

# **BERKELEY MATH CIRCLE**

## **The Math of Chemistry: Avogadro's Number, Moles & Molecules**

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# The Periodic Table

Elements are organized into the Periodic Table of Elements. They are organized into columns by their similarities in chemical properties:

**Periodic Table of the Elements**

1 IA 11A																	18 VIII A 8A
1 <b>H</b> Hydrogen 1.008																	2 <b>He</b> Helium 4.003
3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012											5 <b>B</b> Boron 10.811	6 <b>C</b> Carbon 12.011	7 <b>N</b> Nitrogen 14.007	8 <b>O</b> Oxygen 15.999	9 <b>F</b> Fluorine 18.998	10 <b>Ne</b> Neon 20.180
11 <b>Na</b> Sodium 22.990	12 <b>Mg</b> Magnesium 24.305	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 <b>Al</b> Aluminum 26.982	14 <b>Si</b> Silicon 28.086	15 <b>P</b> Phosphorus 30.974	16 <b>S</b> Sulfur 32.066	17 <b>Cl</b> Chlorine 35.453	18 <b>Ar</b> Argon 39.948
19 <b>K</b> Potassium 39.098	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.956	22 <b>Ti</b> Titanium 47.88	23 <b>V</b> Vanadium 50.942	24 <b>Cr</b> Chromium 51.996	25 <b>Mn</b> Manganese 54.938	26 <b>Fe</b> Iron 55.933	27 <b>Co</b> Cobalt 58.933	28 <b>Ni</b> Nickel 58.693	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.39	31 <b>Ga</b> Gallium 69.732	32 <b>Ge</b> Germanium 72.61	33 <b>As</b> Arsenic 74.922	34 <b>Se</b> Selenium 78.09	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 84.80
37 <b>Rb</b> Rubidium 84.468	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.906	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.906	42 <b>Mo</b> Molybdenum 95.94	43 <b>Tc</b> Technetium 98.907	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.906	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.868	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.760	52 <b>Te</b> Tellurium 127.6	53 <b>I</b> Iodine 126.904	54 <b>Xe</b> Xenon 131.29
55 <b>Cs</b> Cesium 132.905	56 <b>Ba</b> Barium 137.327	57-71	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.948	74 <b>W</b> Tungsten 183.85	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.22	78 <b>Pt</b> Platinum 195.08	79 <b>Au</b> Gold 196.967	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.383	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.980	84 <b>Po</b> Polonium [208.982]	85 <b>At</b> Astatine 209.987	86 <b>Rn</b> Radon 222.018
87 <b>Fr</b> Francium 223.020	88 <b>Ra</b> Radium 226.025	89-103	104 <b>Rf</b> Rutherfordium [261]	105 <b>Db</b> Dubnium [262]	106 <b>Sg</b> Seaborgium [266]	107 <b>Bh</b> Bohrium [264]	108 <b>Hs</b> Hassium [269]	109 <b>Mt</b> Meitnerium [268]	110 <b>Ds</b> Darmstadtium [269]	111 <b>Rg</b> Roentgenium [272]	112 <b>Cn</b> Copernicium [277]	113 <b>Uut</b> Ununtrium unknown	114 <b>F1</b> Flerovium [289]	115 <b>Uup</b> Ununpentium unknown	116 <b>Lv</b> Livermorium [298]	117 <b>Uus</b> Ununseptium unknown	118 <b>Uuo</b> Ununoctium unknown

57 <b>La</b> Lanthanum 138.906	58 <b>Ce</b> Cerium 140.115	59 <b>Pr</b> Praseodymium 140.908	60 <b>Nd</b> Neodymium 144.24	61 <b>Pm</b> Promethium 144.913	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.966	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.925	66 <b>Dy</b> Dysprosium 162.50	67 <b>Ho</b> Holmium 164.930	68 <b>Er</b> Erbium 167.26	69 <b>Tm</b> Thulium 168.934	70 <b>Yb</b> Ytterbium 173.04	71 <b>Lu</b> Lutetium 174.967
89 <b>Ac</b> Actinium 227.028	90 <b>Th</b> Thorium 232.038	91 <b>Pa</b> Protactinium 231.036	92 <b>U</b> Uranium 238.029	93 <b>Np</b> Neptunium 237.048	94 <b>Pu</b> Plutonium 244.064	95 <b>Am</b> Americium 243.061	96 <b>Cm</b> Curium 247.070	97 <b>Bk</b> Berkelium 247.070	98 <b>Cf</b> Californium 251.080	99 <b>Es</b> Einsteinium [254]	100 <b>Fm</b> Fermium 257.095	101 <b>Md</b> Mendelevium 258.1	102 <b>No</b> Nobelium 259.101	103 <b>Lr</b> Lawrencium [262]

Alkali Metal	Alkaline Earth	Transition Metal	Semimetal	Nonmetal	Basic Metal	Halogen	Noble Gas	Lanthanide	Actinide
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## FROM LAST SEMESTER:

*For each element, we can directly relate the amount of protons, electrons and neutrons that exist.  
But first, we need to learn some terms!*

### **Symbol of Element**

*1 or 2 letter abbreviation for each element*

### **Mass Number**

- Not always a whole number (more on this later!)*
- #protons + #neutrons*

### **Atomic Number**

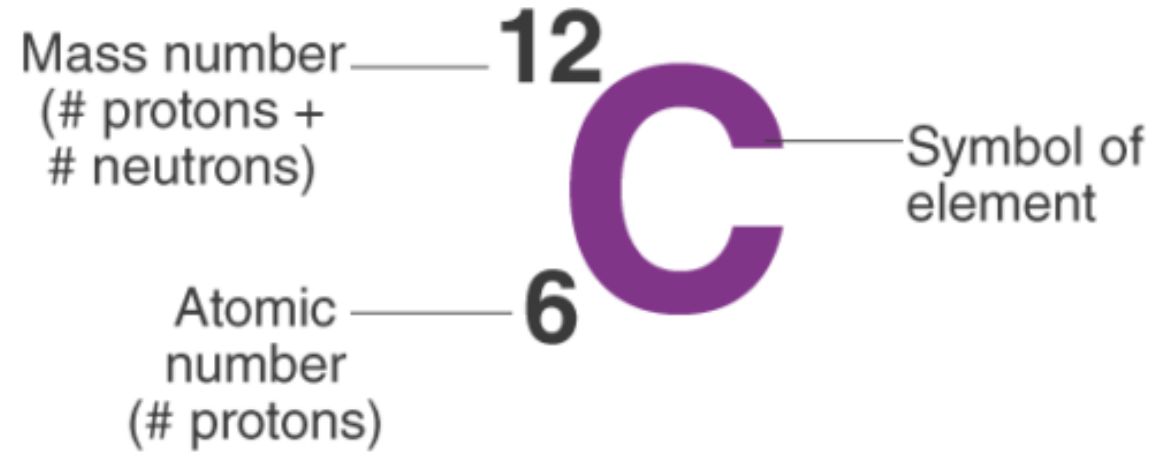
*#protons (defines the element!)*

*Thus,*

*# of protons = atomic number (defines the element!)*

*# of electrons = # of protons (if neutral)*

*# of neutrons = Mass Number - Atomic number*



When we think of atoms, we can't "see" them, but we can measure them. We call this a **microscopic** view. But what about a **macroscopic** view? What things can we see, and then also measure? How do we measure them?

For example:



Pencil = graphite = carbon = C



table salt = sodium chloride = NaCl



balloons = helium = He

If we measure our examples, how do we compare them? By weight? By mass?

Since all of these elements exist as whole atoms, the only way to compare/measure them on **equal standing** is by measure/counting **how many** of them exist. Their mass may be different, but the amount of them may be the same. In essence we, are counting how many particles of each element or molecule exist. Any guesses how many atoms in each of these? **A LOT!!!!**



Since we are dealing with very, very small objects, we need a way to count them in an easily digestible manner. Just like 1 dozen = 12, or 1 kilometer = 1000m, we need small, digestible values to represent INSANELY huge amounts.

We therefore welcome the concept of **Avogadro's Number** (NOT Avocado!)



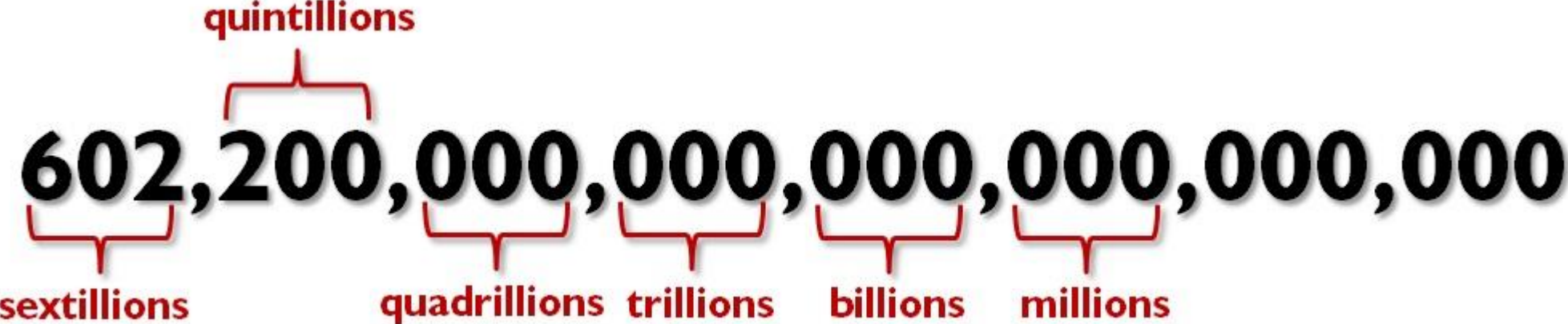
**Avogadro**  $\neq$  **Avocado**

Avogadro's number is  **$6.022 \times 10^{23}$** . That's a HUGE amount!

How huge? Well . . . . .

**602,200,000,000,000,000,000,000,000,000,000**

**602.2 Sextillion!**





What then, does this HUGE number represent?

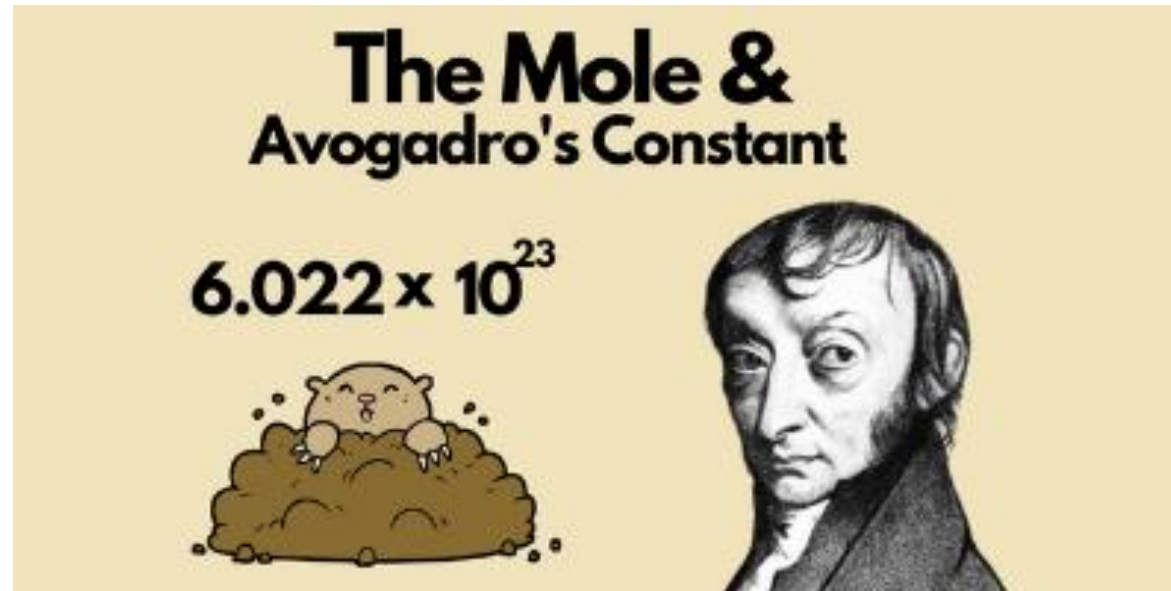
$6.022 \times 10^{23} = 1$  **mole** of things (atoms, particles, molecules)

Again, just like:

1 dozen = 12

1 kilo = 1000

1 mole =  $6.022 \times 10^{23}$





So, we've learned two new concepts:

## Avogadro's Number AND the Mole

How does all relate back to our microscopic and macroscopic view of things? From before:

*Since all of these elements exist as whole atoms, the only way to compare/measure them on **equal standing** is by measure/counting **how many** of them exist.*

So:

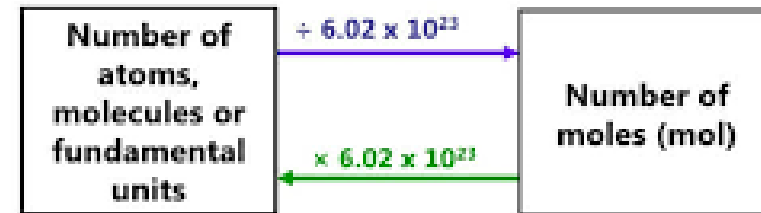
**1 mole of atoms = Avogadro's number of atoms**

**1 mole of atoms =  $6.022 \times 10^{23}$  atoms**

A mole is a unit of quantity.

A mole is  $6.02 \times 10^{23}$  things.

$6.02 \times 10^{23}$  is known as Avogadro's constant ( $N_A$ )



Again, from before:

*Their mass may be different, but the amount of them may be the same. In essence we, are counting how many particles of each element or molecule exist.*

We will relate all of this to mass soon, but first, let's play with scientific notation, powers of ten, and numbers of things!

# Math Fun!

To simplify, let's use  $6.02 \times 10^{23} = 1$  mole of things for Avogadro's Number. You DO NOT need a calculator ;)

1) I have 2 moles of carbon. How many atoms of carbon do I have?

$$\frac{2 \text{ moles Carbon}}{1} \times \frac{6.02 \times 10^{23} \text{ atoms of Carbon}}{1 \text{ mole of Carbon}} = 2 \times (6.02 \times 10^{23}) = 12.04 \times 10^{23} = \mathbf{1.204 \times 10^{24} \text{ atoms of carbon}}$$

2) I have 0.5 moles of salt (NaCl). How many molecules of salt do I have?

$$\frac{0.5 \text{ moles NaCl}}{1} \times \frac{6.02 \times 10^{23} \text{ molecules of NaCl}}{1 \text{ mole of NaCl}} = 1/2 \times (6.02 \times 10^{23}) = \mathbf{3.01 \times 10^{23} \text{ molecules of NaCl}}$$

3) I have 5 moles of water (H<sub>2</sub>O). How many molecules of water do I have?

$$\frac{5 \text{ moles H}_2\text{O}}{1} \times \frac{6.02 \times 10^{23} \text{ molecules of H}_2\text{O}}{1 \text{ mole of H}_2\text{O}} = 5 \times (6.02 \times 10^{23}) = 30.1 \times 10^{23} = \mathbf{3.01 \times 10^{24} \text{ molecules of H}_2\text{O}}$$

# More Math Fun!

To simplify, let's use  $6.02 \times 10^{23} = 1$  mole of things for Avogadro's Number. You DO NOT need a calculator ;)

1) I have  $2.408 \times 10^{28}$  atoms of Calcium (Ca). How many moles of Calcium do I have?

$$\frac{2.408 \times 10^{28} \text{ atoms of Calcium}}{1} \times \frac{1 \text{ mole of Calcium}}{6.02 \times 10^{23} \text{ atoms of Calcium}} = \frac{2.408 \times 10^{28}}{6.02 \times 10^{23}} = \frac{24.08 \times 10^{27}}{6.02 \times 10^{23}} = \mathbf{4 \times 10^4 \text{ moles Ca}}$$

2) I have  $3.01 \times 10^{20}$  molecules of carbon dioxide ( $\text{CO}_2$ ). How many moles of  $\text{CO}_2$  do I have?

$$\frac{3.01 \times 10^{20} \text{ molecules CO}_2}{1} \times \frac{1 \text{ mole of CO}_2}{6.02 \times 10^{23} \text{ atoms of CO}_2} = \frac{3.01 \times 10^{20}}{6.02 \times 10^{23}} = \frac{1 \times 10^{20}}{2 \times 10^{23}} = 0.5 \times 10^{-3} = \mathbf{5 \times 10^{-4} \text{ moles CO}_2}$$

I have  $1.806 \times 10^{25}$  particles of helium gas (He). How many moles of helium do I have?

$$\frac{1.806 \times 10^{25} \text{ particles He}}{1} \times \frac{1 \text{ mole of He}}{6.02 \times 10^{23} \text{ particles He}} = \frac{1.806 \times 10^{25}}{6.02 \times 10^{23}} = \frac{18.06 \times 10^{25}}{6.02 \times 10^{23}} = \mathbf{3 \times 10^2 \text{ particles He}}$$

BUT, how does this relate to what we see and measure in day-to-day life! From before, we had the objects below.  
Can we say?

“I have  $6.022 \times 10^{23}$  atoms of carbon in my pencil”

“Please pass me  $3.01 \times 10^{23}$  particles of salt”

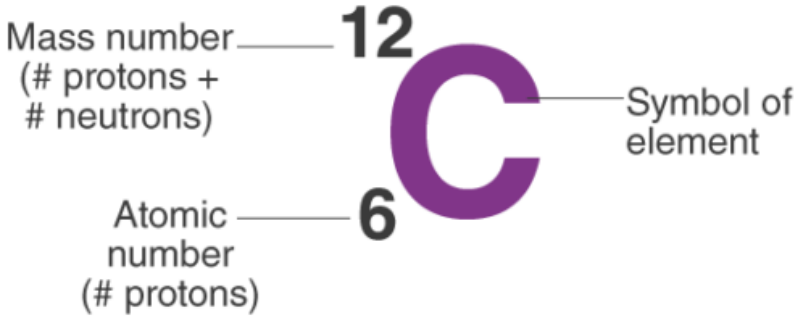
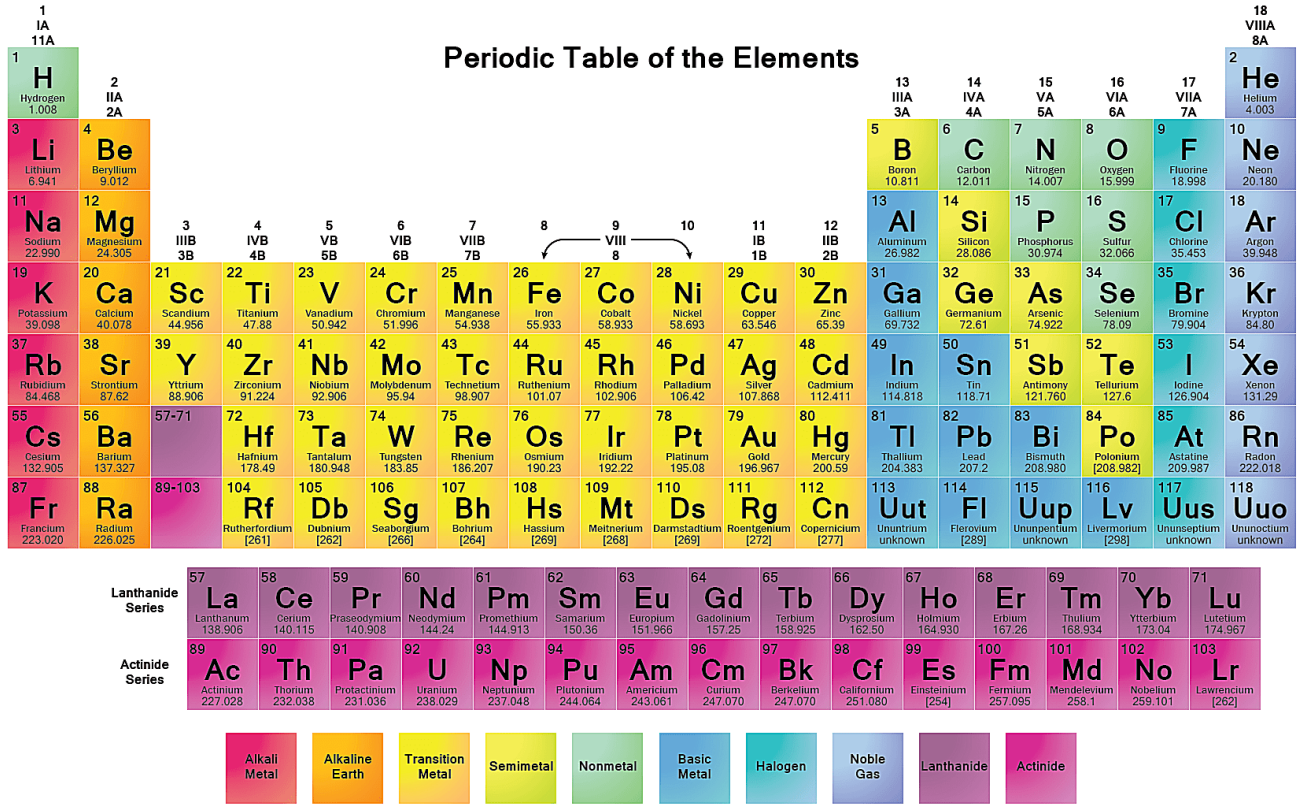
“May you fill my balloon with  $1.04 \times 10^{24}$  atoms of Helium?”

Of course not! **That’s ridiculous!**

We tend to measure things by their mass, and then relate them to how many of them exist (atoms, molecules, moles, etc.). So, we need to a way to do so . . . . .



Our good friend, **The Periodic Table of Elements** is here to help us again! Without getting into all of the background, scientists have discovered that an Avogadro's amount of any element/atom = 1 mole of that element/atom, and is ALSO equal to that element/atom's atomic mass when measured in **grams**.



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chemistry.about.com  
sciencenotes.org

For Example:

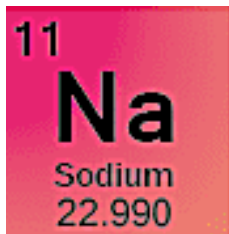


$6.022 \times 10^{23}$  atoms of Lithium  
1 mole of Lithium  
6.941 grams of Lithium



$6.022 \times 10^{23}$  atoms of Aluminum  
1 mole of Aluminum  
26.982 grams of Aluminum

It's also ADDITIVE! Table Salt = Sodium Chloride



+



=

$6.022 \times 10^{23}$  molecules of NaCl

1 mole of NaCl

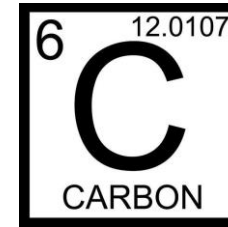
$22.990 + 35.453 = 58.443$  grams of NaCl

# Even More Math Fun!

To simplify, let's use  $6.02 \times 10^{23} = 1$  mole of things for Avogadro's Number. Also, round off mass numbers to their first decimal space. For example, Nitrogen's mass number is listed as 14.007, so use 14.0.

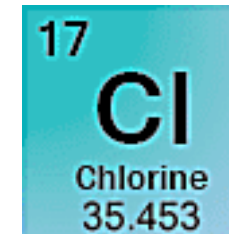
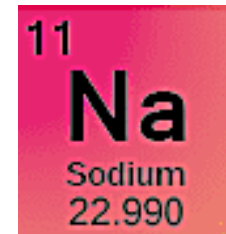
1) I have 2 moles of carbon. How many grams of carbon do I have?

$$\frac{2 \text{ moles of Carbon}}{1} \times \frac{12 \text{ grams Carbon}}{1 \text{ mole of Carbon}} = 24 \text{ grams of Carbon}$$



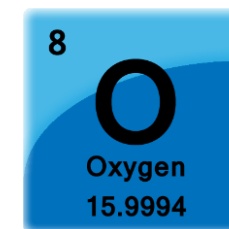
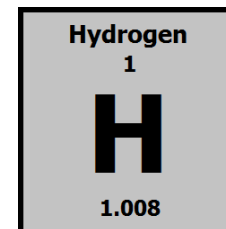
2) I have 0.5 moles of salt (NaCl). How many grams of salt do I have?

$$\frac{0.5 \text{ moles of NaCl}}{1} \times \frac{58.4 \text{ grams NaCl}}{1 \text{ mole of NaCl}} = 29.2 \text{ grams of NaCl}$$



3) I have 5 moles of water (H<sub>2</sub>O). How many grams of water do I have?

$$\frac{5 \text{ moles of H}_2\text{O}}{1} \times \frac{18 \text{ grams H}_2\text{O}}{1 \text{ mole of H}_2\text{O}} = 90 \text{ grams of H}_2\text{O}$$





# More than Even More Math Fun!

To simplify, let's use  $6.02 \times 10^{23} = 1$  mole of things for Avogadro's Number. Also, round off mass numbers to their first decimal space. For example, Nitrogen's mass number is listed as 14.007, so use 14.0.

- 1) I have 80.2 grams of Calcium (Ca). How many moles of Calcium do I have? How many atoms of Calcium do I have?
- 2) I have 132 grams carbon dioxide (CO<sub>2</sub>). How many moles of CO<sub>2</sub> do I have? How many molecules of CO<sub>2</sub> do I have?
- 3) I have 30 grams of helium gas (He). How many moles of helium do I have? How many particles of He do I have?

## **The MOST Math Fun EVER!**

To simplify, let's use  $6.02 \times 10^{23} = 1$  mole of things for Avogadro's Number. Also, round off mass numbers to their first decimal space. For example, Nitrogen's mass number is listed as 14.007, so use 14.0.

- 1) Pick your favorite Element from the PT. Write down it's element abbreviation and mass number.
- 2) Square your age.
- 3) Your age squared is a how many grams of your favorite element you have.
- 4) Calculate how many moles of your element you have.
- 5) Calculate how many atoms of your element you have.