Chapter 3: Stoichiometry

Calculating quantities of reactants and products used during chemical reactions

Haber Process: production of ammonia

$$N_2 + 3 H_2 \rightarrow 2 NH_3$$

$N_2 + 3\,H_2$ ¸ $2\,NH_3$

1 molecule + 3 molecules ¸ 2 molecules

How much nitrogen & hydrogen needed to make 1000 tons of ammonia ?

to make 1 gram of ammonia ?

Atomic Mass

Atoms come in different sizes and masses

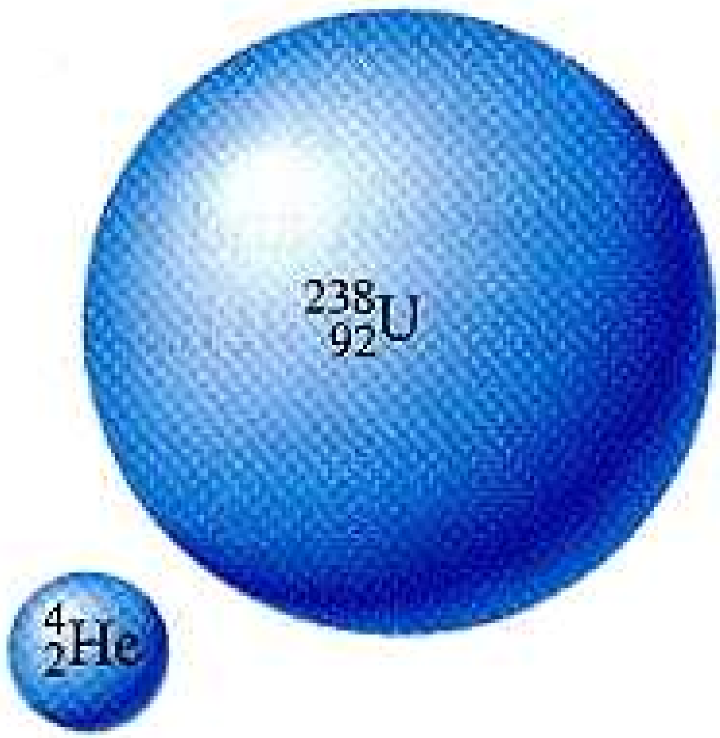
Use a scale of relative masses (weighs)

Elephant : mouse

3000 lbs : 0.2 lbs

- **15,000 : 1**

Could create table of animal weights relative to a mouse



Atoms have relative weights (and sizes)

If hydrogen is 1
helium is 4
carbon is 12
uranium is 238

Atomic Mass

Relative mass of one element compared to another: H = 1.008 C = 12.01

Units: Atomic Mass Units (AMU)

Weighted average of isotopes from % abundance

Carbon-12 99% at 12.00000 amu
Carbon-13 1% at 13.0335 amu

Molecular Mass

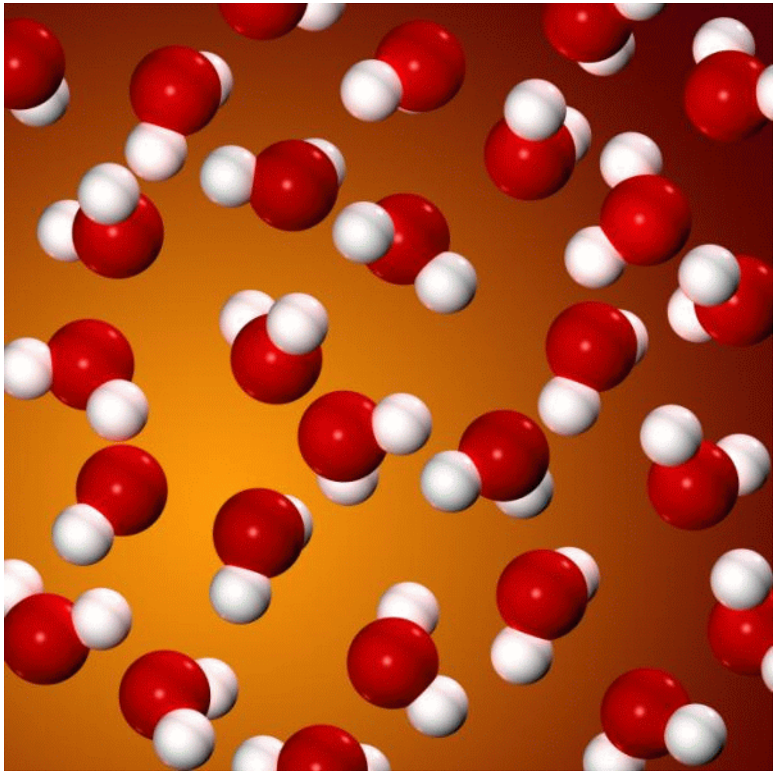
For compounds: add atomic masses

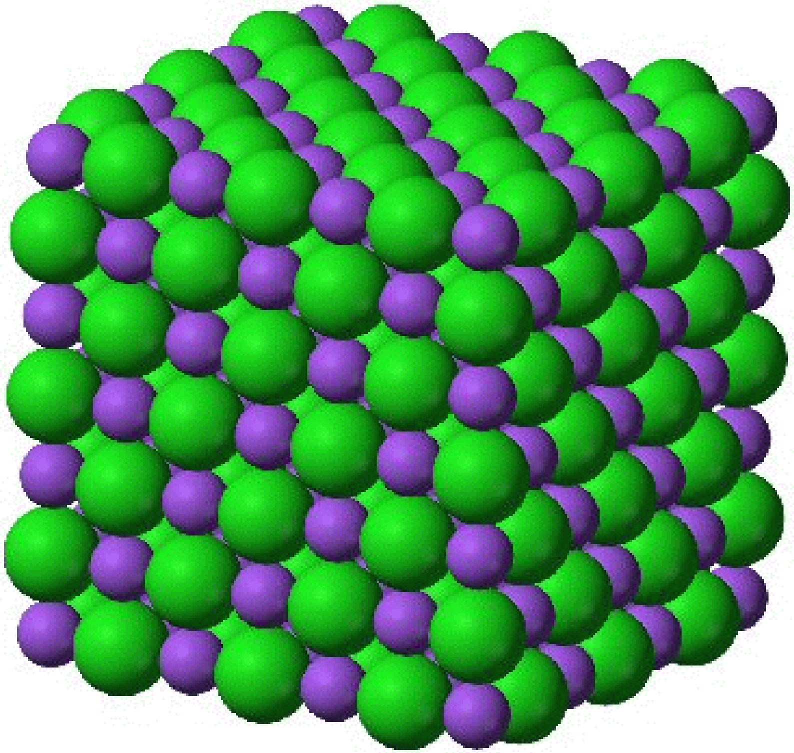
CH_4 12.01 + (4 × 1.008) = 16.042

H_2O = 18.01

Use formula mass for ionic/molecular compounds

Use molecular mass for molecular compounds





Molecular **Ionic**

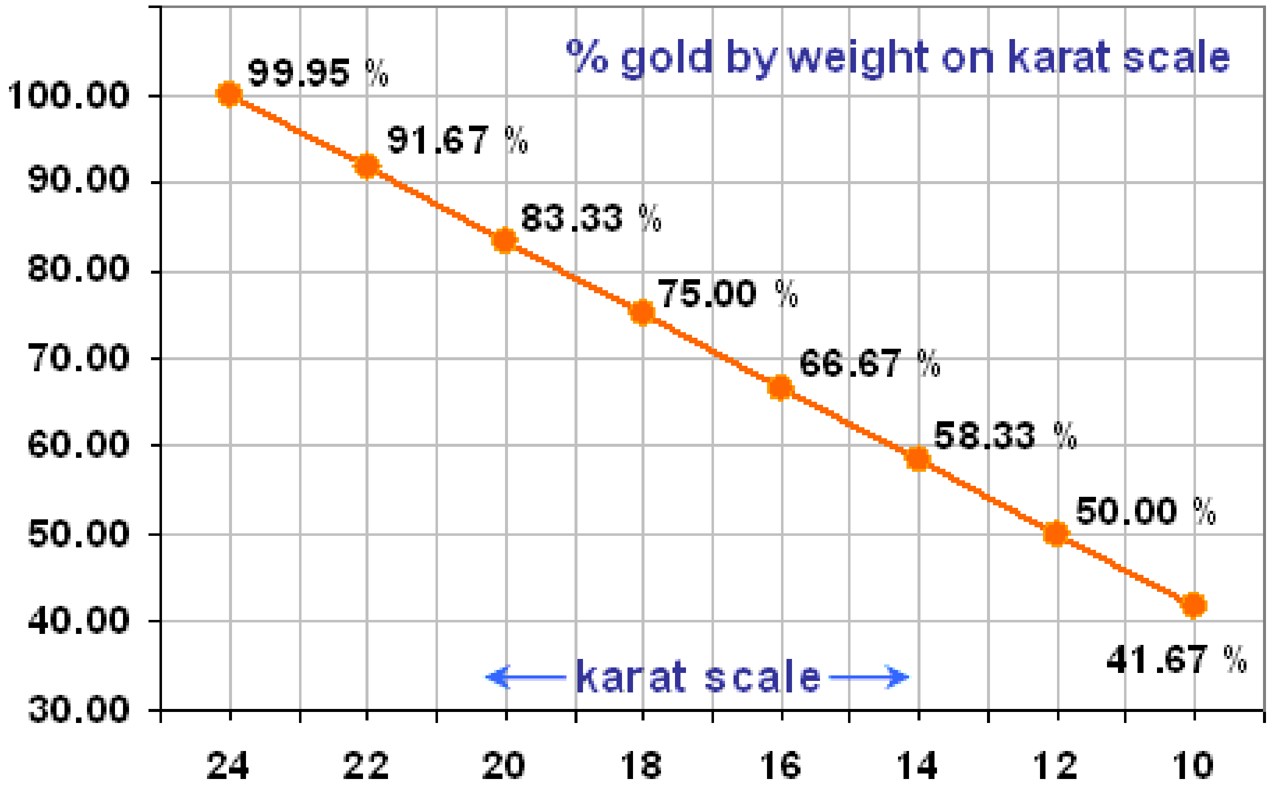
Chemical Calculations

How many atoms of gold in ring?

weight of ring = 3.2 grams

ring is 14 karat gold

Gold karat scale



Chemical Calculations

How many atoms of gold in ring?

weight of ring = 3.2 grams

ring is 14 karat gold

$$14 \text{ kt} = \frac{14}{24} \times 3.2 = 1.9 \text{ grams pure gold}$$

Chemical Calculations

How many atoms in 1.9 g of gold ?

need a conversion factor

use periodic table – atomic mass

when expressed in grams, the atomic mass of each element contains 6×10^{23} atoms

Chemical Calculations

Find atomic masses for:

gold	oxygen	uranium
197	**16**	**238**
197 grams	16 grams	238 grams

Chemical Calculations

Find atomic masses for:

gold oxygen uranium

ALL CONTAIN 6 X 10^{23} ATOMS

197 grams 16 grams 238 grams

Chemical Calculations

Find atomic masses for:

gold oxygen uranium

gram atomic mass of each contains 6 x 10^{23} atoms

197 grams 16 grams 238 grams

Chemical Calculations

THE NUMBER – – – 6×10^{23}

IS CALLED

AVOGADRO'S NUMBER

accurate value: 6.023×10^{23}

Chemical Calculations

Avogadro's number used as conversion factor to convert mass into number of atoms

factor is: $$\frac{6 \times 10^{23}}{\text{atomic mass}}$$

Chemical Calculations

Avogadro's number used as conversion factor to convert mass into number of atoms

factor is: $$\frac{6 \times 10^{23}}{\text{atomic mass}}$$

$$\text{mass in grams} \times \frac{6 \times 10^{23}}{\text{atomic mass}} = \text{number of atoms}$$

Chemical Calculations

In gold ring................

no. atoms = 1.9 grams x $\frac{6 \times 10^{23}}{197}$

$= 5.8 \times 10^{21}$ atoms

= 5,800,000,000,000,000,000,000 atoms

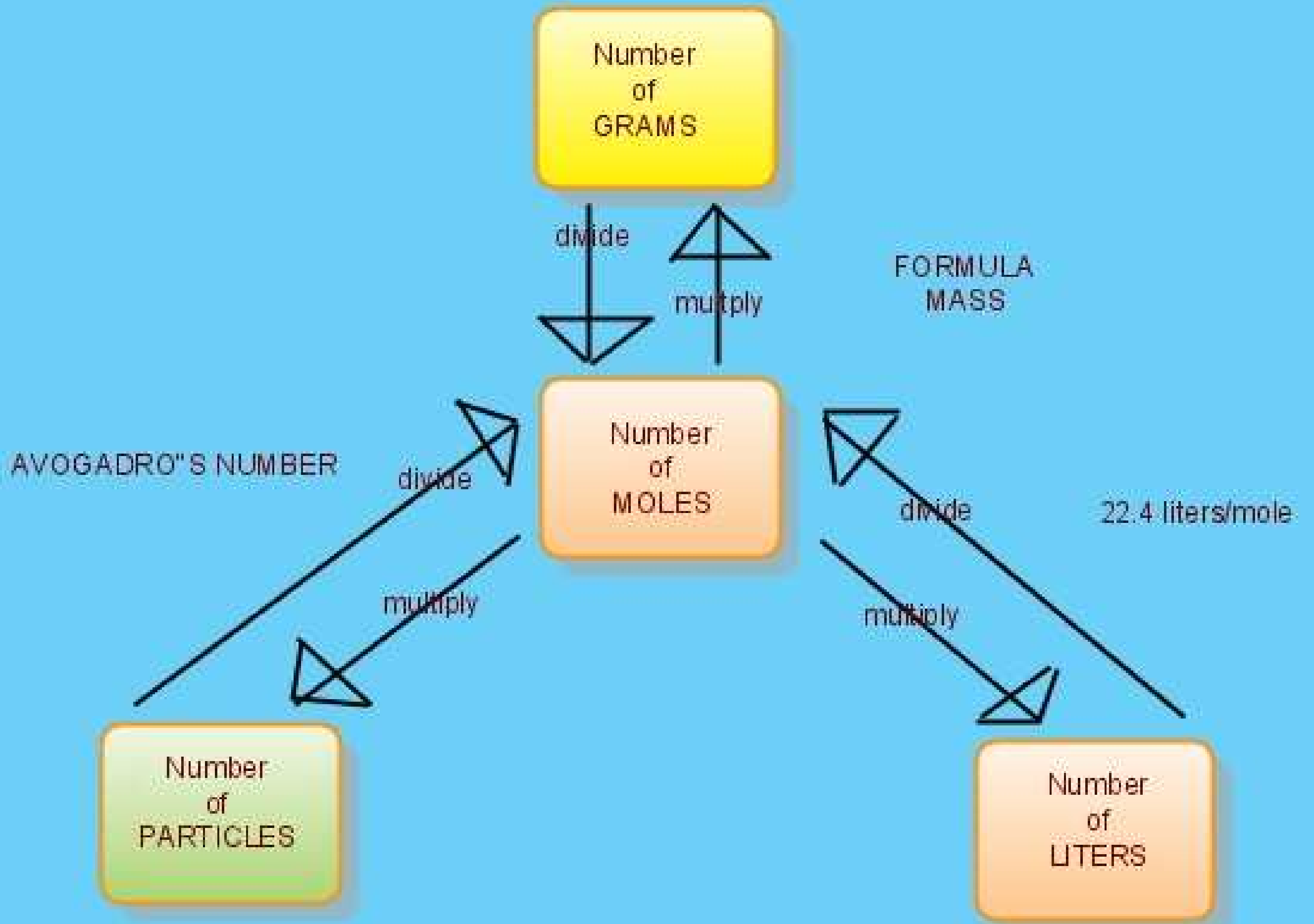
= 5,800 billion billion atoms

Chemical Calculations

Avogadro's number also called....... one mole

Can have one mole of anything

1 mole of gold contains 6×10^{23} gold atoms and weighs 197 grams


Number
of
GRAMS
divide
multiply
FORMULA
MASS
Number
of
MOLES
AVOGADRO"S NUMBER
divide
multiply
divide
multiply
22.4 liters/mole
Number
of
PARTICLES
Number
of
LITERS

Mole map

1 mole of soda cans

Mind-boggling mole measurements

- you could cover the ENTIRE EARTH 200 miles deep in soda cans!
- Or..you could stack 1 mole of soda cans out to a distance of 7.6 million LIGHT YEARS! (our Milky Way is only 100,000 light years in diameter - the Andromeda Galaxy is about 2.9 mil LY away)

Avogadro's number

Atomc mass in grams also called
gram-atomic mass or **molar mass**

Use the atomic mass to convert between mass and moles

Chemical Calculations

Important formulas ....

$$\text{moles} = \frac{\text{mass}}{\text{atomic mass}}$$

$$\text{mass} = \text{atomic mass} \times \text{moles}$$

Example

How many moles of gold in 50 g of gold?

$$\text{moles} = \frac{\text{mass}}{\text{atomic mass}}$$

$$\text{moles} = \frac{50 \text{ grams}}{197} = 0.25 \text{ moles}$$

Example

How many grams in 5.0 moles of nitrogen?

mass = atomic mass x moles

mass = 14 x 5.0 = 70 grams

Chemical Calculations

Relationship between mass and moles also true for compounds ..... use formula masses

How many moles in 10 g of water?

$$\text{moles} = \frac{\text{mass}}{\text{formula mass}}$$

$$= \frac{10}{18.0} = 0.56 \text{ mole}$$

Percent (%) Composition

$$\% = \frac{\text{No. specific objects}}{\text{total No. of objects}} \times 100$$

this is based on counting

can also base % on mass

Percent (%) Composition

$$\% = \frac{\text{mass of No. specific objects}}{\text{total mass of objects}} \times 100$$

Let's turn to molecules.....

Percent (%) Composition

Find % mass of H atoms in H_2O

$$\% H = \frac{2 \times 1.0}{18} \times 100 = 11\%$$

water formula mass

atomic mass of hydrogen

Chemical Formulas

H_2O NaCl CO_2

Empirical formula:
simplest whole number ratio of atoms

water: H_4O_2 ! H_2O

hydrogen peroxide: H_2O_2

empirical formula is: HO

Chemical Formulas

hydrogen peroxide exists only as H_2O_2 molecules, not HO molecules

H_2O_2 is molecular formula

molecular formula:
shows actual number of atoms of each element in a compound

Chemical

How do we know H_2O is formula for water?

By % composition analysis

% composition ° empirical formula
° molecular formula

Unknown substance: C: 85.7%
H: 14.4%
Molecular mass = 42

Chemical

1. Divide each % by atomic mass

C: $\frac{85.7}{12.01}$

H: $\frac{14.4}{1.008}$

C = 7.16

H = 14.3

2. Divide by smaller number

$C = \frac{7.16}{7.16} = 1.00$

$H = \frac{14.3}{7.16} = 2.00$

Chemical

Ratio of C to H is 1:2

Empirical Formula: CH_2

3. molecular mass = empirical mass x N (N = some whole number)

   42 = 14 x N   N = 3

   Molecular Formula = CH_2 X 3 $=C_3H_6$

Chemical Equations

Hydrogen plus oxygen gives water

H_2 + O_2 º H_2O

reactants º products

Equations must be balanced

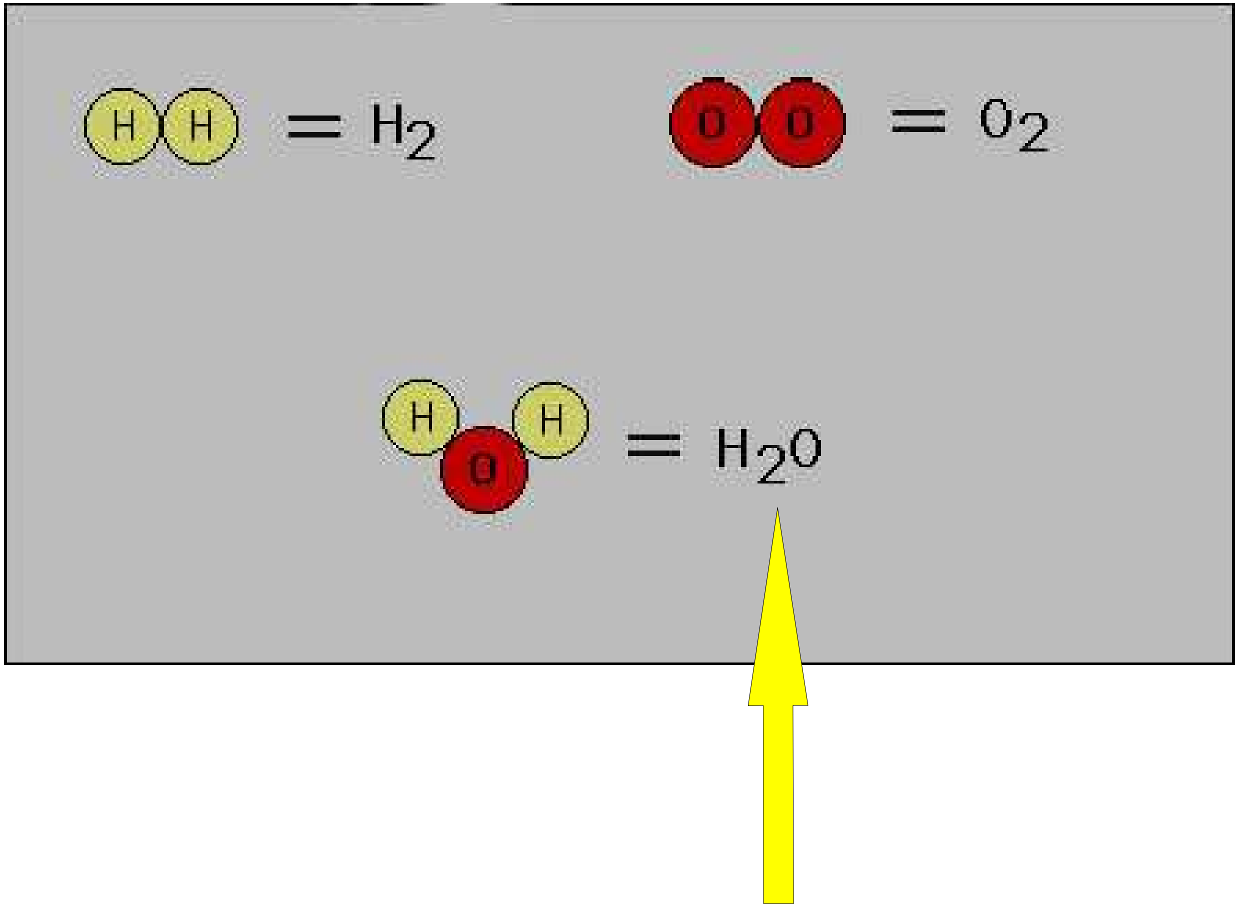
Chemical Equations

Count number of atoms on each side

H_2 + O_2 ° H_2O

H_2 means H + H or two H atoms

O_2 means O + O or two O atoms



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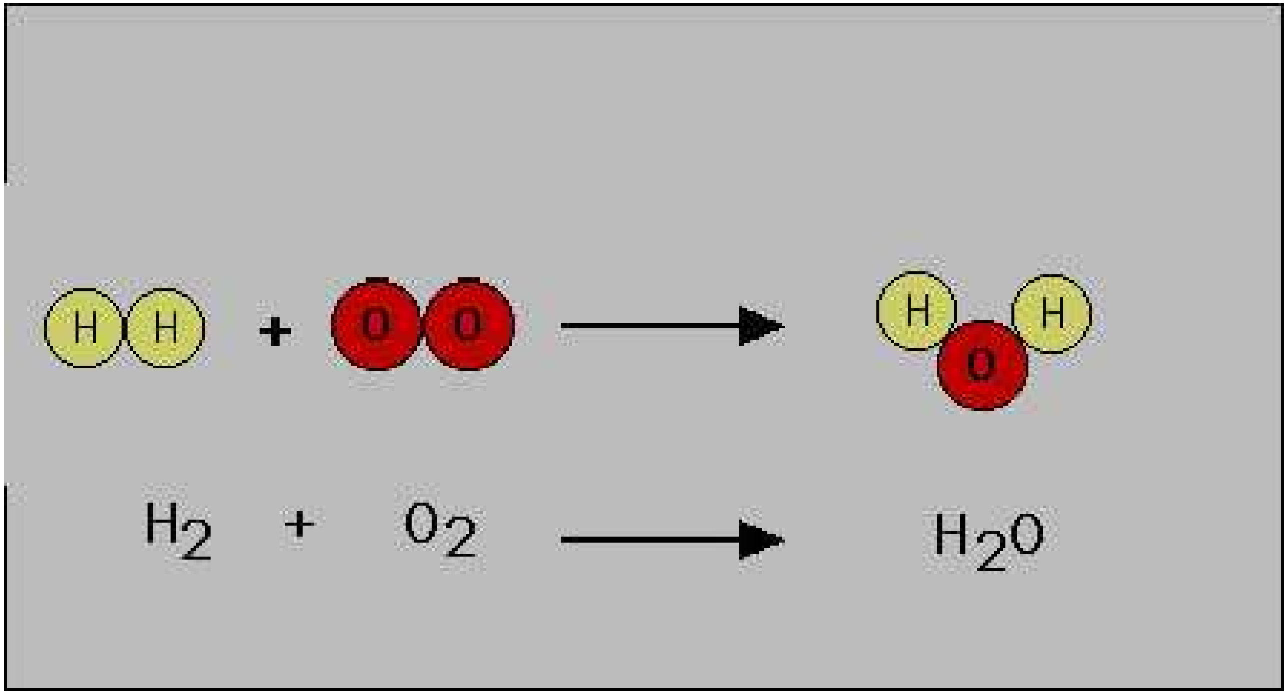

Not a balanced equation

Chemical Equations

Balance equations by adding coefficents

Small, whole numbers before a formula

$2H_2$ + O_2 º $2H_2O$

$(H_2 + H_2)$ + O_2 º $H_2O + H_2O$

Chemical Equations

Chemical equations obey the law of conservation of mass

Balancing Equations

$$2\,C \quad + \quad O_2 \quad \rightarrow \quad 2\,CO$$

Balancing Equations

$3\ N_2 \quad + \quad H_2$ º $2\ NH_3$

Balancing Equations

$2\ K + 2\ H_2O$ º $2\ KOH + H_2$

Balancing Equations

X Fe + 3 O_2 º 2 Fe_2O_3

Balancing Equations

$4\ Fe\ +3\ O_2$ º $2\ Fe_2O_3$

How To Read Equations

$N_2 + 3\,H_2 \rightarrow 2\,NH_3$

1 molecule + 3 molecules $\rightarrow$ 2 molecules

1 mole + 3 mole $\rightarrow$ 2 mole

$1 \times 6 \times 10^{23}$ molecules + $3 \times 6 \times 10^{23}$ molecules $\rightarrow$ $2 \times 6 \times 10^{23}$ molecules

1 mole + 3 mole $\rightarrow$ 2 mole

2x14 g + 3 (2x1) g $\rightarrow$ 2 (14+[3x1]) g

28 g N_2 + 6 g H_2 $\rightarrow$ 34 g NH_3

Yields of Reactions

Theoretical: based on equation, max yield

Actual: Based on amount of product obtained

% yield = (actual ÷ theoretical) × 100

N_2 + $3\ H_2$ ¸ $2\ NH_3$

2x14 g + 3 (2x1) g ¸ 2 (14+[3x1]) g

28 g N_2 + 6 g H_2 ¸ 34 g NH_3

Yields of Reactions

N_2 + 3 H_2 ¸ 2 NH_3

28 g N_2 + 6 g H_2 ¸ 34 g NH_3

example: reaction produces 17 g NH_3
what is % yield?

% yield = (actual ÷ theoretical) × 100

% yield = (17 g ÷ 34 g) × 100 = 50 %

Stoichiometry Calculations

$$N_2 \quad + \quad 3\ H_2 \quad \rightarrow \quad 2\ NH_3$$

1 molecule + 3 molecules → 2 molecules

How much nitrogen and hydrogen needed to make 1000 tons of ammonia ?

to make 1000 grams of ammonia ?

Stoichiometry Calculations

N_2 + 3 H_2 ¸ 2 NH_3

1 molecule + 3 molecules ¸ 2 molecules

28 g N_2 + 6 g H_2 ¸ 34 g NH_3

ratio of N_2 to NH_3 is 28 g to 34 g

Amounts of Reactants/Products

How much N_2 and H_2 is needed to make 1000 g of NH_3?   uses ratios

ratio of N_2 to NH_3 is 28 g to 34 g

$$\frac{28\text{ g}}{34\text{ g}} = \frac{?\text{ g } N_2}{1000\text{ g } NH_3}$$

$$?\text{ g} = \frac{28 \times 1000}{34} = 823\text{ g}$$

A ratio walking analogy

3 miles ¸ 1 hour

ratio of distance to time is 3:1

How far will I walk in 6 hours?

$$\frac{3 \text{ miles}}{1 \text{ hour}} = \frac{? \text{ miles}}{6 \text{ hour}}$$

$$? \text{ miles} = \frac{3 \text{ miles} \times 6 \text{ hours}}{1 \text{ hour}} = 18 \text{ miles}$$

ratio or conversion factor

Amounts of Reactants/Products

Coefficients

$2\ Fe_2O_3$ ¸ $4\ Fe + 3\ O_2$

mole ratio - ratio of molecules or atoms

10 moles Fe_2O_3 ¸ ? moles Fe

use conversion factor also known as factor-label method

$2\ Fe_2O_3$ ¸ $4\ Fe + 3\ O_2$

100 grams Fe_2O_3 ¸ ? grams Fe

3 steps to solve

$2\ Fe_2O_3$ ¸ $4\ Fe + 3\ O_2$

1. convert mass Fe_2O_3 into moles Fe_2O_3

$$\frac{100\ g\ Fe_2O_3}{159.7} = 0.626\ mole\ Fe_2O_3$$

2. convert moles Fe_2O_3 into moles Fe

$$0.626\ moles\ Fe_2O_3 \times \frac{4}{2} = 1.25\ moles\ Fe$$

$2\ Fe_2O_3$, $4\ Fe + 3\ O_2$

3. convert moles Fe into mass Fe

1.25 g Fe x 55.8 = 69.9 g Fe

$2\ Fe_2O_3$, $4\ Fe + 3\ O_2$

Summary of 3 steps:

1. mass (given) to moles (given)

2. moles (given) to moles (needed)

3. moles (needed) to mass (needed)

So, 100 g Fe_2O_3 produces 69.9 g Fe

Limiting & Excess Reactants

$2\ H_2\ +\ O_2 \rightarrow 2\ H_2O$

molecules react in 2:1 ratio

2 molecules H_2 need 1 molecule O_2

2 moles H_2 need 1 mole O_2

4 grams H_2 need 32 grams O_2

what if 5 g H_2 reacted with 32 g O_2 ?

$$2\,H_2 + O_2 \rightarrow 2\,H_2O$$

H_2 would be in excess = **excess reactant**

all the O_2 would react = **limiting reactant**

limiting reactant determines amount of product formed

how to find which is limiting ?

$2\ H_2 + O_2$ ¸ $2\ H_2O$

React 5.0 g H_2 with 10.0 g O_2

What mass of water will form?

Solve problem in steps

Step 1. Write balanced equation

$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

Step 2. Calculate moles of reactants from given masses

5.0 g H_2 with 10.0 g O_2

divide by 2.0
= 2.5 moles H_2

divide by 32.0
= 0.31 moles O_2

Step 3. Is this ratio same as reaction stoichiometry 2:1 ?

If yes:

both reactants completely used up

could use either to find mass of water

If no:

one is excess, one is limiting

2.5 moles H_2 to 0.31 moles O_2

Is this a 2: 1 ratio ?

Step 4. divide by coefficients

$$\frac{2.5}{2} = 1.25 \text{ moles } H_2$$

$$\frac{0.31}{1} = 0.31 \text{moles } O_2$$

1.25 moles H_2 0.31moles O_2

if equal: both used up completely
if unequal: lowest is limiting;
highest is excess

Limiting reactant is: O_2

Step 5. use limiting reactant to solve for mass of water (3 step method)

Amounts of Reactants/Products

Remember……3 steps:

1. **mass (given) to moles (given)**
2. **moles (given) to moles (needed)**
3. **moles (needed) to mass (needed)**