CHEMISTRY 11
Limiting and Excess STOICHIOMETRY

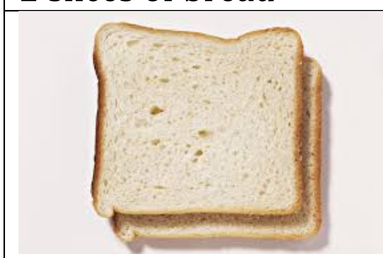
Not all things in life occur exactly as planned.
Even when baking a cake, it is highly probable that, *(although I consider myself a pretty adept baker)*, when I measure my 2 cups of butter and 3 cups of flour, I may inadvertently use a little less or a little more than the required amounts of each ingredient. It may be due to the inaccuracy of the measuring tools I am using, or my own human error in reading these measuring tools.
We can sometimes see the consequences of this in our final baked dessert.

In Chemistry, when we don't have exactly the amount of each reactant that was calculated in our mole stoichiometry, we will see a different outcome of our reaction.

But first...consider the following analogies:

MAKING a GRILLED CHEESE SANDWICH:

The recipe is:

2 slices of bread		1 slice of cheese		1 sandwich
	+		→	

But what if I want to open my own food truck?
And I want to be Toombsy's Cheesy Sandwich Truck. (*The name is still being developed*)

Obviously I will have to make more than one sandwich at a time.
So, for the first day I go out and buy:

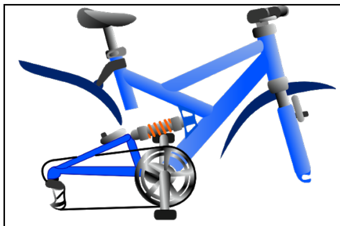
20 slices of bread	AND	10 slices of cheese		How many sandwiches can I make? **10**

The first day is SUCH a success that the next day I have a bulk order delivered and I get:

350 slices of bread	AND	200 slices of cheese		How many sandwiches can I make? **175**

What will be leftover at the end of the day: *25 slices of cheese.*

Don't like grilled cheese sandwiches? *(Seriously?)*
Then how about constructing bicycles:

	+		→	
Consider that I have **21 frames**		Consider that I have **40 bicycle tires**		How many Bikes will I make?
20 frames	+	**40 bicycle tires**	→	**20 bikes**
1 frame will be leftover		All 40 tires will be used		
We call this the **EXCESS REAGENT**		We call this the **LIMITING REAGENT**		

Now let's try this with MOLE STOICHIOMETRY:
1.00 moles of aluminum phosphate (aq) are reacted with 4.00 moles of solid lithium metal. How many moles of products are formed?

$AlPO_4$ (aq) + 3Li (s) → Li_3PO_4 (aq) + Al (s)
1.00 mol
4.00 mol

SCENARIO #1

If the 1.00 mole of $AlPO_4$ (aq) completely reacts, then only 3.00 moles of Li (s) is needed:

$AlPO_4$ (aq) + 3Li (s) → Li_3PO_4 (aq) + Al (s)
1.00 mol **3.00 mol**

SCENARIO #2

If the 4.00 mole of Li (s) completely reacts, then 1.33 moles of $AlPO_4$ (aq) is needed:

$AlPO_4$ (aq) + 3Li (s) → Li_3PO_4 (aq) + Al (s)
1.33 mol **4.00 mol**

But clearly, only SCENARIO #1 can happen.
SCENARIO #2 is impossible, because not enough $AlPO_4$ (aq) was provided to carry that out.
$AlPO_4$ (aq) Is called the **LIMITING REAGENT**: it limits us to the smaller ratio in SCENARIO #1
The limiting reagent will be completely used up (totally reacted).
Li (s) Is called the **EXCESS REAGENT**: We have 1.00 more mole than we need for SCENARIO #2
The excess reagent will be leftover after the reaction is over (you will see unreacted Li (s) still in the test tube).

Limiting and Excess MOLE STOICHIOMETRY:

1) 39.9 g of aluminum chloride reacts with 52.3 grams of sodium carbonate.

Step one. Write the balanced chemical reaction:

$2AlCl_3 + 3Na_2CO_3 \rightarrow Al_2(CO_3)_3 + 6NaCl$

Step two. Convert all given data in moles.

$2AlCl_3 + 3Na_2CO_3 \rightarrow Al_2(CO_3)_3 + 6NaCl$

39.9 g

× 1 mole

133.341 g

= 0.300moles

This is the amount of $AlCl_3$ **that we HAVE**

52.3 g

× 1 mole

105.988 g

= 0.493 moles

This is the amount of Na_2CO_3 **that we HAVE**

Step three.

Determine limiting and excess reactants *(also called reagants)* by using mole stoichiometry (ratios)

$2AlCl_3 + 3Na_2CO_3 \rightarrow Al_2(CO_3)_3 + 6NaCl$

0.300 moles → 0.300 $\times \frac{3}{2}$

= 0.450 moles needed

0.493 $\times \frac{2}{3}$ ← **0.493 moles**

= 0.329 moles needed

NOT POSSIBLE! I don't have 0.329 moles of $AlCl_3$ so I am LIMITED by the amount of $AlCl_3$ that I have, and the second line can not occur. **LIMITING REAGENT IS:** $AlCl_3$ **EXCESS REAGENT IS:** Na_2CO_3

$2AlCl_3$ +	$3Na_2CO_3$ →	$Al_2(CO_3)_3$ +	$6NaCl$
0.300 moles	0.450 moles	0.300 × 1/2	0.300 × 3
		0.150 moles	0.900 mol
		X 233.988 g/mol	**58.443 g/mol**
		= 35.1 g	**= 52.6 g**

LAW OF CONSERVATION OF MASS : CHECK

LS: 39.9 + 52.3 g = 92.2 g **RS:** = 35.1 + 52.6 = 87.7 g

Is there 4.5 g of excess Na_2CO_3? Let's check!

0.493 moles of Na_2CO_3 available

-0.450 moles used up

= 0.043 moles of excess unreacted Na_2CO_3 after the reaction is complete

0.043 moles of excess × 105.988 g/mol = 4.557 g excess, (4.6 g to 2 significant figures)

THIS CHECKS OUT!

2) 4.763 g of Titanium is reacted with 13.98 g of copper (II) chloride to form titanium (IV) chloride and copper:

$Ti + 2CuCl_2 \rightarrow TiCl_4 + 2\ Cu$

4.763 g
× 1 mole
47.867 g
= 0.09950 moles
This is what we HAVE

13.98 g
× 1 mole
134.452 g
= 0.104 moles
THIS IS WHAT WE HAVE

$Ti + 2CuCl_2 \rightarrow TiCl_4 + 2\ Cu$

HAVE 0.09950 moles → need 2 X 0.0995
= 0.199 moles
But we don't have this much
We only HAVE 0.104 moles…

SO…We would need
0.104 moles × 1/2
= 0.0520 moles

A better way to represent this:

Ti +	$2CuCl_2$	→	$TiCl_4$ +	2 Cu
0.09950 moles Excess reactant is Ti	~~0.199 moles~~ ↓			
0.0520 moles	**0.104 moles Limiting reactant is $CuCl_2$**		**0.0520 moles**	**0.104 moles**

Therefore, we HAVE 0.09950 moles of Ti but we will only use up 0.0520 moles
There will be an excess of 0.09950 – 0.0520 moles = 0.0475 moles Ti that is unreacted.

All 0.104 moles of the $CuCl_2$ will react. This is the limiting reactant. There will be none left as all of it turns into products. We use this value to determine the moles of each product formed.

0.0520 moles $TiCl_4$ x 189.679g $TiCl_4$ / Mole = 9.863 g   0.104 moles Cu x 63.546 g Cu / mole = 6.609 g

LAW OF CONSERVATION OF MASS : CHECK

LS: 4.763 g + 13.98 g = 18.743 g   **RS:** = 9.863 g + 6.609 g = 16.472 g

BUT 0.0475 moles excess Ti × 47.867 g / mole = 2.274 g excess

18.743 g - 2.274 g excess unreacted Ti = 16.469 g ☺

3) 33.7 g of aluminum reacts with 114 g of chromium (II) oxide in a single replacement reaction.

a) Name the limiting reactant.
b) Name the excess reactant.
c) Determine the grams of each product formed.
d) Show your check of the Law of Conservation of Mass.
e) Name the amount of excess reactant that remains, in grams.

$$2Al + 3CrO \rightarrow Al_2O_3 + 3\,Cr$$

We have 33.7 g
× 1 mole / 26.982g
=1.25 moles → × 3 CrO / 2 Al
=1.875 moles **needed**

BUT…**We have** 114 g
=1.67 moles
× 1 mole / 67.995g
=1.68 moles → × 2 Al / 3 CrO
= 1.12 moles needed

2Al +	3CrO	→	Al_2O_3 +	3 Cr
1.25 moles excess	~~1.875 moles~~ We don't have enough			
1.12 moles	**1.68 moles** Limiting		**0.560 moles**	**1.68 moles**

0.13 moles of excess Al

ALL 1.68 moles of CrO reacts

30.2 g Al that actually reacts

\+ 114 g CrO

TOTAL: 144.2 g

0.560 moles Al_2O_3 x 101.961g / mole = 57.1 g

1.68 moles Cr x 51.996 g Cr / mole = 87.4 g

144.5 g

LIMITING and EXCESS Stoichiometry Practice Problems

1) 111 g of calcium chloride reacts with 100.0 g of sodium phosphide.
   a) Which reactant is in excess?
   b) Calculate the mass of excess that remains.
   c) Calculate the mass of each product that is produced.
   d) Show your check of the Law of Conservation of Mass.

111 g of $CaCl_2$ ⨉ 110.984 g / mole = 1.00 moles
100.0 g of Na_3P ⨉ 99.9444 g / mole = 1.00 moles

$3CaCl_2$ +	$2Na_3P$	→	Ca_3P_2 +	$6NaCl$
1.00 moles limiting	X 2/3 =0.667 moles		1.00 moles X 1/3 =0.333 moles	1.00 moles X 2 =2.00 moles
X 3/2 ~~=1.50 moles~~ We don't have enough	**1.00 moles** excess			

⨉ 182.182 g / mol = 60.7 g

⨉ 58.443 g / mol = 117 g

1.00 mole available = 100.0 g
Only 0.667 moles reacted = 66.7 g

111 g + 66.7 g = 177.7 g (178 g)

60.7 g + 117 g = 177.7 g (178 g)

2) 10.0 g of calcium carbonate reacts with 6.00 g of sodium chloride.
   a) Which reactant is in excess?
   b) Calculate the mass of excess that remains.
   c) Calculate the mass of each product that is produced.
   d) Show your check of the Law of Conservation of Mass.

10.0 g of $CaCO_3$ ⨉ 100.086 g / mole = 0.0999 moles
6.00 g of NaCl ⨉ 58.443 g / mole = 0.103 moles

$CaCO_3$ +	$2NaCl$	→	Na_2CO_3 +	$CaCl_2$
0.0999 moles excess	X 2 ~~=0.1998 moles~~ We don't have enough			
X ½ = 0.0515 moles	**0.103 moles** limiting		0.515 moles	= 0.515 moles

⨉ 105.961 g / mol = 5.46 g

⨉ 110.984 g / mol = 5.72 g

0.0515 moles ⨉ 100.086 g / mole = 5.13 g of $CaCO_3$ reacted

5.13 6.00 g = 11.13g

5.46 g + 5.72 g = 11.18 g

3) A students spills 35.0 g of calcium hydroxide on the lab table and in an effort to neutralize it, they pour 35.0 g of phosphoric acid onto the spill.
   a) Which reactant is in excess?
   b) Calculate the mass of excess that remains.
   c) Calculate the mass of each product that is produced.
   d) Show your check of the Law of Conservation of Mass.

35.0 g of $Ca(OH)_2$ × 74.092 g / mole = 0.472 moles
35.0 g of H_3PO_4 × 97.994 g / mole = 0.357 moles

$3Ca(OH)_2$ +	$2H_3PO_4$	→	$Ca_3(PO_4)_2$ +	6HOH
0.472 moles **limiting**	× 2/3 =0.315 moles		× 1/3 =0.158 moles	× 2 =0.945 moles
× 3/2 ~~= 0.536 moles~~ We don't have enough	**0.357 moles** excess			
			× 310.174 g / mol = 49.0 g	× 18.015 g / mol = 17.0 g

0.357 moles of H3PO4 available
- 0.315 moles actually used
= 0.042 moles of acid leftover, unreacted
× 97.994 g / mole = 4.1 g of excess acid

35.0 g + 35.0 g – 4.1 g = 65.9 g

49.0 g + 17.0 g = 66.0 g

4) 314 g of sulphuric acid reacts with 70.5 g of lithium hydroxide

   a) Which reactant is in excess?
   b) What mass of sulphuric acid was used in the reaction?
   c) What mass of each product is produced?

1)	H_2SO_4	+	$2LiOH$	→	Li_2SO_4	+	$2H_2O$
given	314 g		70.5 g				
Change to moles	X $\frac{1mol}{98.12g}$ =3.20 mol		X $\frac{1mol}{23.95g}$ =2.94 mol				
Comparing the Mole ratio	3.20 mol is what we have	→	6.40 mol is how much we need to react with the 3.20 mol of H_2SO_4				
	1.47 mol is how much we need to react with the 2.94 mol of LiOH	←	2.94 mol is the amount we have				
a) Decide on the limiting and excess reagent	**This is the EXCESS reagent** because we have 3.20 mol available, but we are only going to use 1.47 mol of it		This is the limiting reagent because we only have 2.94 mol of LiOH, not enough to react with the given amount of acid				
b) Calculate grams of acid used	**1.47 mol reacted** X $\frac{98.12g}{1mol}$ =144 g reacted						
Mole ratio	Only **1.47 mol reacted**		All of the **2.94 mol reacted**		**1.47 mol produced**		**2.94 mol produced**
c) Calculate mass of each product					X $\frac{109.98g}{1mol}$ =162 g		X $\frac{18.02g}{1mol}$ =53.0 g

Check: reactants: 144g + 70.5g = 214.5 g ⍰ products: 162g + 53.0g = 215 g

Alternate check ← Can you figure out what I have done here:

reactants: 314g + 70.5g = 384.5g

⍰ products: 162g + 53.0g = 215g + 170g excess acid remaining = 385g

5) Francium reacts explosively with water. If 325 g of Francium react with 84.5 g of water, will both reactants be totally consumed? What mass of products can we expect from the reaction?

Please note that these answers were calculated using a periodic table that had less significant figures. But you should still be able to compare your answers to ensure you were following the correct method.

Moles Fr=(1mole/223g)(325g)=1.46 moles Fr

Moles H_2O = (1 mole / 18.0 g) (84.5 g) = 4.69 moles H_2O

	2Fr	+	$2H_2O$	→	2FrOH	+	H_2
This line!	1.46 moles		1.46 moles		1.46 moles		0.730 moles
	4.69 moles		4.69 moles		4.69 moles		2.35 moles

Water is present in excess; the excess is (4.69 – 1.46) moles = 3.23 moles
Mass excess water = (18.0 g / mole) (3.23 moles) = 58.1 g H_2O in excess

Mass FrOH = (240. g / mole) (1.46 moles) = 350. g FrOH
Mass H_2 = (2.02 g / mole) (0.730 moles) = 1.48 g H_2

Check:
Σ mass of reactants = Σ mass of products + excess
325g+84.5g=350.g+1.48g+58.1g
410.g=410.g Good!