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MOLES! MOLES! MOLES!

Joe's 2nd Rule of Chemistry

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Think of sugar…

If I told you, that I was running to Wegman's to buy a bag of sugar, how much sugar would you assume I was buying?

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Think of sugar…

If I told you, that I was running to Wegman's to buy a bag of sugar, how much sugar would you assume I was buying?

5 pounds – it's the standard size

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Still thinking sweetly…

If you go to use the sugar, what would be a standard quantity…?

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Still thinking sweetly…

If you go to use the sugar, what would be a standard quantity…?

A teaspoon for coffee (or tea!)
A cup for baking

Why doesn't Wegman's sell it by the teaspoon?!?!?

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Convenience

It would be inconvenient to sell sugar by teaspoons, or even cups (although they used to do it before individual packaging).

But then why not use pounds when baking, or sweetening your coffee…?
Much more convenient to use a cup or a teaspoon.

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Measurements are practical

You don't measure the length of your commute in inches.
You don't measure the size of your waist in miles.

There is a method to the myriad madness of all these UNITS! UNITS! UNITS!

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What about Chemistry?

What's a good unit for doing chemistry?

It depends on what you are doing…
If you are getting a chemical out of the "package", grams or mL make sense:
they are convenient

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At the molecular level…

In a laboratory, ease of measurement determines the unit of choice.

What if I want to think about the actual chemistry that's going on? Does Mother Nature care about grams and mL?

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Mother Nature

If you want to think about chemistry, what is it that you are actually thinking about?

What is Chemistry?

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Chemistry is…

…the making and breaking of bonds between atoms to form new molecules.

A + B = C

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Chemistry is…

…the making and breaking of bonds between atoms to form new molecules.

A + B = C

This is a kind of algebra of atoms, only it is usually written:

$A + B \rightarrow C$

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A + B → C

A + B → C

How should this chemical equation be read?

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A + B → C

A + B → C

How should this chemical equation be read?

Take A, add B to it, get C from the combination.

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Chemistry is cooking

It's kind of like a recipe:

Take flour, add eggs, bake, eat muffin!

The muffin is something very different from the flour alone, and the eggs alone, or even the flour and eggs thrown together but uncooked. (You may try this experiment in your own kitchens if you don't believe me.)

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The Recipe

So, when I write a chemical reaction, I'm really writing a chemical recipe.

$2\ H_2 + O_2 \rightarrow 2\ H_2O$

This is the hard way to get water.

How should I read this recipe?

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$2\ H_2 + O_2 \rightarrow 2\ H_2O$

Take ? hydrogen, add ? oxygen,
get ? water

What the ?

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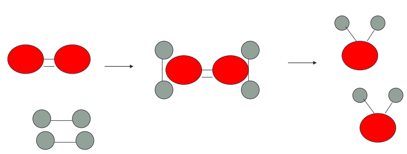
$2\ H_2 + O_2 \rightarrow 2\ H_2O$

It's all about atomic collisions:



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$2 H_2 + O_2 \rightarrow 2 H_2O$

They are actually molecules. What the “recipe” really tells you is:

Take 2 molecules of hydrogen, add 1 molecule of oxygen and you will get 2 molecules of water.

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A molecule is a very little thing

The problem with a recipe written in terms of molecules is that they are very small and a little slippery, so they are hard to pick up!

(I’m only half kidding…)

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Molecules! Molecu…! Mole!

Molecules is simply not a convenient unit.

Any reasonable recipe-sized quantity contains LOTS AND LOTS of molecules (approximately 10^{23})

So, we need a bigger unit!

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$2\,H_2 + O_2 \rightarrow 2\,H_2O$

It's still about individual particles coming together.

A molecule….too small
A dozen molecules…still too small
A gross of molecules…still too small
A mole of molecules….juuuuuust right!

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MOLES! MOLES! MOLES!

A mole is just a big collection of molecules.

1 mole = 6.022×10^{23} molecules

(6.022×10^{23} is called Avogadro's number)

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MOLES! MOLES! MOLES!

A mole is just a big unit for counting molecules.

So, when I'm talking about a chemical reaction, I now have a lab-sized quantity of material.

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$2\ H_2 + O_2 \rightarrow 2\ H_2O$

So, on a lab-sized world, the "recipe" really tells you:

Take 2 MOLES of hydrogen, add 1 MOLE of oxygen and you will get 2 MOLES of water.

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But how do you measure a mole?

If I can't grab one molecule with my tweezers, how can I grab 6.02×10^{23} of them?!?!?

I need a convenient way to measure moles…

What could be easier than weighing them?

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Mass to moles, moles to mass…

Grams is a convenient laboratory unit.

Moles is a convenient chemistry unit.

I need to be able to relate the two units!

Anybody remember what the conversion is?

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Molar Mass

Molar mass (atomic weight) is the conversion from moles to grams.

In fact, molar mass has units of g/mole.

Where do you find the molar mass?

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The Periodic Table is your friend.

Among the most basic information in the Periodic Table of the Elements is the molar mass.

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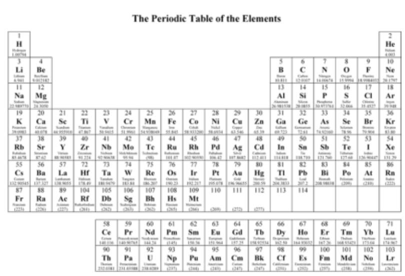

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I want to make water…

I already have the recipe:

$2\ H_2 + O_2 \rightarrow 2\ H_2O$

If I have 5 grams of hydrogen and 5 grams of oxygen – how much water can I make?

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It's like baking a cake…

2 cups of flour + 1 egg = 1 (lousy) cake

If I have 10 cups of flour and a dozen eggs, how many cakes can I make?

5 cakes – after that, I'm out of flour!

This is called a "limiting reagent" problem.

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I want to make water…

I already have the recipe:

$2\ H_2 + O_2 \rightarrow 2\ H_2O$

If I have 5 grams of hydrogen and 5 grams of oxygen – how much water can I make?

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Grams is Good, Moles is Better

$2\,H_2 + O_2 \rightarrow 2\,H_2O$

Think moles!

$5 \text{ grams } H_2 * \frac{1 \text{ mol } H_2}{2.016 \text{ g } H_2} = 2.48 \text{ mol } H_2$

$5 \text{ g } O_2 * \frac{1 \text{ mol } O_2}{32.0 \text{ g } O_2} = 0.156 \text{ mol } O_2$

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It's all in the Stoichiometry

$2\,H_2 + O_2 \rightarrow 2\,H_2O$

Stoichiometry is magic: it turns one molecule into another!

$2.48 \text{ mol } H_2 * \frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2} = 2.48 \text{ mol } H_2O$

$0.156 \text{ mol } O_2 * \frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2} = 0.312 \text{ mol } H_2O$

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Whatever less wins!

I have enough H_2 to make 2.48 mol H_2O, but I only have enough O_2 to make 0.312 mol H_2O.

I run out of O_2 first!

So, assuming 100% yield, I can make 0.312 moles H_2O

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Converting back to grams

In "laboratory units":

$$0.312 \text{ mol } H_2O * \frac{18.01 \text{ g } H_2O}{1 \text{ mol } H_2O} = 5.63 \text{ g } H_2O$$

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Joe's 1st song

Grams to moles, moles to moles, moles to grams!

The most common calculation in chemistry is:

Grams to moles, moles to moles, moles to grams.

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Grams to moles:
Grams is easy to measure, moles is chemistry
Moles to moles: $2 H_2 + O_2 \rightarrow 2 H_2O$
stoichiometry tells me the relative molar amounts of different species.
Moles to grams:
Grams is easy to measure

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Another little problem

Chloride ion can be precipitated by adding $Fe(NO_3)_3$ to create $FeCl_3$. How much (g) of $Fe(NO_3)_3$ would I need to add to a solution containing 1.00 g of chloride ion in order to completely precipitate the chloride ion?

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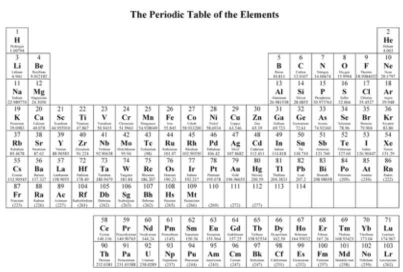

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1st – You need a balanced eqn.

Chemistry is all about reactions. Most chemistry problems require a balanced chemical equation.

$Fe(NO_3)_3$ (s) + 3 Cl^-(aq) $\rightarrow FeCl_3$(s) + 3 NO_3^-(aq)

The balanced equation gives you the stoichiometry: 3 mol Cl-: 1 mol $Fe(NO_3)_3$

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2^{nd} – Grams is good. Moles is better.

1.00 g Cl^- × (1 mol Cl^- / 35.453 g Cl-) = 0.028206 mol Cl-

Balanced equations are about molar relationships!

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3rd – Bring on the Stoich

0.028206 mol Cl^- × (1 mol $Fe(NO_3)_3$ / 3 mol Cl^-) = 9.40×10^{-3} mol $Fe(NO_3)_3$

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4^{th} – Moles is best, but grams is easier (to measure)

9.40×10^{-3} mol $Fe(NO_3)_3$

55.85 g Fe/mol + 3*14.007 g N/mol + 9*16.00 g O/mol = 241.87 g/mol

9.40×10^{-3} mol $Fe(NO_3)_3$ * (241.87 g $Fe(NO_3)_3$ / 1 mol $Fe(NO_3)_3$) = 2.27 g $Fe(NO_3)_3$

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Grams is easy (to measure)…

…if it is a pure substance.

We usually have aqueous solutions (it's a water course), so the mass of a mixture isn't helpful unless I can separate the stuff that reacts from the solvent (water).

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For solutions…

It is usually about concentration and the amount of solvent.

For a chemist, our favorite unit of concentration is Molarity (M).

$$M = \frac{\text{moles solute}}{\text{L solution}}$$

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$M = \frac{\text{moles solute}}{\text{L solution}}$

Think about it!

"moles solute" – just what you need. Chemistry is moles. The solute is the chemical reactant/contaminant. I want to know the moles so I can use the balanced equation to see how it reacts.

"L solution" – easy to measure in the lab. Graduated cylinder (or volumetric flask or buret or pipet) will give me the volume (L) of solution.

I have a chemically relevant unit and a laboratory relevant unit!

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If I have M and I want moles…

…I need…

The Volume

M = <u>mol solute</u> * L solution = mol solute
L solution

Caveat: Do not confuse M with moles!!!!

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If it is a pure substance…

Grams to moles, moles to moles, moles to grams.

Grams to moles (using molar mass), moles to moles (using stoichiometry), moles to grams (using molar mass).

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If it is a solution…

I'm going to start with…??

Molarity!!

Molarity to moles (using…?)

Volume!

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If it is a solution…

Molarity to moles (using volume), moles to moles (using stoichiometry), moles to grams (using molar mass)

OR

Molarity to moles (using volume), moles to moles (using stoichiometry), moles to molarity (using volume)

OR

Molarity to moles (using volume), moles to moles (using stoichiometry), moles to volume (using molarity)

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Same problem with a twist

Chloride ion can be precipitated by adding $Fe(NO_3)_3$ (aq) to create $FeCl_3$ (s). How much 0.500 M $Fe(NO_3)_3$ would I need to add to 250 mL of a solution containing 0.250 M chloride ion in order to completely precipitate the chloride ion?

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1^{st} – You need a balanced eqn.

$Fe(NO_3)_3$ (aq) + 3 Cl^-(aq) $\rightarrow$ $FeCl_3$(s) + 3 NO_3^-(aq)

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2nd – Molarity is great. Moles is better.

$0.250\ M\ Cl^- = \frac{0.250\ mol\ Cl^-}{L\ solution}$

How do I get moles?
Multiply by volume!

$\frac{0.250\ mol\ Cl^-}{L\ solution} * 0.250\ L\ solution = 0.0625\ mol\ Cl^-$

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3rd – Bring on the Stoich

$0.0625\ mol\ Cl^-\ \frac{1\ mol\ Fe(NO_3)_3}{3\ mol\ Cl^-} = 0.02083\ mol\ Fe(NO_3)_3$