

BERKELEY MATH CIRCLE

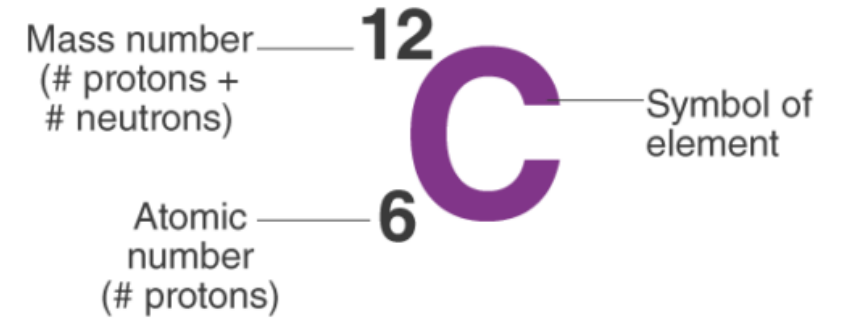
The Math of Chemistry: Avogadro's Number, Moles & Molecules

Patricio Angulo

The Periodic Table

Periodic Table of the Elements

1 1A 11A																	18 VIII A 8A
1 H Hydrogen 1.008	2 He Helium 4.003																
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 III B 3B	4 IV B 4B	5 V B 5B	6 VI B 6B	7 VII B 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.933	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.732	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.09	35 Br Bromine 79.904	36 Kr Krypton 84.80
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71 Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinide Series	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [293]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown



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

Alkali Metal	Alkaline Earth	Transition Metal	Semimetal	Nonmetal	Basic Metal	Halogen	Noble Gas	Lanthanide	Actinide
--------------	----------------	------------------	-----------	----------	-------------	---------	-----------	------------	----------

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?

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?

40.1

$$\frac{80.2 \text{ g Ca}}{1} \times \frac{1 \text{ mole Ca}}{40.1 \text{ g Ca}} = 2 \text{ moles Ca}$$

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?

$$\frac{2 \text{ moles Ca}}{1} \times \frac{6.02 \times 10^{23} \text{ atoms Ca}}{1 \text{ mole Ca}}$$

$$12.04 \times 10^{23} \text{ atoms Ca}$$

$$1.204 \times 10^{24}$$

More than Even More Math Fun!

To simplify, let's use 6.02×10^{23} for 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?

$$\cancel{80.2 \text{ g Ca}} \times \frac{\cancel{1 \text{ mole Ca}}}{\cancel{40.1 \text{ g Ca}}} = 2 \text{ moles Ca}$$

$$\cancel{2 \text{ moles Ca}} \times \frac{6.02 \times 10^{23} \text{ atoms of Ca}}{\cancel{1 \text{ mole Ca}}} = 1.204 \times 10^{24} \text{ atoms Ca}$$

$$1.204 \times 10^{24} = 1.204 \times 10^{24} \text{ atoms Ca}$$

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.

2) I have 132 grams carbon dioxide (CO_2). How many moles of CO_2 do I have? How many molecules of CO_2 do I have?
BONUS Question: How many atoms of Oxygen do I have?

More than Even More Math Fun!

To simplify, let's use 6.02×10^{23} # 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.

2) I have 132 grams carbon dioxide (CO_2). How many moles of CO_2 do I have? How many molecules of CO_2 do I have?
BONUS Question: How many atoms of Oxygen do I have?

$$\text{CO}_2 = 12 + 2(16) = 44 \text{ g/mole}$$

$$\frac{132 \text{ g CO}_2}{44 \text{ g CO}_2} \times 1 \text{ mole CO}_2 = 3 \text{ moles CO}_2$$

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.

2) I have 132 grams carbon dioxide (CO_2). How many moles of CO_2 do I have? How many molecules of CO_2 do I have?
BONUS Question: How many atoms of Oxygen do I have?

~~3 moles CO_2 \times 6.02×10^{23} molecules CO_2~~

~~1 mole CO_2~~

$$18.02 \times 10^{23} = 1.802 \times 10^{24} \text{ molecules } \text{CO}_2$$

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.

2) I have 132 grams carbon dioxide (CO_2). How many moles of CO_2 do I have? How many molecules of CO_2 do I have?
BONUS Question: How many atoms of Oxygen do I have?

$$1.806 \times 10^{24} \text{ molecules } \cancel{\text{CO}_2} \times \frac{2 \text{ Oxy}}{1 \cancel{\text{CO}_2}}$$

$$3,612 \times 10^{24} \text{ atoms O}$$

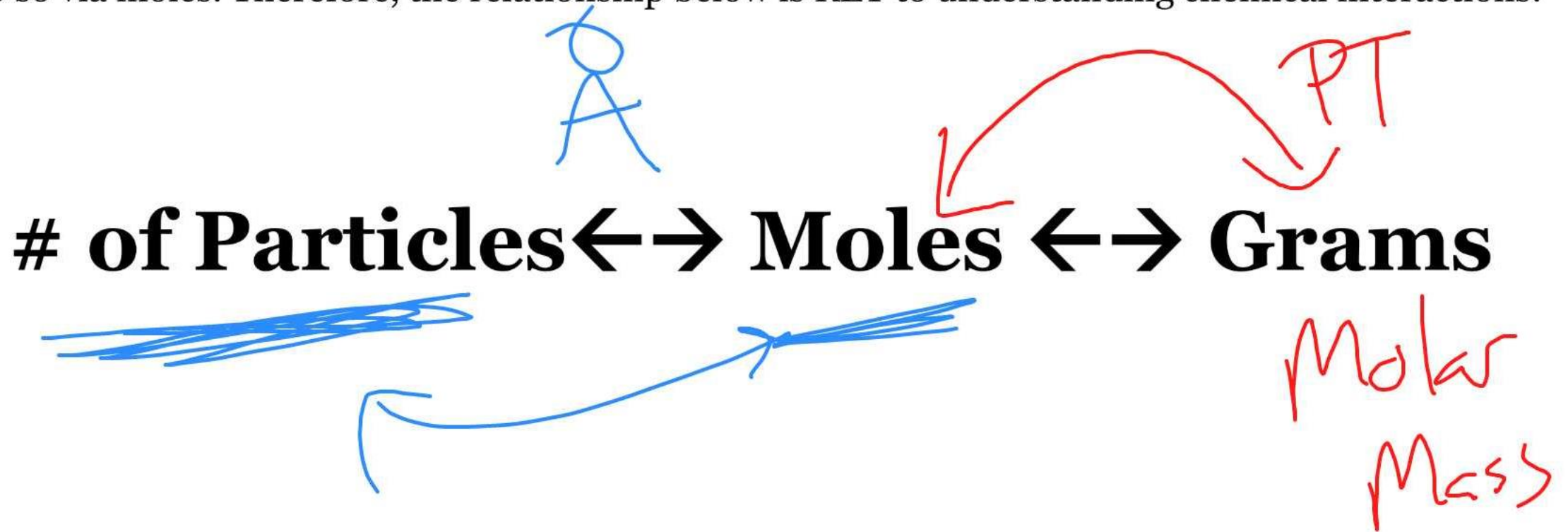
What Have We Learned?

We relate quantities in Chemistry but how many PHYSICAL items exist. This is why knowing Avogadro's number and the concept of a mole is so important! If we are trying to calculate specifically what is happening, we MUST know how many things are interacting with how many other things, and we do so via moles. Therefore, the relationship below is KEY to understanding chemical interactions:

of Particles \leftrightarrow Moles \leftrightarrow Grams

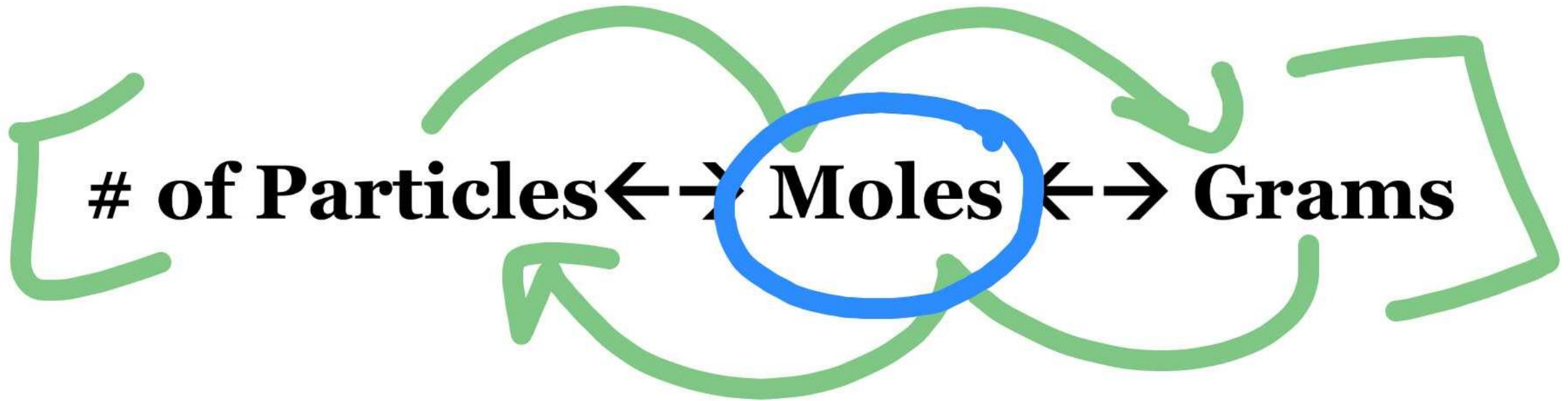
What Have We Learned?

We relate quantities in Chemistry but how many PHYSICAL items exist. This is why knowing Avogadro's number and the concept of a mole is so important! If we are trying to calculate specifically what is happening, we MUST know how many things are interacting with how many other things, and we do so via moles. Therefore, the relationship below is KEY to understanding chemical interactions:



What Have We Learned?

We relate quantities in Chemistry but how many PHYSICAL items exist. This is why knowing Avogadro's number and the concept of a mole is so important! If we are trying to calculate specifically what is happening, we MUST know how many things are interacting with how many other things, and we do so via moles. Therefore, the relationship below is KEY to understanding chemical interactions:



Let's Expand This!

Let's use our NEW understanding to understand something we probably ALL have done: the famous at-home volcano experiment!

Does anyone know what is happening in that experiment?



Let's Expand This!

The basics are that we mix vinegar with baking soda and BOOM! But what's happening on a chemical level?

Vinegar contains Acetic Acid (CH_3COOH). This is found in liquid form.

Baking Soda contains sodium bicarbonate (NaHCO_3). This is found in solid form.

So,

$\text{CH}_3\text{COOH} + \text{NaHCO}_3 \rightarrow \text{Na}^+ + \text{CH}_3\text{COO}^- + \text{H}_2\text{CO}_3$ (carbonic acid, which decomposes (see below))

And then

$\text{H}_2\text{CO}_3 \rightarrow \text{H}_2\text{O} + \text{CO}_2$

Carbon Dioxide is a gas which then escapes into the air. This is what causes the “lava” movement in the experiment!

Relating back to Earlier . . .



One can relate how much acetic acid and sodium carbonate will react (assuming a full reaction) by using our previous relationship and expanding on it

Previously we had . . .

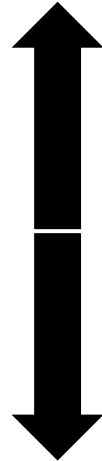
of Particles \leftrightarrow Moles \leftrightarrow Grams

And we can use this for BOTH the acetic acid and sodium carbonate.

BUT, how do we relate them to each other?

The Mole Bridge!

of Particles \leftrightarrow **Moles** \leftrightarrow **Grams**



of Particles \leftrightarrow **Moles** \leftrightarrow **Grams**

The Mole Bridge!

of Particles \leftrightarrow Moles \leftrightarrow Grams

of Particles \leftrightarrow Moles \leftrightarrow Grams



The Mole Bridge!

The mole bridge is part of a concept in Chemistry called Stoichiometry.

Stoichiometry = the relationship between the relative quantities of substances taking part in a reaction

Back to volcanoes then



Volcano Problem



If I used 100 grams of Acetic Acid, how many grams of Sodium Bicarbonate will I need to measure out in order to react all of the 100 grams of Acetic Acid?

Volcano Problem

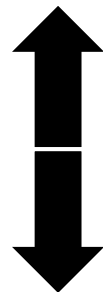
$\text{CH}_3\text{COOH} \rightarrow 60\text{g}/1 \text{ mole}$ (from PT table)

$\text{NaHCO}_3 \rightarrow 84\text{g}/1 \text{ mole}$ (from PT table)

1:1 ratio of CH_3COOH to NaHCO_3 from chemical equation

100 grams CH_3COOH x 1 mole/60 g = $5/3$ moles CH_3COOH \leftarrow 1:1 ratio \rightarrow $5/3$ moles NaHCO_3 x 84 g/mole = 140 g

of Particles \leftrightarrow Moles \leftrightarrow Grams

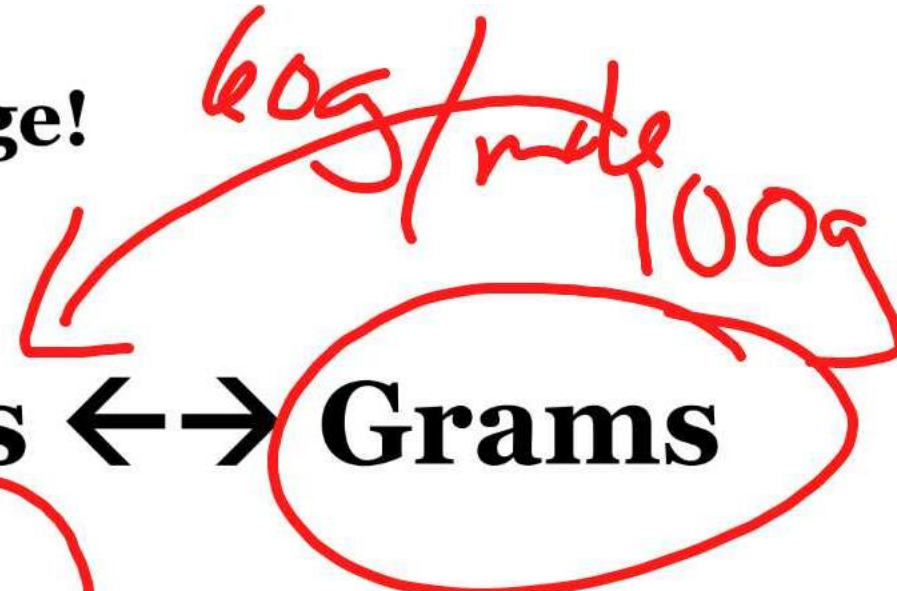


of Particles \leftrightarrow Moles \leftrightarrow Grams

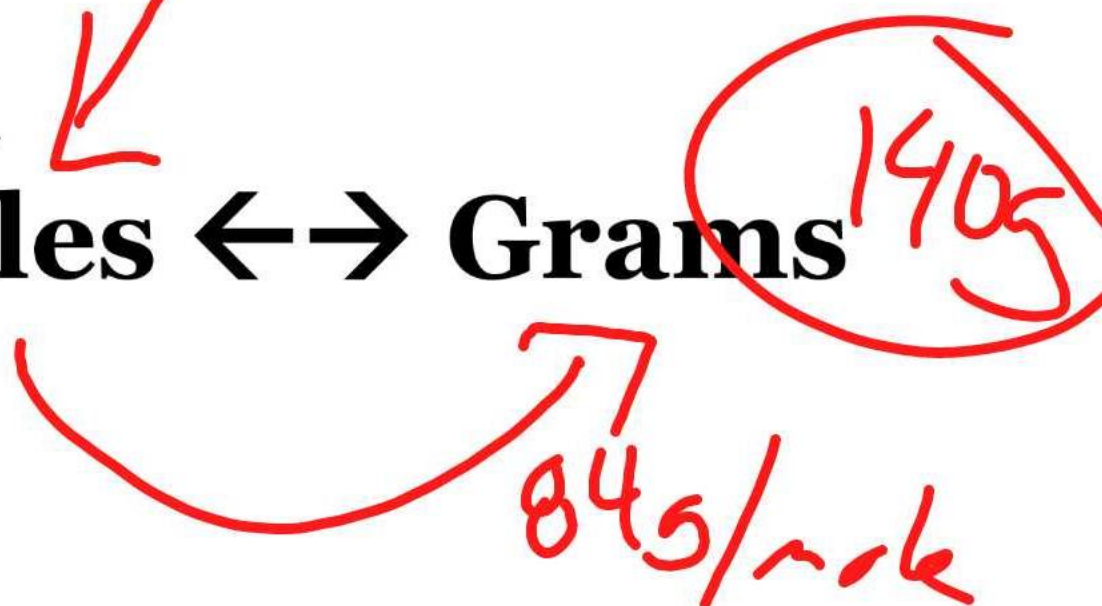
The Mole Bridge!

Acetic Acid

of Particles \leftrightarrow Moles \leftrightarrow Grams



of Particles \leftrightarrow Moles \leftrightarrow Grams



NaHCO₃

$$100\cancel{\text{g AA}} \times \frac{1\cancel{\text{mole}}}{68\cancel{\text{g}}} \times \frac{1\cancel{\text{NaHCO}_3}}{1\cancel{\text{AA}}} \times \frac{84\cancel{\text{g}}}{1\cancel{\text{mole}}}$$

140g NaHCO₃