be needed to construct 3 complete race cars? Show work with units.
   - Body (B): $3 \cdot \frac{1 B}{1 Rc} = 3 B$
   - Cylinder (Cy): $3 \cdot \frac{3 Cy}{1 Rc} = 9 Cy$
   - Engine (E): $3 \cdot \frac{1 E}{1 Rc} = 3 E$
   - Tire (Tr): $3 \cdot \frac{4 Tr}{1 Rc} = 12 Tr$

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 work with units.
      - $2C \cdot \frac{15 Cy}{3 Cy} = 5 Rc$
   b. How many of each remaining part would be needed to make this number of cars? Show work with units.
      - Body (B): $6C \cdot \frac{1 B}{1 Rc} = 5 B$
      - Engine (E): $5 \cdot \frac{1 E}{1 Rc} = 5 E$
      - Tire (Tr): $5 \cdot \frac{4 Tr}{1 Rc} = 20 Tr$
**Model 2 – Manufacturing Race Cars**

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

<table>
<thead>
<tr>
<th>Body (B)</th>
<th>Cylinder (Cy)</th>
<th>Engine (E)</th>
<th>Tire (Tr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>2</td>
<td>9</td>
</tr>
</tbody>
</table>

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.

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.

**C P** We don’t have enough other parts to make the 3rd car, we would only have 1 of the 4 needed tires, and no more engines.

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 with units.

   $3C \text{ (work, comparing, ans)} \cdot P \cdot \frac{1 \text{ Rc}}{5 \text{ E}} = 5 \text{ Rc}$;
   
   $12 \cdot \frac{1 \text{ Rc}}{3 \text{ Cy}} = 4 \text{ Rc}$ so we can only make 4 race cars

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

   Explain how you know. **C P** There were only enough cylinders to make 4 Rc, but were enough engines to make 5 Rc.

**12C 2U 10P**
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  

<table>
<thead>
<tr>
<th>Container</th>
<th>Bodies</th>
<th>Cylinders</th>
<th>Tires</th>
<th>Engines</th>
<th>Max. # Complete Cars</th>
<th>Limiting Part</th>
<th>Unused parts After All Cars are Made</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bodies</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
<td>10</td>
<td>9</td>
<td>2</td>
<td>2</td>
<td>Engines</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>50</td>
<td>12</td>
<td>50</td>
<td>5</td>
<td>4</td>
<td>Cy</td>
<td>46</td>
</tr>
<tr>
<td>C</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>4</td>
<td>Tr</td>
<td>12</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>9</td>
<td>16</td>
<td>6</td>
<td>3</td>
<td>Cy</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
<td>20</td>
<td>36</td>
<td>40</td>
<td>24</td>
<td>10</td>
<td>Tr</td>
<td>10</td>
</tr>
</tbody>
</table>

**Table: 24C 24P**

6C (max Rc 3 pts: Work, compare, ans; Num left: 3pts work and ans [0.5 each]) 5U (max Rc: 2pts in work and work units clearly give correct ans units; Num left: 3pts units in work and ans [0.5 each])

E and B = # possible Rc (1 part: 1 Rc ratio), so we need to compare those to Num. of Rc that can be made from Cy and Tr and pick the lowest num. Rc.

\[
B: 50 B, 5 E, 12 Cy \cdot \frac{1 Rc}{3 Cy} = 4 Rc; 50 Tr \cdot \frac{1 Rc}{4 Tr} = 12 Rc
\]

\[
C: 16 B, 16 E, 16 Cy \cdot \frac{1 Rc}{3 Cy} = 5 Rc; 16 Tr \cdot \frac{1 Rc}{4 Tr} = 4 Rc
\]

\[
D: 4 B, 6 E, 9 Cy \cdot \frac{1 Rc}{3 Cy} = 3 Rc; 16 Tr \cdot \frac{1 Rc}{4 Tr} = 4 Rc
\]

\[
E: 20 B, 24 E, 36 Cy \cdot \frac{1 Rc}{3 Cy} = 12 Rc; 40 Tr \cdot \frac{1 Rc}{4 Tr} = 10 Rc
\]

Number left, need to find number needed and subtract from what we have (bodies and engines are are 1:1 with # Rc, so are just the # Rc)

\[
B: 50B - 4B = 46B; 5E - 4E = 1E; 50Tr \cdot \frac{4 Rc}{4 Tr} \cdot \frac{1 Rc}{3 Cy} = 34Tr
\]

\[
C: 16B - 4B = 12B; 16E - 4E = 12E; 16Cy \cdot \frac{1 Rc}{3 Cy} = 4Cy
\]

\[
D: 4B - 3B = 1B; 6E - 3E = 3E; 16Tr \cdot \frac{3 Rc}{4 Tr} \cdot \frac{1 Rc}{4 Tr} = 4Tr
\]

\[
E: 20B - 10B = 10B; 24E - 10E = 14E; 36Cy \cdot \frac{10 Rc}{3 Cy} \cdot \frac{1 Rc}{1 Rc} = 6Cy
\]
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), so an “oodle” is just a count, like a “dozen” or a “mole”.

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

<table>
<thead>
<tr>
<th>Body (B)</th>
<th>Cylinder (Cy)</th>
<th>Engine (E)</th>
<th>Tire (Tr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 oodles</td>
<td>5 oodles</td>
<td>8 oodles</td>
<td>8 oodles</td>
</tr>
</tbody>
</table>

8C (6pts for at least 3 sets of work/reasoning with intermediate answers, 1 pt. comparison, 1 pt. overall ans) 6U (2pt. units in at least 2 sets of work with units [one set could be conceptual], 3pts units on the intermediate ans. 1pt Units on final answer) P

I’ll abbreviate oodles as ‘o’, so oB → oodles of Bodies, etc.

\[
\begin{align*}
4 \ oB & \cdot \frac{1 \ oRc}{1 \ oB} = 4 \ oRc \\
5 \ oCy & \cdot \frac{1 \ oRc}{3 \ oCy} = \frac{5}{3} \ oRc \\
8 \ oE & \cdot \frac{1 \ oRc}{1 \ oE} = 8 \ oRc \\
8 \ oTr & \cdot \frac{1 \ oRc}{4 \ oTr} = 2 \ oRc \\
\end{align*}
\]

So max number of cars is \(1.667 \ oodles \ of \ Rc\)

b. Explain why it is not necessary to know the number of parts in an “oodle” to solve the problem in part a. C P

As long as ‘oodles’ is a defined amount, the ratio of parts would be the same because we’d be multiplying both numerator and denominator by a constant number, and in ratio form that could be reduced to the same ratio it was before multiplying.

e.g. \(\frac{3 \ Cy}{4 \ Tr}\) is a 3:4 ratio, \(\frac{3 \ oodle \ Cy}{4 \ oodle \ Tr}\) is also a 3:4 ratio

39C 11U 26P
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.

2C 2P No, since all don’t have a 1:1 ratio we can’t just compare the numbers. For example 4 bodies was the smallest number in D, but we could only make 3 race cars due to the 9 cylinders. Likewise in C, all had the same value of 16, but the limit was 4 due to the tires.

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? _______ C U P __ 2 mol H₂O _______
   b. How many moles of hydrogen molecules are needed to react with one mole of oxygen molecules? _______ C U P __ 2 mol H₂ _______

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?

C P Oxygen (all moles of O₂ became part of water molecules, but there was still 1 mol H₂ left)
   b. Which reactant (oxygen or hydrogen) was present in excess and remained after the production of water was complete?

C P Hydrogen (there was still 1 mol H₂ left)
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 (so each group member must have the work shown for at least one of the rows).** 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.

\[2H_2 + O_2 \rightarrow 2H_2O\]  

**Table: 12C 12P**

<table>
<thead>
<tr>
<th>Container</th>
<th>Moles of Hydrogen</th>
<th>Moles of Oxygen</th>
<th>Max. Moles of Water Produced</th>
<th>Limiting Reactant</th>
<th>Reactant in Excess</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>7</td>
<td>3</td>
<td>6</td>
<td>O_2</td>
<td>7 mol H_2 present – 6 mol H_2 needed = 1 mole H_2 excess</td>
</tr>
<tr>
<td>R</td>
<td>8 (≤ 8 mol H_2O)</td>
<td>3 (≤ 6 mol H_2O)</td>
<td>6</td>
<td>O_2</td>
<td>2 mol H_2</td>
</tr>
<tr>
<td>S</td>
<td>10 (≤ 10 mol H_2O)</td>
<td>5 (≤ 10 mol H_2O)</td>
<td>10</td>
<td>neither</td>
<td>neither</td>
</tr>
<tr>
<td>T</td>
<td>5 (≤ 5 mol H_2O)</td>
<td>5 (≤ 10 mol H_2O)</td>
<td>5</td>
<td>H_2</td>
<td>2.5 mol O_2</td>
</tr>
<tr>
<td>U</td>
<td>8 (≤ 8 mol H_2O)</td>
<td>6 (≤ 12 mol H_2O)</td>
<td>8</td>
<td>H_2</td>
<td>2 mol O_2</td>
</tr>
</tbody>
</table>

**5C (2pts work/reasoning and ans for max; 1pt limiting, 2pts work and ans excess); 2U (1 pt units for max; 1 pt [0.5 each] for units in work and ans for excess)**

The H_2O:H_2 ratio is \(\frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2}\) (which reduces to 1:1), so \(H_2O_{\text{max}} = H_2\), with excess O_2. The H_2O:O_2 ratio is \(\frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2}\), so \(H_2O_{\text{max}} = 2 \cdot O_2\), with excess H_2. These give the ‘≤ x mol H_2O’ results shown in the table. For excess, use moles of water to find how much reactant in excess is needed, then subtract that from the amount present.

R: \(6 \text{ mol } H_2O \cdot \frac{1 \text{ mol } H_2}{1 \text{ mol } H_2O} = 6 \text{ mol } H_2, 8 \text{ mol } H_2 - 6 \text{ mol } H_2 = 2 \text{ mol } H_2\)

S: \(10 \text{ mol } H_2O \cdot \frac{1 \text{ mol } H_2}{1 \text{ mol } H_2O} = 10 \text{ mol } H_2, 10 \text{ mol } H_2 - 10 \text{ mol } H_2 = 0 \text{ mol } H_2\)

T: \(5 \text{ mol } H_2O \cdot \frac{1 \text{ mol } O_2}{2 \text{ mol } H_2O} = 2.5 \text{ mol } O_2, 5 \text{ mol } O_2 - 2.5 \text{ mol } O_2 = 2.5 \text{ mol } O_2\)

U: \(8 \text{ mol } H_2O \cdot \frac{1 \text{ mol } O_2}{2 \text{ mol } H_2O} = 4 \text{ mol } O_2, 6 \text{ mol } O_2 - 4 \text{ mol } O_2 = 2 \text{ mol } O_2\)

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.

**2C 2P** No, in cases S and U, O_2 had fewer moles than H_2, but it wasn’t limiting in either (O_2 was tied with H_2 in case S and was in excess in case U), and in case T, the number of moles were the same, but hydrogen was still the limiting. **19C 2U 14P**
15. Below are three examples of mathematical calculations that could be performed to find the limiting reactant for Container U in Question 13.

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\frac{8 \text{ mol H}_2}{1} \times \frac{2 \text{ mol H}_2O}{2 \text{ mol H}_2} = 8 \text{ mol H}_2O)</td>
<td></td>
</tr>
<tr>
<td>(\frac{6 \text{ mol O}_2}{1} \times \frac{2 \text{ mol H}_2O}{1 \text{ mol O}_2} = 12 \text{ mol H}_2O)</td>
<td></td>
</tr>
<tr>
<td>The amount of H(_2) present makes less of the product, so H(_2) must be the limiting reactant.</td>
<td></td>
</tr>
</tbody>
</table>

For each pair of reactants, find how much of one reactant is required if all of the other reactant were used up.

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\frac{8 \text{ mol H}_2}{1} \times \frac{1 \text{ mol O}_2}{2 \text{ mol H}_2} = 4 \text{ mol O}_2)</td>
<td></td>
</tr>
<tr>
<td>There are 6 moles of O(_2) present, but using all of the H(_2) only requires 4 moles of O(_2), so we have more than enough O(_2), meaning H(_2) must be the limiting reactant.</td>
<td></td>
</tr>
</tbody>
</table>

a. Do all the calculations give the same answer to the problem? **Yes, all 3 give answers of H\(_2\) as the limiting reactant**

b. Which method was used most by your group members in Question 13? **Whichever one was used by more of the group.**

c. Which method seems “easier,” and why? **User preference, some find actually seeing the amount of product produced for all reactants, as in the left-hand case, easier to visualize. Others see less math in the right-hand case as being easier. Other feel like since the moles of a reactant needed per mole of reactions is always a whole number, they feel the bottom method is easier because the number you’re dividing by is always a whole number, never any other ratio.**

d. Did your group use any other method(s) of solving this problem that were scientifically and mathematically correct? If so, explain the method. **Some might like to draw out the possible formations to visually see which one works (though that really only works for whole numbers of moles used).**
Extension Questions
16. Consider the synthesis of water as shown in Model 3. A container is filled with 10.0 g of H₂ and 5.0 g of O₂.
   a. Which reactant (hydrogen or oxygen) is the limiting reactant in this case? Show your work with units. *Hint:* Notice that you are given reactant quantities in mass units here, not moles.

   ![5C (4 pts. at least 2 sets of work and intermediate answers, 1 pt. limiting reactant) 4U (units in work and intermediate answers for both sets of work) 3P (2 intermediate answers and limiting)]

   \[
   10 \text{ g H}_2 \cdot \frac{1 \text{ mol H}_2}{2.0159 \text{ g H}_2} = 4.961 \text{ mol H}_2
   \]

   \[
   5 \text{ g O}_2 \cdot \frac{1 \text{ mol O}_2}{31.9988 \text{ g O}_2} = 0.1563 \text{ mol O}_2
   \]

   If all H₂ is used, then we’d need:

   \[
   4.961 \text{ mol H}_2 \cdot \frac{1 \text{ mol O}_2}{2 \text{ mol H}_2} = 2.480 \text{ mol O}_2 \text{ required,}
   \]

   Since we only have 0.1563 mol O₂, we’ll run out of O₂ long before all the H₂ is reacted.

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

   ![2C 2U P]

   \[
   0.1563 \text{ mol O}_2 \cdot \frac{2 \text{ mol H}_2 \text{O}}{1 \text{ mol O}_2} \cdot \frac{18.0153 \text{ g H}_2 \text{O}}{1 \text{ mol H}_2 \text{O}} = 5.630 \text{ g H}_2\text{O}
   \]

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

   ![3C (2 pts. work and ans for mol or g of H₂ needed, 1 pt. for amount left work and ans [0.5 pts each]) 3U (2 pts. for units in work and ans of mol or g of H₂ needed, 1pt. for units in work and ans. of the amount left [0.5 pts each]) 2P (amount of H₂ needed and amount of H₂ left)]

   \[
   \text{H}_2 \text{ is in excess.}
   \]

   \[
   0.1563 \text{ mol O}_2 \cdot \frac{2 \text{ mol H}_2 \text{O}}{1 \text{ mol O}_2} \cdot \frac{2.0159 \text{ g H}_2}{1 \text{ mol H}_2} = 0.630 \text{ g H}_2\text{O needed}
   \]

   10.0 g H₂ present - 0.630 g H₂ used = 9.37 g H₂ left

   ![10C 9U 5P]