Exchange Chemistry

- Three kinds of exchange chemistry.

① PRECIPITATION ← Formation of IONIC SOLID

② ACID/BASE or NEUTRALIZATION

③ GAS FORMATION (formation of unstable molecules)

SOME (but not all) reactions that form gases are examples of exchange chemistry.

Formation of MOLECULES!

Just because you mix together two ionic compounds does NOT mean that a reaction will occur. You need a DRIVING FORCE for a reaction.

PRECIPITATION REACTIONS

- driving force is the formation of an insoluble ionic compound.

$$3MgCl_2(aq) + 2Na_3PO_4(aq) \rightarrow 6NaCl(aq) + \underline{Mg_3(PO_4)_2(s)}$$

ions: Mg^{2+} Cl^- Na^+ PO_4^{3-}

Formation of INSOLUBLE magnesium phosphate drives this precipitation reaction!

When you're trying to complete a precipitation reaction:

① Write the IONS that form when the reactants are dissolved.

② Make NEW compounds by pairing up cations with anions. Don't forget that the positive and negative charges must balance each other out!

③ Use the solubility rules to determine the PHASE of each new compound - solid or aqueous.

④ Balance the overall equation.

$MgCl_2(aq) + NaC_2H_3O_2(aq) \rightarrow$ NO REACTION!*

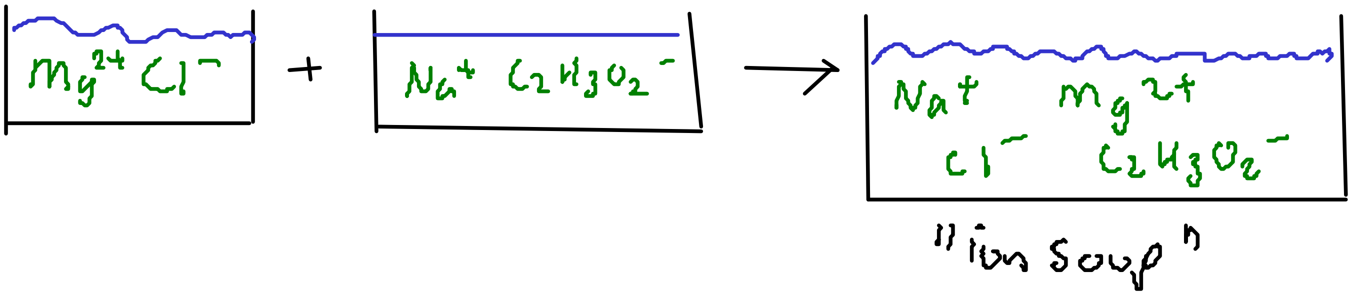
ions: Mg^{2+} Cl^- Na^+ $C_2H_3O_2^-$

"exchange"

$Mg(C_2H_3O_2)_2$ ... dissolves in water

$NaCl$ ... dissolves in water

So, no solid forms here. All possible combinations of these four ions result in compounds that dissolve readily in water.



NO CHANGE, therefore NO DRIVING FORCE, and NO REACTION

* We will learn about other driving forces than the formation of solid, but these driving forces do not apply to this reaction

ACID/BASE REACTIONS (also called NEUTRALIZATION REACTIONS)

- There are several stable molecules that may be formed in double replacement reactions, but the most common is WATER!

- Double replacement reactions that form water are also called "neutralizations"

$$\underset{\text{acid}}{HA} + \underset{\text{base}}{BOH} \longrightarrow H_2O + \underset{\text{salt}}{BA}$$

"HOH"

ionic compound

$$H^+ \; A^- \qquad B^+ \; OH^-$$

* To make water (H_2O), you need a source of hydrogen ion (H^+) and hydroxide ion (OH^-)

$$\underbrace{H^+(aq) + OH^-(aq)}_{} \longrightarrow H_2O(l)$$

This is the
NET IONIC
EQUATION
for many
neutralizations

... assumes you're reacting STRONG acid with STRONG base!

ACIDS

- compounds that release hydrogen ion (H^+), when dissolved in water.

Properties of acids:

- Corrosive: React with most metals to give off hydrogen gas
- Cause chemical burns on contact
- Taste sour (like citrus - citric acid!)
- Changes litmus indicator to RED

BASES

- Substances that release hydroxide ion (OH^-) when dissolved in water

Properties of bases:

- Caustic: Attack and dissolve organic matter (think lye, which is NaOH)
- Cause skin/eye damage on contact
- Taste bitter
- changes litmus indicator to BLUE

Due to the dissolving action of base on your skin, bases will feel "slippery". The base ITSELF is not particularly slippery, but what's left of your skin IS!

ACID/BASE or NEUTRALIZATION reactions continued

- the driving force of these reactions is the formation of water molecules.

$$\underbrace{H^+(aq)}_{\text{From the acid}} + \underbrace{OH^-(aq)}_{\text{From the base}} \rightarrow H_2O(l)$$

Net ionic equation

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow \underbrace{2H_2O(l)} + Na_2SO_4(aq)$$

ions: H^+ SO_4^{2-} Na^+ OH^-

Formation of liquid WATER molecules drives this reaction!

- How can this reaction be detected?
    - pH detector (indicator paper, etc.)
    - do the products have similar chemical properties to the reactants?
    - release of heat!

... formation of water is usually accompanied by a release of heat

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 ...

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

$$\begin{tikzcd} H^+ & SO_4^{2-} \arrow[r, bend right] & Na^+ & HCO_3^- \arrow[lll, bend left] \end{tikzcd}$$

... 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.

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

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

Other molecules of interest:

H_2SO_3: sulfurous acid - React an ACID with a SULFITE

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

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

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

A few more exchange examples:

$CaCl_2(aq) + 2AgNO_3(aq) \xrightarrow{} 2AgCl(s) + Ca(NO_3)_2(aq)$ ✓

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

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

Formation of SOLID AgCl drives this PRECIPITATION reaction

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

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

Formation of WATER molecules drives this NEUTRALIZATION reaction.

$KCl(aq) + NaNO_3(aq) \xrightarrow{}$ ~~$KNO_3(aq) + NaCl(aq)$~~ NO REACTION

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

We conclude NO REACTION, because there is no driving force for reaction here (No ionic solids, and no molecules formed...)

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

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

$H_2CO_3 \rightarrow H_2O + CO_2$

Formation of (and decomposition of) carbonic acid molecules drives this reaction!

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

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)

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

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

$$2Ag^+ + 2e^- \rightarrow 2Ag(s)$$ reduction

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

- COMBUSTION

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

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

$$O_2(g) + 4e^- \rightarrow 2O^{2-}$$ 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: $\boxed{A \longrightarrow B + C + \ldots}$

Example:

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

* 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:

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

$$\overset{0}{Zn}(s) + \overset{+1}{H_2}SO_4(aq) \longrightarrow \overset{+2}{Zn}SO_4(aq) + \overset{0}{H_2}(g)$$

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.

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

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.

  thermal expansion!

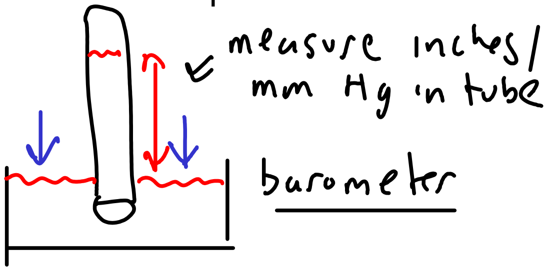
  - Gases show a much larger change of volume on heating or cooling than the other phases.

  - 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

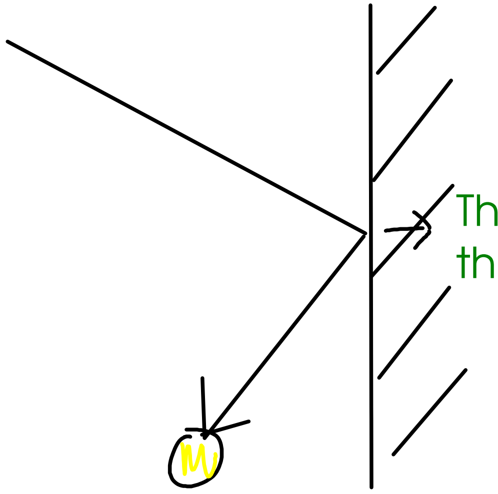
- is a way to explain the behavior of gases.
- views the properties of gases as arising from them being molecules in motion.

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



$$\boxed{760 \text{ mm Hg} = 1 \text{ atm}}$$

- 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

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

- 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!

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