Ch07

Counting Atoms

The weight of 6.022×10^{23} singles

The chemists dozen.

version 1.5

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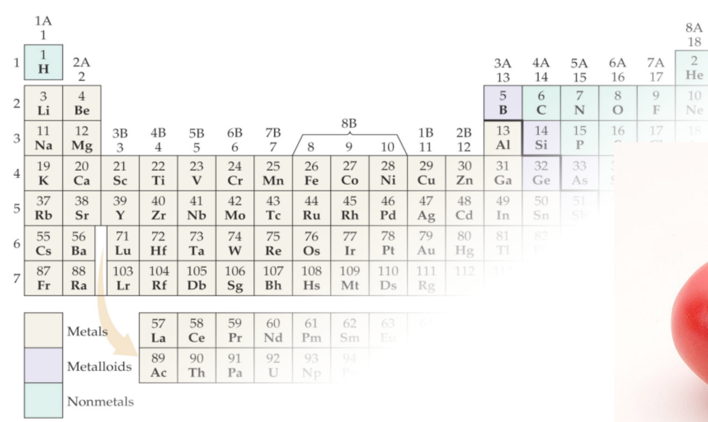
- Counting by Weight
  - Counting Coins (constant weight)
  - Counting Tomatoes (average weight)
  - Counting Atoms
    - The amu
    - Isotopes, Natural Abundance
- The Chemists Dozen, the Mole
  - Defining the Mole
    - scaling between amu and grams
    - calculations with mols
  - New Conversion Factors
    - Avogadro’s Number
    - Formula Weight
      - (aka Molecular Weight, Formula Mass)
    - Molar Weight (aka Molar Mass)
  - Mapping Problems
    - g ➞ mol ; atoms ➞ mol ; g ➞ atoms
- Using Chemical Formula
  - Moles of Molecules
  - Moles of Atoms
    - Formulas as conversion factors
  - Molar Mass of Compounds

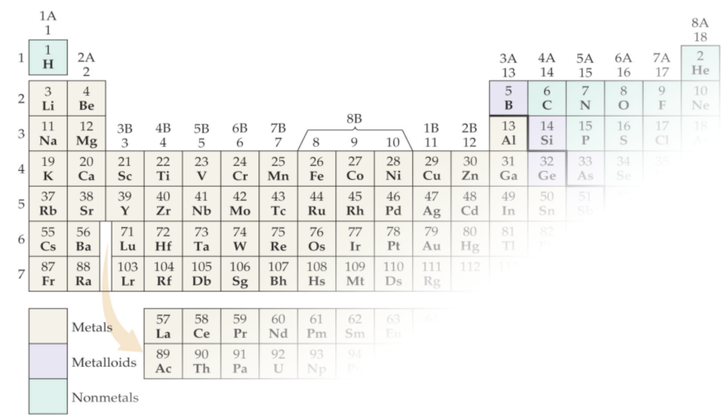
$^{63}_{29}Cu$

$^{65}_{29}Cu$



Counting by Weight

- A banker doesn't count pennies.
    - He know's how much a penny weighs. If you give him a bag of pennies he will weigh the bag, divide it by a pennies weight and tell you the bags value.

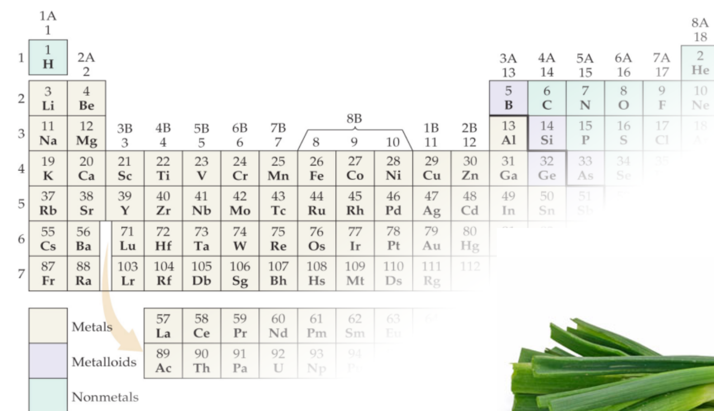


$$508\,g \times \frac{1\ \text{Penny}}{2.50\,g} = 203.2\ \text{Pennies}$$

$$\boxed{203\ \text{Pennies}}$$

Counting by Weight

- A banker doesn't count pennies.
  - He know's how much a penny weighs. If you give him a bag of pennies he will weigh the bag, divide it by a pennies weight and tell you the bags value.
- A banquet chef does the same.
  - If a recipe calls for 2 tomatoes per serving, he won't count out tomatoes to feed a thousand folks, he'll calculate the weight of 2,000 tomatoes and put baskets of them on the scale until he gets that weight.
  - But tomatoes don't have a single weight, like pennies do.
  - They come in different sizes.
  - So the chef needs to know the average weight of his tomatoes.



Weighted Averages

- How do you find the average mass of a tomato?
- If you have two tomatoes, you add their mass and divide by the number of tomatoes.

200 grams

100 grams

$$\frac{200g + 100g}{2} = 150g$$

$$\frac{200g + 200g + 100g + 100g + 100g + 100g + 100g + 100g + 100g + 100g}{10} = 120g$$

Weighted Averages

- How do you find the average mass of a tomato?
- If you have two tomatoes, you add their mass and divide by the number of tomatoes.

200 grams

100 grams

$$\frac{200g + 100g}{2} = 150g$$

- If you have a lot of tomatoes, it might be easier to multiply the amount of tomatoes you have of each mass by that value rather than add them one at a time.
- The number of tomatoes at each mass over the total number of tomatoes is also the percent at each mass – if 8 of your 10 tomatoes is 100 grams, that's 80% of your tomatoes.

$$\frac{2 x 200g + 8 x 100g}{10}$$

$$= \frac{2}{10} x 200g + \frac{8}{10} x 100g$$

$$= 20\% \text{ of } 200g + 80\% \text{ of } 100g$$

$$= 0.20 \times 200g + 0.80 \times 100g$$

$$= 40g + 80g$$

$$= 120g$$

- If you have so many tomatoes you don't know the total number, you can take a sample of them and determine the percent that are 100 g and 200 g in your sample.
- As long as the sample is a good representation of the total, it produces the same average mass as if we added the mass of all the tomatoes and divided by the total.
- We weight the heavier value 80% because those tomatoes occur four times as often as the tomatoes we apply the 20% weighting factor to.
- We might not know how many tomatoes we have, but if we know 20% of them mass 200 g and 80% mass 100 g we know that if we pick up a random bucket of tomatoes the average mass for that bucket will be 120g each.

20% of 200g + 80% of 100g

$= 0.20 \times 200\text{g} + 0.80 \times 100\text{g}$

$= 40\text{g} + 80\text{g}$

$= 120\text{g}$

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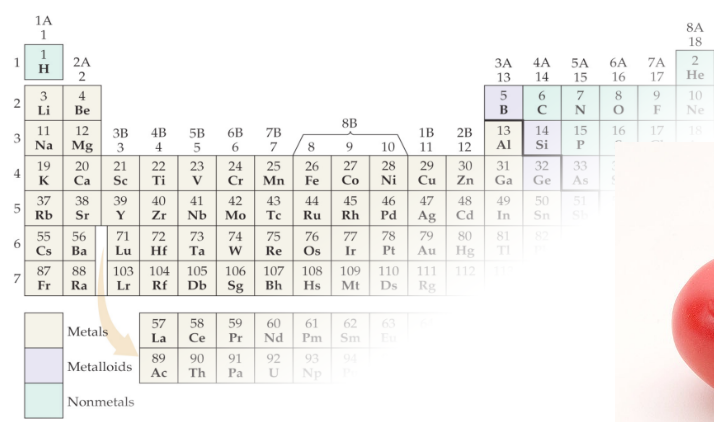

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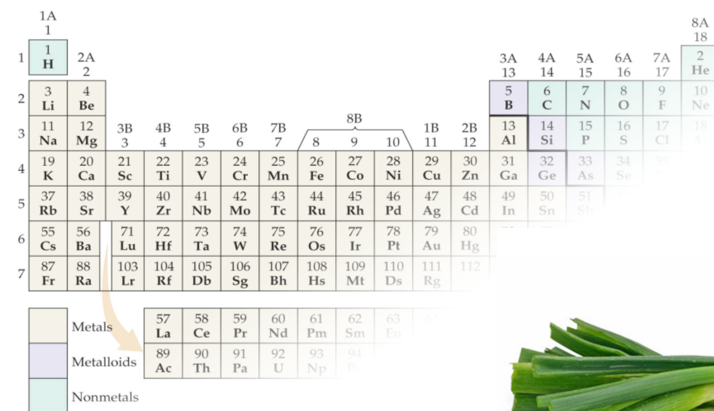
- A banquet chef does the same.
  - If a recipe calls for 2 scallions per serving, he won't count out scallions to feed a thousand folks, he'll calculate the weight of 2,000 scallions and put baskets of them on the scale until he gets that weight.
- Chemists are in the same boat.
  - Our recipe calls for 2 atoms of hydrogen and 1 of oxygen per serving, to make water. But we need 10^{23} servings to fill a thimble with water.
  - Just like a banker needs to know the weights of quarters and pennies, we need to know the weights of carbon atoms, nitrogen atoms, and hydrogen atoms. We need the weights of our elements.

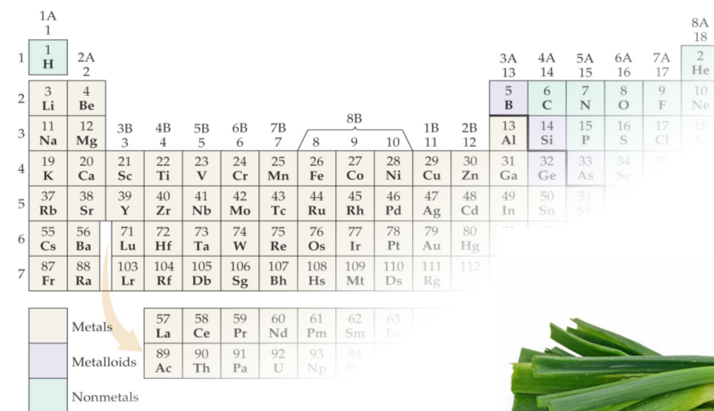


Counting by Weight

- Every flavor atom is made of neutrons & protons.
    - It’s convenient when we’re working on a molecular scale to have a unit of weight about the size of a neutron or proton.
    - We call that unit amu (atomic mass unit).
    - Most interesting molecules are made of carbon.
    - The most common isotope of carbon is made almost entirely of 6 protons and 6 neutrons.
    - An amu is defined as:

        exactly $\frac{1}{12}$ the mass of Carbon-12

    - 1 amu is measured to be 1.6606 x 10^{-24} g.
        - ➡ (you don’t need to memorize this)
- A chef weighing tomatoes doesn’t use the weight of the largest tomato or the smallest. He uses the average weight of a tomato.
- Not all carbon atoms weigh the same, if we’re weighing out carbon atoms we want to use average weight of a carbon atom.
- How do we get the average weight?



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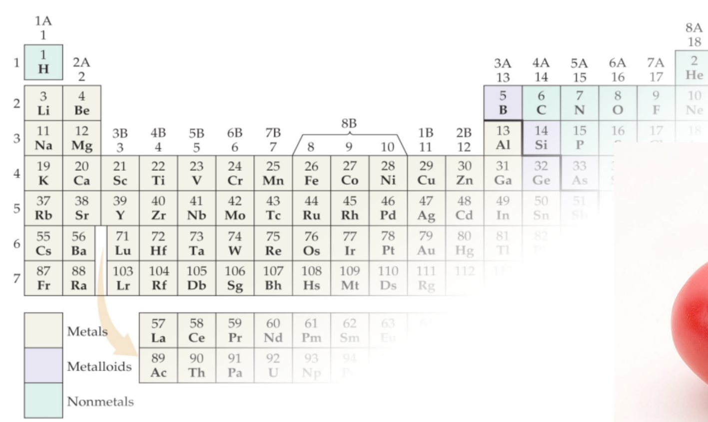


Average Atomic Mass

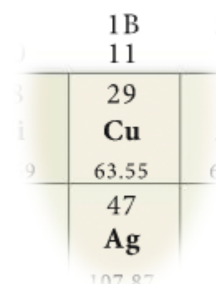
- The periodic table only reports one mass for each element, how does that work if each element has isotopes of different masses?
- The ratio of naturally occurring isotopes of each element is known.
- Every time we pour out a sample of copper, we know 69% of it's atoms are copper-63 and 31% are copper-65.
- Everytime.
- So we don't care what the mass of each isotope is, just what the mass – on average – of a copper atom.
- The periodic table represents an average atomic mass for that element.

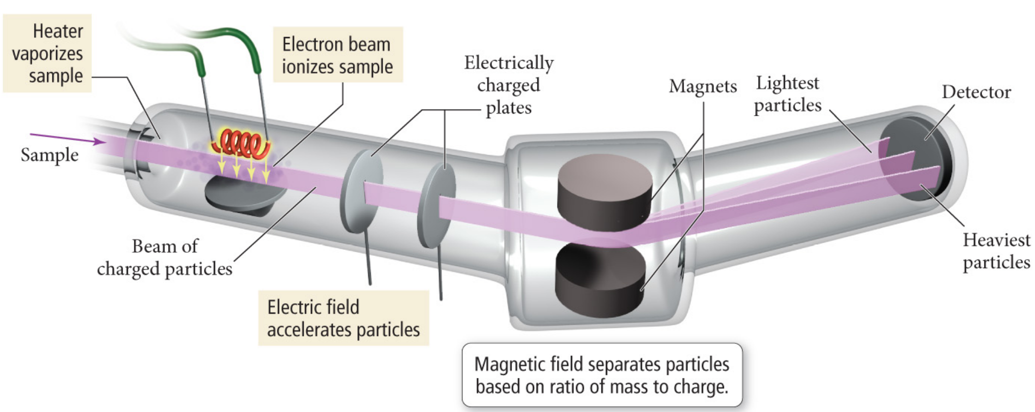
Isotope	Isotopic mass (amu)	Abundance (%)	Average atomic mass (amu)
$^{63}_{29}Cu$	62.9298	69.09	63.55
$^{65}_{29}Cu$	64.9278	30.91	

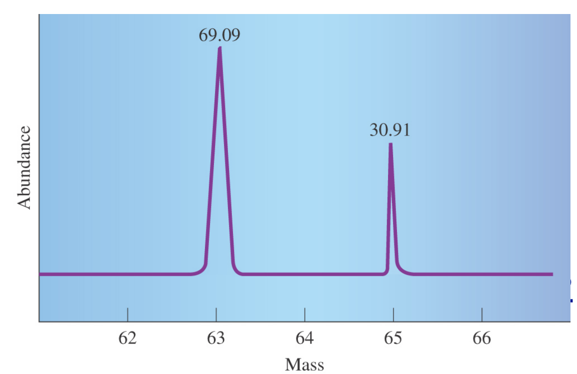
62.9298 amu × 0.6909 = 43.48 amu

64.9278 amu × 0.3091 = 20.07 amu

63.55 amu







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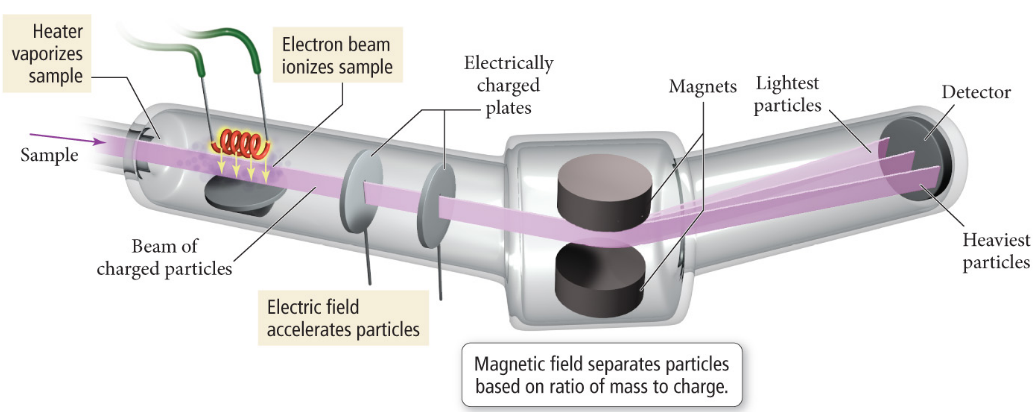
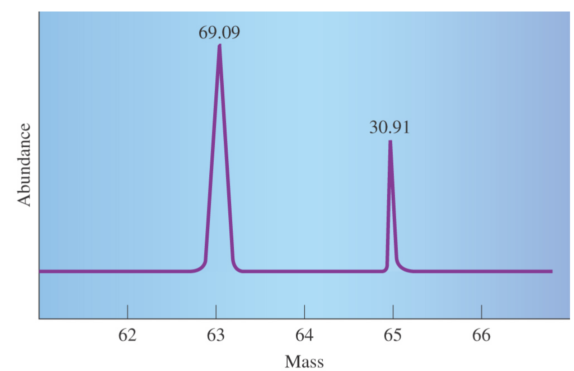
Period	1A[a] 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	8B 9	8B 10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1	1 H 1.008																	2 He 4.003
2	3 Li 6.94	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc [98]	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
6	55 Cs 132.91	56 Ba 137.33	57 La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po [208.98]	85 At [209.99]	86 Rn [222.02]
7	87 Fr [223.02]	88 Ra [226.03]	89 Ac [227.03]	104 Rf [261.11]	105 Db [262.11]	106 Sg [266.12]	107 Bh [264.12]	108 Hs [269.13]	109 Mt [268.14]	110 Ds [271]	111 Rg [272]	112 Cn [285]	113	114 Fl [289]	115	116 Lv [292]	117*	118

58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm [145]	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97
90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np [237.05]	94 Pu [244.06]	95 Am [243.06]	96 Cm [247.07]	97 Bk [247.07]	98 Cf [251.08]	99 Es [252.08]	100 Fm [257.10]	101 Md [258.10]	102 No [259.10]	103 Lr [262.11]

1B 11
29 Cu 63.55
47 Ag





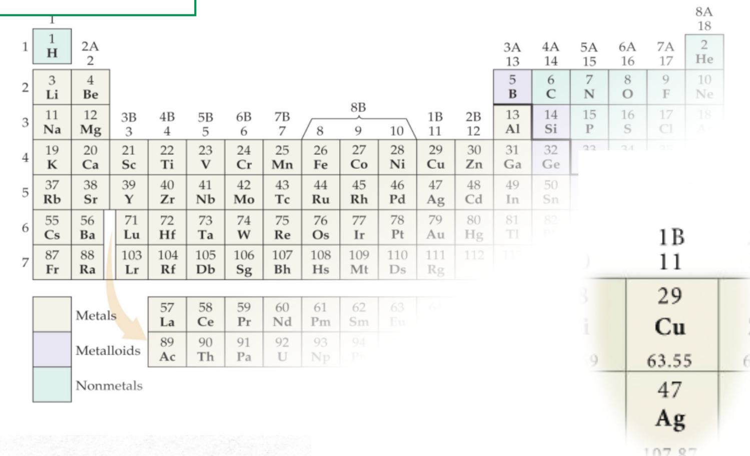
Average Atomic Mass

Important:
This is about 63½ protons. No copper atom has ever weighed this.
Protons don't come in ½'s. This is an **average** weight.

1 Cu = 63.55 amu

What's the average weight of a copper atom?

$$1\ Cu \times \frac{63.55\ amu}{1\ Cu} = 63.55\ amu$$



What's the weight of 17 copper atoms?

$$17\ Cu \cdot \frac{63.55\ amu}{1\ Cu} = 1{,}080.35\ amu$$

(counting # ∞ s.f.) 4 s.f. = 1,080 amu

1080. amu
or
1.080×10^3 amu

How many copper atoms in two pennies?

(a penny weighs about 3.0 grams, an amu = 1.6606×10^{-24} g)

penny → g → amu → atoms

$$2\ penny \cdot \frac{3.0\ g}{1\ penny} \cdot \frac{1\ amu}{1.6606\times10^{-24}\ g} \cdot \frac{1\ Cu}{63.55\ amu} = 5.68553\times10^{22}$$

(counting # ∞ sf.) 2 sf. 5 sf. 4 s.f.

5.7×10^{22} copper atoms

Problems:
- we need a ratio of atoms for our recipes (ie H_2O)
- in the lab we want to use grams
- we don't want to have to convert to amu every time we need to count atoms
- and $x10^{24}$ is awkward number to work with anyway.

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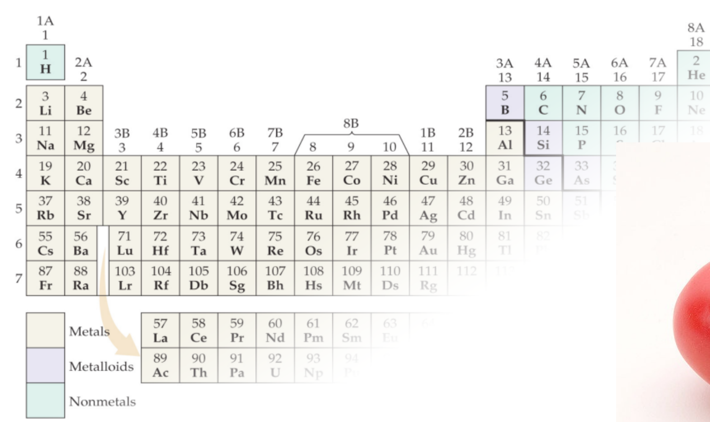
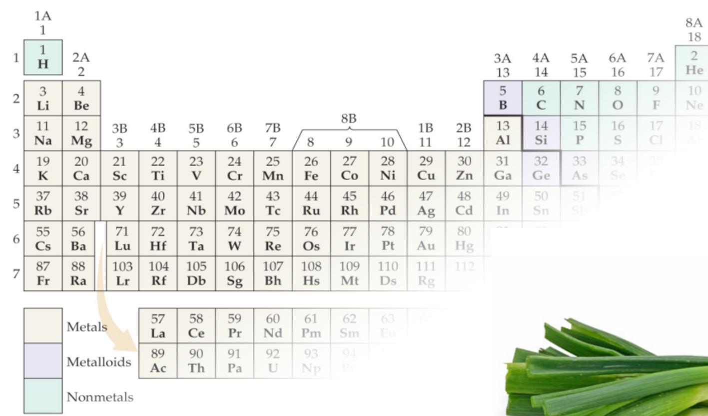


The Chemist's Dozen

- A recipe doesn't always list ingredients by single servings. Sometimes it uses dozens, score, or gross.
- When you're cooking for large groups, your recipe might call for 4 dozen eggs or 6 gross of dumplings.
    - 1 dozen = 12 singles
    - 1 score = 20 singles
    - 1 gross = 144 singles
- Working with dozens instead of singles let's a chef prepare on a scale 12x his design scale.
- We need a chemists dozen.
- We need to go from amu things (1 amu = 1.6606×10^{-24} g) to gram things (lab scale).
    - 1 gram ÷ 1 amu (in grams) = 6.022×10^{23}
    - 1 gram ÷ 1.661×10^{-24} grams = 6.022×10^{23}
- We call 6.022×10^{23} singles a mole.
- It's the chemists dozen. We abbreviate mole as mol.
- A mol is a measurement, we will determine it to 4 sig figs and use it with 4 sig figs for most of this class.
- The number of singles in a mol is called Avogadro's Number.
- A mol is officially defined as the number of Carbon-12 atoms in 12 grams of pure Carbon-12 (you get the same number)

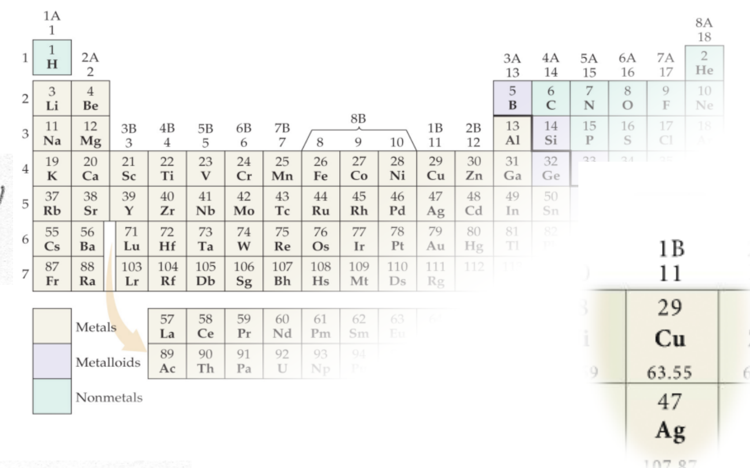
the tool for going between molecular scale (amu) and lab scale (grams).



The Chemist's Dozen

1 mol = 6.022 x 10^{23} singles

How many atoms in exactly 1 mol Copper (Cu)?



$$\text{exactly } 1 \text{ mol Cu} \cdot \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = \boxed{6.022 \times 10^{23} \text{ atoms Cu}}$$

How many atoms in 2.53 mol Copper (Cu)?

$$2.53 \text{ mol Cu} \cdot \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = 1.52357 \times 10^{24} \text{ atoms Cu}$$

$$\boxed{1.52 \times 10^{24} \text{ atoms Cu}}$$

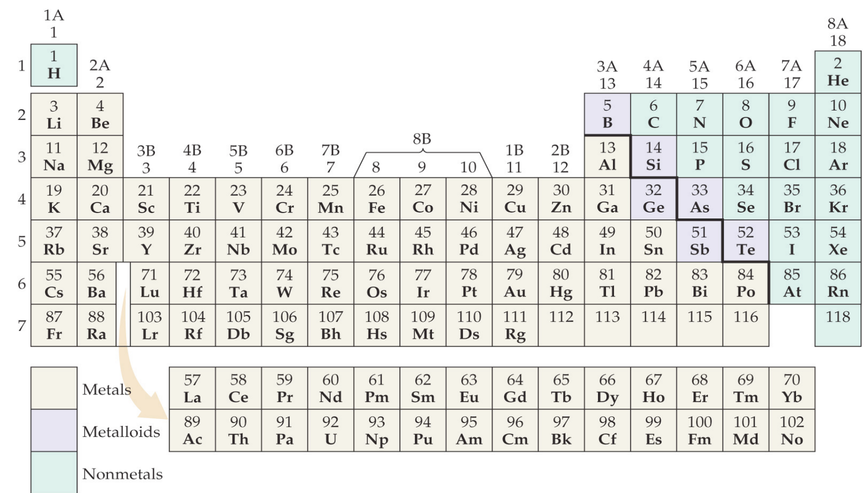
How many mol Cu in 30.5 grams Cu?

g → amu → atoms → mol   Theres an easier way!

How many Cu atoms in 30.5 grams Cu?

Atomic Weights / Molar Weights

- Weights are listed in the periodic table without units.
- The weight listed is the average mass of one atom of each element, in amu.



- $1 \text{ gram} \div 1.6606 \times 10^{-24} \text{ grams} = 6.022 \times 10^{23}$

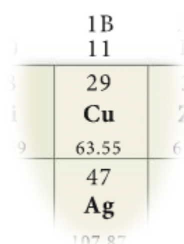
  $1 \text{ gram} \div 1 \text{ amu} = 1 \text{ mol}$

  $1 \text{ gram} = 1 \text{ mol} \times 1 \text{ amu}$

- That means:

1 mol of *anything* will weigh in grams,
what a single of that *anything* weighs in amu.

- If a cat weighs X amu, a mol of cats weighs X grams.
- That means each weight in the periodic table is:
  - the weight of 1 atom of that element, in amu
  - the weight of 1 mol of that element, in grams
- Reading from the periodic table...
  - a hydrogen atom (H) weighs 1.008 amu
  - a mol of hydrogen atoms (H) weigh 1.008 g
  - a copper atom (Cu) weighs 63.55 amu
  - a mol of copper atoms (Cu) weighs 63.55 g



1 H = 1.008 amu

1 mol H = 1.008 g

1 Cu = 63.55 amu

1 mol Cu = 63.55 g

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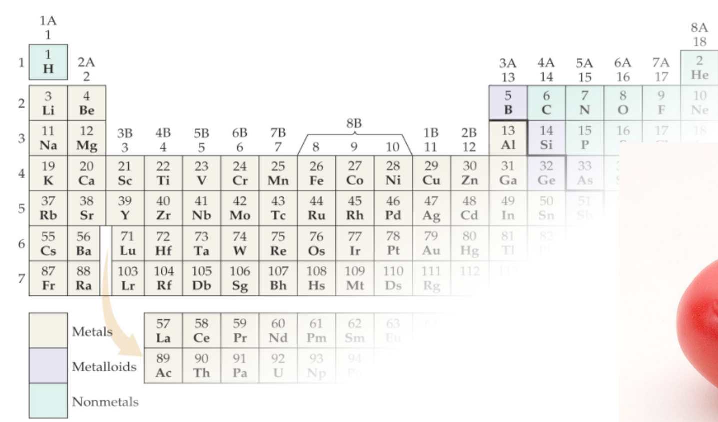
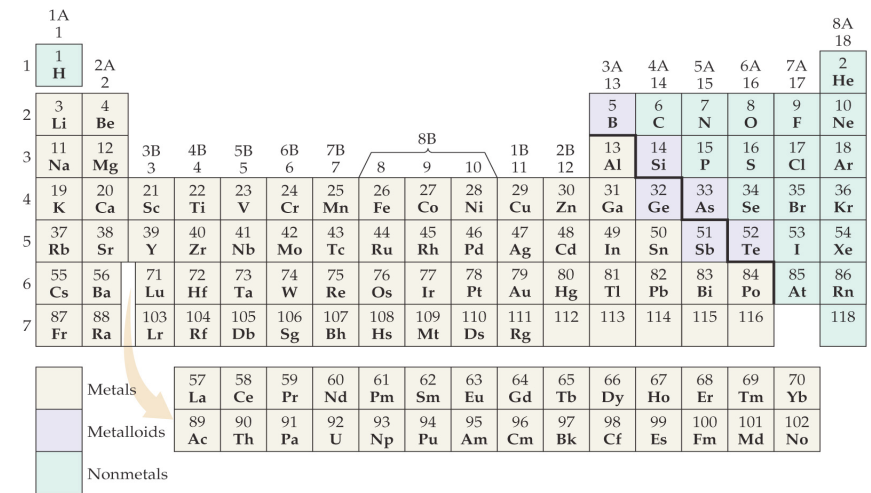


New Conversion Factors

You are responsible for these conversion factors, a periodic table will be provided.



Avogadro's Number

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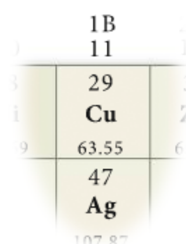
Atomic Mass

1 copper atom = 63.55 amu



Molar Mass

1 mol copper atoms = 63.55 grams

Atomic Mass & Avogadro's Number

Elements like Copper (Cu)

- Two important conversion factors:
  - Molar Mass/Atomic Mass
    (the **average** mass of atoms of that elements)
    - We get this from the periodic table
    - It tell's us the weight of:
      - 1 mol of a substance (in grams)
      - 1 atom of a substance (in amu)

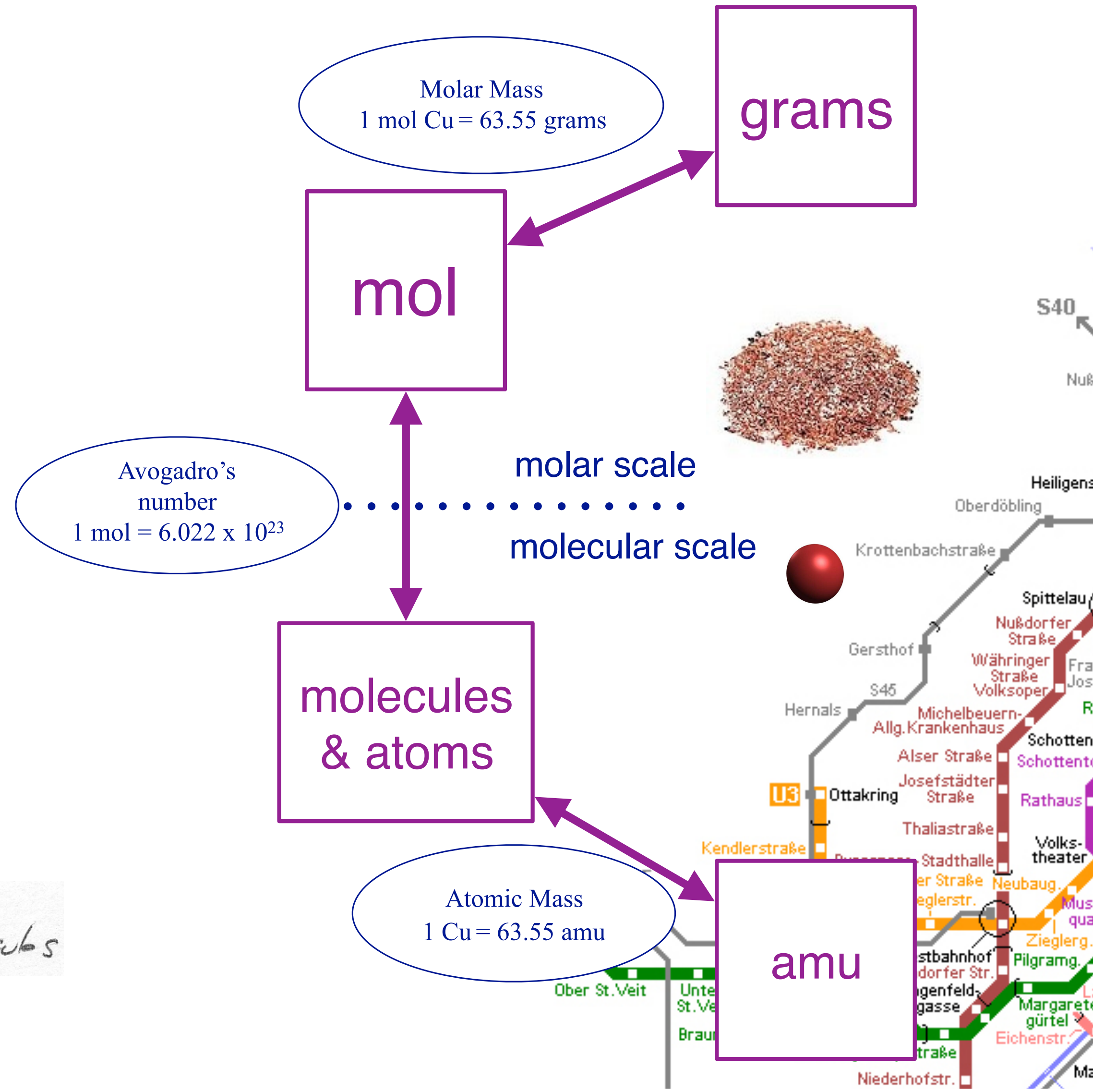
grams → mol

$$16.5\,g\,Cu \cdot \frac{1\,mol}{63.55\,g} = 0.260\,mol\,Cu$$

  - Avogadro's Number
    - 6.022 x 1023
      - It's a measurement
      - You have to memorize it
    - It let's us go from the moles to molecules or atoms

mol → molecules

$$0.260\,mol\,Cu \cdot \frac{6.022 \times 10^{23}}{1\,mol} = 1.56 \times 10^{23}\,molecules$$



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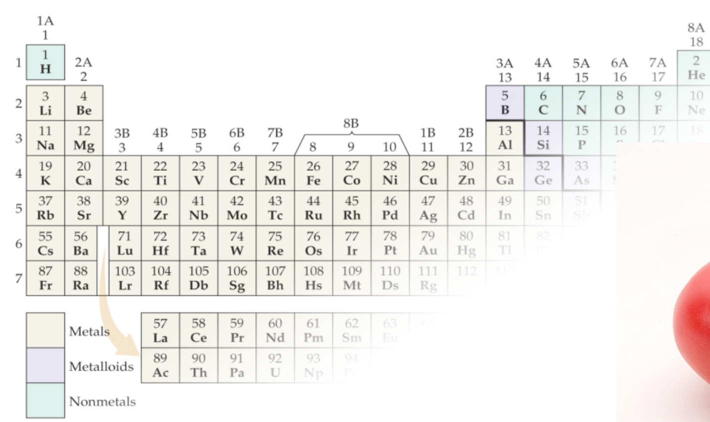

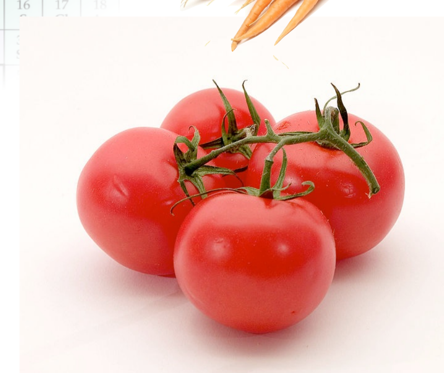

Counting by Weight

1 mol = 6.022×10^{23} singles

How many atoms in exactly 1 mol Copper (Cu)?

exactly 1 mol Cu $\cdot \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = \boxed{6.022 \times 10^{23} \text{ atoms Cu}}$

1 Cu = 63.55 amu

1 mol Cu = 63.55 g

How many atoms in 2.53 mol Copper (Cu)?

2.53 mol Cu $\cdot \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = 1.52357 \times 10^{24}$ atoms Cu

$\boxed{1.52 \times 10^{24} \text{ atoms Cu}}$

How many mol Cu in 30.5 grams Cu?

g → mol

30.5 g Cu $\cdot \frac{1 \text{ mol}}{63.55 \text{ g}} = 4.79937 \times 10^{-1}$ mol Cu

3 sf　　4 sf.

$\boxed{0.480 \text{ mol Cu}}$

How many Cu atoms in 30.5 grams Cu?

g → mol → atoms

30.5 g Cu $\cdot \frac{1 \text{ mol}}{63.55 \text{ g}} \cdot \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = 2.8901809 \times 10^{23}$ atoms

3 sf　　4 sf.　　4 sf.

$\boxed{2.89 \times 10^{23} \text{ atoms Cu}}$

How many atoms?

A gold ring weighs 1.24 grams. How many atoms of gold are in it?

g → mol → atoms

199.97 g/mol

$6.022 \times 10^{23} \frac{\text{single atoms}}{\text{mol atoms}}$

$$1 \text{ ring} \cdot \frac{1.24 \text{ g}}{1 \text{ ring}} \times \frac{1 \text{ mol}}{199.97 \text{ g}} \times \frac{6.022 \times 10^{23}}{1 \text{ mol}}$$

$$= 3.73 \times 10^{21} \text{ atoms}$$

How many grams?

An experiment calls for 4.3 mols of Calcium atoms, how many grams of pure calcium should you weigh out?

mols → g

Ca 40.08 g/mol

$4.3 \text{ mol Ca} \cdot \frac{40.08 \text{ g}}{1 \text{ mol}} = 172.344 \text{ g}$

170 g Ca

Weight of 4 atoms?

A phosphorus molecule is composed of 4 atoms of phosphorus. What is it's weight in AMUs?

atoms → amu

P $30.97 \frac{\text{amu}}{\text{atom}}$

$$4 \text{ atoms P} \cdot \frac{30.97 \text{ amu}}{1 \text{ atom}} = 123.88 \text{ amu}$$

123.9 amu

Ch07

Counting Atoms

- Counting by Weight
  - Counting Coins (constant weight)
  - Counting Tomatoes (average weight)
  - Counting Atoms
    - The amu
    - Isotopes, Natural Abundance
- The Chemists Dozen, the Mole
  - Defining the Mole
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  - New Conversion Factors
    - Avogadro's Number
    - Formula Weight
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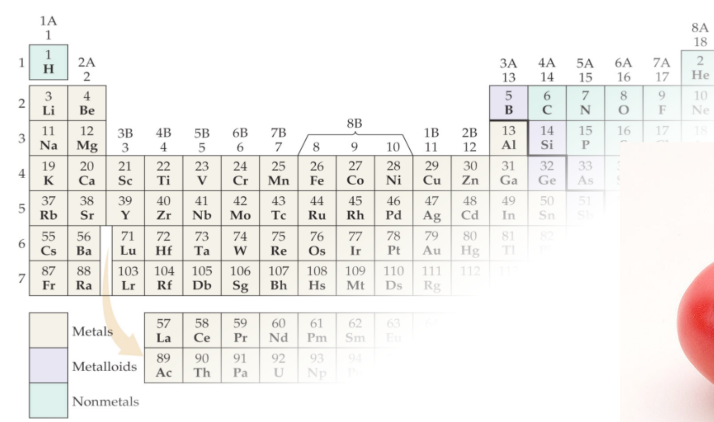
    - Molar Weight (aka Molar Mass)
  - Mapping Problems
    - g → mol ; atoms → mol ; g → atoms

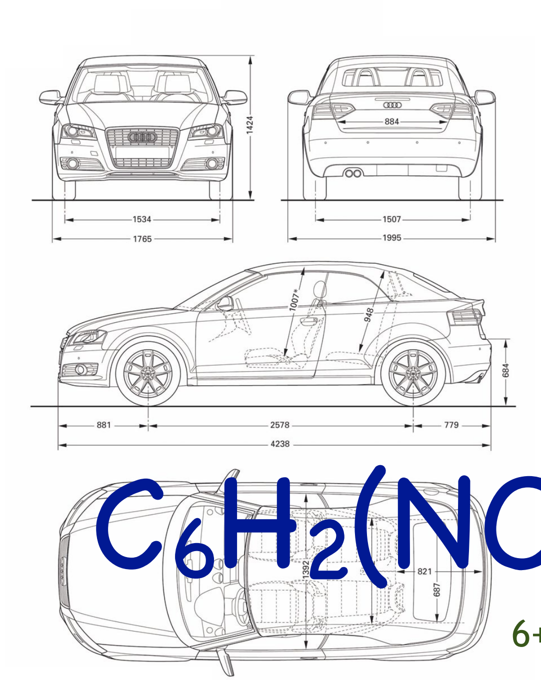
- Using Chemical Formula
  - Moles of Molecules
  - Moles of Atoms
    - Formulas as conversion factors
  - Molar Mass of Compounds

$^{63}_{29}Cu$

$^{65}_{29}Cu$



The Molecular Blueprint



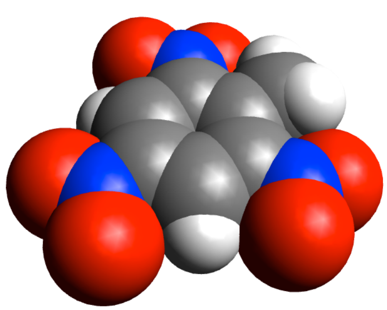
$C_6H_2(NO_2)_3CH_3$

6+1 Carbon Atoms

2+3 Hydrogen Atoms

3 NO_2 Groups

- 3 (3x1) Nitrogen Atoms
- 6 (3x2) Oxygen Atoms



- Chemical Formulas Identify Compounds
  - We use them as shorthand to name of a substance ("Pass me the H_2O")
- Chemical Formulas indicate the composition of a substance.
  - Each element is indicated with it's symbol.
  - The a subscript indicates the total number of atoms of that element.
    - Subscripts of 1 are omitted.
    - Omitted subscripts mean 1.
  - Parenthesis are used to indicate groups of atoms.
- Chemical Formulas may contain hints of the connectivity of the atoms.
- Chemical Formulas may show a CH_3 group of atoms and three NO_2 groups of atoms are bonded to a C_6H_2 group by writing:

$C_6H_2(NO_2)_3CH_3$

instead of: $C_7H_5N_3O_6$

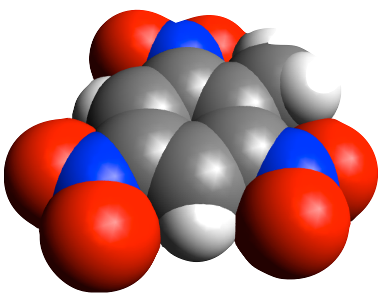
Problem:

You have 2.85 mols of $C_6H_2(NO_2)_3CH_3$ (trinitrotoluene). How many atoms of oxygen do you have?

Solution

mol TNT → molecules TNT → atoms O

6.022×10^{23} singles = 1 mol



1 $C_6H_2(NO_2)_3CH_3$ = 6 O

$$2.85 \text{ mol TNT} \cdot \frac{6.022 \times 10^{23} \text{ molecules}}{1 \text{ mol}} \cdot \frac{6 \text{ oxygen atoms}}{1 \text{ molecule TNT}}$$

$$= 1.029762 \times 10^{25} \text{ atoms}$$

$$= \boxed{1.03 \times 10^{25} \text{ atoms O}}$$

Molecular Weight/Molar Mass

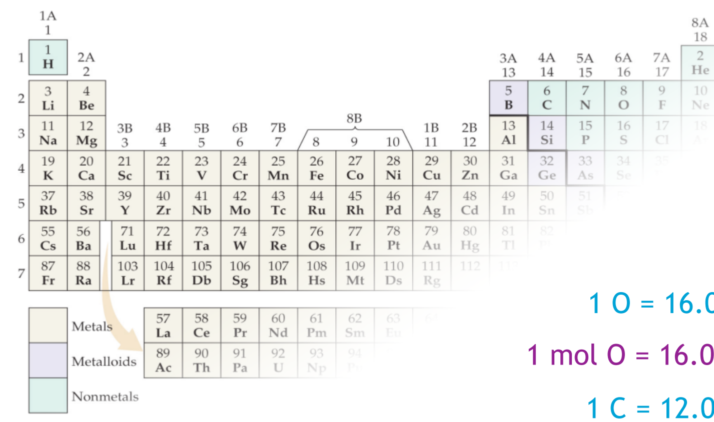
- Molar Mass also applies to molecules and compounds.
- We know the atomic weight of elements, what one atoms weighs in amu and what one mole of atoms weigh in grams.
- We can use that information to figure out for compounds what one molecule weighs or one mole of molecules weigh.

What is the molecular weight of CO_2? (in amu)

1 C atom	12.01 amu	
2 O atom	32.00 amu	(2 × 16.00 amu)
1 CO_2 =	44.01 amu	

What is the molar mass of CO_2? (in grams)

1 mol C	12.01 grams	
2 mol O	32.00 grams	(2 × 16.00 g)
1 mol CO_2 =	44.01 grams	

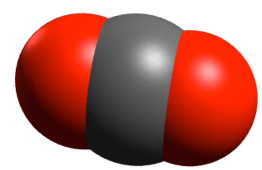


1 O = 16.00 amu

1 mol O = 16.00 g

1 C = 12.01 amu

1 mol C = 12.01 g



What does 2.57 mol of CO_2 weigh?

$$2.57 \text{ mol } CO_2 \cdot \frac{44.01\text{ g}}{1 \text{ mol } CO_2} = 113.1057\text{ g}$$

3 sf. 4 sf. 113 g CO_2 (3 sf.)

How many moles of CO_2 are in 53.256 grams?

$$53.256\text{ g } CO_2 \cdot \frac{1 \text{ mol } CO_2}{44.01\text{ g}} = 1.2100886 \text{ mol}$$

5 sf. 4 sf. 1.210 mol CO_2 (4 sf)

Molecular Formula & Molar Mass

Molecules like Water (H_2O)

- Two more conversion factors.
  - Molecular Formula (& Empirical Formula)
    - It let's us understand the composition of molecules.
    - We can use it as a conversion factor to go from molecules to how many atoms of any kind are in that molecule.

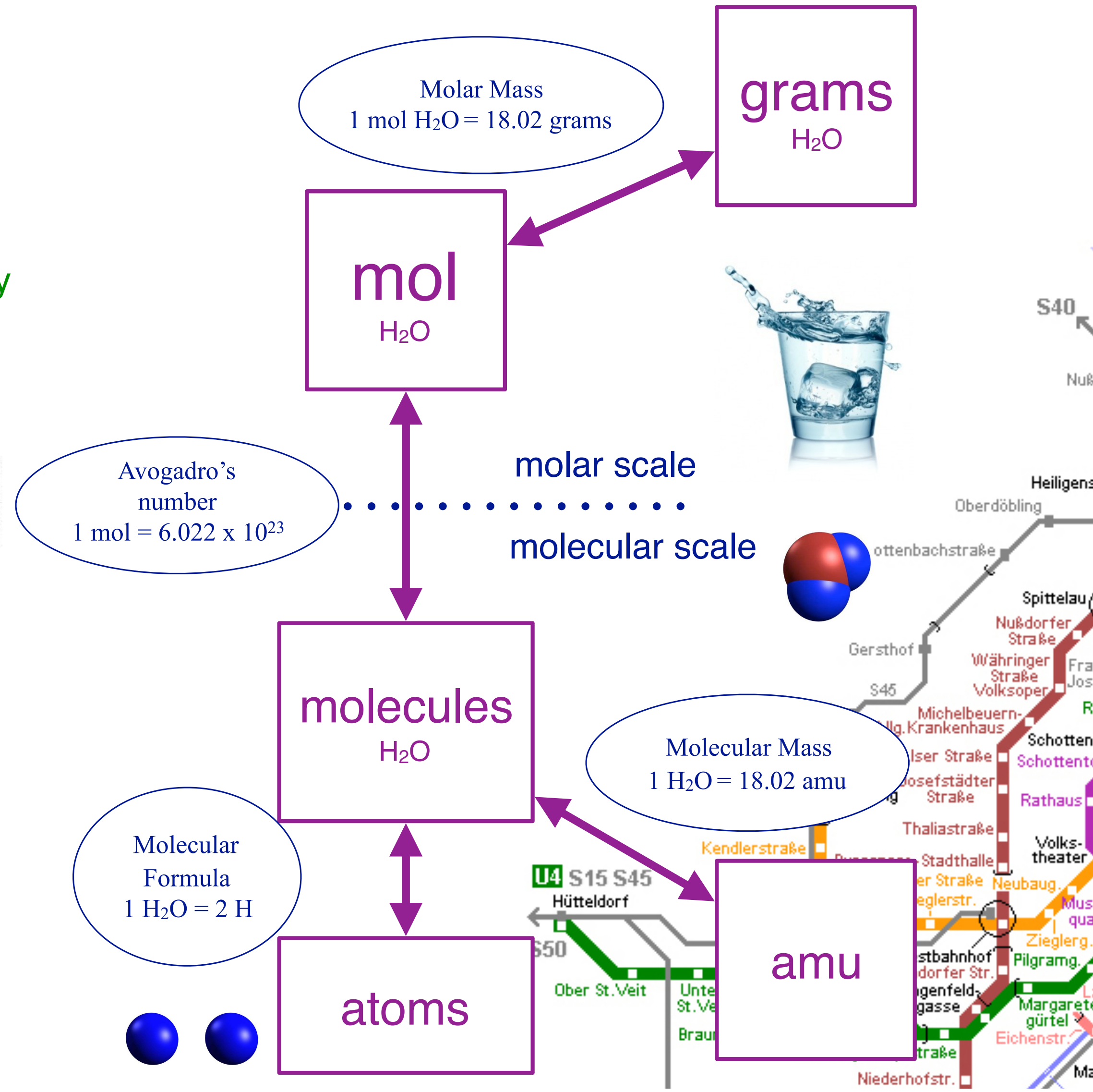
molecules H_2O → atoms H

$$725 \text{ molecules } H_2O \cdot \frac{2\,H}{1\,H_2O} = 1{,}450 \text{ atoms } H$$

  - Molar Mass/Molecular Mass
    - It relates weight to mols for whole molecules.

mol → grams

$$2.5 \text{ mol } H_2O \cdot \frac{18.02\text{ g}}{1\text{ mol}} = 45.05\text{ g } H_2O$$



Problem:

Your experiment requires 4.26 mols of magnesium chloride ($MgCl_2$). What mass of magnesium chloride do you weigh out for this experiment?

Solution

① Find molar mass of CO_2.

② mol → g

C 12.01 g/mol

O 16.00 g/mol

①
$$1(C) = 1(12.01) = 12.01$$
$$2(O) = 2(16.00) = 32.00$$
$$+ \quad 44.01 \text{ g/mol}$$

②
$$3.4 \text{ mol } CO_2 \cdot \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2} = 149.634 \text{ g } CO_2$$

150 g CO_2

Problem:

Your experiment requires 4.26 mols of magnesium chloride ($MgCl_2$). What mass of magnesium chloride do you weigh out for this experiment?

Solution

① Find molar mass of $MgCl_2$

② mol → g

Mg 24.31 g/mol

Cl 35.45 g/mol

① $1(Mg) = 1(24.31) = 24.31\ g$

$2(Cl) = 2(35.45) = 70.90\ g$

$95.21\ g$

$MgCl_2$ 95.21 g/mol

② $4.26\ mol\ MgCl_2 \cdot \frac{95.21\ g}{1\ mol} = 405.5946\ g$

406 g $MgCl_2$

Problem:

You do an experiment that produces 15.35 grams of nitrogen trioxide (NO_3).

How many moles of NO_3 were produced?

Solution

① Find molar mass of NO_3

② g → mol

N = 14.01 g/mol

O = 16.00 g/mol

① 1 (N) = 1 (14.01) = 14.01 g

3 (O) = 3 (16.00) = 48.00 g

62.01 g

NO_3 62.01 g/mol

② $15.35\,g\ NO_2 \cdot \frac{1\,mol}{62.01\,g} = 0.2475407\,g$

$= \boxed{0.2475\,g}$

Ch07

Counting Atoms

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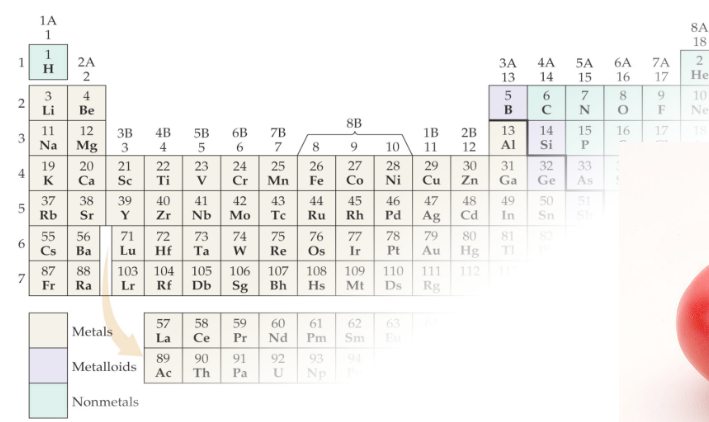
$^{63}_{29}Cu$

$^{65}_{29}Cu$



Questions?