The Mole

Molecular mass and formula mass

- Atomic mass unit is the standard for measuring mass of atoms or compounds.
  - Atomic mass unit (amu) Dalton
- Molecular mass refers to the mass of a molecule
- Formula mass is the mass of an ionic compound

Avagadro's Number

- is based on the amount of mass in grams that 1 amu is equal to
  - 1 amu = 1.6606×10^{-24}g
    - Oxygen has a mass of 16 amu,
      - so 16 amu x 1.6606×10^{24g}/1amu gives the mass of one O atom at 2.657×10^{-23} grams,
      - and 16 g O x 1atom O / 2.657×10^{-23}g = 6.022×10^{23} atoms
  - 6.022×10^{23} atoms is Avogadro's number

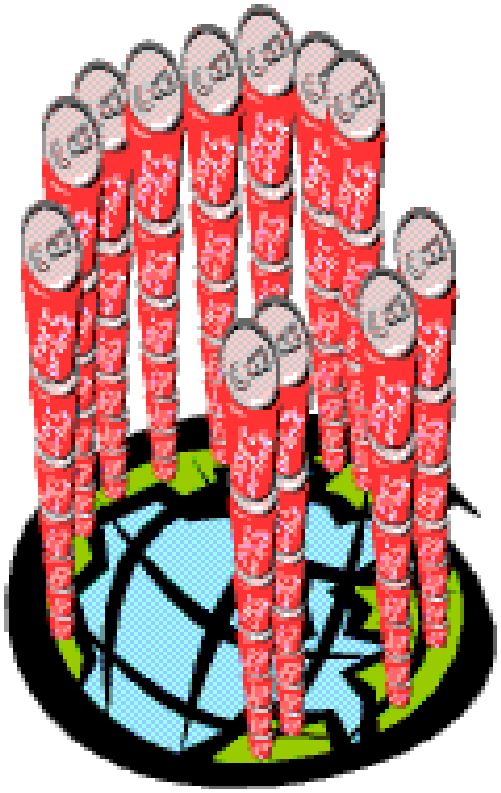
The Mole

$$6.02 \times 10^{23}$$

The Mole

- **A counting unit**
- **Similar to a dozen, except instead of 12, it's 602 billion trillion 602,000,000,000,000,000,000,000**
- **6.02×10^{23} (in scientific notation)**
- **This number is named in honor of Amedeo _____ (1776 – 1856), who studied quantities of gases and discovered that no matter what the gas was, there were the same number of molecules present**

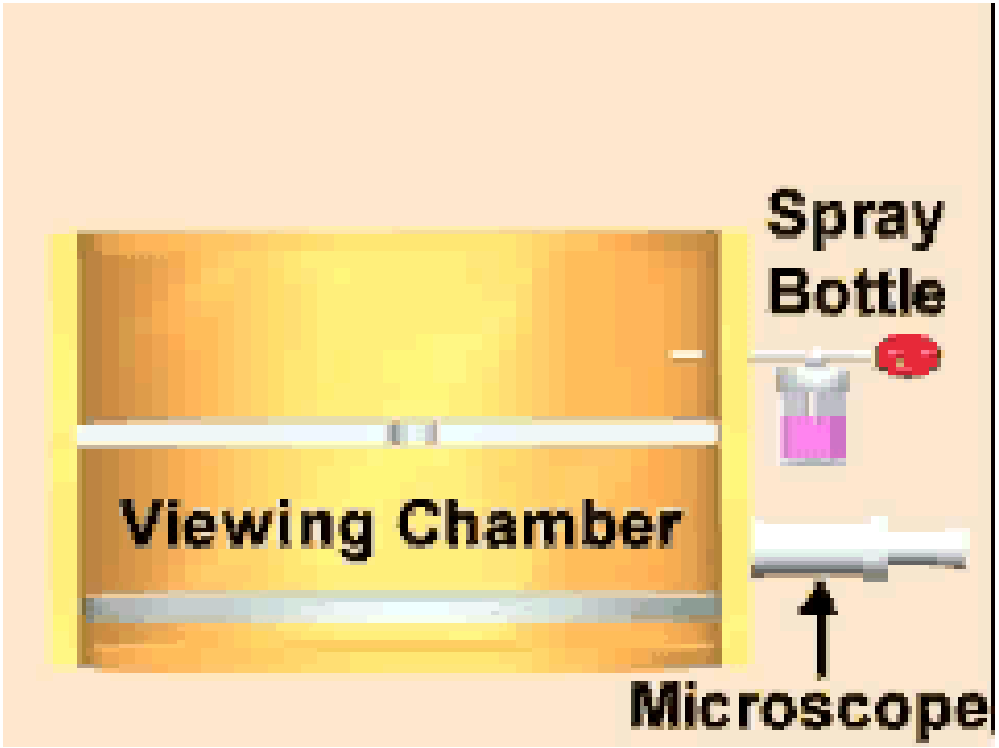
Just How Big is a Mole?



- **Enough soft drink cans to cover the surface of the earth to a depth of over 200 miles.**
- **If you had Avogadro's number of unpopped popcorn kernels, and spread them across the United States of America, the country would be covered in popcorn to a depth of over 9 miles.**
- **If we were able to count atoms at the rate of 10 million per second, it would take about 2 billion years to count the atoms in one mole.**

Everybody Has Avogadro's Number!
But Where Did it Come From?

- **It was NOT just picked! It was MEASURED.**
- **One of the better methods of measuring this number was the Millikan Oil Drop Experiment**
- **Since then we have found even better ways of measuring using x-ray technology**



Learning Check

Suppose we invented a new collection unit called a rapp. One rapp contains 8 objects.

1. How many paper clips in 1 rapp?

a) 1 **b) 4** **c) 8**

2. How many oranges in 2.0 rapp?

a) 4 **b) 8** **c) 16**

3. How many rapps contain 40 gummy bears?

a) 5 **b) 10** **c) 20**

The Mole

- **1 dozen cookies = 12 cookies**
- **1 mole of cookies = 6.02 X 10^{23} cookies**

- **1 dozen cars = 12 cars**
- **1 mole of cars = 6.02 X 10^{23} cars**

- **1 dozen Al atoms = 12 Al atoms**
- **1 mole of Al atoms = 6.02 X 10^{23} atoms**

Note that the NUMBER is always the same, but the MASS is very different!

Mole is abbreviated mol (gee, that's a lot quicker to write, huh?)

A Mole of Particles

Contains 6.02×10^{23} particles

1 mole C = 6.02×10^{23} C atoms

1 mole H_2O = 6.02×10^{23} H_2O molecules

1 mole NaCl = 6.02×10^{23} NaCl "molecules"

(technically, ionics are compounds not molecules so they are called formula units)

6.02×10^{23} Na^+ ions and

6.02×10^{23} Cl^- ions

Avogadro's Number as Conversion Factor

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

or

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

Note that a particle could be an atom OR a molecule!

Learning Check

1. Number of atoms in 0.500 mole of Al

a) 500 Al atoms

b) 6.02×10^{23} Al atoms

c) 3.01×10^{23} Al atoms

2.Number of moles of S in 1.8×10^{24} S atoms

a) 1.0 mole S atoms

b) 3.0 mole S atoms

c) 1.1×10^{48} mole S atoms

Molar Mass

- **The Mass of 1 mole (in grams)**
- **Equal to the numerical value of the average atomic mass (get from periodic table)**

1 mole of C atoms	**=**	**12.0 g**
1 mole of Mg atoms	**=**	**24.3 g**
1 mole of Cu atoms	**=**	**63.5 g**

Molar Mass of Molecules and Compounds

Mass in grams of 1 mole equal numerically to the sum of the atomic masses

1 mole of $CaCl_2$ = 111.1 g/mol

1 mole Ca x 40.1 g/mol

+ 2 moles Cl x 35.5 g/mol = 111.1 g/mol $CaCl_2$

---

1 mole of N_2O_4 = 92.0 g/mol

Learning Check!

Find the molar mass

(usually we round to the tenths place)

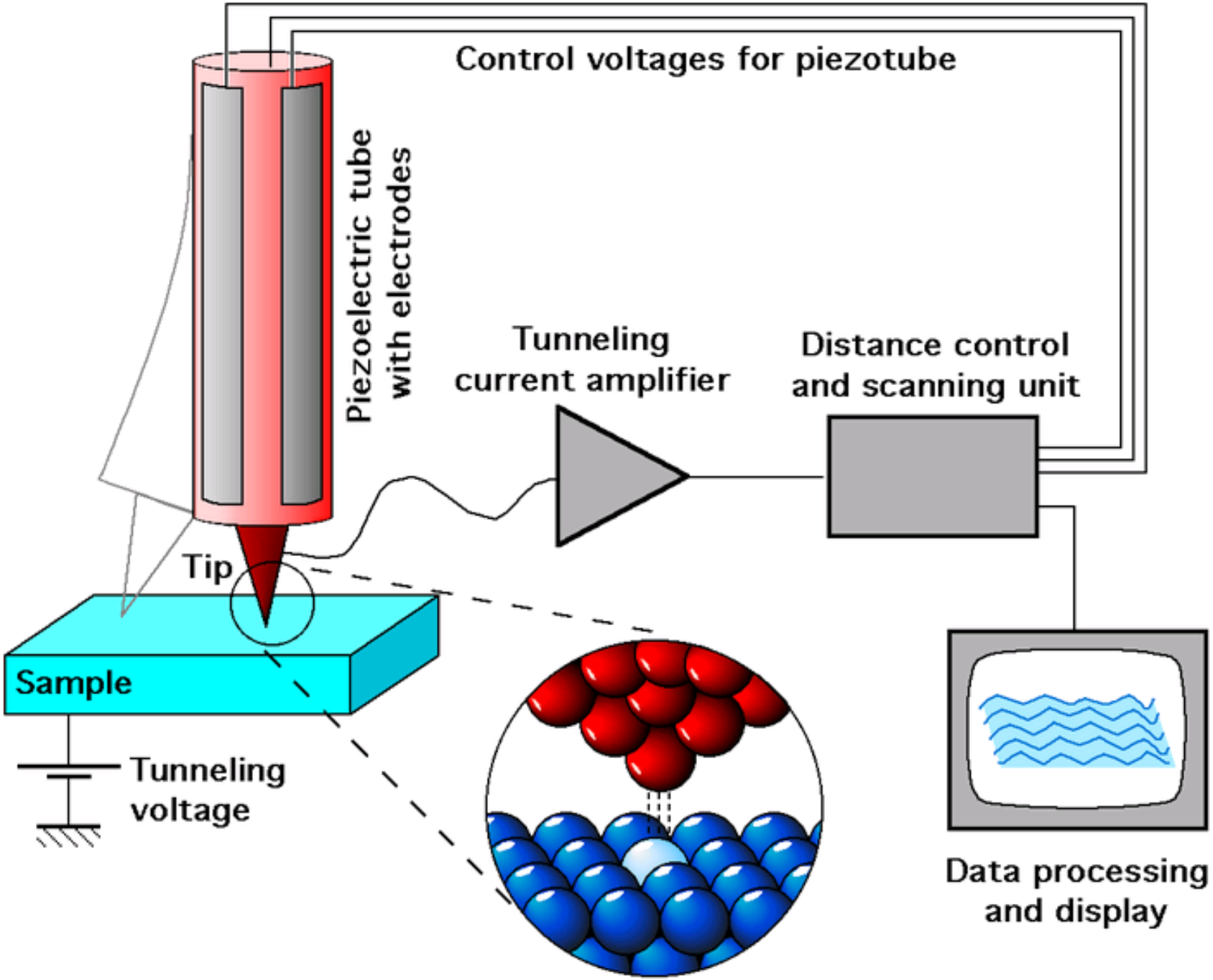
A. 1 mole of Br atoms = 79.9 g/mole

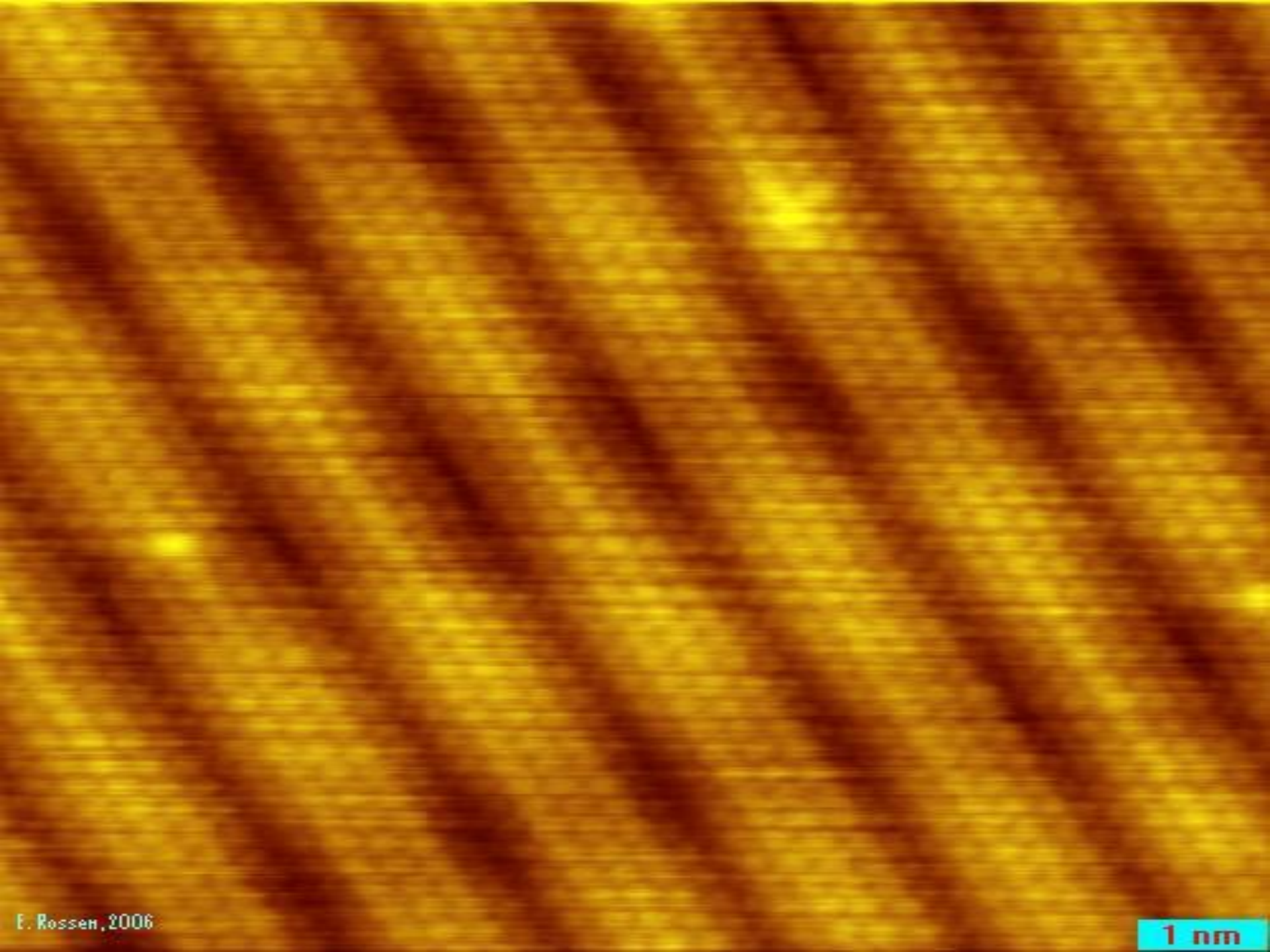
B. 1 mole of Sn atoms = 118.7 g/mole

Learning Check!

A. **Molar Mass** of K_2O = ? Grams/mole

B. **Molar Mass** of antacid $Al(OH)_3$ = ? Grams/mole


Control voltages for piezotube
Piezoelectric tube with electrodes
Tunneling current amplifier
Distance control and scanning unit
Tip
Sample
Tunneling voltage
Data processing and display


E. Rossen, 2006
1 nm

Learning Check

Prozac, $C_{17}H_{18}F_3NO$, is a widely used antidepressant that inhibits the uptake of serotonin by the brain. Find its molar mass.

Calculations with Molar Mass

molar mass

Grams ⟷ **Moles**

Converting Moles and Grams

Aluminum is often used for the structure of light-weight bicycle frames. How many grams of Al are in 3.00 moles of Al?

3.00 moles Al → ? g Al

1. Molar mass of Al **1 mole Al = 27.0 g Al**

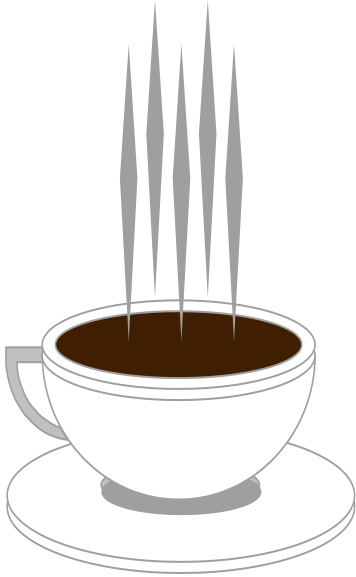
2. Conversion factors for Al

$$\frac{27.0\text{g Al}}{1\text{ mol Al}} \quad \text{or} \quad \frac{1\text{ mol Al}}{27.0\text{ g Al}}$$

3. Setup $$3.00\text{ moles Al} \times \frac{27.0\text{ g Al}}{1\text{ mole Al}}$$

Answer **= 81.0 g Al**

Learning Check!

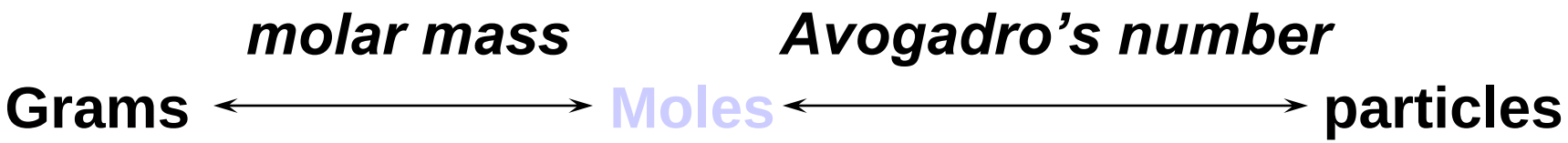


The artificial sweetener aspartame (Nutra-Sweet) formula $C_{14}H_{18}N_2O_5$ is used to sweeten diet foods, coffee and soft drinks. How many moles of aspartame are present in 225 g of aspartame?

Atoms/Molecules and Grams

- **Since 6.02 X 10^{23} particles = 1 mole**
  AND
  1 mole = molar mass (grams)
- **You can convert atoms/molecules to moles and then moles to grams! (Two step process)**
- **You can't go directly from atoms to grams!!!! You MUST go thru MOLES.**
- **That's like asking 2 dozen cookies weigh how many ounces if 1 cookie weighs 4 oz? You have to convert to dozen first!**

Calculations



Everything must go through Moles!!!

Atoms/Molecules and Grams

How many atoms of Cu are present in 35.4 g of Cu?

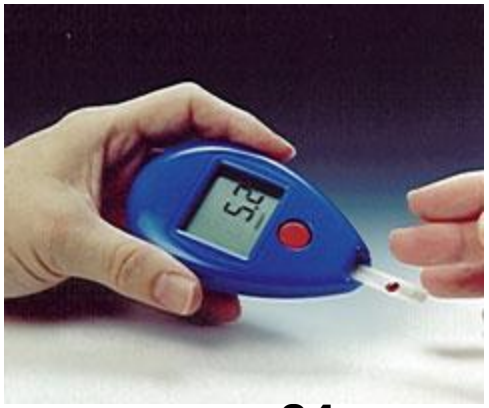
$$35.4\ \text{g Cu} \times \frac{1\ \text{mol Cu}}{63.5\ \text{g Cu}} \times \frac{6.02 \times 10^{23}\ \text{atoms Cu}}{1\ \text{mol Cu}}$$

$= 3.4 \times 10^{23}$ atoms Cu

Learning Check!

How many atoms of K are present in 78.4 g of K?

Learning Check!



What is the mass (in grams) of 1.20 X 10^{24} molecules of glucose ($C_6H_{12}O_6$)?

$$\frac{1.20 \times 10^{24} \text{ molecules}}{} \cdot \frac{1 \text{ mole}}{6.02 \times 10^{23} \text{ molecules}} \cdot \frac{180 \text{ g } C_6H_{12}O_6}{1 \text{ mole}}$$

Learning Check!

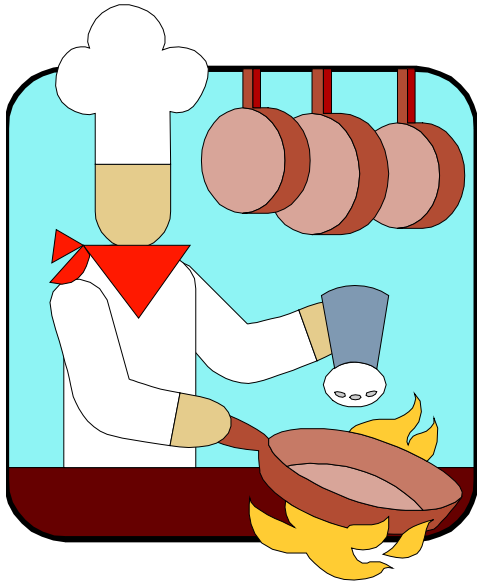
How many **atoms** of O are present in 78.1 g of oxygen?

$$78.1\ \text{g}\ O_2 \times \frac{1\ \text{mol}\ O_2}{32.0\ \text{g}\ O_2} \times \frac{6.02 \times 10^{23}\ \text{molecules}\ O_2}{1\ \text{mol}\ O_2} \times \frac{2\ \text{atoms O}}{1\ \text{molecule}\ O_2}$$

Percent Composition

What is the percent carbon in $C_5H_8NO_4$ (the glutamic acid used to make MSG monosodium glutamate), a compound used to flavor foods and tenderize meats?

a) 8.22 %C
b) 24.3 %C
c) 41.1 %C



Chemical Formulas of Compounds

- **Formulas give the relative numbers of atoms or moles of each element in a formula unit - always a whole number ratio (the law of definite proportions).**

  NO_2 2 atoms of O for every 1 atom of N

  1 mole of NO_2 : 2 moles of O atoms to every 1 mole of N atoms

- **If we know or can determine the relative number of moles of each element in a compound, we can determine a formula for the compound.**

Types of Formulas

- **Empirical Formula**

  The formula of a compound that expresses the *smallest whole number ratio* of the atoms present.

  Ionic formula are always empirical formula

- **Molecular Formula**

  The formula that states the *actual* number of each kind of atom found in *one molecule* of the compound.

To obtain an *Empirical Formula*

1. **Determine the mass in grams of each element present, if necessary.**
2. **Calculate the number of *moles* of each element.**
3. **Divide each by the smallest number of moles to obtain the *simplest whole number ratio.***
4. **If whole numbers are not obtained* in step 3), multiply through by the smallest number that will give all whole numbers**

* **Be careful! Do not round off numbers prematurely**

A sample of a brown gas, a major air pollutant, is found to contain 2.34 g N and 5.34g O. Determine a formula for this substance.

require *mole* ratios so convert grams to moles

moles of N = $\frac{\text{2.34g of N}}{\text{14.01 g/mole}}$ = 0.167 moles of N

moles of O = $\frac{\text{5.34 g}}{\text{16.00 g/mole}}$ = 0.334 moles of O

Formula:

$$N_{0.167}O_{0.334} \qquad N_{\frac{0.167}{0.167}}O_{\frac{0.334}{0.167}} = NO_2$$

Empirical formula - the formula giving the simplest ratio between atoms

- 1. Example: What is the empirical formula for a compound if a 2.5 g sample contains .900 g Ca and 1.6 g Cl.
  a. First you must calculate the moles of each
  b. .900 g Ca x $\frac{1\text{mol Ca}}{40.1\text{ g Ca}}$ = .0224 mole Ca

  1.60 g Cl x $\frac{1\text{ mole Cl}}{38.5\text{ g Cl}}$ = .0451 mole Cl

  c. Then divide by the smallest #
  a) .0224/.0224 =1
  b) .0451/.0224 = 2
  d. The ration then is 2 Cl to 1 Ca so the empirical formula is $CaCl_2$

Calculation of the Molecular Formula

A compound has an empirical formula of NO_2. The colourless liquid, used in rocket engines has a molar mass of 92.0 g/mole. What is the *molecular formula* of this substance?

Calculating Percentage Composition

Calculate the percentage composition of magnesium carbonate, $MgCO_3$.

From previous slide:

24.31 g + 12.01 g + 3(16.00 g) = 84.32 g

$$Mg = \left(\frac{24.31}{84.32}\right) \bullet 100 = 28.83\%$$

$$C = \left(\frac{12.01}{84.32}\right) \bullet 100 = 14.24\%$$

$$O = \left(\frac{48.00}{84.32}\right) \bullet 100 = 56.93\%$$

$$\underline{\qquad\qquad}$$

$$100.00$$

Empirical Formula from % Composition

A substance has the following composition by mass: 60.80 % Na ; 28.60 % B ; 10.60 % H

What is the empirical formula of the substance?

Consider a sample size of 100 grams

This will contain 28.60 grams of B and 10.60 grams H

Determine the number of moles of each

Determine the simplest whole number ratio

Percent composition -

- the percentage of the total mass of a compound contributed by an element

  1. Percent composition of aluminum sulfate $Al_2(SO_4)_3$

  2 Al - 2 x 27.0 = 54.0

  3 S - 3 x 32.0 = 96.0

  12 O - 12 x 16 = 102

  342

  Percent Al $\frac{54}{342}$ x 100 = 15.8 %

  Percent S $\frac{96}{342}$ x 100 = 28.1 %

  Percent O $\frac{192}{342}$ x 100 = 56.1 %

Example:

Molecular mass of benzene is 78.0 and its empirical formula is CH. What is the molecular formula

Mass of Carbon = 12

Mass of Hydrogen = 1

Mass of CH = 13

$\frac{78}{13} = 6$

Since the ratio is 1:1 then 6 times would be 6:6 giving C_6H_6

Molecular Formula -

- shows the actual # of atoms of each element present
  - Emperical formula is given and molecular mass is given
  - Find the empirical formula mass and then divide it into the molecular mass

Finding the Molecular Formula

The empirical formula for adipic acid is $C_3H_5O_2$. The molecular mass of adipic acid is 146 g/mol. What is the molecular formula of adipic acid?

2. Divide the molecular mass by the mass given by the emipirical formula.

3(12.01 g) + 5(1.01) + 2(16.00) = 73.08 g

$$\frac{146}{73} = 2$$

Moles in a solution

- is called molarity which is a relationship between the moles of solute put in the volume of solvent
- Molarity = moles/liter = moles/dm^3
  - Example: What is the molarity of a 2.5 x 10^2 cm^3 of solution containing 9.46 g CsBr?

    $\frac{9.46g\ CsBr}{250\ cm^3} \times \frac{1\ mole}{213\ g} \times \frac{1000\ cm^3}{dm^3} = .178\ mole/dm^3$

    = .178 M (Molar) solution
  - Example: How would you make 500 cm^3 of a .133 M solution of $MnSeO_4$

    $\frac{.5\ dm^3}{} \times \frac{.133\ mole}{1dm^3} \times \frac{198\ g}{1\ mole} = 13.2g\ MnSeO_4$

Hydrate calculation

- means it contains H_2O
  - Example Calculation:
    .391 g Li_2SiF_6, .0903 g H_2O

    $$.391\ g\ Li_2SiF_6 \times \frac{1\ mole}{156g\ Li_2SiF_6} = .00251\ mole$$

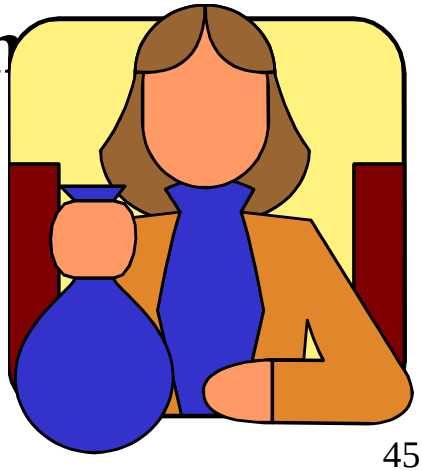
    $$.0905\ g\ H_2O \times \frac{1\ mole}{18.0\ g\ H_2O} = .00502\ mole$$

    .00502/.00251= 2:1 ratio,
    So the answer is $Li_2SiF_6 \cdot 2H_2O$

Molarity (M)

A concentration that expresses the moles of solute in 1 L of solution

$$\text{Molarity (M)} = \frac{\text{moles of solute}}{\text{1 liter solution}}$$



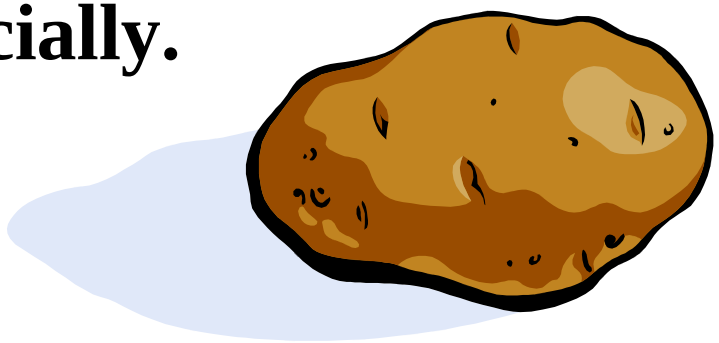
Units of Molarity

$$\text{2.0 M HCl} = \frac{\text{2.0 moles HCl}}{\text{1 L HCl solution}}$$

$$\text{6.0 M HCl} = \frac{\text{6.0 moles HCl}}{\text{1 L HCl solution}}$$

Molarity Calculation

NaOH is used to open stopped sinks, to treat cellulose in the making of nylon, and to remove potato peels commercially.



If 4.0 g NaOH are used to make 500. mL of NaOH solution, what is the molarity (M) of the solution?

Calculating Molarity

1) 4.0 g NaOH x $\frac{1 \text{ mole NaOH}}{40.0 \text{ g NaOH}}$ = 0.10 mole NaOH

2) 500. mL x $\frac{1 \text{ L}}{1000 \text{ mL}}$ = 0.500 L

3. $\frac{0.10 \text{ mole NaOH}}{0.500 \text{ L}}$ = $\frac{0.20 \text{ mole NaOH}}{1 \text{ L}}$

= 0.20 M NaOH

Learning Check M1

A KOH solution with a volume of 400 mL contains 2 mole KOH. What is the molarity of the solution?

1) 8 M
2) 5 M
3) 2 M

Solution M1

A KOH solution with a volume of 400 mL contains 2 moles of KOH. What is the molarity of the solution?

2) 5 M

$$M = \frac{2 \text{ mole KOH}}{0.4 \text{ L}} = 5 \text{ M}$$

Learning Check M2

A glucose solution with a volume of 2.0 L contains 72 g glucose ($C_6H_{12}O_6$). If glucose has a molar mass of 180. g/mole, what is the molarity of the glucose solution?

1) **0.20 M**
2) **5.0 M**
3) **36 M**

Solution M2

A glucose solution with a volume of 2.0 L contains 72 g glucose ($C_6H_{12}O_6$). If glucose has a molar mass of 180. g/mole, what is the molarity of the glucose solution?

1) 72 g x $\frac{1 \text{ mole}}{180. \text{ g}}$ x $\frac{1}{2.0 \text{ L}}$ = 0.20 M

Molarity Conversion Factors

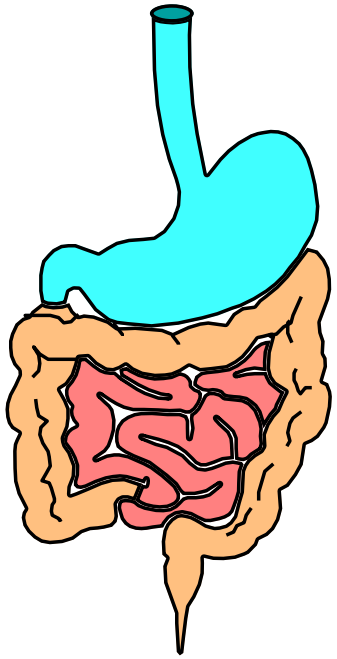
A solution is a 3.0 *M* NaOH. Write the molarity in the form of conversion factors.

$$\frac{\text{3.0 moles NaOH}}{\text{1 L NaOH soln}} \quad \textbf{and} \quad \frac{\text{1 L NaOH soln}}{\text{3.0 moles NaOH}}$$

Learning Check M3

Stomach acid is a 0.10 M HCl solution. How many moles of HCl are in 1500 mL of stomach acid solution?

1) **15 moles HCl**
2) **1.5 moles HCl**
3) **0.15 moles HCl**



Solution M3

3) 1500 mL x $\frac{1\ L}{1000\ mL}$ = 1.5 L

1.5 L x $\frac{0.10\ mole\ HCl}{1\ L}$ = 0.15 mole HCl

(Molarity factor)

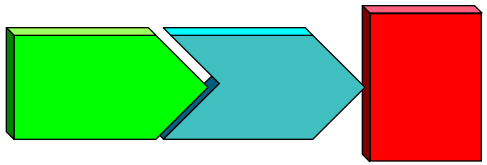
Learning Check M4

How many grams of KCl are present in 2.5 L of 0.50 M KCl?

1) 1.3 g

2) 5.0 g

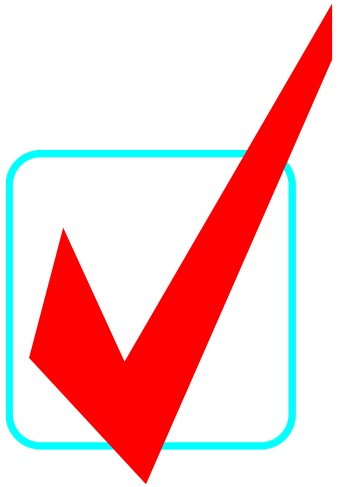
3) 93 g



Solution M4

3)

$$2.5\ \text{L} \times \frac{0.50\ \text{mole}}{1\ \text{L}} \times \frac{74.6\ \text{g KCl}}{1\ \text{mole KCl}} = 93\ \text{g KCl}$$



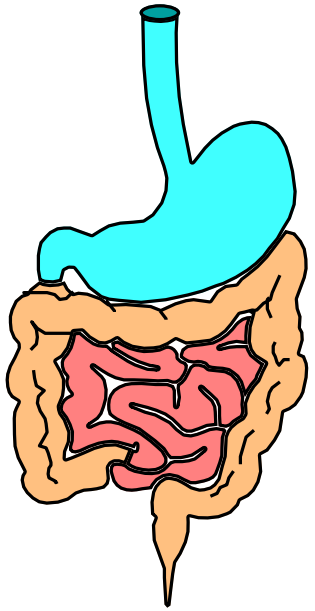
Learning Check M5

How many milliliters of stomach acid, which is 0.10 M HCl, contain 0.15 mole HCl?

1) 150 mL

2) 1500 mL

3) 5000 mL



Solution M5

2) 0.15 mole HCl x $\frac{\text{1 L soln}}{\text{0.10 mole HCl}}$ x $\frac{\text{1000 mL}}{\text{1 L}}$

(Molarity *inverted*)

= 1500 mL HCl

Learning Check M6

How many grams of NaOH are required to prepare 400. mL of 3.0 *M* NaOH solution?

1) 12 g

2) 48 g

3) 300 g

Solution M6

2) 400. mL x $\frac{1\ L}{1000\ mL}$ = 0.400 L

0.400 L x $\frac{3.0\ mole\ NaOH}{1\ L}$ x $\frac{40.0\ g\ NaOH}{1\ mole\ NaOH}$

(molar mass)

= 48 g NaOH

"Talk about trunk space, this beauty has thirteen cubic feet! That's enough room to hold more than sixteen moles of any gas at STP."