STOICHIOMETRY

The branch of chemistry

dealing with

mass relationships of elements within compounds

and

among reactants and products in chemical reactions.

Atomic Mass

The mass in
atomic mass units
of an element

Molecular Mass

The mass in
atomic mass units
of a molecule

Formula Mass

The mass in
atomic mass units
of an ionic compound

NaCl

Na - 23.0 X 1 = 23.0

Cl - 35.5 X 1=35.5

58.5 amu

CO_2

C - 12 X 1 = 12

O - 16 X 2 = 32

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44 amu

Moles

- The quantity of matter containing Avogadro's number of particles
- 6.022×10^{23} particles
- Particles may include:
  - subatomic particles
  - ions
  - atoms
  - molecules

Molar Mass

The mass of
one mole of a substance
in
grams

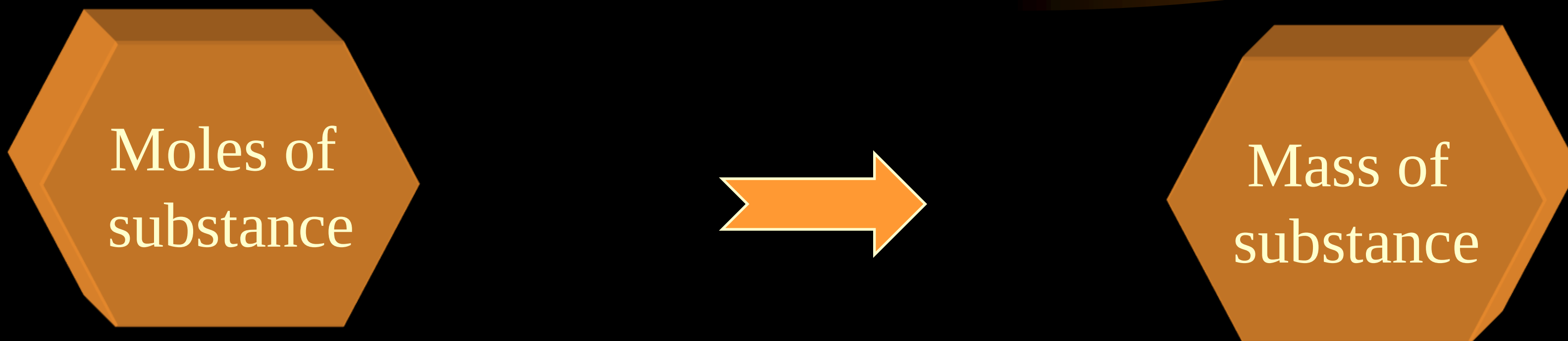
Stoichiometric Calculations

Calculating moles from grams

Mass of Substance → Mole of Substance

Divide grams by molar mass

Calculating grams from moles



Multiply moles by molar mass

Solutions

A homogeneous mixture of two or more substances

- Components
  - Solvent
  - Solute
- Concentration
  - General
    - dilute
    - concentrated
  - Specific
    - molarity

Molarity (M)

Mass of A → Moles of A → Molarity of A

M = moles of solute / L of solution

An Example:

White vinegar is a solution of acetic acid, CH_3CO_2H, in water. Vinegar, with an acidity of 5.00%, contains 50.4 g of acetic acid in 1.00 L of vinegar. Determine the concentration in moles per liter.

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Convert grams of CH_3CO_2H to moles:

$$mol\ CH_3CO_2H =$$

$$50.4g\ CH_3CO_2H \times \frac{1\ mol\ CH_3CO_2H}{60.0\ g\ CH_3CO_2H} =$$

$$0.839\ mol\ CH_3CO_2H$$

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$$\frac{0.839\ mol\ CH_3CO_2H}{1.00L} =$$

$$0.839\ molar\ CH_3CO_2H$$

Titration

A process for determining the concentration of a solution by allowing a carefully measured volume to react with a solution of a second substance whose concentration is known.

Percent Composition

$$\% X = \frac{mass\ of\ X}{mass\ of\ sample} \times 100\%$$

CO_2 an example:

$$\text{C: } 1 \times 12.0\,\text{amu} = 12.0\,\text{amu}$$

$$\text{O: } 2 \times 16.0\,\text{amu} = \underline{32.0\ \text{amu}}$$

$$44.0\,\text{amu}$$

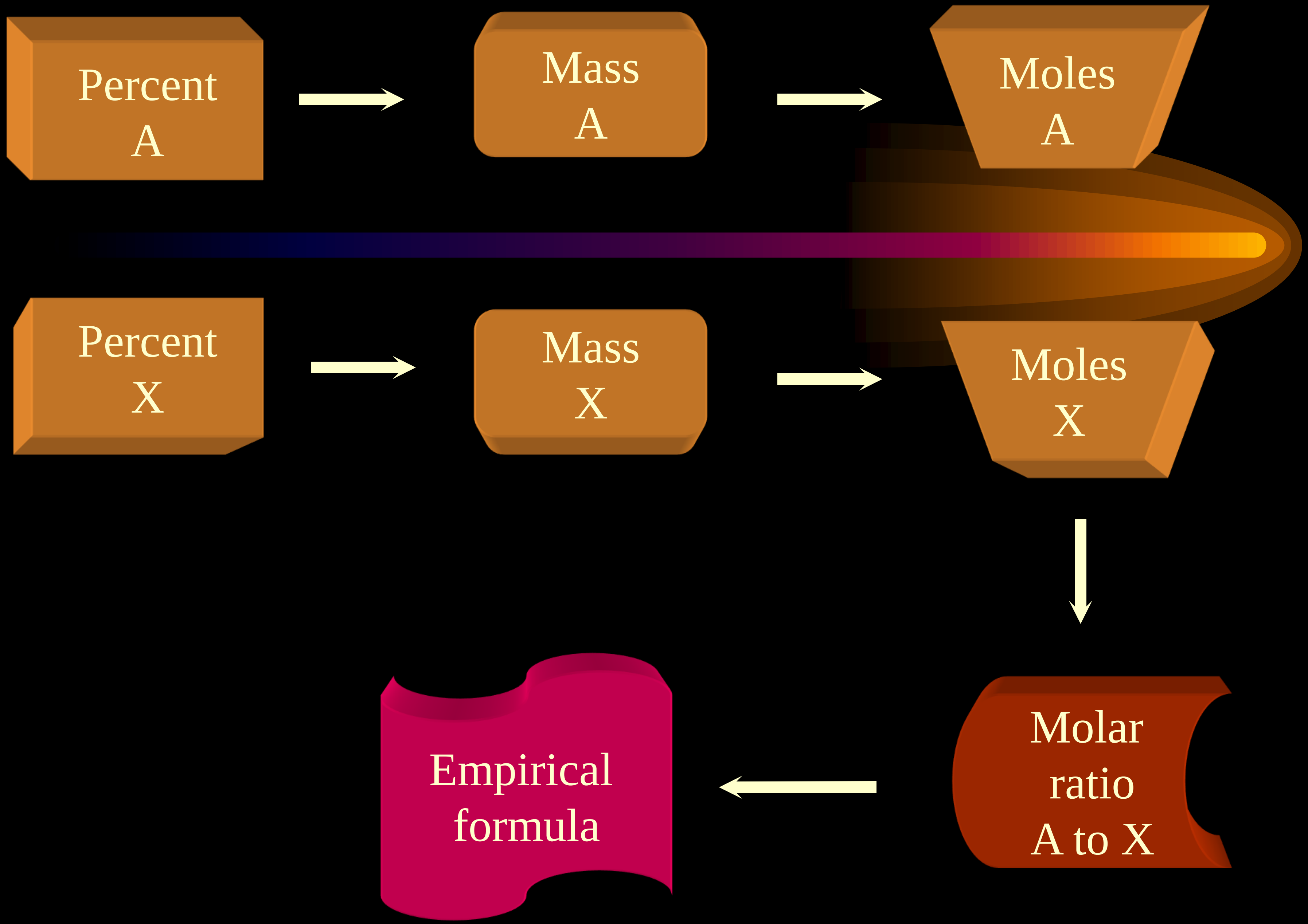
Then...

$$\text{C: } \left(12.0\,\text{amu} \div 44.0\,\text{amu}\right) \times 100\% = 27.3\%$$

$$\text{O: } \left(32.0\,\text{amu} \div 44.0\,\text{amu}\right) \times 100\% = 72.7\%$$

Empirical Formula

$$moles\ X = \frac{mass\ X}{molar\ mass}$$


Percent A
Mass A
Moles A
Percent X
Mass X
Moles X
Molar ratio A to X
Empirical formula

Types of data used in calculating the empirical formula

- Percentage Composition Data
  - utilizes data as percentages of substance

- Relative Mass Data
  - utilizes data as grams of substance

An example:

43.6% phosphorus and
56.4% oxygen

$$\text{P: } 43.6\% \Rightarrow 43.6g \times \frac{1mol}{31.0\,g} = 1.41\,\text{mol}$$

$$\text{O:} 56.4\% \Rightarrow 56.4g \times \frac{1mol}{16.0\,g} = 3.52\,\text{mol}$$

Then…

$$\text{P: } 1.41mol \div 1.41mol = 1$$

$$\text{O: } 3.52\,mol \div 1.41mol = 2.5$$

Since the ratios are not intergers… (multiply by 2)

$$P: 1 \times 2 = 2 \quad \text{and} \quad O: 2.5 \times 2 = 5$$

So.... P_2O_5

Determination of Molecular Formula

$(\text{empirical formula})_x$ = molecular formula

$$x = \frac{molecular\ \ mass}{empirical\ \ formula\ mass}$$

An example: A compound of carbon and hydrogen contains 92.3% C and has a molecular mass of 78.1 amu. Determine its molecular formula.

$$\text{C: } 92.3\% \Rightarrow 92.3g \times \frac{1mol}{12.0\,g} = 7.69\,\text{mol}$$

$$\text{H: } 7.7\% \Rightarrow 7.7g \times \frac{1mol}{1.01g} = 7.62\,\text{mol}$$

Then...

$$\text{C: } 7.69\,mol \div 7.62\,mol = 1$$

$$\text{H: } 7.62\,mol \div 7.62mol = 1 \quad So...\,CH$$

An example: A compound of carbon and hydrogen contains 92.3% C and has a molecular mass of 78.1 amu. Determine its molecular formula.

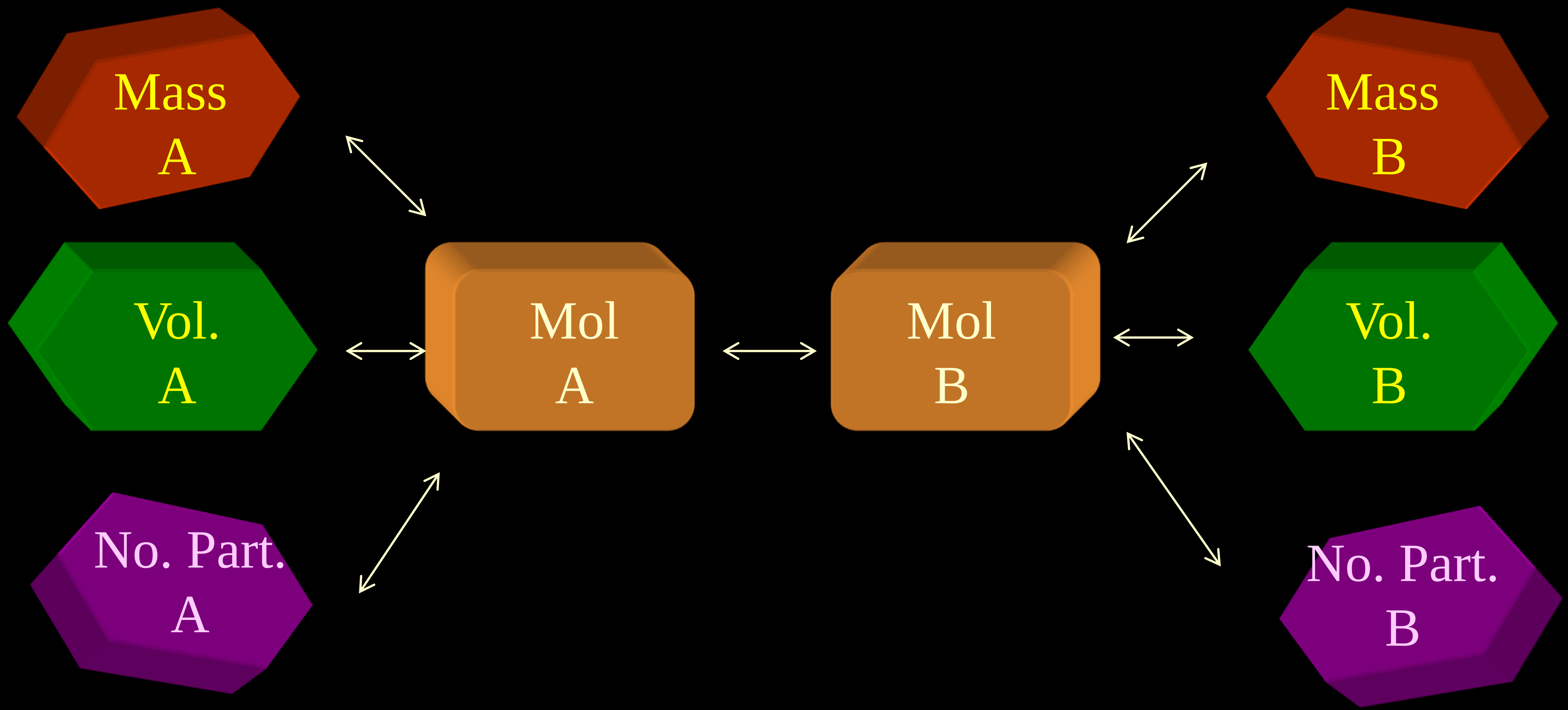
But… molecular mass is 78.1 amu

So… $x = \frac{78.1\ amu}{formula\ mass} = \frac{78.1\ amu}{13.0\ amu}$ =**6.00**

Then… $(CH)_x = (CH)_6 = C_6H_6$

Equation Based Calculations

- Mole to Mole
- Mole to Mass
- Mass to Mole
- Mass to Mass



Mass A
Vol. A
No. Part. A
Mol A
Mol B
Mass B
Vol. B
No. Part. B

Procedure

- Write a balanced chemical equation
- Determine what is given and what is to be determined
- Determine the molar ratios
- Use dimensional analysis to:
  - convert mass to moles
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An Example:

- What mass of oxygen gas, O_2, from the air is consumed in the combustion of 702 g (1 L) of octane, C_8H_{18}, one of the principal components of gasoline?

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$$

$$xg\ O_2 = 702\ g\ C_8H_{18} \times \frac{1\ mol\ C_8H_{18}}{114.26\ g\ C_8H_{18}} \times \frac{25\ mol\ O_2}{2\ mol\ C_8H_{18}} \times \frac{32.00g\ O_2}{1\ mol\ O_2}$$

$$xg\ O_2 = 2.46 \times 10^3\ g\ O_2$$

Another Example:

- What mass of sodium hydroxide, NaOH, would be required to produce 16 g of the antacid milk of magnesia [magnesium hydroxide, $Mg(OH)_2$] by the reaction of magnesium chloride, $MgCl_2$, with NaOH?

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$$MgCl_2 + 2NaOH \rightarrow Mg(OH)_2 + 2NaCl$$

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$$x\ g\ NaOH = 16\ g\ Mg(OH)_2 \times \frac{1\ mol\ Mg(OH)_2}{58.3\ g\ Mg(OH)_2} \times \frac{2\ mol\ NaOH}{1\ mol\ Mg(OH)_2} \times$$

$$\frac{40.0g\ NaOH}{1\ mol\ NaOH} = 22\ g\ NaOH$$

Percentage Yield

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

A Percent Yield Example:

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$$x\ g\ Cu = 1.274\ g\ CuSO_4 \times \frac{1\,mol\ CuSO_4}{159.6\ g\ CuSO_4} \times \frac{1\,mol\ Cu}{1\,mol\ CuSO_4} \times$$

$$\frac{63.54 g\ Cu}{1\,mol\ Cu} = 0.5072\ g\ Cu$$

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$$1\,mol \qquad\qquad 1\,mol$$

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From the previous calculation

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$$\text{so:} \quad \text{Percent yeild} = \frac{0.392\text{ g}}{0.5072} \times 100\% = 77.3\%$$

Limiting Reagents

- Calculate a mass to mass stoichiometric problem using one of the two givens.
- Calculate the same problem, but using the second of the two givens.
- Determine which one limits the other
- This is the limiting reagent.

An Example…

Lithium oxide was used aboard the space shuttle to remove water from the air supply. If 80.0 Kg of water is to be removed and 65 Kg of Li_2O is available, which reactant is liniting? Now many kilograms of the excess reactant remain?

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65 Kg 80.0 Kg

$$Li_2O + H_2O \rightarrow 2LiOH$$

Chose either LiO or H_2O as your "unknown"

Let's use H_2O for the "unknown"

65 Kg x Kg

$$Li_2O + H_2O \rightarrow 2LiOH$$

1 mol 1 mol

65 Kg   x Kg

$$Li_2O + H_2O \rightarrow 2LiOH$$

1 mol   1 mol

$$65 \text{ Kg } Li_2O \text{ X } \frac{1000g}{1\ Kg} \text{X} \frac{1.oo\ mol\ Li_2O}{29.88\ g\ Li_2O} \text{X} \frac{1.00\ mol\ H_2O}{1.oo\ mol\ Li_2O} \text{X} \frac{18.02\ g\ H_2O}{1\ mol\ H_2O} \text{X} \frac{1\ Kg}{1000g} =$$

39.2 Kg H_2O

65 Kg of Li_2O will react with only 39.2 Kg of water. 80.0 Kg of water are to be removed. Therefore there is insufficient Li_2O , so Li_2O then limits the reaction.