Limiting Reagents

Mole

Mole: formula weight of a substance (in gram).

12g of C = 1 mol C

23g of Na = 1 mol Na

58.5 g of NaCl = 1 mol NaCl

18 g of H_2O = 1 mol of H_2O

Avogadro's number (6.02×10^{23}): number of formula units in one mole.

1 mole of apples = 6.02×10^{23} apples

1 mole of A atoms = 6.02×10^{23} atoms of A

1 mole of A molecules = 6.02×10^{23} molecules of A

1 mole of A ions = 6.02×10^{23} ions of A

Molar mass (g/mol): mass of 1 mole of substance (in gram)
(Formula weight)

molar mass of Na = 23 g/mol
molar mass of H_2O = 18 g/mol

Stoichiometry

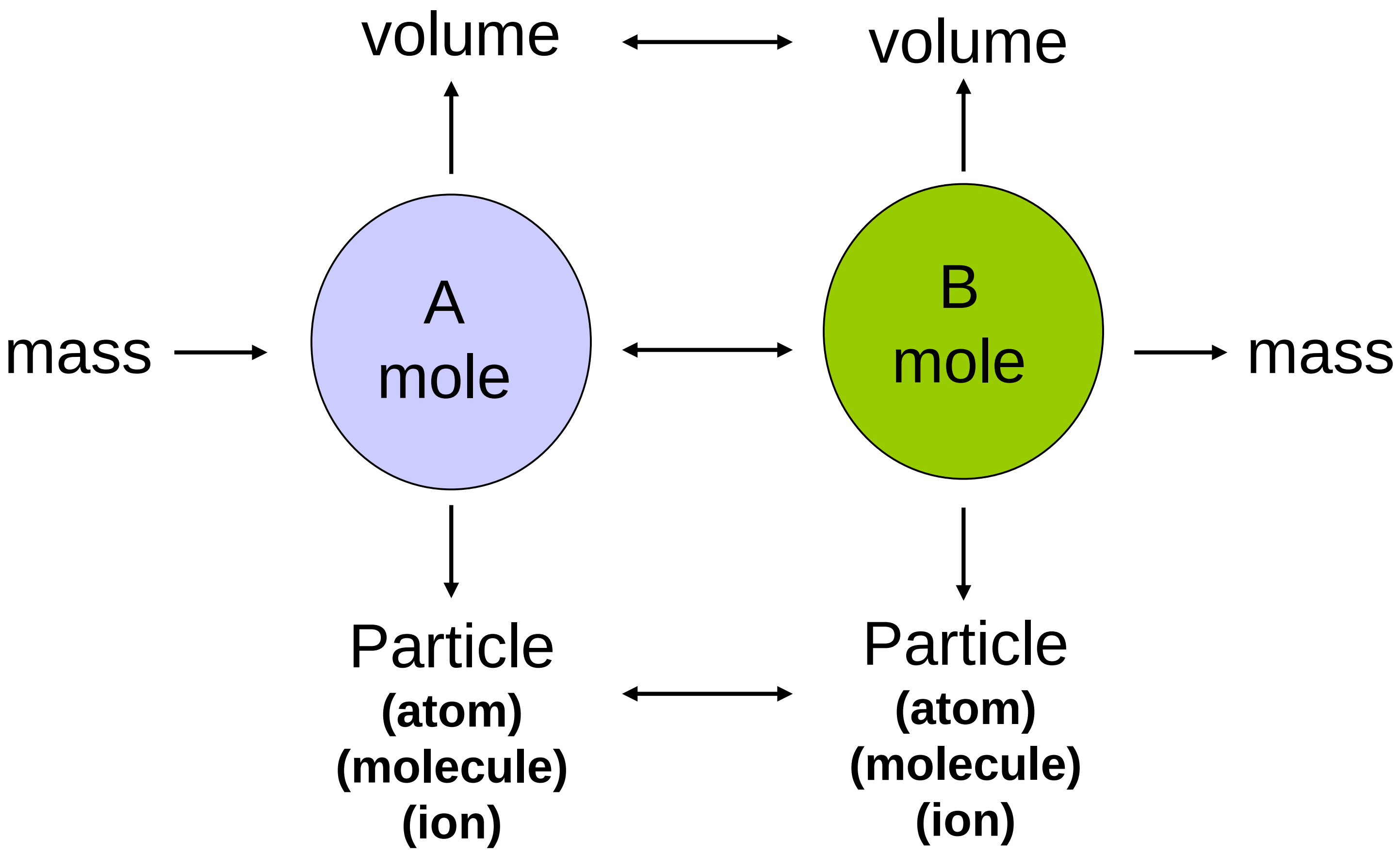
Relationships between amounts of substances in a chemical reaction.

Look at the Coefficients!

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$

2	2	1
2 moles	2 moles	1 mole
2 liters	2 liters	1 liter
2 particles	2 particles	1 particle
~~2 grams~~	~~2 grams~~	~~1 gram~~

Stoichiometry

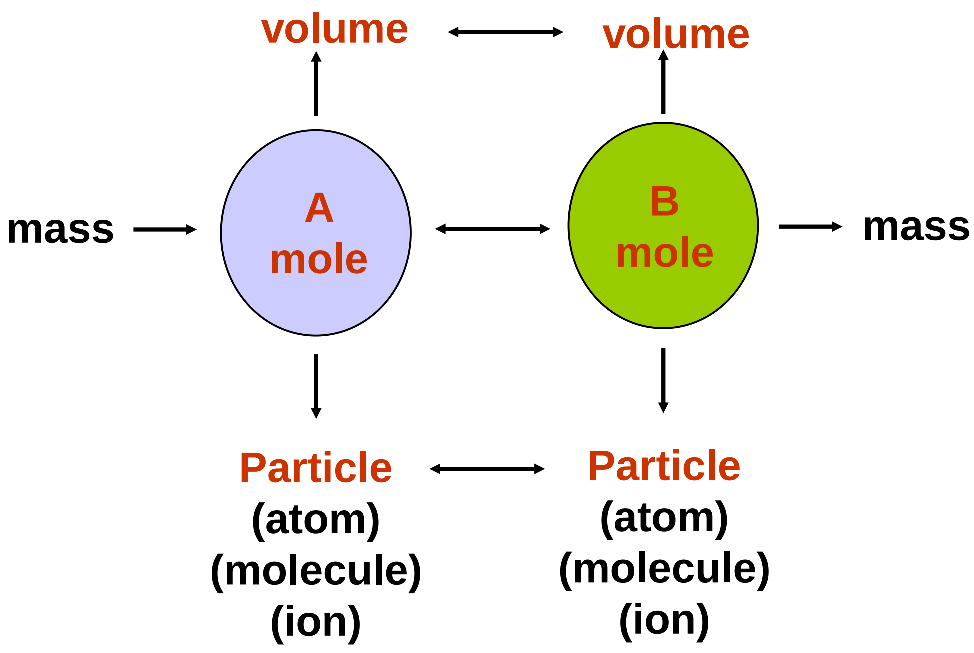


1 Step

Mole A ↔ Mole B

Volume A ↔ Volume B

# of Particles A ↔ # of Particles B



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

A B

23 mole CH_4 = ? moles H_2O

$$23\ \text{mole}\ CH_4 \left(\frac{2\ \text{moles}\ H_2O}{1\ \text{mole}\ CH_4}\right) = 46\ \text{moles}\ H_2O$$

A B

10 cc O_2 = ? cc CO_2

$$10\ \text{cc}\ O_2 \left(\frac{1\ \text{cc}\ CO_2}{2\ \text{cc}\ O_2}\right) = 5\ \text{cc}\ CO_2$$

A B

2×10^{26} molecules H_2O = ? molecules O_2

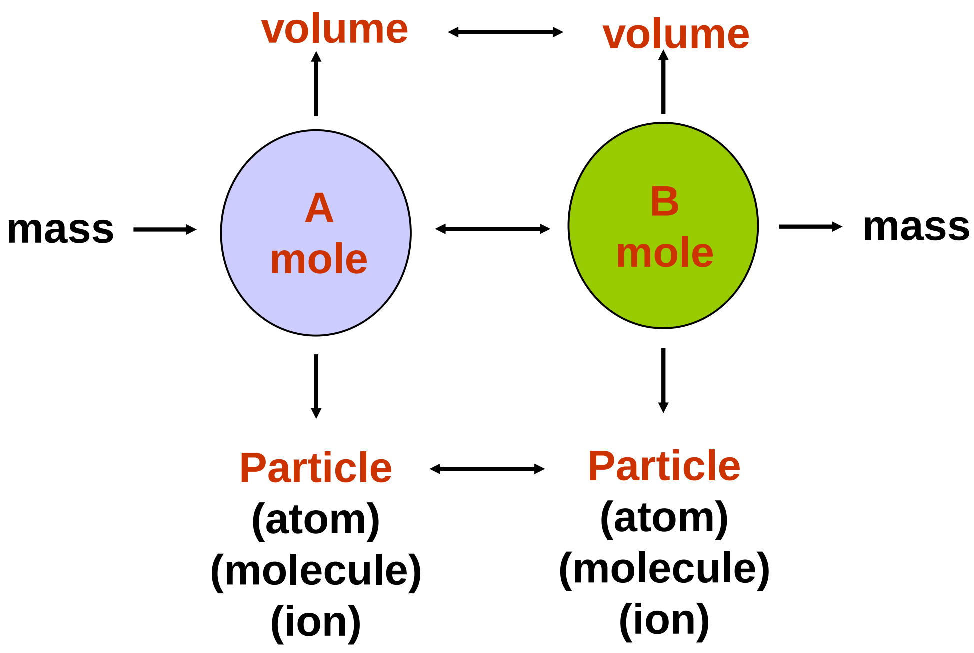
$$2\times10^{26}\ \text{molecules}\ H_2O \left(\frac{2 \times (6.02\times10^{23}\ \text{molecules}\ O_2)}{2 \times (6.02\times10^{23}\ \text{molecules}\ H_2O)}\right) = 2\times10^{26}\ \text{molecules}\ O_2$$

2 Steps

Mole A ↔ Volume B

Mass A ↔ Mole B or Volume A

# of Particles A ↔ Mole B or Volume A



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

A B

$32\ g\ CH_4 = ?\ moles\ CO_2$

$$32\ g\ CH_4 \left(\frac{1\ mole\ CH_4}{16\ g\ CH_4}\right)\left(\frac{1\ mole\ CO_2}{1\ mole\ CH_4}\right) = 2.0\ mole\ CO_2$$

A A

$40.\ g\ CH_4 = ?\ L\ CH_4$

$$40.\ g\ CH_4 \left(\frac{1\ mole\ CH_4}{16\ g\ CH_4}\right)\left(\frac{22.4\ L\ CH_4}{1\ mole\ CH_4}\right) = 56\ L\ CH_4$$

STP: **1 mole of substance (gas) = 22.4 L = 22400 cc (cm^3 or mL)**

A B

$5\ moles\ CO_2 = ?\ molecules\ O_2$

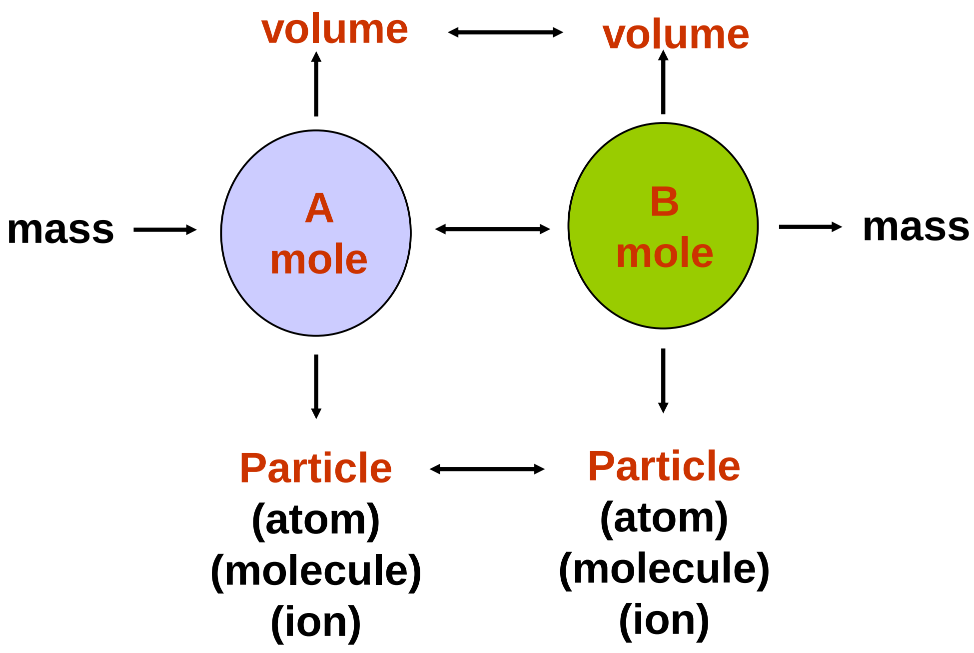
$$5\ moles\ CO_2 \left(\frac{2\ mole\ O_2}{1\ mole\ CO_2}\right)\left(\frac{6.02\times10^{23}\ molecules\ O_2}{1\ mole\ O_2}\right) = 6\times10^{24}\ molecules\ O_2$$

3 Steps

Mass A ↔ Mass B

Mass A ↔ Volume B or # of Particles B

# of Particles A ↔ Volume B



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

A B

46.0 g CH_4 = ? g H_2O

$$46.0\ g\ CH_4 \left(\frac{1\ mole\ CH_4}{16\ g\ CH_4}\right)\left(\frac{2\ mole\ H_2O}{1\ mole\ CH_4}\right)\left(\frac{18\ g\ H_2O}{1\ mole\ H_2O}\right) = 104\ g\ H_2O$$

Limiting Reagents

$$N_2(g) + O_2(g) \rightarrow 2NO(g)$$

	$N_2(g)$	$O_2(g)$	$2NO(g)$
Stoichiometry:	1 mole	1 mole	2 moles
Before reaction:	1 mole	4 moles	
After reaction:	0 mole	3 moles	2 moles

Limiting Reagents

$$N_2(g) + O_2(g) \rightarrow 2NO(g)$$

	$N_2(g)$	$O_2(g)$	$2NO(g)$
Stoichiometry:	1 mole	1 mole	2 moles
Before reaction:	1 mole	4 moles	
After reaction:	0 mole	3 moles	2 moles

Used up first (0 mole) — **Left over** (3 moles)

Limiting Reagents

Limiting reagent → $N_2(g)$

$$N_2(g) + O_2(g) \rightarrow 2NO(g)$$

	$N_2(g)$	$O_2(g)$	$2NO(g)$
Stoichiometry:	1 mole	1 mole	2 moles
Before reaction:	1 mole	4 moles	
After reaction:	0 mole	3 moles	2 moles

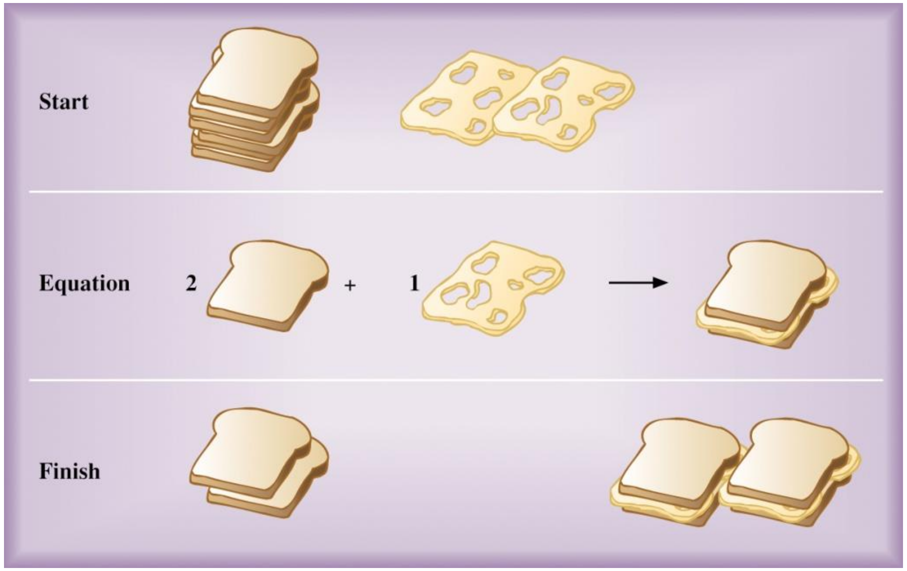
Used up first (0 mole)

Left over (3 moles)

Limiting Reagents

Limiting reagent: is the reactant that is used up first.

Limiting reagents can control a reaction:



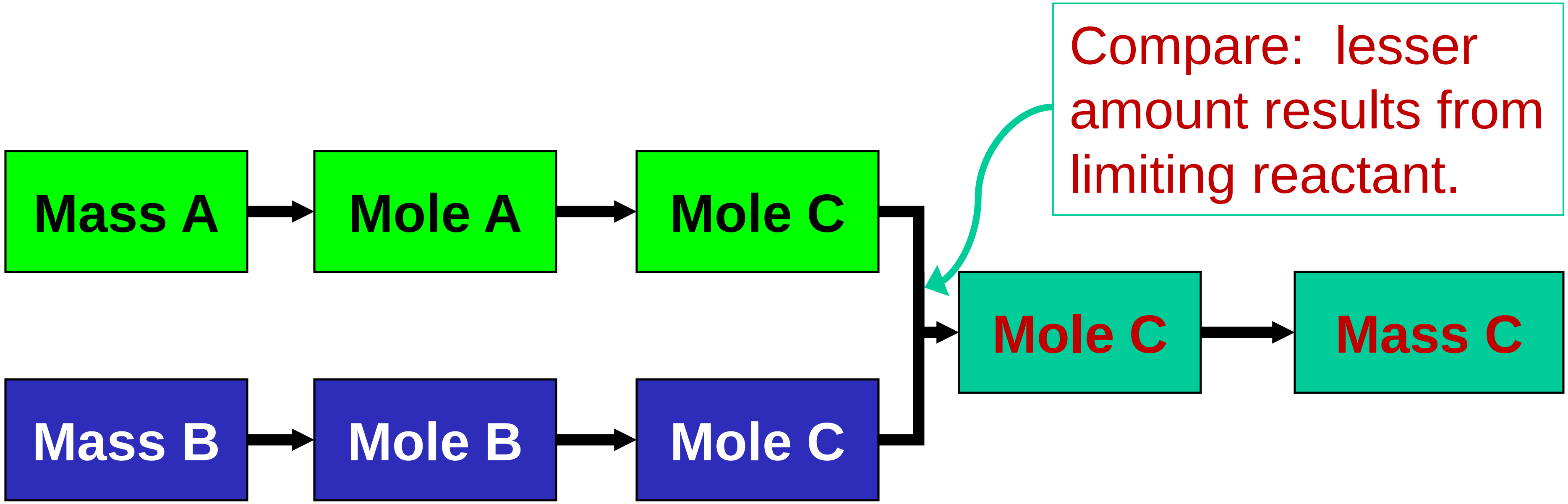
$$N_2(g) + O_2(g) \rightarrow 2NO(g)$$

Limiting Reagents

- To solve these problems, follow these steps:

$$A + B \rightarrow C + D$$

  - Convert reactant A to moles of C (or D).
  - Convert reactant B to moles of C (or D).
  - Compare moles of C (or D) produced by A and B.



Limiting Reagents

Example:

$$2\ Al(s) + 3\ Cl_2(g) \rightarrow 2\ AlCl_3(s)$$

A chemist combines 10.0 g of each reactant. Which is the limiting reagent?

$$10.0\ g\ Al \times \frac{1\ mol\ Al}{26.98\ g\ Al} \times \frac{2\ mol\ AlCl_3}{2\ mol\ Al} = \mathbf{0.371\ mol\ AlCl_3}$$

$$\boxed{10.0\ g\ Cl_2} \times \frac{1\ mol\ Cl_2}{70.9\ g\ Cl_2} \times \frac{2\ mol\ AlCl_3}{3\ mol\ Cl_2} = \boxed{\mathbf{0.0940\ mol\ AlCl_3}}$$

The *smallest* number is the result of the limiting reactant. So, **Cl_2 is the limiting reactant**.

Limiting Reagents

2. What mass of product is produced (in g)?

$$2\ Al(s) + 3\ Cl_2(g) \rightarrow 2\ AlCl_3(s)$$

$$0.0940 \text{ mol } AlCl_3 \times \frac{133.33 \text{ g } AlCl_3}{1 \text{ mol } AlCl_3} = \boxed{\mathbf{12.54\ g\ AlCl_3}}$$

3.What species are present in the final mixture?

$AlCl_3$*(s)* and some left-over Al*(s)* are present.

Limiting Reagents

4. How much Al*(s)* remains?

$$2\ \mathrm{Al}(s) + 3\ \mathrm{Cl_2}(g) \rightarrow 2\ \mathrm{AlCl_3}(s)$$

Limiting reagent

$$10.0\ \mathrm{g\ Cl_2} \times \frac{1\ \mathrm{mol\ Cl_2}}{70.9\ \mathrm{g\ Cl_2}} \times \frac{2\ \mathrm{mol\ Al}}{3\ \mathrm{mol\ Cl_2}} \times \frac{26.98\ \mathrm{g\ Al}}{1\ \mathrm{mol\ Al}} = \mathbf{2.54\ g\ Al}$$

(reacted)

- 10.0 g original – 2.54 g used = **7.46 g Al*(s)*** remains

Limiting Reagents

Example:

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$$

1. A chemist combines 10.0 g of each reactant. Which is the limiting reagent?

2. What mass of each product is produced (in g)?

3. What species are present in the final mixture?

Limiting Reagents

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$$

1. A chemist combines 10.0 g of each reactant. Which is the limiting reagent?

$$10.0\text{ g } C_3H_8 \times \frac{1\text{ mol } C_3H_8}{44.09\text{ g } C_3H_8} \times \frac{3\text{ mol } CO_2}{1\text{ mol } C_3H_8} = \mathbf{0.680\ mol\ CO_2}$$

$$\boxed{10.0\text{ g } O_2} \times \frac{1\text{ mol } O_2}{32.00\text{ g } O_2} \times \frac{3\text{ mol } CO_2}{5\text{ mol } O_2} = \boxed{\mathbf{0.188\ mol\ CO_2}}$$

The *smallest* number is the result of the limiting reactant. So, **O_2 is the limiting reactant**.

Limiting Reagents

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$$

2.What mass of each product is produced (in g)?

$$0.188\text{ mol } CO_2 \times \frac{44.01\text{ g } CO_2}{1\text{ mol } CO_2} = \boxed{\mathbf{8.27\text{ g } CO_2}}$$

$$10.0\text{ g } O_2 \times \frac{1\text{ mol } O_2}{32.00\text{ g } O_2} \times \frac{4\text{ mol } H_2O}{5\text{ mol } O_2} \times \frac{18.016\text{ g } H_2O}{1\text{ mol } H_2O} = \boxed{\mathbf{4.50\text{ g } H_2O}}$$

Limiting reagent

3.What species are present in the final mixture?

$CO_2(g)$, $H_2O(g)$ and some remaining $C_3H_8(g)$.

Limiting Reagents

Example:

$$CS_2(l) + 3\ O_2(g) \rightarrow CO_2(g) + 2\ SO_2(g)$$

- You have 1.55 g of $CS_2(l)$ and excess $O_2(g)$. What mass of each product forms?

$$1.55 \text{ g } CS_2 \times \frac{1 \text{ mol } CS_2}{76.15 \text{ g } CS_2} \times \frac{1 \text{ mol } CO_2}{1 \text{ mol } CS_2} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = \boxed{\mathbf{0.896 \text{ g } CO_2}}$$

$$1.55 \text{ g } CS_2 \times \frac{1 \text{ mol } CS_2}{76.15 \text{ g } CS_2} \times \frac{2 \text{ mol } SO_2}{1 \text{ mol } CS_2} \times \frac{64.07 \text{ g } SO_2}{1 \text{ mol } SO_2} = \boxed{\mathbf{2.61 \text{ g } SO_2}}$$

Percent Yield

Percentage yield: a comparison of actual to theoretical yield.

$$\text{Percent yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100\%$$

actual yield: **mass of product formed (exprimental determination)**

theoretical yield: **mass of product that should form according to limiting reactant calculation. (according to stoichiometry)**

Note: percentage yields can be calculated using units of either moles or grams.

Percent Yield

Example:

- Analysis for sulfate (SO_4^{2-}) uses barium cation (Ba^{2+}).

$$SO_4^{2-}(aq) + BaCl_2(aq) \rightarrow BaSO_4(s) + 2\ Cl^-(aq)$$

- If a sample containing 1.15 g of SO_4^{2-} is reacted with excess barium chloride, how much $BaSO_4$ should form? If a chemist actually collects 2.02 g $BaSO_4$, what is the percent yield?

Percent Yield

How much $BaSO_4$ should form?

$$SO_4^{2-}(aq) + BaCl_2(aq) \rightarrow BaSO_4(s) + 2\ Cl^-(aq)$$

$$1.15\ g\ SO_4^{2-} \times \frac{1\ mol\ SO_4^{2-}}{96.07\ g\ SO_4^{2-}} \times \frac{1\ mol\ BaSO_4}{1\ mol\ SO_4^{2-}} \times \frac{233.37\ g\ BaSO_4}{1\ mol\ BaSO_4} = \mathbf{2.79\ g}\ BaSO_4$$

- If a chemist actually collects 2.02 g $BaSO_4$, what is the percent yield?

$$P.Y.\% = \frac{2.02\ g\ BaSO_4}{2.79\ g\ BaSO_4} \times 100\% = \mathbf{72.4\ \%}$$

At-Home Practice

- **Practice problem:** A chemist reacts 7.67 g of H_2 gas with 30.46 g of O_2 gas. What is the theoretical yield of water in grams? (Limiting reactant calculation.)
- The actual experimentally measured amount is only 28.6 g of H_2O. What is the percent yield?
- Next lecture, our clicker questions will be:
  - ❖ What is the theoretical yield?
  - ❖ What is the percent yield?