Limiting & Excess Reagents

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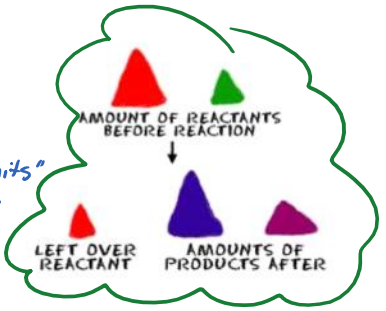
Stoichiometry of Limiting & Excess Quantities

Limiting Reactant: (LR) The reactant which runs out first, this "Limits" the amount of product formed. When the LR runs out, the reaction stops.



Excess Reactant: The reactant which does not run out. There will be some left over, or "in excess" when the reaction is complete.

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

ANIMATION: https://phet.colorado.edu/en/simulation/reactants-products-and-leftovers

Let's consider an analogy: Suppose I'm making a sandwich. In each sandwich I want:

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

molecular formula of product

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

BUT...what if I had 10 slices of bread, 26 tomatoes and 12 chicken slices?

"start with knowns" amount of each reactant

10Br	1 sandwich 2 Br	= 5 sandwiches
26To	1 sandwich 4 To	= 6.5 sandwiches
12 Ch	1 sandwich 2 Ch	= 6 sandwiches

How much (MOLES) product can be made from each reactant

5 sandwiches Limiting reactant
* always smallest number of moles

excess reactants (4 moles)

Br is the limiting reactant (reagent), because we can only make 5 sandwiches, then we are all out of bread, and have an excess of To + Ch

...Similarly, chemical reactions frequently are carried out in such a way that one or more of the reactants actually are present in EXCESS amounts.

Some reasons for having an excess amount:

- deliberately adding an excess of 1 reactant to make sure all of a second reactant used (maybe too expensive to waste, or harmful to the environment)
- unavoidably having a reactant in excess because a limited amount of another reactant is available.

The reactant that gets used up first is called the ***limiting reactant*** because it limits how far the reaction can go. All other reactants that are left over after the reaction is finished are called ***excess reactants***.

Consider the simple reaction: $2\ Na(s) + Cl_2(g) \rightarrow 2\ NaCl(s)$. synthesis.

- How many moles of Cl_2 would you need to use up 2 moles of sodium? *Answer: 1 mole.*
- What would happen if 3.0 moles of sodium and 2.0 moles of chlorine reacted?

  Answer: Since 3.0 moles of sodium is only sufficient to react with 1.5 moles of chlorine, all of the sodium will be consumed and 0.50 moles of chlorine will be left in excess.

- If 50.0 g Na and 80.5 g Cl_2 were reacted?

  Answer: You cannot directly compare numbers of atoms by comparing masses. You must convert to moles to compare: moles Na = 50.0 g / 23.0 g/mol = 2.17 mol
  moles Cl_2 = 80.5 g/ 71.0 g/mol = 1.13 mol

  You don't have enough Na to use up the Cl_2 (need 2.26 mol Na to use up 1.13 mol Cl_2).

  So Na *is the limiting reactant,* 1.085 *mole of* Cl_2 *reacts, and* 0.045 *mole of* Cl_2 *remains.*

To use up all 2.17 moles of Na you would need 1.085 *moles of* Cl_2

How to Determine the Limiting Reactant, Amount of Product(s) and Quantity of Excess Reactant(s):

1. Start by assuming that the first reactant is the limiting reactant (***i.e.*** it gets used up before the others). Calculate how much product it could theoretically produce.
2. Repeat step 1, in turn, for each of the other reactants.
3. Identify the **Limiting Reactant** (***LR***) – the one that can make the least amount of product.
   Amount of Product Formed = amount of product formed based on amount of LR that reacted
4. Identify the **Excess Reactants** (***XSR***) that remain unreacted.
5. Use the *LR* to find out how much of the other *XSR(s)* remain. ***Amount of XSR remaining = $XSR_{initial}$ − $XSR_{reacted}$***

Consider the reaction between carbon monoxide and oxygen gas:

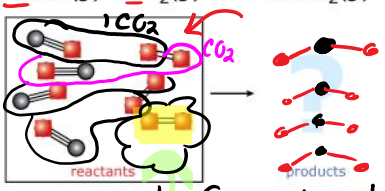
$2\ CO_{(g)}$	$O_{2(g)}$	$2\ CO_{2(g)}$
2 molecules	1 molecule	2 molecules
2 mol	1 mol	2 mol
2L	1L	2L
2(28.0g)=56.0g	32.0 g	2(44.0g)=88.0g

Stoichiometric quantities would be present IF the amounts or volumes of CO:O_2 reduced to 2:1

extra

reality $4CO + 3O_2 \rightarrow 4CO_2$

$2\ CO(g) + 1O_2(g) \longrightarrow 2\ CO_2(g)$



1 O_2 molecule left.

However, this is rarely the case in the "real world". It is more likely that the number of particles will **NOT be in stoichiometric quantities**, or "perfect" ratios.

* One or more reactant(s) is likely to be in excess.

Meaning, there will be more that enough of one reactant to completely react with the other.

a) Which of the reactant is in excess? O_2

1 O_2 molecule remains.

b) Sketch any remaining reactants and products to show what will be present once the reaction is complete.

c) How many CO2 particles are formed? $4\ CO_2$

d) How many excess reactant particles remain?

$1O_2$

2 Parts to Questions:

(A) In **limiting and excess problems**, you will be given the mass of all of the reactant species and you must determine which of these are in excess...and more importantly, *which is the limiting reactant* (or reagent) that limits the amount of the product that can form.

(B) You may also have to determine **how much of the excess species remains** once the reaction is complete.

Example 1 * What volume of hydrogen gas, measured at STP, is produced when 8.0g of lithium metal is reacted with 10.0g of water? What mass of the excess reactant remains once the reaction is completed?

H_2 mass (g) 22.4L Li(s) Base single replacement $H_2O_{(\ell)}$

balanced equation *(single replacement)*

$$2\,Li_{(s)} + 2\,H_2O_{(\ell)} \rightarrow 1\,H_{2(g)} + 2\,LiOH_{(aq)}$$

(1) determine which reactant is in excess: compare moles → mass/volume of product (L of $H_{2(g)}$)

*start with known amounts of reactants.

$8.0g\ Li \rightarrow \_\_\ H_{2(g)}$
$10.0g\ H_2O \rightarrow \_\_\ H_{2(g)}$
} whichever produces the least product = Limiting reactant

which reagent is in excess?

which reagent is limiting?

The equation shows that ____mol Li would require ____mol H_2O to completely react. That means there is **insufficient** ____ to use up all the _____

$8.0g\ Li$	$1\ mol\ Li$	$1\ mol\ H_2$	$22.4\ L$
	$6.9g\ Li$	$2\ mol\ Li$	$1\ mol\ H_2$

*excess Li = 12.99 L $H_{2(g)}$

What Volume of $H_{2(g)}$ is produced by Li?

by H_2O?

$10.0g\ H_2O$	$1\ mol\ H_2O$	$1\ mol\ H_2$	$22.4\ L$
	$18.0g\ H_2O$	$2\ mol\ H_2O$	$1\ mol\ H_2$

= 6.22 L $H_{2(g)}$

The reactant that produces the lowest yield (amount of product) is

H_2O is the limiting reactant.

*The reactant that forms the **greater quantity of product** is in*

∴ 6.22 L of $H_{2(g)}$ will be formed (not 12.99L) (based on the L.K.)

Therefore the actual amount of product formed in this reaction will be

(B) → If 8.0g of Li reacts with 10.0g of water, and H_2O runs out ... how much Li was used?

To determine *"mass of the excess reactant that remains once the reaction is completed"*

$10.0g\ H_2O$	$1\ mol\ H_2O$	$2\ mol\ Li$	$6.9g\ Li$
	$18.0g\ H_2O$	$2\ mol\ H_2O$	$1\ mol\ Li$

= 3.8 g Li (amount of Li used up in the reaction)

- begin with the **limiting reagent**
- use stoichiometry to determine how much of the **excess reactant** this will "use up"
- Subtract the amount used from the amount of "excess reagent" present at the start
- check significant figures *(sig figs)*

So what is left? What is "excess"?

8.0g (starting amount Li) − 3.8g (used up reacting with H_2O) = 4.2g Li remain, "in excess"

Example 2 20.0 g of hydrogen react with 100.0 g of oxygen.
Identify the limiting reactant and determine the mass of water formed and the mass of the excess reactant.

Start by calculating the mass of product, H_2O, that would be formed by these amounts of each reactant

mass of H_2O (based on H_2) =

mass of H_2O (based on O_2) =

There is enough Hydrogen to make _____ of H_2O, but only enough Oxygen to make _____
So we say that "sets a limit" on the amount of H_2O formed. Therefore _____ is the LIMITING REAGENT

_____ is the excess reagent, and by how many grams?

We find the mass of ____ in excess by finding the mass of ___ which actually reacts based on either:

-mass of the limiting reactant

-or the mass of a product formed by the limiting reactant

Then, subtract the mass of H_2 which reacts from it's starting mass.

* when you don't need mass (or volume) of product; just find the L.R. by comparing moles.

Example 3 Determine the mass of the excess reactants when 56.8 g of ferrous chloride react with 14.0 g of potassium nitrate and 40.0 g of muriatic acid react as follows:

$$3\ FeCl_2 + KNO_3 + 4\ HCl \longrightarrow 3\ FeCl_3 + NO + 2\ H_2O + KCl$$

56.8g 14.0g 40.0g

in rxns with multiple products pick 1 only!

* mol NO (based on $FeCl_2$): $\frac{56.8\text{g } FeCl_2}{126.8\text{g } FeCl_2} \left| \frac{1\text{ mol } FeCl_2}{3\text{ mol } FeCl_2} \right| \frac{1\text{ mol NO}}{} = 0.149$ mol NO excess

which

* mol NO (based on $FeCl_2$): 56.8 g $FeCl_2$ × (1 mol $FeCl_2$ / 126.8 g $FeCl_2$) × (1 mol NO / 3 mol $FeCl_2$) = 0.149 mol NO (excess)

mol NO (based on KNO_3): 14.0 g KNO_3 × (1 mol KNO_3 / 101.1 g KNO_3) × (1 mol NO / 1 mol KNO_3) = 0.138 mol NO (Limiting reactant)

mol NO (based on HCl): 40.0 g HCl × (1 mol HCl / 36.5 g HCl) × (1 mol NO / 4 mol HCl) = 0.274 mol NO (excess)

which forms the least amount of product? = L.R.

∴ $FeCl_2$ AND HCl are excess reactants. But how much of each are used up by 14.0 g KNO_3?

14.0 g KNO_3 (Limiting R.) × (1 mol KNO_3 / 101.1 g KNO_3) × (3 mol $FeCl_2$ / 1 mol KNO_3) × (126.8 g $FeCl_2$ / 1 mol $FeCl_2$) = 52.7 g $FeCl_2$ ← used in rxn

56.8 g − 52.7 g = 4.1 g $FeCl_2$ excess

14.0 g KNO_3 (L.R.) × (1 mol KNO_3 / 101.1 g KNO_3) × (4 mol HCl / 1 mol KNO_3) × (36.5 g HCl / 1 mol HCl) = 20.2 g HCl ← used up.

40.0 g − 20.2 g = 19.8 g HCl excess

Homework *Assignment #3: Exercises # 26-32*

Complete ALL assignments on a separate piece of paper and attach to your booklet when handing in at the end of the unit. Be sure to ***clearly number each assignment with a heading.***

26. What mass of CS_2 is produced when 17.5 g of C are reacted with 39.5 g of SO_2 according to the equation
$$5\,C + 2\,SO_2 \longrightarrow CS_2 + 4\,CO\ ?$$
What mass of the excess reactant will be left over?

27. What mass of NO is produced when 87.0 g of Cu are reacted with 225 g of HNO_3 according to the equation
$$3\,Cu + 8\,HNO_3 \longrightarrow 3\,Cu(NO_3)_2 + 2\,NO + 4\,H_2O\ ?$$
What mass of the excess reactant will be left over?

28. What mass of P_4 is produced when 41.5 g of $Ca_3(PO_4)_2$, 26.5 g of SiO_2 and 7.80 g of C are reacted according to the equation
$$2\,Ca_3(PO_4)_2 + 6\,SiO_2 + 10\,C \longrightarrow P_4 + 6\,CaSiO_3 + 10\,CO\ ?$$
How many grams of each excess reactant will remain unreacted?

29. What mass of Br_2 is produced when 25.0 g of $K_2Cr_2O_7$, 55.0 g of KBr and 60.0 g of H_2SO_4 are reacted according to the equation
$$K_2Cr_2O_7 + 6\,KBr + 7\,H_2SO_4 \longrightarrow 4\,K_2SO_4 + Cr_2(SO_4)_3 + 3\,Br_2 + 7\,H_2O\ ?$$
How many grams of each excess reactant will remain unreacted?

30. What volume of $CO_2(g)$ at STP can be made when 0.0250 L of $C_5H_{12}(l)$ (density = 626.0 g/L), is reacted with 40.0 L of $O_2(g)$ at STP, according to the equation
$$C_5H_{12}(l) + 8\,O_2(g) \longrightarrow 5\,CO_2(g) + 6\,H_2O(l)\ ?$$

31. If 50.0 mL of 0.100 M HCl is allowed to react with 30.0 mL of 0.200 M NaOH according to the reaction
$$HCl + NaOH \longrightarrow NaCl + H_2O,$$
which reactant is in excess?

32. If 0.250 g of $Ba(OH)_2$ is mixed with 15.0 mL of 0.125 M HBr, what mass of $BaBr_2$ can be formed?
$$Ba(OH)_2 + 2\,HBr \longrightarrow BaBr_2 + 2\,H_2O$$