CHAPTER 7

Chemical Quantities

How do we measure matter?

- Counting
- Weight (Mass)
- Volume

Chemical Quantities

Mole: the SI unit that measures the amount of a substance

It can be related to:

- The number of particles
- Mass
- Volume

So What is a Mole?

A mole (mol) of a substance represents:

6.02×10^{23} representative particles of a substance and is called *Avogadro's* number

Avogadro's number

Named in honor of Amedeo Avogadro di Quaregna (1776-1856)

Avogadro:

He proposed:

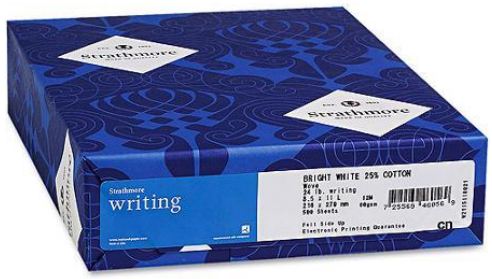
- Equal volumes of different gases at the same temperature and pressure, contain the same number of particles.

The Mole is a Measurement Number

- How do you buy donuts?
- How do you buy computer paper?
- How do you buy pencils?
- How do you buy soda?
- You use a counting/measuring amount!

The Mole: A Measurement of Matter

- 1 dozen donuts = 12 donuts
- 1 ream of paper = 500 sheets
- 1 gross of pencils = 144 pieces.
- 1 case of soda = 24 cans



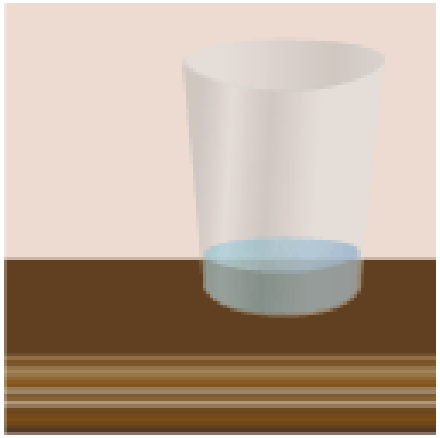
The mole

- 602,000,000,000,000,000,000,000
- 1 mole of paperclips: goes around earth 4 trillion times
- 1 mole of large marshmallows: covers the continental USA 650 miles deep
- 1 mole of marbles: 116 times the size of Mt. Everest
- 1 mole of pennies stacked up: distance to the moon 1.55×10^{12} times

Mole of Water

Is equal to 18 mL

…that's how small molecules really are!



Representative Particle

Refers to the species present

- Atoms
- Molecules
- Formula units
- Ions

Representative Particles

Substance	Representative Particle	Chemical Formula	Particles in 1 mole
Pure carbon	Atom	C	6.02×10^{23}
Pure iron	Atom	Fe	6.02×10^{23}
Nitrogen gas	Molecule	N_2	6.02×10^{23}
Water	Molecule	H_2O	6.02×10^{23}
Calcium ion	Ion	Ca^{2+}	6.02×10^{23}
Calcium fluoride	Formula Unit	CaF_2	6.02×10^{23}
Sucrose	Molecule	$C_{12}H_{22}O_{11}$	6.02×10^{23}

Atomic Mass Units

In previous chapters we expressed atomic mass in atomic mass units

- Atomic mass of atoms is relative
- Carbon is 12 times the size of Hydrogen
  - This still holds true when we express atomic mass in grams

Gram Atomic Mass (GAM)

Gram atomic mass is the atomic mass of an element expressed in grams

- Example:
  - Carbon- atomic mass = 12.011
  - Gram atomic mass = 12.011 grams

Atomic mass & Avogadro's Number

12.01 grams of Carbon and 1.008 grams of Hydrogen contain the same number of atoms

- 6.022×10^{23} atoms
- The gram atomic mass of any two elements must contain the same number of atoms

Molar mass:

Molar mass is the mass in grams of one mole of a substance

- Molar mass can be the equivalent of:
  - gram atomic mass(gam),
  - gram molecular mass(gmm), or
  - gram formula mass(gfm).

It depends on what the substance is: is it an element, a molecular or ionic substance?

Molar Mass:

Gram molecular mass is the mass that contains 1 mole of a compound

- May be calculated from gram atomic masses
  - GMM = the sum of the masses of the elements in a compound
  - GMM = the molecular mass expressed in grams

Molar Mass

GMM example:

Calculate the molar mass of C_2H_6 (ethane)

$2 \times C = 2 \times 12.01 = 24.02$

$6 \times H = 6 \times 1.008 = \underline{\quad 6.048}$

$30.068 = 30.07$ g/mole

Molar Mass

GFM = gram formula mass used for ionic compounds

- Ionic compounds = formula units
- GFM = the mass of one mole of an ionic compound
  - GFM is calculated the same way as a GMM
  - GFM = the sum of the atomic masses of the ions in the formula of the compound

Molar Mass

GFM example:

Calculate the formula mass of NaCl

1 x Na = 1 x 22.99

1 x Cl = 1 x 35.45

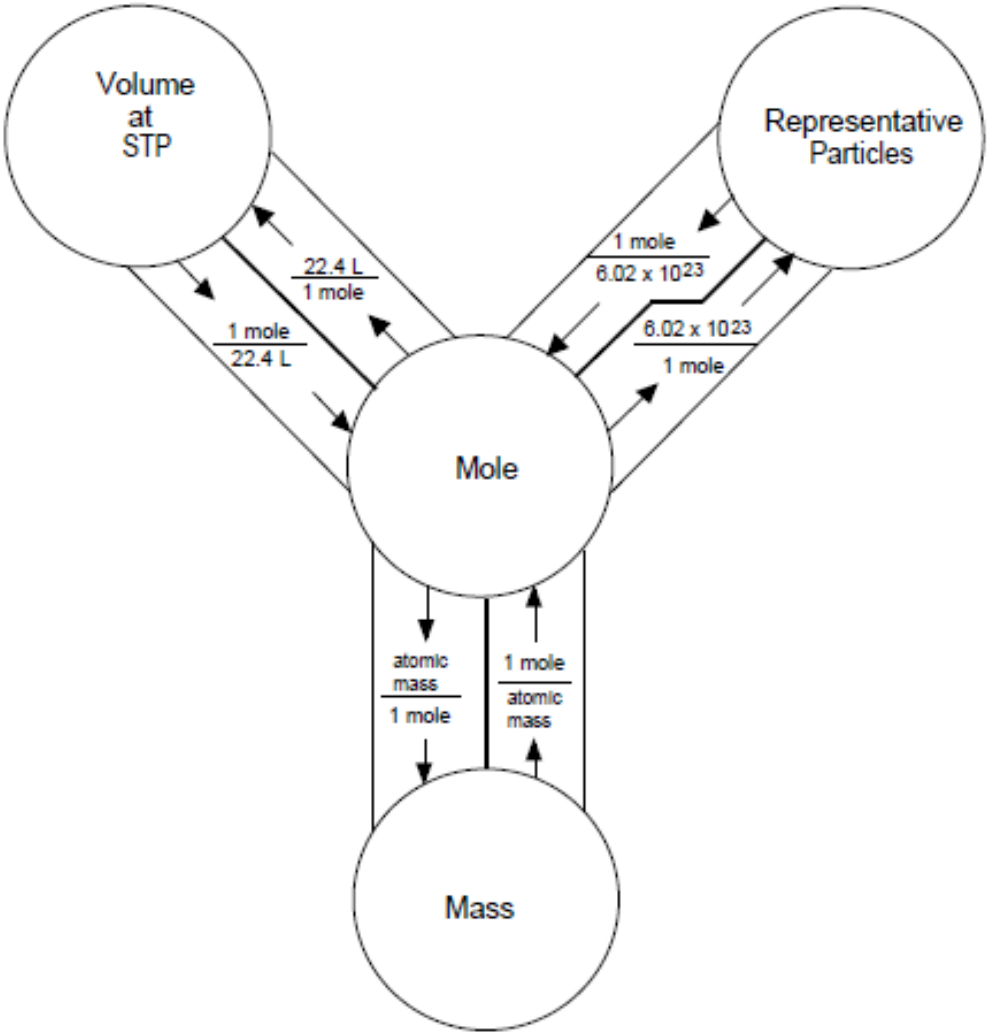
58.44 g/mole

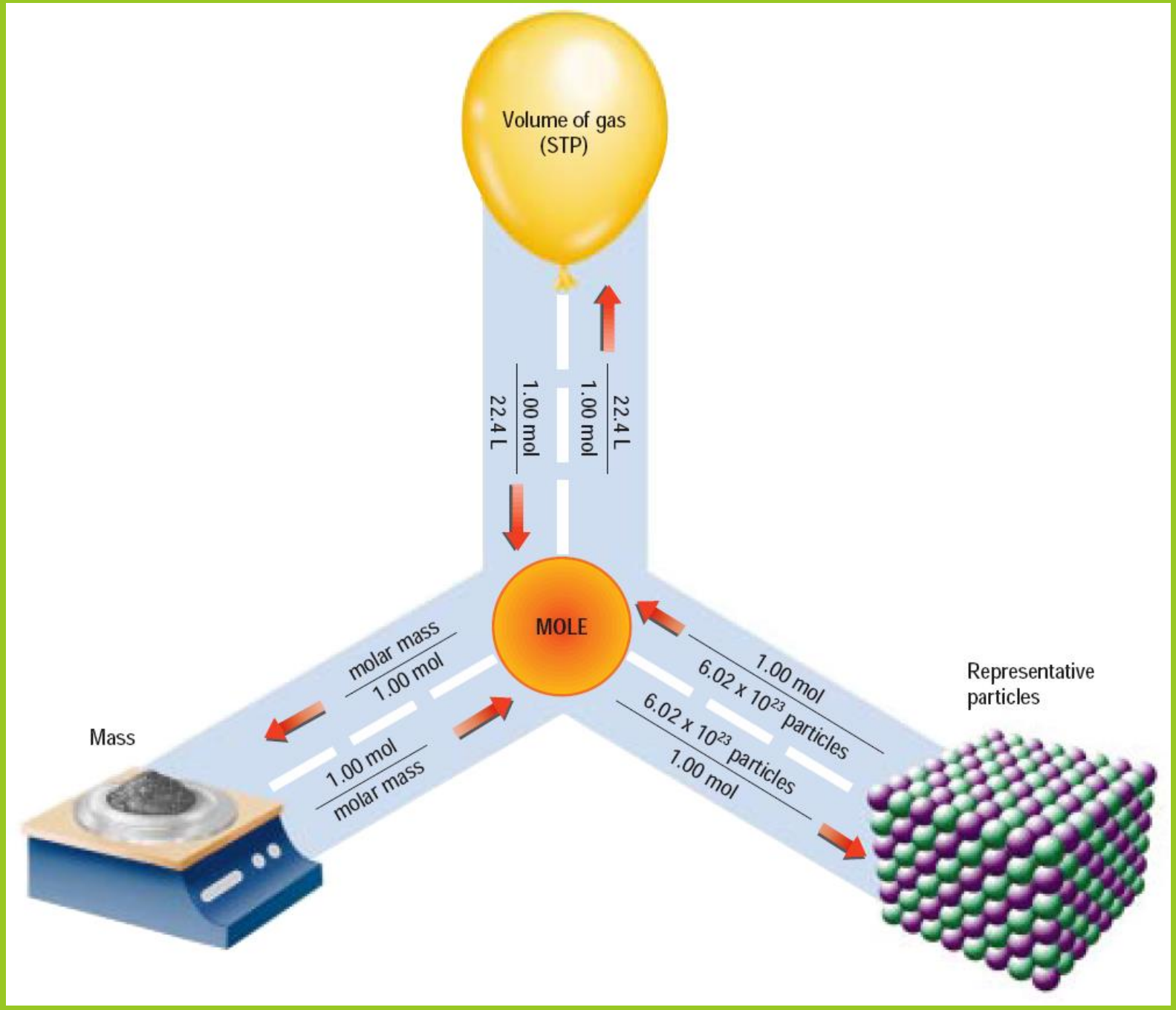
Mole Conversions

Three types of Mole Conversions

- Mole – mass (g)
- Mole – representative particles (molecules, atoms, formula units)
- Mole – volume (L)

THE MOLE ROAD MAP




Volume of gas
(STP)
22.4 L
1.00 mol
1.00 mol
22.4 L
MOLE
molar mass
1.00 mol
1.00 mol
molar mass
Mass
1.00 mol
6.02 x 10^23 particles
6.02 x 10^23 particles
1.00 mol
Representative
particles

Mole-Mass Problem

What is the mass of 4.00 moles of NaCl?

Given:

Unknown:

Conversion Factor:

Solve:

Molar Volume

If one mole of Helium weighs 4.00 g/mol, how much does 2 moles weigh?

Can you weigh out something less dense then air?

Molar Volume

You CANNOT weigh a gas less dense then air!

Gravity does not pull it down on the scale!

Molar Volume

The volume of mole of a gas is much more predictable than that of a liquid or solid

That is, under the same physical conditions (STP), a mole of any gas occupies a volume of 22.4 L

- Standard temperature and pressure
  - Standard Temperature is 0^0C (273 K)
  - Standard Pressure is 1atm (760 mm; 101.3 kPa)

Molar Volume

At STP, one mole of any gas will have a volume of 22.4 L

- 22.4 L is known as the **molar volume** of a gas

What does it mean?

- It means that 22.4 L of any gas at STP contains 6.02×10^{23} representative particles of that gas.

Molar Volume

Standard Temperature and Pressure (STP):
specific conditions that can be reached in the lab

- Standard Pressure: 1 atmosphere (atm)
- Standard Temperature: 0°C or 273 K

Mole-Volume Problem

How many moles are in 145.6 L of O_2 gas at STP?

Given:

Unknown:

Conversion Factor:

Solve:

Mole-Representative Particle Problem

How many moles is 2.107×10^{24} molecules of O_2?

Given:

Unknown:

Conversion Factor:

Solve:

Mole-Representative Particle Problem

How many moles is 2.107×10^{24} molecules of O_2?

Given: 2.107×10^{24} molecules

Unknown: ? moles

Conversion Factor: $1 \text{ mol} = 6.01 \times 10^{23}$ molecules

Solve: $$2.107 \times 10^{24} \text{ molecules} \times \frac{1 \text{ mole}}{6.02 \times 10^{23} \text{molecules}} = 3.500 \text{ moles}$$

Mole Road Map Problems

How many liters of gas are 3.612×10^{24} atoms of Neon gas at STP?

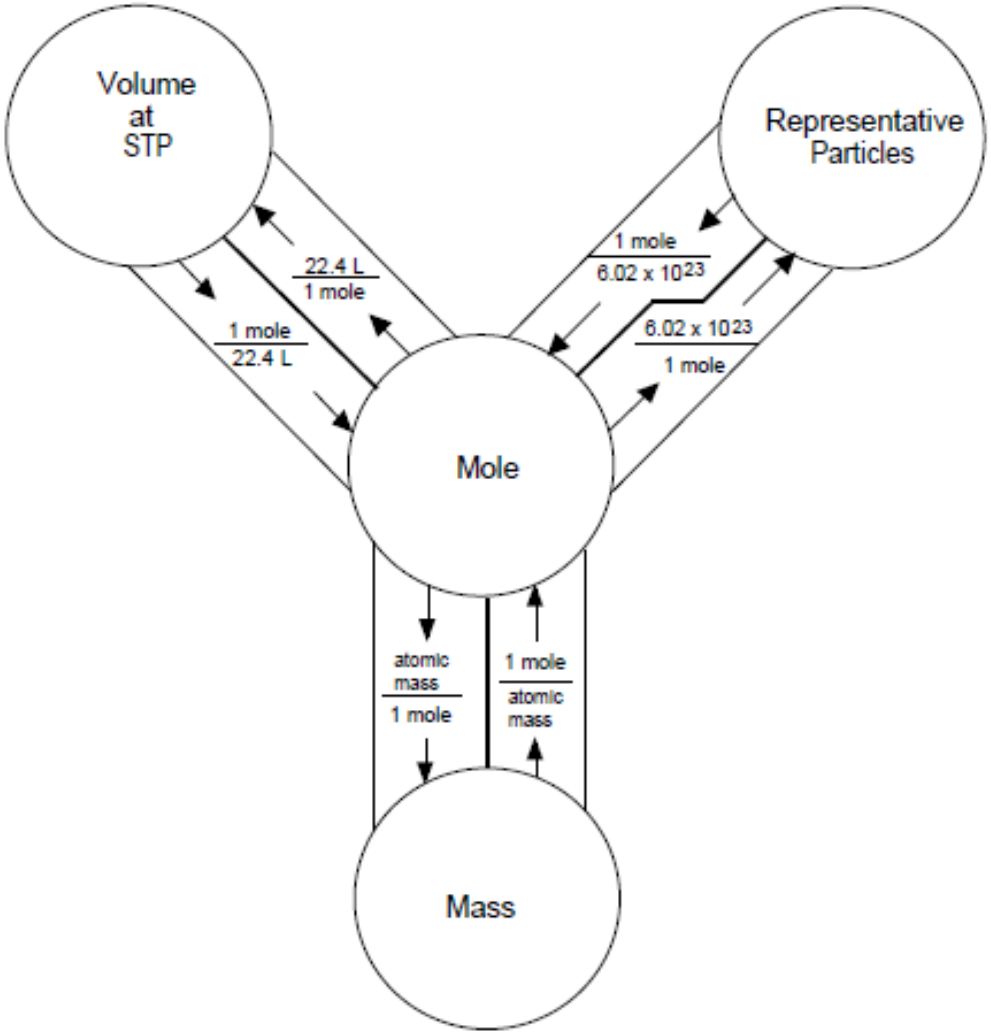
Given:

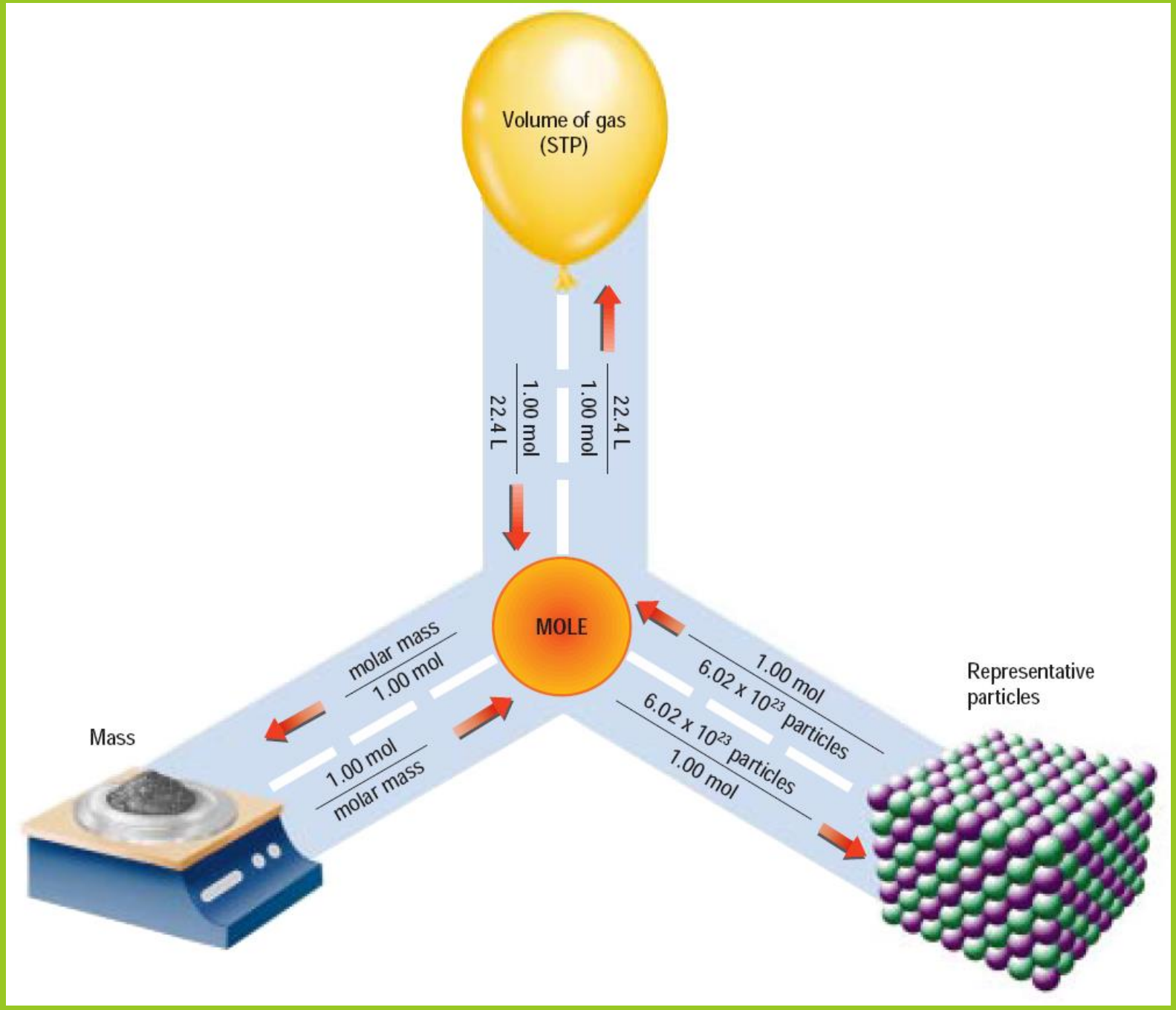
Unknown:

Conversion Factor:

Solve:

THE MOLE ROAD MAP

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Mass
1.00 mol
6.02 x 10^23 particles
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Representative
particles

PERCENT COMPOSITION AND CHEMICAL FORMULAS

Percent composition of a compound:

- The percent by mass of each element in a compound
- Percent composition must always equal 100

Example: percent by mass

- Number of grams of an element divided by the number of grams of a compound multiplied by 100%
- Example: percent of potassium in potassium chromate(K_2CrO_4)

Percent composition:

- First use chemical formula to calculate molar mass
- Divide the grams of an element in one mole of compound by the molar mass
- Multiple by 100%

% Composition Of K_2CrO_4

2 x K = 2 x 39.10 = 78.20g

1 x Cr = 1 x 52.00 = 52.00g

4 X O = 4 x 16.00 = 64.00g

Molar Mass = 194.20 g/mol

%K = (78.20g/194.20g) x 100 = 40.27%

%Cr =(52.00g/194.20g) x 100 = 26.78%

%O = (64.00g/194.20g) x 100 = 32.96%

Using percent as a conversion factor:

- Converting from percent composition to grams
- Must use a conversion factor based on the percent composition

Calculating Empirical Formula

Empirical formula is the lowest whole number ratio of the atoms of the element in a compound

Using % as a conversion factor:

- Converting from percent composition to grams
- Assume 100 grams and turn % into grams

Calculating Empirical Formula

Empirical formula is the lowest whole number ratio of the atoms of the element in a compound

Calculating Empirical Formula

1. Convert % Composition to grams. (Assume 100 g sample)
2. For each element convert grams to moles using atomic mass.
3. Divide each element by the smallest number of moles to determine the ratio.

Calculating Molecular Formulas:

The molecular formula is either the same as its experimentally determined empirical formula, or it is a simple whole – number multiple of it

Calculating Molecular Formulas:

To determine molecular formula, you need:

- Empirical formula
- Or Molar mass

EFM= empirical formula mass: the molar mass of the empirical formula

Calculating Molecular Formulas:

- Divide the molar mass by the empirical formula mass
- This gives you the number of empirical formula units in a molecule of the compound and is the multiplier to convert to molecular formula

Calculating Molecular Formulas:

- The molecular formula of a compound is either the same as its experimentally determined empirical formula, or it is a simple whole – number multiple of it
- Example: H_2O_2
- The empirical formula is HO

Calculating Molecular Formulas:

To determine molecular formula, you need:

- Empirical formula
- Molar mass

- EFM= empirical formula mass: the molar mass of the empirical formula

Calculating Molecular Formulas:

- The ratio of the molar mass to the empirical formula mass allows you to find the true formula.
- This gives you the multiplier to convert from empirical to molecular formula

Molecular Formula Example

A substance has a molar mass of 32.08. The empirical formula of the compound is CH_4. What is the molecular formula?

First calculate the Empirical formula mass:

1 x C = 12.01 The Ratio $= \frac{MFM}{Efm} = \frac{32.08}{16.04} = 2$

4 x H = 4.032

EFM = 16.04 So the Molecular formula is 2 x EF

Molecular Formula is C_2H_8