Chapter 12 – The Mole

12.1 Avogadro's Number and the Mole

Avogadro's Number, N_A, is the amount of a substance in one mole of that same substance. Much like 12 is the amount in a dozen, 6.02×10^{23} is the amount in a mole.

The mole is also defined as the number of carbon atoms in 12 grams of Carbon-12. So 1 mole of C atoms is 6.02×10^{23} atoms = 12.01 grams

- **One mole = 6.02×10^{23} entities**
  - **These "entities" can be anything. Some common uses are:**
    - atoms (e.g. Ag, Na, He)
    - ions (e.g. K^+, Cl^-, S^{2-}, Ba^{2+})
    - molecules (e.g. H_2, H_2O, N_2O_4 – molecular compounds)
    - formula units (e.g. NaCl, Al_2O_3, $CaBr_2$ – ionic compounds)

⇒ The mole is used to compare two entities that have different masses. Once you have one mole of each, you now have 6.02×10^{23} entities of each so you can now compare the two.

12.2 Molar Mass

If you were to count out 6.02×10^{23} atoms of gold, Au, you would have one mole of gold. If you were to place this same one mole of gold on a balance to measure the mass it would weigh 196.97 grams.

6.02×10^{23} atoms Au = 1 mole Au = 196.97 g Au

This is the **molar mass** of gold, Au. The numbers from the periodic table represent the mass of one mole (or 6.02×10^{23} atoms) of that element.

⇒ Recall atomic mass is average mass for one atom of an element. (units = amu)

Molar Mass - mass in grams of 1 mole of substance. (units = g/mol)
⇒ Numerically same as atomic mass, but units are different.

Example 1: What is the molar mass of helium, He?
Answer: The molar mass is **4.00 g/mol** -*This value comes from the Periodic Table.*

Example 2: What is the molar mass of chlorine gas?
Answer: Since chlorine gas is a diatomic molecule, the formula is Cl_2. There are two chlorine atoms in the molecule. Each Cl atom has a molar mass of 35.45 g/mol. Therefore the molar mass for Cl_2 is 2(35.45 g/mol) = **70.90 g/mol**

Example 3: What is the molar mass of water, H_2O?
Answer: (2 H atoms x 1.01 g/mol) + (1 O atom x 16.00 g/mol) = **18.02 g/mol**

12.3 Mole Calculations

Mole Calculations I:

- Avogadro's number is a useful conversion factor.

$$\frac{6.02x10^{23}\,atoms}{1\;mole} \quad \text{or} \quad \frac{6.02x10^{23}\,molecules}{1\;mole}$$

Example 1: Calculate the number of atoms in 3.56 moles of aluminum, Al.

Answer: 3.56 mol Al x $\frac{6.02x10^{23}\text{ atoms Al}}{1\text{ mol Al}}$ = **$2.14x10^{24}$ atoms Al**

Example 2: Calculate the number of moles of Mg when there is $5.77x10^{24}$ atoms of Mg.

Answer: $5.77x10^{24}$ atoms Mg x $\frac{1\text{ mol Mg}}{6.02x10^{23}\text{ atoms Mg}}$ = **9.58 mol Mg**

Mole Calculations II:

- Molar Mass is also a useful conversion factor between grams to moles and moles to grams
  - ⇒ Use the unit analysis method & write molar mass as a fraction - make sure that the units cancel and give you the units that you are solving for.

Example 1: Calculate the number of water molecules in 2.50 g H_2O.

Answer: 2.50 g H_2O x $\frac{1\text{ mole }H_2O}{18.02\text{ g }H_2O}$ x $\frac{6.02x10^{23}\text{ molecules }H_2O}{1\text{ mol }H_2O}$ = **8.35×10^{22} molecules H_2O**

Example 2: Calculate the mass of NaCl when there are $8.90x10^{24}$ formula units of NaCl.

Answer: $8.90x10^{24}$ formula units NaCl x $\frac{1\text{ mol NaCl}}{6.02x10^{23}\text{ formula units NaCl}}$ x $\frac{58.44\text{ g NaCl}}{1\text{ mol NaCl}}$ = **864 g NaCl**

12.4 Molar Volume

Avogadro's Law: An equal number of gas molecules at the same temperature and pressure will occupy the same volume.

⇒ **Molar volume** is the volume occupied by 1 mole of a gas at a given temperature and pressure.

STP conditions: Standard Pressure = 1 atm, Standard Temperature = O °C

At STP, 1 mole of ANY gas occupies 22.4 L

Write 2 unit factors for the molar volume at STP:

$$\frac{22.4\text{ L}}{1\text{ mole}} \quad \text{or} \quad \frac{1\text{ mole}}{22.4\text{ L}}$$

Example: Calculate the volume, in L, of 5.00 g of oxygen gas at STP.
Answer: Oxygen gas is O_2. The molar mass for O_2 is 2(16.00 g/mol) = 32.00 g/mol

$$5.00\text{ g }O_2 \text{ x } \frac{1\,mole\,O_2}{32.00\,g\,O_2} \text{ x } \frac{22.4\,L\,O_2\,@\,STP}{1\,mole\,O_2\,@\,STP} = \mathbf{3.50\ L}\ O_2\text{ gas @ STP}$$

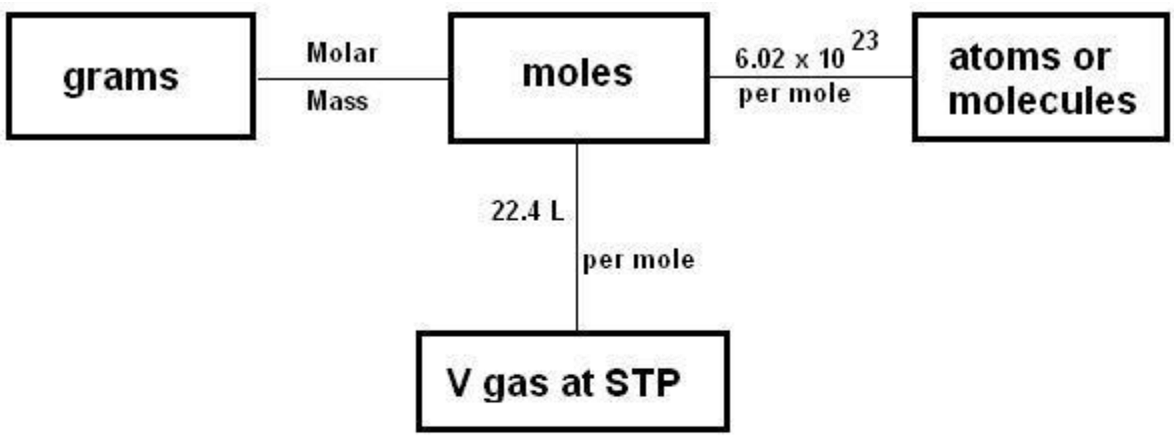
⇒ **Gas Density**

- Gas densities are about 1000 times lower than densities for solids and liquids
- The densities for gases are often reported in grams per liter (g / L).

⇒ Can use molar mass and volume to find density at STP:

Density of a gas: d = mass / volume = Molar Mass / Molar Volume

Summary of mole calculations:



12.5 Percent Composition

Percent Composition is the mass % of each element in a compound. For example H_2O is 11.2% hydrogen and 88.79% oxygen. These percentages are true always, regardless of where the water came from. To calculate you assume you have one mole of the compound. You add up the molar mass of the compound – the mass of one mole in grams. You then divide the molar mass of each element in the compound by the total molar mass of the compound.

⇒ Recall: Percent % = $\frac{Part}{Whole}\ x\ 100$

- The part is the molar mass of the individual element.
- The whole is the molar mass of the entire compound.

Example: Calculate the percent composition for H and O in water.
Answer: Water is H_2O. Molar mass of the two H's is 2.02 grams/mol. Molar mass of the one oxygen is 16.00 grams/mol. And the total compound has a molar mass of 18.02 grams/mol.

$$\%\ H = \frac{2.02\ g\ H}{18.02\ g\ H_2O}\ x\ 100 = 11.2\ \%\ H \qquad \%\ O = \frac{16.00\ g\ O}{18.02\ g\ H_2O}\ x\ 100 = 88.79\ \%\ O$$

You can check yourself: Note that 11.2 + 88.79 is 100%. (99.99)

YouTube Videos:	Avogadro 1: https://youtu.be/_rZ3JM1aIuM Avogadro 2: https://youtu.be/WWvxsE5xX6w Molar Mass 1: https://youtu.be/dM2Nyb2RDB4 Molar Mass 2: https://youtu.be/WOOpuY2w-_4

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CHAPTER 12 PRACTICE PROBLEMS

1. How many atoms are in 10.0 moles of Pb?

2. How many moles of C atoms are present in a sample of 1.25×10^{24} C atoms?

3. Calculate the molar masses of NaCl, CO_2, K_2SO_4, and $(NH_4)_3PO_4$.

4. What is the mass in grams of 0.0235 moles of Na?

5. What is the mass in grams of 3.75 moles of $FeCl_3$?

6. How many moles are in 12.6 grams of H_2O?

7. Find the density of N_2 gas at STP.

8. Find the density of CO_2 gas at STP.

9. Find the volume in Liters for 0.500 g O_2 gas at STP.

10. Find the mass in grams for 1.5 L of NO_2 gas at STP

11. Calculate the percent composition for $C_{10}H_{16}N_2O_8$.

Answers to Practice Problems

1. $\frac{10.0 \text{ moles Pb}}{1}\times\frac{6.02\times10^{23}\text{ Pb atoms}}{1\text{ mole Pb}}$ = **6.02×10^{24} Pb atoms**

2. $\frac{1.25\times10^{24}\text{ C atoms}}{1}\times\frac{1\text{ mole C}}{6.02\times10^{23}\text{ C atoms}}$ = **2.08 moles C**

3. NaCl: **1(22.99 g/mol) + 1(35.45 g/mol) = 58.44 g/mol**

   CO_2: **1(12.01 g/mol) + 2(16.00 g/mol) = 44.01 g/mol**

   K_2SO_4: **2(39.10 g/mol) + 1(32.07 g/mol) + 4(16.00 g/mol)= 174.27 g/mol**

   $(NH_4)_3PO_4$: **3(14.01 g/mol) + 12(1.01 g/mol) + 1(30.97 g/mol) + 4(16.00 g/mol) = 149.12 g/mol**

4. $\frac{0.0235 \text{ mol Na}}{1} \times \frac{22.99 \text{ g Na}}{1 \text{mol Na}}$ = **0.540 g Na**

5. $\frac{3.75 \text{ mol } FeCl_3}{1} \times \frac{162.20 \text{ g } FeCl_3}{1 \text{mol } FeCl_3}$ = **608 g $FeCl_3$**

6. $\frac{12.6 \text{ g } H_2O}{1} \times \frac{1 \text{ mol } H_2O}{18.02 \text{g } H_2O}$ = **0.699 mol H_2O**

7. $d\ N_2 = \left(\frac{28.02 \text{ g } N_2}{\text{mol } N_2}\right)\left(\frac{\text{mol } N_2}{22.4 \text{ L } N_2}\right)$ = **1.25 g/L N_2**

8. $d\ CO_2 = \left(\frac{44.01 \text{ g } CO_2}{\text{mol } CO_2}\right)\left(\frac{\text{mol } CO_2}{22.4 \text{ L } CO_2}\right)$ = **1.96 g/L CO_2**

9. $\left(\frac{0.500 \text{ g } O_2}{1}\right)\left(\frac{\text{mol } O_2}{32.00 \text{ g } O_2}\right)\left(\frac{22.4 \text{ L } O_2}{1 \text{ mol } O_2}\right)$ = **0.350 L O_2**

10. $\left(\frac{1.5 \text{ L } NO_2}{1}\right)\left(\frac{\text{mol } NO_2}{22.4 \text{ L } NO_2}\right)\left(\frac{46.01 \text{ g } NO_2}{\text{mol } NO_2}\right)$ = **3.1 g NO_2**

11. $C_{10}H_{16}N_2O_8$ has a molar mass of 292.28 grams. The % are 41.09% C, 5.53% H, 9.587% N, and 43.79% O.