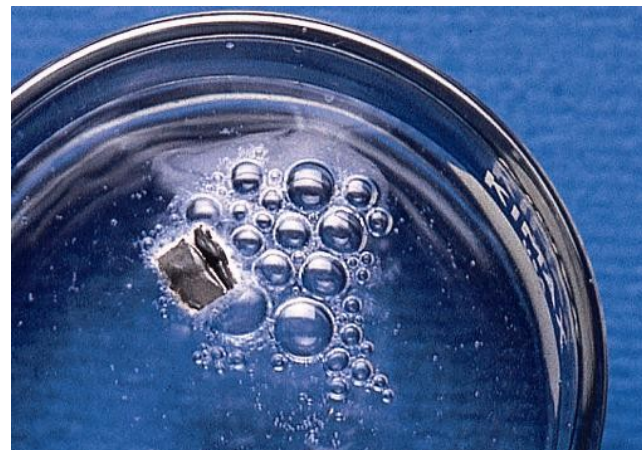


Mass Relationships in Chemical Reactions

Chapter 3



Micro World
atoms & molecules



Macro World
grams

Atomic mass is the mass of an atom in atomic mass units (amu)

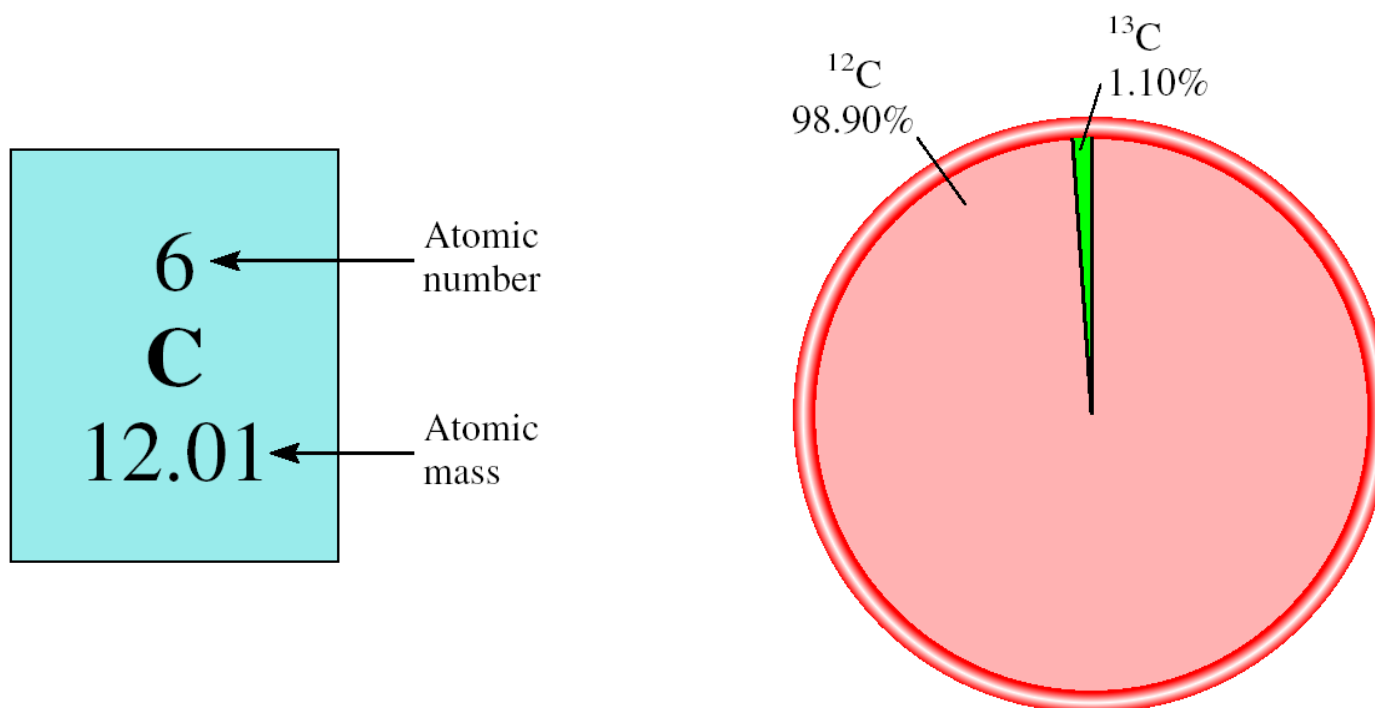
By definition:
1 atom ^{12}C “weighs” 12 amu

On this scale

$^1\text{H} = 1.008 \text{ amu}$

$^{16}\text{O} = 16.00 \text{ amu}$

The ***average atomic mass*** is the weighted average of all of the naturally occurring isotopes of the element.



Naturally occurring lithium is:

7.42% ${}^6\text{Li}$ (6.015 amu)

92.58% ${}^7\text{Li}$ (7.016 amu)

Average atomic mass of lithium:

$$\frac{7.42 \times 6.015 + 92.58 \times 7.016}{100} = 6.941 \text{ amu}$$

1 1A																	18 8A						
1 H Hydrogen 1.008	2 2A											13 3A	14 4A	15 5A	16 6A	17 7A	2 He Helium 4.003						
3 Li Lithium 6.941	4 Be Beryllium 9.012																	5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95						
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.88	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.59	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80						
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3						
55 Cs Cesium 132.9	56 Ba Barium 137.3	57 La Lanthanum 138.9	72 Hf Hafnium 178.5	73 Ta Tantalum 180.9	74 W Tungsten 183.9	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (210)	85 At Astatine (210)	86 Rn Radon (222)						
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (257)	105 Db Dubnium (260)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (269)	111 Rg Roentgenium (272)	112	113	114	115	116	(117)	118						

10
Ne
Neon
20.18

Atomic number

Atomic mass

Average atomic mass (6.941)

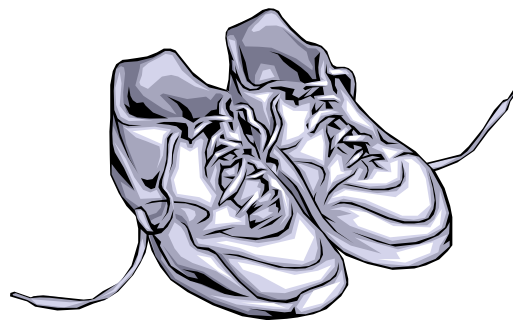
Average atomic mass (6.941)

	Metals
	Metalloids
	Nonmetals

58 Ce Cerium 140.1	59 Pr Praseodymium 140.9	60 Nd Neodymium 144.2	61 Pm Promethium (147)	62 Sm Samarium 150.4	63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 175.0
90 Th Thorium 232.0	91 Pa Protactinium (231)	92 U Uranium 238.0	93 Np Neptunium (237)	94 Pu Plutonium (242)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (249)	99 Es Einsteinium (254)	100 Fm Fermium (253)	101 Md Mendelevium (256)	102 No Nobelium (254)	103 Lr Lawrencium (257)

The Mole (mol): A unit to count numbers of particles

Dozen = 12



Pair = 2

The ***mole (mol)*** is the amount of a substance that contains as many elementary entities as there are atoms in exactly 12.00 grams of ^{12}C

$$1 \text{ mol} = N_A = 6.0221367 \times 10^{23}$$

Avogadro's number (N_A)

Molar mass is the mass of 1 mole of eggs
shoes
marbles
atoms in grams

$$1 \text{ mole } ^{12}\text{C atoms} = 6.022 \times 10^{23} \text{ atoms} = 12.00 \text{ g}$$

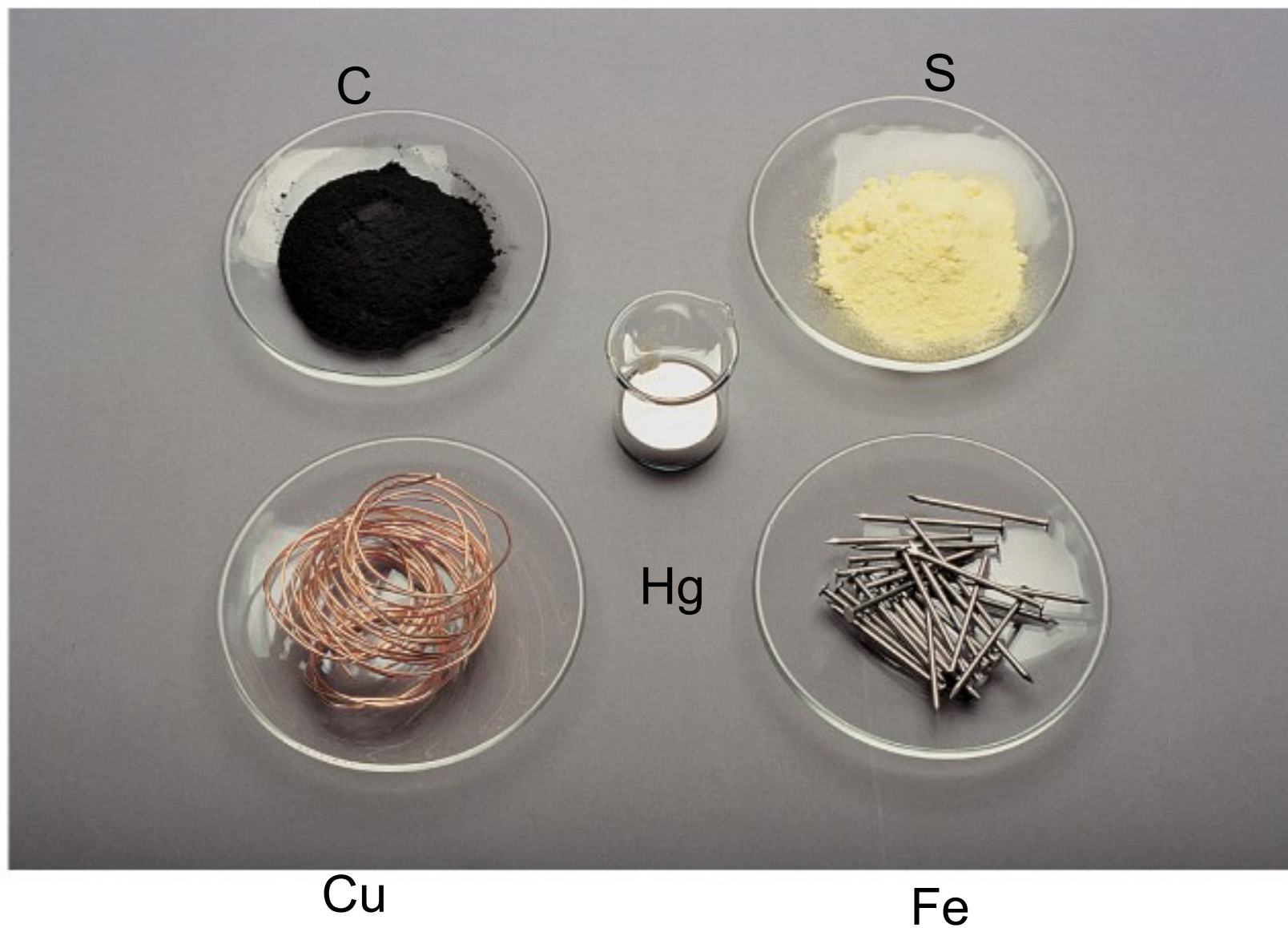
$$1 \text{ } ^{12}\text{C atom} = 12.00 \text{ amu}$$

$$1 \text{ mole } ^{12}\text{C atoms} = 12.00 \text{ g } ^{12}\text{C}$$

$$1 \text{ mole lithium atoms} = 6.941 \text{ g of Li}$$

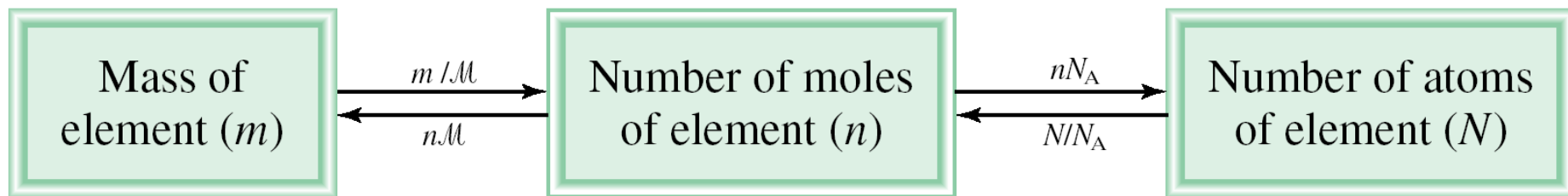
For any element
atomic mass (amu) = molar mass (grams)

One Mole of:



$$\frac{1 \text{ }^{12}\text{C} \text{ atom}}{12.00 \text{ amu}} \times \frac{12.00 \text{ g}}{6.022 \times 10^{23} \text{ }^{12}\text{C atoms}} = \frac{1.66 \times 10^{-24} \text{ g}}{1 \text{ amu}}$$

$$1 \text{ amu} = 1.66 \times 10^{-24} \text{ g} \quad \text{or} \quad 1 \text{ g} = 6.022 \times 10^{23} \text{ amu}$$

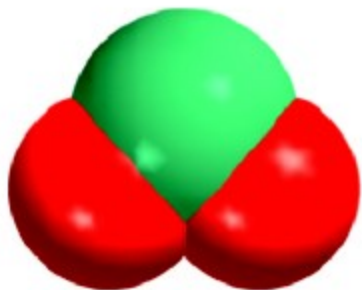


M = molar mass in g/mol

N_A = Avogadro's number

How many atoms are in 0.551 g of potassium (K) ?

Molecular mass (or molecular weight) is the sum of the atomic masses (in amu) in a molecule.



SO₂

1S	32.07 amu
2O	+ 2 x 16.00 amu
SO ₂	<hr/> 64.07 amu

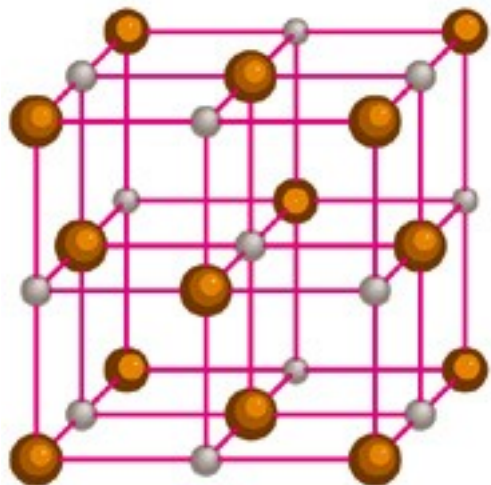
For any molecule
molecular mass (amu) = molar mass (grams)

$$1 \text{ molecule SO}_2 = 64.07 \text{ amu}$$

$$1 \text{ mole SO}_2 = 64.07 \text{ g SO}_2$$

How many H atoms are in 72.5 g of $\text{C}_3\text{H}_8\text{O}$?

Formula mass is the sum of the atomic masses (in amu) in a formula unit of an ionic compound.



1Na	22.99 amu
1Cl	+ 35.45 amu
NaCl	<hr/> 58.44 amu

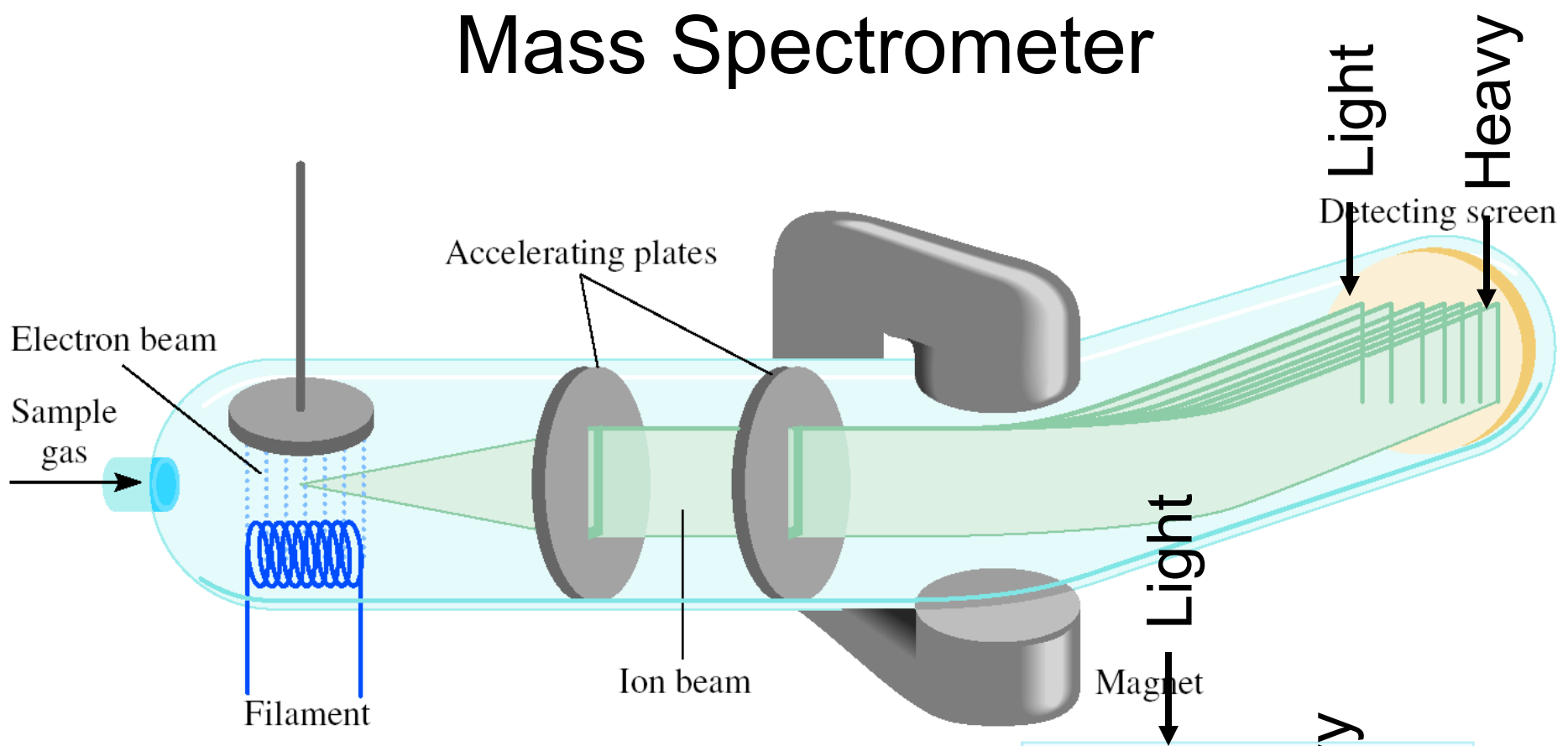
For any ionic compound
formula mass (amu) = molar mass (grams)

$$1 \text{ formula unit NaCl} = 58.44 \text{ amu}$$

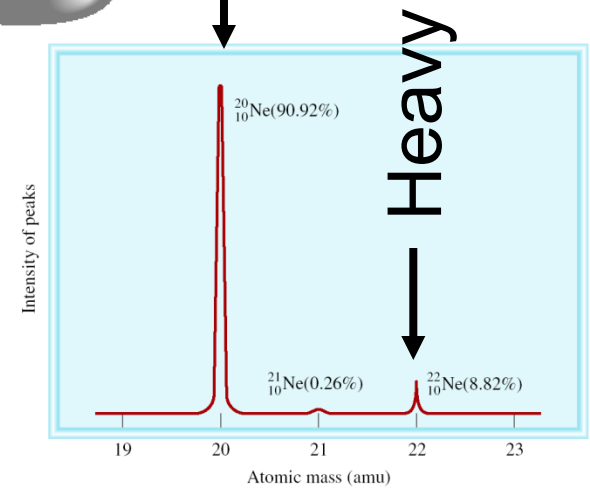
$$1 \text{ mole NaCl} = 58.44 \text{ g NaCl}$$

What is the formula mass of $\text{Ca}_3(\text{PO}_4)_2$?

Mass Spectrometer



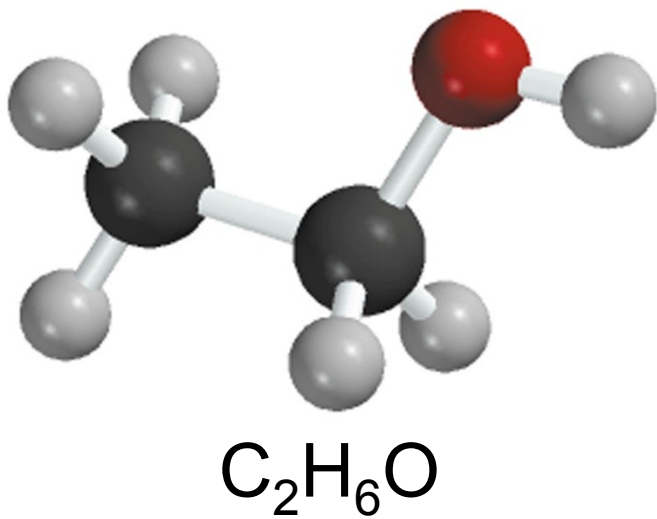
Mass Spectrum of Ne



Percent composition of an element in a compound =

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

n is the number of moles of the element in **1 mole** of the compound



$$\%C = \frac{2 \times (12.01 \text{ g})}{46.07 \text{ g}} \times 100\% = 52.14\%$$

$$\%H = \frac{6 \times (1.008 \text{ g})}{46.07 \text{ g}} \times 100\% = 13.13\%$$

$$\%O = \frac{1 \times (16.00 \text{ g})}{46.07 \text{ g}} \times 100\% = 34.73\%$$

$$52.14\% + 13.13\% + 34.73\% = 100.0\%$$

Percent Composition and Empirical Formulas

Determine the empirical formula of a compound that has the following percent composition by mass:
K 24.75, Mn 34.77, O 40.51 percent.

Mass
percent

↓ Convert to grams and
divide by molar mass

Moles of
each element

↓ Divide by the smallest
number of moles

Mole ratios
of elements

↓ Change to
integer subscripts

Empirical
formula

Percent Composition and Empirical Formulas

Mass
percent

↓ Convert to grams and
divide by molar mass

Moles of
each element

↓ Divide by the smallest
number of moles

Mole ratios
of elements

↓ Change to
integer subscripts

Empirical
formula

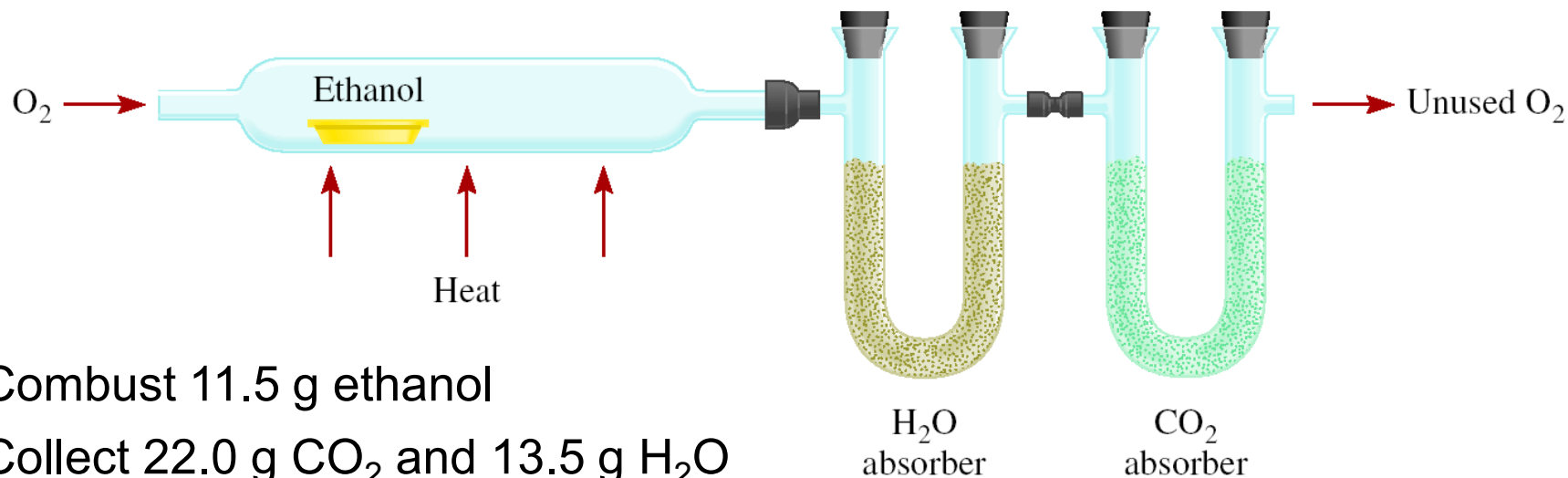
$$n_{\text{K}} = 0.6330, n_{\text{Mn}} = 0.6329, n_{\text{O}} = 2.532$$

$$\text{K} : \frac{0.6330}{0.6329} \approx 1.0$$

$$\text{Mn} : \frac{0.6329}{0.6329} = 1.0$$

$$\text{O} : \frac{2.532}{0.6329} \approx 4.0$$





Combust 11.5 g ethanol

Collect 22.0 g CO₂ and 13.5 g H₂O

g CO₂ \longrightarrow mol CO₂ \longrightarrow mol C \longrightarrow g C 6.0 g C = 0.5 mol C

g H₂O \longrightarrow mol H₂O \longrightarrow mol H \longrightarrow g H 1.5 g H = 1.5 mol H

g of O = g of sample – (g of C + g of H) 4.0 g O = 0.25 mol O

Empirical formula C_{0.5}H_{1.5}O_{0.25}

Divide by smallest subscript (0.25)

Empirical formula C₂H₆O

A process in which one or more substances is changed into one or more new substances is a ***chemical reaction***

A ***chemical equation*** uses chemical symbols to show what happens during a chemical reaction

reactants \longrightarrow products

3 ways of representing the reaction of H_2 with O_2 to form H_2O

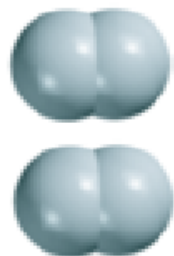
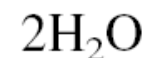
Two hydrogen molecules + One oxygen molecule \longrightarrow Two water molecules



+



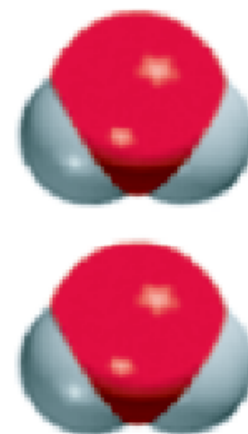
\longrightarrow



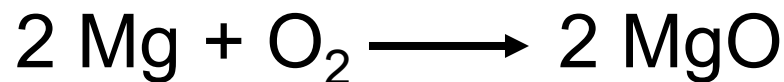
+



\longrightarrow



How to “Read” Chemical Equations



2 atoms Mg + 1 molecule O₂ makes 2 formula units MgO

2 moles Mg + 1 mole O₂ makes 2 moles MgO

48.6 grams Mg + 32.0 grams O₂ makes 80.6 g MgO

NOT

2 grams Mg + 1 gram O₂ makes 2 g MgO

Balancing Chemical Equations

1. Write the **correct** formula(s) for the reactants on the left side and the **correct** formula(s) for the product(s) on the right side of the equation.

Ethane reacts with oxygen to form carbon dioxide and water

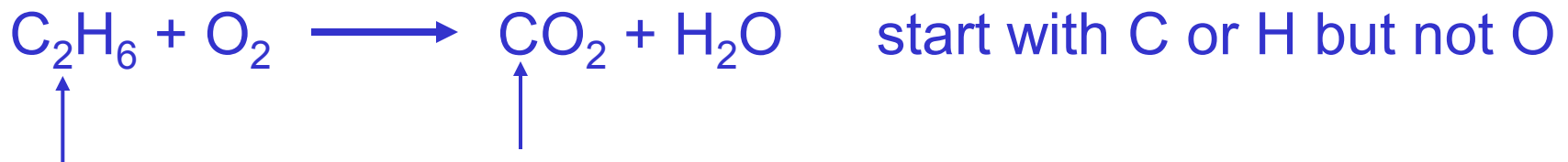


2. Change the numbers in front of the formulas (***coefficients***) to make the number of atoms of each element the same on both sides of the equation. Do not change the subscripts.



Balancing Chemical Equations

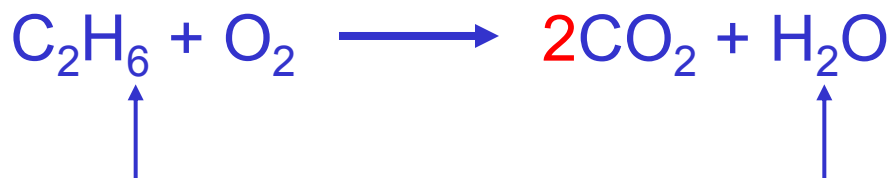
3. Start by balancing those elements that appear in only one reactant and one product.



2 carbon
on left

1 carbon
on right

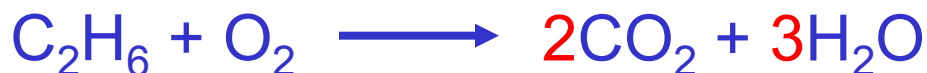
multiply CO₂ by 2



6 hydrogen
on left

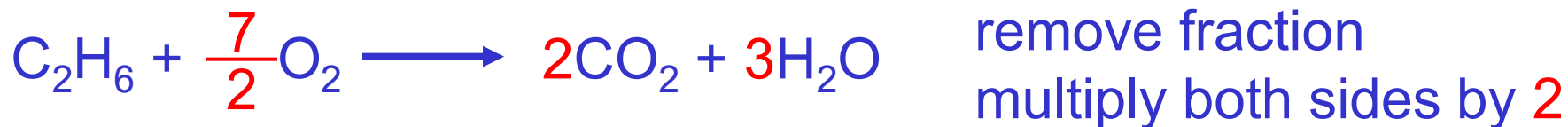
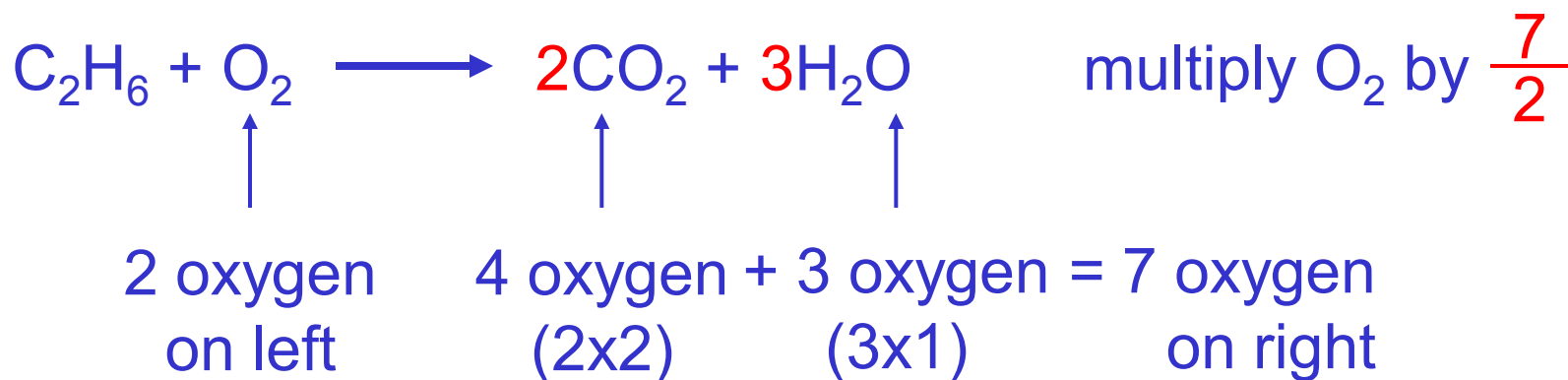
2 hydrogen
on right

multiply H_2O by 3



Balancing Chemical Equations

4. Balance those elements that appear in two or more reactants or products.



Balancing Chemical Equations

5. Check to make sure that you have the same number of each type of atom on both sides of the equation.



4 C (2 x 2)

4 C

12 H (2 x 6)

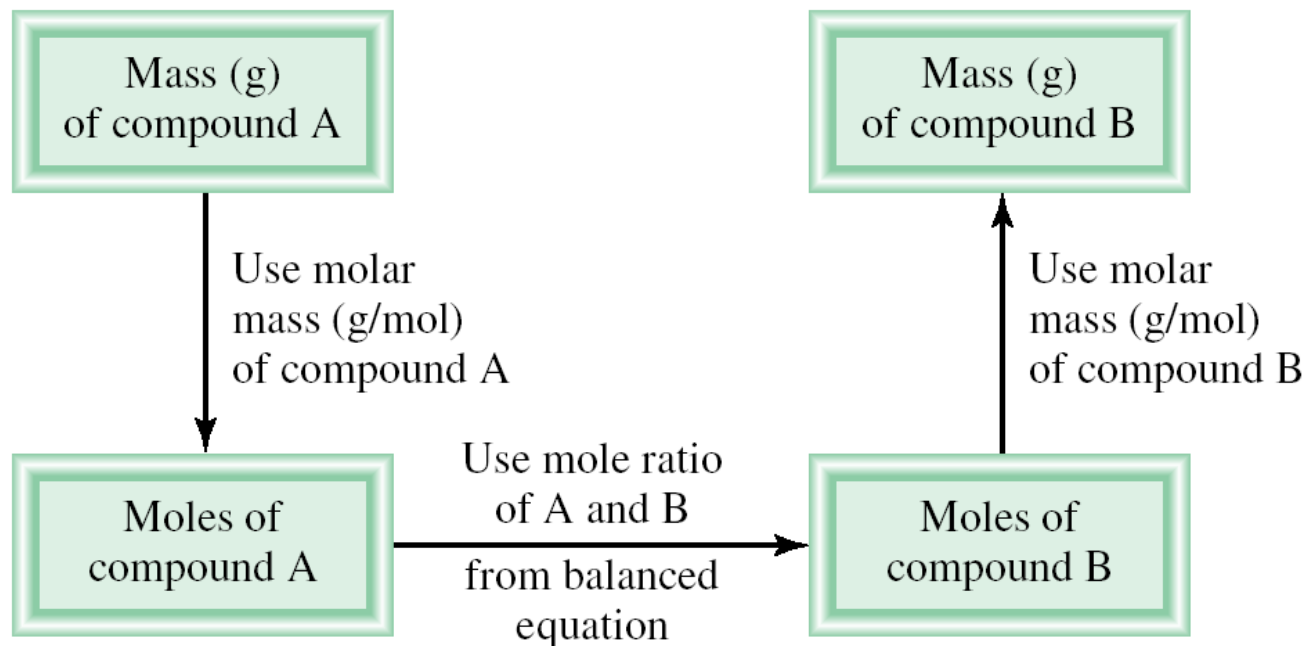
12 H (6 x 2)

14 O (7 x 2)

14 O (4 x 2 + 6)

Reactants	Products
4 C	4 C
12 H	12 H
14 O	14 O

Amounts of Reactants and Products



1. Write balanced chemical equation
2. Convert quantities of known substances into moles
3. Use coefficients in balanced equation to calculate the number of moles of the sought quantity
4. Convert moles of sought quantity into desired units

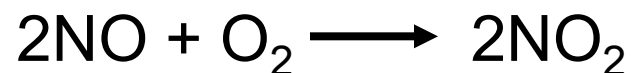
Methanol burns in air according to the equation



If 209 g of methanol are used up in the combustion, what mass of water is produced?

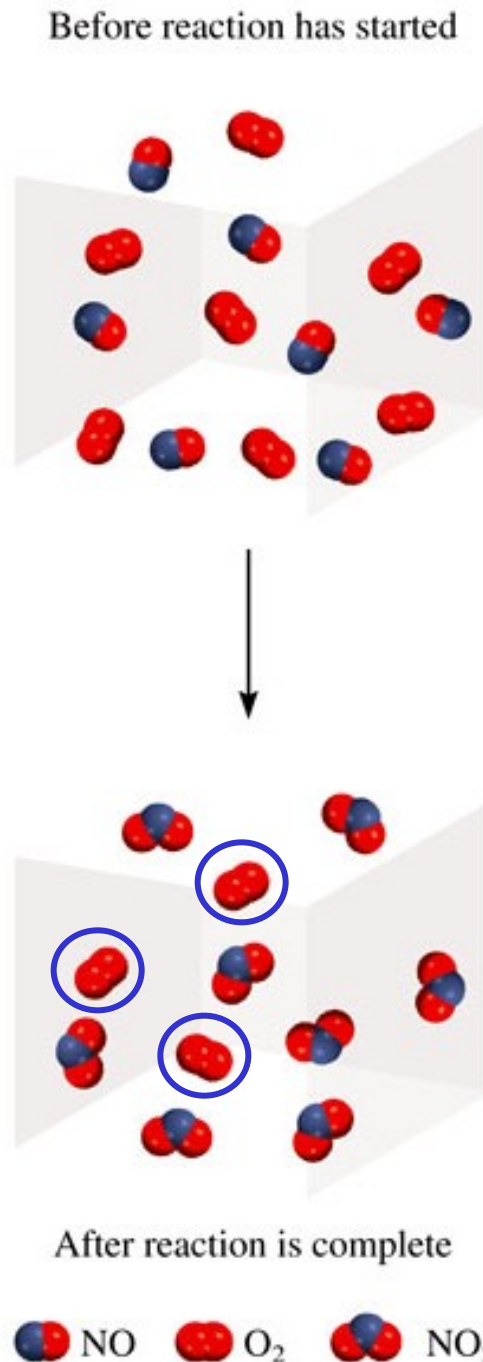
Limiting Reagent:

Reactant used up first in the reaction.



NO is the limiting reagent

O_2 is the excess reagent



In one process, 124 g of Al are reacted with 601 g of Fe₂O₃



Calculate the mass of Al₂O₃ formed.

Reaction Yield

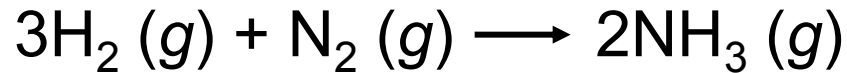
Theoretical Yield is the amount of product that would result if all the limiting reagent reacted.

Actual Yield is the amount of product actually obtained from a reaction.

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

Chemistry In Action: Chemical Fertilizers

Plants need: N, P, K, Ca, S, & Mg



fluorapatite

