The Mole Concept

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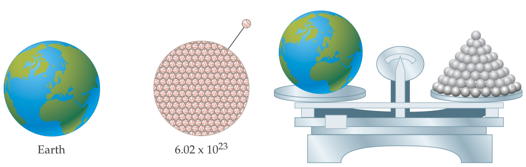
Avogadro's Number

- Avogadro's Number (symbol *N*) is the number of atoms in 12.01 grams of carbon.
- Its numerical value is 6.02×10^{23}.
- Therefore, a 12.01 g sample of carbon contains 6.02×10^{23} carbon atoms.

How Big Is a Mole?

- The volume occupied by one mole of softballs would be about the size of the Earth.
- One mole of Olympic shot put balls has about the same mass as the Earth.



How Big is a Mole?

One mole of marbles would cover the entire Earth (oceans included) for a depth of three miles.

One mole of $100 bills stacked one on top of another would reach from the Sun to Pluto and back 7.5 million times.

It would take light 9500 years to travel from the bottom to the top of a stack of 1 mole of $1 bills.

Particles in a Mole

Amadeo Avogadro

Amedeo Avogadro (1766-1856) never knew his own number; it was named in his honor by a French scientist in 1909. its value was first estimated by Josef Loschmidt, an Austrian chemistry teacher, in 1895.

? quadrillions trillions billions millions thousands

1 mole = 602213673600000000000000

or 6.022 x 10^{23}

There is Avogadro's number of particles in a mole of any substance.

Careers in Chemistry - Philosopher

Q: *How much is a mole?*
A: *A mole is a quantity used by chemists to count atoms and molecules. A mole of something is equal to 6.02 x 10^{23} "somethings."*

1 mole = 602 200 000 000 000 000 000 000

Q: *Can you give me an example to put that number in perspective?*
A: *A computer that can count 10,000,000 atoms per second would take 2,000,000,000 years to count 1 mole of a substance.*

Counting to 1 Mole

Is that right? *A computer counting 10 million atoms every second would need to count for 2 billion years to count just a single mole.*

Lets look at the mathematics.

$$x \text{ sec} = 1 \cancel{\text{year}} \left(\frac{365 \cancel{\text{days}}}{1 \cancel{\text{year}}}\right)\left(\frac{24 \cancel{\text{hours}}}{1 \cancel{\text{day}}}\right)\left(\frac{60 \cancel{\text{min}}}{1 \cancel{\text{hour}}}\right)\left(\frac{60 \text{ sec}}{1 \cancel{\text{min}}}\right) = 31{,}536{,}000 \text{ sec}$$

Therefore 1 year has 31,536,000 seconds or 3.1536×10^7 sec.
A computer counting 10,000,000 atoms every second could count 3.153×10^{14} atoms every year.

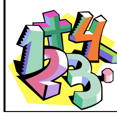
Finally, 6.02×10^{23} atoms divided by 3.1536×10^{14} atoms every year equals 1,908,929,477 years or approximately 2 billion years!

Dimensional Analysis Method of Solving Problems

1. Determine which unit conversion factor(s) are needed
2. Carry units through calculation
3. If all units cancel except for the *desired unit(s)*, then the problem was solved correctly.

given quantity x conversion factor = desired quantity

$$\cancel{\text{given unit}} \times \frac{\text{desired unit}}{\cancel{\text{given unit}}} = \text{desired unit}$$



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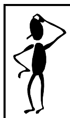

The speed of sound in air is about 343 m/s. What is this speed in miles per hour?

conversion units needed:

meters to miles
seconds to hours

1 mi = 1609 m 1 min = 60 s 1 hour = 60 min

$$343 \frac{\cancel{m}}{\cancel{s}} \times \frac{1 \text{ mi}}{1609 \cancel{m}} \times \frac{60 \cancel{s}}{1 \cancel{\text{min}}} \times \frac{60 \cancel{\text{min}}}{1 \text{ hour}} = 767 \frac{\text{mi}}{\text{hour}}$$

1.9

The Mole

- The mole (mol) is a unit of measure for an amount of a chemical substance.
- A mole is Avogadro's number of particles, that is 6.02×10^{23} particles.

  1 *mol* = Avogadro's Number = 6.02×10^{23} units
- We can use the mole relationship to convert between the number of particles and the mass of a substance.

Mole Calculations I

- How many sodium atoms are in 0.120 mol Na?
  - Step 1: we want atoms of Na
  - Step 2: we have 0.120 mol Na
  - Step 3: 1 mole Na = 6.02×10^{23} atoms Na

$$0.120 \cancel{\text{mol Na}} \times \frac{6.02 \times 10^{23} \text{ atoms Na}}{1 \cancel{\text{mol Na}}} = 7.22 \times 10^{22} \text{ atoms Na}$$

Mole Calculations I

- How many moles of potassium are in 1.25×10^{21} atoms K?
  - Step 1: we want moles K
  - Step 2: we have 1.25×10^{21} atoms K
  - Step 3: 1 mole K = 6.02×10^{23} atoms K

$$1.25 \times 10^{21} \cancel{\text{atoms K}} \times \frac{1 \text{ mol K}}{6.02 \times 10^{23} \cancel{\text{atoms K}}} = 2.08 \times 10^{-3} \text{ mol K}$$

Molar Mass

- The atomic mass of any substance expressed in grams is the ***molar mass*** (MM) of that substance.
- The atomic mass of iron is 55.85 amu.
- Therefore, the molar mass of iron is 55.85 g/mol.
- Since oxygen occurs naturally as a diatomic, O_2, the molar mass of oxygen gas is 2 times 16.00 g or 32.00 g/mol.

Calculating Molar Mass

- The molar mass of a substance is the sum of the molar masses of each element.
- What is the molar mass of magnesium nitrate, $Mg(NO_3)_2$?
- The sum of the atomic masses is:

$$24.31 + 2(14.01 + 16.00 + 16.00 + 16.00) =$$
$$24.31 + 2(62.01) = 148.33 \text{ amu}$$

- The molar mass for $Mg(NO_3)_2$ is 148.33 g/mol.

Mole Calculations II

- Now we will use the molar mass of a compound to convert between grams of a substance and moles or particles of a substance.

$$6.02 \times 10^{23} \text{ particles} = \mathbf{1\ mol} = \text{molar mass}$$

- If we want to convert particles to mass, we must first convert particles to moles and than we can convert moles to mass.

Mass-Mole Calculations

- What is the mass of 1.33 moles of titanium, Ti?
- We want grams, we have 1.33 moles of titanium.
- Use the molar mass of Ti: 1 mol Ti = 47.88 g Ti

$$1.33 \cancel{\text{mole Ti}} \times \frac{47.88 \text{ g Ti}}{1 \cancel{\text{mole Ti}}} = 63.7 \text{ g Ti}$$

Mole Calculations II

- What is the mass of 2.55×10^{23} atoms of lead?
- We want grams, we have atoms of lead.
- Use Avogadro's number and the molar mass of Pb

$$2.55 \times 10^{23} \cancel{\text{atoms Pb}} \times \frac{1 \cancel{\text{mol Pb}}}{6.02{\times}10^{23} \cancel{\text{atoms Pb}}} \times \frac{207.2 \text{ g Pb}}{1 \cancel{\text{mole Pb}}}$$

$$= 87.8 \text{ g Pb}$$

Mole Calculations II

- How many O_2 molecules are present in 0.470 g of oxygen gas?
- We want molecules O_2, we have grams O_2.
- Use Avogadro's number and the molar mass of O_2

$$0.470 \cancel{\text{g } O_2} \times \frac{1 \cancel{\text{mol } O_2}}{32.00 \cancel{\text{g } O_2}} \times \frac{6.02{\times}10^{23} \text{ molecules } O_2}{1 \cancel{\text{mole } O_2}}$$

$$8.84 \times 10^{21} \text{ molecules } O_2$$

Law of Definite Composition

- The ***law of definite composition*** states that "*Compounds always contain the same elements in a constant proportion by mass*".
- Sodium chloride is always 39.3% sodium and 60.7% chlorine by mass, no matter what its source.
- Water is always 11.2% hydrogen and 88.8% oxygen by mass.

Law of Definite Composition

A drop of water, a glass of water, and a lake of water all contain hydrogen and oxygen in the same percent by mass.

Percent Composition

- The ***percent composition*** of a compound lists the mass percent of each element.
- For example, the percent composition of water, H_2O is:
  - 11% hydrogen and 89% oxygen
- All water contains 11% hydrogen and 89% oxygen by mass.

Calculating Percent Composition

- There are a few steps to calculating the percent composition of a compound. Lets practice using H_2O.
  - Assume you have 1 mole of the compound.
  - One mole of H_2O contains 2 mol of hydrogen and 1 mol of oxygen.
  - 2(1.01 g H) + 1(16.00 g O) = molar mass H_2O
  - 2.02 g H + 16.00 g O = 18.02 g H_2O

Calculating Percent Composition

- Next, find the percent composition of water by comparing the masses of hydrogen and oxygen in water to the molar mass of water:

$$\frac{2.02\text{ g H}}{18.02\text{ g H}_2\text{O}} \times 100\% = 11.2\%\text{ H}$$

$$\frac{16.00\text{ g O}}{18.02\text{ g H}_2\text{O}} \times 100\% = 88.79\%\text{ O}$$

Percent Composition Problem

- TNT (trinitrotoluene) is a white crystalline substance that explodes at 240°C. Calculate the percent composition of TNT, $C_7H_5(NO_2)_3$.
- 7(12.01 g C) + 5(1.01 g H) + 3 (14.01 g N + 32.00 g O) = g $C_7H_5(NO_2)_3$
- 84.07 g C + 5.05 g H + 42.03 g N + 96.00 g O = 227.15 g $C_7H_5(NO_2)_3$.

Percent Composition of TNT

$$\frac{84.07\text{ g C}}{227.15\text{ g TNT}} \times 100\% = 37.01\%\text{ C}$$

$$\frac{1.01\text{ g H}}{227.15\text{ g TNT}} \times 100\% = 2.22\%\text{ H}$$

$$\frac{42.03\text{ g N}}{227.15\text{ g TNT}} \times 100\% = 18.50\%\text{ N}$$

$$\frac{96.00\text{ g O}}{227.15\text{ g TNT}} \times 100\% = 42.26\%\text{ O}$$

Empirical Formulas

- The ***empirical formula*** of a compound is the simplest whole number ratio of ions in a formula unit or atoms of each element in a molecule.
- The molecular formula of benzene is C_6H_6
  - The empirical formula of benzene is CH.
- The molecular formula of octane is C_8H_{18}
  - The empirical formula of octane is C_4H_9.

Calculating Empirical Formulas

- We can calculate the empirical formula of a compound from its composition data.
- We can determine the mole ratio of each element from the mass to determine the formula of radium oxide, $Ra_?O_?$.
- A 1.640 g sample of radium metal was heated to produce 1.755 g of radium oxide. What is the empirical formula?
- We have 1.640 g Ra and 1.755-1.640 = 0.115 g O.

Calculating Empirical Formulas

- The molar mass of radium is 226.03 g/mol and the molar mass of oxygen is 16.00 g/mol.

$$1.640\text{ g }\cancel{\text{Ra}} \times \frac{1\text{ mol Ra}}{226.03\text{ g }\cancel{\text{Ra}}} = 0.00726\text{ mol Ra}$$

$$0.115\text{ g }\cancel{\text{O}} \times \frac{1\text{ mol O}}{16.00\text{ g }\cancel{\text{O}}} = 0.00719\text{ mol O}$$

- We get $Ra_{0.00726}O_{0.00719}$. Simplify the mole ratio by dividing by the smallest number.
- We get $Ra_{1.01}O_{1.00}$ = RaO is the empirical formula.

Calculating Empirical Formulas

- *1. <u>Percent to mass:</u> Pretend you have the same number of grams as your percents.*
- *2. <u>Mass to moles:</u> use the molar mass from the periodic table to change each mass into moles.*
- *3. <u>Divide by small:</u> divide each of the moles (found in #2) by the smallest number of moles that you found.*
- *4. <u>Multiply 'till whole:</u> If a number in the ratio has a .5, .33, .25, etc. you have to multiply by 2, 3 or 4 so that all the numbers are whole in the end.*

Empirical Formulas from Percent Composition

- We can also use percent composition data to calculate empirical formulas.
- Assume that you have 100 grams of sample.
- Benzene is 92.2% carbon and 7.83% hydrogen, what is the empirical formula.
- If we assume 100 grams of sample, we have 92.2 g carbon and 7.83 g hydrogen.

Empirical Formulas from Percent Composition

- Calculate the moles of each element:

$$92.2 \ \cancel{\text{g C}} \times \frac{1 \text{ mol C}}{12.01 \ \cancel{\text{g C}}} = 7.68 \text{ mol C}$$

$$7.83 \ \cancel{\text{g H}} \times \frac{1 \text{ mol H}}{1.01 \ \cancel{\text{g H}}} = 7.75 \text{ mol H}$$

- The ratio of elements in benzene is $C_{7.68}H_{7.75}$. Divide by the smallest number to get the formula.

$$C_{\frac{7.68}{7.68}} H_{\frac{7.75}{7.68}} = C_{1.00}H_{1.01} = CH$$

Molecular Formulas

- The empirical formula for benzene is CH. This represents the ratio of C to H atoms of benzene.
- The actual ***molecular formula*** is some multiple of the empirical formula, $(CH)_n$.
- Benzene has a molar mass of 78 g/mol. Find n to find the molecular formula.

$$\frac{(CH)_n}{CH} = \frac{78 \text{ g/mol}}{13 \text{ g/mol}}$$

$n = 6$ and the molecular formula is C_6H_6.