CHEM 103
Masses and Moles

Lecture Notes
February 14, 2006
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Agenda

- Masses and moles of compounds
- Empirical formulas
- Determining % composition of compounds

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What you can do to practice with chemical nomenclature

- List cations on one page and anions on another.
- Choose one cation and one anion.
- Write the name of the ionic compound or acid.
- Determine the correct neutral formula.

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What is a Mole?

- Convenient way of counting particles
- Analogous to dozen, pair, gross, case, ream,…
- One mole of particles always contains the same number of particles, regardless of the identity of the particle

1 mole of X = 6.022×10^{23} particles of X

e.g., 1 *mol* Ar = 6.022×10^{23} Ar atoms

1 *mol* O_3 (*g*) = 6.022×10^{23} O_3 molecules

1 *mol* NaCl (*s*) = 6.022×10^{23} NaCl units

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Moles scale from atoms

- How many atoms of O are in one unit of each of the following compounds?

  H_2SO_4 $Ca(NO_3)_2$ $C_{12}H_{22}O_{11}$

- How many moles of O atoms are in 1 mol of each of the following compounds?

  H_2SO_4 $Ca(NO_3)_2$ $C_{12}H_{22}O_{11}$

Possible conversions are:

or

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What is the Mass of a Mole?

- Different kinds of particles have different masses
- Since the quantity of particles in a mole is the same for any particle, the mass of a mole of particles varies depending on the identity of the particles
- By definition,

$$1\,mol \text{ of } {}^{12}_{6}\text{C particles} = 12\ g \text{ exactly}$$

- Other molar masses always in reference to definition.

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Molar Mass

Molar mass means the mass of one mole

- For monatomic elements, use atomic weight on the Periodic Table
- Examples:

  What is the mass of 1.000 mol of Ar?

$$1.000\ mol\ \mathrm{Ar} \times \frac{39.95\ g\ \mathrm{Ar}}{1\ mol\ \mathrm{Ar}} = 39.95\ g\ \mathrm{Ar}$$

  What is the mass of 2.5 mol of Xe?

$$2.5\ mol\ \mathrm{Xe} \times \frac{131.3\ g\ \mathrm{Xe}}{1\ mol\ \mathrm{Xe}} = 328.25\ g\ \mathrm{Xe}$$

330 *g* Xe

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What is the amount of money here?

How did you figure this out?

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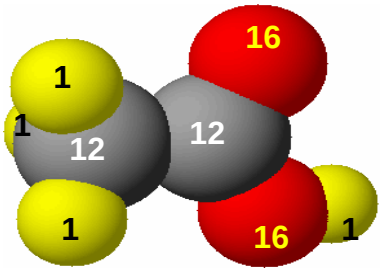
What is the amount of amu's here?



Answer:

How did you figure this out?

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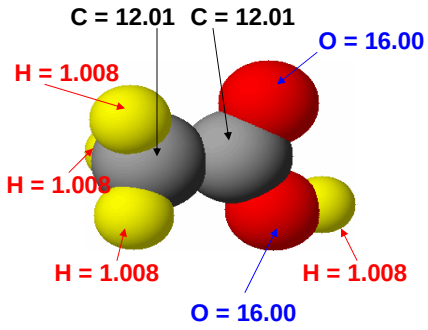
Actually, the masses aren't integers



Mass of one molecule of CH_3COOH is

60.05 amu

Mass of 1 mole of CH_3COOH molecules is

60.05 grams

Important note: Since there is always the same number of particles in a mole, when you determine the amu's of a unit, you are determining the mass in grams of a mole of that unit.

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Moles and masses, so far

- Mass (in grams) of a mole is the same number as the mass (in amu) of one unit in the mole
- Use the average atomic weights on the periodic table as masses of individual atoms
- There are many names for this quantity:
  - Molar mass
  - Molecular weight (when the unit is a molecule)
  - Formula weight (when the unit is the simplest ratio of ions in an ionic crystal)

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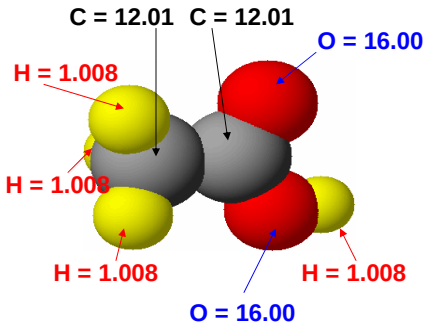
More on Molar Mass

What is the mass of 0.00497 mol of CH_3COOH?



Molar mass = 60.05 g/mol

$$0.00497\ mol\ CH_3COOH \times \frac{60.05\ g}{1\ mol} = 0.298\ g\ CH_3COOH$$

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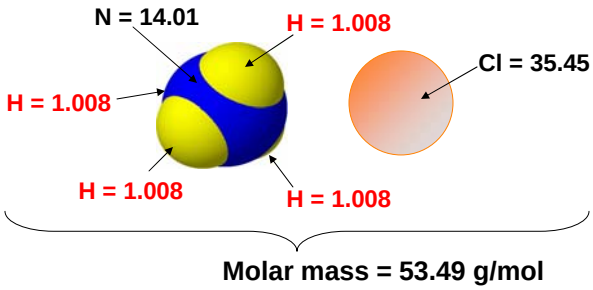
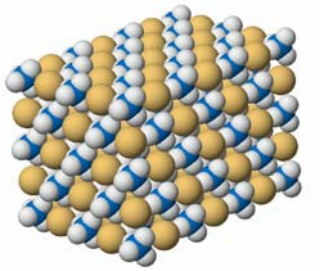
More on Molar Mass

- For ionic compounds, sometimes also called formula weight
- To determine molar mass (or formula weight) of one unit of ionic compound: sum the parts

Formula weight of NH_4Cl crystals: One unit is (one NH_4^+) plus (one Cl^-)

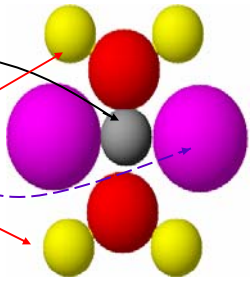




Hydrated Ionic Compounds

How many moles are in 5.55 g of $BaCl_2 \cdot 2H_2O$?

One unit of ionic formula consists of:



Formula weight = 244.2 g/mol

$$5.55\ g\ BaCl_2 \bullet 2H_2O \times \frac{1\ mol}{244.2\ g} = 0.0227\ mol\ BaCl_2 \bullet 2H_2O$$

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Conversions possible so far

(look for opportunities to use these in dimensional analysis)

- Moles ↔ mass (grams)
- Moles of atoms ↔ moles of a unit (e.g., molecule, neutral ionic crystal formula)
- Moles of something ↔ particles in the something

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Combining molar mass and numbers of atoms

Example

How many atoms of hydrogen are in 1.63 grams of water (H_2O)?

$$1.63\ g\ H_2O \times \frac{?\ something}{?\ g\ H_2O} \times \frac{?\ another\ thing}{?\ something} \times \frac{?\ atoms\ of\ H}{?\ another\ thing} = ?\ atoms\ of\ H$$

3 sig figs

$$1.63\ g\ H_2O \times \frac{?\ mol\ H_2O}{?\ g\ H_2O} \times \frac{?\ molecules\ of\ H_2O}{?\ mol\ H_2O} \times \frac{?\ atoms\ of\ H}{?\ molecule\ of\ H_2O} = ?\ atoms\ of\ H$$

3 sig figs

How Many Molecules?

Too many to count!

How many molecules of water are in a 2.00-L bottle that is filled with water? Water has a density of 1.000 g/mL.

Start **End**

2.00 L of H_2O

$$\frac{}{1} \times \frac{1000\ mL}{1\ L} \times \frac{1.000\ g}{1\ mL} \times \frac{1\ mol}{18.02\ g} \times \frac{6.022 \times 10^{23}\ molecules}{1\ mol} = \frac{6.68 \times 10^{25}\ molecules\ of\ H_2O}{1}$$

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Composition of a …

- Usually composition is given in mass percent (also called weight %)
- Use the chemistry definition of percent

$$\% = \frac{part}{whole} \times 100\%$$

- Know the difference between fraction and percent – a fraction can be expressed as a percent by multiplying by 100 ("percent" means part out of 100)

Fraction 0.7585 is the same as 75.85%

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Composition of a Mixture

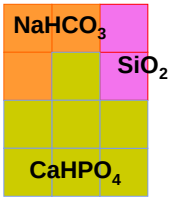
Baking powder is a mixture of ingredients. A sample of baking powder contains 3.50 g of calcium hydrogen phosphate ($CaHPO_4$), 1.50 g of sodium bicarbonate ($NaHCO_3$), and 1.00 g of silicon dioxide (SiO_2). Calculate the percent composition by mass.

$$\%\mathrm{CaHPO_4} = \frac{3.50g}{3.50+1.50+1.00g} \times 100\% = 58.3\%$$

$$\%\mathrm{NaHCO_3} = \frac{1.50g}{6.00g} \times 100\% = 25.0\%$$

$$\%\mathrm{SiO_2} = 100 - (58.3 + 25.0)\% = 16.7\%$$

A picture of the mixture (to assist in estimating)



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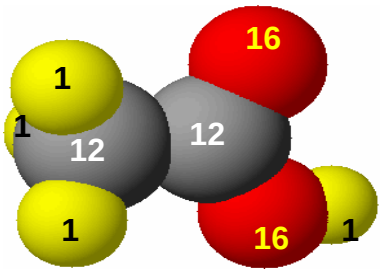
What does % composition mean?



Note: These are approximate atomic masses, for the purpose of demonstrating % composition. When actually calculating % composition, use the values from the Periodic Table.

<u>% Composition by Mass</u>

$$fraction\ \mathrm{C} = \frac{2\times12}{60} = 40.\%$$

$$fraction\ \mathrm{H} = \frac{4\times1}{60} = 6.7\%$$

$$fraction\ \mathrm{O} = \frac{2\times16}{60} = 53\%$$

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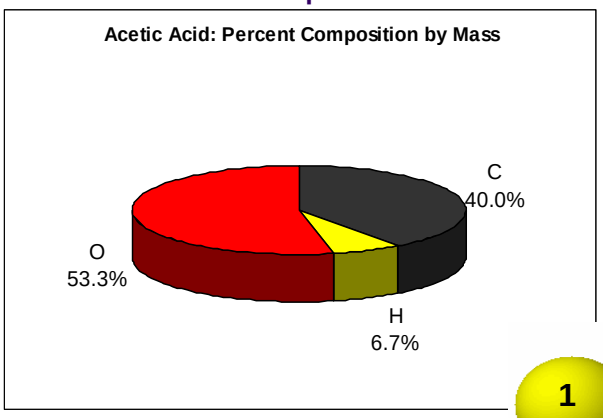
What does % composition mean?



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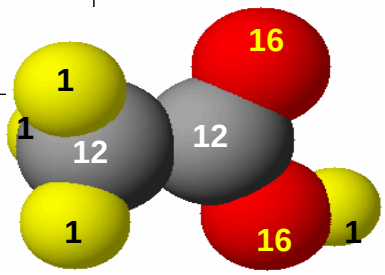


Composition of a Compound

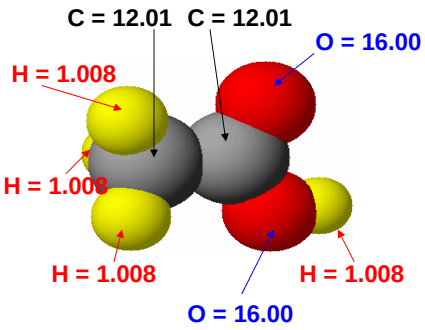
What is the composition by mass of acetic acid (CH_3COOH)?

$$\%C = \frac{24.02}{60.05} \times 100\% = 40.00\%$$

$$\%H = \frac{4.032g}{60.05g} \times 100\% = 6.714\%$$

$$\%O = \frac{32.00g}{60.05g} \times 100\% = 53.29\%$$

Check : $40.00 + 6.714 + 53.29 = 100.00\%$



Recall from earlier:
Molar mass = 60.05 g/mol

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Composition of a Hydrated Compound

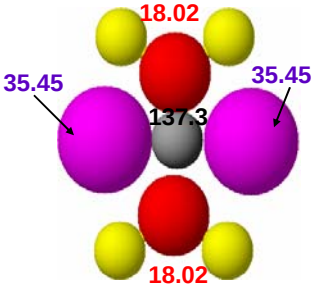
Heating barium chloride dihydrate ($BaCl_2 \bullet 2H_2O$) drives off the water, leaving the anhydrous compound ($BaCl_2$). The chemical reaction is

$$BaCl_2 \bullet 2H_2O\ (s) \rightarrow BaCl_2\ (s) + 2\ H_2O\ (g)$$

If you begin with a 10.0 g sample of the hydrated compound, what mass of water will be lost?

$$\%H_2O = \frac{2 \times 18.02}{244.2} \times 100\% = 7.379\%$$

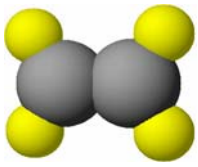
$$\begin{aligned} \text{mass of } H_2O \text{ in sample} &= 7.379\% \text{ of } 10.0\ g \\ &= 0.07379 \times 10.0 g \\ &= 0.738 g \end{aligned}$$



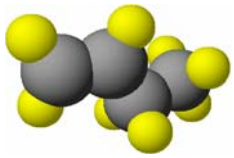
Formula weight = 244.2 g/mol

Chemical Compounds and Mass

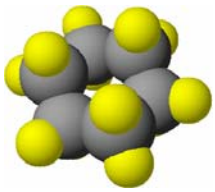
- Chemical formula to percent composition
  - Need to determine parts and whole
  - Use definition of percent
- Going the other direction
  - Percent composition alone is not enough information to determine molecular formula



C_2H_4



C_4H_8



C_6H_{12}

All three of these have 14.37% H and 85.63% C by mass

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Empirical Formula

Lowest whole number ratio of elements in a chemical formula

Chemical formula	Empirical formula
C_2H_4	CH_2
C_4H_8	CH_2
C_6H_{12}	CH_2
$C_6H_{12}O_6$	
$Na_2C_2O_4$	
CH_3COOH	
H_2O_2	
H_2O	

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Chemical Compounds and Mass

- Chemical formula to percent composition
  Ratio of moles → Percent by mass

- Percent composition (or relative masses) to empirical formula
  Percent by mass → Ratio of moles

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