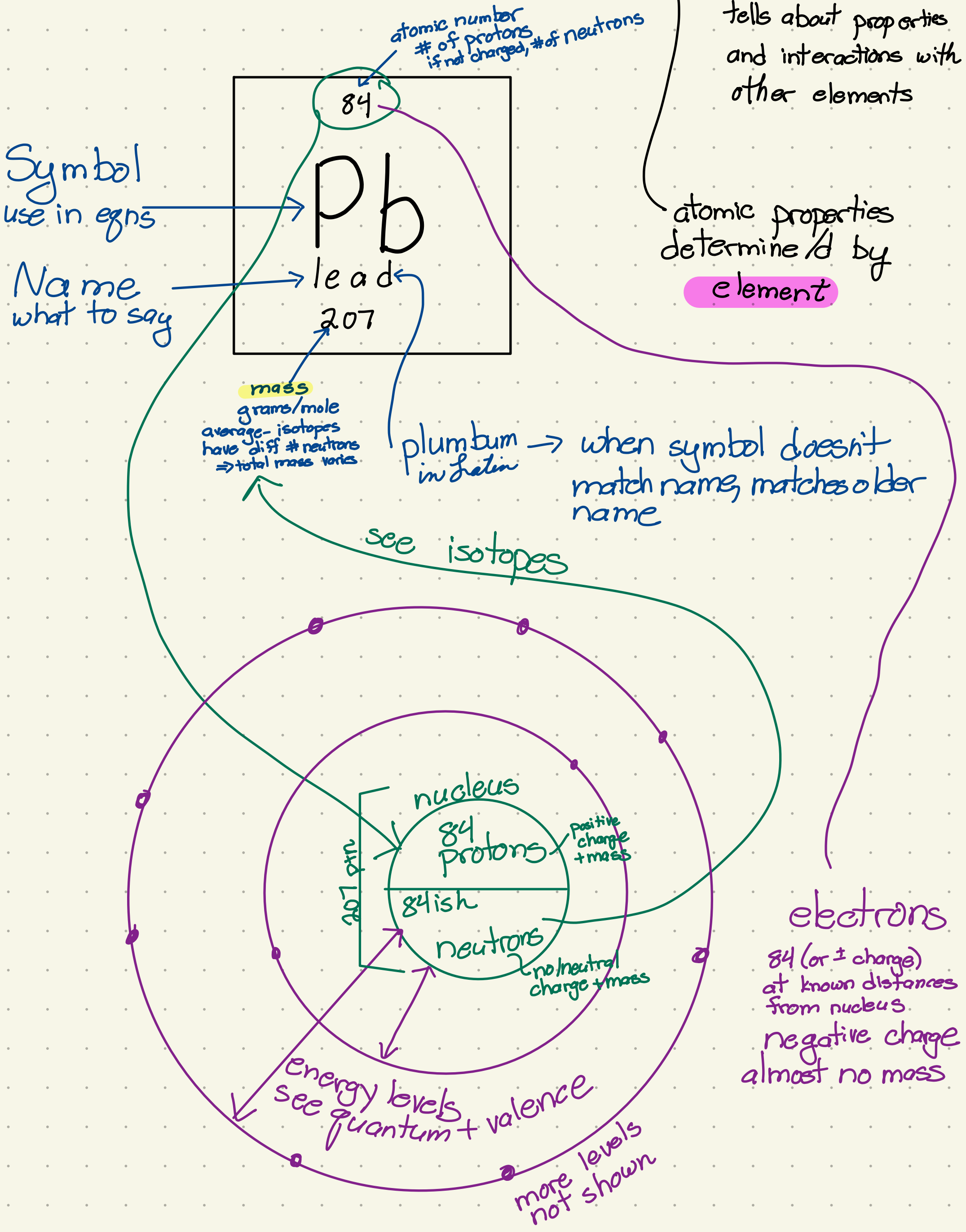
The periodic table tells you about atoms '

charge +mass
+location in chart
tells about properties
and interactions with
other elements

atomic properties
determine/d by
element



plumbum in Latin → when symbol doesn't match name, matches older name

Periodic table-organization

Ca⊕ions

positively charged

donate e⁻

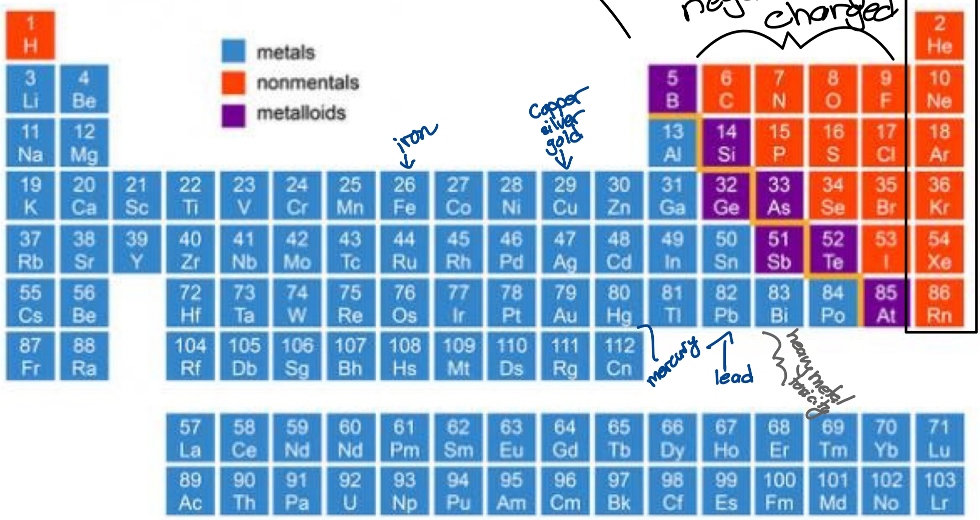
egative

anions

negatively charged

noble gases - not + or -

unlikely to react - inert



1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Be		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn						
			57 La	58 Ce	59 Nd	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

🟦 metals
🟥 nonmentals
🟪 metalloids

iron

copper silver gold

mercury

lead

heavy metal toxicity

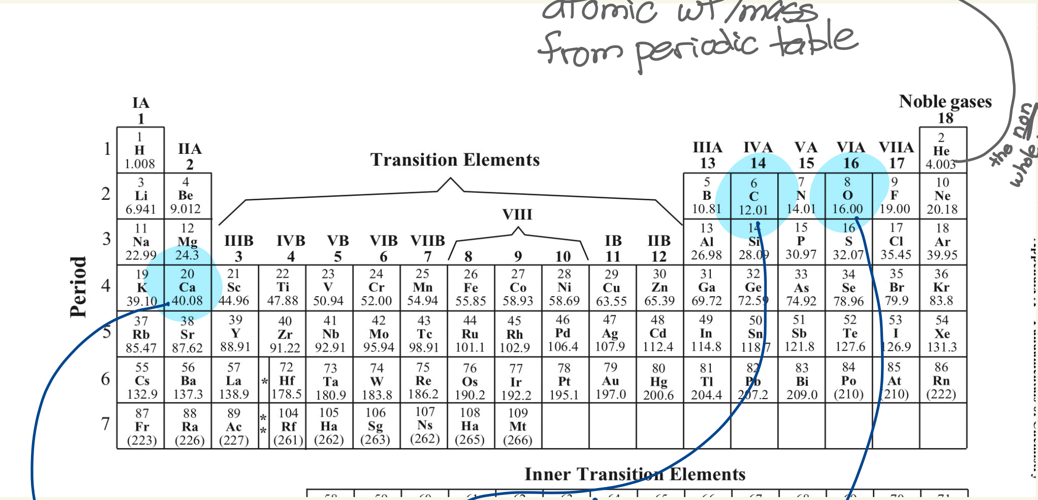
getting heavier

how atoms react/combine

Molecular weights $= \underset{\text{(sum)}}{\sum}$ atomic wt.

atomic wt/mass from periodic table

the non whole number



Period	IA 1	IIA 2	IIIB 3	IVB 4	VB 5	VIB 6	VIIB 7	VIII 8	9	10	IB 11	IIB 12	IIIA 13	IVA 14	VA 15	VIA 16	VIIA 17	Noble gases 18
1	1 H 1.008																	2 He 4.003
2	3 Li 6.941	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 24.3											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	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 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.9	36 Kr 83.8
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc 98.91	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
6	55 Cs 132.9	56 Ba 137.3	57 La 138.9 *	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89 Ac (227) **	104 Rf (261)	105 Ha (262)	106 Sg (263)	107 Ns (262)	108 Ha (265)	109 Mt (266)									

Transition Elements

Inner Transition Elements

12.01

40.08 $Ca\,C\,O_3$ 16

$$40.08\,g/mol + 12.01\,g/mol + \underbrace{3x\ 16\,g/mol}_{48}$$

$$\begin{array}{r} 40.08 \\ 12.01 \\ +48 \\ \hline 100.09 \end{array} \rightarrow$$

molecular weight of Calcium carbonate

=100.09g/mol

Writing and Balancing Chemical Reactions
Stoichiometry

One of the major principles we will use when solving problems in environmental engineering is the conservation of matter. While matter is conserved, there are many transformations that can occur. Sometimes physical processes will transport (blowing wind, flowing river) or structurally alter (evaporate, grind/erode) a material, and you can track the location and form of the matter. During chemical reactions, there may seem to be more permanent loss of matter, but it is just another transformation. This document will serve as a handy reference for doing the accounting to track the atoms during chemical reactions. We call this process stoichiometry, or just balancing chemical reactions.

Parts of a chemical equation

Before we can balance a chemical equation, we need to know the parts. A chemical reaction looks like

$$a\,\mathrm{A}_x\mathrm{B}_y + c\,\mathrm{C}_z \longrightarrow d\,\mathrm{A}_\alpha\mathrm{C}_\gamma + f\,\mathrm{B}_\beta$$

REACTANTS
react away
LHS = left hand side

PRODUCTS
are produced, end product
RHS = right hand size

where

- A, B, C are the symbols for **elements** from the periodic table

- x, y, z, γ, α, β are the chemical **subscripts** that describe the molecular formula of the compounds considered

- a, c, d, f are the **balancing coefficients**.
  This is the only part you'll change when balancing the reaction.
  If they are not explicitly written, then the coefficient is 1.

Conservation

Because matter is conserved, the number of atoms of each element must be the same on both sides of the arrow. This means that although the molecular formula has changed, the constituent atoms that make up each molecule are conserved. We will count these up to determine the balance. The balancing coefficients can then be viewed as a ratio of atoms of each type, or the number of moles of each molecule.

The easiest way to track this is to make a table and just count up the number of each element that appears in the equation. The number of atoms/moles of each element or ion can be calculated by multiplying the balancing coefficient by the subscript. So if we want to find the values of a, b, and c above:

ion or element	Reactants	Products
A	$a \times x$	$d \times \alpha$
B	$a \times y$	$f \times \beta$
C	$c \times z$	$d \times \gamma$

Once you have the boxes in each row equal to each other, you are done. If the two columns in a row aren't equal, modify the balancing coefficients and recalculate any affected rows.

Particularly as you start to deal with more complex reactions, you may want to look at grouped elements as ions. e.g. ${CO_3}^{2-}$

Specific Examples

Combustion of Methane:
$a\,CH_4 + b\,O_2 \longrightarrow x\,CO_2 + y\,H_2O$

Note that O is in two places on the product side.

Element	Reactants	Products
C	$a \times 1$	$x \times 1$
H	$a \times 4$	$y \times 2$
O	$b \times 2$	$x \times 2 + y \times 1$

Now you can try to use algebra or a guess and check method to try to determine the values of the coefficients. The system of equations would look like:

$$a = x$$
$$4a = 2y$$
$$2b = 2x + y$$

Since we know that $a = x$ and that b and y must be larger, we might start an iterative table with $a = x = 1$ and $b = y = 2$.

Element	Reactants	Products	
C	$1 \times 1 = 1$	$1 \times 1 = 1$	✓
H	$1 \times 4 = 4$	$2 \times 2 = 4$	✓
O	$2 \times 2 = 4$	$1 \times 2 + 2 \times 1 = 4$	✓

Our educated guess was useful, because we already have each row balanced. Our final balanced reaction is:
$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$
Note that the 1s in front of methane and carbon dioxide, initially represented by the a and x placeholders, are implicit you don't need to expressly write those out. A trick if you're writing this by ions is that water (H_2O) written structurally is actually HOH.

Try it yourself

1. Balance the equation:

____ Mg + ____ HCl $\longrightarrow$ ____$MgCl_2$ + ____H_2

2. Write a balanced complete combustion reaction for fuel oil has the molecular formula $C_{10}H_{20}$. (Hint: Complete combustion oxidizes fuel in oxygen producing only CO_2 and water.)

3. What's the molecular weight of the fuel?

4. How many moles of water (vapor) are produced per mole of fuel burned?

Getting more complex:
$a\,NaOH + b\,H_2SO_4 \longrightarrow x\,Na_2SO_4 + y\,H_2O$
This would be a good candidate to break down by ions instead of elements, and I'll show you both.

Element	Reactants	Products	
Na	1	2	×
O	$1 + 4 = 5$	$1 + 4 = 5$	✓
H	$1 + 2 = 3$	2	×
S	1	1	✓

Lots of initial mismatch so let's try to add some coefficients. Let's start by focusing on sodium (Na) since it's only on one spot on each side.
$2\,NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O$

Element	Reactants	Products	
Na	2	2	✓
O	6	5	×
H	4	2	×
S	1	1	✓

We still have two matching rows, but now the two mis-matched elements both show up in water. (Or think of it as H is still mismatched but only shows up in one place on the right.) Let's try:
$2\,NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2\,H_2O$

Element	Reactants	Products	
Na	2	2	✓
O	6	6	✓
H	4	4	✓
S	1	1	✓

So that's our balanced reaction!

The other way to look at this is by breaking down ions instead of elements. The starting point would then be:

Ion	Reactants	Products	
Na^+	1	2	×
OH^-	1	1	✓
H^+	2	1	×
${SO_4}^{2-}$	1	1	✓

Then our balanced reaction from above would be:

Ion	Reactants	Products	
Na^+	2	2	✓
OH^-	1	1	✓
H^+	2	2	✓
${SO_4}^{2-}$	1	1	✓

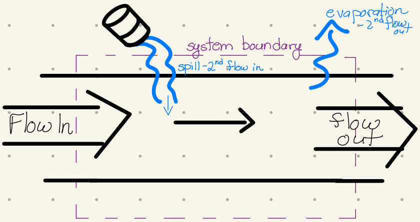
You can see how the ionic version might be a little smoother and easier, but requires you to be able to dissect the molecules in that way. Sometimes these will be written in parenthesis with their own subscripts, e.g. $(NH_4)_2SO_4$ ammonium sulfate, is composed of ${NH_4}^+$ and ${SO_4}^{2-}$.

Conservation of Mass

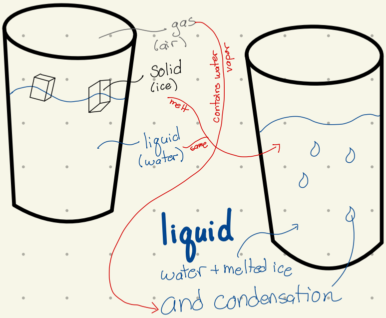
Matter can not be created nor destroyed, therefore mass can all be tracked

Tricks to track its continued existence

Flows in+ out



Phase Change



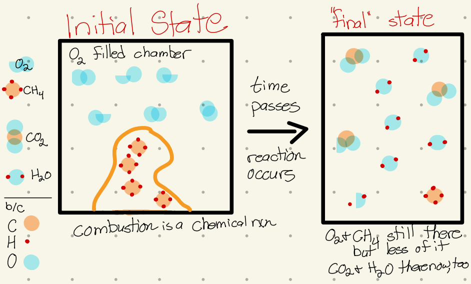
liquid

water + melted ice

and condensation

Chemical Reactions

sometimes called non conservative because substances are not conserved, but atoms+ mass are conserved



$$6O_2 + 4CH_4 \rightarrow 3CO_2 + 6H_2O$$

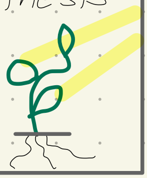
$$+1\,CH_4$$

C	4	3+1
H	16	12+4
O	12	6+6

Biology

breaks down to chemistry

e.g. nitrification, photosynthesis

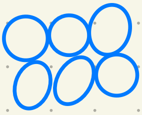


Phases of Matter

at a molecular level

solid

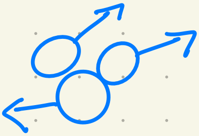
rigid



Relative molecular position constant

liquid

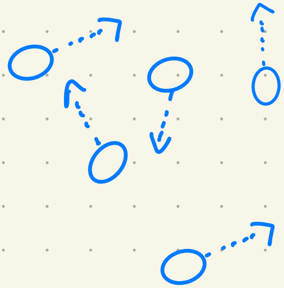
flowy



constant distance
position moves

gas

bouncy



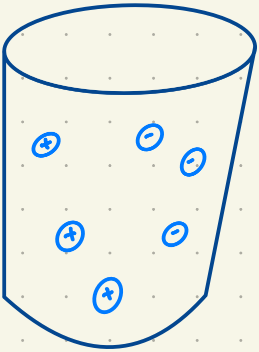
Important Properties

$\frac{PV}{T}$ relationship constant, but no specific unit constant (expands to fill container)

solution*

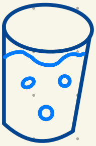
* technically not a phase
"it's not a phase, Mom"

chemical solution



solute dissociates to ions → changes at a molecular level

colloidal mixture

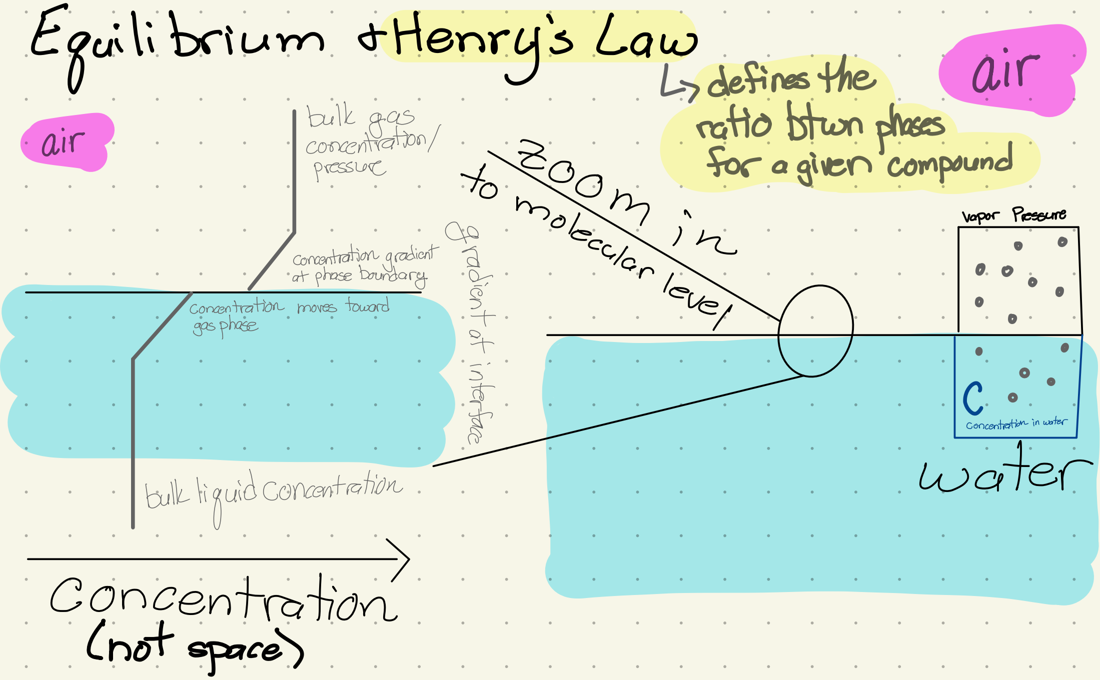


no chemistry
small solids suspended in liquid

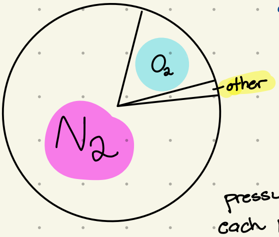
Plasma - not used here

Equilibrium + Henry's Law

↳ defines the ratio btwn phases for a given compound



Partial Pressure



Reminder

$P = \frac{\text{Force}}{\text{Area}}$

$P_{tot} = \sum P$ exerted by ea. mc.

$= \sum_{N_2} P + \sum_{O_2} P + \sum_{other} P$

Dalton's Law of Partial P.

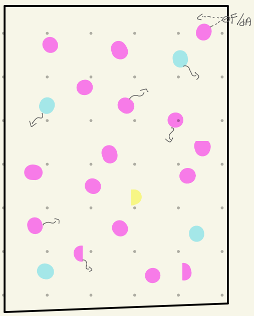
P exerted by each gas $\rightarrow i$ is proportional to the volume percent of that gas

$\Rightarrow P_i = P_{total} \underbrace{X_i}_{\text{mole fraction or concentration}}$

$i = N_2, O_2,$ etc

@ sea level
P = 1 atm

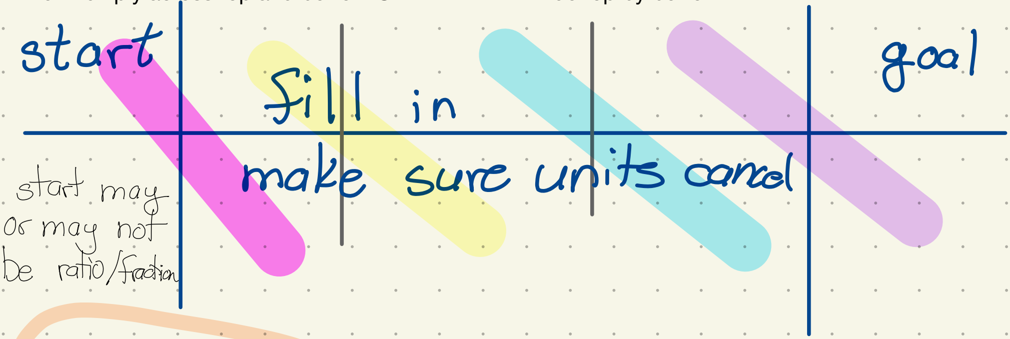
pressure exerted by each molecule bouncing around



Dimensional Analysis

Steps

1. Write down all values and ratios – create a "word bank"
2. Look for "hidden" ratios
   -stoichiometry, conversion factors….can add later, too
3. write starting and ending points
4. fill in the middle with ratios such that all units cancel except the "goal" /end point
5. Multiply across top and bottom SEPARATELY. Divide top by bottom.



Example problem

The average yard (photo)synthesizes 500 moles of glucose each day. What carbon footprint (ton/year) would ensure that the CO2 absorbed by your yard would equal the CO2 produced due to your activities.

$6\ CO_2 + 6\ H_2O + \overset{h\nu}{\text{sunlight}} + \text{chlorophyl} \longrightarrow \overset{\text{glucose}}{C_6H_{12}O_6} + 6\ O_2$

"word bank":

$\frac{500\text{ moles glucose}}{\text{day}}$ prob statement

$\frac{1\text{ mole glucose}}{6\text{ mole }CO_2}$

$\frac{44g\ CO_2}{\text{mole }CO_2}$

$\frac{1{,}000g}{1\text{ kg}}$ $\frac{1{,}000\text{kg}}{1\text{ tonne}}$

realize we have 2 time units that don't match ⇒ find conversion factor

multiply across top + bottom separately

solve:

500 ~~moles glucose~~	6 ~~moles CO_2~~	44 ~~g CO_2~~	1 ~~kg CO_2~~	tonne CO_2	365 ~~days~~	48,180,000	tons CO_2
~~day~~	1 ~~mole glucose~~	~~mole CO_2~~	1000 ~~g CO_2~~	10^3 ~~kg~~ CO_2	yr	10^6	year

goal

divide top/bottom → 48 tons CO_2/yr