

## CHE 1031: General Chemistry I



### 3. Composition of substances & solutions

3.1: Formula mass & mole concept

3.2: Determining empirical & molecular formulas

3.3: Molarity

3.4: Other units for solution concentration *[optional]*

## 3. Composition of substances & solutions



### 3.1: Formula mass & mole concept

- Calculate formula masses (MW)
- Define the mole & Avogadro's number; explain the relationship between moles, atoms & molecules and convert one to another

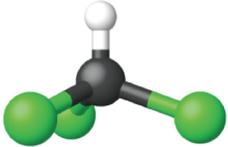
## Formula mass (aka molecular weight)



**Formula mass** (aka MW): the sum of all the atomic masses in a molecule or compound

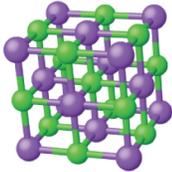
Chloroform,  $\text{CHCl}_3$ , was used as a surgical anesthetic & is now used as a building block for creating teflon, tetrafluoroethylene.

Element	Quantity		Average atomic mass (amu)	=	Subtotal (amu)
C	1	×	12.01	=	12.01
H	1	×	1.008	=	1.008
Cl	3	×	35.45	=	106.35
<b>Molecular mass</b>					<b>119.37</b>



NaCl is common table salt.

Element	Quantity		Average atomic mass (amu)	=	Subtotal
Na	1	×	22.99	=	22.99
Cl	1	×	35.45	=	35.45
<b>Formula mass</b>					<b>58.44</b>



## Try these molecular compounds



Calculate the formula masses (aka molecular weights) of:

- Aspirin,  $\text{C}_9\text{H}_8\text{O}_4$  (acetylsalicylic acid)

①

- Ibuprofen,  $\text{C}_{13}\text{H}_{18}\text{O}_2$



## Enormous numbers are hard to 'get'

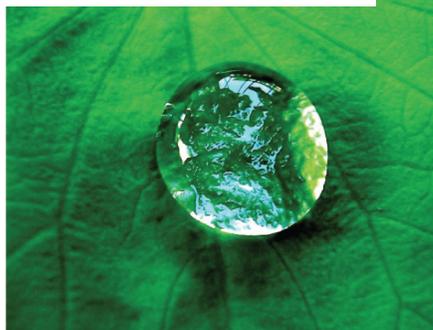


This **droplet of water** contains about 0.002275 moles of water.

$$\frac{2.275 \text{ E-3 moles}}{1 \text{ mole}} \times 6.02 \text{ E23 molecules} = 1.369 \text{ E21 molecules}$$

Global population = 7.6 billion = 7.6 E9

$$\frac{1.369 \text{ E21 molecules}}{7.6 \text{ E9 people}} = 1.80 \text{ E11} \rightarrow > 100 \text{ billion X as many}$$

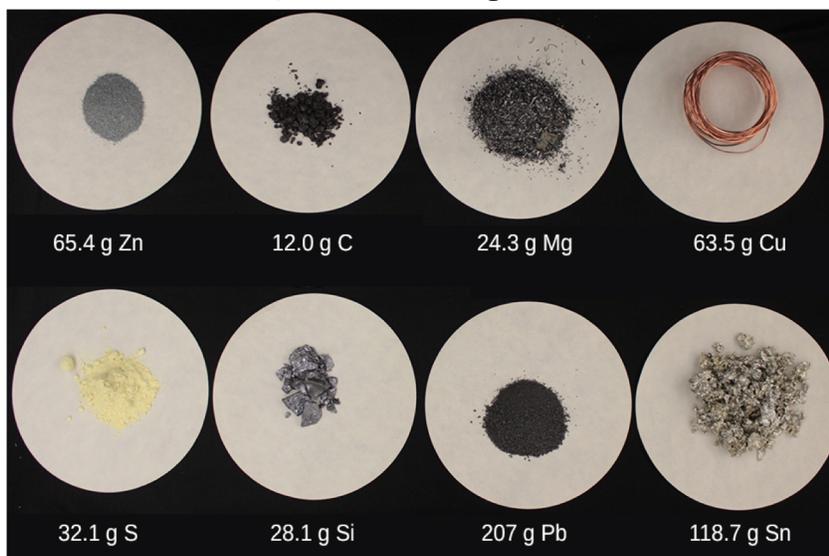


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## Compare a mole



Each is a mole. So, replace amu with **grams/mole**.

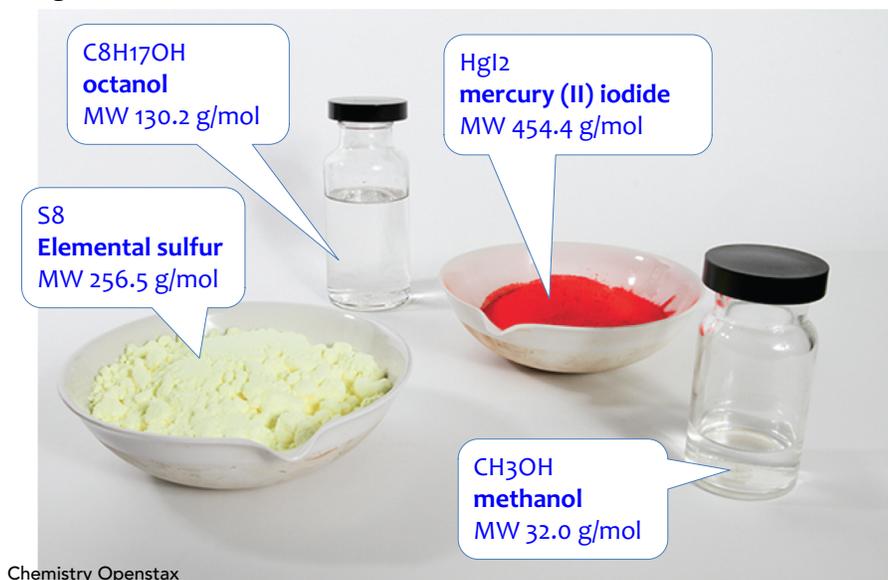


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## Compare a mole



Again, each is a mole.



## Converting mass to moles



**Atomic mass or formula mass (MW)** can be used to convert mass to moles (or vice versa).

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USDA nutritional guidelines suggest a daily intake of 4.7 g of potassium. What's the requirement in moles of K?

Beryllium, a very light element, is used to make transparent x-ray windows for imaging devices. How many moles of Be are in a thin window that weighs 3.24 g?

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## Converting mass to atoms or molecules



Add **Avogadro's number** to convert masses of atoms or molecules into moles, and then numbers of atoms or molecules.

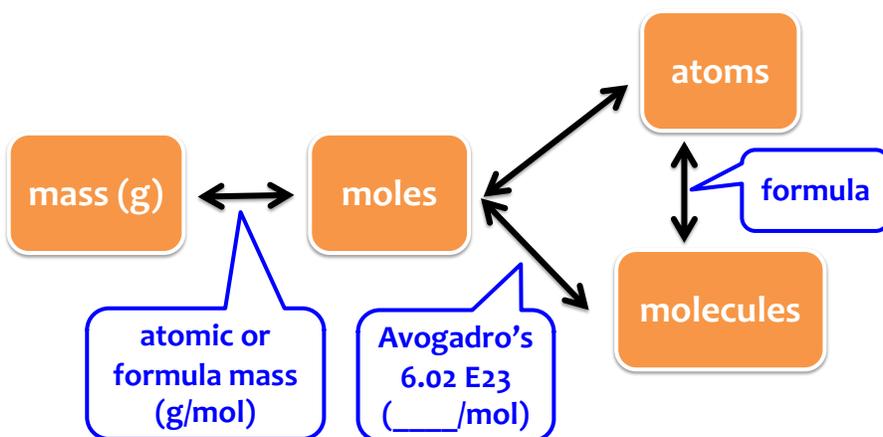
Copper is used to make electrical wire. How many copper atoms are there in 5.00 g of wire? 5

A prospector collects 15.00 g of pure gold from a river. How many gold atoms (Au) are there? 6

## Let's start building a mole map



By the end of this course you'll be using a bunch of conversion factors to make the change of chemistry happen. It helps to have a **map to guide your choice of conversion factors**.



*Flip conversion factors to solve for your 'destination' units.*

## First test drive



Vitamin C has the molecular formula  $C_6H_8O_6$ . The recommended daily dose for kids aged 4-8 years is  $1.42 \times 10^{-4}$  moles. 7

*How many grams should you give them?*

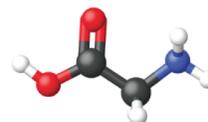
## Longer trip



Our bodies make amino acids, the building blocks of proteins. The simplest amino acid is glycine,  $C_2H_5O_2N$ . 8

*How many moles of glycine molecules are there in 28.35 g?*

*How many hydrogen atoms in the 28.35 g?*

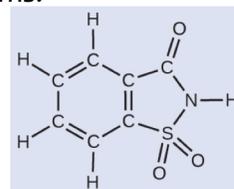


## Long trip back



Saccharin,  $C_7H_5NO_3S$ , is the old 'pink' sugar substitute.  
 How many g of sacchirin have 9.20 E21 carbon atoms?

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## Can you?



- (1) Calculate a formula mass or molecular mass (aka molar mass or molecular weight, MW)?
- (2) Understand just how massive Avogadro's number is?
- (3) Understand how and why a mole of different elements and compounds can have radically different masses?
- (4) Use atomic mass, molar mass, Avogadro's number and formula subscripts as conversion factors to convert mass to moles to molecules to atoms?
- (5) Use a 'mole map' to help you choose conversion factors and the number of steps for conversion problems?

## 3. Composition of substances & solutions



### 3.2: Determining empirical & molecular formulas

- Compute the percent composition of a compound
- Determine the empirical formula of a compound
- Determine the molecular formula of a compound

## Unknown compound?



What can you do to figure out what it is?

- What elements does it contain?
- What percent of the substance's mass is made up of each element (ie **percent composition**)

For example, a gas is found to contain only carbon and hydrogen. Analysis of a 10.0-g sample finds 2.5 g are C & 7.5 g are H. *What's the compound's percent composition?*

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## Try this



A 12.04-g sample of an unknown liquid is analyzed & found to contain 7.34 g C, 1.85 g H and 2.85 g N.

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Calculate its percent composition.

## Calculate % composition from formulas



To add nitrogen to a crop, farmers can use several different fertilizers: ammonia ( $\text{NH}_3$ ); ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ); or urea ( $\text{CH}_4\text{N}_2\text{O}$ ). If prices were equal, which delivers the most N per formula weight?

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## Try this



Aspirin's formula is  $C_9H_8O_4$ . Calculate its percent composition.

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## Working it the other way



How can we work this process the other way and use percent composition to calculate empirical formula?

A sample contains 1.71 g of C and 0.287 g of H.

*What's its empirical formula?*

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## What about molecular formulas?



With one more piece of information, formula mass or MW, we can determine the **molecular formula** too.

Nicotine, responsible for the addictive nature of cigarettes is 74.02% C, 8.710% H, 17.27% N. And 40.57 g contains 0.2500 moles. What is the molecular formulas of nicotine?

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## Try this



What's the molecular formula of a compound with 49.47 % C, 5.201 % H, 28.84 % N and 16.48% O. The formula mass is 194.2 g/mol.

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## Can you?



- (1) Calculate percent composition of a compound if given masses of each element in the compound?
- (2) Calculate percent composition from a molecular formula?  
*List the steps needed to do it?*
- (3) Calculate empirical formula from percent composition?  
*List the steps needed to do this?*
- (4) Calculate molecular formula from percent composition?  
*List the steps needed and the extra piece of information?*

## 3. Composition of substances & solutions



### 3.3: Molarity

- Describe the fundamental properties of solutions
- Calculate solution concentration using molarity
- Perform dilution calculations using the dilution equation

## Solutions



Remember that **solutions** are homogenous mixtures. Solutions can occur in all physical states, but we'll be focusing on liquid and gaseous solutions.

Liquid solutions can be described as mixtures of:

**solutes:** the compound present in lesser amounts; &

**solvents:** the compound present in larger amounts.

On our planet, the dominant solvent is **water**. Solutions made by **dissolving** solutes in water are called **aqueous**.



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## Molarity



**Concentration** is a measure of the amount of solute in solvent.

**Molarity (M)** is a unit that we'll use to express solution concentration.

$$\text{molarity (M)} = \frac{\text{mol solute}}{1 \text{ L solution}}$$

*Note that M uses the volume of solutions, not solvents. Why?*

A 335-mL soft drink contains 0.133 mol of sucrose (table sugar).  
What is the molar concentration of sucrose in the drink?

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## Try this



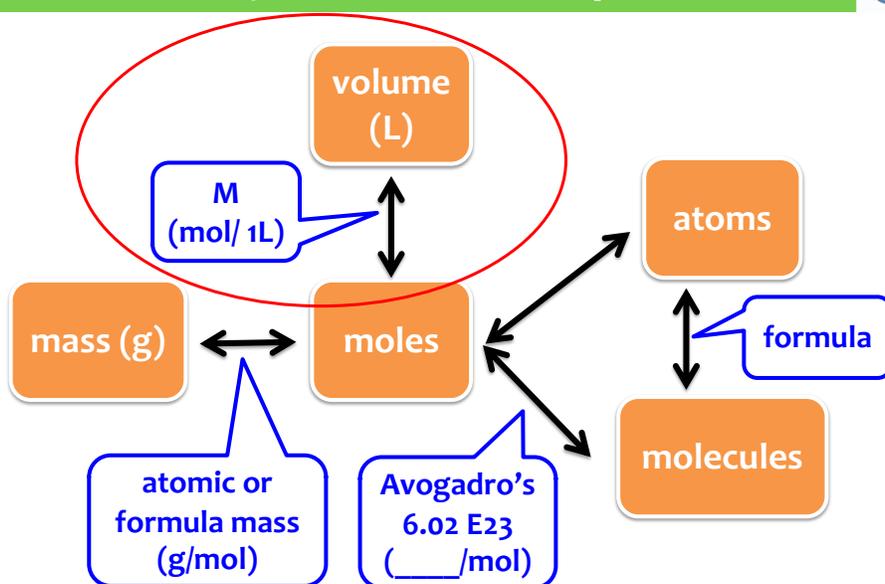
A teaspoon of sugar has 0.01 mol of sucrose. What's the molarity of sucrose if the sugar is dissolved in a cup of tea with a volume of 200 mL?

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A sip of tea has a volume of 10 mL. How many moles of sucrose are there in one sip?

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## Add molarity to the mole map



Flip conversion factors to solve for your 'destination' units.

## Two more variations



How many grams of NaCl are there in 0.250 L of a 5.30 M solution?

20

What volume (mL) of this salt solution contains 20.0 g of NaCl?

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## Dilution

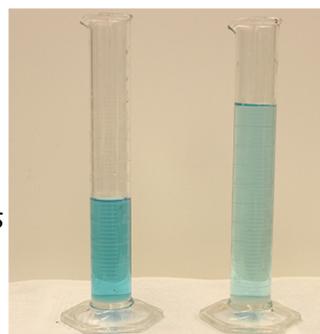


**Dilution:** *the process of adding more solvent to decrease the concentration of a solution*

- Also the process of preparing solutions at the desired concentration from more concentrated **stock solutions** or from dry (solid) compounds

$$n = (M)(L) \quad \text{where } n = \text{moles}$$

$$M_1L_1 = M_2L_2 \quad \text{where 1 \& 2 are sol'ns of different concentrations}$$



**concentrated**      **dilute**  
Both contain the same mass of copper.

## Apply the dilution 'formula'



If 0.850 L of a 5.00 M solution of copper (II) nitrate is diluted to a volume of 1.80L by the addition of water, what is the molarity of the diluted solution?

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*Sanity check: should the M increase or decrease?*

## A different angle



What volume of 0.12 M HBr can be prepared from 11 mL of 0.45 M solution?

23

*Sanity check: should the volume increase or decrease?*

*Note that volume can take any units as long as they are the same on both sides.*

## Can you?



- (1) Define the terms solution, solute, solvent, dissolve, aqueous, concentration, molarity and dilution?
- (2) Calculate molarity from moles or mass and volume?
- (3) Use molarity as a conversion factor?
- (4) Use the dilution 'formula'?

## 3. Composition of substances & solutions



### 3.4: Other units for solution concentrations

- Define the concentration units of mass percentage, volume percentage, mass-volume percentage, parts per million (ppm), & parts per billion (ppb)
- Perform calculations relating a solution's concentration and its components' volume and / or masses with these units

*optional*

## Mass percentage



**Mass percentage:** the ratio of solute mass to solution mass, multiplied by 100

- % mass or % (w/w)

The label of a bottle of bleach lists its active ingredient, sodium hypochlorite (NaOCl), as 7.4%.

- So, 100.0 grams of bleach would contain 7.4 g of NaOCl.

A 5.0-g sample of spinal fluid contains 3.75 mg of glucose. What is the percent by mass of glucose in spinal fluid?

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optional

## Using mass percentage



Concentrated hydrochloric acid is a 37.2% aqueous solution with a density of 1.19 g/mL. What mass of HCl is there in 0.500 L of concentrated HCl solution?

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optional

## Volume percentage



**Volume percentage:** expresses the concentration of a liquid solute dissolved in a liquid solvent, % (v/v)

$$\% (v/v) = \frac{\text{volume solute}}{\text{volume solution}} (100)$$

Rubbing alcohol (isopropanol) is usually sold as a 70% (v/v) aqueous solution. If the density of isopropanol is 0.785 g/mL, how many grams of isopropyl alcohol are present in 355 mL of rubbing alcohol?

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optional

## Mass-volume percentage



**Mass-volume percentage:** expresses the ratio of a solute's mass to the solution's volume as a percentage

$$\% (w/v) = \frac{\text{g solute}}{100 \text{ mL sol'n}}$$



saline sol'n = 0.9% (w/v) NaCl



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optional

## ppm & ppb

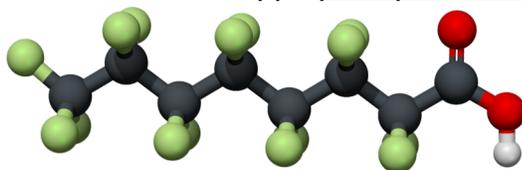


Very low solute concentrations are often expressed as **parts per million (ppm)** or **parts per billion (ppb)**.

$$\text{ppm} = \frac{\text{mass solute}}{\text{mass sol'n}} \quad (1 \text{ E}6) \text{ ppm}$$

$$\text{ppb} = \frac{\text{mass solute}}{\text{mass sol'n}} \quad (1 \text{ E}9) \text{ ppb}$$

Some wells in Vermont are contaminated with PFOA (perfluorooctanoic acid). Vermont has set safe levels at 20 ppt, parts per trillion.



Chemistry Openstax; [https://en.wikipedia.org/wiki/Perfluorooctanoic\\_acid](https://en.wikipedia.org/wiki/Perfluorooctanoic_acid)  
<http://www.healthvermont.gov/health-environment/drinking-water/perfluorooctanoic-acid-pfoa>



## Try this



EPA rules say that if lead levels in drinking water reach 15 ppb, remedies must be taken.

(a) Convert this to ppm.

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(b) What mass of lead ( $\mu\text{g}$ ) would be in a 300-mL glass of water?

optional

## Can you?



- (1) Define the terms mass percentage, volume percentage, ppm and ppb?
- (2) Use mass percentage, volume percentage and mass-volume percentage 'equations' in calculations?
- (3) Convert ppm and ppb to other units of concentration?

*optional*

## Lecture 3, Composition... Terms to know



aqueous solution  
Avogadro's number  
concentrated  
concentration  
dilute  
dilution  
dissolved  
empirical formula mass  
formula mass  
mass percentage  
mass-volume percentage  
molar mass  
molarity (M)  
mole  
parts per billion (ppb)  
parts per million (ppm)  
percent composition  
solute  
solvent  
volume percentage