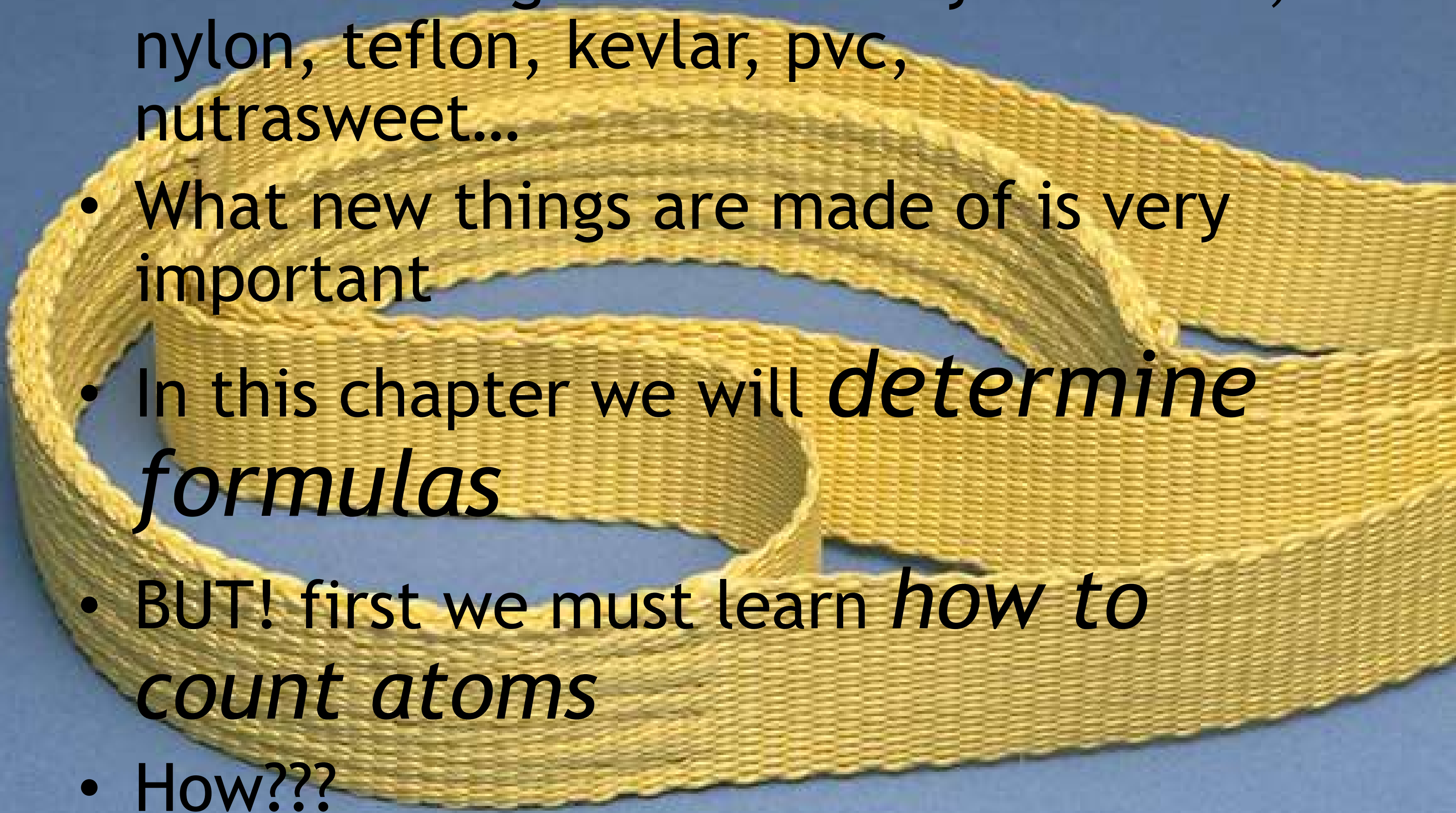
chapter 6 chemical composition

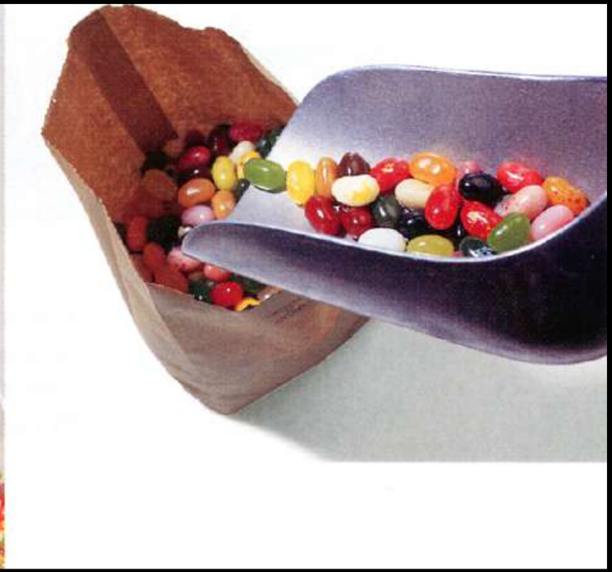


- A ton of things have been synthesized; nylon, teflon, kevlar, pvc, nutrasweet…
- What new things are made of is very important
- In this chapter we will *determine formulas*
- BUT! first we must learn *how to count atoms*
- How???

6.1 counting by weighing

- How does one count candy, or pennies, or nails, or M&Ms, or recycled Aluminum cans??? they're so numerous, and small! help!
- **Count them by weighing them! (?)**
- However, we must assume that all the "things" are 1) Identical OR 2) They have an average weight

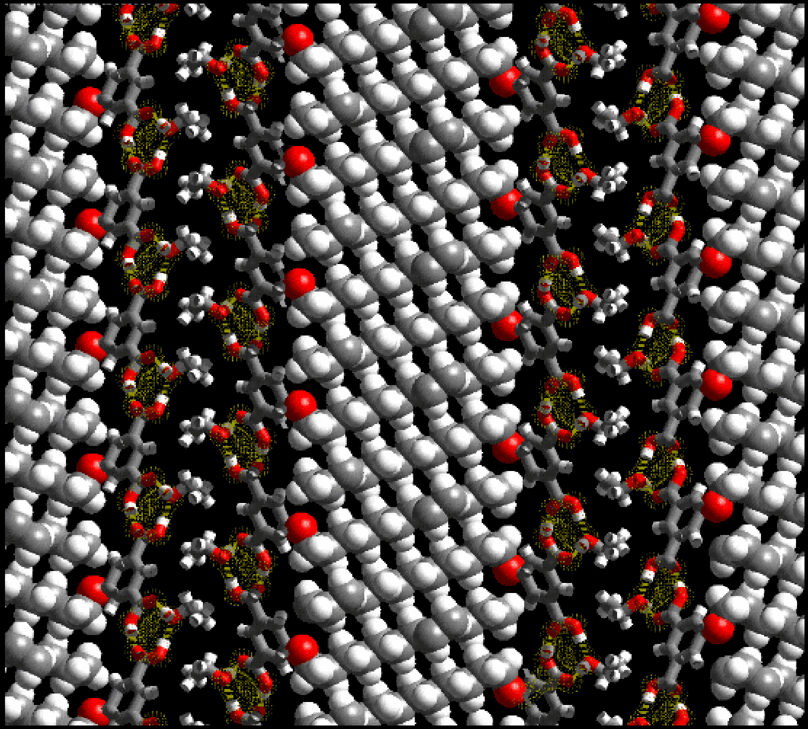
- Since most things don't occur identically, *one must take an average of mass of those things…*

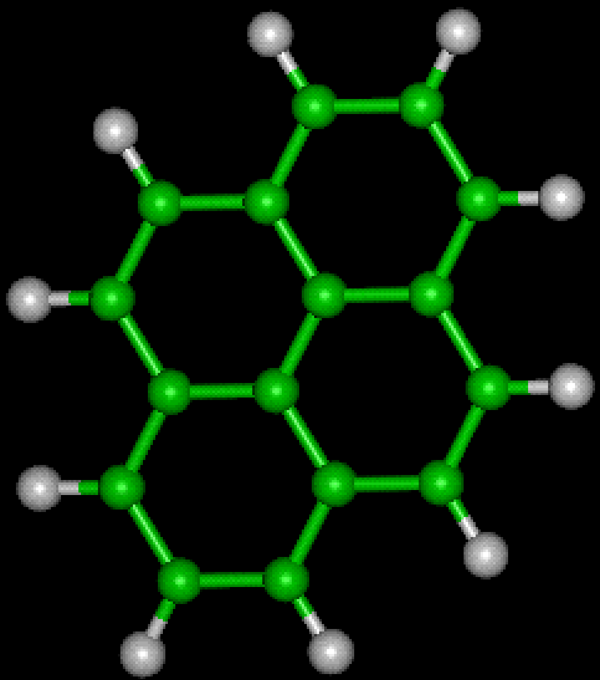


- If you *act* as if they are all that average weight, it's easy:
- *Take how much the whole pile weighs*
- *Divide it by the average mass of them*
- ba-da-bing! you know how many there are!
- we do the same thing with tiny invisible atoms; we count by weighing!

6.2 Atomic masses: counting atoms by weighing

- OK, now we move to atoms
- Chemistry is wants to find out **how many** of these are needed to react with a **certain number** of those to get **so many** of these
- meaning: ***Numbers of things are Super - important***
- time for thinking cap!





- The mass of an atom is unbelievably small (e.g. a C atom weighs 1.99×10^{-23} g)
- So kg and g are out!
- We need a **new unit** small enough to deal with these tiny guys reasonably
- Chemists use the **atomic mass unit (amu)**
- 1 amu = 1.66×10^{-24} g
- ***atoms will weigh so many amu's***
- now back to atoms and counting by weighing…

- Remember isotopes? not all atoms are the same?!
- Carbon exists as:
  C-12, C-13, and C-14
- They occur in different types, but altogether they can give us **an average mass**
- The average atomic mass for carbon on this planet is 12.01 amu *(all the rest are listed on the Periodic Table)*
- Let's act, for the rest of chemistry, as if atoms have this one mass, the one listed on the Periodic Table

One carbon atom has a mass of 12 atomic mass units

Examples

- what is the mass, in amu, of 75 Al atoms? (1 Al = 26.98 amu)

$$\left.\frac{75\ \text{atoms}}{}\right|\frac{26.98\ \text{amu}}{1\ \text{atom}} = 2024\ \text{amu}$$

- *what is the mass (in amu) of a C sample with 62 atoms? (1 C = 12.01 amu)*
- **744.6 amu**
- *what's the amu mass of 15 iron atoms? (1 Fe = 55.85 amu)*
- **837.8 amu**

More Examples

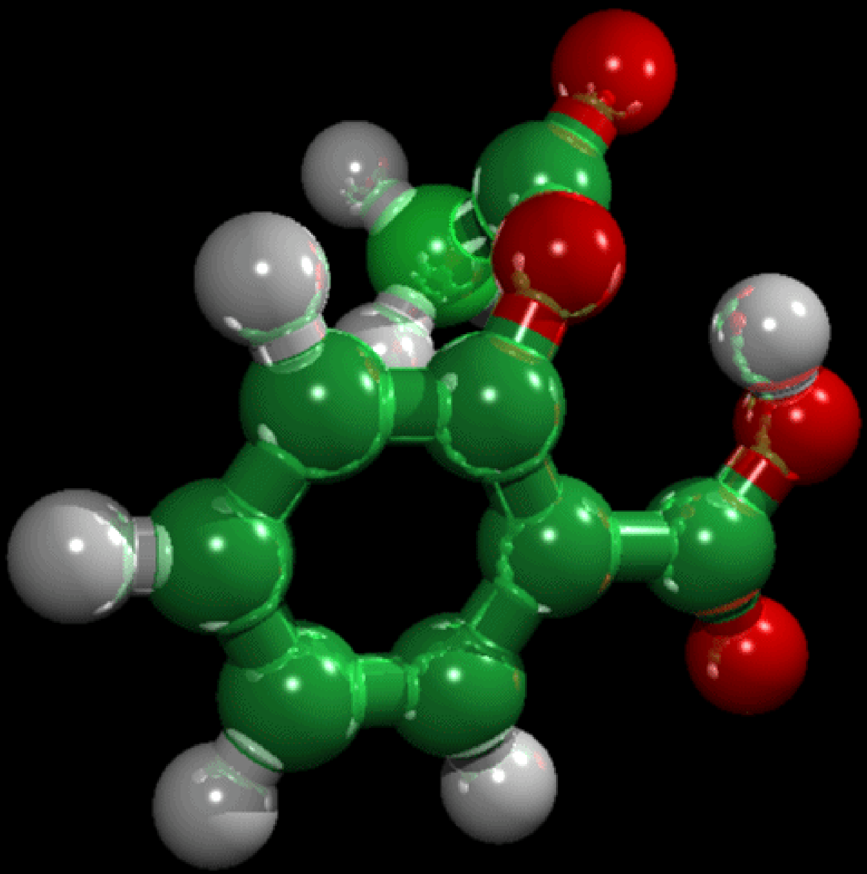
- *how many atoms are in 1172.49 amu of Na atoms? (1 Na = 22.99 amu)*

$$\frac{1172.49 \text{ amu}}{\;} \,\Bigg|\, \frac{1 \text{ Na atom}}{22.99 \text{ amu}}$$

= 51.00 Na atoms

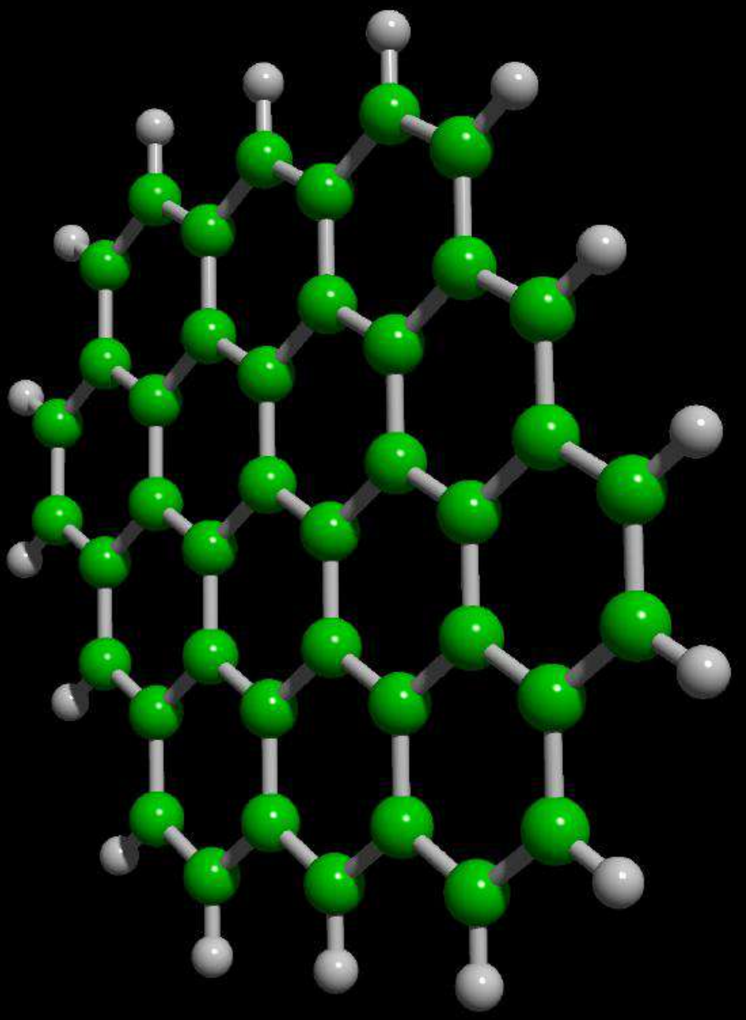
- *How many Cu atoms are in a 1779.4 amu sample? (1 Cu = 63.55 amu)*
- 28.00 atoms
- *How many Ar atoms in 3755.3 amu? (1 Ar = 39.95 amu)*
- 94.00 atoms

6.3 The mole



- Up to this point we've used submicroscopic amounts of stuff
- *What about realistic amounts???* ready?
- How about making it easy for everyone?…

- How about we pick the number of atoms which will change amu’s to grams?
- What number will take…
  12.01 amu C -> 12.01 g C
  26.98 amu Al -> 26.98 g Al
  63.55 amu Cu -> 63.55 g
- Just one number, Avogadro’s number, the number all chemists throughout the world use every day of their miserable lives, the one, the only..



The mole

6.022×10^{23}

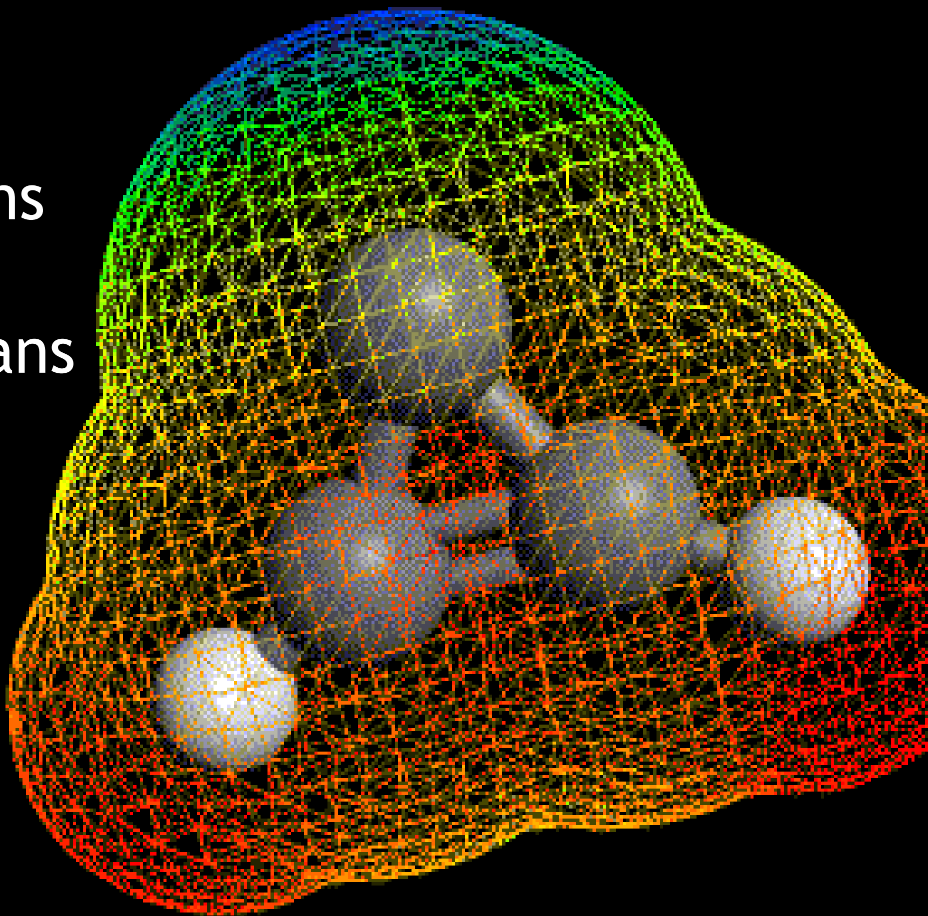
- 1 dozen = 12
  1 ream = 500
  1 pair = 2
  1 gross = 144
  1 mol = 6.022×10^{23}

- Counting this number would take 2000 trillion years; a mole of sand could cover LA in 600 meters of sand; a mole of marbles would cover Earth in 50 miles of marbles; but!
  a mole of water you can cup in one hand!
- *An element that weighs as much as the number of grams listed on the PeriodicTable has a mol, 6.022×10^{23}, atoms in it*

- Now we can count atoms just by knowing:
  1. how much we have (g) and
- 2. The number on the Periodic Table which now represents a mol of stuff in grams

more than the molar mass means > 1 mol of stuff

- less than the molar mass means < 1 mol of stuff
- let’s start off easy…



Example (atoms-mol)

How many atoms in 2.2 mol C?

$$2.2\ \text{mol C} \times \frac{6.022\times10^{23}\ \text{atoms C}}{1\ \text{mol C}} = 1.3\times10^{24}\ \text{atoms C}$$

Examples (g-mol)

26 g C = ? mol

$$\frac{26\text{ g}}{} \left| \frac{1\text{ mol C}}{12.01\text{ g C}} \right. = 2.2\text{ mol C}$$

25 g Ni = ? mol 0.43 mol

2.50 mol Cu = ? g Cu 159 g

Examples (g-mol-atoms)

25.0 g Ca = ? mol = ? atoms

$$\frac{\cancel{25.0\text{g Ca}}}{} \left| \frac{1\text{ mol Ca}}{\cancel{40.08\text{g Ca}}} \right. = 0.624\text{ mol Ca}$$

$$\frac{\cancel{0.624\text{ mol Ca}}}{} \left| \frac{6.022 \times 10^{23}\text{ atoms}}{\cancel{1\text{ mol Ca}}} \right. = 3.76 \times 10^{23}\text{ Ca atoms}$$

57.7 g S = ? mol S = ? atoms S

1.80 mol S

1.08×10^{24} S atoms

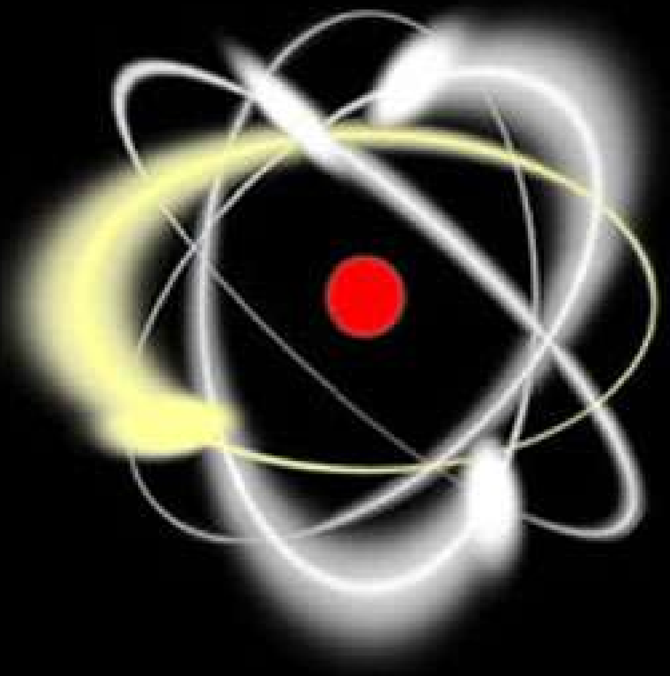
Examples (g-mol-atoms)

$5.00x\ 10^{20}$ Cr atoms = ? mol = ? g

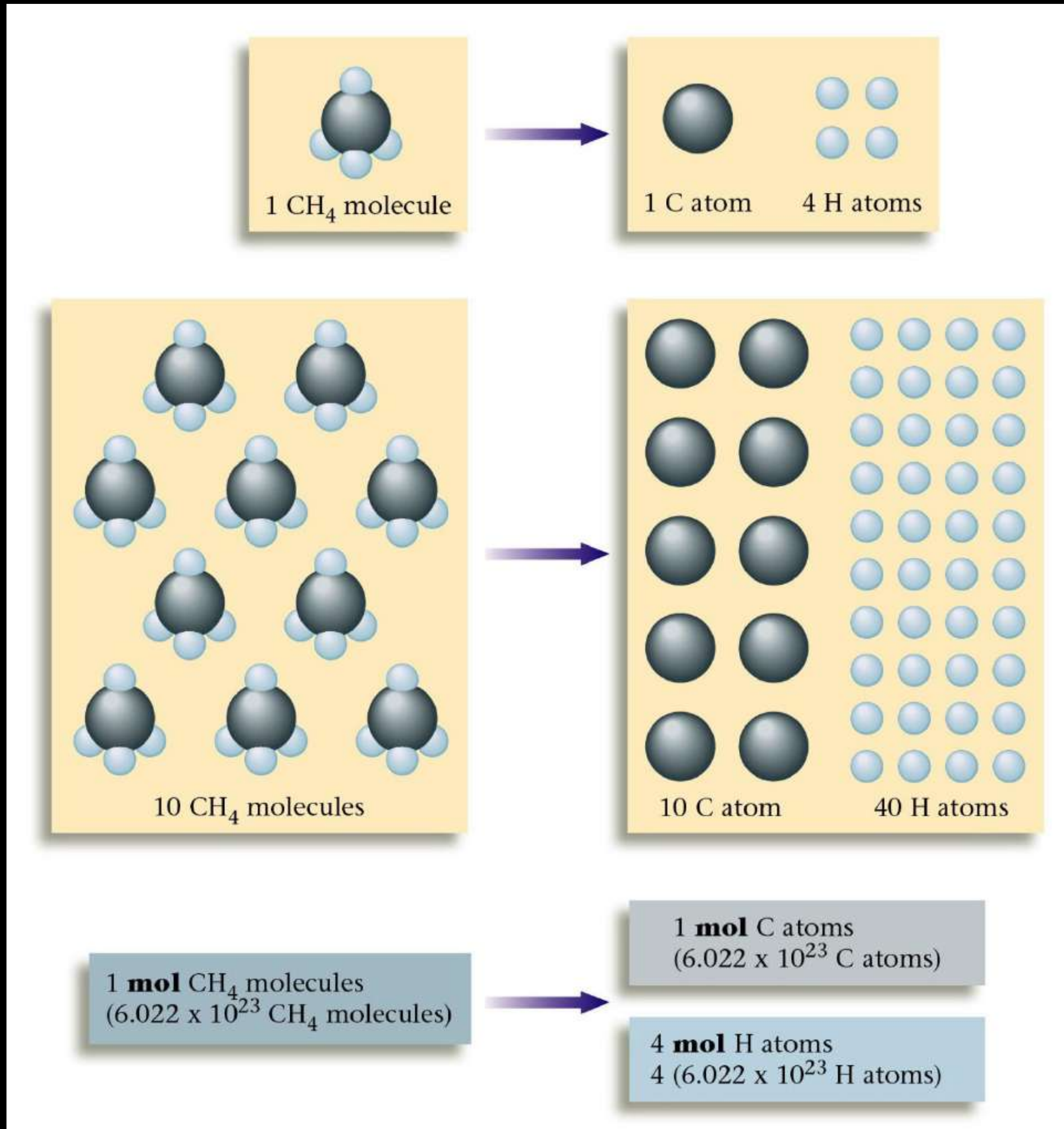
$$5.00 \text{ x } 10^{20}\text{ atoms} \;\Big|\; \frac{1\text{ mol Cr}}{6.022 \text{ x } 10^{23}\text{ Cr atoms}} = 8.30 \text{ x } 10^{-4}\text{ mol Cr}$$

$$8.30 \text{ x } 10^{-4}\text{ mol Cr} \;\Big|\; \frac{52.00\text{ g Cr}}{1\text{ mol Cr}} = 4.32 \text{ x } 10^{-2}\text{ g Cr}$$

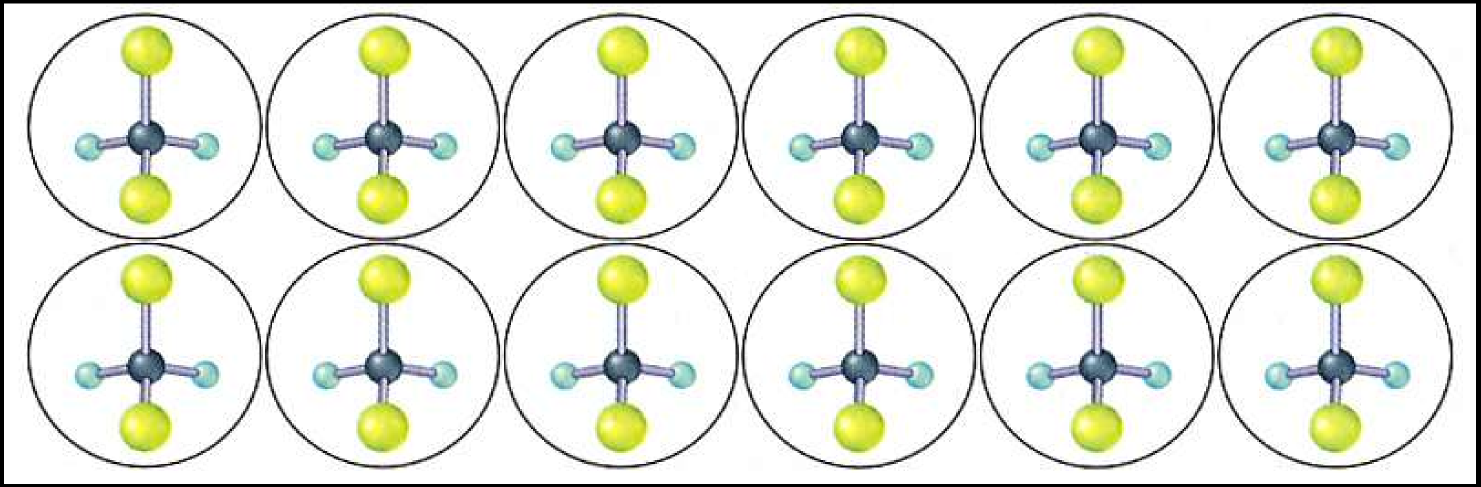
6.4 molar mass



- We dig further into the molar mass thing, and…
- converting moles into mass (visa versa) for ***compounds*** now
- see next the relationship between micro and macro



1 CH_4 molecule
1 C atom
4 H atoms
10 CH_4 molecules
10 C atom
40 H atoms
1 **mol** CH_4 molecules
(6.022×10^{23} CH_4 molecules)
1 **mol** C atoms
(6.022×10^{23} C atoms)
4 **mol** H atoms
4 (6.022×10^{23} H atoms)



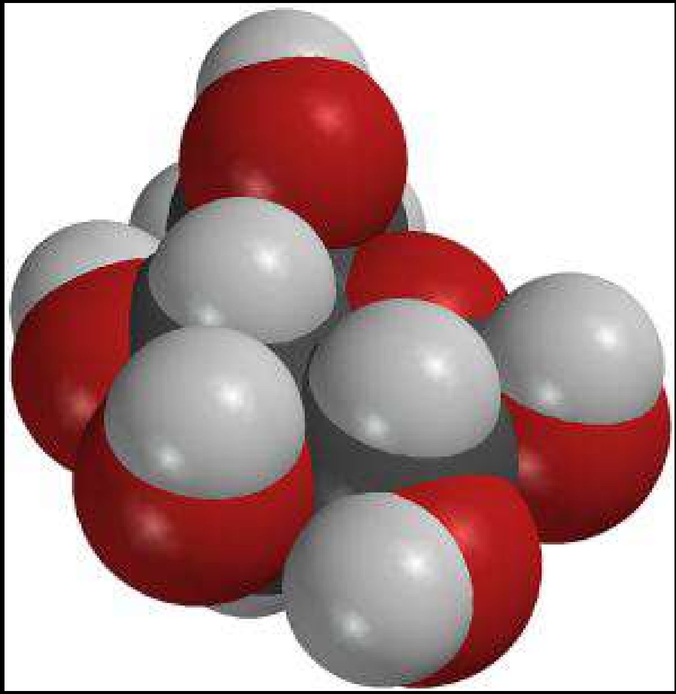
- Do you want to find the molar mass of methane? (yes!)
- Just add up the little guys in the compound!
- for methane that would be:
  12.01 (C) + 1.01(H) + 1.01(H) + 1.01(H) + 1.01(H)
- = 16.05 g/mol

= **molar mass**

- Just like before: get me a mass of 16.05 g of methane and you've given me a mol of it

examples

- *what is the molar mass of sulfur dioxide?* (this is why you need to remember names/formulae)
- sulfur dioxide is SO_2
- a mol of SO_2 has 1 mol S and 2 mol O
- = (1 x 32.07) + (2 x 16.00)
- **= 64.07 g/mol**



examples

- *what is the molar mass of:*
- water?
- **H_2O = 18.02 g/mol**
- ammonia?
- **NH_3 = 17.03 g/mol**
- propane, C_3H_8?
- **= 44.09 g/mol**
- glucose, $C_6H_{12}O_6$?
- **= 180.2 g/mol**

examples

- can do the same with ionic compounds!
- *what is molar mass of*:
- calcium sulfate?
- **$CaSO_4$ = 136.3 g/mol**
- sodium carbonate?
- **Na_2CO_3 = 106.0 g/mol**
- barium hydroxide?
- **$Ba(OH)_2$ = 171.3 g/mol**

a mol of each

examples (mol to mass)

- *calculate molar mass of calcium carbonate what is the mass of 4.86 mol of this stuff?*
- molar mass $CaCO_3$ = **100.09 g/mol**

$$\frac{4.86 \text{ mol } CaCO_3 \;\Big|\; 100.09 \text{ g } CaCO_3}{\;\Big|\; 1 \text{ mol } CaCO_3} = \mathbf{486 \text{ g } CaCO_3}$$

molar mass of sodium sulfate? **142.05 g**

300.0 g is how many mol? **2.112 mol Na_2SO_4**

examples (mass to mol)

- *calculate molar mass of juglone ($C_{10}H_6O_3$) what is the mol of 1.56 g of this stuff?*
- molar mass $C_{10}H_6O_3$ = **174.1 g/mol**

$$\frac{1.56 \text{ g } C_{10}H_6O_3}{} \left| \frac{1 \text{ mol } C_{10}H_6O_3}{174.1 \text{ g } C_{10}H_6O_3} \right. = \mathbf{0.00896\ mol}\ C_{10}H_6O_3$$

mol formaldehyde (H_2CO) in 7.55-g sample? **0.251 mol**

mol tetraphosphorus decoxide in a 250.0-g sample? **0.8805 mol**

examples (mass to molecules)

- *how many molecules of Teflon (C_2F_4) are in a 135-g sample? (hint: do you expect a little or gigantic answer?)*
- think! g --> mol --> molecules
- you'll need molar mass C_2F_4 = **100.02 g/mol**

$$\begin{array}{c|c} 135\ \text{g}\ C_2F_4 & 1\ \text{mol}\ C_2F_4 \\ \hline & 100.02\ \text{g}\ C_2F_4 \end{array} = \mathbf{135\ mol}\ C_2F_4$$

$$\begin{array}{c|c} 135\ \text{mol}\ C_2F_4 & 6.022 \times 10^{23}\ \text{atoms} \\ \hline & 1\ \text{mol}\ C_2F_4 \end{array} = 8.13 \times 10^{23}\ C_2F_4\ \text{atoms}$$

6.5 percent composition of compounds

- which score is better? 28/50 or 32/75?
- *percent* can answer the question
- ***percent*** is merely taking a **part** and dividing by **total** (then multiplying by 100)
- same with **% comp**...
- take **mass contributed by one element** and divide by **total mass of cmpd** (x 100)

- Can you tell the % composition just from looking at a formula?
  e.g. is SO_2 33% S and 67% O?
- NO! % composition is a **gram** ratio thing not a **mole** ratio thing!!!
- so first change the mole in the formula to grams, then find %…

example

- ***What is the % composition of SO_2?***
- SO_2 weighs in at 64.07 g/mol
- S contributes 32.07 of it, oxygen 2 x 16.00
- %S = (32.07/64.07) • 100 = 50.05%
- %O = (32.00/64.07) • 100 = 49.94%

example

- ***What is the % composition of $C_{10}H_{14}O$?***
- $C_{10}H_{14}O$ weighs in at 150.2 g/mol
- C contributes 120.1 of it, H gives it 14.11, and O 16.00
- %C = (120.1/150.2) • 100 = 79.96%
- %H = (14.11/150.2) • 100 = 9.394%
- %O = (16.00/150.2) • 100 = 10.65%

example

- you have:
  a 36-g sample = 28 g Fe, 8 g O
  a 160-g sample = 112 g Fe, 48 g O
- *are they the same substance?*
- CAN'T TELL FROM JUST LOOKING AT GRAMS!!!!
- BUT, if they have the same % comp… ta da!

- for the 36-g sample = 28 g Fe
- (28 g Fe / 36 g total) • 100 = 78% Fe
- for the 160-g sample = 112 g Fe
- (112 g Fe / 160 g total) • 100 = 70% Fe
- *Not the same!*

example

- #1: 45.0-g sample = 35.1 g Fe, 9.9 g O
- #2: 215.0-g sample = 167.7 g Fe, 47.3 g O
- *are they the same?*
- (35.1 g Fe / 45.0 g total) • 100 = 78% Fe
- (167.7 g Fe / 215.0 g total) • 100 = 78% Fe
- *they are the same!*
- (the oxygen percents will be the same, too)

example

- #1: 75.0-g sample = 20.5 g C, 54.5 g O
- #2: 135.0-g sample = 67.5 g C, 90.0 g O
- *are they the same?*
- (20.5 g C / 75.0 g total) • 100 = 27.3% C
- (67.5g C / 135.0 g total) • 100 = 50.0% C
- *they are not the same!*

6.6 formulas of compunds 6.7 calculation of empirical formulas

- smallest whole number ratio of a cmpd is *empirical formula*
- C_6H_6 : simplest formula = CH
- C_6H_{12} : simplest formula = CH_2
- C_3H_8 : simplest formula = C_3H_8
- $C_6H_{12}O_6$: simplest formula = CH_2O

- to determine the empirical formula you must find MOLE RATIOS of elements in a compound!!!
- the easy way?
- *just change % → g → mol*

example

- *36-g iron oxide sample is 78% iron. What is the emperical form? (remember: think moles)*
- 78% Fe → 78g Fe
- 22% O → 22g O
- 78g Fe →1.4 mol Fe
- 22g O → 1.4 mol O
- *1.4 mol Fe : 1.4 mol O is a 1:1 mol ratio*
- Therefore, FeO

example

- *27-g sulfur oxide sample has 50% S. What is the emp form?*
- 50% S → 50g S
- 50% O → 50g O
- 50g S → 1.56 mol S
- 50g O → 3.12 mol O
- *1.56 mol S : 3.12 mol O is a 1:2 mol ratio*
- Therefore, SO_2

- If the ratio isn't obvious, divide mol of each substance by the smallest number…(See Page 178)
- e.g. what if the ratio ends up being something weird like *0.195 Fe*:*0.291 O* ???
- 0.195 / 0.195 = 1
- 0.291 / 0.195 = 1.5
- This is a 1:1.5 ratio *which is really 2:3*
- therefore Fe_2O_3

example

- 18.94 g Al reacts with O to make 35.74 g aluminum oxide. what is the empirical formula? *(note: where is g O?)*
- 18.94 g Al ➔ 0.701 mol Al
- 16.80 g O ➔ 1.05 mol O
- 0.701 / 0.701 = 1 Al
- 1.05 / 0.701 = 1.5 O
- This is a 2:3 ratio, therefore Al_2O_3

6.8 calculation of molecular formulas

- molecular formula is the *real formula*
- Molec. Form.= *a multiple of emp form*
- molecular form = *empirical form* • *n*
- ***n*** = *molecular mass / empirical mass*

example

- The empirical formula for a cmpd is P_2O_5. The molecular mass is 283.88 g/mol. *What is the molecular formula?*
- emp mass = 141.94 g/mol
- divide 283.88 / 141.94 = **2**
- so, "multiply" P_2O_5 by two to get P_4O_{10}

big person example

- *In a 32.0-g sample of hydrazine, there are 28.0 g N and 4.0 g H. The molar mass is 32.0 g/mol. What is the molecular formula?*
- 1) find emp formula
  - 28.0 g N → 2.0 mol N
  - 4.0 g H → 4.0 mol H
  - Emp formula = NH_2
- 2) find molar mass ratios
  - molar mass (32.0) / emp mass (16.0) = 2
- 3) multiply by 2 to get formula = N_2H_4

big person example 2

- *An additive for gasoline is 71.65% Cl, 24.27% C, 4.07% H. The molar mass is 98.96 g/mol. What is the molecular formula?*
- 1) find emp formula
  - 71.65 % Cl → 71.65 g Cl → 2.021 mol Cl
  - 24.27 % C → 24.27 g C → 2.021 mol C
  - 4.07 % H → 4.07 g H → 4.04 mol H
  - Emp formula = $ClCH_2$
- 2) find molar mass ratios
  - molar mass (98.96) / emp mass (49.48) = 2
- 3) multiply by 2 to get formula = $Cl_2C_2H_4$