

# Outline

- Chemical Calculations
- Limiting Reactant
- Heat of Reaction

# Chemical Calculations

Stoichiometry is the study of numerical relationships in chemical reactions

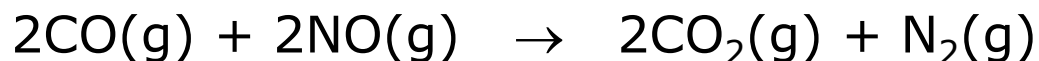
Coefficients in balanced chemical equations used to generate mol-mol relationships...



$$\frac{1 \text{ mol P}_4\text{O}_{10}}{4 \text{ mol H}_3\text{PO}_4} \quad \text{and} \quad \frac{4 \text{ mol H}_3\text{PO}_4}{1 \text{ mol P}_4\text{O}_{10}}$$

Mole ratios used to relate one chemical species to another in chemical calculations

Two air pollutants in car exhaust are CO and NO. These pollutants react within the car's catalytic converter to form CO<sub>2</sub> and N<sub>2</sub>.



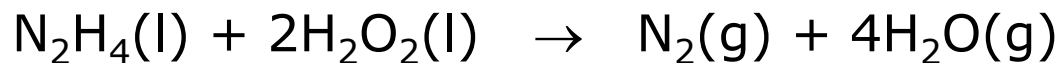
How many mol of N<sub>2</sub> are produced from 3.50 mol CO?

$$3.50 \text{ mol CO} \times \frac{1 \text{ mol N}_2}{2 \text{ mol CO}} = \underline{1.75 \text{ mol N}_2}$$

How many mol of NO are needed to react with 2.31 mol CO?

$$2.31 \text{ mol CO} \times \frac{2 \text{ mol NO}}{2 \text{ mol CO}} = \underline{2.31 \text{ mol NO}}$$

A mixture of hydrazine ( $\text{N}_2\text{H}_4$ ) and hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) is used as a fuel for rocket engines. These substances react as follows:



How many mol of  $\text{N}_2\text{H}_4$  will react to form 2.58 mol  $\text{H}_2\text{O}$ ?

$$2.58 \text{ mol H}_2\text{O} \times \frac{1 \text{ mol N}_2\text{H}_4}{4 \text{ mol H}_2\text{O}} = \underline{0.645 \text{ mol N}_2\text{H}_4}$$

How many mol of  $\text{H}_2\text{O}_2$  are needed to react with 1.25 mol  $\text{N}_2\text{H}_4$ ?

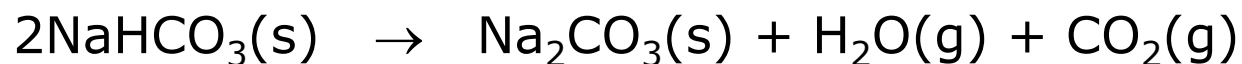
$$1.25 \text{ mol N}_2\text{H}_4 \times \frac{2 \text{ mol H}_2\text{O}_2}{1 \text{ mol N}_2\text{H}_4} = \underline{2.50 \text{ mol H}_2\text{O}_2}$$

Chemical equations are also used to relate masses...

General steps:

1. write balanced chemical equation
2. convert mass to mol
3. obtain mol ratio
4. perform calculation
5. convert mol to mass

When baking soda ( $\text{NaHCO}_3$ ) is heated, it decomposes, producing carbon dioxide. The carbon dioxide is responsible for the rising of the dough. How many grams of  $\text{CO}_2$  are produced from 1.0 g of  $\text{NaHCO}_3$ ?



$$1.0 \text{ g NaHCO}_3 \times \frac{1 \text{ mol}}{84.01 \text{ g}} = 0.0119 \text{ mol NaHCO}_3$$

$$0.0119 \text{ mol NaHCO}_3 \times \frac{1 \text{ mol CO}_2}{2 \text{ mol NaHCO}_3} = 0.00595 \text{ mol CO}_2$$

$$0.00595 \text{ mol CO}_2 \times \frac{44.01 \text{ g}}{1 \text{ mol}} = \underline{0.26 \text{ g CO}_2}$$

Air bags inflate when sodium azide ( $\text{NaN}_3$ ) rapidly decomposes into sodium metal and nitrogen gas. How many grams of nitrogen are produced when 130 g of  $\text{NaN}_3$  decomposes?



$$130 \text{ g NaN}_3 \times \frac{1 \text{ mol}}{65.02 \text{ g}} = 1.\underline{99} \text{ mol NaN}_3$$

$$1.\underline{99} \text{ mol NaN}_3 \times \frac{3 \text{ mol N}_2}{2 \text{ mol NaN}_3} = 2.\underline{99} \text{ mol N}_2$$

$$2.\underline{99} \text{ mol N}_2 \times \frac{28.02 \text{ g}}{1 \text{ mol}} = \underline{84 \text{ g N}_2}$$

# Limiting Reactant

When mixed in stoichiometric quantities, all reactants are used up in a chemical reaction

Ordinarily, reactants are not mixed in the exact ratio required

Reactants that are...

... not used up: excess reactants

... used up: limiting reactants

Limiting reactants limit the amount of product that can form



	$\text{H}_2(\text{g})$	+	$\text{Cl}_2(\text{g})$	$\rightarrow$	$2\text{HCl}(\text{g})$
initial	1 mol		2 mol		0 mol
change	-1 mol		-1 mol		+2 mol
final	0 mol		1 mol		2 mol

$\text{H}_2$  is the limiting reactant...  $\text{Cl}_2$  is the excess reactant

To determine which reactant is limiting...

1. Calculate amount of product formed by each reactant
2. Limiting reactant will produce smallest of calculated amounts

A 50.0 g sample of calcium carbonate reacts with 13.0 g of hydrochloric acid. How many grams of calcium chloride are produced?



$$50.0 \text{ g CaCO}_3 \times \frac{1 \text{ mol}}{100.09 \text{ g}} \times \frac{1 \text{ mol CaCl}_2}{1 \text{ mol CaCO}_3} = 0.500 \text{ mol CaCl}_2$$

$$13.0 \text{ g HCl} \times \frac{1 \text{ mol}}{36.46 \text{ g}} \times \frac{1 \text{ mol CaCl}_2}{2 \text{ mol HCl}} = 0.178 \text{ mol CaCl}_2 \quad (\text{LR})$$

$$0.178 \text{ mol CaCl}_2 \times \frac{110.98 \text{ g}}{1 \text{ mol}} = \underline{19.8 \text{ g CaCl}_2} \quad (\text{TY})$$

Theoretical yield is amount of product formed when limiting reactant is completely consumed

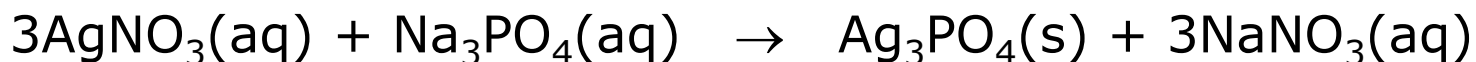
How many grams of calcium carbonate are in excess?

$$13.0 \text{ g HCl} \times \frac{1 \text{ mol}}{36.46 \text{ g}} = 0.3565 \text{ mol HCl (used)}$$

$$0.3565 \text{ mol HCl} \times \frac{1 \text{ mol CaCO}_3}{2 \text{ mol HCl}} \times \frac{100.09 \text{ g}}{1 \text{ mol}} = 17.8 \text{ g CaCO}_3 \text{ (used)}$$

$$50.0 \text{ g CaCO}_3 - 17.8 \text{ g CaCO}_3 = \underline{32.2 \text{ g CaCO}_3} \text{ (excess)}$$

How many grams of silver phosphate can be formed from mixing 1.2 g of silver nitrate and 4.8 g of sodium phosphate?



$$1.2 \text{ g AgNO}_3 \times \frac{1 \text{ mol}}{169.88 \text{ g}} \times \frac{1 \text{ mol Ag}_3\text{PO}_4}{3 \text{ mol AgNO}_3} = 0.00235 \text{ mol Ag}_3\text{PO}_4 \quad (\text{LR})$$

$$4.8 \text{ g Na}_3\text{PO}_4 \times \frac{1 \text{ mol}}{163.94 \text{ g}} \times \frac{1 \text{ mol Ag}_3\text{PO}_4}{1 \text{ mol Na}_3\text{PO}_4} = 0.0292 \text{ mol Ag}_3\text{PO}_4$$

$$0.00235 \text{ mol Ag}_3\text{PO}_4 \times \frac{418.58 \text{ g}}{1 \text{ mol}} = 0.98 \text{ g Ag}_3\text{PO}_4 \quad (\text{TY})$$

Actual yield is the amount of product that is actually obtained

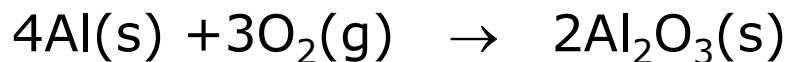
Percent yield is the percent of theoretical yield that is actually obtained

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

What is the percent yield if only 0.82 g  $\text{Ag}_3\text{PO}_4$  are obtained?

$$\begin{aligned} \% \text{ Yield} &= \frac{0.82 \text{ g}}{0.98 \text{ g}} \times 100 \\ &= \underline{84\% \text{ Yield}} \end{aligned}$$

Aluminum and oxygen react to form aluminum oxide. In an experiment 75.0 g of Al and 200.0 g of O<sub>2</sub> produce 125 g of Al<sub>2</sub>O<sub>3</sub>.



What is the theoretical yield (in g) of Al<sub>2</sub>O<sub>3</sub>?

$$75.0 \text{ g Al} \times \frac{1 \text{ mol}}{26.98 \text{ g}} \times \frac{2 \text{ mol Al}_2\text{O}_3}{4 \text{ mol Al}} = 1.389 \text{ mol Al}_2\text{O}_3 \quad (\text{LR})$$

$$200.0 \text{ g O}_2 \times \frac{1 \text{ mol}}{32.00 \text{ g}} \times \frac{2 \text{ mol Al}_2\text{O}_3}{3 \text{ mol O}_2} = 4.1666 \text{ mol Al}_2\text{O}_3$$

$$1.389 \text{ mol Al}_2\text{O}_3 \times \frac{101.96 \text{ g}}{1 \text{ mol}} = \underline{142 \text{ g Al}_2\text{O}_3} \quad (\text{TY})$$

What is the percent yield of  $\text{Al}_2\text{O}_3$ ?

$$\% \text{ Yield} = \frac{125 \text{ g}}{142 \text{ g}} \times 100 = \underline{88.0 \% \text{ Yield}}$$

How many grams of  $\text{O}_2$  are in excess?

$$75.0 \text{ g Al} \times \frac{1 \text{ mol}}{26.98 \text{ g}} = 2.779 \text{ mol Al} \quad (\text{used})$$

$$2.779 \text{ mol Al} \times \frac{3 \text{ mol O}_2}{4 \text{ mol Al}} \times \frac{32.00 \text{ g}}{1 \text{ mol}} = 66.71 \text{ g O}_2 \quad (\text{used})$$

$$200.0 \text{ g O}_2 - 66.71 \text{ g O}_2 = \underline{133.3 \text{ g O}_2} \quad (\text{excess})$$

# Heat of Reaction

Bonds are broken and formed in chemical reactions...

Energy absorbed in breaking bonds, and released in forming bonds

Energy balance determines net loss or net gain of energy

The energy change in a reaction is the heat of reaction

Heat of reaction is also known as enthalpy change ( $\Delta H$ )

$\Delta H$  is +:            endothermic

$\Delta H$  is -:            exothermic



Endothermic reactions proceed with net gain of energy

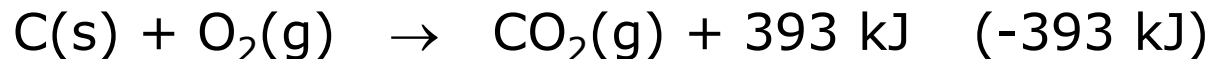
energy is “reactant”... requires continuous input of energy



the surroundings cool down

Exothermic reactions proceed with net loss of energy

energy is “product”... energy continuously released



the surroundings warm up

How many kilojoules of energy are released when 10.0 g of hydrogen react with an excess of oxygen?



$$10.0 \text{ g H}_2 \times \frac{1 \text{ mol H}_2}{2.016 \text{ g H}_2} \times \frac{-484 \text{ kJ}}{2 \text{ mol H}_2} = \underline{-1200 \text{ kJ}}$$

How many grams of water are produced in a reaction that releases 36.3 kJ of energy?

$$-36.3 \text{ kJ} \times \frac{2 \text{ mol H}_2\text{O}}{-484 \text{ kJ}} \times \frac{18.02 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = \underline{2.70 \text{ g H}_2\text{O}}$$