GAS FORMATION / OTHER MOLECULES

- There are a few other molecules that can be made with exchange-type chemistry.
- Most of these molecules are unstable and can break apart to form gases.

- Formation of a weak acid:
    - The formation of ANY weak acid in an exchange-type reaction can be a driving force.
    - Some weak acids are unstable and can break apart into gas molecules.

$$H_2CO_3(aq) \longrightarrow H_2O(l) + \boxed{CO_2(g)}$$

Gas bubbles can leave solution!

... but how would you form carbonic acid in an exchange-type reaction?

acid + carbonate CO_3^{2-}

OR

acid + bicarbonate HCO_3^-

$$H_2SO_4(aq) + 2NaHCO_3(aq) \rightarrow 2H_2CO_3(aq) + Na_2SO_4(aq)$$

Ions: H^+ SO_4^{2-} Na^+ HCO_3^-

Formation of carbonic acid drives the reaction ... BUT ...

$$H_2SO_4(aq) + 2NaHCO_3(aq) \rightarrow Na_2SO_4(aq) + \boxed{2H_2CO_3(aq)}$$

$$H^+ \quad SO_4^{2-} \quad Na^+ \quad HCO_3^-$$

... but when we mix sulfuric acid and sodium bicarbonate, we observe BUBBLES. We need to write an equation that agrees with our observations. We know that carbonic acid decomposes, so we go ahead and put that into our equation.

$$H_2CO_3(aq) \longrightarrow H_2O(\ell) + CO_2(g)$$

$$H_2SO_4(aq) + 2NaHCO_3(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell) + 2CO_2(g)$$

Other molecules of interest:

H_2SO_3: sulfurous acid - React an ACID with a SULFITE

$$H_2SO_3(aq) \rightarrow H_2O(\ell) + SO_2(g)$$

H_2S: hydrogen sulfide (gas) - React an ACID with a SULFIDE

$$H_2SO_4(aq) + Na_2S(aq) \rightarrow Na_2SO_4(aq) + H_2S(g)$$

A few more exchange examples:

* Transition metals DO NOT change their charge in exchange reactions!

$CaCl_2(aq) + 2\overset{*}{Ag}NO_3(aq) \longrightarrow \underline{2AgCl(s)} + Ca(NO_3)_2(aq)$ ✓

Ca^{2+} Cl^- Ag^+ NO_3^-

Formation of SOLID AgCl drives this PRECIPITATION reaction.

$H_3PO_4(aq) + 3NaOH(aq) \longrightarrow \underline{3H_2O(l)} + Na_3PO_4(aq)$ ✓

H^+ PO_4^{3-} Na^+ OH^-

Formation of water MOLECULES drives this NEUTRALIZATION

$KCl(aq) + NaNO_3(aq) \longrightarrow$ ~~$NaCl(aq) + KNO_3(aq)$~~ NO REACTION

K^+ Cl^- Na^+ NO_3^-

Both "products" are soluble ionic compounds. They exist in water as FREE IONS (not paired), which is the same way they existed before the reaction. There's no driving force, therefore NO REACTION!

$H_2SO_4(aq) + Na_2CO_3(aq) \longrightarrow H_2CO_3(aq) + Na_2SO_4(aq)$

H^+ SO_4^{2-} Na^+ CO_3^{2-}

$H_2CO_3 \longrightarrow H_2O + CO_2$

$H_2SO_4(aq) + Na_2CO_3(aq) \longrightarrow H_2O(l) + CO_2(g) + Na_2SO_4(aq)$ ✓

Formation of carbonic acid MOLECULES (and their decomposition into WATER and CARBON DIOXIDE drives this reaction.

OXIDATION / REDUCTION CHEMISTRY

- Exchange reactions involve ions pairing up, but the ions themseves are not formed in exchange reactions. Exchanges start with pre-existing ions.

... but the ions have to be produced somehow - through a chemistry that involves the transfer of electrons.

- oxidation / reduction chemistry ("redox" chemistry) involves transfer of electrons and can make ions.

$$2Al(s) + 3Br_2(l) \rightarrow 2AlBr_3(s)$$

Elemental, metallic aluminum. Uncharged!

Al^0

Aluminum cation

Al^{3+}

These are called "half-reactions"

$$Al \rightarrow Al^{3+} + 3\underbrace{e^-}_{\text{electron}}$$

oxidation: loss of electrons

$$Br_2 + 2e^- \rightarrow 2Br^-$$

reduction: gain of electrons

- oxidation and reduction always occur together. In other words, we can't just make free electrons using oxidation without giving them somewhere to go.
- Many of the types of reactions that we learned about in previous courses are redox reactions!

  - COMBINATIONS (often but not always redox)
  - DECOMPOSITIONS (often redox)
  - SINGLE REPLACEMENT (always redox)

$$Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$$

$$Cu \rightarrow Cu^{2+} + 2e^- \quad \text{oxidation}$$

$$2Ag^+ + 2e^- \rightarrow 2Ag(s) \quad \text{reduction}$$

net ionic → $Cu(s) + 2Ag^+(aq) \rightarrow Cu^{2+}(aq) + 2Ag(s)$

  - COMBUSTION

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

$$2Mg(s) \rightarrow 2Mg^{2+} + 4e^- \quad \text{oxidation}$$

$$O_2(g) + 4e^- \rightarrow 2O^{2-} \quad \text{reduction}$$

A review of the reaction types we just mentioned:

① COMBINATION REACTIONS

- Reactions that involve two or more simple substances COMBINING to form a SINGLE product
- Often involve large energy changes. Sometimes violent!
- Form: $\boxed{A + B + \ldots \longrightarrow C}$

Example:

$$2\,Al(s) + 3\,Br_2(l) \longrightarrow 2\,AlBr_3(s)$$

② DECOMPOSITION REACTIONS

- Reactions where a SINGLE REACTANT breaks apart into several products

- Form: $\boxed{A \longrightarrow B + C + ...}$

Example:

$$2\,H_2O_2(l) \longrightarrow 2\,H_2O(l) + O_2(g)$$

* This reaction is NOT a combustion reaction, even though O_2 is involved!

* Combustion reactions CONSUME O_2, while this reaction PRODUCES O_2

③ COMBUSTION REACTIONS

- Reactions of substances with MOLECULAR OXYGEN (O_2) to form OXIDES.
- Combustion forms an OXIDE of EACH ELEMENT in the burned substance!

- Form: $\boxed{AB + O_2 \longrightarrow AO + BO}$

Oxide: a compound containing OXYGEN and one other element!

* Combustion of hydrocarbons makes carbon dioxide and water, if enough oxygen is present. In low-oxygen environments, carbon monoxide is made instead!

Examples:

Oxides!

*

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

$$\underbrace{2Mg(s) + O_2(g) \longrightarrow 2MgO(s)}$$

This reaction can also be called a combination! Two reactants form a single product.

④ SINGLE REPLACEMENT REACTIONS

- Reactions where one element REPLACES another element in a compound.

- Can be predicted via an ACTIVITY SERIES (p151, 9th edition) (p153, 10th ed)

- Form: $\boxed{A + BC \longrightarrow AC + B}$

"A" and "B" are elements., often metals.

- Easy to spot, since there is an element "by itself" on each side of the equation.

Examples:

$$\overset{0}{Cu}(s) + 2\overset{+1}{Ag}NO_3(aq) \longrightarrow \overset{+2}{Cu}(NO_3)_2(aq) + 2\overset{0}{Ag}(s)$$

$$\overset{0}{Zn}(s) + \overset{+1}{H}_2SO_4(aq) \longrightarrow \overset{+2}{Zn}SO_4(aq) + \overset{0}{H}_2(g)$$

REDOX LANGUAGE

"oxidizer"

- "Oxidation" is loss of electrons, but an OXIDIZING AGENT is something that causes ANOTHER substance to lose electrons. An oxidizing agent is itself reduced during a redox reaction.

- "Reduction" is gain of electrons, but a REDUCING AGENT is something that causes ANOTHER substace to gain electrons. Reducing agents are themselves oxidized during a redox reaction.

$$2\overset{0}{\text{Al}}(s) + 3\overset{0}{\text{Br}_2}(l) \longrightarrow 2\overset{+3}{\text{Al}}\overset{-1}{\text{Br}_3}(s)$$

Aluminum is OXIDIZED during this process. We say that metallic aluminum is a REDUCING AGENT!

Bromine is REDUCED during this process. We say that bromine is an OXIDIZING AGENT!

* Strong oxidizers (oxidizing agents) can cause spontaneous fires if placed into contact with combustibles (safety issue!).

* Reactive metals tend to be REDUCING AGENTS, while oxygen-rich ions like NITRATES tend to be OXIDIZING AGENTS. HALOGENS (Group VIIA) also tend to be OXIDIZING AGENTS

END OF CHAPTER 4 MATERIAL

GASES

- Gases differ from the other two phases of matter in many ways:

  - They have very low viscosity (resistance to flow), so they flow from one place to another very easily.

  - They will take the volume of their container. In other words, gas volumes are variable.

  - They are the least dense of all three phases.

  - Most gases are transparent, and many are invisible.

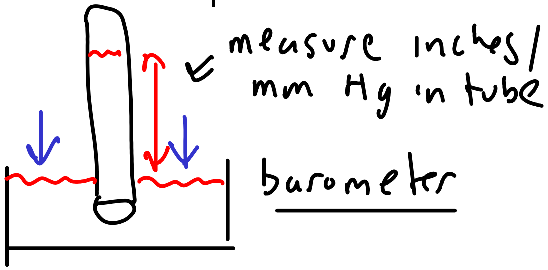
  - Gases show a much larger change of volume on heating or cooling than the other phases. ↙ thermal expansion!

  - Gases react to changes in temperature and pressure in a very similar way. This reaction often does not depend on what the gas is actually made of.

KINETIC THEORY

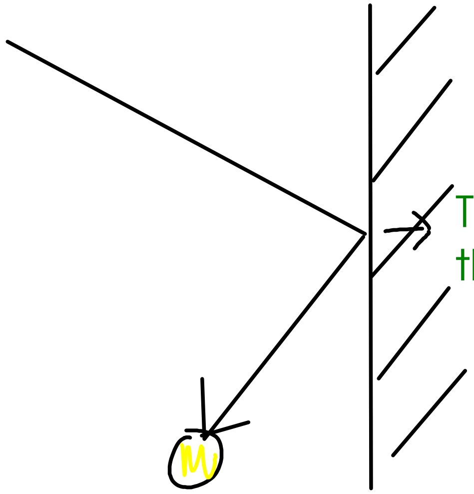
- is a way to explain the behavior of gases.
- views the properties of gases as arising from them being molecules in motion.

- Pressure: force per unit area. Units: Pascal, bar, mm Hg, in Hg, atm, etc.



760 mm Hg = 1 atm

- According to kinetic theory, pressure is caused by collisions of gas molecules with each other and the walls of the container the gas is in.



This collision exerts a force on the wall!

135- Temperature:

- a measure of the average kinetic energy of the molecules of the gas

$$E_K = \frac{1}{2}\,\underset{\text{mass}}{\underset{\uparrow}{m}}\,\underset{\boxed{\text{velocity}}}{\underset{\uparrow}{v}}^{2}$$

- The faster the gas molecules move, the higher the temperature!

- The temperature scales used when working with gases are ABSOLUTE scales.

- ABSOLUTE: scales which have no values less than zero.

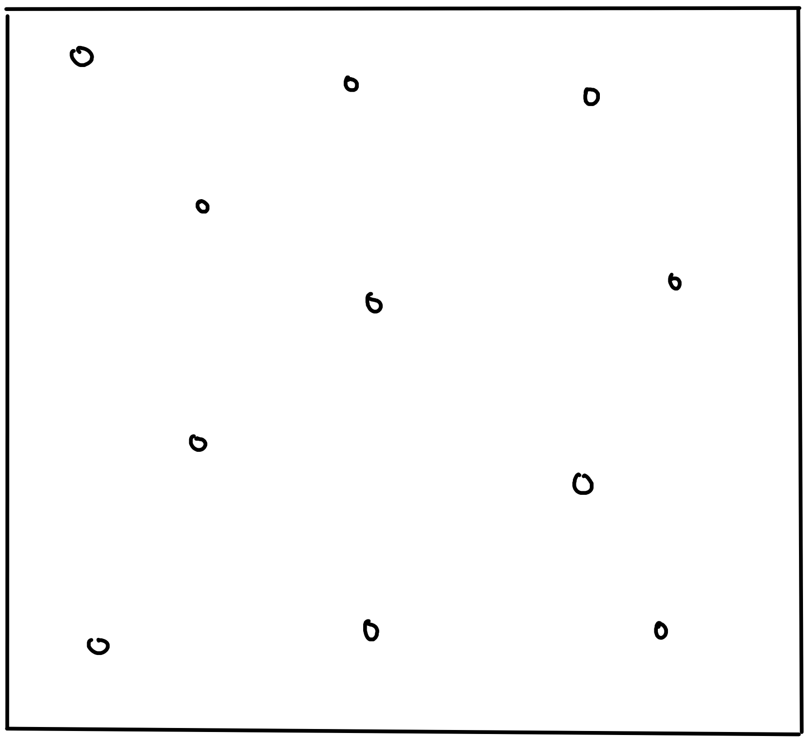
- KELVIN: metric absolute temperature scale.

$$\boxed{K = 273.15 + {}^{\circ}C}$$

Quick comparison of temperature scales!

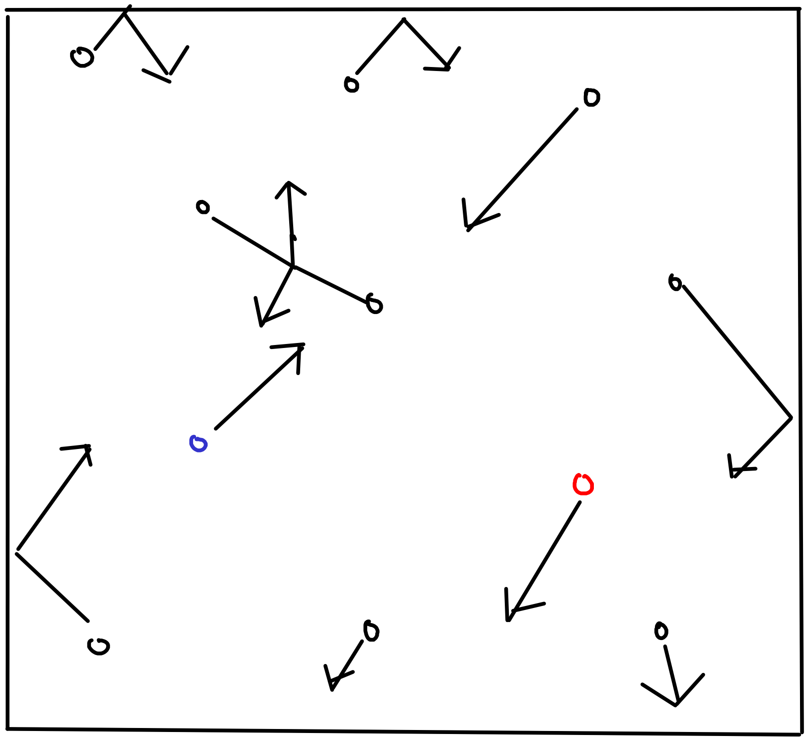
°F	°C	K	
212	100	373	Water boils
77	25	298	Room temperature
32	0	273	Water freezes
-460	-273	0	Absolute zero!

THE KINETIC PICTURE OF GASES



① Gas molecules are small compared to the space between the gas molecules!

LOW DENSITY!



② Gas molecules are constantly in motion. They move in straight lines in random directions and with various speeds.

③ Attractive and repulsive forces between gas molecules are so small that they can be neglected except in a collision.

- Each gas molecule behaves independently of the others.

④ Collisions between gas molecules and each other or the walls are ELASTIC.

⑤ The average kinetic energy of gas molecules is proportional to the absolute temperature.

How does this picture explain the properties of gases?

- Gases expanding to fill their container? Agrees with kinetic picture, since gas molecules are independent
- Thermal expansion of gas at constant pressure? Agrees, because the container has to EXPAND to keep the pressure (from collisions) constant when the gas molecules move faster.
- Pressure increases with temperature at constant volume: Agrees, because the number and force of collisions increases with molecular speed.

GAS LAWS

- were derived by experiment long before kinetic theory, but agree with the kinetic picture!

Boyle's Law:

$$PV = \text{constant}$$

True at constant temperature

$$P_1V_1 = \text{constant} \qquad P_2V_2 = \text{constant}$$

$$\boxed{P_1V_1 = P_2V_2}$$

True at constant temperature

Charles's Law:

$$\frac{V}{T} = \text{constant}$$

True at constant pressure, and using ABSOLUTE temperature

$$\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}}$$

True at constant pressure, and using ABSOLUTE temperature

Combined gas law:

$$\frac{PV}{T} = \text{constant}$$

Must use ABSOLUTE temperature units!

$$\downarrow$$

$$\boxed{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}}$$

Must use ABSOLUTE temperature units!

↑ amount (moles) of gas must be constant!

Avogadro's law:

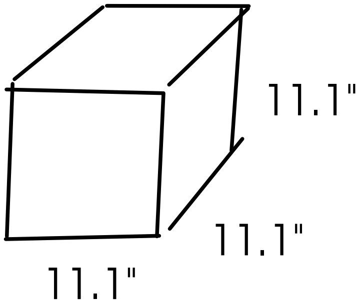
- a mole of any gas at the same conditions has the same volume.

1 mol gas molecules @ 0°C and 1 atm

volume = 22.4 L

"STP"

Standard Temperature and Pressure



= 22.4 L

Ideal gas law:

$$\frac{PV}{T} = \text{constant}$$

... but this constant actually depends on the amount of gas!

$$= n \times \text{"}R\text{"}$$

The ideal gas constant.

$$0.08206 \ \frac{L \cdot atm}{mol \cdot K}$$

... combining these together ...

$$\frac{PV}{T} = nR$$

$$\downarrow$$

$$\boxed{PV = nRT}$$

P = pressure atm

V = volume L

T = ABSOLUTE temperature K

R = ideal gas constant

n = number of moles of gas molecules