CHAPTER 11

The Mole

11.1 The Mole: *A* Measurement of Matter

Matter is measured in one of three ways:

1. **Counting** *(How many?)*
2. **Weighing**
3. **Volume**

Mole

- **SI unit that measures the "amount of a substance"**
- **A mole of a substance represents 6.02×10^{23} representative particles of that substance.**

Representative Particle

Refers to the species present in a substance: usually **atoms**, **molecules**, or **formula units**
(Ionic)

Types of Representative Particles

- **Atoms**: Fe, Ag, Au, Ni, Mg Not bonded to anything
  7 atoms exist only as molecules.
- **Molecules**: H_2O, SO_2, CO_2, SCl_6
  Diatomic: H_2, O_2, N_2, Cl_2, F_2, Br_2, I_2
- **Formula Units**: Ionic Compounds
  $CaCl_2$, $MgSO_4$, $Al(OH)_3$, $Pb(CO_3)_2$
- **Ions**: Ca^{2+}, Br^-, Al^{3+}

One mole of …

- **Fe = 6.02×10^{23} atoms**
- **H_2O = 6.02×10^{23} molecules**
- **$CaCl_2$ = 6.02×10^{23} formula units**
- **Al^{3+} = 6.02×10^{23} ions**

Comparing Atoms

1 mole Li	1 mol Fe	1 mol Ca
6.02 x 10^{23} atoms	6.02 x 10^{23} atoms	6.02 x 10^{23} atoms
gam = 7g	gam = 56g	gam = 40g

Comparing Molecules

1 mol H_2O	1 mol H_2O_2
6.02 x 10^{23} molecules	6.02 x 10^{23} molecules
H: O:	H: O:
gmm = 18g	gmm = 34g

Comparing Ionic Compounds

1 mol $CaCl_2$	1 mol $Al_2(CO_3)_3$
6.02 x 10^{23} form units	6.02 x 10^{23} form units
Ca: Cl:	Al: C: O:
gfm = 111-g	gfm = 234g

11.2 Mass of a Mole of an Element

- Mass of one mole of any element is the molar mass.
- Gram atomic mass: mass of one mole of atoms of an element.

Mass of a Mole of a Compound

Molar Mass: Mass of one mole

- Expressed in **g/mol**.
- Gram formula mass: the mass of one mole of an ionic compound.
- Gram molecular mass: the mass of one mole of a molecule.

Dinitrogen pentoxide	Cobalt (II) nitrate
6.02 x 10^{23} molecules	6.02 x 10^{23} form units
N: O:	Co: N: O:

Conversion Factors

Moles ←→ Rep Particles

$\frac{1 \text{ mole}}{6.02 \times 10^{23}}$ **OR** $\frac{6.02 \times 10^{23}}{1 \text{ mole}}$

Converting (Moles → Representative Particles)

1.22 mol of Fe

4.03×10^2 mol of CO_2

2.71 mol of $MgSO_4$

Converting (Representative Particles → Moles)

8.72×10^{23} atoms of Mg

3.046×10^{24} molecules of H_2O

5.13×10^{22} formula units of $CaCl_2$

11.3 Mole-Mass and Mole-Volume Relationships

- You can use the number of moles to determine the volume or mass of an atom, molecule, or ionic compound.
- You can also use the volume or mass to determine the number of moles in an atom, molecule, or ionic compound.

Mole-Mass Relationship

- The molar mass of an atom, molecule, or ionic compound is used to convert moles of a substance into grams.
- The molar mass is also used to convert grams into moles.
- Correctly use gmm, gam, or gfm for molar mass.

Conversion Factors

Moles ←→ Mass

$\frac{1 \text{ mole}}{\text{Molar Mass}}$ **OR** $\frac{\text{Molar Mass}}{1 \text{ mole}}$

Converting (Moles into Mass)

3.504 mol of NaCl

5.13 mol of gold

7.28 mol of CO_2

Converting (Mass into Moles)

39.2 grams of NH_3

157.8 grams of $MgCl_2$

91.79 grams of Calcium

Molar Mass

- Mass of 1-mole of a substance
- Different for every substance
- Must use correct formula and the periodic table to determine the molar mass.
- The molar mass does not change!

Mole-Volume Relationship

- STP: *(This is very important!)*
- Standard Temperature & Pressure
- Temperature: 0° C or 32° F
- Pressure: 101.3 kPa or 1 atm

Molar Volume

- Volume of 1-mole of a substance
- Gases only
- 22.4 – L per 1 mole
- The molar volume is the same for all gases @ STP

Molar Volume

- At STP, 1 mole of any gas occupies a volume of 22.4 L.
- 22.4 L is known as the molar volume of a gas.
- 22.4 L contains Avogadro's number of particles.

Conversion Factors

Moles ←→ Volume @ STP

$$\frac{1 \text{ mole}}{22.4\text{-L}} \quad \text{OR} \quad \frac{22.4\text{-L}}{1 \text{ mole}}$$

Convert (Moles into Volume)

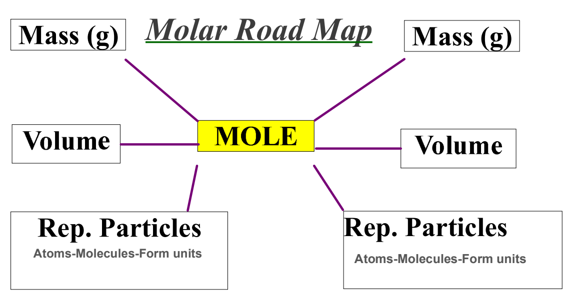
0.603 mol SO_2 @ STP

1.25 mol of oxygen @ STP

Convert (Volume into Moles)

8.06 L of Fluorine @ STP

1.49 L of CO_2 @ STP



CONVERTING BETWEEN UNITS WITH MOLES

- Change from one unit to another, use the mole as a middle step. *(p. 303)*

- **Rep. Particles to Moles to Mass**
- **Mass to Moles to Volume**
- **Volume to Moles to Rep. Particles**

Convert @ STP

59.4 g of CO_2 into Liters

71.8 g of nitrogen into molecules

Convert @ STP

8.43×10^{22} molecules of H_2O into Liters

9.06×10^{24} form units of $CaCl_2$ into Mass

Convert @ STP

57.9 L of Chlorine into Mass

18.7 L of C_2H_6 into Rep. Particles

GAS DENSITY AND THE MOLAR MASS

- The density of a gas is usually measured in the units g/L.
- Remember that molar mass is measured in g/mol.
- You must convert L → moles.

Converting (Density of gas into Molar Mass)

1.964 g/L of CO_2 @ STP.

2.857 g/L of SO_2 @ STP.

Sample Problems

WWhat is the density of NH_3 at STP?

- **Determine the molar mass of NH_3. (17g/mol)**
- **Convert the molar mass into density**

Sample Problem

An unknown gas is 8.20-grams & occupies 4.00-liters @ STP. Is the sample N_2O, NO, NO_2, N_2O_5 or N_2O_3?

- **Determine the density in g/L.**
- **Convert density into molar mass.**
- **Which sample has the matching molar mass.**

N_2O = 44-g
NO = 30-g
NO_2 = 46-g
N_2O_3 = 76-g
N_2O_5 = 108-g

Sample Problem

Given 250-mL of gas with mass of 0.335-g.
Is the sample N_2O, NO, NO_2 N_2O_5 or N_2O_3?

- **Determine the density in g/L.**
- **Convert density into molar mass.**
- **Which sample has the matching molar mass?**

N_2O = 44-g
NO = 30-g
NO_2 = 46-g
N_2O_3 = 76-g
N_2O_5 = 108-g

Determining Ions and Atoms

1. How many formula units in 1 mole of Fe_2O_3? ________________

- How many "Fe" ions are in 1 formula unit? __________
- How many "O" ions are in 1 formula unit? ___________

2. How many molecules in 1 mole of H_2O? ________________

- How many "H" atoms are in 1 molecule? ____________
- How many "O" atoms are in 1 molecule? ____________

Sample Problems

How many hydrogen atoms are there in 3.2 mol of water? H_2O

- **Moles into molecules into atoms**

Sample Problems

How many oxygen ions are there in 0.674 mol of Iron (III) oxide? Fe_2O_3

- Moles into formula units into ions

11.4 Percent Composition and Chemical Formulas

- Percent Composition: the percent by mass of each element in a compound.
- The percentages of each element should add up to 100%.
- Used to determine the formula of new substances.

Determining Percent Composition

- **What is the percent composition of each element in the compound $CaCO_3$?**

Ca: 1 x 40 = 40
C: 1 x 12 = 12
O: 3 x 16 = 48

Molar Mass = 100

% Ca: 40/100 x 100 = 40%

% C:12/100 x 100 = 12%

% O:48/100 x 100 = 48%

Determining Percent Composition

- What is the percent composition of each element in the compound CO_2?

C: 1 x 12 = 12
O: 2 x 16 = 32

Molar Mass = 44

% C:12/44 x 100 = 27.3 %

% O:32/44 x 100 = 72.7%

Sample Problem

You have a 500-gram sample of Carbon dioxide? What is the mass of oxygen within that sample? *(Hint: first find % Composition)*

% C:27.3 %

% O: 72.7%

Determining Percent Composition

What is the mass and percent composition of each element in a sample containing Magnesium and oxygen? The sample's mass is 57.89-g and the mass of the oxygen is 22.98-g?

Magnesium = _____
Oxygen: 22.98-g

Sample's Mass = 57.89- g

Mg: ________/57.89 x 100 = _______

O: 22.98/57.89 x 100 = 39.6%

Sample Problem

What is the mass of calcium in 6.51 grams of calcium carbonate?

% Ca: 40%

% C: 12%

% O: 48%

Sample Problem

- What is the mass of sodium in 4.6 grams of sodium chloride?

% Na: 39.3%

% Cl: 60.7%

EMPIRICAL FORMULAS

- The empirical formula gives the lowest whole number ratio of the atoms of the elements in a compound.

Ionic Compounds (Ionic Bonds)	Molecular Compounds (Covalent Bonds)
Always Empirical	* NOT ALWAYS EMPIRICAL

Determining Empirical Formula

1. Percent Composition
2. Assume 100 g *(Use %)*
3. Change to Moles *(No scientific notation)*
4. Divide by smallest mole
5. Change to whole number
6. Assign to elements

Determining Empirical Formula

- **Carbon = 79.9%, Hydrogen = 20.1%**

Determining Empirical Formula

- **Hg = 67.6%, S = 10.8%, O = 21.6%**

Determining Empirical Formula

- **Oxygen = 74.1%, Nitrogen = 25.9%**

MOLECULAR FORMULAS

- To calculate the molecular formula, you need the empirical formula mass and the molar mass of the compound.
- Divide the mass of the compound by the mass of the empirical formula.
- Multiply that number by each number of atoms in the empirical formula.

MOLECULAR FORMULAS

- **The molecular formula can be the same as the empirical formula.**
- **Several compounds can have the same empirical formula.**
- **The empirical formula cannot be greater than a molecular formula.**

Determining Molecular Formulas

- **Empirical Formula = CH_4N**
- **Molar mass = 60.0 g/mol**

Determining Molecular Formulas

- **Empirical Formula = CH_3**
- **Molar mass is 30.0 g/mol**

Determining Molecular Formulas

- **A compound consists of 58.8% C, 9.8% H, & 31.4% O. Determine the empirical formula for the compound and then the molecular formula for a compound with a molar mass of 102.0 g.**

11.5 Hydrates

- Water molecules are an integral part of the crystal structure of many substances.
- The water in a crystal is called the **water of hydration** or **water of crystallization**
- Ex. $CuSO_4 \cdot 5H_2O$

- If a hydrate has a vapor pressure higher than that of the water vapor in air, the hydrate will effloresce by losing the water of hydration...becoming Anhydrous.

Anhydrous Salt: a hydrate that has lost water

- Salts and other compounds that remove moisture from air are said to be **hygroscopic**

- Hygroscopic substances are used as drying agents, or desiccants.
- **They have Less vapor pressure in the compound than in the air.**
- These deliquescent compounds remove sufficient water from the air to dissolve completely and form solutions

What is the percentage of water in the hydrate $CoCl_2 \bullet 6H_2O$?

Co: 1 x 59= 59-grams
Cl: 2 x 35.5 = 71-grams
130 grams

$6H_2O$: 6 x 18-grams = 108-grams

Total Mass of Hydrate: 238-grams

$CoCl_2: \frac{130}{238} \times 100$

$H_2O: \frac{108}{238} \times 100$

%$CoCl_2$: 54.6 %
%H_2O: 45.4 %

How many grams of $CoCl_2$ will remain if 54.0-grams of the hydrate $CoCl_2 \bullet 6H_2O$ is heated until only the anhydrous salt remains?

%$CoCl_2$: 54.6 %
%H_2O: 45.4 %

After heating 5.0-grams of a hydrate, 3.9-grams of anhydrous salt remained. What was the percentage of water in the hydrate?