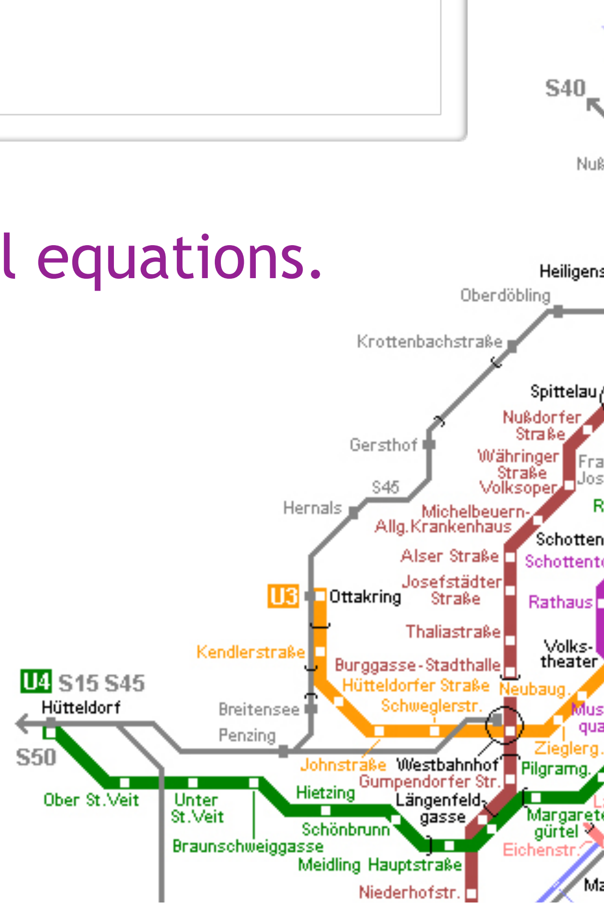
Equations

Mapping & exploring reactions with chemical equations.

“The Molar Subway”

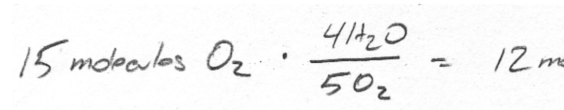


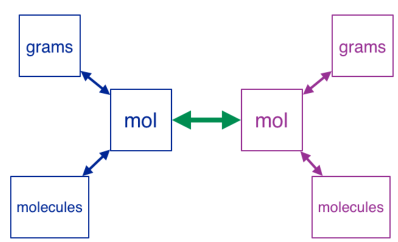
version 1.5

Ch05

Equations

- Chemical Change
  - Chemical Reaction
  - Chemical Equations
    - Describing Chemical Change
  - Writing Chemical Equations
- Classifying Reactions
  - by Kinetics
    (mutually exclusive labels)
    - Combination, Decomposition, Single & Double Displacement
  - by Reactivity
    (not mutually exclusive labels)
    - Combustion, Gas Evolution, Precipitation, Reduction/Oxidation
- Balanced Equations
  - Balanced Equations
  - Balancing
- The Mole Ratio
  - A new conversion factor
  - Mapping it all out
- Stoichiometry Calculations
  - mol → mol calcs (2 steps)
  - mass → mol;
    mol → mass calcs (3 steps)
  - mass → mass (4 steps)
- Limiting Reagent & Yield





heat & pressure

Chemical Change

Iron

- hard to burn
- burns bright yellow

Sulfur

- easy to burn
- burns dull

stir together →

heat & pressure →

Iron Pyrite

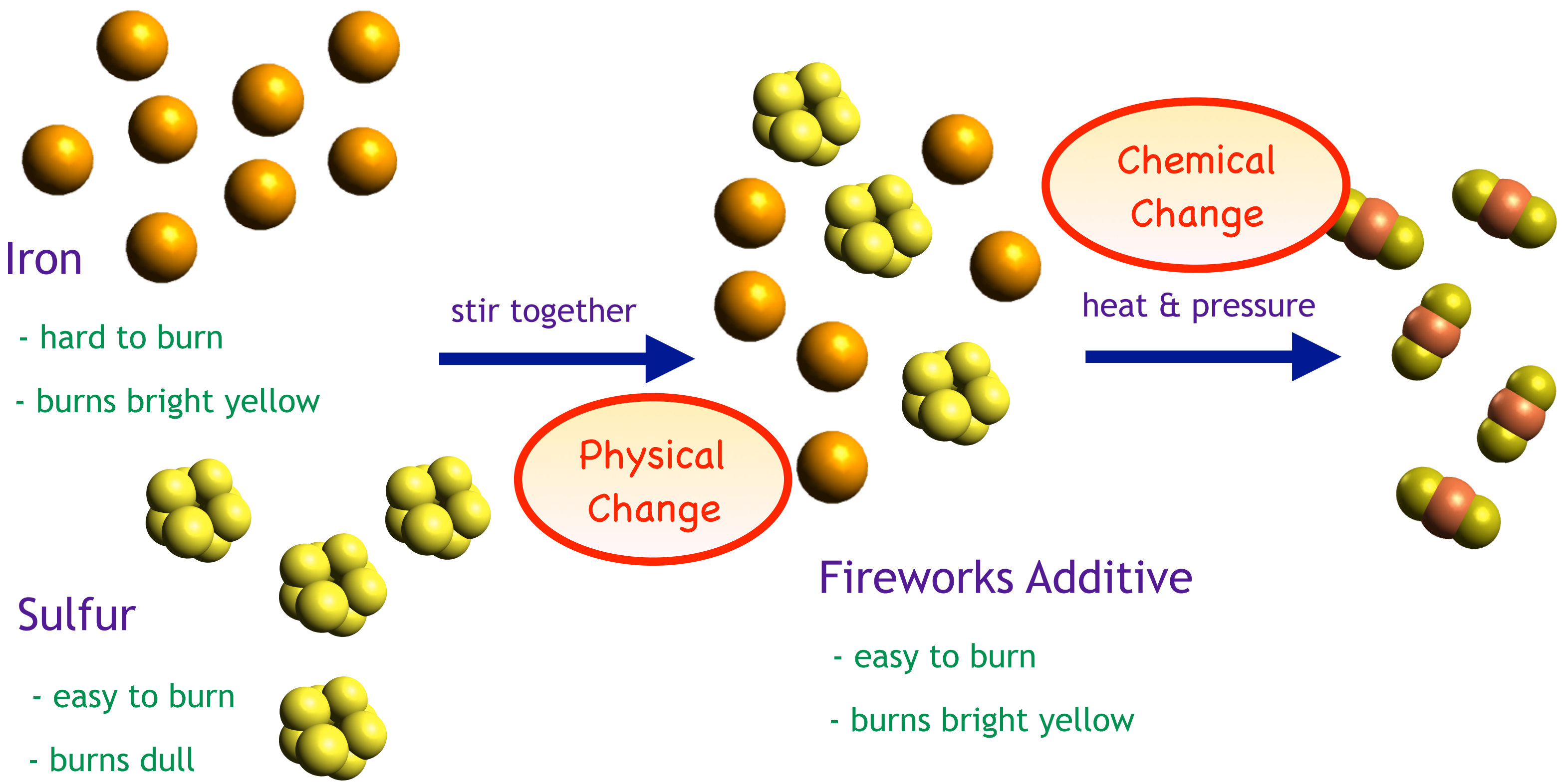
- does not burn
- lustrous (shiny)
- maleable
- not attracted to magnets
- cannot be separated mechanically
- has constant properties
- is always 46.6% iron and 53.4 % sulfur
- a pure substance

Fireworks Additive

- easy to burn
- burns bright yellow

- How did we go from a mixture to a pure substance?
  - We changed the particles — we created a new substance.
- We know a new substance was created because we see properties that didn't exist before.
  - Not just more or less of a property that was already there, but something entirely new.
- We can isolate a pure substance that did not exist in the original mixture.
- A new substance, responsible for the new properties.

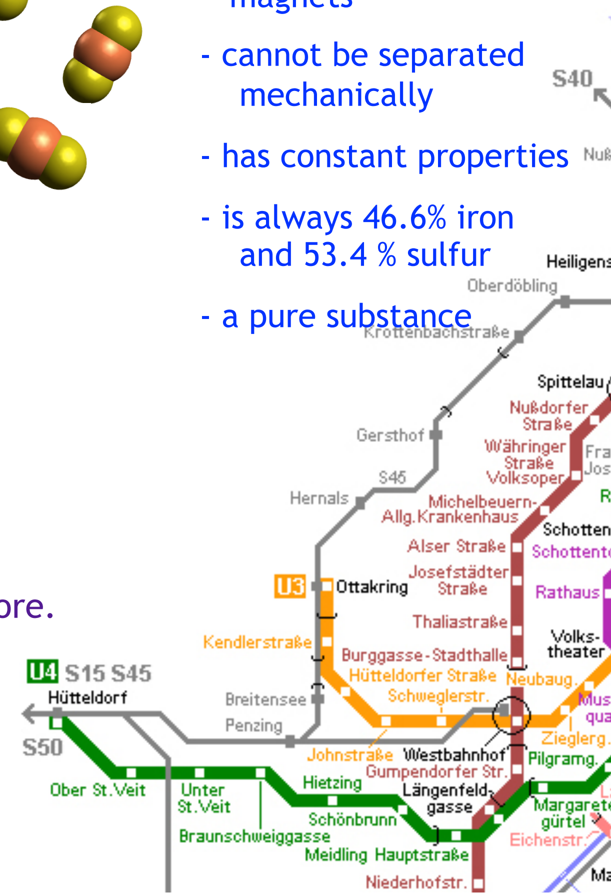
Chemical Change



Iron Pyrite

- does not burn
- lustrous (shiny)
- maleable
- not attracted to magnets
- cannot be separated mechanically
- has constant properties
- is always 46.6% iron and 53.4 % sulfur
- a pure substance

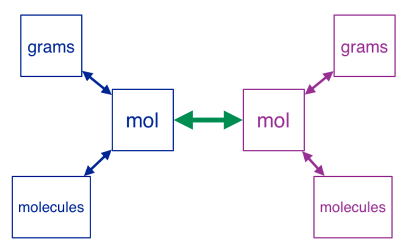
- How did we go from a mixture to a pure substance?
  - We changed the particles — we created a new substance.
- We know a new substance was created because we see properties that didn't exist before.
  - Not just more or less of a property that was already there, but something entirely new.
- We can isolate a pure substance that did not exist in the original mixture.
- A new substance, responsible for the new properties.

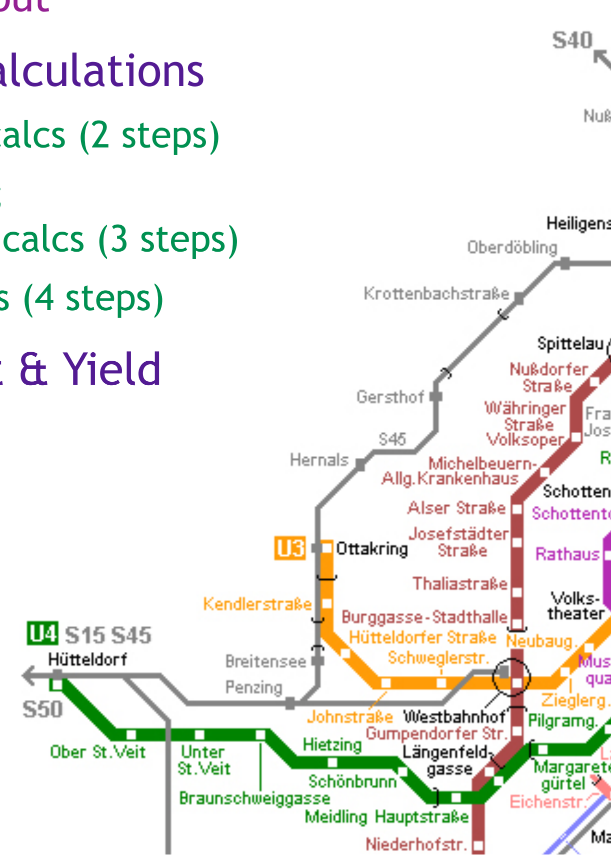


Reaction

- Chemical Change
  - Chemical Reaction
  - Chemical Equations
    - Describing Chemical Change
  - Writing Chemical Equations
- Classifying Reactions
  - by Kinetics (mutually exclusive labels)
    - Combination, Decomposition, Single & Double Displacement
  - by Reactivity (not mutually exclusive labels)
    - Combustion, Gas Evolution, Precipitation, Reduction/Oxidation
- Balanced Equations
  - Balanced Equations
  - Balancing
- The Mole Ratio
  - A new conversion factor
  - Mapping it all out
- Stoichiometry Calculations
  - mol → mol calcs (2 steps)
  - mass → mol; mol → mass calcs (3 steps)
  - mass → mass (4 steps)
- Limiting Reagent & Yield

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





Parts of a Chemical Equation

- Reactants are what you start with.
  - They are always on the left.
- Then an arrow pointing to the right.
  - → by default, read it "yields"
  - ⇄ means reversible (equilibrium)
  - Do not use ↔ or ⇒ or ←
    (they mean other things)
- Products are what you end up with.
  - They are always on the right.
- Put a "+" between substances
- Order doesn't matter.
- Over the arrow is optional:
  - Δ means add heat
  - hν means add light
  - chemical formula is solvent
  - temperature means temperature
  - ⇅ means reflux (boil)

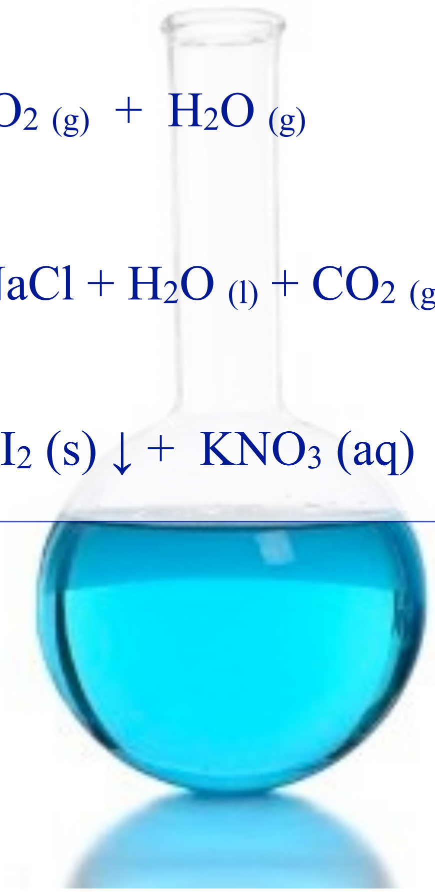
$$H_2\ (g) + O_2\ (g) \rightarrow H_2O\ (l)$$

$$C_2H_4 + Br_2 \overset{h\nu}{\rightleftarrows} C_2H_4Br_2$$

$$C_3H_{8\ (g)} + O_{2\ (g)} \xrightarrow{\Delta} CO_{2\ (g)} + H_2O_{\ (g)}$$

$$Na_2CO_3 + HCl_{\ (aq)} \xrightarrow{H_2O} NaCl + H_2O_{\ (l)} + CO_{2\ (g)}\uparrow$$

$$KI\ (aq) + Pb(NO_3)_2\ (aq) \xrightarrow{\upharpoonleft\downharpoonright} PbI_2\ (s)\downarrow + KNO_3\ (aq)$$



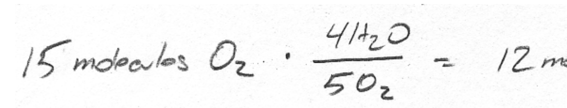
- After the substance (can be written subscript):
  - (aq) means in water
  - (s), (l), (g) means solid, liquid, gas state
  - ↑ means gas evolved (escaped)
  - ↓ means precipitate (solid fell out)

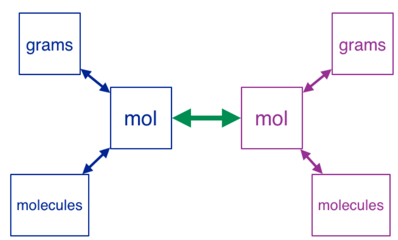
Ch05

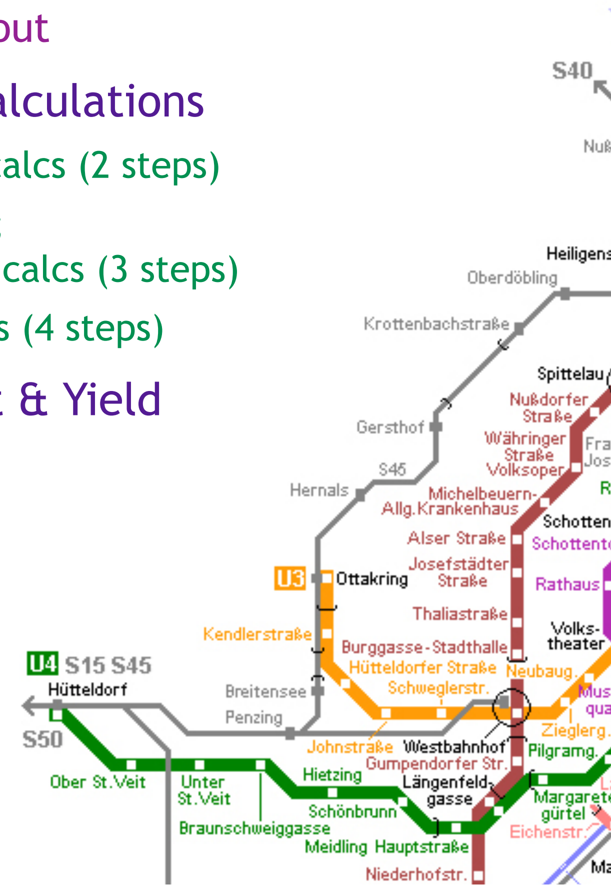
Reaction

- Chemical Change
  - Chemical Reaction
  - Chemical Equations
    - Describing Chemical Change
  - Writing Chemical Equations
- Classifying Reactions
  - by Kinetics (mutually exclusive labels)
    - Combination, Decomposition, Single & Double Displacement
  - by Reactivity (not mutually exclusive labels)
    - Combustion, Gas Evolution, Precipitation, Reduction/Oxidation

- Balanced Equations
  - Balanced Equations
  - Balancing
- The Mole Ratio
  - A new conversion factor
  - Mapping it all out
- Stoichiometry Calculations
  - mol → mol calcs (2 steps)
  - mass → mol; mol → mass calcs (3 steps)
  - mass → mass (4 steps)
- Limiting Reagent & Yield







heat & pressure

Labeled by Kinetics

Combination Reaction:

$$A + B \rightarrow C$$

eg. $C(s) + O_2\ (g) \rightarrow CO_2\ (g)$

Decomposition Reaction:

$$A \rightarrow B + C$$

eg. $Cu(OH)_2\ (s) \rightarrow CuO\ (s) + H_2O\ (l)$

Single Displacement Reaction:

$$A + BC \rightarrow B + AC$$

eg. $Zn\ (s) + SnCl_2\ (aq) \rightarrow Sn\ (s) + ZnCl_2\ (aq)$

Double Displacement Reaction:

"trade partners"

$$AB + CD \rightarrow AD + CB$$

eg. $2\ KI_{(aq)} + Pb(NO_3)_{2\ (aq)} \rightarrow PbI_{2\ (s)} \downarrow + 2\ KNO_{3\ (aq)}$

- Labels based on what "boxes" the atoms fall into and the general pattern of what moves where.
- A very generic label.
- Each label is mutually exclusive, reaction is one or another – never two.

Labeled by Reactivity

- Patterns we see frequently in reactions.
- These labels are not mutually exclusive, with each other or with kinetics.
  - Combustion Reaction (in oxygen is generally assumed)
    - Pattern: "something" + $O_2 \xrightarrow{\Delta} CO_2 + H_2O + NO_2$ ...
    - Burning something. (Yes, you can use something other than oxygen but it's uncommon.)
    - Ex: $C_3H_8\,_{(g)} + O_2\,_{(g)} \rightarrow CO_2\,_{(g)} + H_2O\,_{(l)}$
  - Gas Evolution
    - Pattern: Reactants → Products + $X_{(g)} \uparrow$
    - One product is gas and it floats away.
    - Ex: $2\ KClO_3\ (s) \rightarrow 2\ KCl\ (s) + 3\ O_2\,_{(g)} \uparrow$
  - Precipitation
    - Pattern: Reactants $_{(aq)}$ → Products $_{(aq)}$ + $X_{(s)} \downarrow$
    - Reaction in solution, a solid forms and it falls out.
    - Ex: $NaCl_{(aq)} + AgNO_3\,_{(aq)} \rightarrow NaNO_3\,_{(aq)} + AgCl_{(s)} \downarrow$
  - more coming: Red-Ox, Acid-Base, and Neutralization Rxns

Writing Chemical Equations

- "When sulfur trioxide reacts with water, a solution of sulfuric acid forms"

sulfur trioxide + water → sulfuric acid (aq)

$$SO_3 + H_2O \rightarrow H_2SO_4(aq)$$

- "An aqueous solution of lead (II) nitrate is mixed with an aqueous solution of sodium iodide an aqueous solution of sodium nitrate is formed and a yellow solid lead (II) iodide appears."

lead (II) nitrate (aq) + sodium iodide → sodium nitrate (aq) + lead (II) iodide (s)↓

$$Pb(NO_3)_2(aq) + NaI \rightarrow NaNO_3(aq) + PbI_2(s)\downarrow$$

- "When liquid phosphorus trichloride is added to water, it reacts to form aqueous phosphoric acid and hydrochloric acid."

phosphorus trichloride (l) + water → phosphoric acid + hydrochloric acid

$$PCl_3(l) + H_2O(l) \rightarrow H_3PO_4 + HCl(aq)$$

- "Hydrogen sulfide gas is passed over hot iron (III) hydroxide, the resulting reaction produces solid iron (III) sulfide and gaseous water."

hydrogen sulfide (g) + iron (III) hydroxide →(Δ) iron (III) sulfide (s) + water (g)

$$H_2S(g) + Fe(OH)_3 \xrightarrow{\Delta} Fe_2S_3(s) + H_2O(g)$$

Problem:

Magnesium metal was put in a solution containing aluminum nitrate. The solution bubbled, a new metal appears as the magnesium dissolved. What happened? (write the chemical equation describing the reaction)

copper silver nitrate $\rightarrow$

$Mg + Al(NO_3)_3$

$Mg^0 + Al^{3+} NO_3^{1-} \rightarrow Al^0 + Mg^{2+} NO_3^{1-}$

Single Displacement

$Al + Mg(NO_3)_2$

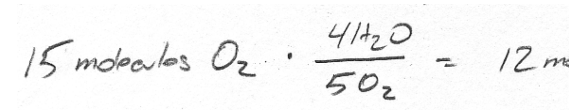
$Mg + Al(NO_3)_3 \rightarrow Al + Mg(NO_3)_2$

Ch05

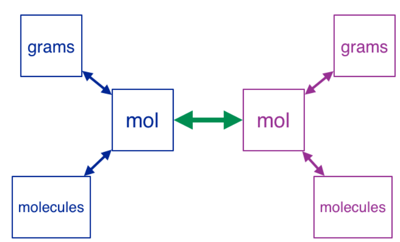
Reaction

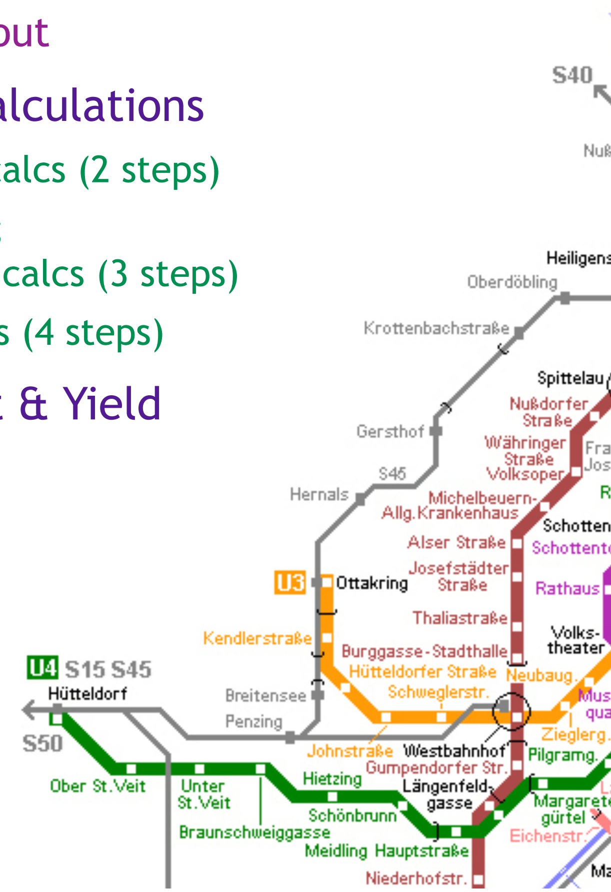
- Chemical Change
  - Chemical Reaction
  - Chemical Equations
    - Describing Chemical Change
  - Writing Chemical Equations
- Classifying Reactions
  - by Kinetics (mutually exclusive labels)
    - Combination, Decomposition, Single & Double Displacement
  - by Reactivity (not mutually exclusive labels)
    - Combustion, Gas Evolution, Precipitation, Reduction/Oxidation

- Balanced Equations
  - Balanced Equations
  - Balancing
- The Mole Ratio
  - A new conversion factor
  - Mapping it all out



- Stoichiometry Calculations
  - mol → mol calcs (2 steps)
  - mass → mol; mol → mass calcs (3 steps)
  - mass → mass (4 steps)
- Limiting Reagent & Yield



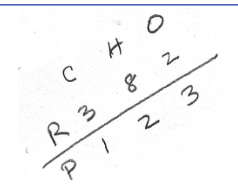


Balanced Equations

- Both equations are valid chemical equations.
- The difference is the addition of coefficients.
- Coefficients indicate relative quantities.
- The second equation has the same number and flavor of atoms in reactants as it does in products.
- All the mass is accounted for.
- We say the second equations is balanced.
- We can do a **lot** with a balanced equation.

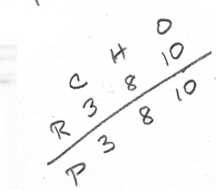
Eq 1:

$$C_3H_8\ (g) + O_2\ (g) \rightarrow CO_2\ (g) \uparrow + H_2O\ (l)$$



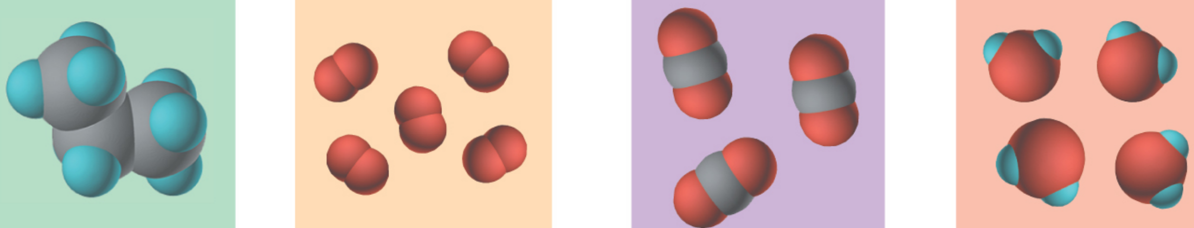
Eq 2:

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

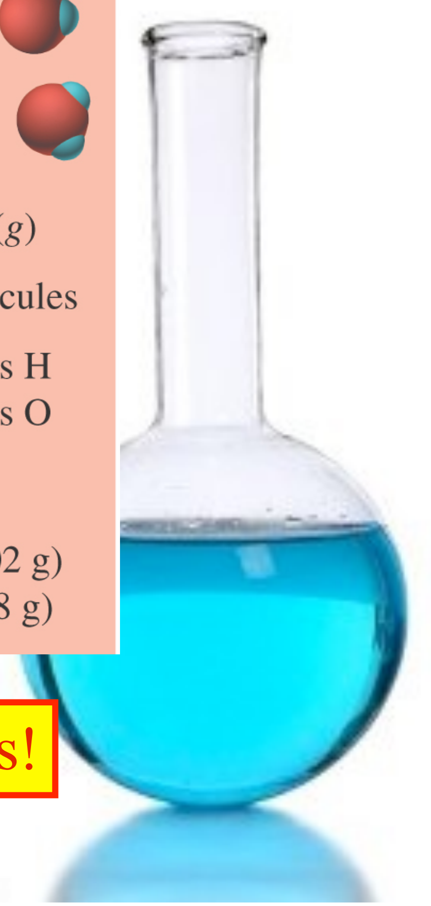


Reading a Balanced Equation

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



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)

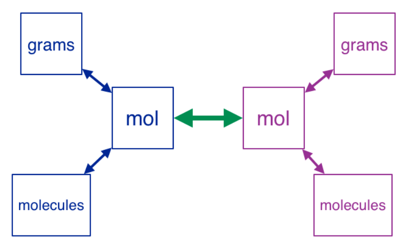


Don't confuse coefficients and subscripts!

Reaction

- Chemical Change
  - Chemical Reaction
  - Chemical Equations
    - Describing Chemical Change
  - Writing Chemical Equations
- Classifying Reactions
  - by Kinetics (mutually exclusive labels)
    - Combination, Decomposition, Single & Double Displacement
  - by Reactivity (not mutually exclusive labels)
    - Combustion, Gas Evolution, Precipitation, Reduction/Oxidation
- Balanced Equations
  - Balanced Equations
  - Balancing
- The Mole Ratio
  - A new conversion factor
  - Mapping it all out
- Stoichiometry Calculations
  - mol → mol calcs (2 steps)
  - mass → mol; mol → mass calcs (3 steps)
  - mass → mass (4 steps)
- Limiting Reagent & Yield

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



Balancing Equations

- The process:
  - Step 1: Write the skeleton.
  - Step 2: Translate everything into formulas.
  - Step 3: Take Stock. See if it's balanced. If it is goto step 5.
  - Step 4: Rewrite the equation, add a coefficient to balance a component.
    - Repeat Steps 3-4.
  - Step 5: Make sure all coefficients are whole numbers.
  - You're done.

- Tips to Win:
  - Always start with the most complicated molecule.
  - Always finish with the simplest, preferably H_2 or O_2
  - It's iterative, you gotta experiment.
  - You can use polyatomic ions instead of elements, <u>**if**</u> they're kept whole in the reaction.
  - Use fractions (e.g. ½ or 2⅓) to get to the end, but *don't leave it that way*. (see step 5)

Problem:

Diphosphorus trioxide is formed by direct combination of its elements. Find the balanced eqn.

Tip: Save O_2 or H_2 for last.

oxygen + phosphorus → diphosphorus trioxide

$$O_2 + P_4 \rightarrow P_2O_3$$

	O	P
R	2	4
P	3	2

$$O_2 + P_4 \rightarrow 2\,P_2O_3$$

R	2	4
P	6	4

$$3\,O_2 + P_4 \rightarrow 2\,P_2O_3$$

R	6	4
P	6	4

Problem:

Phosphoric acid and calcium hydroxide react to form water and calcium phophate.
Find the balanced eqn.

Tip: use polyatomic ions instead of elements, if they're kept whole in the reaction.

Phosphoric Acid + Calcium Hydroxide → water + Calcium Phosphate

$$H_3PO_4 + Ca(OH)_2 \rightarrow H_2O + Ca_3(PO_4)_2$$

	PO_4	Ca	H	O
R	1	1	5	2
P	2	3	2	1

$$\underline{2}\,H_3PO_4 + Ca(OH)_2 \rightarrow H_2O + Ca_3(PO_4)_2$$

R	2	1	8	2
P	2	3	2	1

$$2H_3PO_4 + \underline{3}\,Ca(OH)_2 \rightarrow H_2O + Ca_3(PO_4)_2$$

R	2	3	12	6
P	2	3	2	1

$$2H_3 + 3Ca(OH)_2 \rightarrow \underline{6}\,H_2O + Ca_3(PO_4)_2$$

R	2	3	12	6
P	2	3	12	6

Problem:

Ethane is burnt in air. Find the balanced eqn.

Tip: Use fractions to get to the end, but don't leave it that way.

Ethane + oxygen → carbon dioxide + water

	C	H	O
R	2	6	2
P	1	2	3

$$C_2H_6 + O_2 \rightarrow CO_2 + H_2O$$

R	2	6	2
P	2	2	5

$$C_2H_6 + O_2 \rightarrow 2CO_2 + H_2O$$

R	2	6	2
P	2	6	7

$$C_2H_6 + O_2 \rightarrow 2CO_2 + 3H_2O$$

R	2	6	7
P	2	6	7

$$C_2H_6 + \frac{7}{2}O_2 \rightarrow 2CO_2 + 3H_2O$$

R	4	12	14
P	4	12	14

$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

Some More Equations to Balance

- $H_2SO_4 + Fe \rightarrow Fe_2(SO_4)_3 + H_2$
- $Al + O_2 \rightarrow Al_2O_3$
- $MnO_2 + CO \rightarrow Mn_2O_3 + CO_2$
- $SO_2 + O_2 \rightarrow SO_3$
- $KI + Br_2 \rightarrow KBr + I_2$
- $K_3PO_4 + BaCl_2 \rightarrow KCl + Ba_3(PO_4)_2$

Some More Equations to Balance

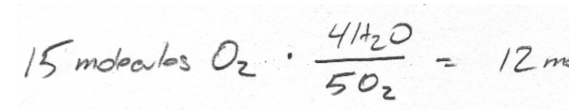
- $Al + MnO_2 \rightarrow Mn + Al_2O_3$
- Copper(II) chloride and water result from the reaction of copper(II) oxide and hydrochloric acid.
- Sugar, $C_{12}H_{22}O_{11}$, is burned in air.
- Hydrogen sulfide gas is passed over hot iron (III) hydroxide, the resulting reaction produces solid iron (III) sulfide and gaseous water.
- When liquid phosphorus trichloride is added to water, it reacts to form aqueous phosphoric acid and hydrochloric acid.

Ch05

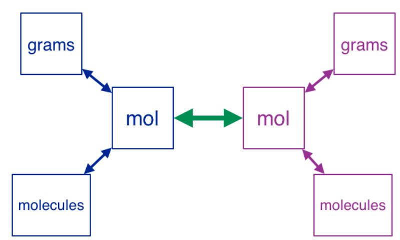
Reaction

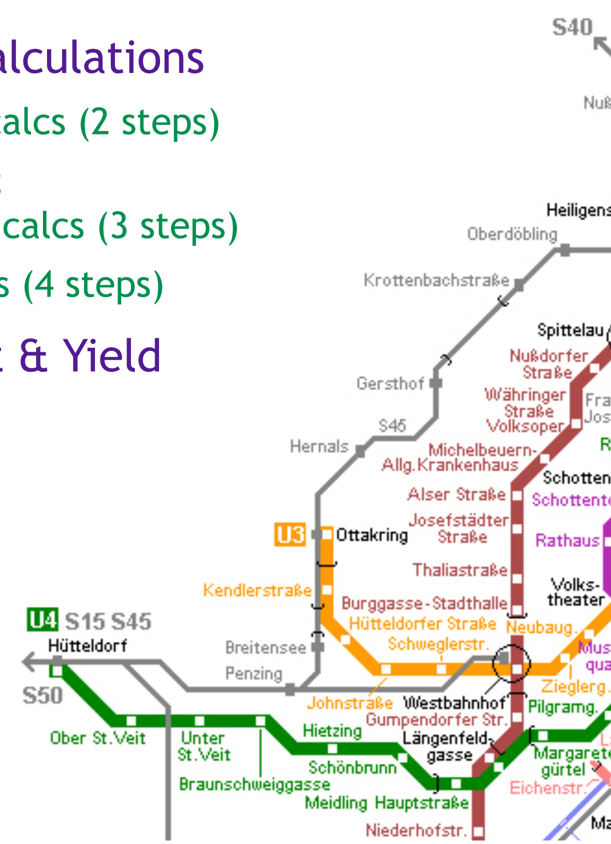
- Chemical Change
  - Chemical Reaction
  - Chemical Equations
    - Describing Chemical Change
  - Writing Chemical Equations
- Classifying Reactions
  - by Kinetics
    (mutually exclusive labels)
    - Combination, Decomposition, Single & Double Displacement
  - by Reactivity
    (not mutually exclusive labels)
    - Combustion, Gas Evolution, Precipitation, Reduction/Oxidation

- Balanced Equations
  - Balanced Equations
  - Balancing
- The Mole Ratio



  - A new conversion factor
  - Mapping it all out
- Stoichiometry Calculations
  - mol → mol calcs (2 steps)
  - mass → mol;
    mol → mass calcs (3 steps)
  - mass → mass (4 steps)
- Limiting Reagent & Yield





Stoichiometry

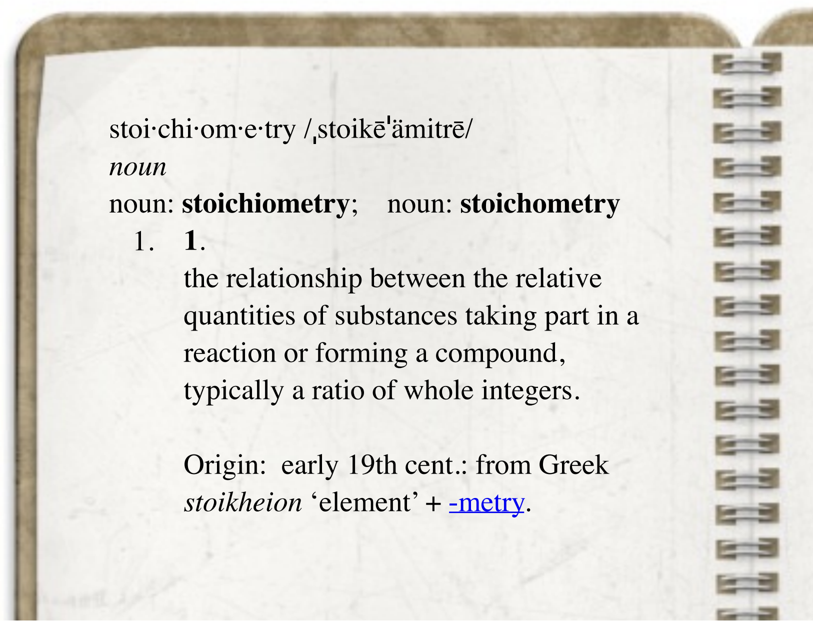
- Stoichiometry is the relationship between relative quantities of substances in a reaction or molecular formula.
- Having a balanced equation let's us see the ratio of products formed from reactants.
- In the balanced equation to the right, we can see that every propane molecule (C_3H_8) produces three 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

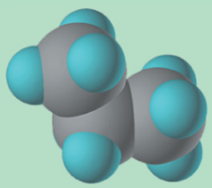
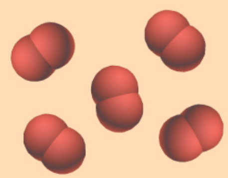
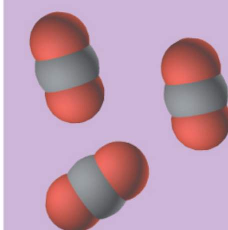
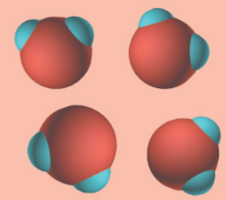
noun: **stoichiometry**; noun: **stoichometry**

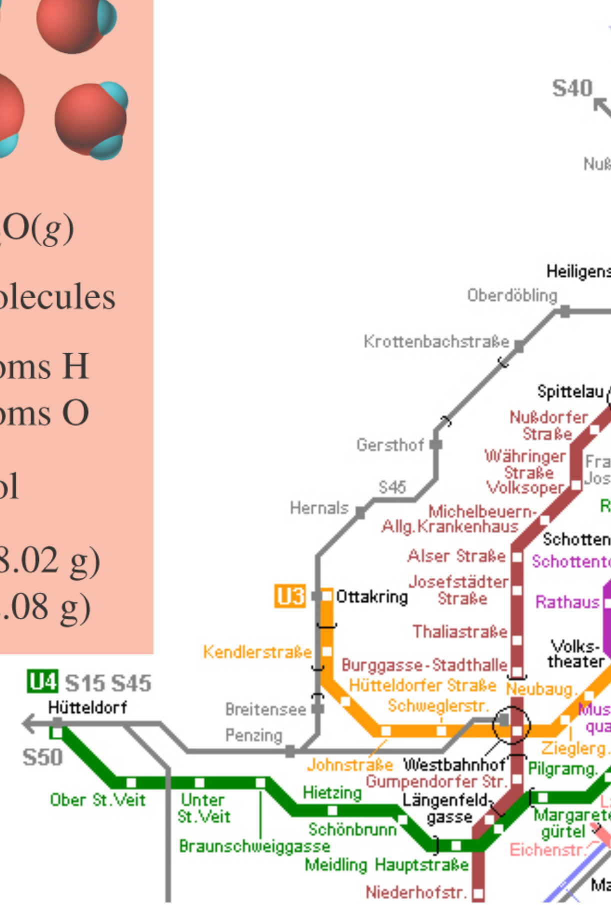
1. **1.**
   the relationship between the relative quantities of substances taking part in a reaction or forming a compound, typically a ratio of whole integers.

   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?

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

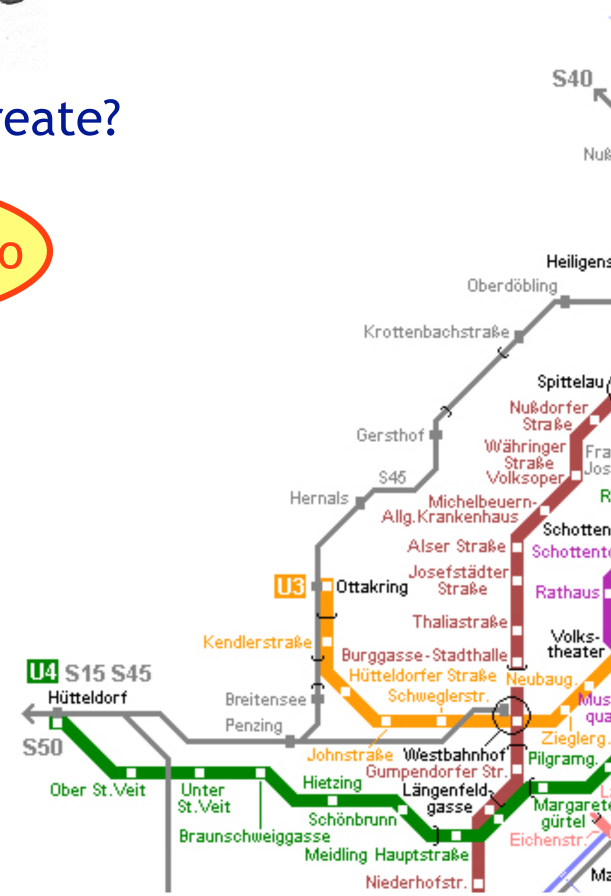
- If I consume 2.7 mol oxygen, how many mol water do I create?
  - … and how many mol CO_2 do I create?
  - … and how many mol C_3H_8 do I consume?

The mole ratio

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

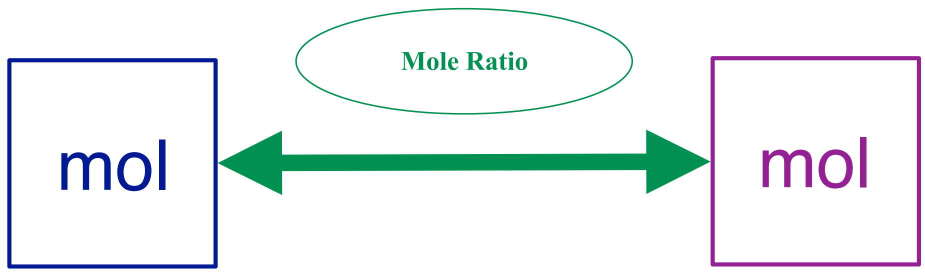
$$2{,}7 \text{ mol } O_2 \cdot \frac{3 CO_2}{5 O_2} = 1{,}6 \text{ mol } CO_2$$

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



The mole ratio

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



$5\ O_2 = 3\ CO_2$

$5\ O_2 = 4\ H_2O$

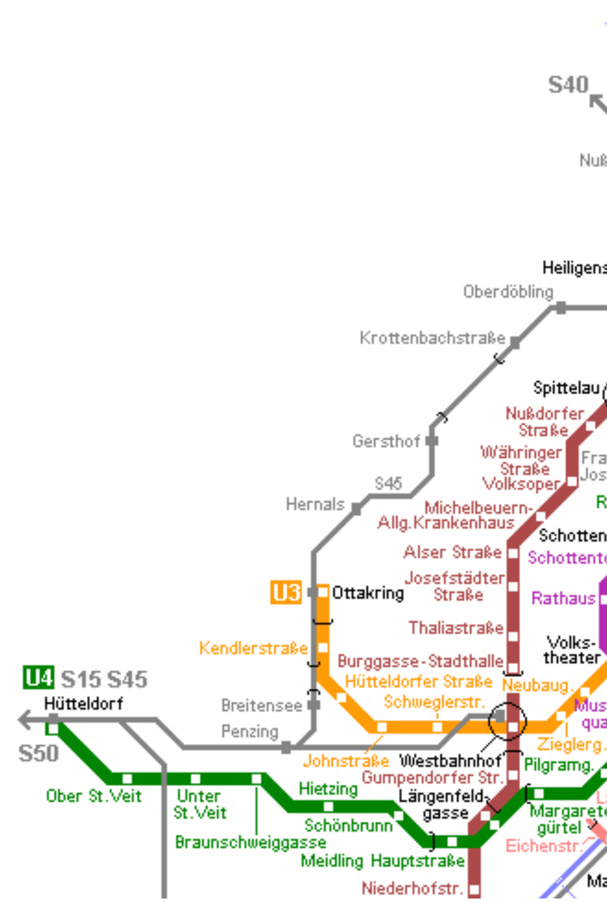
$1\ C_3H_8 = 3\ CO_2$

$3\ CO_2 = 4\ H_2O$

...

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.



Atomic Mass & Avogadro's Number

Elements like Copper (Cu)

- In chapter 2
  we introduced two important conversion factors:
  - Molar Mass/Atomic Mass
    (the **<u>average</u>** 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)

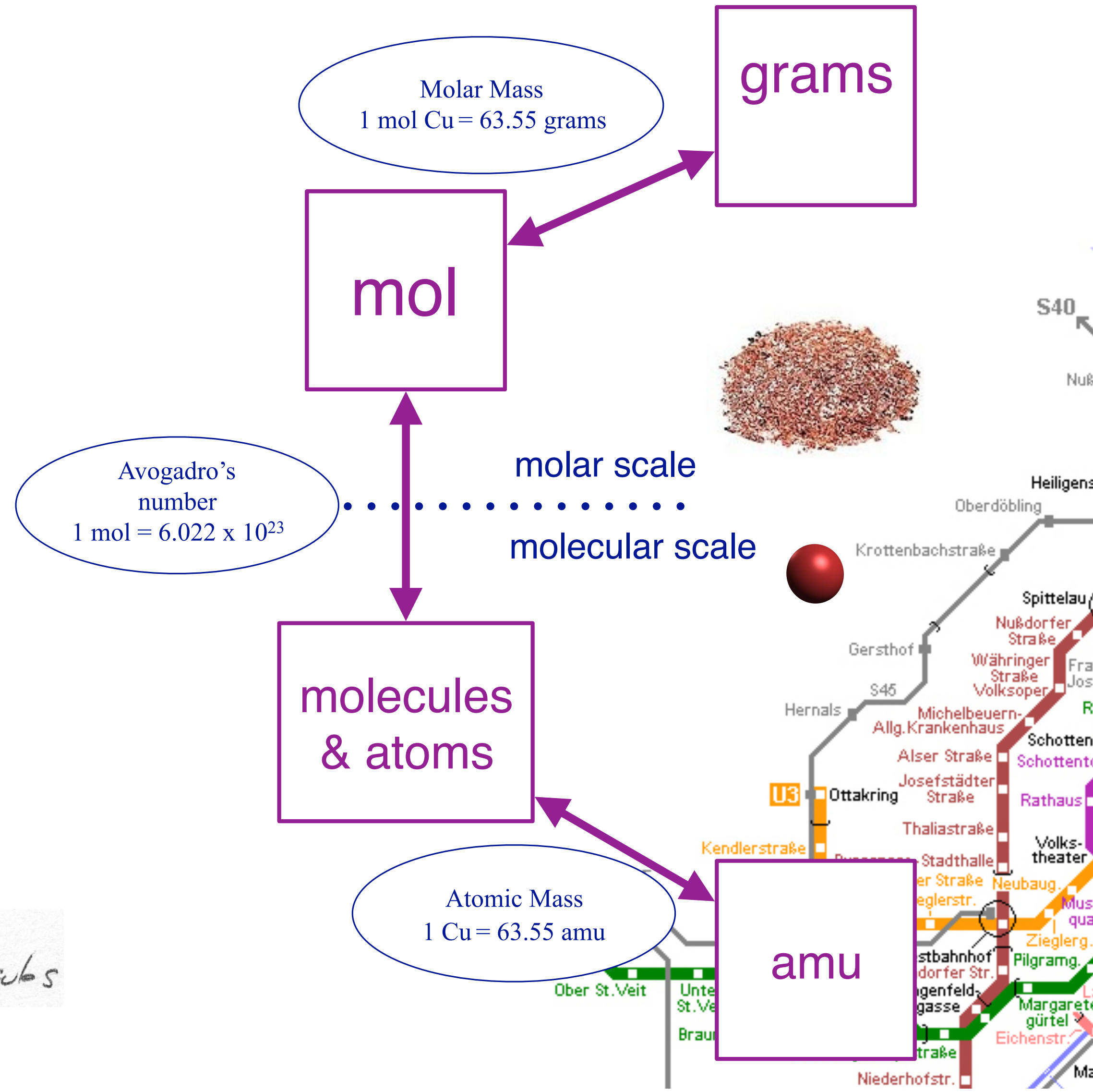
grams → mol

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

  - 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

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



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.

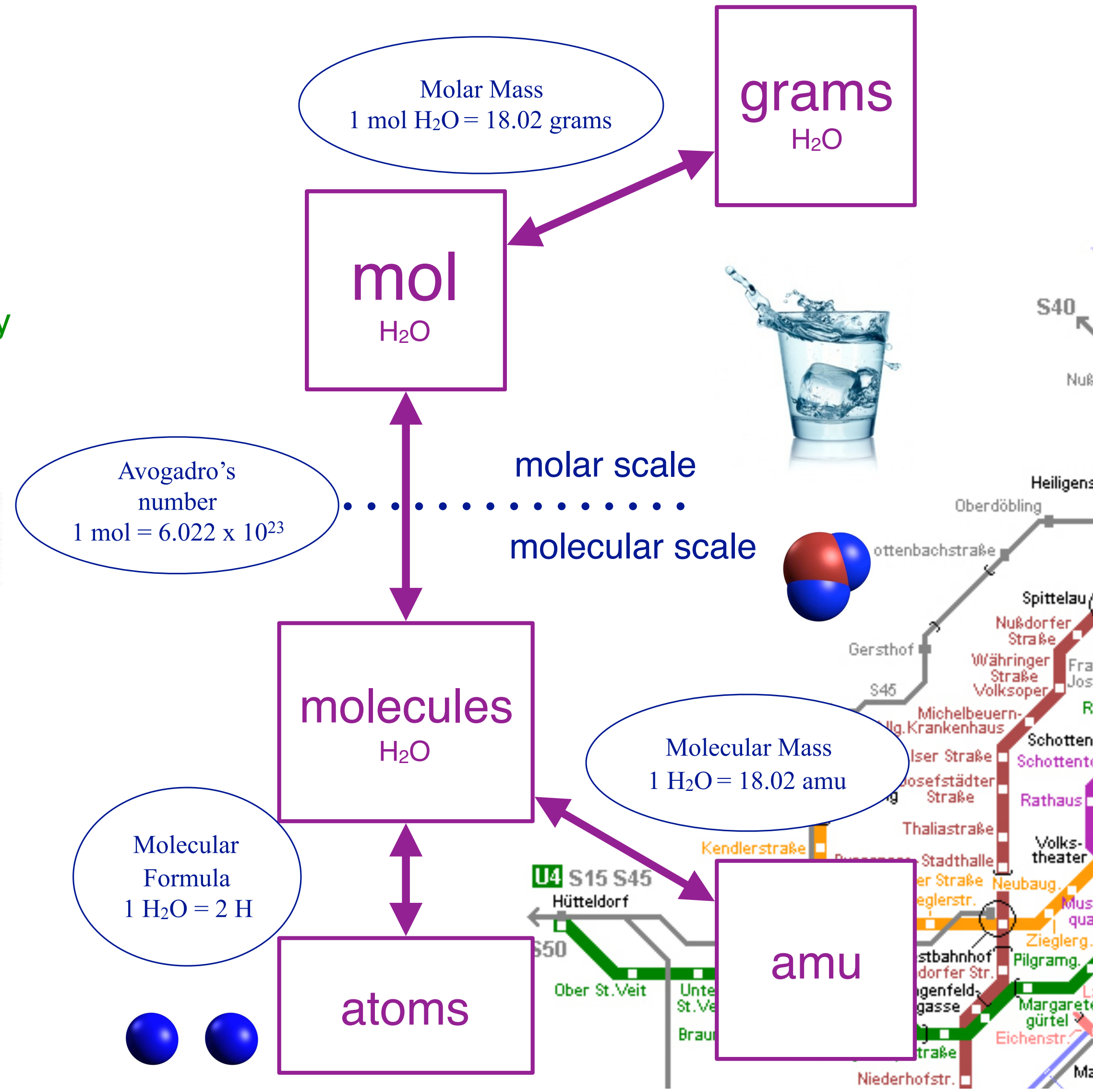
molecules H_2O → atoms H

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

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

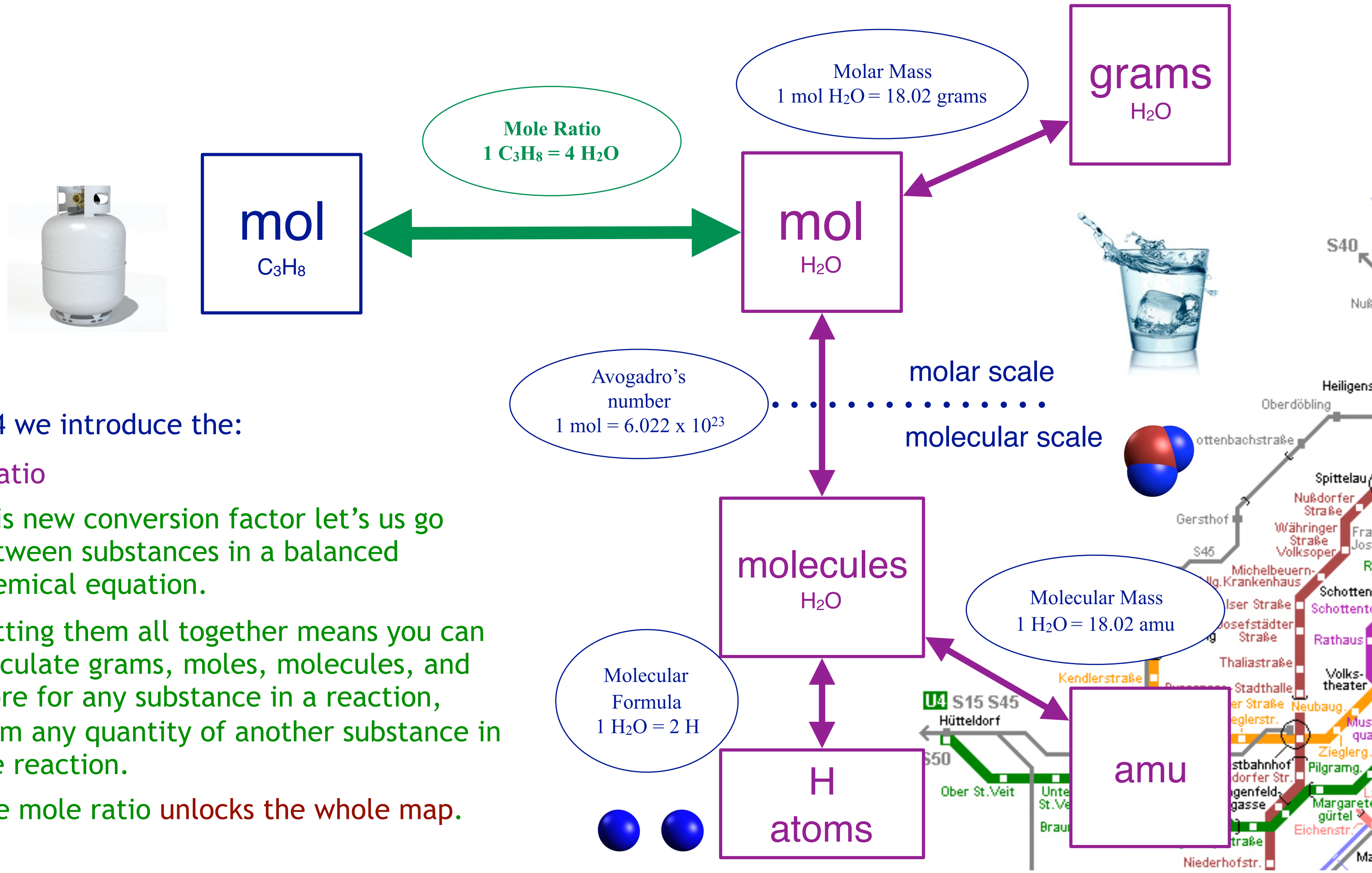
mol → grams

$$2.5 \text{ mol } H_2O \cdot \frac{18.02\text{ g}}{1\text{ mol}} = 45.05\text{ g } H_2O$$



Chapter 4: the Mole Ratio

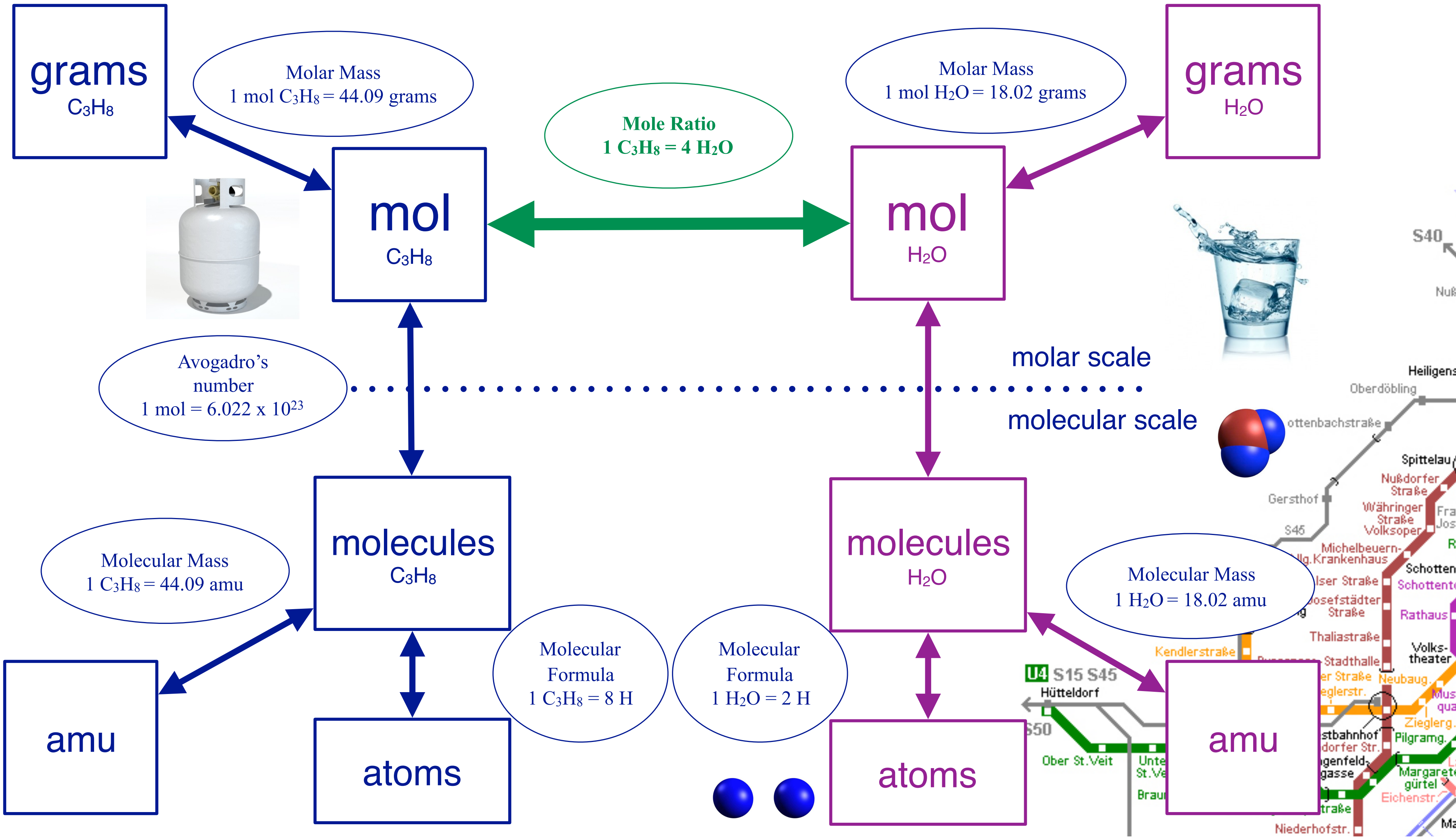
$$C_3H_8\ (g) + 5\ O_2\ (g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O\ (g)$$



- 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.

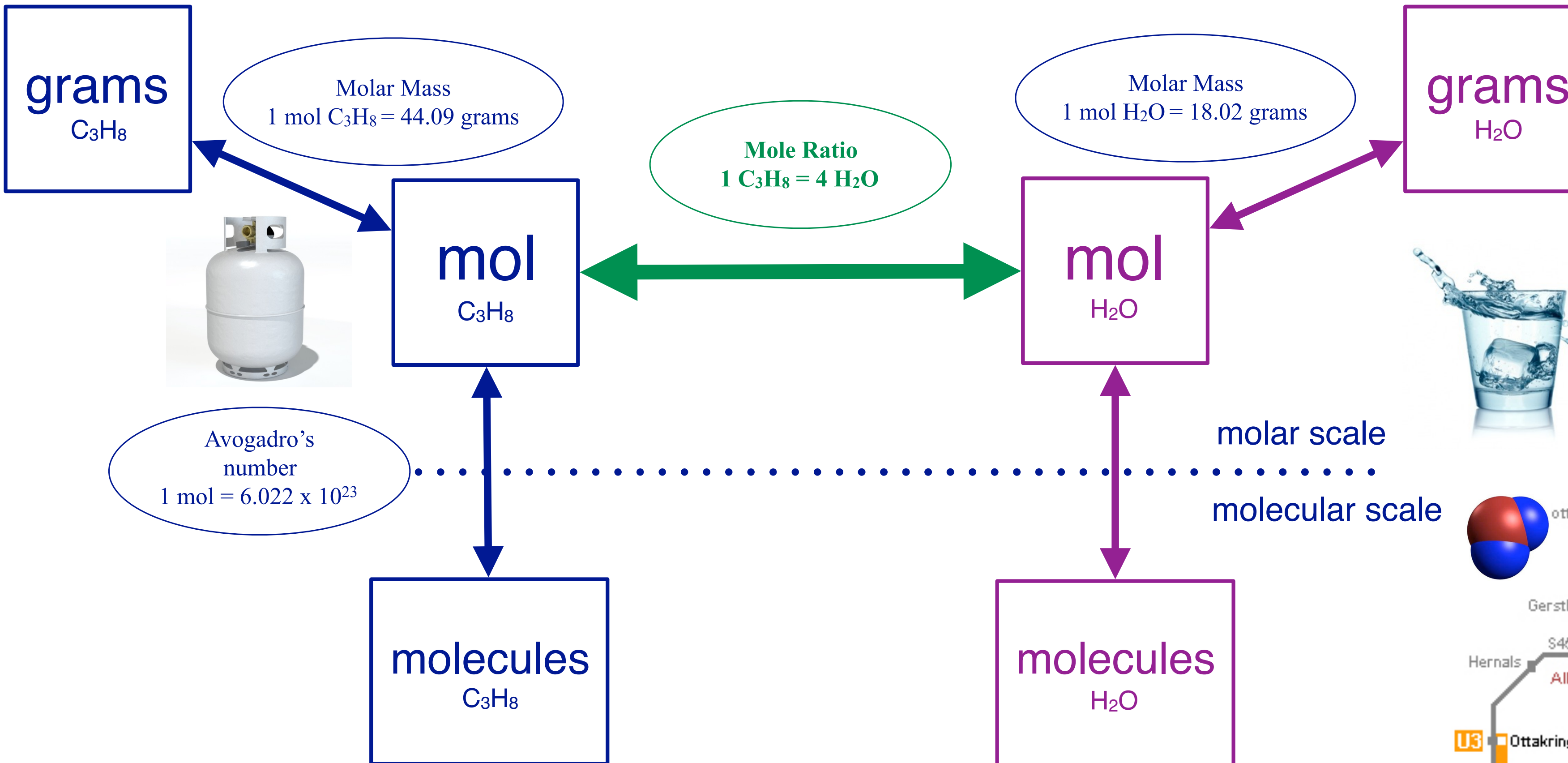
Using a Balanced Equation

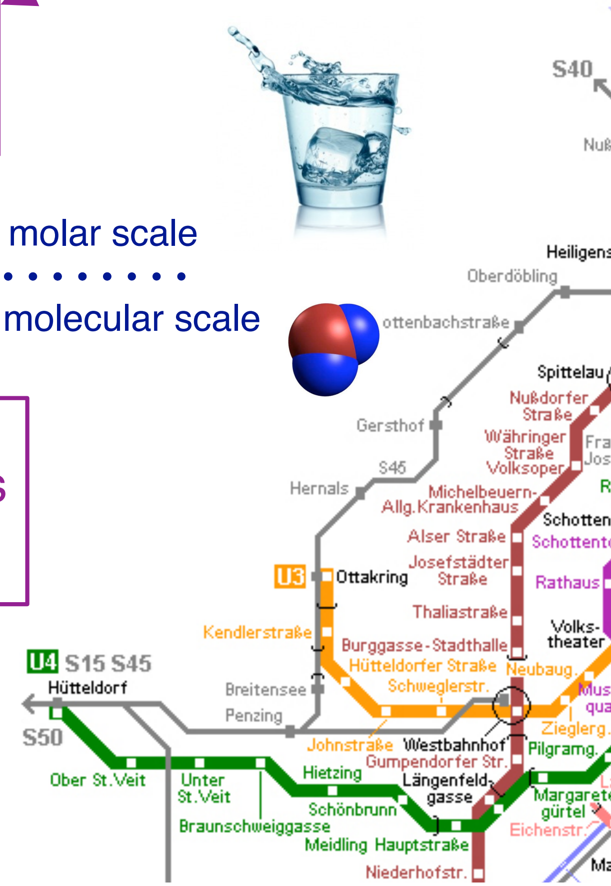
$$C_3H_8\ (g) + 5\ O_2\ (g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O\ (g)$$



Using a Balanced Equation

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

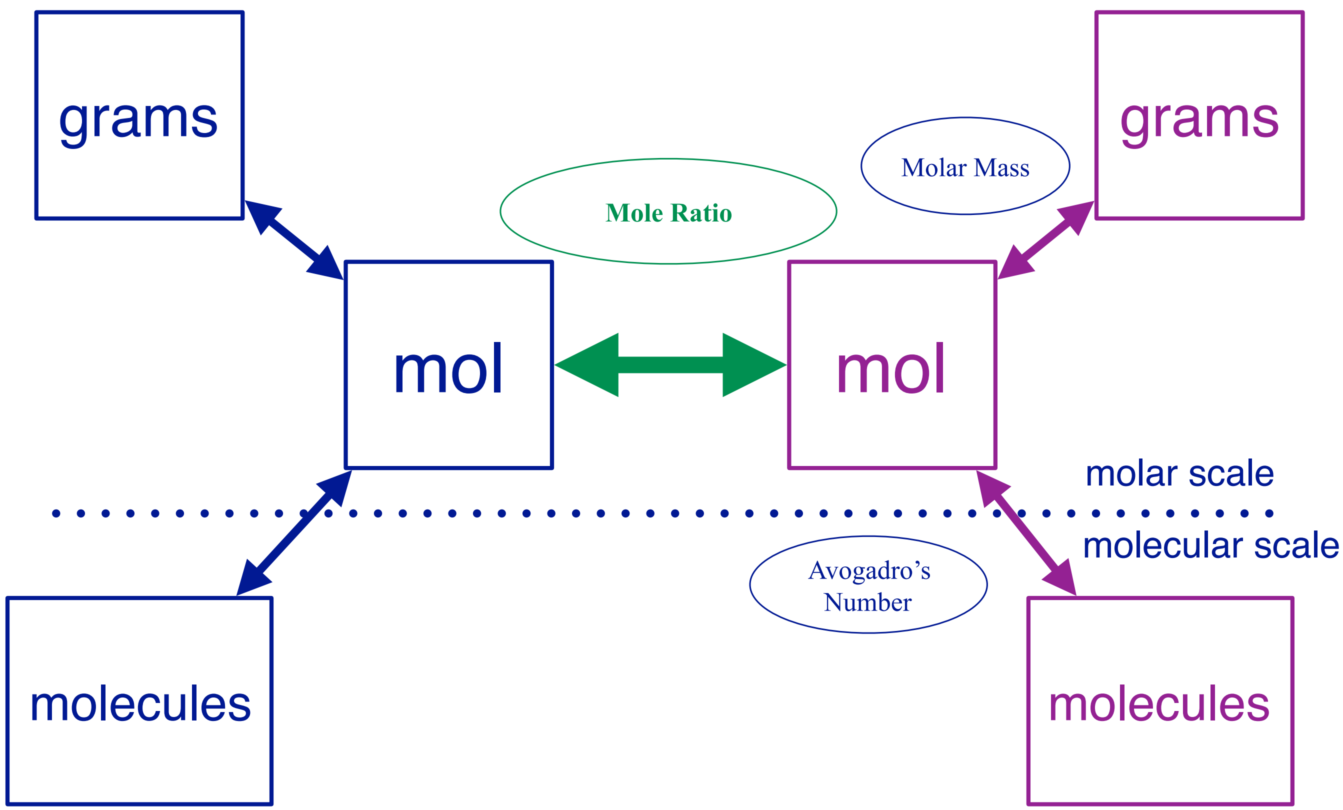


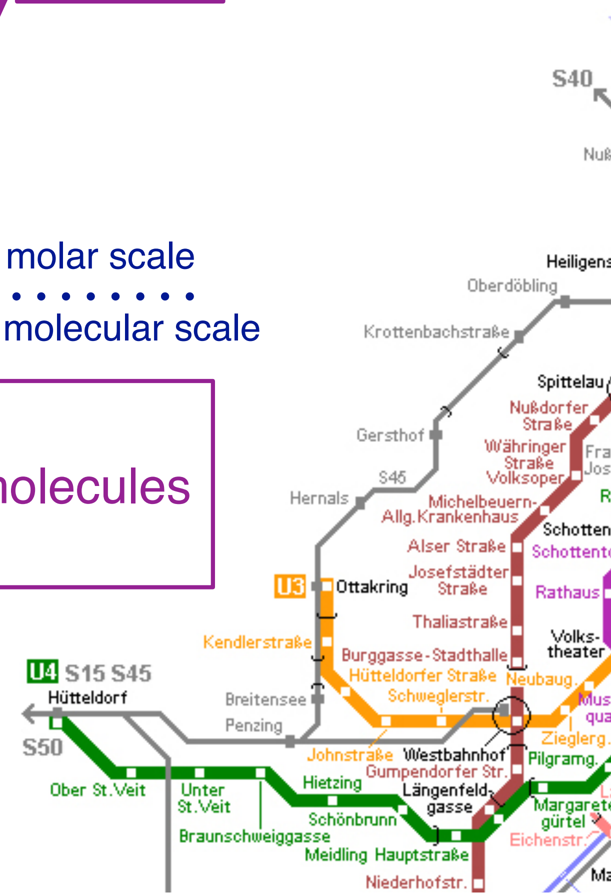


- For this discussion we will focus on grams, moles, and molecules.
- You are responsible for using these conversion factors.

Using a Balanced Equation

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





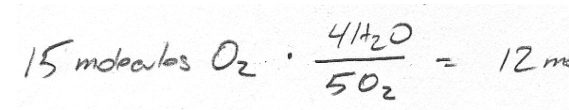
- We will use the molecular scale to design and understand reactions.
- We will use the molar scale to conduct reactions.
- We will add more conversion factors that start with mols, in future chapters.
- But the mole ratio will stay at the heart of all our reaction stoichiometry maps.

Ch05

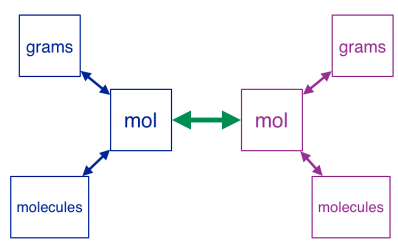
Reaction

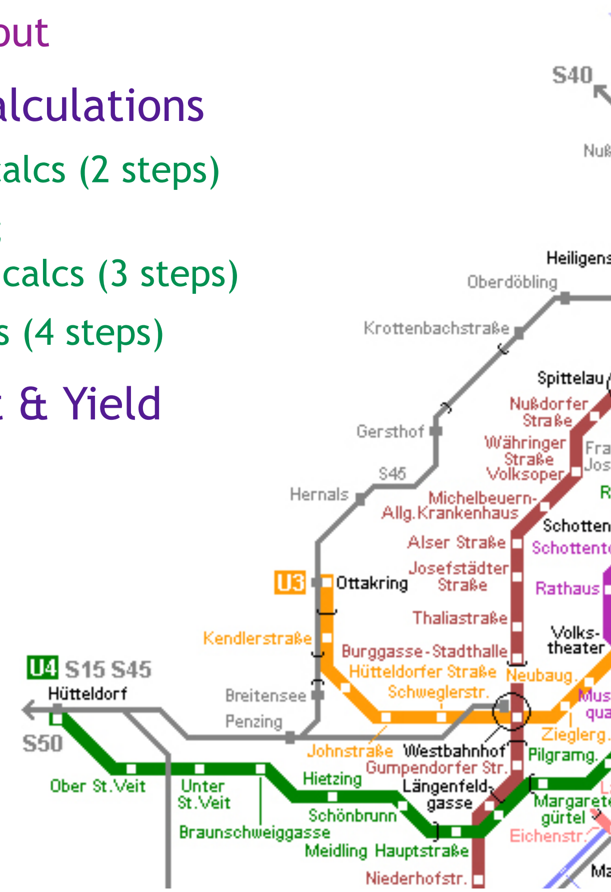
- Chemical Change
  - Chemical Reaction
  - Chemical Equations
    - Describing Chemical Change
  - Writing Chemical Equations
- Classifying Reactions
  - by Kinetics (mutually exclusive labels)
    - Combination, Decomposition, Single & Double Displacement
  - by Reactivity (not mutually exclusive labels)
    - Combustion, Gas Evolution, Precipitation, Reduction/Oxidation

- Balanced Equations
  - Balanced Equations
  - Balancing
- The Mole Ratio



  - A new conversion factor
  - Mapping it all out
- Stoichiometry Calculations
  - mol → mol calcs (2 steps)
  - mass → mol; mol → mass calcs (3 steps)
  - mass → mass (4 steps)
- Limiting Reagent & Yield

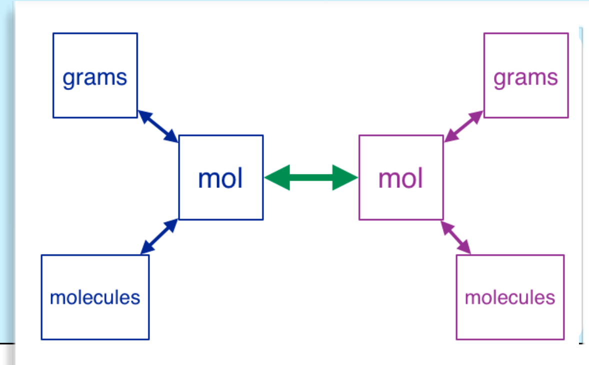




heat & pressure

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)

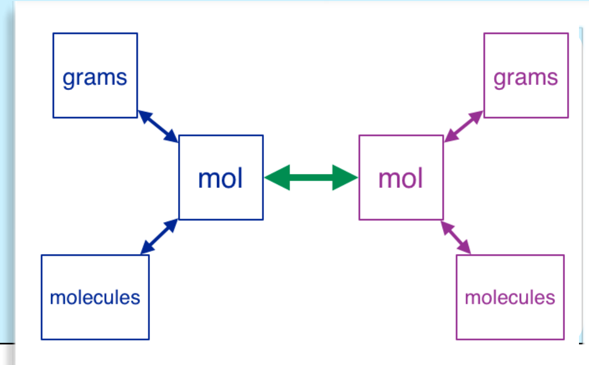
mol O_2 → mol C_3H_8

(1) $5\ O_2 = 1\ C_3H_8$

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

Problem:

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



Solution

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

① molar mass CO_2

1(C) 12.011
2(O) 32.001 +
44.011

1mol = 44.01 g

② mole ratio CO_2 / C_3H_8

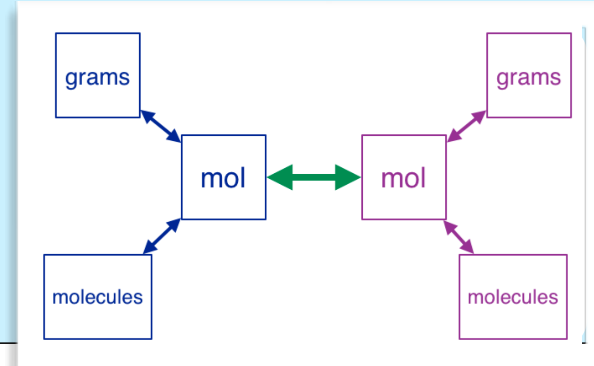
$3\ CO_2 = 1\ C_3H_8$

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

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

Problem:

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



Solution

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

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

① molar mass C_3H_8

3(C)	36.03
8(H)	8.064
	44.094

$44.09\ g = 1\ mol$

② mol ratio $C_3H_8 : H_2O$

$1\ C_3H_8 = 4\ H_2O$

③ molar mass H_2O

2(H)	2.016
1(O)	16.00
	18.016

$18.02\ g = 1\ mol$

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

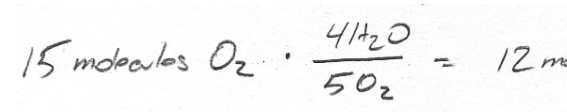
$39.56307553\ g$

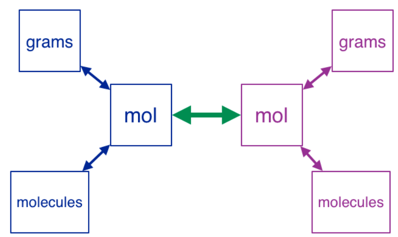
39.6 g H_2O

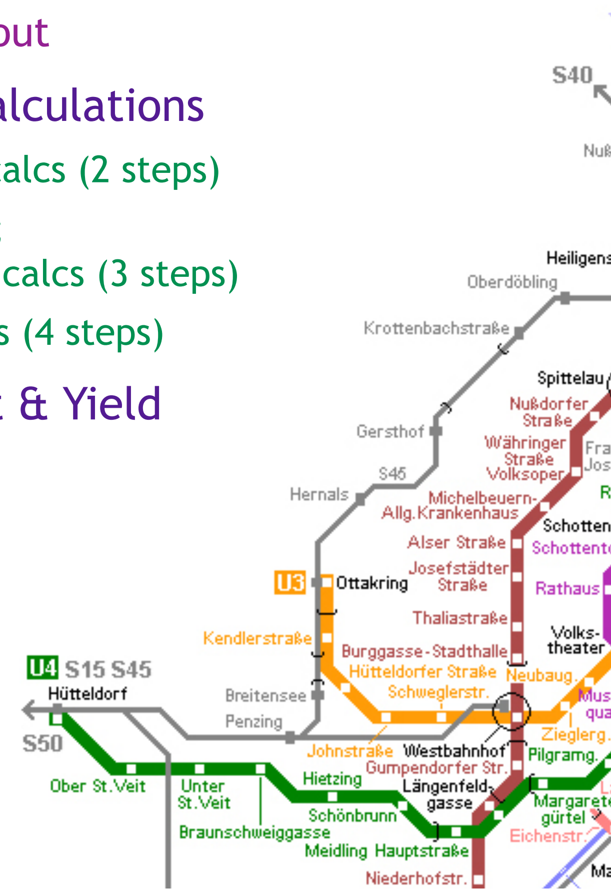
Ch05

Reaction

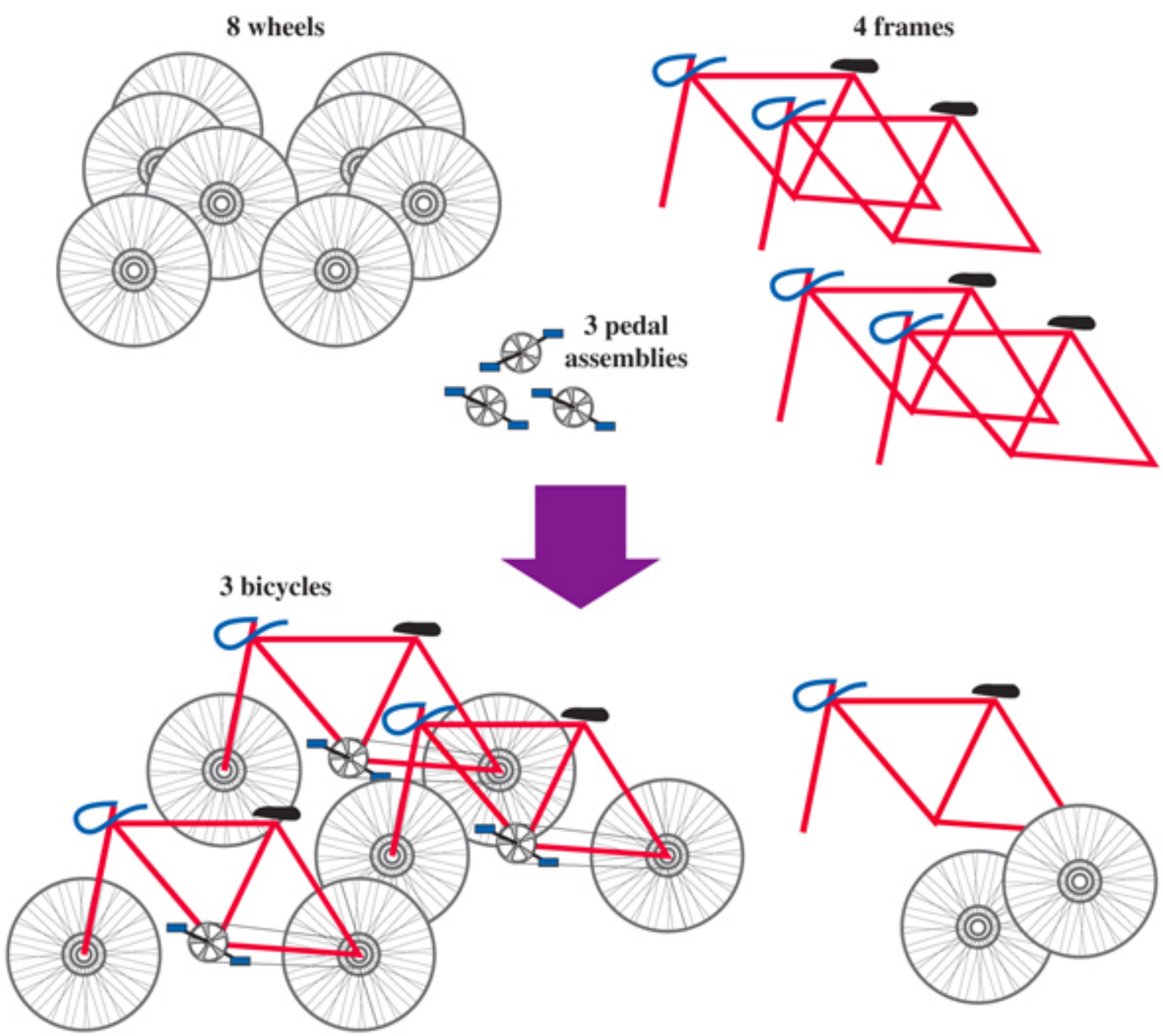
- Chemical Change
  - Chemical Reaction
  - Chemical Equations
    - Describing Chemical Change
  - Writing Chemical Equations
- Classifying Reactions
  - by Kinetics (mutually exclusive labels)
    - Combination, Decomposition, Single & Double Displacement
  - by Reactivity (not mutually exclusive labels)
    - Combustion, Gas Evolution, Precipitation, Reduction/Oxidation
- Balanced Equations
  - Balanced Equations
  - Balancing
- The Mole Ratio
  - A new conversion factor
  - Mapping it all out
- Stoichiometry Calculations
  - mol → mol calcs (2 steps)
  - mass → mol; mol → mass calcs (3 steps)
  - mass → mass (4 steps)
- Limiting Reagent & Yield







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

$$Fe + S_8 \rightarrow Fe_2S_3$$

	Fe	S
R	1	8
P	2	3

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

R	1	3
P	2	3

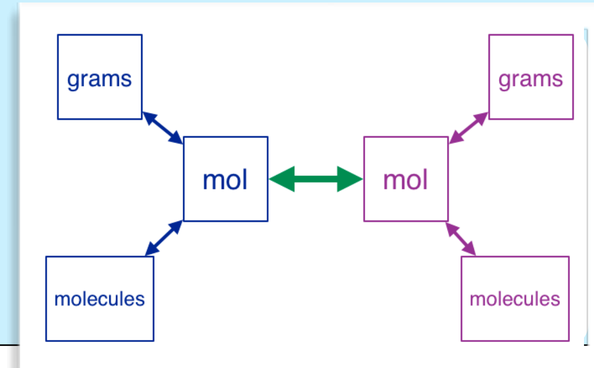
$$2Fe + \frac{3}{8} S_8 \rightarrow Fe_2S_3$$

R	2	3
P	2	3

$$16Fe + 3S_8 \rightarrow 8Fe_2S_3$$

Problem:

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



Solution

$$16\,Fe + 3\,S_8 \rightarrow 8\,Fe_2S_3$$

g Fe —①→ mol Fe —②→ mol Fe_2S_3

g S_8 —③→ mol S_8 —④→ 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 $8\,(S) = 32.07 \times 8 = 256.6\,g/mol$

④ $3\,S_8 = 8\,Fe_2S_3$

Fe

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

S_8

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

So Iron Runs out First.

Iron is the limiting reagent
Sulfur is the excess reagent.

A word about yield...

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

- 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

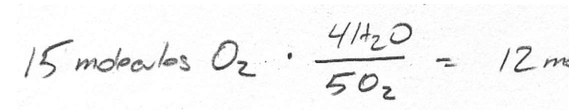
$$\%Y = \frac{0.135}{0.208} = 64.9\%$$

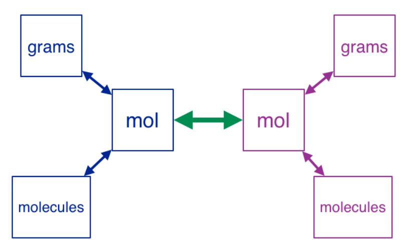
Ch05

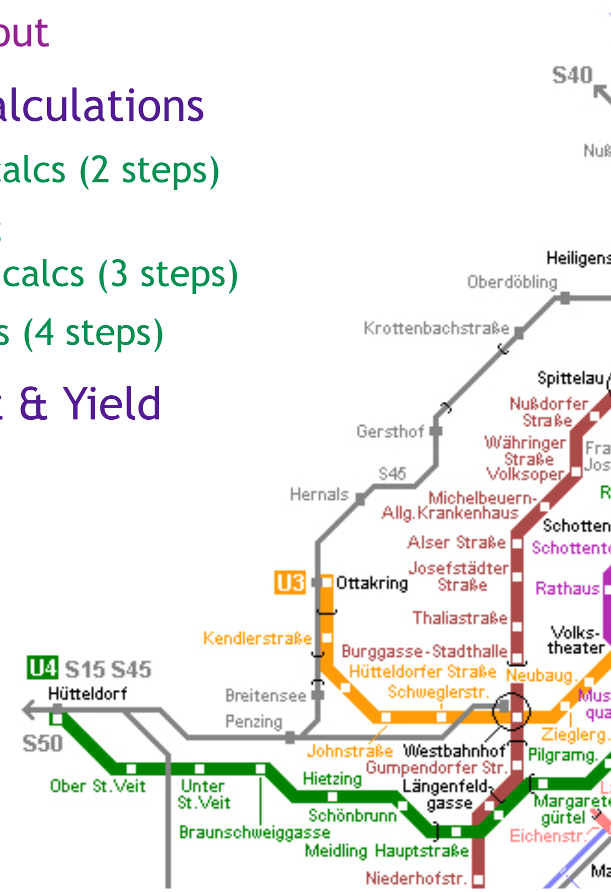
Reaction

- Chemical Change
  - Chemical Reaction
  - Chemical Equations
    - Describing Chemical Change
  - Writing Chemical Equations
- Classifying Reactions
  - by Kinetics
    (mutually exclusive labels)
    - Combination, Decomposition, Single & Double Displacement
  - by Reactivity
    (not mutually exclusive labels)
    - Combustion, Gas Evolution, Precipitation, Reduction/Oxidation

- Balanced Equations
  - Balanced Equations
  - Balancing
- The Mole Ratio
  - A new conversion factor
  - Mapping it all out
- Stoichiometry Calculations
  - mol → mol calcs (2 steps)
  - mass → mol;
    mol → mass calcs (3 steps)
  - mass → mass (4 steps)
- Limiting Reagent & Yield







heat & pressure →

Questions?

S40
Oberdöbling
Krottenbachstraße
Spittelau
Nußdorfer Straße
Gersthof
Währinger Straße Volksoper
S45
Hernals
Michelbeuern-Allg.Krankenhaus
Alser Straße
Josefstädter Straße
U3
Ottakring
Rathaus
Thaliastraße
Volks-theater
Kendlerstraße
Burggasse-Stadthalle
Hütteldorfer Straße
Neubaug.
U4 S15 S45
Hütteldorf
Breitensee
Schweglerstr.
Penzing
S50
Johnstraße
Westbahnhof
Pilgramg.
Gumpendorfer Str.
Ober St.Veit
Unter St.Veit
Hietzing
Längenfeld-gasse
Schönbrunn
Braunschweiggasse
Meidling Hauptstraße
Eichenstr.
Niederhofstr.