Stoichiometry Notes Key

Unit 7 - STOICHIOMETRY

1. Introduction to Stoichiometry
2. Mole-Mole Stoichiometry
3. Mass-Mole Stoichiometry
4. Mass-Mass Stoichiometry
5. Mass-Volume & Volume-Volume Stoichiometry
6. Excess & Limiting Reactants

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1. Introduction to Stoichiometry

Stoichiometry: the calculation of the quantities of chemical substances involved in chemical reactions.

The chemical 'recipe' necessary to combine substances to make new substances

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Stoichiometry

Derived from the Greek "*stoicheion*" or element and "*metron*" or measure.
This is the term we use to refer to all quanititative aspects of chemical composition and reaction

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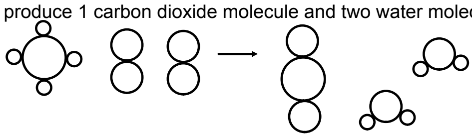
Stoichiometry is the relationship between the amount of reactants used and the amount of products produced in a chemical reaction.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

1 methane molecule reacts with two oxygen molecules to produce 1 carbon dioxide molecule and two water molecules



The balanced reaction is the ratio or 'recipe' we need for the reaction to occur.

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An analogy:

Consider making sandwiches. In each sandwich I'd like to have:

- 2 pieces of bread (Br)
- 4 tomato slices (To)
- 2 pieces of chicken (Ch)
- 1 piece of lettuce (Le)
- Sandwich equation:

$2Br + 4To + 2Ch + 1Le \rightarrow 1Br_2To_4Ch_2Le$

1 sandwich

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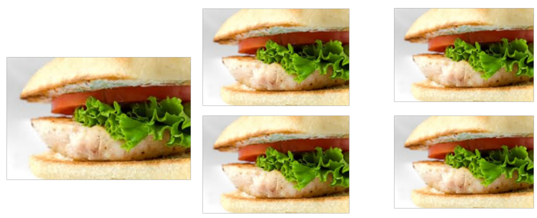
But what if I wanted to make 5 sandwiches for some friends? How much of each component would I need?

$2Br + 4To + 2Ch + 1Le \rightarrow 1Br_2To_4Ch_2Le$



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Stoichiometry Notes Key

2Br + 4To + 2Ch + 1Le -> $1Br_2To_4Ch_2Le$

= 1 sandwich

5 sandwiches	2Br
	1 sandwich

= 10 Bread Slices

5 sandwiches	4 To
	1 sandwich

= 20 Tomatoes

5 sandwiches	2 Ch
	1 sandwich

= 10 Chicken Slices

5 sandwiches	1 Le
	1 sandwich

= 5 Lettuce pieces

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recipe for 1 sandwich:

2Br + 4To + 2Ch + 1Le -> $1Br_2To_4Ch_2Le$

x 5

recipe for 5 sandwiches

10Br + 20To + 10Ch + 5Le -> $5Br_2To_4Ch_2Le$

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And now for some chemicals!
Determining the amount of each component of a sandwich is like using moles in a chemical equation.

In chemistry, you can only use moles to compare one chemical to another within a reaction.

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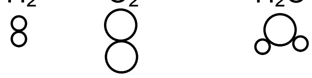
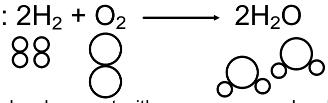
When hydrogen gas reacts with oxygen gas, water is formed. What is the chemical recipe (the stoichiometry) for this reaction?

$H_2 + O_2 \longrightarrow H_2O$



BALANCE: $2H_2 + O_2 \longrightarrow 2H_2O$



2 hydrogen molecules react with one oxygen molecule to make two water molecules. OR
2 dozen hydrogen molecules react with one dozen oxygen molecules to make two dozen water molecules. OR
2 MOLES of hydrogen react with one MOLE of oxygen to make two MOLES of water

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The coefficients refer to the amount of molecules which are involved in a reaction.

The amount of molecules can also be termed as the amount in moles.

Eg. $2\ H_2 + O_2 \rightarrow 2H_2O$
Is the same as:
$2\text{ mol } H_2 + 1\text{ mol } O_2 \rightarrow 2\text{ mol } H_2O$

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So how many moles of oxygen are needed to react with 6 moles of hydrogen?

$$6\text{ mol } H_2 \times \frac{1\text{ mol } O_2}{2\text{ mol } H_2} = 3\text{ mol } O_2$$

How many moles of water are produced if you react 2.5 moles of oxygen?

$$2.5\text{ mol } O_2 \times \frac{2\text{ mol } H_2O}{1\text{ mol } O_2} = 5\text{ mol } H_2O$$

If 0.5 moles of water are produced, how many moles of hydrogen reacted? oxygen?

$$0.5\text{ mol } H_2O \times \frac{2\text{ mol } H_2}{2\text{ mol } H_2O} = 0.5\text{ mol } H_2$$

$$0.5\text{ mol } H_2O \times \frac{1\text{ mol } O_2}{2\text{ mol } H_2O} = 0.25\text{ mol } O_2$$

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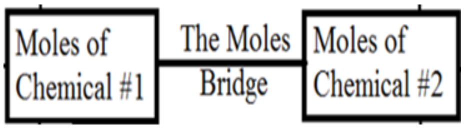
2. Mole - Mole Stoichiometry



Example:
How many moles of water are produced if you react 2.5 moles of oxygen?

2.5 mol O_2	2 mol H_2O
	1 mol O_2

= 5 mol H_2O

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Can ask how much reactant is needed:

Eg. $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

- How many moles of O_2 react with 6 moles of C_2H_6?

6 moles C2H6	7 moles O2
	2 moles C2H6

= 21 moles O_2

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Can ask how much product is formed:

- $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

How many moles of H_2O are produced when 12 moles of C_2H_6 react?

12 moles C2H6	6 moles H2O
	2 moles C2H6

= 36 moles H_2O

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3. $3I_2(g) + 6F_2(g) \rightarrow 2IF_5(g) + I_4F_2(g)$

- How many moles of $I_4F_2(g)$ are produced by 5.40 mol of $F_2(g)$?

5.40 mol F2(g)	1 mol I4F2(g)
	6 mol F2(g)

= 0.9 mol $I_4F_2(g)$

- How many moles of $F_2(g)$ are required to produce 4.50 mol of $IF_5(g)$?

4.50 mol IF5(g)	6 mol F2(g)
	2 mol IF5(g)

= 13.5 mol $F_2(g)$

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HOMEWORK:
Stoichiometry Worksheet 1 - Mole-Mole Conversions

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3. Mass - Mole Stoichiometry

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Stoichiometry Notes Key

What if a quantity other than moles is used?

Commonly, in the laboratory, quantities are measured in grams using the balance.

Example:
How many moles of silver metal are produced if 85.0g of copper metal react?

$Cu_{(s)} + 2AgNO_{3(aq)} \longrightarrow 2Ag_{(s)} + Cu(NO_3)_{2(aq)}$

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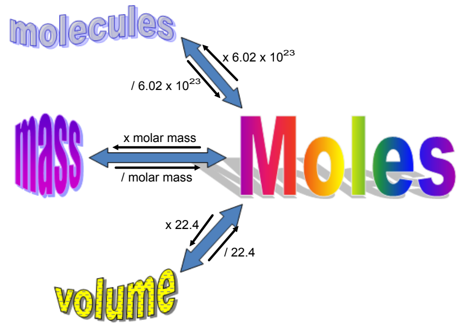
Mole Unit:



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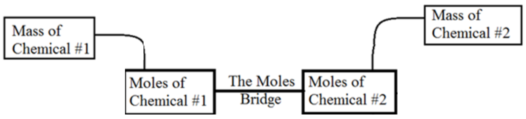
Example:
How many moles of silver metal are produced if 85.0g of copper metal react?

$Cu_{(s)} + 2AgNO_{3(aq)} \longrightarrow 2Ag_{(s)} + Cu(NO_3)_{2(aq)}$



Step 1: mass of chemical #1 (Cu) to moles of chemical #1 (Cu)
Step 2: moles of chemical #1 (Cu) to moles of chemical #2 (Ag)

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From mass of chemical #1 to moles of chemical #2, there are two steps:

- Convert mass of chemical #1 to moles of chemical #1 by dividing by the molar mass:

85.0g Cu	1 mol Cu
	63.5g Cu

= 1.3386 mol Cu

- Convert moles of chemical #1 to moles of chemical #2 using the mole ratio (coefficient ratio).

1.3386 mol Cu	2 mol Ag
	1 mol Cu

= 2.68 mol Ag

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This entire calculation can be done in one table:

mass chemical #1	1 mol chemical #1	Moles chemical #2
	molar mass chemical #1	Moles chemical #1

Mass given

Step 1 – divide by molar mass

Step 2 – multiply by mole ratio (mole bridge OR coefficient ratio)

= moles of chemical #2

85.0g Cu	1 mol Cu	2 mol Ag
	63.5g Cu	1 mol Cu

= 2.68 mol Ag

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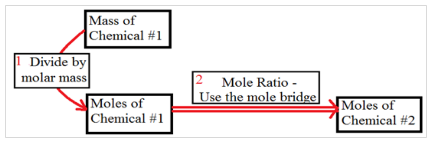

- In the reaction $2Na_2CO_3 \rightarrow 4Na + 2CO_2 + O_2$, there are 0.50g of sodium carbonate reacting. How many moles of Na does it produce?

0.50 g Na2CO3	1 mol Na2CO3	4 mol Na
	106.0 g Na2CO3	2 mol Na2CO3

Step 1

Step 2

= 9.4×10^{-3} mol Na

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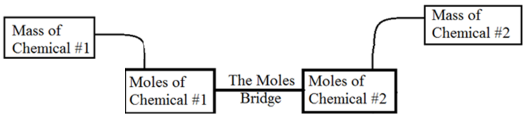
Stoichiometry Notes Key

If the amount of moles is given, and the mass needs to be found, reverse the order of operations:



- In the reaction $2Na_2CO_3 \rightarrow 4Na + 2CO_2 + O_2$, there are 4.50 mol of oxygen produced. How many grams of CO_2 does it produce?

4.50 mol O_2	2 mol CO_2	44.0g CO_2
	1 mol O_2	1 mol CO_2

= 396 g CO_2

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Try these two questions with the person sitting next to you. Write your answer in the next square using a calculation table:

- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- In this reaction, there were $3.00x10^{-3}$ mol of carbon dioxide produced. How many grams of CH_4 were used?

- $1\ Fe_2O_3 + 3\ CO \rightarrow 2\ Fe + 3CO_2$
- In this reaction, 5.00g of iron (III) oxide were reacted. How many moles of CO react?

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- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
-

$3.00x10^{-3}$mol CO_2	1 mol CH_4	16.0g CH_4
	2 mol CO_2	1 mol CH_4

0.0480 g CO_2

- $Fe_2O_3 + 3\ CO \rightarrow 2\ Fe + 3CO_2$

5.00g Fe_2O_3	1 mol Fe_2O_3	3 mol CO
	159.6g Fe_2O_3	1 mol Fe_2O_3

= 0.0940 mol CO

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<u>HOMEWORK:</u>
Stoichiometry Worksheet #2

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4. Mass - Mass Stoichiometry

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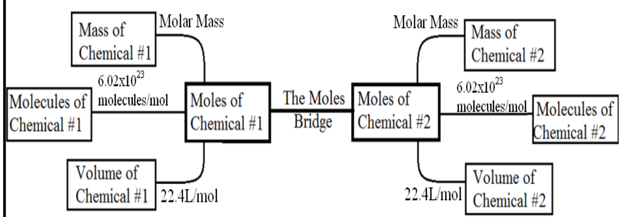
Stoichiometry Map



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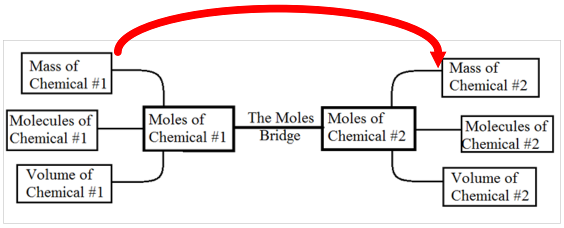

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From mass of chemical #1 to mass of chemical #2, there are three steps:

- Convert chemical #1 from mass to moles by dividing by the molar mass
- Convert moles of chemical #1 to moles of chemical #2 using the mole ratio (coefficients).
- Convert chemical #2 from moles to mass by multiplying by the molar mass

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This is usually shown in one step:

mass compound 1	1 mol compound 1	Mole compound 2	Molar mass compound 2
	molar mass compound 1	Moles compound 1	1 mol compound 2
Mass given	molar mass	mole ratio (mole bridge)	molar mass

= mass (in g) of compound 2

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An example:

- In the reaction $2Na_2CO_3 \rightarrow 4Na + 2CO_2 + O_2$, there are 0.50g of sodium carbonate reacting. How many grams of CO_2 does it produce?

0.50 g Na_2CO_3	1 mol Na_2CO_3	2 mol CO_2	44.0 g CO_2
	106.0g Na_2CO_3	2 mol Na_2CO_3	1 mol CO_2

= 0.21 g CO_2

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An example:

- $2Al + 3 CuO \rightarrow Al_2O_3 + 3Cu$
- What mass of Aluminum would react with 120g of CuO?

120 g CuO	1 mol CuO	2 mol Al	27.0g Al
	81.6g CuO	3 mol CuO	1 mol Al

= 26 g Al

- What mass of Copper would be produced from 15.5g of Aluminum?

15.5 g Al	1 mol Al	3 mol Cu	63.5 g Cu
	27.0g Al	2 mol Al	1 mol Cu

= 54.7g Cu

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<u>HOMEWORK:</u>
Stoichiometry Worksheet #3

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5. Mass–Volume and Volume-Volume Stoichiometry

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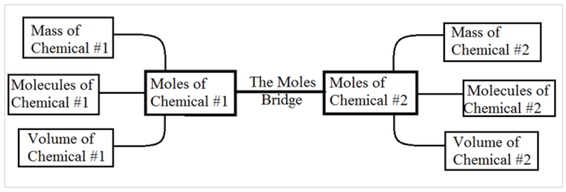

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There are three steps if you start and end with a quantity other than moles:

- Convert quantity given to moles for chemical #1 (using its molar mass, Avogadro's number, or molar volume of 22.4L/mol of gas)
- Use the mole ratio (from coefficients) to convert from moles of chemical #1 to moles of chemical #2.
- Change moles of chemical #2 to the quantity required by using molar mass, Avogadro's number, or molar volume of 22.4L/mol of gas.

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An example:

- $3NO_{2(g)} + H_2O_{(l)} \rightarrow 2HNO_{3(aq)} + NO_{(g)}$
- At STP, what mass of water is needed to react with 15.5L of nitrogen dioxide?

15.5L NO_2	1 mol NO_2	1 mol H_2O	18.0g H_2O
	22.4L NO_2	3 mol NO_2	1 mol H_2O

= 4.15 g H_2O

- At STP, what volume of nitrogen monoxide would be produced from 100.0g of water?

100.0g H_2O	1 mol H_2O	1 mol NO	22.4L NO
	18.0gH_2O	1 mol H_2O	1 mol NO

= 124L NO

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An example:

- $2NH_{3(g)} \rightarrow N_{2(g)} + 3H_{2(g)}$

At STP, what volume of H_2 is produced when 20.0L of NH_3 react?

20.0L NH_3	1 mol NH_3	3 mol H_2	22.4L H_2
	22.4L NH_3	2 mol NH_3	1 mol H_2

= 30.0 L H_2

Notice that when volume-volume calculations are done, the molar volume cancels out. The above calculations could be written like a mole-mole problem:

20.0L NH_3	3 mol H_2	= 30.0 L H_2
	2 mol NH_3	

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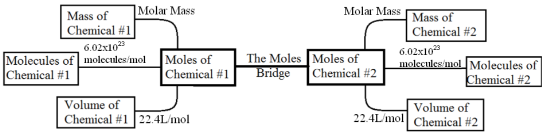
Stoichiometry Map



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An example:

3. $2C_6H_{14(s)} + 19O_{2(g)} \rightarrow 12CO_{2(g)} + 14H_2O_{(l)}$

a) At STP, what volume of CO_2 is produced when $2.45x10^{23}$ molecules of C_6H_{14} react?

2.45×10^{23} molec C_6H_{14}	1 mol C_6H_{14}	12 mol CO_2	22.4 L CO_2
	$6.02x10^{23}$molecC_6H_{14}	2 mol C_6H_{14}	1 mol CO_2

= 54.7 L CO_2

b) What volume of oxygen is required to produce 18.93L of liquid H_2O (density of $0.97g/cm^3$) at 60 degrees C?

*** Note that $1L = 1000cm^3$

$$2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(l)}$$

18.93L H_2O	1000 cm^3	0.97g H_2O	1 mol H_2O	1 mol O_2	22.4L O_2
	1 L H_2O	1 cm^3	18.0g H_2O	2 mol H_2O	1 mol O_2

$= 1.1 \times 10^4$ L O_2

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HOMEWORK:

Stoichiometry Worksheet #4

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6. Excess and Limiting Reactants

http://www.dlt.ncssm.edu/core/Chapter6-Stoichiometry/Chapter6-Animations/LimitingReactant.html

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Excess and Limiting Reactant Definitions

Limiting reactant: the reactant which runs out first, which "limits", or stops, the reaction. It controls how much product is formed.

Excess reactant: the reactant which will not run out. There will be some of this reactant left over, or in "excess" when the reaction is finished.

Since the limiting reactant is what determines when the reaction is over, it is this quantity that we use for stoichiometric calculation.

May 3-8:15 AM

An analogy:

Consider making a sandwich. In each sandwich I'd like to have:

- 2 pieces of bread (Br)
- 4 tomato slices (To)
- 2 pieces of chicken (Ch)

$2Br + 4To + 2Ch \rightarrow 1Br_2To_4Ch_2$

1 sandwich

May 3-8:15 AM

But what if I had 10 bread, 26 tomatoes, and 12 chicken slices?

10 Br	**1 sandwich**
	2 Br

= 5 sandwiches

26 To	**1 sandwich**
	4 To

= 6.5 sandwiches

12 Ch	**1 sandwich**
	2 Ch

= 6 sandwiches

Bread is the limiting reactant, as we can only make 5 sandwiches, and then we are out of bread.

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Excess tomatoes and cheese:

5 sandwiches	**4 To**
	1 sandwich

= 20 tomatoes

There will be 26 - 20 = **6 tomatoes in excess**

5 sandwiches	**2 Ch**
	1 sandwich

= 10 cheese

There will be 12 - 10 = **2 pieces of cheese in excess**

http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/limitr15.swf

May 26-7:20 AM

Example

$2Al + 3\ CuO \rightarrow Al_2O_3 + 3Cu$

Calculate the grams of Al_2O_3 produced when 54.0g Al reacts with 124g of CuO?

1. Calculate moles of both potential product amounts.

54.0g Al	1 mol Al	1 mol Al_2O_3
	27.0 g Cu	2 mol Al

= 1.00 mol Al_2O_3

124g CuO	1 mol CuO	1 mol Al_2O_3
	79.5g CuO	3 mol CuO

= 0.520 mol Al_2O_3

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$2Al + 3\ CuO \rightarrow Al_2O_3 + 3Cu$

Calculate the grams of Al_2O_3 produced when 54.0g Al reacts with 124g of CuO?

2. Pick the smallest answer. This reactant will be the limiting reactant and this is the moles of product formed.

Al: can potentially make 1.00 mol Al_2O_3

CuO: can potentially make 0.520 mol Al_2O_3

Therefore,
CuO is the limiting reactant, as it produces the least amount of product!

CuO is the **limiting reactant**. Therefore, 0.520 mol Al_2O_3 are produced. Al is in **excess.**

May 3-8:15 AM

$2Al + 3\ CuO \rightarrow Al_2O_3 + 3Cu$

Calculate the grams of Al_2O_3 produced when 54.0g Al reacts with 124g of CuO?

3. Convert the limiting reactant moles to grams.

0.520 mol Al2O3	**102.0g Al2O3**
	1 mol Al2O3

= 53.04g Al_2O_3 = 53.0g Al_2O_3

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$2Al + 3\ CuO \rightarrow Al_2O_3 + 3Cu$

Calculate the grams of Al_2O_3 produced when 54.0g Al reacts with 124g of CuO?

4. To find the mass of excess reactant left over, use moles of product formed to determine mass of reactant. Then subtract from the original amount.

0.520mol Al2O3	2 mol Al	27.0g Al
	1mol Al2O3	1 mol Al

= 28.1g Al

54.0g - 28.1g = 25.9g Al in excess

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Stoichiometry Notes Key

Example:

$2Ca_3(PO_4)_2 + 6SiO_2 + 10C \Rightarrow P_4 + 6CaSiO_3 + 10CO$

A) What mass of P_4 is produced when 41.5g of $Ca_3(PO_4)_2$, 26.5g of SiO_2, and 7.80g of C are reacted?
B) How many grams of each excess reactant will remain unreacted?

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1. Potential moles of product:

41.5g Ca3(PO4)2	1mol Ca3(PO4)2	1mol P4
	310.3g Ca3(PO4)2	2mol Ca3(PO4)2

= 0.0669 mol P_4

26.5g SiO2	1mol SiO2	1mol P4
	60.1g SiO2	6mol SiO2

= 0.0735 mol P_4

7.80g C	1mol C	1mol P4
	12.0g C	10 mol C

= 0.0650 mol P_4

2. Carbon is the limiting reactant as it produces the fewest moles of product!

May 25-2:58 PM

3. Mass of P_4 produced:

0.0650 mol P4	**124.0g P_4**
	1 mol P4

= 8.06 g P_4

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4. Mass of $Ca_3(PO_4)_2$ in excess:

0.0650mol P4	2mol Ca3(PO4)2	310.3g Ca3(PO4)2
	1mol P4	1mol Ca3(PO4)2

= 40.3g $Ca_3(PO_4)_2$

41.5g - 40.3g = 1.2g excess $Ca_3(PO_4)_2$

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4. Mass of SiO_2 in excess:

0.0650mol P4	6mol SiO2	60.1g SiO2
	1mol P4	1mol SiO2

= 23.4g SiO_2

26.5g - 23.4g = 3.1g excess SiO_2

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<u>HOMEWORK:</u>
Limiting Reactant Worksheet

May 26-8:03 AM