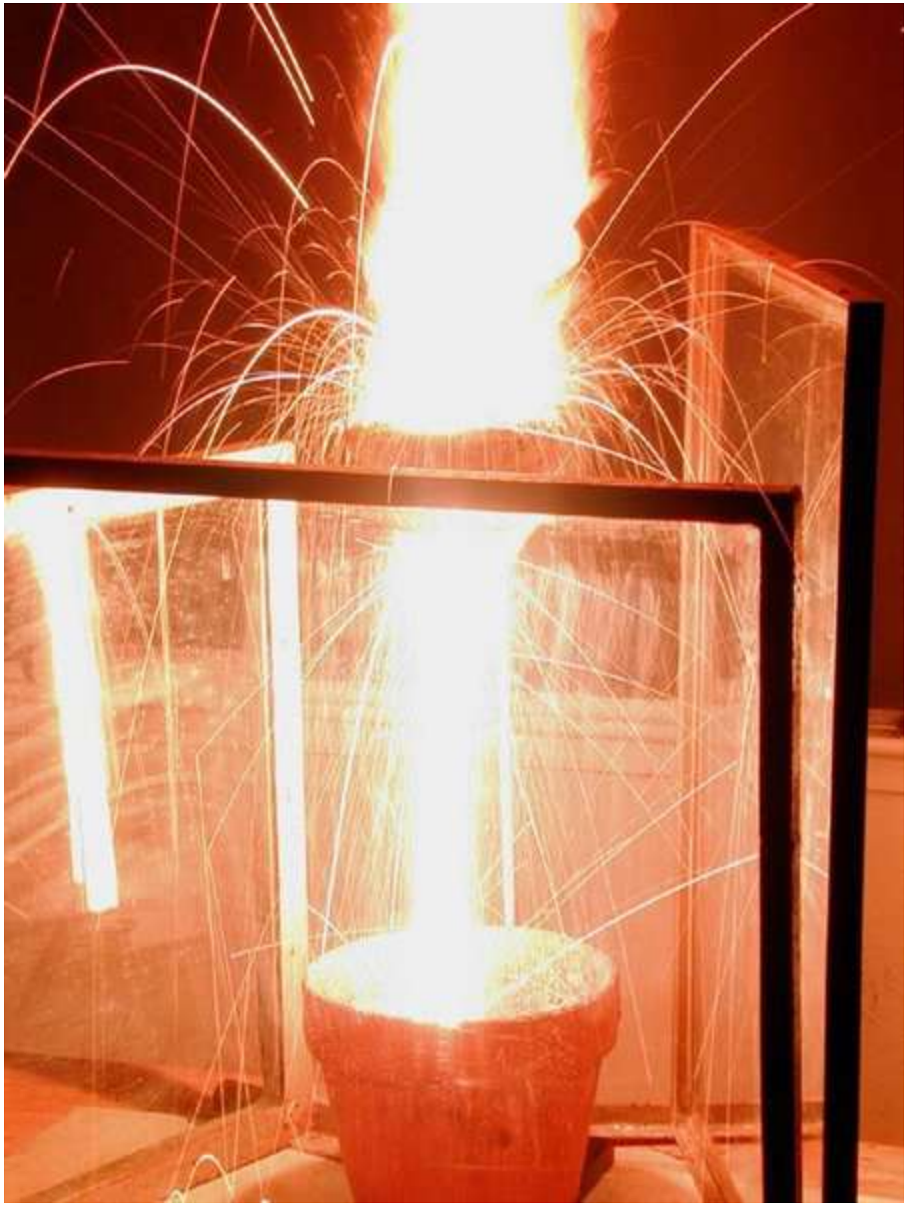
AP Chemistry Stoichiometry

In the thermite reaction, a mixture of powdered aluminum and powdered iron(III) oxide react to yield iron and aluminum oxide. The reaction burns hot enough to be useful in under-water welding.

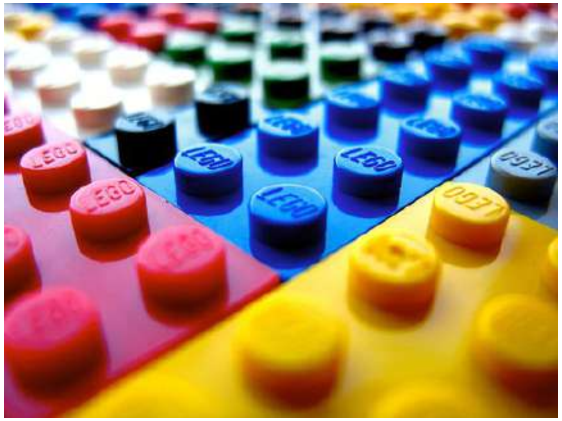


$$2\,Al + Fe_2O_3 \rightarrow 2\,Fe + Al_2O_3 + \text{energy}$$

Chemical Equations

In a reaction:

atoms are rearranged



AND

mass
energy
charge } are conserved

Balancing Chemical Equations

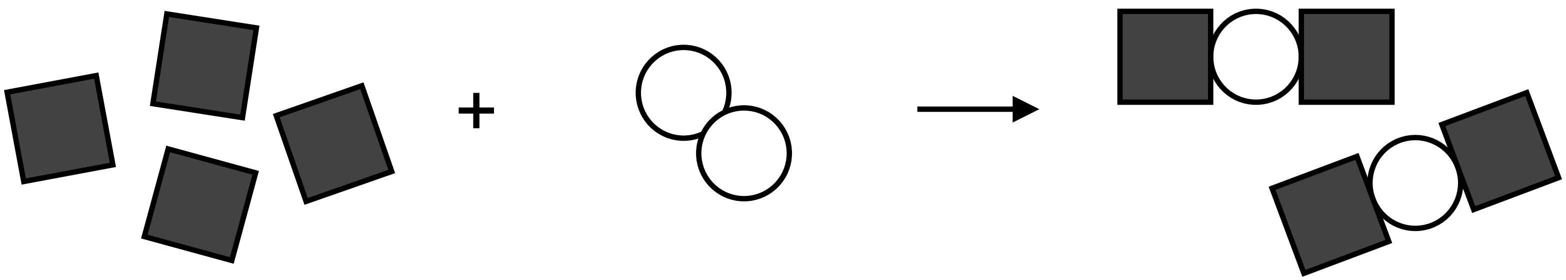
law of conservation of mass	=	same # of atoms of each type on each side of equation

Hint: Start with most complicated substances first and leave simplest substances for last.

Solid lithum reacts w/oxygen to form solid lithium oxide.

Li^{+} O^{2-}

$$4\ Li(s) + O_2(g) \longrightarrow 2\ Li_2O(s)$$



Aqueous aluminum sulfate reacts w/aqueous barium chloride to form a white precipitate of barium sulfate. The other compound remains in solution.

Al^{3+} SO_4^{2-} Ba^{2+} Cl^{-}

$$Al_2(SO_4)_3\,(aq) + 3\ BaCl_2\,(aq) \rightarrow 3\ BaSO_4\,(s) + 2\ AlCl_3\,(aq)$$

Methane gas (CH_4) reacts with oxygen to form carbon dioxide gas and water vapor.

Furnaces burn primarily methane.

$$CH_4(g) + 2\,O_2(g) \longrightarrow CO_2(g) + 2\,H_2O(g)$$

$$CaC_2(s) + H_2O(l) \longrightarrow C_2H_2(g) + CaO(s)$$

$$3\,CaSi_2 + 2\,SbI_3 \longrightarrow 6\,Si + 2\,Sb + 3\,CaI_2$$

$$2\,Al + 6\,CH_3OH \longrightarrow 2\,Al(CH_3O)_3 + 3\,H_2$$

$$2\ C_2H_2(g) + 5\ O_2(g) \longrightarrow 4\ CO_2(g) + 2\ H_2O(l)$$

$$C_3H_8 + 5\ O_2 \longrightarrow 3\ CO_2 + 4\ H_2O$$

$$2\ C_4H_{10} + 13\ O_2 \longrightarrow 8\ CO_2 + 10\ H_2O$$

Complete combustion of a <u>hydrocarbon</u>, or of a compound containing C, H, and O (e.g., methanol, CH_3OH) yields CO_2 and H_2O.

Another pattern of reactivity:

alkali metal + water ⟶ metal hydroxide + hydrogen gas

e.g., $2\ Rb(s) + 2\ H_2O(l) \rightarrow 2\ RbOH(aq) + H_2(g)$

$$2\ C_2H_2(g) + 5\ O_2(g) \longrightarrow 4\ CO_2(g) + 2\ H_2O(l)$$

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Two (of the several) Types of Reactions

combination (synthesis): simpler substances combine to form more complex substances

-- form:

$A + B \rightarrow AB$ $AB + C \rightarrow ABC$ $A + B + C \rightarrow ABC$

sodium + chlorine gas → sodium chloride

$$2\ Na + Cl_2 \longrightarrow 2\ NaCl$$

decomposition: complex substances are broken down into simpler ones

-- form:

$AB \rightarrow A + B$ $ABC \rightarrow AB + C$ $ABC \rightarrow A + B + C$

lithium chlorate → lithium chloride + oxygen

Li^{+} ClO_3^{-} Li^{+} Cl^{-}

$$2\ LiClO_3 \longrightarrow 2\ LiCl + 3\ O_2$$

water → hydrogen gas + oxygen gas

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

formula weight: the mass of all of the atoms in a chemical formula (unit is amu)

-- If the substance is a molecular substance (e.g., C_3H_8), then the term molecular weight is also used.

molar mass: the mass of one mole of a substance (unit is usually grams)

-- recall that 1 mole of any substance = particles of that substance formula weight: the mass of all of the atoms in a chemical formula (unit is amu)

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molar mass: the mass of one mole of a substance (unit is usually grams)

-- recall that 1 mole of any substance = 6.02×10^{23} particles of that substance

Find the molar mass and formula weight of ammonium phosphate.

NH_4^+ PO_4^{3-}

$(NH_4)_3PO_4$

N: 3 (14.0 g) = 42.0 g

H: 12 (1.0 g) = 12.0 g

P: 1 (31.0 g) = 31.0 g

O: 4 (16.0 g) = 64.0 g

m.m. = 149.0 g

f.w. = 149.0 amu

percentage composition: the mass % of each element in a compound

equation:

$$\% \text{ of element} = \frac{\text{g element}}{\text{molar mass of compound}} \times 100$$

Find the percentage of oxygen, by mass, in calcium nitrate.

$Ca(NO_3)_2$

$$\% \text{ O} = \frac{6(16.0)}{40.1 + 2(14.0) + 6(16.0)} = 58.5\% \text{ O}$$

Empirical Formula and Molecular Formula

Empirical Formula: lowest-terms formula

Molecular Formula: shows the true number and type of atoms in a m'cule

Compound	Molecular Formula	Empirical Formula
glucose	$C_6H_{12}O_6$	CH_2O
propane	C_3H_8	C_3H_8
butane	C_4H_{10}	C_2H_5
naphthalene	$C_{10}H_8$	C_5H_4
sucrose	$C_{12}H_{22}O_{11}$	$C_{12}H_{22}O_{11}$
octane	C_8H_{18}	C_4H_9

Finding an Empirical Formula from Experimental Data

1. Find # of g of each element.
2. Convert each g to mol.
3. Divide each "# of mol" by the smallest "# of mol."
4. Use ratio to find formula.

"What's your flavor of ice cream?"

A ruthenium/sulfur compound is 67.7% Ru. Find its empirical formula.

$$67.7\ \text{g Ru}\left(\frac{1\ \text{mol Ru}}{101.1\ \text{g Ru}}\right) = 0.670\ \text{mol Ru} \quad \div\ 0.670 \ \rightarrow\ 1$$

$$32.3\ \text{g S}\left(\frac{1\ \text{mol S}}{32.1\ \text{g S}}\right) = 1.006\ \text{mol S} \quad \div\ 0.670 \ \rightarrow\ 1.5$$

$$RuS_{1.5} \longrightarrow \boxed{Ru_2S_3}$$

A sample of a compound contains 4.63 g lead, 1.25 g nitrogen, and 2.87 g oxygen. Name the compound.

$$4.63\ \text{g Pb}\left(\frac{1\ \text{mol Pb}}{207.2\ \text{g Pb}}\right) = 0.0223\ \text{mol Pb} \div 0.0223 \rightarrow 1$$

$$1.25\ \text{g N}\left(\frac{1\ \text{mol N}}{14.0\ \text{g N}}\right) = 0.0893\ \text{mol N} \div 0.0223 \rightarrow 4$$

$$2.87\ \text{g O}\left(\frac{1\ \text{mol O}}{16.0\ \text{g O}}\right) = 0.1794\ \text{mol O} \div 0.0223 \rightarrow 8$$

? PbN_4O_8 ?

$Pb(NO_2)_4$

$Pb^{?}$ $4\ NO_2^-$

lead(IV) nitrite

To find molecular formula…

A. Find empirical formula. ("What's your flavor?")

B. Find molar mass of empirical formula.

C. Find $n = \frac{\text{mm molecular}}{\text{mm empirical}}$

D. Multiply all parts of empirical formula by n. ("How many scoops?")

(How many empiricals "fit into" the molecular?)

A sample of a compound has 26.33 g nitrogen, 60.20 g oxygen, and molar mass 92 g. Find molecular formula.

$$26.33\ \cancel{g}\,N \left(\frac{1\ \text{mol N}}{14.0\ \cancel{g}\,N}\right) = 1.881\ \text{mol N} \div 1.881 \rightarrow 1$$

$$60.20\ \cancel{g}\,O \left(\frac{1\ \text{mol O}}{16.0\ \cancel{g}\,O}\right) = 3.763\ \text{mol O} \div 1.881 \rightarrow 2$$

$\underline{NO_2}$

$$mm_{emp} = 46\ g \longrightarrow \frac{92\ g}{46\ g} = 2 \longrightarrow N_2O_4$$

Hydrates and Anhydrous Salts

anhydrous salt: an ionic compound (i.e., a salt) that attracts water molecules and forms weak chemical bonds with them; symbolized by MN

"anhydrous" = "without water"

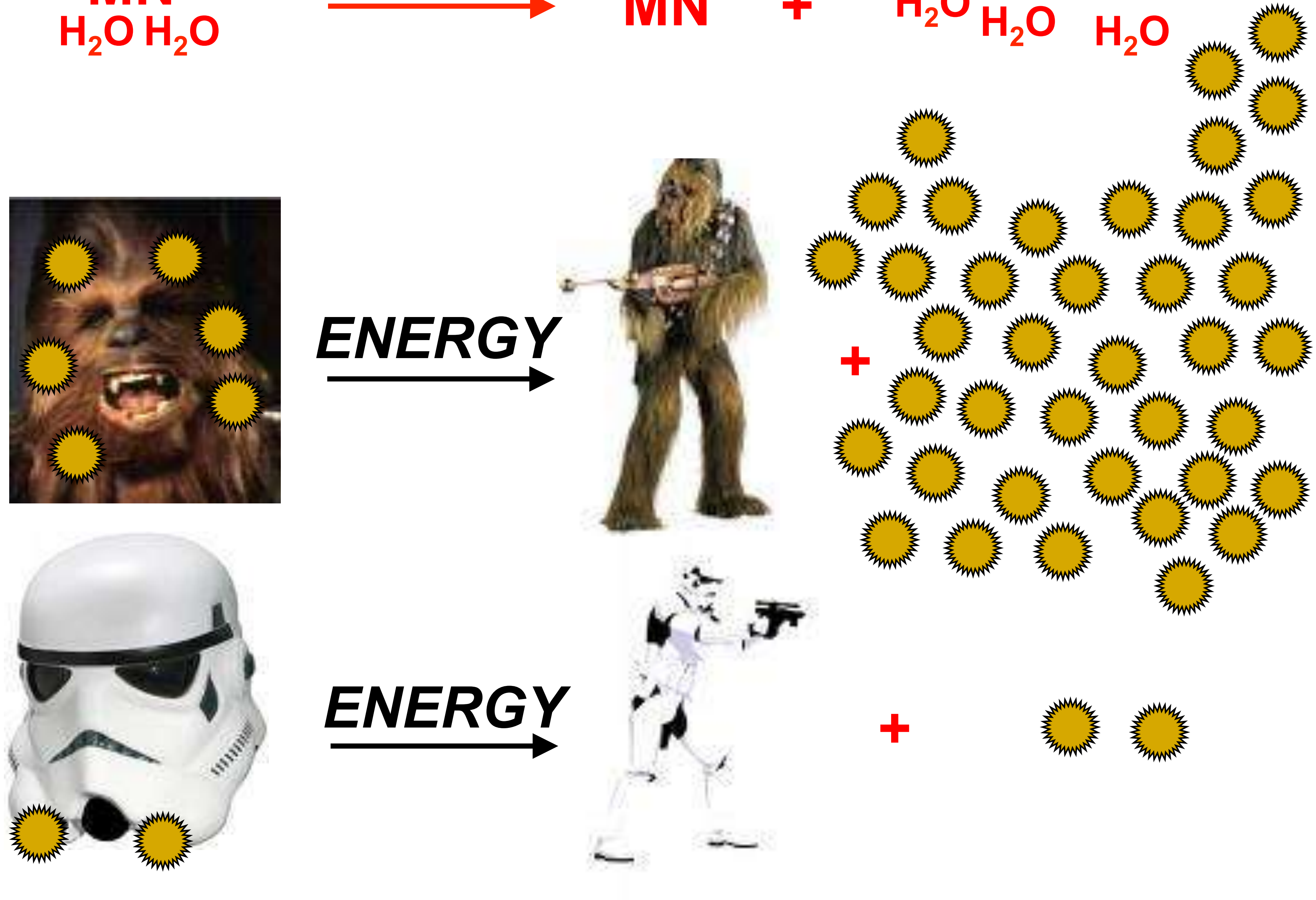
Same idea as with… desiccants in leather goods, electronics, vitamins

hydrate: an anhydrous salt with the water attached

-- symbolized by MN · ? H_2O

Examples: $CuSO_4 \cdot 5\ H_2O$ $BaCl_2 \cdot 2\ H_2O$ $Na_2CO_3 \cdot 10\ H_2O$ $FeCl_3 \cdot 6\ H_2O$

$$[MN \cdot 6H_2O] \xrightarrow{HEAT} MN + 6H_2O$$



Finding the Formula of a Hydrate

1. Find the # of g of MN and # of g of H_2O.
2. Convert g to mol.
3. Divide each “# of mol” by the smallest “# of mol.”
4. Use the ratio to find the hydrate’s formula.

Strontium chloride is an anhydrous salt on which the following data were collected. Find formula of hydrate.

beaker = 65.2 g

beaker + sample before heating = 187.9 g

beaker + sample after heating = 138.2 g

beaker + salt + water

beaker + salt

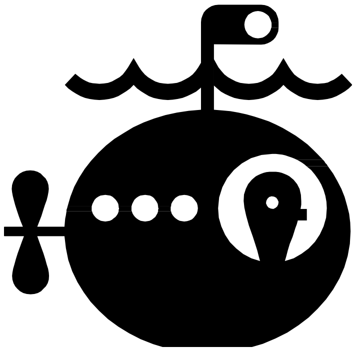
Sr^{2+} Cl^{-} $SrCl_2$

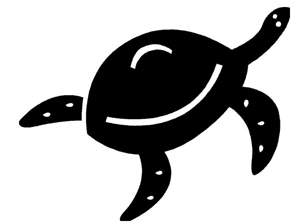
$$73.0\ \cancel{\text{g MN}}\left(\frac{1\ \text{mol MN}}{158.6\ \cancel{\text{g MN}}}\right) = 0.46\ \text{mol MN} \div 0.46 \rightarrow 1$$

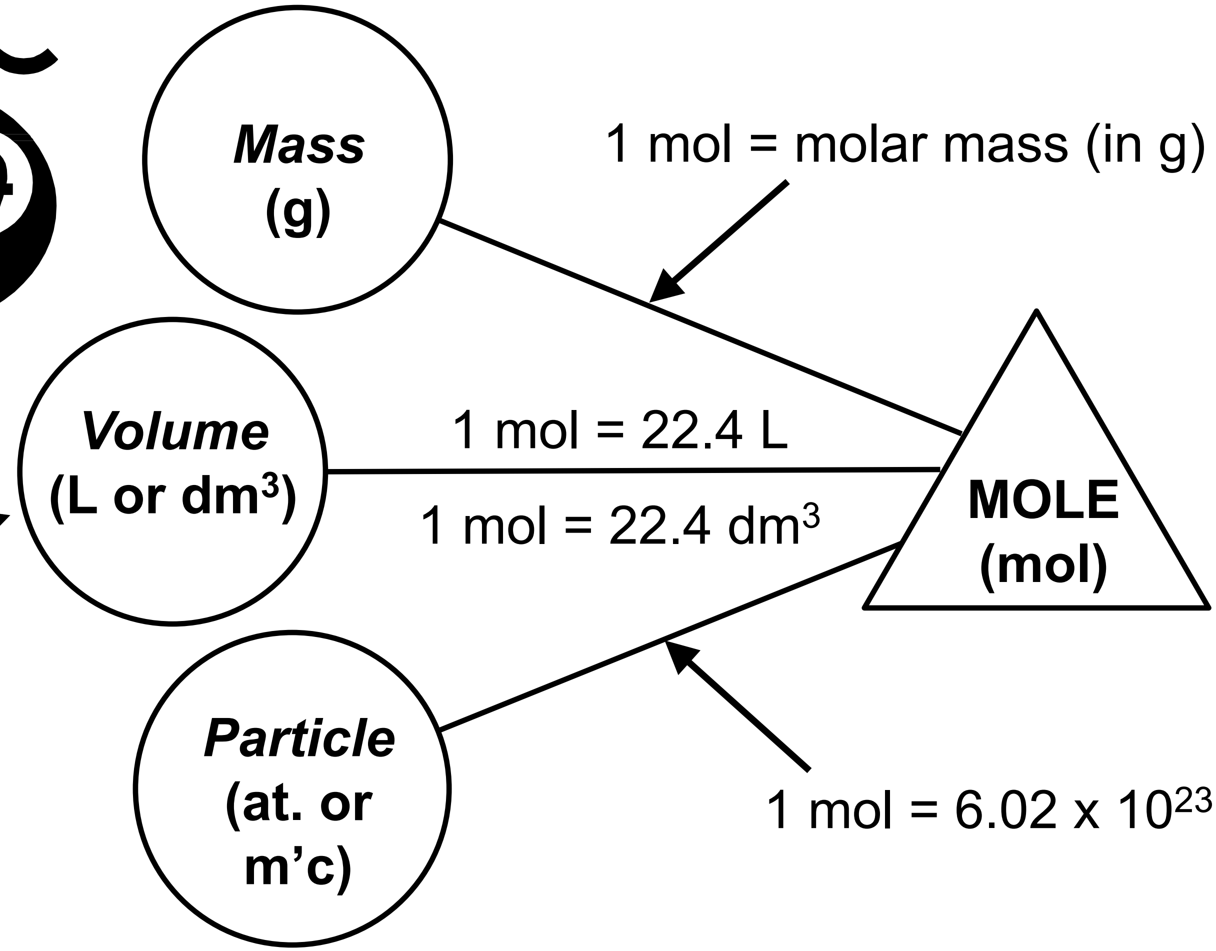
$$49.7\ \cancel{\text{g } H_2O}\left(\frac{1\ \text{mol } H_2O}{18\ \cancel{\text{g } H_2O}}\right) = 2.76\ \text{mol } H_2O \div 0.46 \rightarrow 6$$

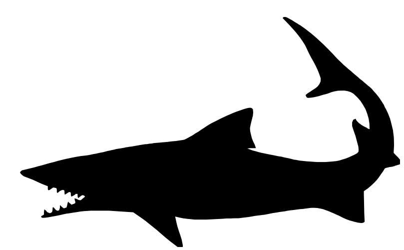
$SrCl_2 \cdot 6\ H_2O$

Converting Between Various Units







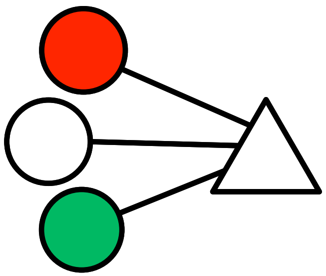


One-Substance Island Diagram

What mass is 6.29×10^{24} m'cules aluminum sulfate ?

Al^{3+} SO_4^{2-}

$Al_2(SO_4)_3$

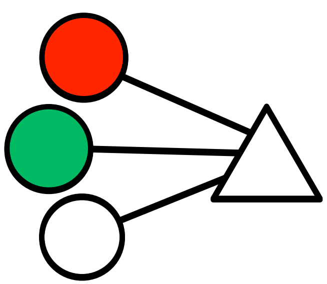


$$6.29 \times 10^{24}\ \text{m'c} \left(\frac{1\ \text{mol}}{6.02 \times 10^{23}\ \text{m'c}}\right)\left(\frac{342.3\ \text{g}}{1\ \text{mol}}\right)$$

$$= \boxed{3580\ \text{g}}$$

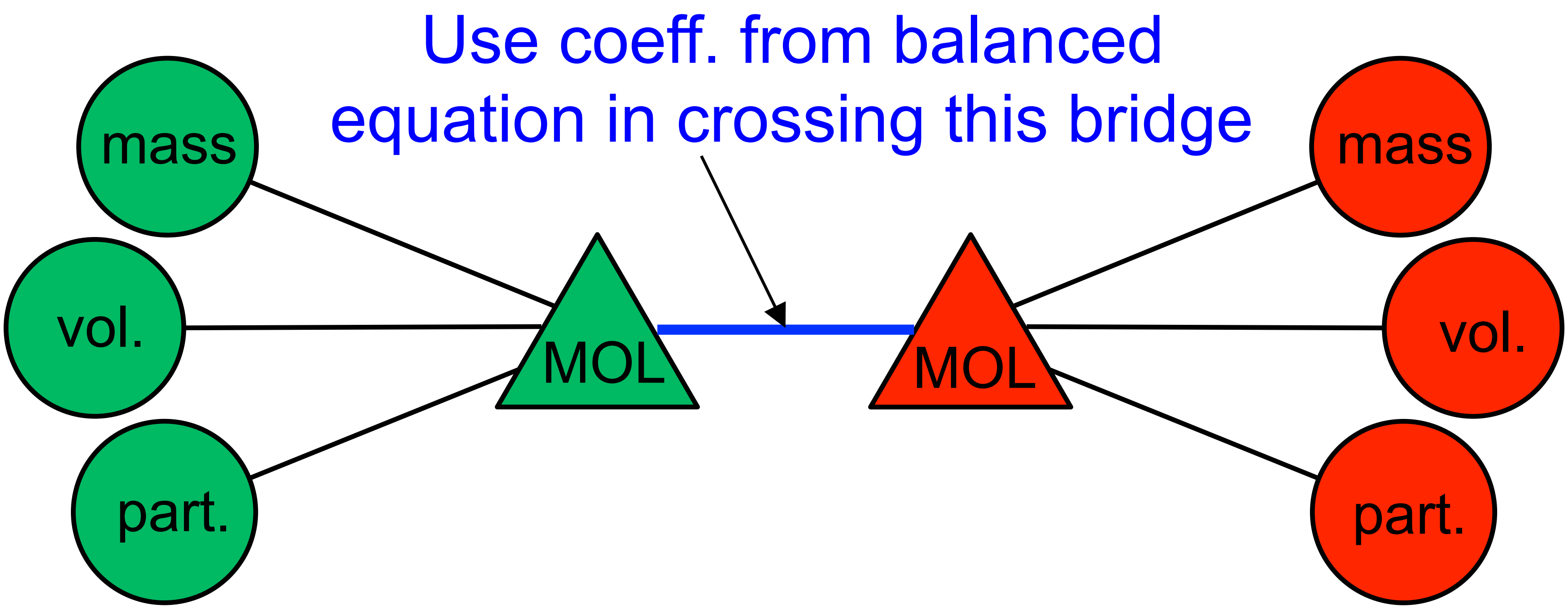
At STP, how many g is 87.3 dm^3 of nitrogen gas?

N_2



$$87.3\ \text{L} \left(\frac{1\ \text{mol}}{22.4\ \text{L}}\right)\left(\frac{28.0\ \text{g}}{1\ \text{mol}}\right) = \boxed{109\ \text{g}}$$

When going from moles of one substance to moles of another, use the coefficients from the balanced equation.



SUBSTANCE "A"
(known)

SUBSTANCE "B"
(unknown)

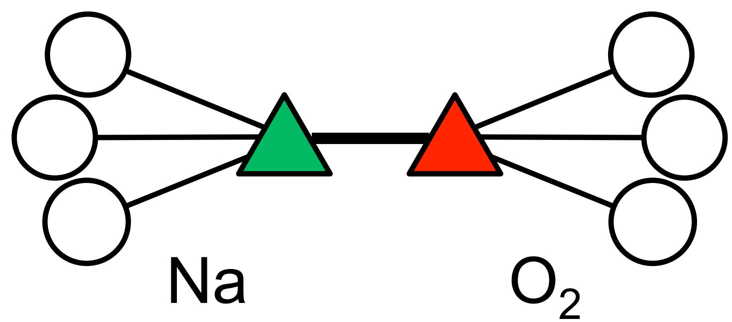
"Straight" Stoichiometry

-- the quantity of only one substance is given

-- for gases, the conditions are STP

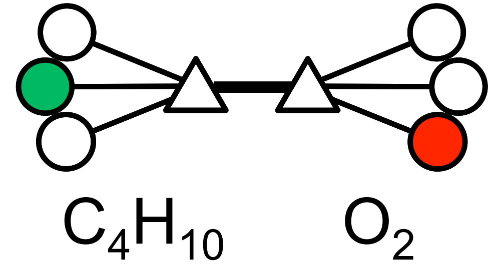
How many moles oxygen will react with 16.8 moles sodium?

$$4\ Na + O_2 \longrightarrow 2\ Na_2O$$



$$16.8\ \cancel{\text{mol Na}} \left(\frac{1\ \text{mol}\ O_2}{4\ \cancel{\text{mol Na}}} \right) = \boxed{4.20\ \text{mol}\ O_2}$$

At STP, how many molecules of oxygen react with 632 dm^3 butane (C_4H_{10})?



$$\underline{2}\ C_4H_{10} + \underline{13}\ O_2 \longrightarrow \underline{8}\ CO_2 + \underline{10}\ H_2O$$

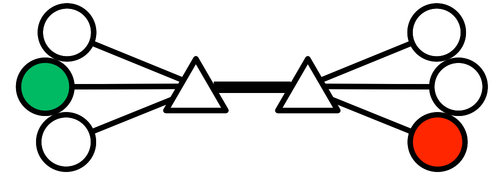
$$632\ dm^3\ C_4H_{10}\left(\frac{1\ mol\ C_4H_{10}}{22.4\ dm^3\ C_4H_{10}}\right)\left(\frac{13\ mol\ O_2}{2\ mol\ C_4H_{10}}\right)\left(\frac{6.02 \times 10^{23}\ m'c\ O_2}{1\ mol\ O_2}\right)$$

$$= \boxed{1.10 \times 10^{26}\ m'c\ O_2}$$

Suppose the question had been “how many ATOMS of O…”

$$1.10 \times 10^{26}\ m'c\ O_2\left(\frac{2\ atoms\ O}{1\ m'c\ O_2}\right) = \boxed{2.20 \times 10^{26}\ at.\ O}$$

At STP, how many molecules of oxygen react with 632 dm^3 butane (C_4H_{10})?



C_4H_{10} O_2

$$\underline{2}\ C_4H_{10} + \underline{\mathbf{13}}\ O_2 \longrightarrow \underline{\mathbf{8}}\ CO_2 + \underline{\mathbf{10}}\ H_2O$$

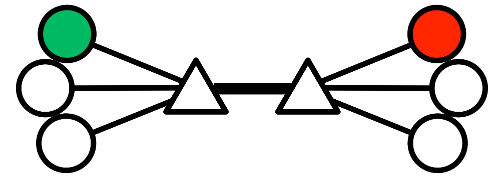
$$632\ \text{dm}^3\ C_4H_{10}\left(\frac{1\ \text{mol}\ C_4H_{10}}{22.4\ \text{dm}^3\ C_4H_{10}}\right)\left(\frac{13\ \text{mol}\ O_2}{2\ \text{mol}\ C_4H_{10}}\right)\left(\frac{6.02 \times 10^{23}\ \text{m'c}\ O_2}{1\ \text{mol}\ O_2}\right)$$

$$= \boxed{1.10 \times 10^{26}\ \text{m'c}\ O_2}$$

Suppose the question had been "how many ATOMS of O…"

$$1.10 \times 10^{26}\ \text{m'c}\ O_2\left(\frac{2\ \text{atoms O}}{1\ \text{m'c}\ O_2}\right) = \boxed{2.20 \times 10^{26}\ \text{at. O}}$$

How many grams potassium will react with 465 grams nickel(II) phosphide?



$$6\ K + Ni_3P_2 \longrightarrow 3\ Ni + 2\ K_3P$$

$$465\ g\ Ni_3P_2 \left(\frac{1\ mol\ Ni_3P_2}{238.1\ g\ Ni_3P_2}\right)\left(\frac{6\ mol\ K}{1\ mol\ Ni_3P_2}\right)\left(\frac{39.1\ g\ K}{1\ mol\ K}\right)$$

$$= \boxed{458\ g\ K}$$

Limiting Reactants (a.k.a., Limiting Reagents)

limiting reactant (LR): the reactant that runs out first

-- Amount of EVERYTHING depends on the LR.

Any reactant you don't run out of is an excess reactant (ER).

How to Find the Limiting Reactant

For the generic reaction

$$R_A + R_B \longrightarrow P,$$

assume that the amounts of R_A and R_B are given. Should you use R_A or R_B in your calculations?

1. Calc. # of mol of R_A and R_B you have.
2. Divide by the respective coefficients in balanced equation.
3. Reactant having the smaller result is the LR.

$$2\ H_2(g) + O_2(g) \longrightarrow 2\ H_2O(g)$$

13 g H_2 80. g O_2

How many g H_2O are formed?

$$13\ \cancel{g\ H_2}\left(\frac{1\ mol\ H_2}{2\ \cancel{g\ H_2}}\right) = 6.5\ mol\ H_2 \div 2 = 3.25$$

(HAVE)

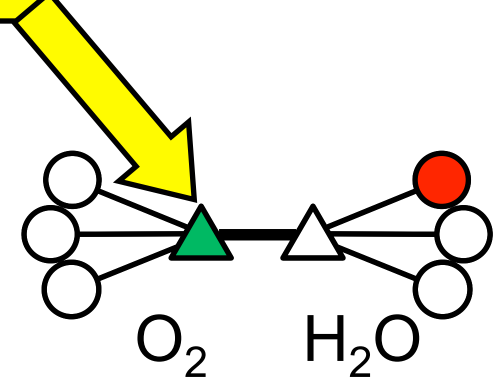
LR = O_2

$$80\ \cancel{g\ O_2}\left(\frac{1\ mol\ O_2}{32\ \cancel{g\ O_2}}\right) = 2.5\ mol\ O_2 \div 1 = 2.50$$

(HAVE)

"Oh, bee-HAVE!"

(And start every calc. with the LR.)



$$2.5\ \cancel{mol\ O_2}\left(\frac{2\ \cancel{mol\ H_2O}}{1\ \cancel{mol\ O_2}}\right)\left(\frac{18\ g\ H_2O}{1\ \cancel{mol\ H_2O}}\right) = 90.\ g\ H_2O$$

$$2\ Fe(s) + 3\ Cl_2(g) \longrightarrow 2\ FeCl_3(s)$$

223 g Fe 179 L Cl_2

At STP, what is the limiting reactant?

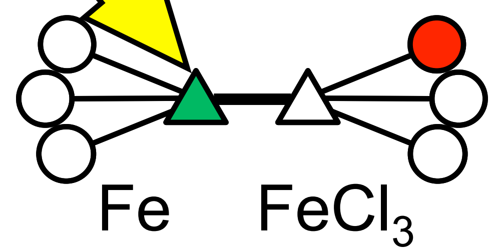
$$223\ \text{g Fe}\left(\frac{1\ \text{mol Fe}}{55.8\ \text{g Fe}}\right) = 4.0\ \text{mol Fe (HAVE)} \quad \div 2 = 2.0$$

LR = Fe

$$179\ \text{L } Cl_2\left(\frac{1\ \text{mol } Cl_2}{22.4\ \text{L } Cl_2}\right) = 8.0\ \text{mol } Cl_2\ \text{(HAVE)} \quad \div 3 = 2.66$$

What mass of $FeCl_3$ is produced?

("Oh, bee-HAVE!")



$$4.0\ \text{mol Fe}\left(\frac{2\ \text{mol } FeCl_3}{2\ \text{mol Fe}}\right)\left(\frac{162.3\ \text{g } FeCl_3}{1\ \text{mol } FeCl_3}\right) = 649\ \text{g } FeCl_3$$

Theoretical Yield, Actual Yield, and Percent Yield

The amount of product we get if the reaction is perfect is called the theoretical yield.

-- It is found by calculation.

If we ACTUALLY DO the reaction and measure the actual yield, we will find that this amount is less than the theoretical yield (i.e., % yield can never be > 100%).

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

Highest career BA: Ty Cobb, .366

Highest career FT%: Mark Price, .904

$$2\ ZnS + 3\ O_2 \longrightarrow 2\ ZnO + 2\ SO_2$$

100. g 100. g X g

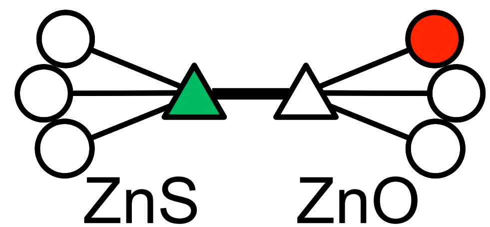
Assume 81% yield.

Strategy:

1. Balance and find LR.
2. Use LR to calc. X g ZnO (theo. yield)
3. Actual yield is 81% of theo. yield.

$$100\text{ g ZnS}\left(\frac{1\text{ mol}}{97.5\text{ g}}\right) = 1.026\text{ mol ZnS (HAVE)} \div 2 = 0.513 \quad \text{LR}$$

$$100\text{ g } O_2\left(\frac{1\text{ mol}}{32\text{ g}}\right) = 3.125\text{ mol } O_2 \text{ (HAVE)} \div 3 = 1.042$$



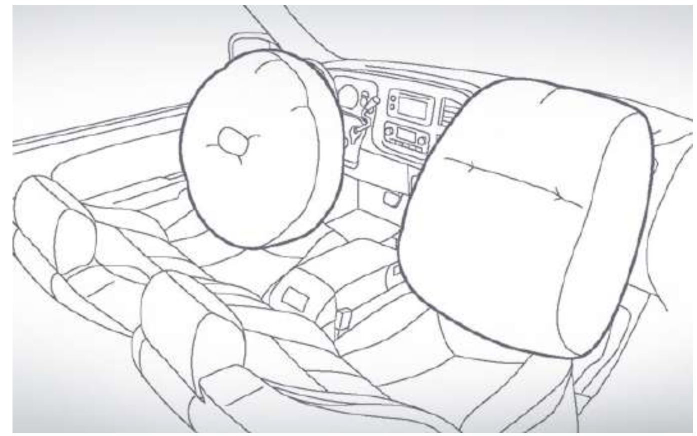
$$1.026\text{ mol ZnS}\left(\frac{2\text{ mol ZnO}}{2\text{ mol ZnS}}\right)\left(\frac{81.4\text{ g ZnO}}{1\text{ mol ZnO}}\right) = 83.5\text{ g ZnO}$$

Actual g ZnO = 83.5 (0.81) = **68 g ZnO**

Automobile air bags inflate with nitrogen via the decomposition of sodium azide:

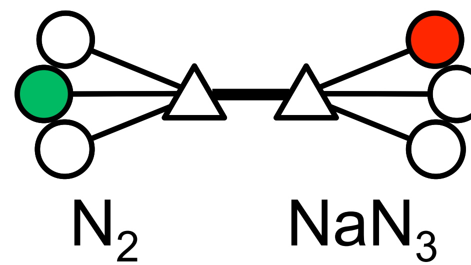
$$2\ NaN_3(s) \longrightarrow 3\ N_2(g) + 2\ Na(s)$$

At STP and a % yield of 85%, what mass sodium azide is needed to yield 74 L nitrogen?



$$\%\ yld = \frac{actual}{theo}$$

$$0.85 = \frac{74\ L\ N_2}{theo\ L\ N_2} \rightarrow theo = 87.1\ L\ N_2$$



$$87.1\ \cancel{L\ N_2}\left(\frac{1\ \cancel{mol\ N_2}}{22.4\ \cancel{L\ N_2}}\right)\left(\frac{2\ \cancel{mol\ NaN_3}}{3\ \cancel{mol\ N_2}}\right)\left(\frac{65\ g\ NaN_3}{1\ \cancel{mol\ NaN_3}}\right) = \boxed{170\ g\ NaN_3}$$