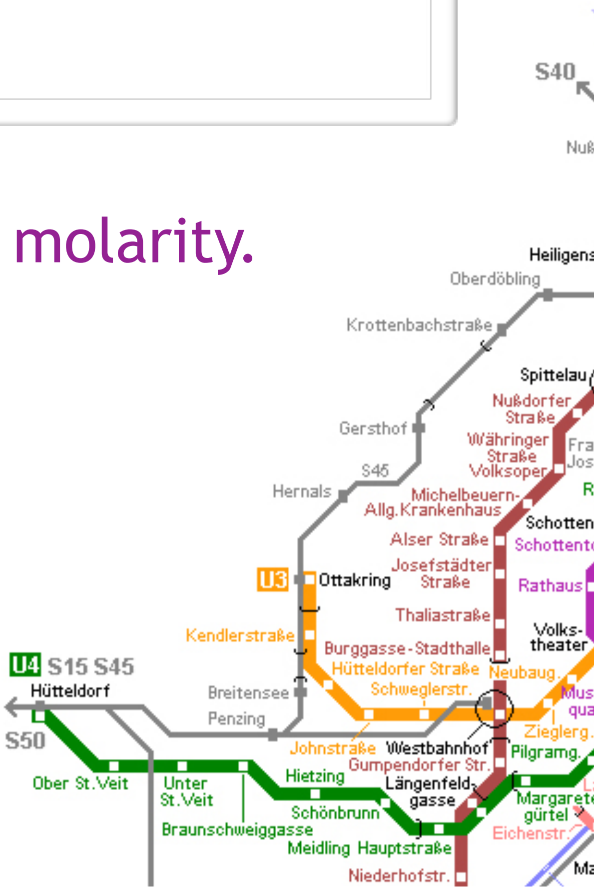
Ch10

Stoichiometry

Using balanced equations, mole ratios and molarity.

"The Molar Subway"

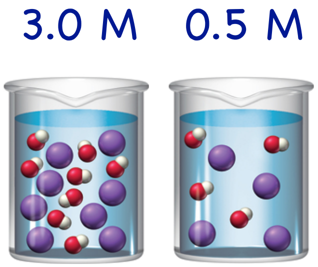


version 1.5


Brunner Str.
Nußdorf
Aderklaaer Straße
Rennbahnweg
S7
U6
Floridsdorf
Breitenleer Str.
Kagraner Platz
X
Heiligenstadt
U4
Oberdöbling
S45
Handelskai
Neue Donau
gran
Krottenbachstraße
Dresdner Straße
Alte Donau
S8
Spittelau
Traisengasse
Nußdorfer Straße
Jägerstraße
Kaisermühlen - Vienna International Centre
Gersthof
Friedensbrücke
Donauinsel
Währinger Straße Volksoper
Franz-Josefs-Bhf.
S45
Erzherzog-Karl-Straße
Hernals
Praterstern
Vorgartenstraße
Hardegg-gasse
Michelbeuern-Allg.Krankenhaus
Roßauer Lände
Taborstr.
Messe Prater
Stadlau
2010
U2
Schottenring
Alser Straße
Schottentor
Nestroyplatz
Donauspital
Aspernstr.
Josefstädter Straße
Rathaus
Herren-gasse
Schwedenplatz
Krieau
U3
Ottakring
U2
Donaustadtbrücke
Thaliastraße
Stephansplatz
Stadion
Kendlerstraße
Volks-theater
Landstraße Wien Mitte
Burggasse-Stadthalle
U2
Stubentor
Donaumarina
Lobau
U4 S15 S45
Hütteldorfer Straße
Neubaug.
Stadt-park
Rochusgasse
Hütteldorf
Breitensee
Schweglerstr.
Museums-quartier
Karlsplatz
Praterkai
Penzing
Kardinal-Nagl-Platz
Zieglerg.
Taub-stummeng.
Renn-weg
S50
Johnstraße
Westbahnhof
Pilgramg.
Südtiroler Platz
St. Marx
Schlachthausgasse
Gumpendorfer Str.
Ketten-brückeng.
Ober St.Veit
Unter St.Veit
Hietzing
Längenfeldgasse
Laurenzg.
Erdberg
Margareten-gürtel
Südbahnhof
Schönbrunn
Haidestraße
Braunschweiggasse
Reinprechtsdorfer Str. / Eichenstr.
Gasometer
Meidling Hauptstraße
Klieberg.
Matzleinsdorfer Platz
Kepler-platz
Zippererstraße
Niederhofstr.
Enkplatz
Wolfgangg.
Lokalbahn
Geiselbergstr.
Philadelphiabrücke
Reumannplatz
Blechturmgasse
U1
Speising
S15
Meidling
Simmering
U3
Tscherttegasse
Schöpfwerk
Hetzendorf
Grillgasse
Am Schöpfwerk
Gutheil-Schoder-Gasse
S7
S60
Inzersdorf-Ort
Atzgersdorf
Alterlaa
S
Inzersdorf-Personenbahnhof
S6
Erlaaer Straße
Neu-Erlaa
Perfektastraße
Schönbrunner Allee
Liesing
Siebenhirten
U6
Vösendorf-Siebenhirten
Danube
Donau

Ch10

Stoichiometry



- Stoichiometry & the mole ratio.
  - A new conversion factor.
  - Already in our tool box:
    - Atomic Mass; Molar Mass; Avogadro's #
      (chapter 2)
    - Molecular Mass; Molecular Formula
      (chapter 3)
- The balanced equation.
  - Example Stoichiometry Calculations
    - mol → mol calcs (2 steps)
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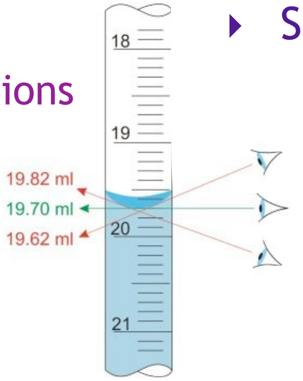

- Solution concentration.
  - What concentration means?
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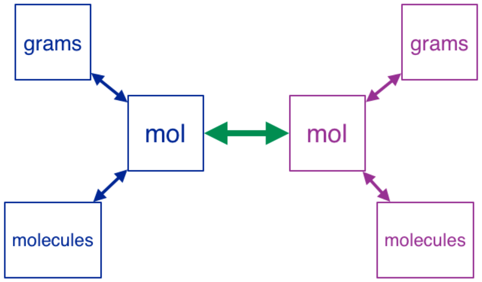
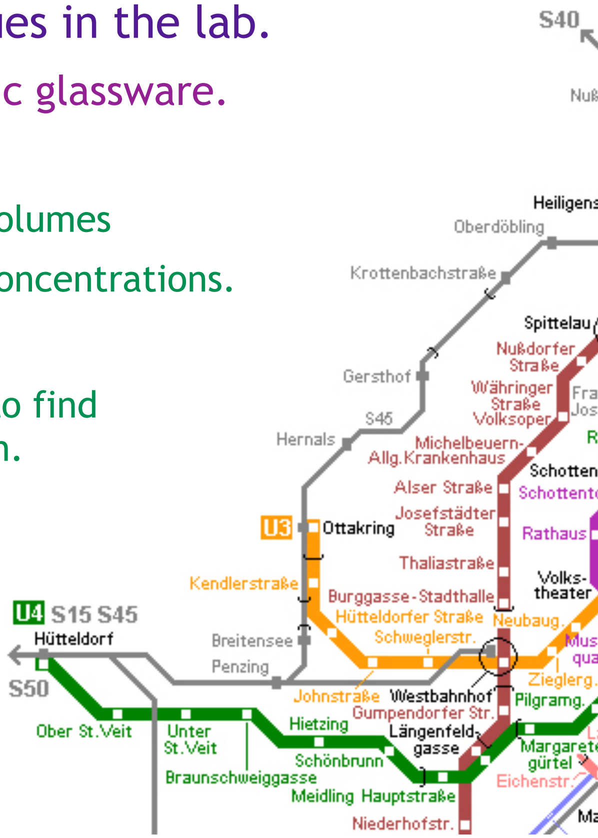
    - A technique to find concentration.


grams
mol
molecules
mol
grams
molecules



Stoichiometry

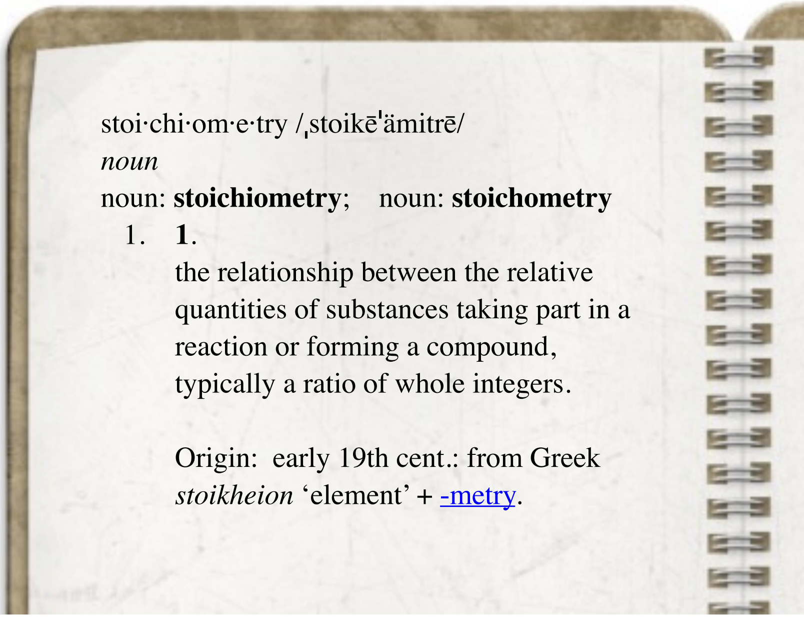
- Stoichiometry is the relationship between relative quantities of substances in a reaction or molecular formula.
- Having a balanced equation let's us see the ratio of products formed from reactants.
- In the balanced equation to the right, we can see that every propane molecule (C_3H_8) produces three carbon dioxide (CO_2) molecules.
- Therefore any number of propane molecules burnt, will produce three times as many carbon dioxide molecules.
- The balanced equation reveals all the possible stoichiometric relationships between reactants and products.
- It let's us answer any stoichiometric question about about a system described by that equation.

Eq 1:

$$C_3H_8\,_{(g)} + O_2\,_{(g)} \rightarrow CO_2\,_{(g)}\uparrow + H_2O\,_{(l)}$$

Eq 2:

$$C_3H_8\,_{(g)} + 5\ O_2\,_{(g)} \rightarrow 3\ CO_2\,_{(g)} + 4\ H_2O\,_{(l)}$$



stoi·chi·om·e·try /ˌstoikēˈämitrē/

noun

noun: **stoichiometry**; noun: **stoichometry**

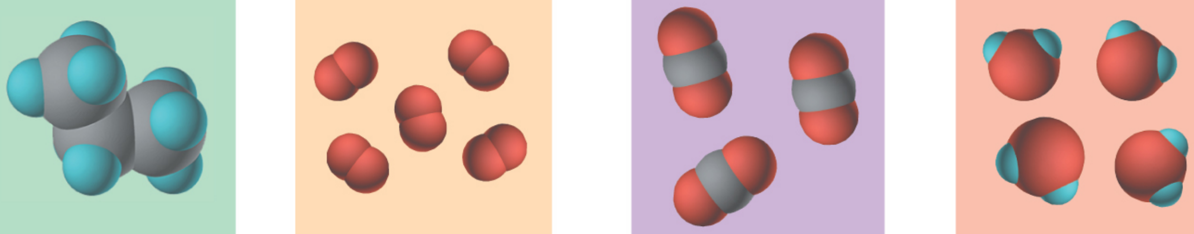
1. **1.**

the relationship between the relative quantities of substances taking part in a reaction or forming a compound, typically a ratio of whole integers.

Origin: early 19th cent.: from Greek *stoikheion* 'element' + -metry.

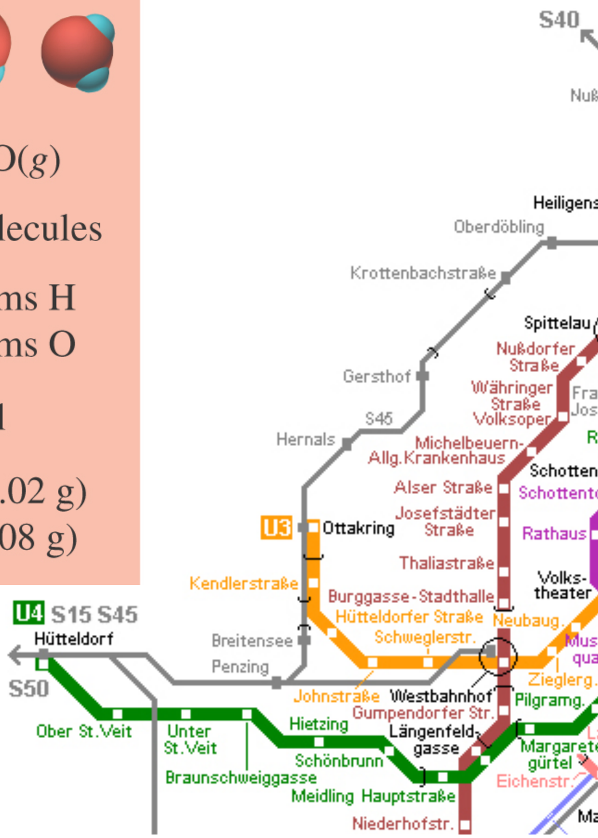
Stoichiometry

$$C_3H_8\ (g) + 5\ O_2\ (g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O\ (g)$$



Propane		Oxygen		Carbon dioxide		Water
$C_3H_8(g)$	+	$5\ O_2(g)$	→	$3\ CO_2(g)$	+	$4\ H_2O(g)$
1 molecule		5 molecules		3 molecules		4 molecules
3 atoms C 8 atoms H		10 atoms O		3 atoms C 6 atoms O		8 atoms H 4 atoms O
1 mol		5 mol		3 mol		4 mol
44.09 g		5 (32.00 g) (160.0 g)		3 (44.01 g) (132.0 g)		4 (18.02 g) (72.08 g)

Don't confuse coefficients and subscripts!



The mole ratio

$$C_3H_8\ (g) + 5\ O_2\ (g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O\ (g)$$

- If I consume 15 molecules oxygen, how many water molecules do I create?

$$15 \text{ molecules } O_2 \cdot \frac{4 H_2O}{5 O_2} = 12 \text{ molecules } H_2O$$

- If I consume 2.7 mol oxygen, how many mol water do I create?
  - … and how many mol CO_2 do I create?
  - … and how many mol C_3H_8 do I consume?

The mole ratio

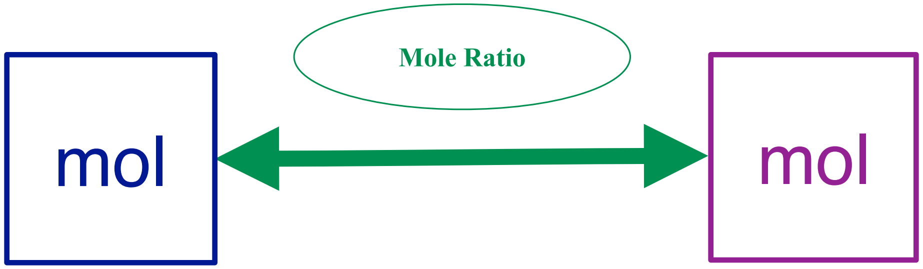
$$2{,}7 \text{ mol } O_2 \cdot \frac{4 H_2O}{5 O_2} = 2{,}2 \text{ mol } H_2O$$

$$2{,}7 \text{ mol } O_2 \cdot \frac{3 CO_2}{5 O_2} = 1{,}6 \text{ mol } CO_2$$

$$2{,}7 \text{ mol } O_2 \cdot \frac{1 C_3H_8}{5 O_2} = 0{,}54 \text{ mol } C_3H_8$$

The mole ratio

C_3H_8 (g) + 5 O_2 (g) → 3 CO_2 (g) + 4 H_2O (g)



mol

Mole Ratio

mol

5 O_2 = 3 CO_2
5 O_2 = 4 H_2O
1 C_3H_8 = 3 CO_2
3 CO_2 = 4 H_2O
…

There are 12 combinations in this reaction.
12 mole ratio conversion factors.
The Balanced Equation unlocks them all.

This tool is especially powerful when we
combine it with tools from the previous chapters.

Elements like Copper (Cu)

- In chapter 2
  we introduced 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)

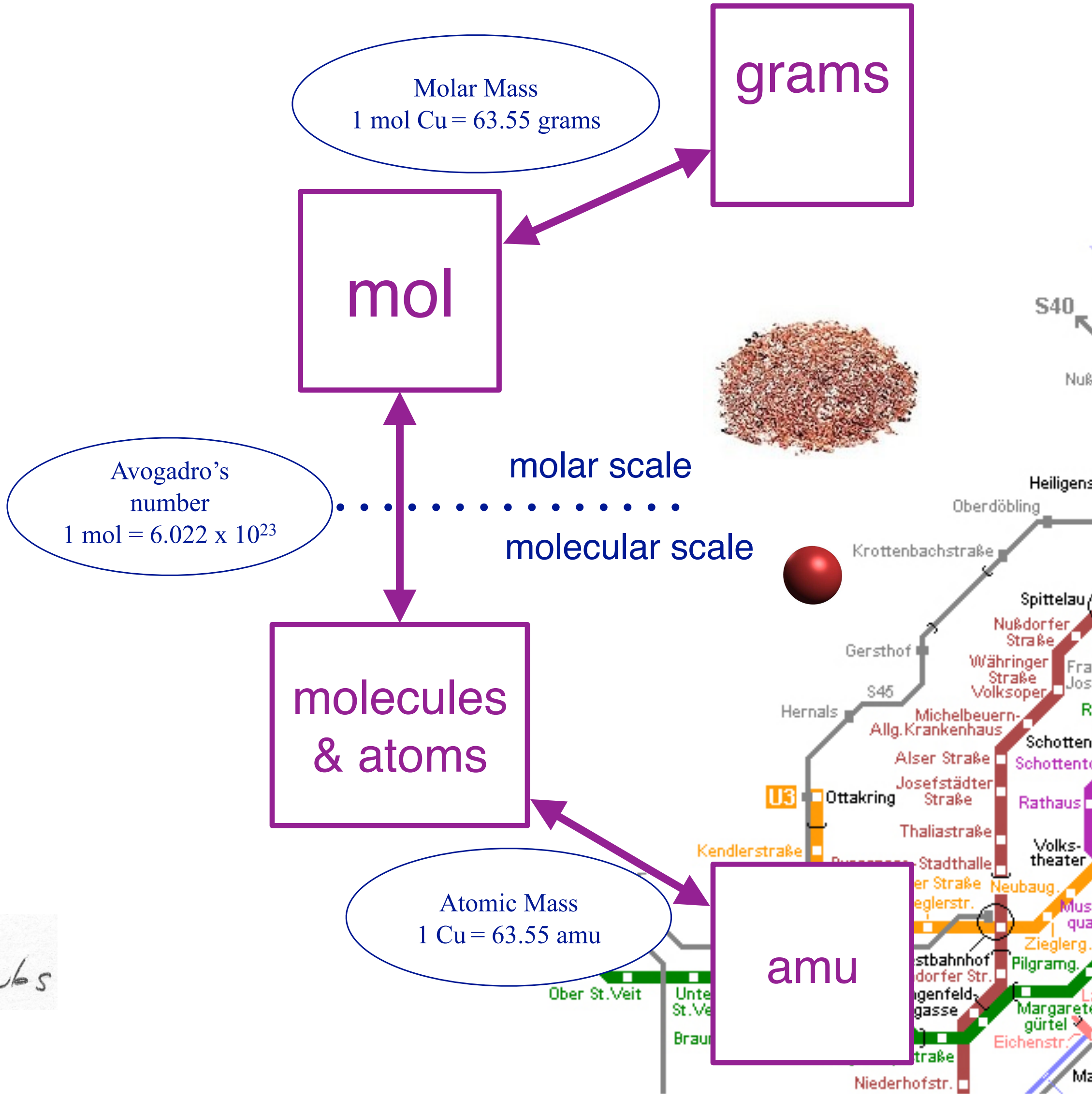
grams → mol

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

  - 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

$$0.260\,mol\ Cu \cdot \frac{6.022\times10^{23}}{1\,mol} = 1.56\times10^{23}\,molecules$$



Molar Mass
1 mol Cu = 63.55 grams

grams

mol

Avogadro's
number
1 mol = 6.022 x 10^{23}

molar scale

molecular scale

molecules
& atoms

Atomic Mass
1 Cu = 63.55 amu

amu

Chapter 3: Molecular Formula & Molar Mass

Molecules like Water (H_2O)

- In chapter 3, we took apart molecules and introduced new 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.

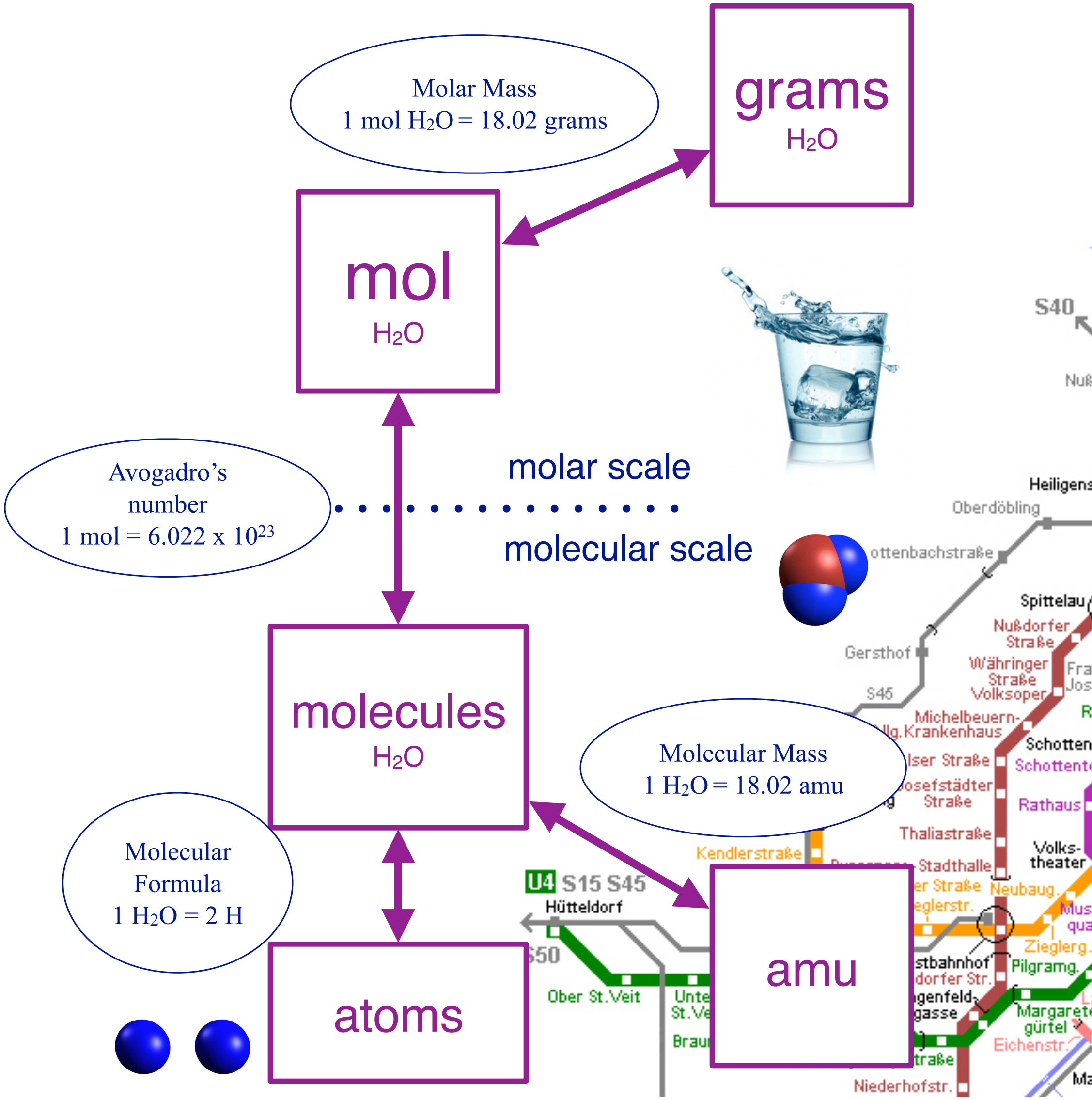
molecules $H_2O \rightarrow$ atoms H

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

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

mol $\rightarrow$ grams

$2.5 \text{ mol } H_2O \cdot \frac{18.02 \text{ g}}{1 \text{ mol}} = 45{,}05 \text{ g } H_2O$



Molar Mass
1 mol H_2O = 18.02 grams

grams
H_2O

mol
H_2O

Avogadro's number
1 mol = 6.022×10^{23}

molar scale

molecular scale

molecules
H_2O

Molecular Mass
1 H_2O = 18.02 amu

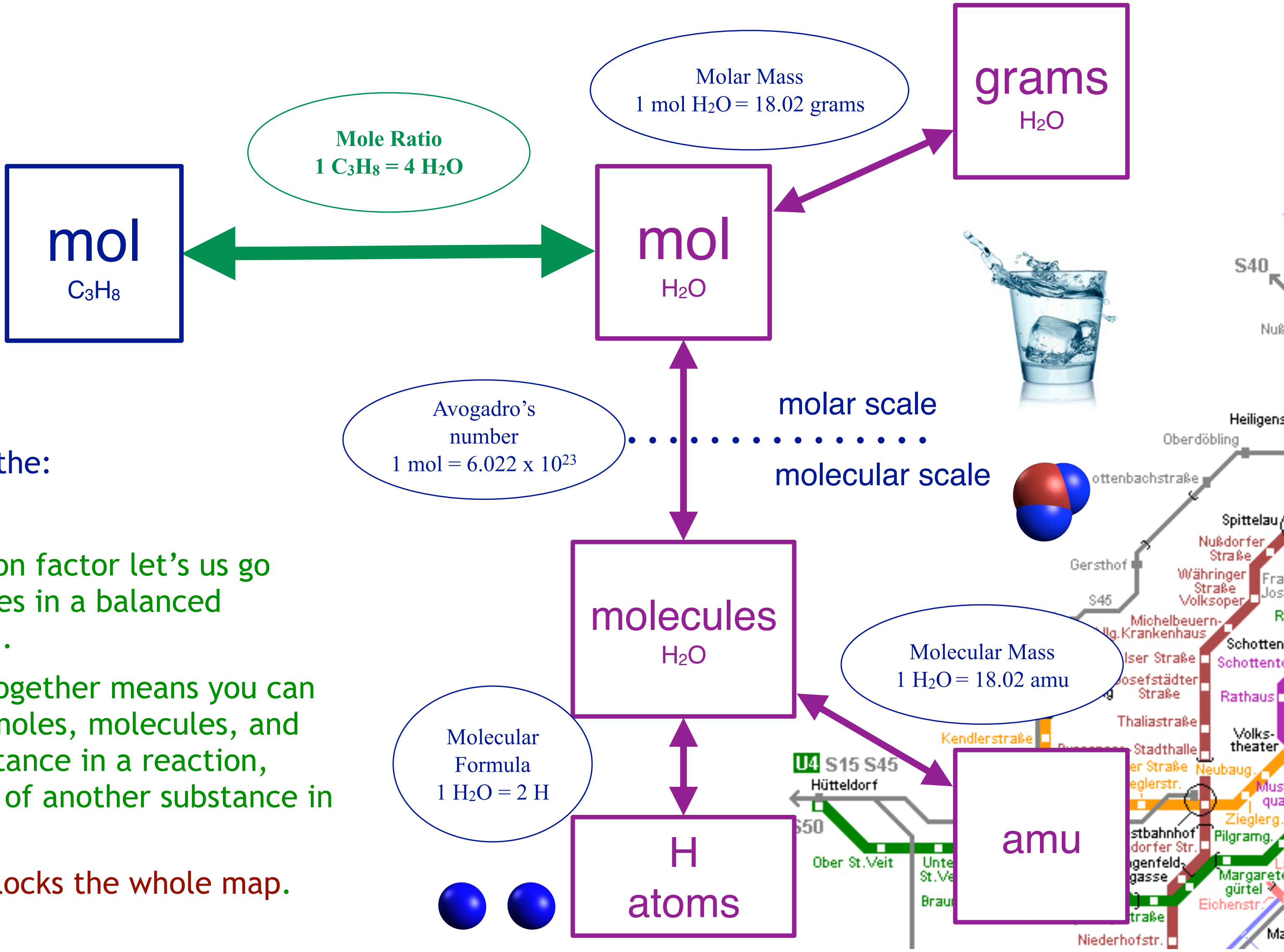
Molecular Formula
1 H_2O = 2 H

atoms

amu

Chapter 4: the Mole Ratio

$$C_3H_8\ (g) + 5\ O_2\ (g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O\ (g)$$



Mole Ratio
1 C_3H_8 = 4 H_2O

Molar Mass
1 mol H_2O = 18.02 grams

Avogadro's number
1 mol = 6.022×10^{23}

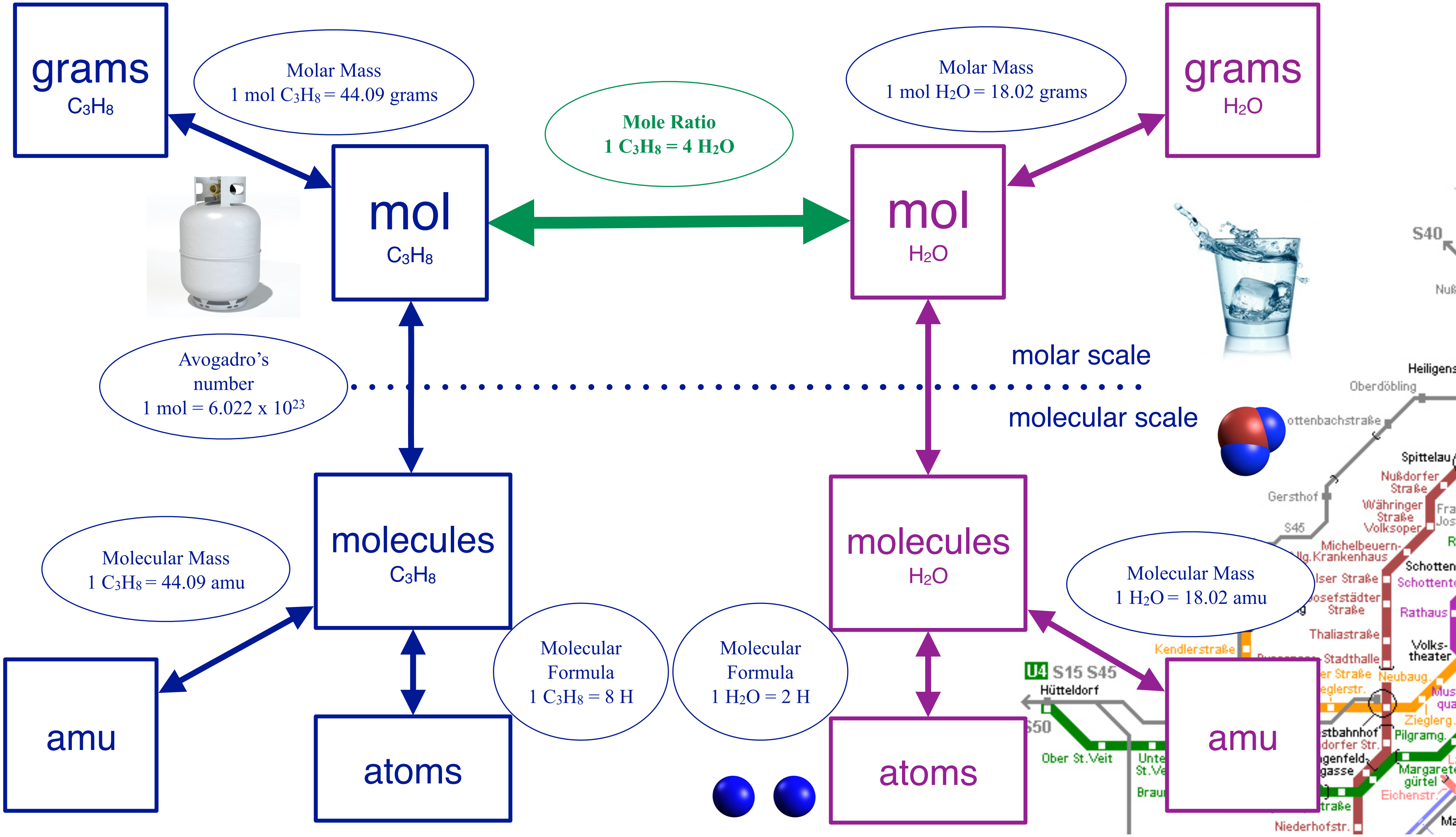
Molecular Formula
1 H_2O = 2 H

Molecular Mass
1 H_2O = 18.02 amu

- In chapter 4 we introduce the:
  - Mole Ratio
    - This new conversion factor let's us go between substances in a balanced chemical equation.
    - Putting them all together means you can calculate grams, moles, molecules, and more for any substance in a reaction, from any quantity of another substance in the reaction.
    - The mole ratio unlocks the whole map.

Using a Balanced Equation

$C_3H_8\ (g) + 5\ O_2\ (g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O\ (g)$



grams C_3H_8

Molar Mass
1 mol C_3H_8 = 44.09 grams

mol C_3H_8

Mole Ratio
1 C_3H_8 = 4 H_2O

Molar Mass
1 mol H_2O = 18.02 grams

grams H_2O

mol H_2O

Avogadro's number
1 mol = 6.022 x 10^{23}

molar scale

molecular scale

Molecular Mass
1 C_3H_8 = 44.09 amu

molecules C_3H_8

molecules H_2O

Molecular Mass
1 H_2O = 18.02 amu

amu

Molecular Formula
1 C_3H_8 = 8 H

Molecular Formula
1 H_2O = 2 H

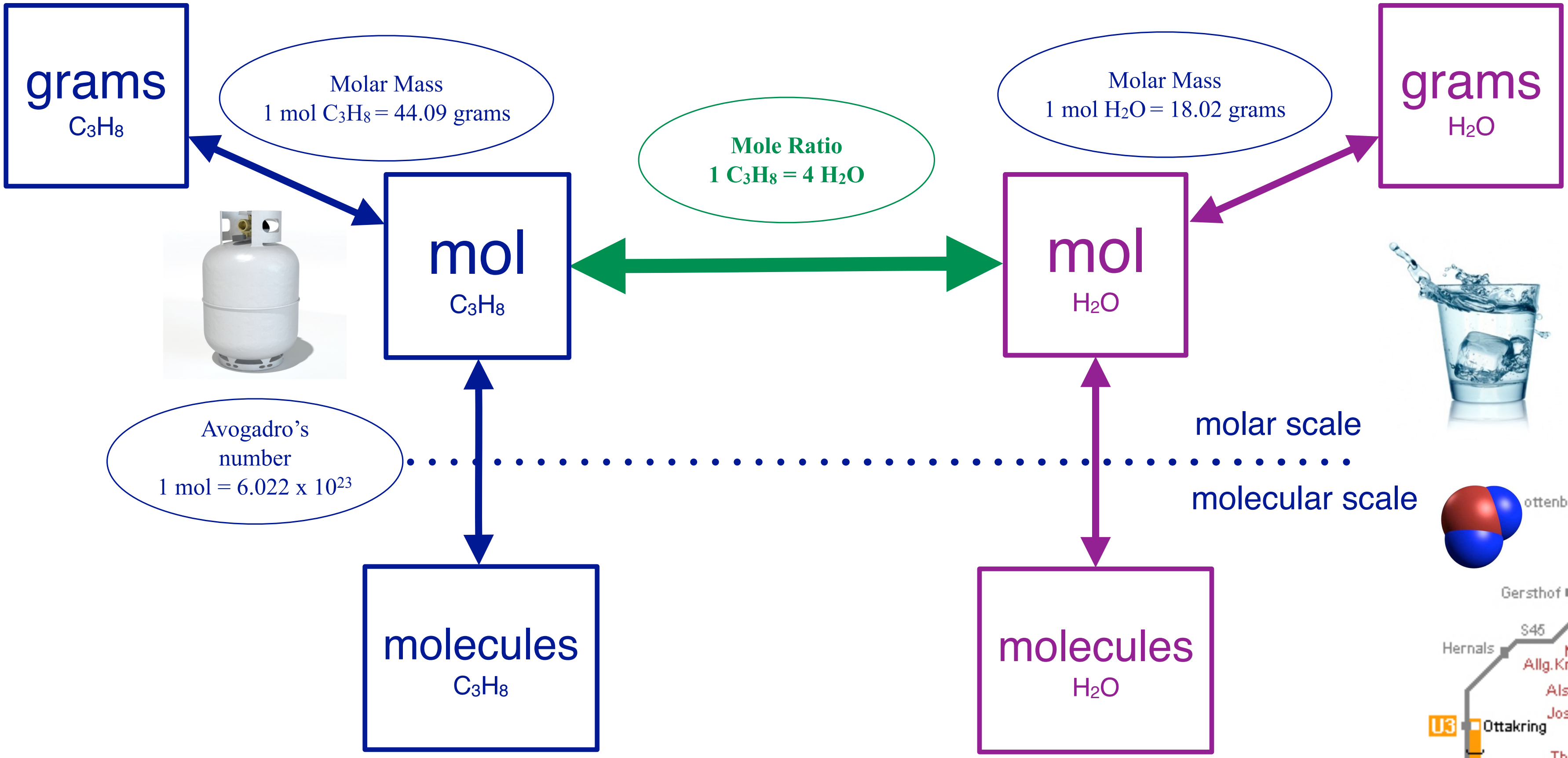
atoms

atoms

amu

Using a Balanced Equation

$C_3H_8\ (g) + 5\ O_2\ (g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O\ (g)$



grams C_3H_8

Molar Mass
1 mol C_3H_8 = 44.09 grams

mol C_3H_8

Mole Ratio
1 C_3H_8 = 4 H_2O

mol H_2O

Molar Mass
1 mol H_2O = 18.02 grams

grams H_2O

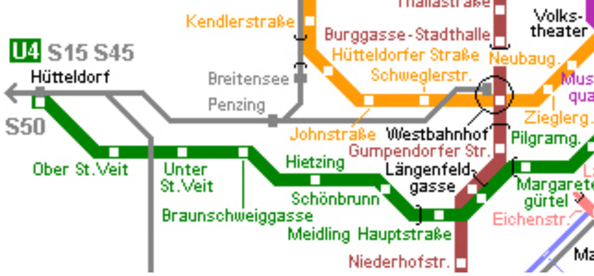
Avogadro's number
1 mol = 6.022 x 10^{23}

molar scale

molecular scale

molecules C_3H_8

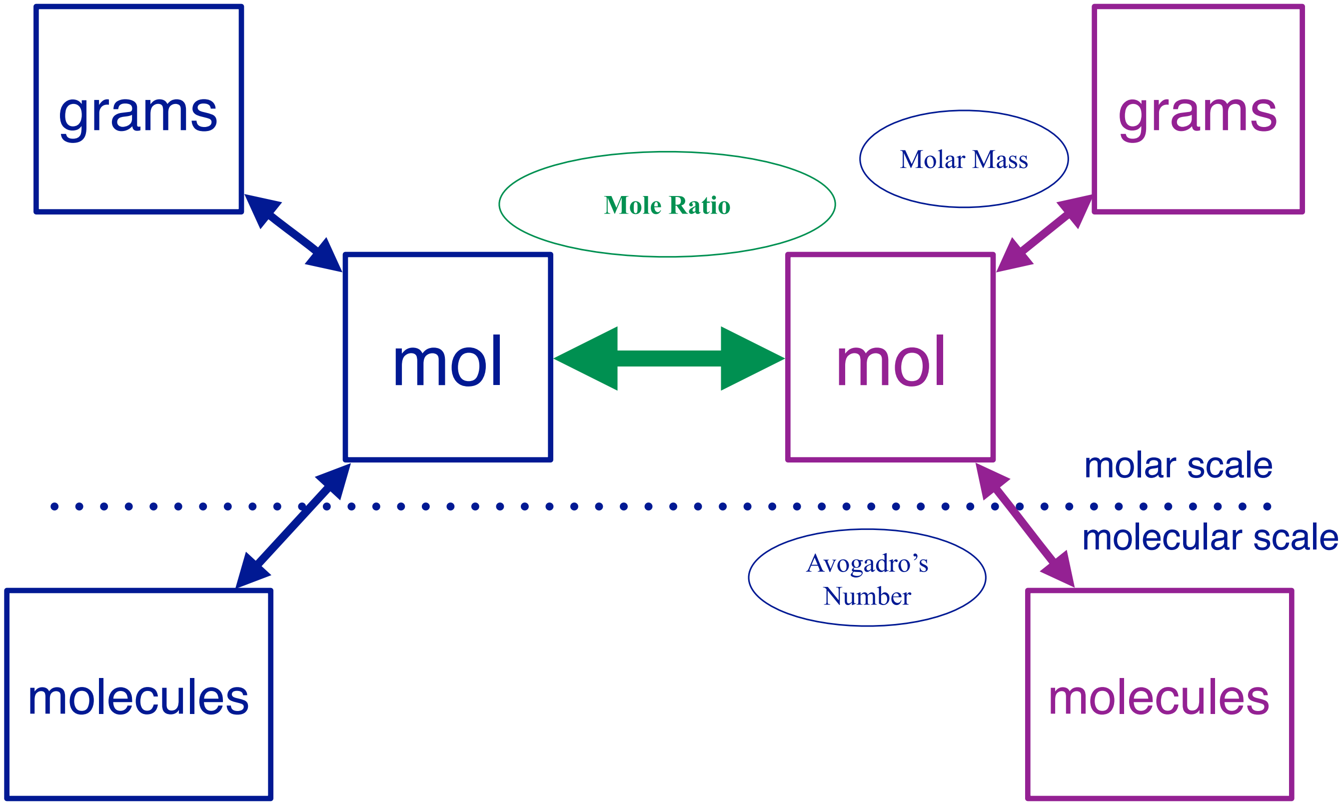
molecules H_2O



- For this discussion we will focus on grams, moles, and molecules.
- You are responsible for all the conversions in chapter 2 and 3 as well.

Using a Balanced Equation

$$C_3H_8\ (g) + 5\ O_2\ (g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O\ (g)$$



grams

Mole Ratio

Molar Mass

grams

mol

mol

molar scale

molecular scale

Avogadro's Number

molecules

molecules

- We will use the molecular scale to design and understand reactions.
- We will use the molar scale to conduct reactions.
- We will add more conversion factors that start with mols, in future chapters.
- But the mole ratio will stay at the heart of all our reaction stoichiometry maps.

Ch10

Stoichiometry

- Stoichiometry & the mole ratio.
  - A new conversion factor.
  - Already in our tool box:
    - Atomic Mass; Molar Mass; Avogadro's # (chapter 2)
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- The balanced equation.
  - Example Stoichiometry Calculations
    - mol → mol calcs (2 steps)
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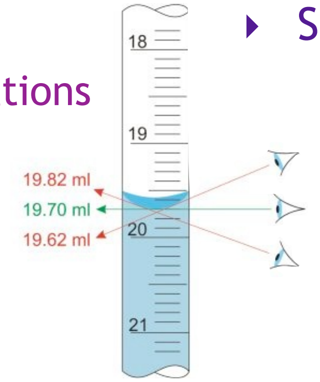

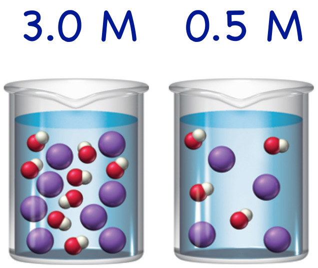

- Solution concentration.
  - What concentration means?
  - Measures of concentration.
    - Molarity and others.
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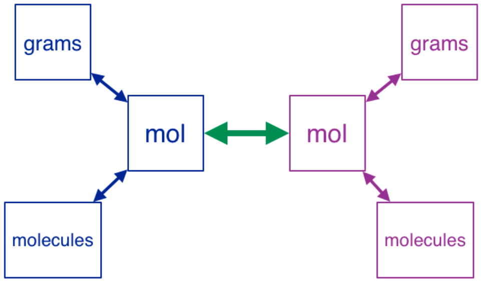
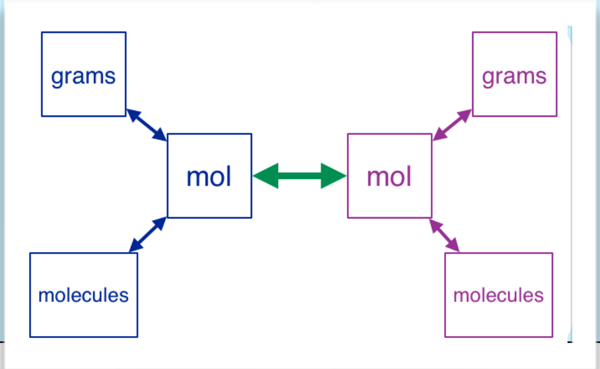


Problem:

How many moles of C_3H_8 can you burn in 19.2 mol of oxygen gas?



Solution

$$C_3H_8\ (g) + 5\ O_2\ (g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O\ (g)$$

①

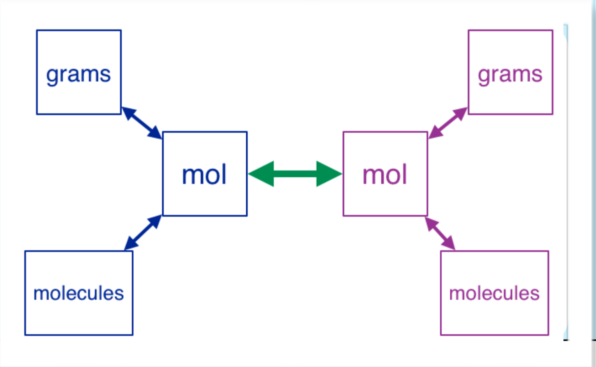
mol O_2 → mol C_3H_8

① $5\ O_2 = 1\ C_3H_8$

$$19.2 \text{ mol } O_2 \cdot \frac{1\ C_3H_8}{5\ O_2} = \boxed{3.84 \text{ mol } C_3H_8}$$

Problem:

How many moles of C_3H_8 were burnt to produce 26.2g of carbon dioxide?


grams
mol
molecules
grams
mol
molecules

Solution

$$C_3H_8\ (g) + 5\ O_2\ (g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O\ (g)$$

$$g\ CO_2 \xrightarrow{①} mol\ CO_2 \xrightarrow{②} mol\ C_3H_8$$

① molar mass CO_2

$$\begin{array}{lr} 1(C) & 12.011 \\ 2(O) & 32.00 \\ + & \overline{44.011} \end{array}$$

1mol = 44.01g

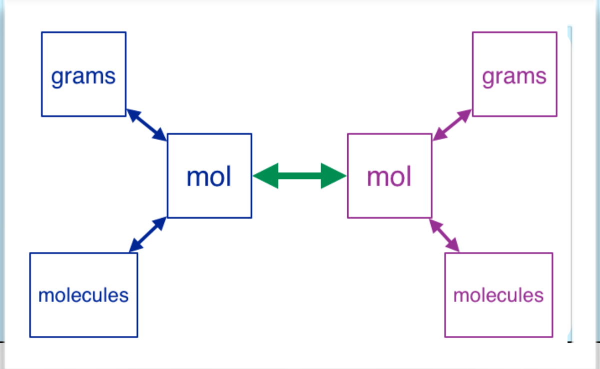
② mole ratio CO_2 / C_3H_8

$3\ CO_2 = 1\ C_3H_8$

$$26.2g\ CO_2 \cdot \frac{1 mol}{44.01g} \cdot \frac{1\ C_3H_8}{3\ CO_2} = \boxed{0.198\ mol\ C_3H_8}$$

Problem:

How many grams of water were produced when you burnt 24.2 grams C_3H_8?


grams

mol

molecules

mol

grams

molecules

Solution

$$C_3H_8\ (g) + 5\ O_2\ (g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O\ (g)$$

① molar mass C_3H_8

3(C) 36.03|4

8(H) 8.06|4

44.09|4

44.09 g = 1 mol

② mol ratio C_3H_8 : H_2O

1 C_3H_8 = 4 H_2O

③ molar mass H_2O

2(H) 2.01|6

1(O) 16.00|

18.01|6

18.02 g = 1 mol

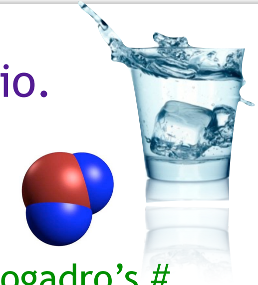
$$g\ C_3H_8 \xrightarrow{①} mol\ C_3H_8 \xrightarrow{②} mol\ H_2O \xrightarrow{③} g\ H_2O$$

$$24.2\,g\ C_3H_8 \cdot \frac{1\,mol}{44.09\,g} \cdot \frac{4\ H_2O}{1\ C_3H_8} \cdot \frac{18.02\,g}{1\,mol} =$$

39.56307553 g

$$\boxed{39.6\,g\ H_2O}$$

Stoichiometry



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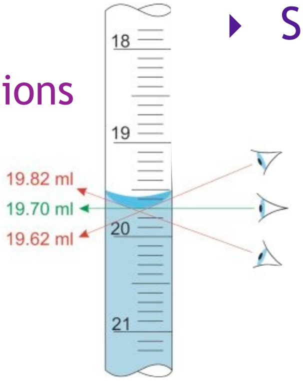

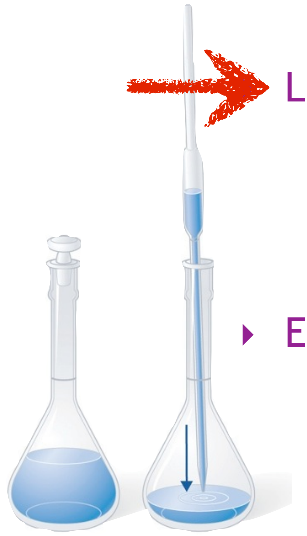

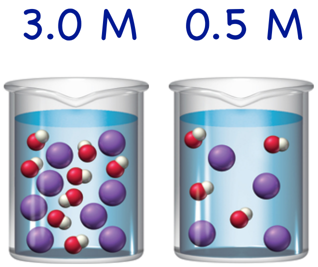

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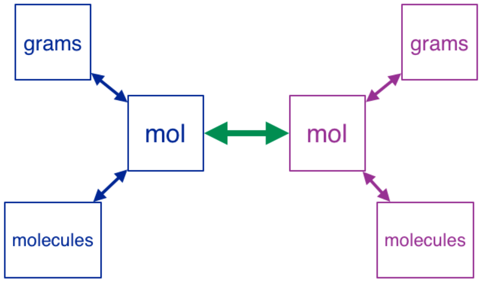
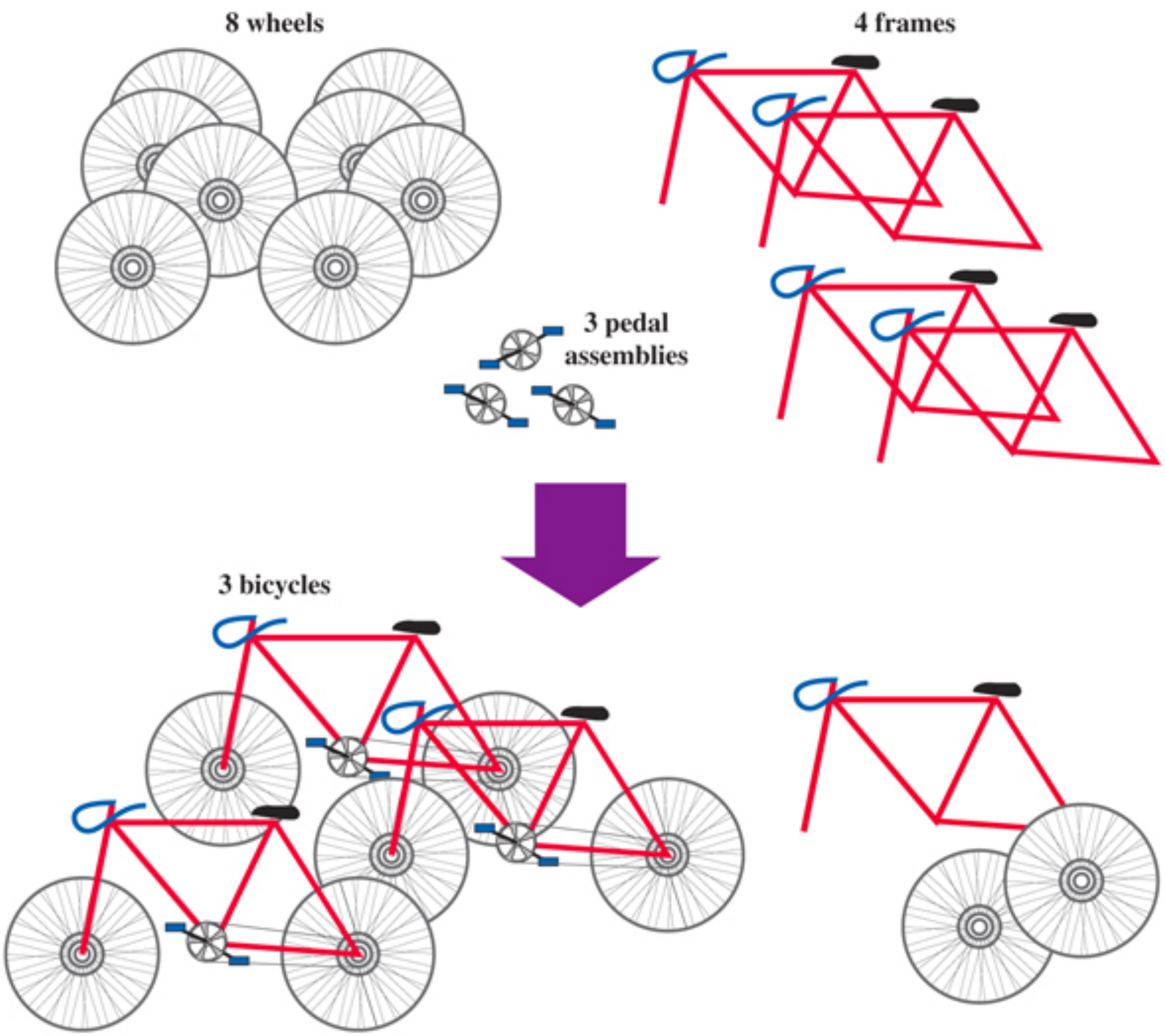
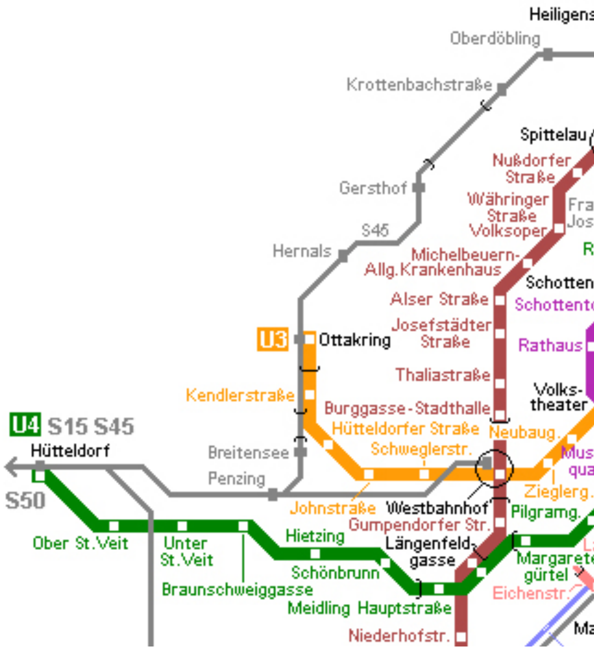


Limiting/Excess Reagents



- The limiting reactant (or limiting reagent) is the reactant that limits the amount of product that can be made.
  - The reaction stops when the limiting reactant is used up.
  - The amount of limiting reactant controls how much product is formed.
- The excess reactant is the reactant that remains when the reaction stops.
  - There is always left over excess reactant.



Limiting/Excess Reagents

- Iron and sulfur react to make iron (III) sulfide. If I have 20.0 grams of each, which is the limiting reagent?

It's just like making bicycles
— which pile runs out first?

Answer: start making bicycles,
the one that makes the least
bicycles is the limiting reagent.

(bicycles = any product)

Limiting/Excess Reagents

- Iron and sulfur react to make iron (III) sulfide. If I have 20.0 grams of each, which is the limiting reagent?

Iron + Sulfur → Iron (III) Sulfide

$Fe + S_8 \longrightarrow Fe_2S_3$

	Fe	S
R	1	8
P	2	3

$Fe + \frac{3}{8} S_8 \longrightarrow Fe_2S_3$

R	1	3
P	2	3

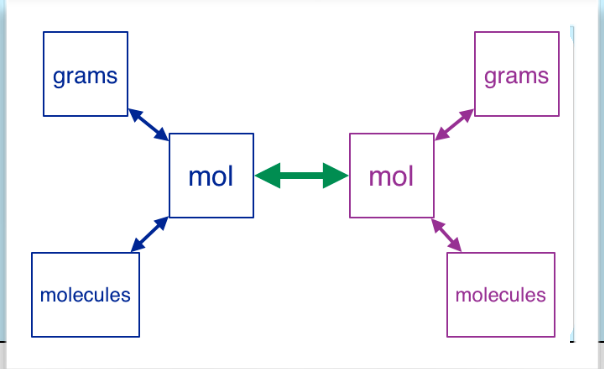
$2Fe + \frac{3}{8} S_8 \longrightarrow Fe_2S_3$

R	2	3
P	2	3

$$\boxed{16Fe + 3S_8 \longrightarrow 8Fe_2S_3}$$

Problem:

Iron and sulfur react to make iron (III) sulfide. If I have 20.0 grams of each, which is the limiting reagent?



Solution

$$\boxed{16Fe + 3S_8 \rightarrow 8Fe_2S_3}$$

$$\text{g Fe} \xrightarrow{\textcircled{1}} \text{mol Fe} \xrightarrow{\textcircled{2}} \text{mol } Fe_2S_3$$

$$\text{g } S_8 \xrightarrow{\textcircled{3}} \text{mol } S_8 \xrightarrow{\textcircled{4}} \text{mol } Fe_2S_3$$

whichever makes the least Fe_2S_3 is the limiting reagent.

① $55.85 g = 1 mol$

② $16 Fe = 8 Fe_2S_3$

③ $8(S) = 32.07 \times 8$
$\approx 256.6 g/mol$

④ $3 S_8 = 8 Fe_2S_3$

Fe

$$20.0g\ Fe \cdot \frac{1 mol}{55.85g} \cdot \frac{8 Fe_2S_3}{16 Fe} = 0.179 \text{ mol } Fe_2S_3$$

S_8

$$20.0g\ S_8 \cdot \frac{1 mol}{256.6g} \cdot \frac{8 Fe_2S_3}{3 S_8} = 0.208 \text{ mol } Fe_2S_3$$

So Iron Runs out First.

Iron is the limiting reagent
Sulfur is the excess reagent.

A word about yield...

$$\frac{S_8}{20.0\text{g } S_8} \cdot \frac{1 \text{ mol}}{256.6\text{g}} \cdot \frac{8 Fe_2S_3}{3 S_8} = 0.208 \text{ mol } Fe_2S_3$$

- So our theoretical yield for this reaction is 0.208 moles (or the equivalent in grams).
- But we rarely achieve a theoretical yield.
- Our actual yield (aka experimental yield) is always less.
- We report the percent yield for any reaction to show how close we came.
  - Percent yield = (experimental yield / theoretical yield) x 100

If our experiment produced 0.135 moles

$$\% Y = \frac{0.135}{0.208} = \underline{64.9\%}$$

Stoichiometry

- Stoichiometry & the mole ratio.
  - A new conversion factor.
  - Already in our tool box:
    - Atomic Mass; Molar Mass; Avogadro's # (chapter 2)
    - Molecular Mass; Molecular Formula (chapter 3)
- The balanced equation.
  - Example Stoichiometry Calculations
    - mol → mol calcs (2 steps)
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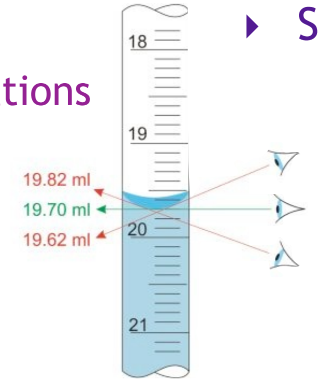

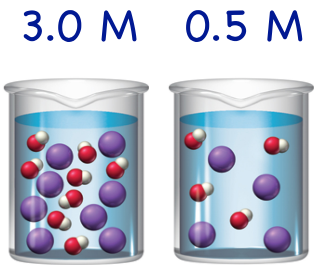

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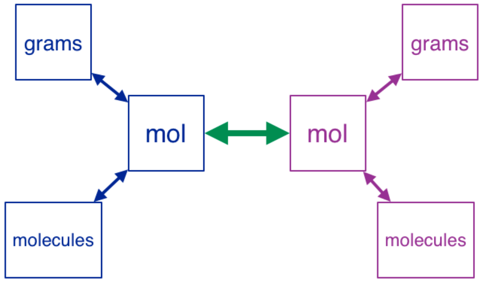


grams

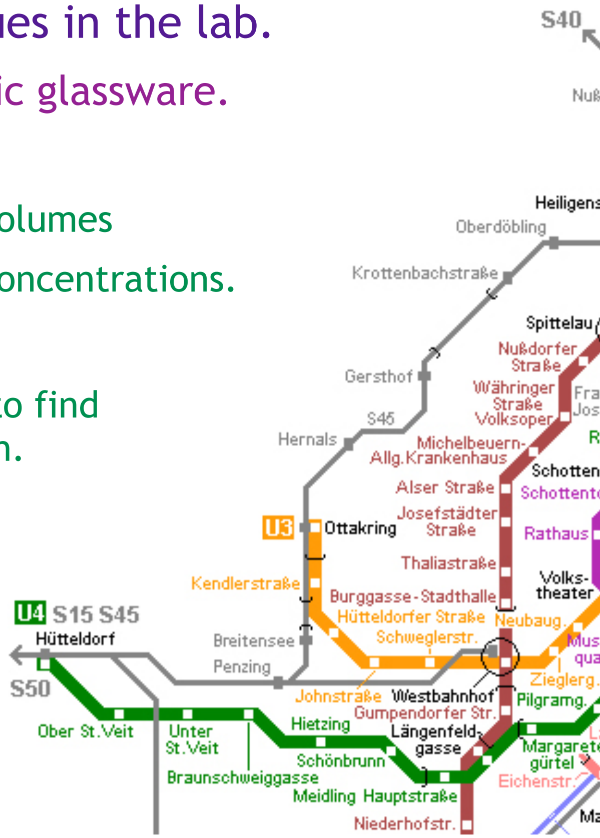
grams

mol

mol

molecules

molecules



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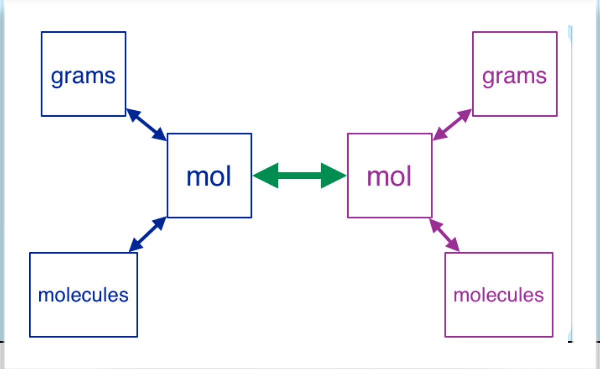
How much of the excess reagent is left over?



Solution

$$\boxed{16\,Fe + 3\,S_8 \rightarrow 8\,Fe_2S_3}$$

$$g\,Fe \xrightarrow{\textcircled{1}} mol\,Fe \xrightarrow{\textcircled{5}} mol\,S_8 \xrightarrow{\textcircled{3}} g\,S_8 \text{ (consumed)}$$

① $55.85\,g = 1\,mol$

② $16\,Fe = 8\,Fe_2S_3$

③ $8\,(S) = 32.07 \times 8$
$= 256.6\,g/mol$

④ $3\,S_8 = 8\,Fe_2S_3$

So Iron Runs out First.
Iron is the limiting reagent
Sulfur is the excess reagent.

⑤ $3\,S_8 = 16\,Fe$

$$20.0\,g\,Fe \cdot \frac{1\,mol}{55.85\,g} \cdot \frac{3\,S_8}{16\,Fe} \cdot \frac{256.6\,g}{1\,mol} = 17.2\,g\,S_8$$

$$\begin{array}{rl} 20.0\,g & \text{(start)} \\ -\ 17.2\,g & \text{(consumed)} \\ \hline 2.8\,g & \text{(left over)} \end{array}$$

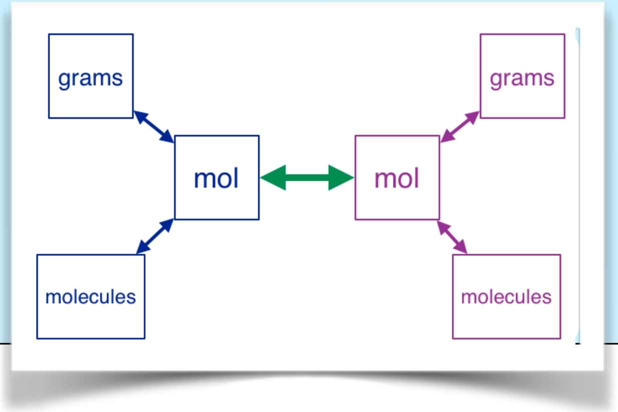
$$\boxed{2.8\,g\,S_8 \text{ leftovr}}$$

Problem:

Stannic oxide (32.4 g) and carbon monoxide (14.3 g) react to form stannous oxide and carbon dioxide.

(a) What is the limiting reagent?

(b) How much of the excess reagent is left over?



Solution

A plan:

Step 1: Find the balanced chemical equation.

Step 2: Figure out how much product (any product) you could get from each reagent. (hint: you'll need mole ratios)

Step 3: Identify the limiting reagent (the one that runs out first)

Step 4: Figure out how much of the excess reagent you actually use.

Step 5: Subtract what you used, from what you started with, to find out how much of the excess reagent is left over.

Problem:

Stannic oxide (32.4 g) and carbon monoxide (14.3 g) react to form stannous oxide and carbon dioxide.

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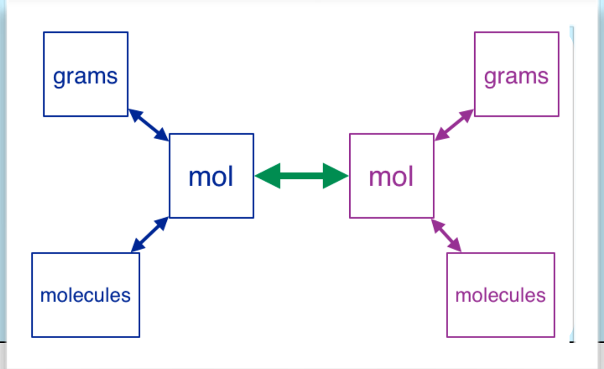

Solution

stannic oxide + carbon monoxide -> stannous oxide + carbon dioxide

Sn^{+4} O^{2-} Sn^{2+} O^{2-}

$$SnO_2 + CO \longrightarrow SnO + CO_2$$

	Sn	C	O
R	1	1	3
P	1	1	3

Problem:

Stannic oxide (32.4 g) and carbon monoxide (14.3 g) react to form stannous oxide and carbon dioxide.

(a) What is the limiting reagent?

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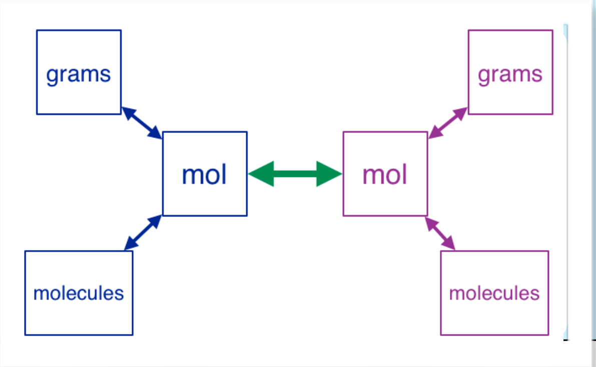


Solution

$SnO_2 + CO \rightarrow SnO + CO_2$

Find Limiting Reagent

$g\,SnO_2 \xrightarrow{①} mol\,SnO_2 \xrightarrow{②} mol\,CO_2$

$g\,CO \xrightarrow{③} mol\,CO \xrightarrow{④} mol\,CO_2$

Find Excess Left Over

$g\,SnO_2 \xrightarrow{①} mol\,SnO_2 \xrightarrow{⑤} mol\,CO \xrightarrow{③} g\,CO$

then subtract from initial grams.

① 1 mol SnO_2 = 150.71 g

$$\begin{array}{r} 118.71 \\ +\ 32.00 \\ \hline 150.71 \end{array}$$

② 1 mol SnO_2 = 1 mol CO_2

③ 1 mol CO = 28.01 g

$$\begin{array}{r} 12.01 \\ +\ 16.00 \\ \hline 28.01 \end{array}$$

④ 1 mol CO = 1 mol CO_2

SnO_2 is Limiting Reagent.

⑤ 1 mol SnO_2 = 1 mol CO

Find Limiting Reagent

$$32.4\,g\,SnO_2 \cdot \frac{1\,mol}{150.71\,g} \cdot \frac{1\,CO_2}{1\,SnO_2} = 0.215\,mol \leftarrow \text{Limiting Reagent}$$

$$14.3\,g\,CO \cdot \frac{1\,mol}{28.01\,g} \cdot \frac{1\,CO_2}{1\,CO} = 0.511\,mol$$

(a) $\boxed{SnO_2 \text{ is the Limiting Reagent}}$

Find Excess Left Over

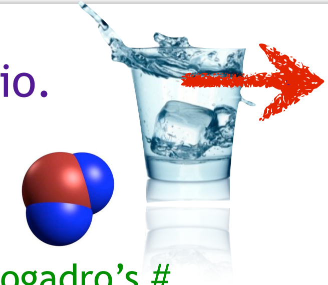
$$32.4\,g\,SnO_2 \cdot \frac{1\,mol}{150.71\,g} \cdot \frac{1\,CO}{1\,SnO_2} \cdot \frac{28.01\,g}{1\,mol} = 6.02\,g\,CO$$

$$\begin{array}{rl} 14.3\,g\,CO & \text{initial} \\ -\ 6.02\,g\,CO & \text{used} \\ \hline 8.28 & \end{array}$$

(b) $\boxed{8.3\,g\,CO \text{ Left Over}}$

Ch10

Stoichiometry



- Stoichiometry & the mole ratio.
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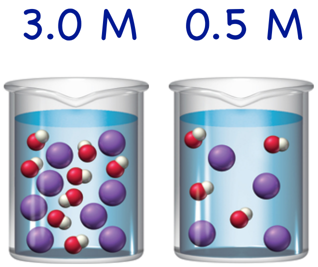

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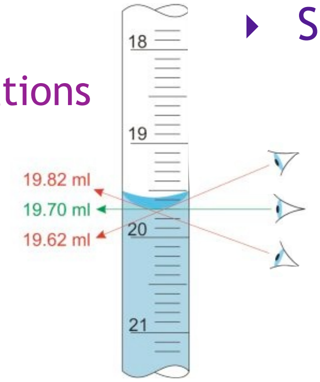
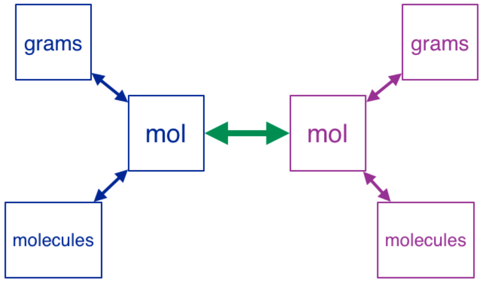
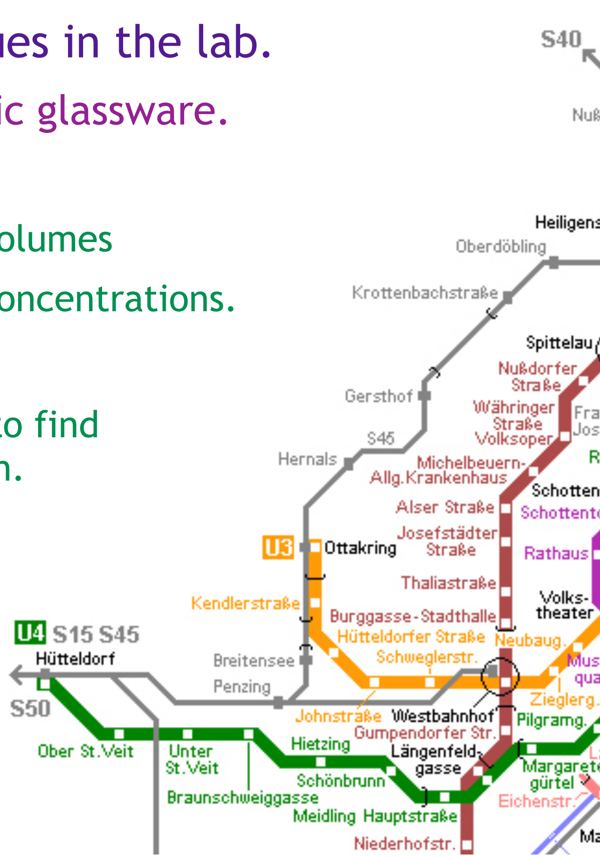




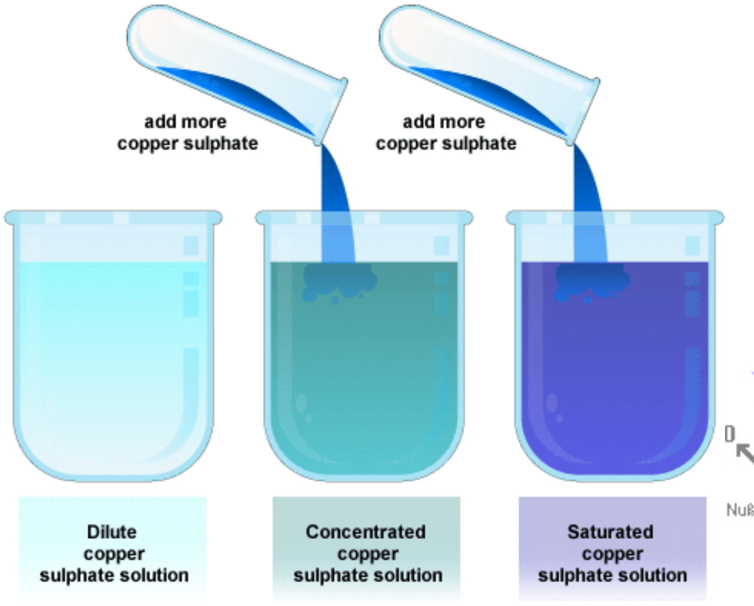


Solutions & Concentration

- Solutions are homogeneous mixtures.
- We know mixtures have tunable properties.
- The properties vary with the ratio of the pure substances that make up that mixture.

We describe that ratio as concentration.

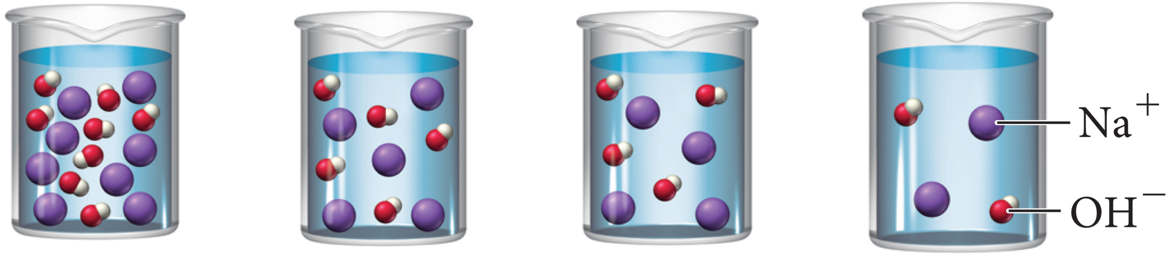
- Concentration is the relationship between amount of a minor component of the mixture (a solute) to the major component of the mixture (the solvent).
- Concentration is how “crowded” the mixture is in a substance.
- Concentration is the amount of a solute in a given quantity of solvent.
- Solutions that contain greater amounts of solute are said to be more concentrated.
- Solutions that contain lesser amounts of solute are said to be more dilute.
- Solutions that contain the maximum amount of solute a solution can hold are said to be saturated.



A solution is a homogenous mixture.

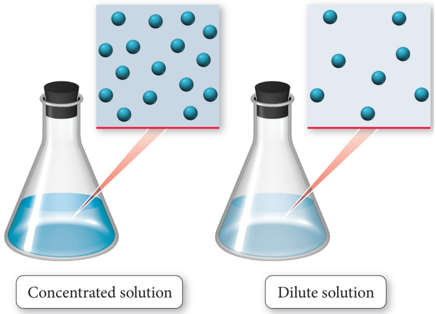
A solvent is the largest component of the mixture.

A solute is a smaller components of the mixture.



Measures of Concentration

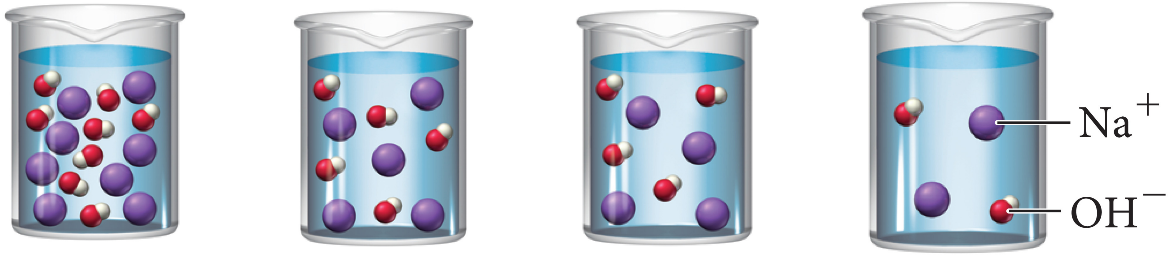
- There are a lot of ways we measure concentration.
- Three common ones are:
  - Mole Fraction (X)
    - Moles of solute per mole of solution.
    - We'll use this when we discuss gases, it's less useful for liquids.
  - Molality (m)
    - Moles of solute, per kg of solution.
    - We won't use this.
  - Molarity (M)
    - Moles of solute per liter of solution.
    - We'll use this **a lot** for liquids.

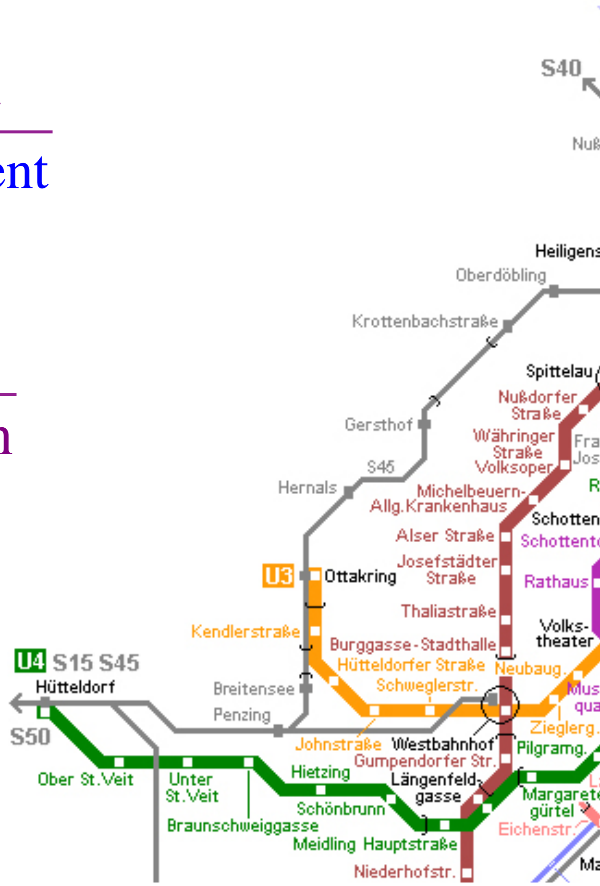


$$X = \frac{\text{moles of solute}}{\text{moles of solution}}$$

$$m = \frac{\text{moles of solute}}{\text{kilogram of solvent}}$$

$$M = \frac{\text{moles of solute}}{\text{liters of solution}}$$

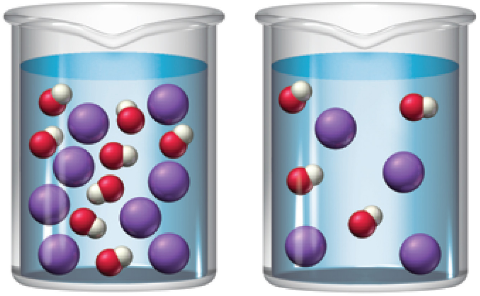




Molarity

$$\frac{\text{mol solute}}{\text{L solution}}$$

- Molarity is a measure of concentration.
- The units of molarity are mol/L. We abbreviate mol/L as “M”
- Molarity is the moles of a solute divided by the volume of the solution.
  - Don’t confuse volume of solution with volume of solvent.
  - Because the solute(s) also add to the volume of the solution Molarity is not the same thing as dividing the moles of solute by volume of solvent.
- It is easier to calculate molarity if we know the total volume of the solution rather than the volume of the solvent.



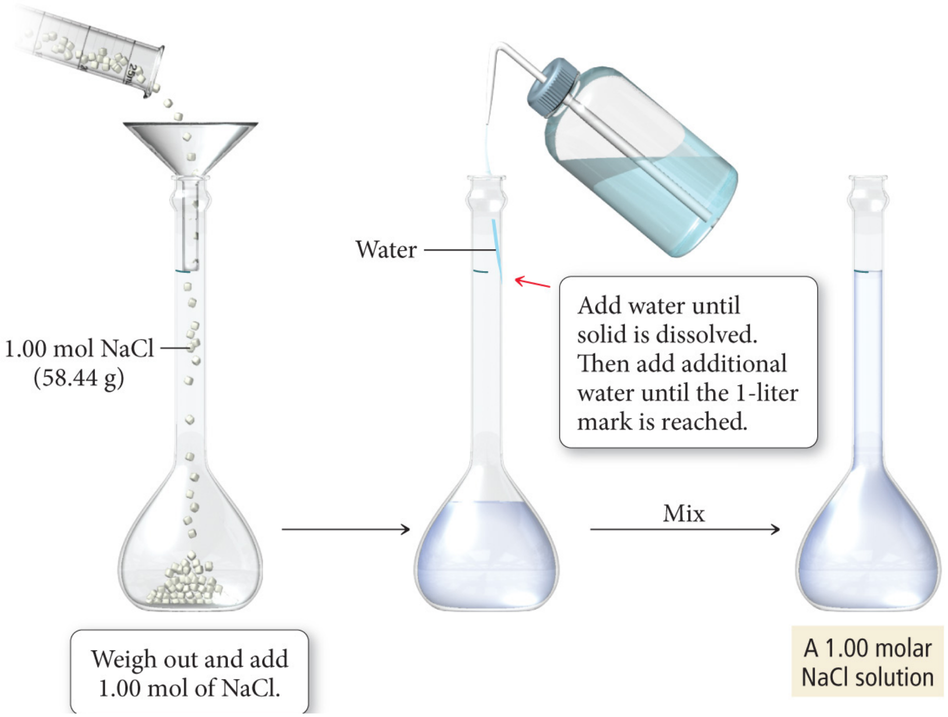
3.0 mol H_2SO_4 $\underline{\underline{\text{dissolved}}}$ in 1.0 L water is:

$$\frac{3.0 \text{ mol } H_2SO_4}{1.0 \text{ L water} + 160 \text{ mL } H_2SO_4} = \frac{3.0 \text{ mol } H_2SO_4}{1.16 \text{ L solution}} =$$

2.6 molar or 2.6 M

3.0 mol H_2SO_4 $\underline{\underline{\text{diluted}}}$ to 1.0 L in water is:

$$\frac{3.0 \text{ mol } H_2SO_4}{1.0 \text{ L solution}} = 3.0 \text{ molar or } 3.0 \text{ M}$$



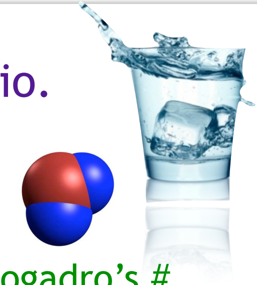
Add water until solid is dissolved. Then add additional water until the 1-liter mark is reached.

Weigh out and add 1.00 mol of NaCl.

A 1.00 molar NaCl solution

Ch10

Stoichiometry



- Stoichiometry & the mole ratio.
  - A new conversion factor.
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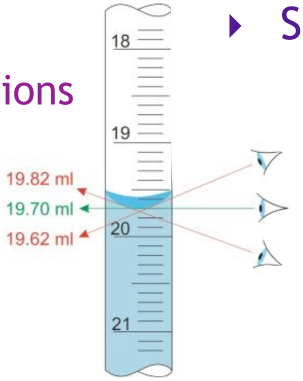

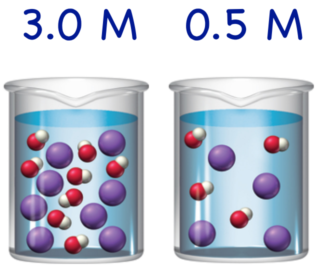

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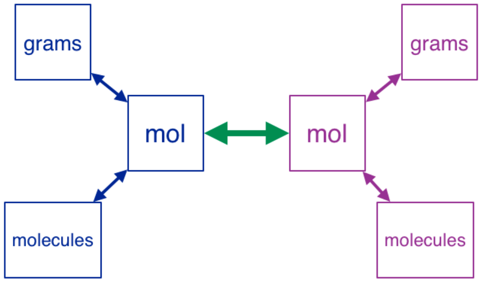


Molarity

mol solute

L solution

- Molarity is the number of moles of a solute divided by the total volume of
- Molarity makes it easy to interconvert between volumes of a solution and mols of solute.
- e.g. if I have 3.0 M H_2SO_4
  - How many mols H_2SO_4 in 0.150 L?

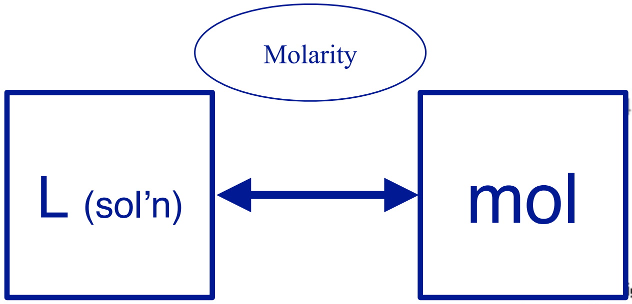
$L \xrightarrow{①} mol$ ① $3.0\,mol = 1\,L$

$$0.150\,L \cdot \frac{3.0\,mol}{1\,L} = 0.45\,mol\ H_2SO_4$$

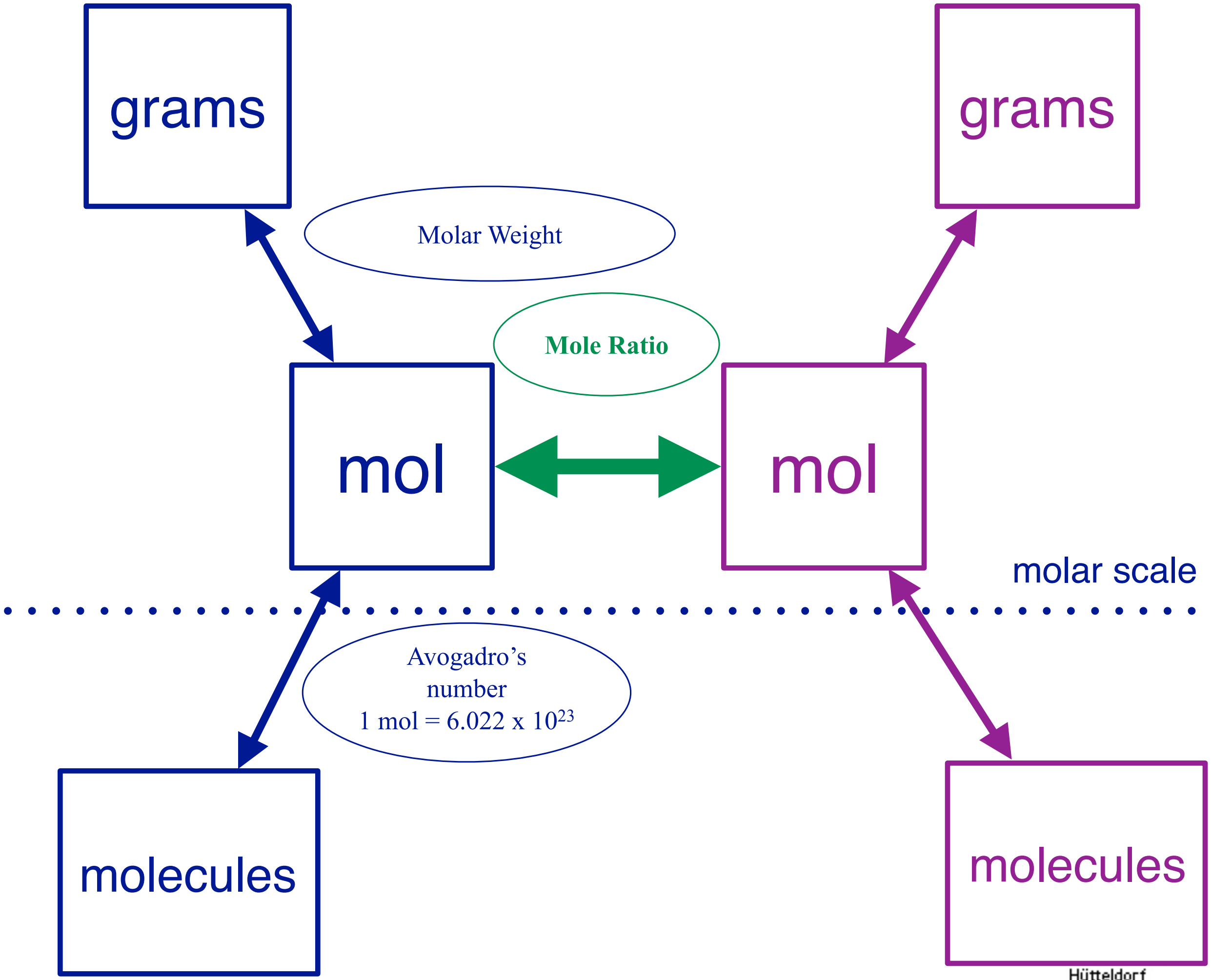
  - What volume do I need to get 0.42 mol?

$mol \xrightarrow{①} L$ ① $3.0\,mol = 1\,L$

$$0.42\,mol \cdot \frac{1\,L}{3.0\,mol} = 0.14\,L \quad (140\,mL)$$



The Molar Subway



grams

grams

Molar Weight

Mole Ratio

mol

mol

molar scale

Avogadro's number

$1\ \text{mol} = 6.022 \times 10^{23}$

molecules

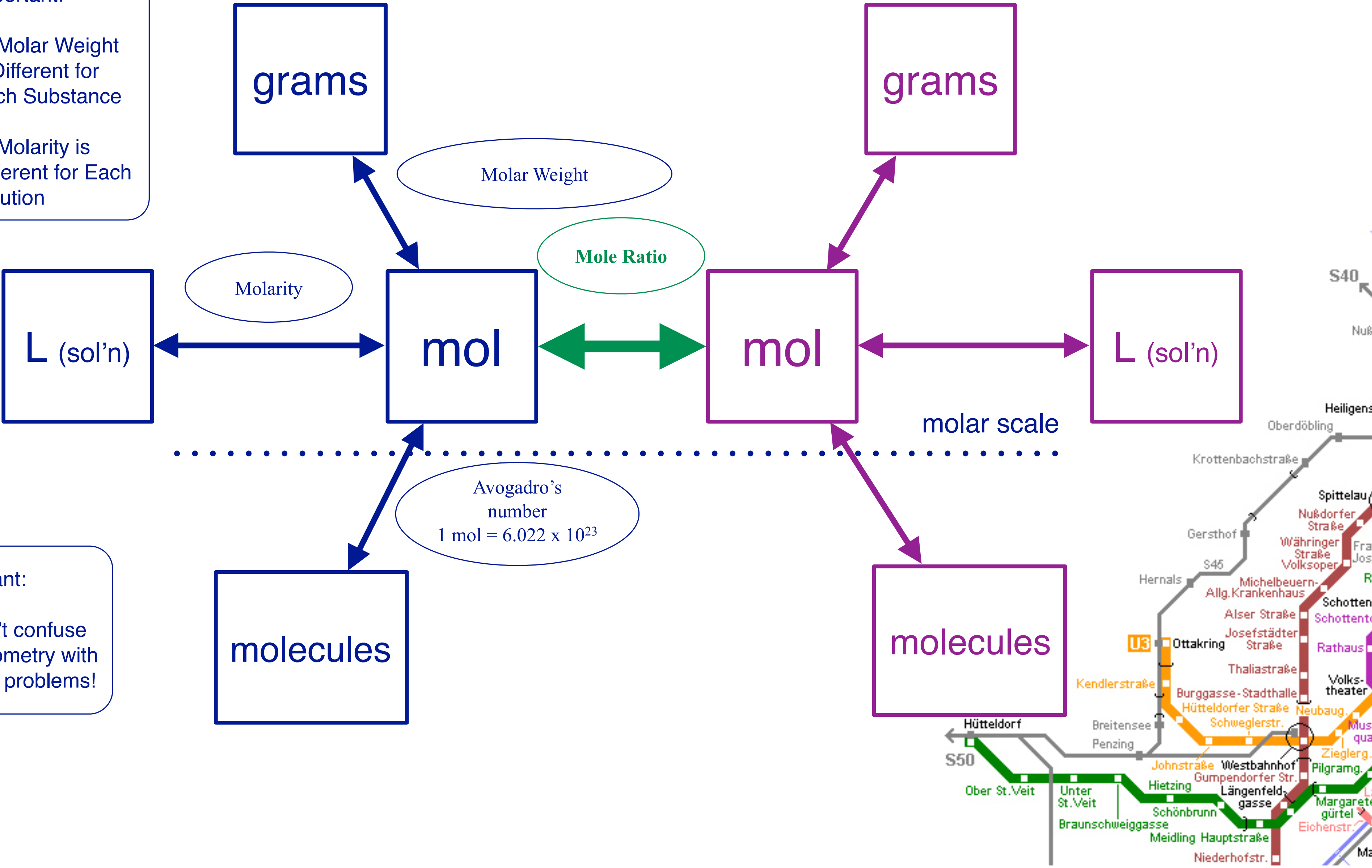
molecules

The Molar Subway

Important:

— Molar Weight is Different for Each Substance

— Molarity is Different for Each Solution



grams

Molar Weight

grams

Mole Ratio

Molarity

L (sol'n)

mol

mol

L (sol'n)

molar scale

Avogadro's number
1 mol = 6.022 x 10^{23}

molecules

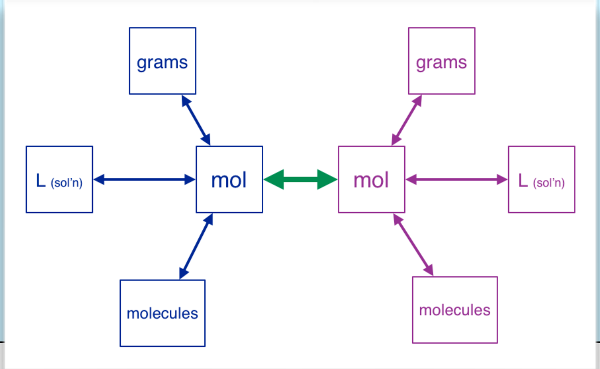
molecules

Important:

— Don't confuse stoichiometry with dilution problems!

Problem:

How many grams of $CaCl_2$ are needed to completely react with 25.0 mL of 0.100 M $AgNO_3$?



Solution

$$CaCl_{2\,(s)} + 2\ AgNO_{3\,(aq)} \rightarrow Ca(NO_3)_{2\,(aq)} + 2\ AgCl_{(s)}$$

$$\underbrace{mL \xrightarrow{①} L \xrightarrow{②} mol}_{AgNO_3} \xrightarrow{③} \underbrace{mol \xrightarrow{④} g}_{CaCl_2}$$

① 1000 mL = 1 L

② 0.100 mol = 1 L

③ $2\ AgNO_3 = 1\ CaCl_2$

④

$$\begin{array}{lr} 1\ (Ca) & 40.078 \\ 2\ (Cl) & 70.906 \\ \hline & 110.984 \end{array}$$

110.984 g = 1 mol

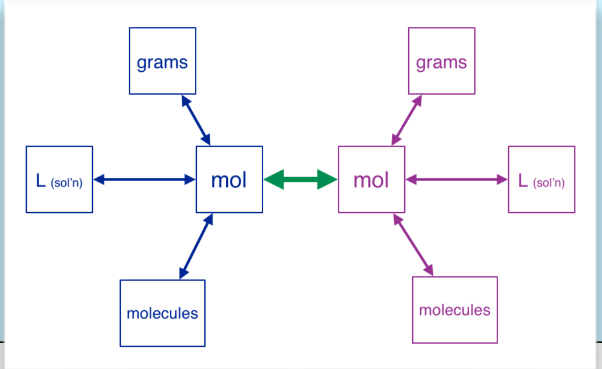
$$\overset{3\ s.f.}{25.0\ mL} \cdot \overset{\infty}{\frac{1\ L}{1000\ mL}} \cdot \overset{3\ s.f.}{\frac{0.100\ mol}{1\ L}} \cdot \overset{\infty}{\frac{1\ CaCl_2}{2\ AgNO_3}} \cdot \overset{6\ s.f.}{\frac{110.984\ g}{1\ mol}} =$$

$$0.13873\ g$$

$$= \boxed{0.139\ g\ CaCl_2}$$

Problem:

How many mL of 3.0 M HNO_3 are needed to completely consume 2.7 g Mg?



Solution

$$Mg_{(s)} + 2\ HNO_{3\,(aq)} \rightarrow Mg(NO_3)_{2\,(aq)} + H_{2(g)}$$

$$\underbrace{g\,Mg \xrightarrow{①} mol\,Mg}_{Mg} \xrightarrow{②} \underbrace{mol \xrightarrow{③} L \xrightarrow{④} mL}_{HNO_3}$$

① 24.3050g = 1mol

② 1 Mg = 2 HNO_3

③ 3.0 M HNO_3

④ 1L = 1000 mL

$$2.7g \cdot \frac{1\,mol}{24.3050g} \cdot \frac{2\,HNO_3}{1\,Mg} \cdot \frac{1\,L}{3.0\,mol} \cdot \frac{1000\,mL}{1\,L} = \boxed{74\,mL}$$

Ch10

Stoichiometry

- Stoichiometry & the mole ratio.
  - A new conversion factor.
  - Already in our tool box:
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      (chapter 2)
    - Molecular Mass; Molecular Formula
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- The balanced equation.
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    - What is a limiting reagent?
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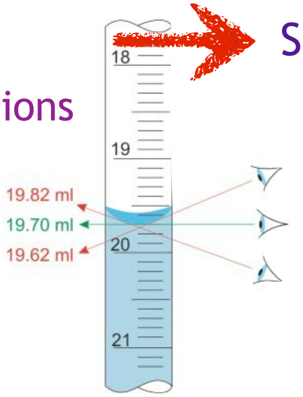

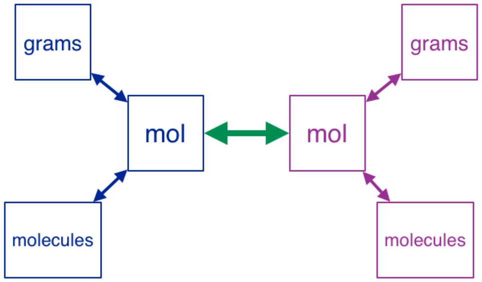

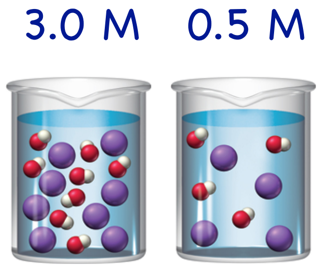

- Solution concentration.
  - What concentration means?
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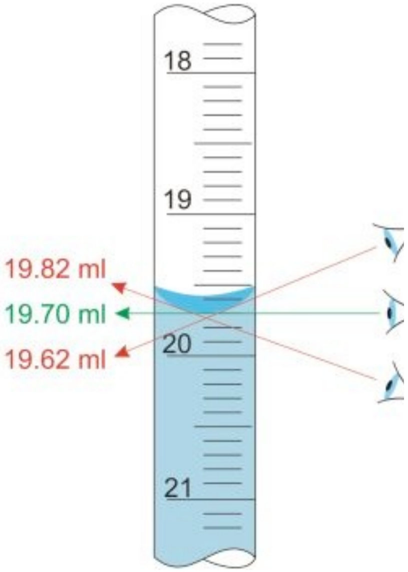
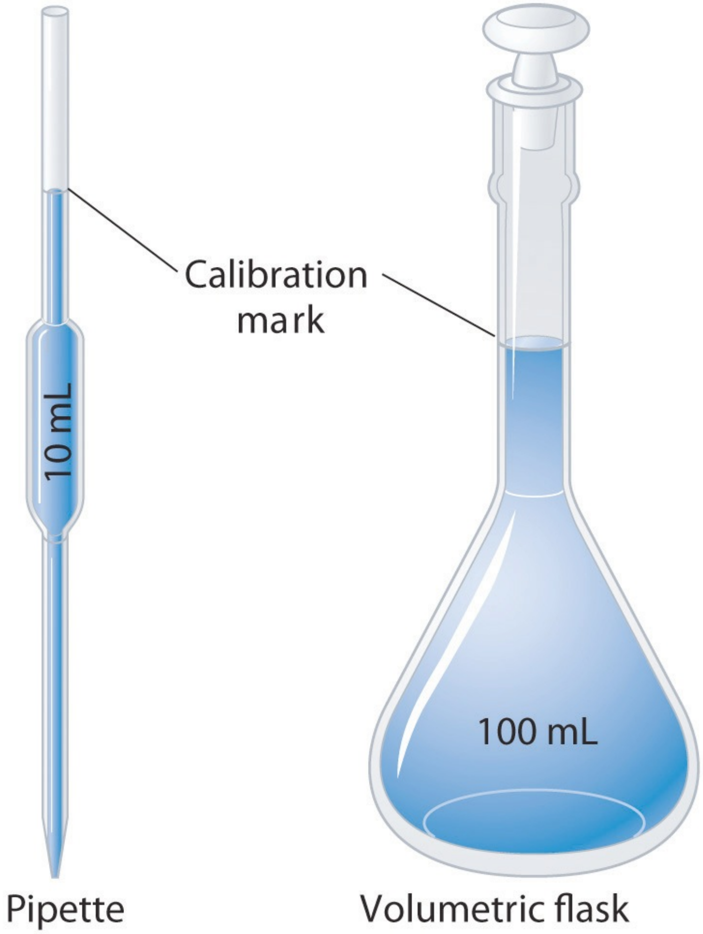
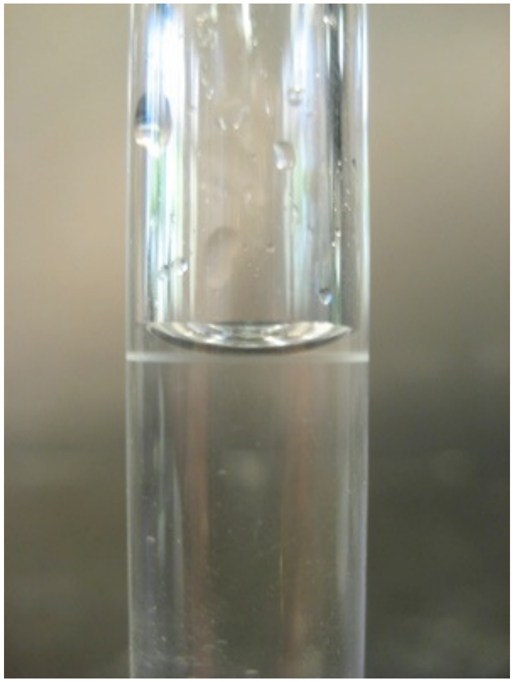
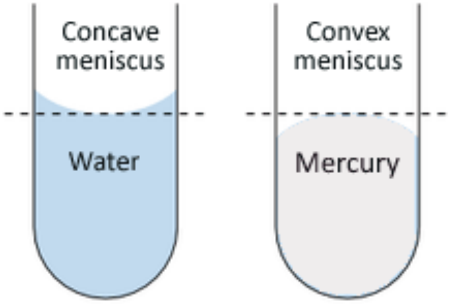
Volumetric Glassware

- Volumetric Pipets and Volumetric Flasks have a long thin neck and with a calibration mark.
- Small changes in volume make big changes in the level of the liquid allowing you to precisely measure the volume for which the device is calibrated.
- The volume is right when the meniscus of the liquid meets the calibration mark.









Dilution

- Stock solutions are solutions of known concentration.
- Most solutions are made by diluting a stock solution to a new molarity.
- Dilution just means adding more solvent.
- Dilution never changes the number of mols dissolved in the solution.
  - just the volume of the solution around them.
- Molarity and volume change with dilution, but because the mols don't change…
  - the ratio of volume to molarity is constant.

- What volume must you dilute 25 mL of 8.0 M $Ca(NO_3)_2$ to make a 2.0 M solution?

$$V_A = \frac{V_B M_B}{M_A} = \frac{8.0M \cdot 25mL}{2.0M} = 100mL$$

$$(1.0 \times 10^2 mL)$$

- How many mL of 6.0 M $HCl_{(aq)}$ do you need to make 200. mL of 2.0 M $HCl_{(aq)}$?

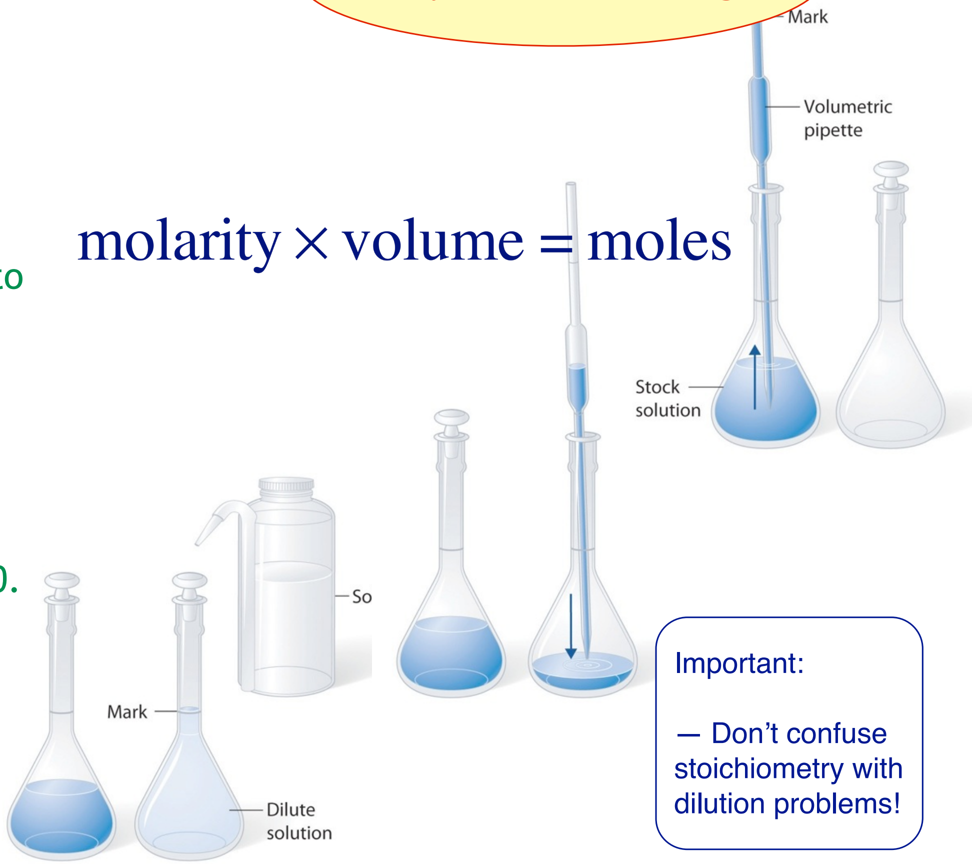
$$V_B = \frac{V_A M_A}{M_B} = \frac{200.mL \cdot 2.0M}{6.0M} = 67mL$$

moles before = moles after

$$v_{before} M_{before} = v_{after} M_{after}$$

only when diluting!

molarity × volume = moles



Important:

— Don't confuse stoichiometry with dilution problems!

Ch10

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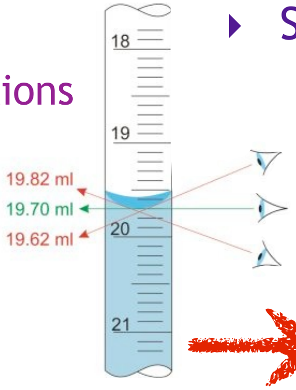

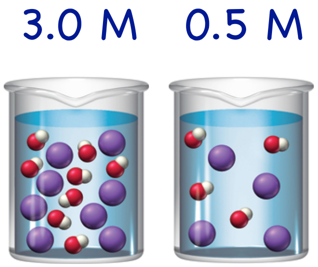

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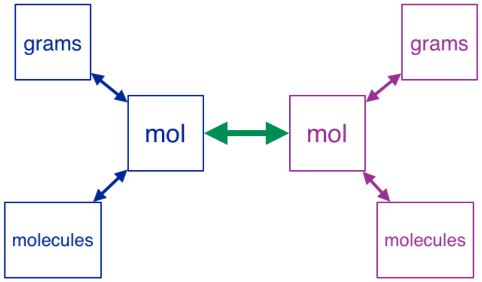
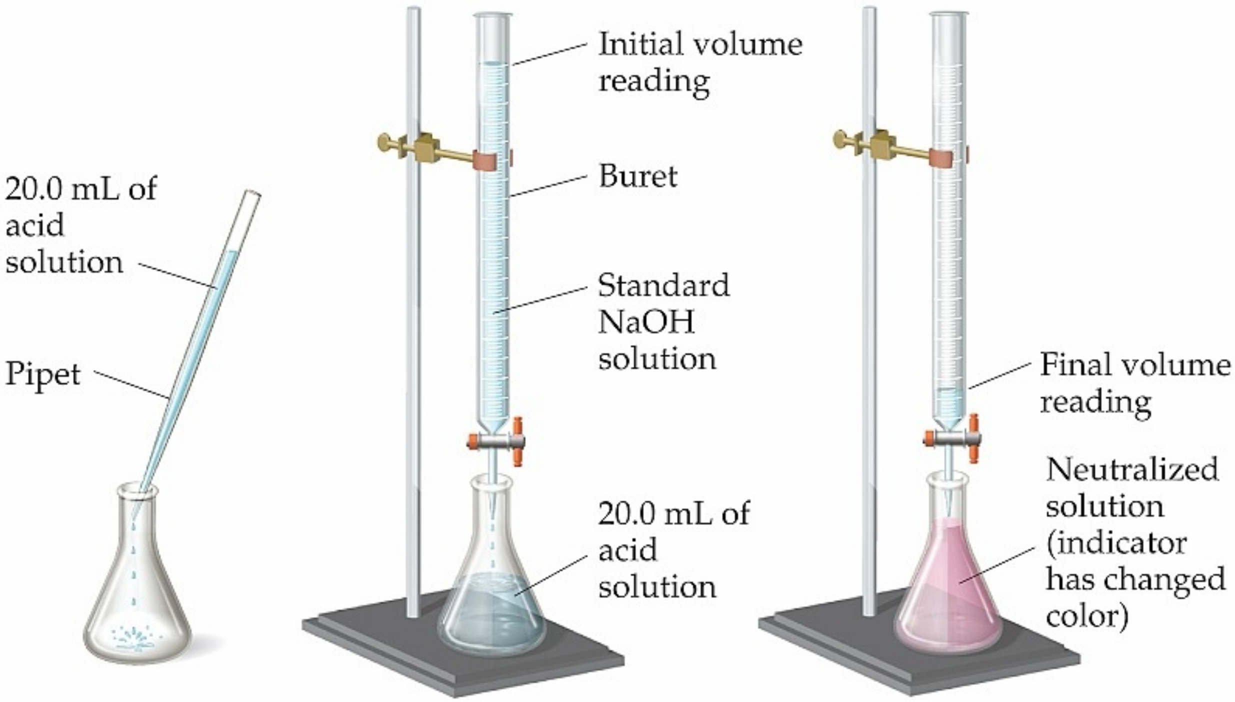


Titration

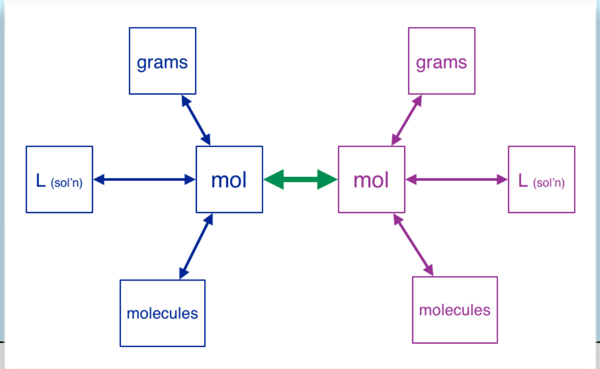
$HCl_{(aq)} + NaOH_{(aq)} \rightarrow H_2O_{(l)} + NaCl_{(aq)}$

- Titration is an analytic technique for determining the concentration in one solution by carefully adding a measured quantity of a known solution and observing a clear end point.
- The unknown is called an analyte.
- The standard solution is called a titrant or titrator.
- The end point is the point in the experiment where an indicator suggests the quantities of analyte and titrant are equal.
- The equivalence point is the point where they actually are.
  - With a good chemical indicator, the two should be close, but your equivalence point is almost always reached before you see the end point.
- An indicator is a chemical added to the mixture that changes color close to the equivalence point.
- Finding the end point with a chemical indicator requires some skill.



Problem:

A 20.0 mL sample of $NaOH_{(aq)}$ is titrated to an end point with 45.7 mL of 0.500 M $H_2SO_{4\,(aq)}$, what is concentration of the NaOH solution?



Solution

$$2\ NaOH_{(aq)} + H_2SO_{4\,(aq)} \rightarrow Na_2SO_{4\,(aq)} + 2\ H_2O_{(l)}$$

$$\underbrace{mL \xrightarrow{\textcircled{1}} L \xrightarrow{\textcircled{2}} mol}_{H_2SO_4} \xrightarrow{\textcircled{3}} mol\ NaOH \quad ; \quad \frac{mol}{vol} = molarity$$

① 1000 mL = 1 L

② 0.500 mol = 1 L

③ 2 NaOH = 1 H_2SO_4

Part A

$$45.7\,mL \cdot \frac{1\,L}{1000\,mL} \cdot \frac{0.500\,mol}{1\,L} \cdot \frac{2\,NaOH}{H_2SO_4} = 4.57\times10^{-2}\,mol$$

Part B

20.0 mL = 0.0200 L

$$\frac{4.57\times10^{-2}\,mol}{0.0200\,L} = \boxed{2.29\ M}$$

Stoichiometry

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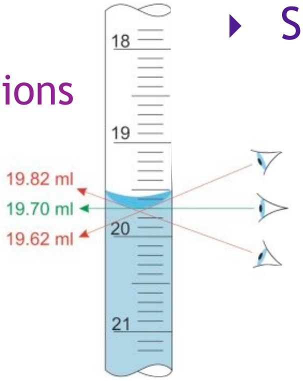

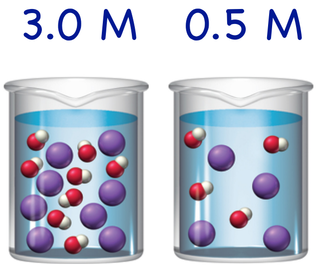

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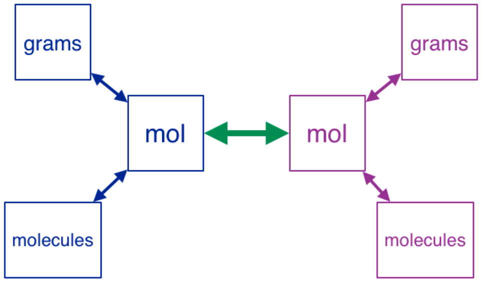

Questions?

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Spittelau
Nußdorfer Straße
Gersthof
Währinger Straße Volksoper
S45
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Michelbeuern-Allg.Krankenhaus
Schottentor
Alser Straße
U3
Ottakring
Josefstädter Straße
Rathaus
Thaliastraße
Volks-theater
Kendlerstraße
Burggasse-Stadthalle
Hütteldorfer Straße
Neubaug.
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Penzing
Zieglerg.
S50
Johnstraße
Westbahnhof
Pilgramg.
Gumpendorfer Str.
Ober St.Veit
Unter St.Veit
Hietzing
Längenfeldgasse
Margaretengürtel
Schönbrunn
Eichenstr.
Braunschweiggasse
Meidling Hauptstraße
Niederhofstr.