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Chapter 13

Chemical Reactions

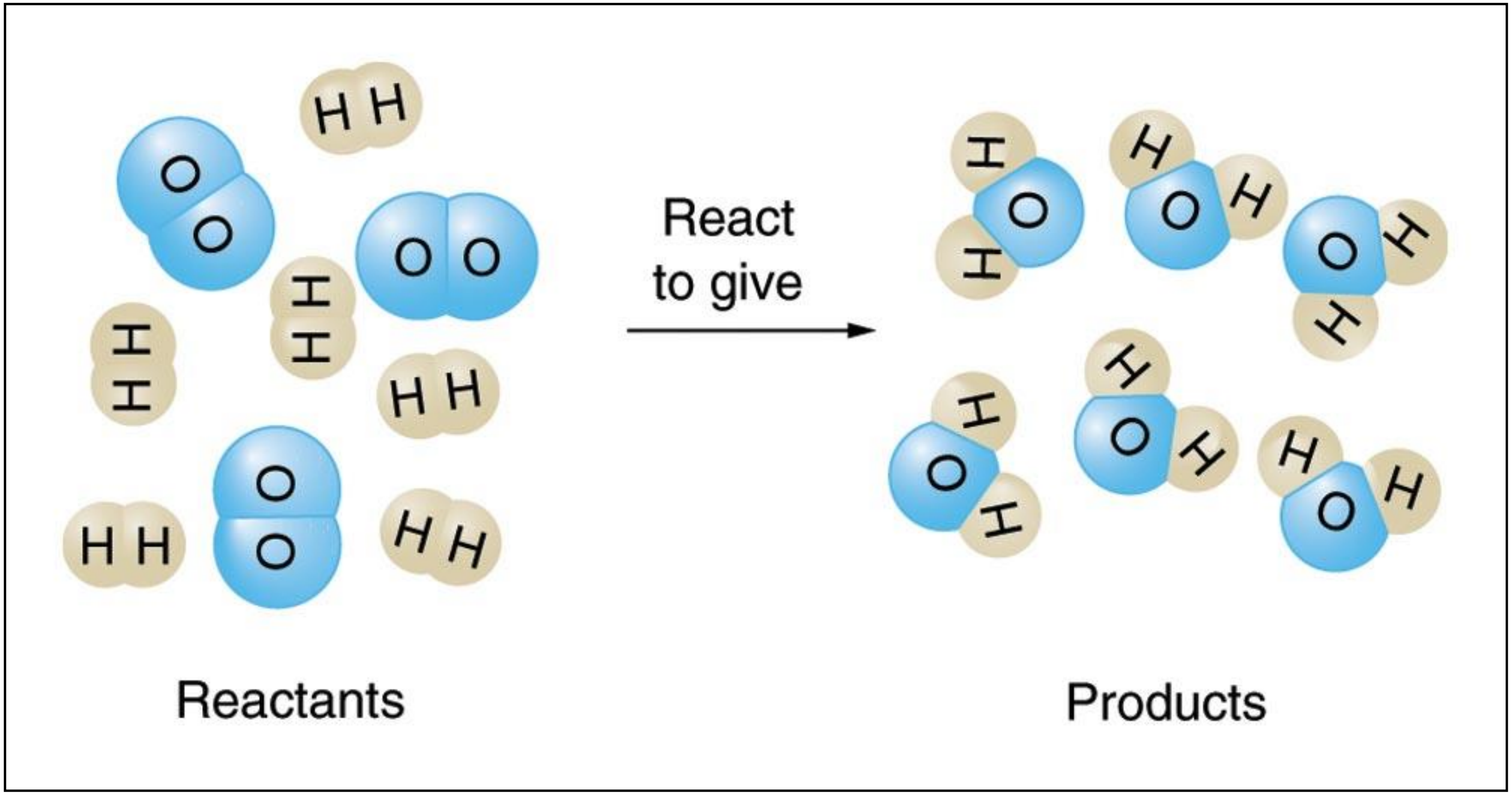
Properties

- Properties – the characteristics of a substance
- Physical Properties – do not describe the chemical reactivity of the substance
  - Example: Density, hardness, phase, color, melting point, electrical conductivity, specific heat
- Chemical Properties – reflect the ways in which a substance can be transformed into another substance
  - Describe a substance’s chemical reactivity
  - Burning, rusting, decomposition

Chemical Reactions

- Chemical Reaction – a change that alters the chemical composition of a substance and results in the formation of one or more new substances
  - Decomposition of water (H_2O) into hydrogen (H_2) and oxygen (O_2) gases
- A chemical reaction is simply a rearrangement of the atoms. Some of the original chemical bonds are broken and new bonds form.
  - New and different chemical structures are formed

Chemical Reaction – Rearrangement of Atoms



Chemical Reactions

- Generally, the atom’s valence electrons are the only ones directly involved in the chemical reaction.
  - The nucleus is unchanged and therefore the identity of the atom is unaffected
- Consider the following generalized reaction
- $A + B \rightarrow C + D$
- Reactants – original substances $A + B$
- Products – the new substances $C + D$
- “→” means “reacts to form” or “yields”

Common Symbols in Chemical Equations

Table 13.2 Common Symbols in Chemical Equations

Symbol	Meaning
$+$	Plus, or and
$\rightarrow$	Reacts to form, or yields
(g)	Gas
(l)	Liquid
(s)	Solid
(aq)	Aqueous (water) solution
$\xrightarrow{MnO_2}$	Catalyst (MnO_2, in this case) *
$\rightleftharpoons$	Equilibrium (equal reaction rates)

*Memorize all of these (except *)*

Chemical Reactions

- In any chemical reaction three things occur:
  1) Reactants disappear or are diminished
  2) New substances are formed as products
     - These products have different chemical / physical properties from the original reactants
  3) Energy is either released or absorbed.
     - Heat, light, electricity, sound

Table 13.3	Clues That a Chemical Reaction Has Occurred
1.	The color changes.
2.	The odor changes.
3.	Gas bubbles form.
4.	Solid particles form in solution (*precipitate*).
5.	Heat is produced or absorbed.

Chemical Equations

- A chemical equation can be written for every chemical reaction.
- The correct chemical formulas must be used and the equation must be balanced (same number of each type of atom on the reactant and product side of reaction)

- End 9am class on 9/17/18

Balancing Chemical Reactions

- Most chemical reactions can be balanced by trial and error, using three simple principles:
  1) An equal number of atoms of each kind must be represented on each side of the reaction arrow
  2) The formulas may not be changed, only the coefficients in front of the formulas
  3) The final set of coefficients used should be the smallest whole numbers that will satisfy the equation

Balancing Chemical Reactions – *Example*

- $HI \rightarrow H_2 + I_2$ – an unbalanced equation
- The formulas cannot be changed but a coefficient of "2" can be used, as below
- $2\ HI \rightarrow H_2 + I_2$ – a balanced equation
- The following equations are not exactly wrong but not the best:
  - $HI \rightarrow \frac{1}{2}\ H_2 + \frac{1}{2}\ I_2$

    end 9/17/18 11 am class
    - Fractions should not be used
  - $4\ HI \rightarrow 2H_2 + 2I_2$
    - Smallest possible whole numbers should be used

Tips to Balance Equations

- You must be able to properly count the atoms.
  - $4Al_2(SO_4)_3$ – in this equation there are 8 Al atoms, 12 S atoms, and 48 O atoms
- Start by balancing an element that is present in only one place on both sides of the reaction.
  - In the reaction $C + SO_2 \rightarrow CS_2 + CO$, start by balancing the S or the O (not the C)
- Insert the lowest coefficient possible on either side to get the same number of atoms of that element on each side

end class 9/19 11 am class

Tips to Balance Equations

- When polyatomic ions remain intact during the reaction, balance them as a unit (example: SO_4^{-2} don't separate out the S and O, CO_3^{2-} don't separate out the C and O)

- If both sides balance only by the use of a fractional coefficient in one place, multiply all the coefficients by the denominator of the fraction.
  - $C_2H_2 + 5/2\ O_2 \rightarrow 2\ CO_2 + H_2O$
  - Multiply by 2 (the denominator of 5/2)
  - $2\ C_2H_2 + 5\ O_2 \rightarrow 4\ CO_2 + 2\ H_2O$
  - Resulting in a balanced equation with no fractions

Balancing Equations – *Example*

- $Mg + O_2 \rightarrow MgO$ – an unbalanced equation
- Balance the oxygen first.
- $Mg + O_2 \rightarrow 2\ MgO$
  - Oxygen is balanced but not magnesium.
- $2\ Mg + O_2 \rightarrow 2\ MgO$
  - Now both magnesium and oxygen are balanced.

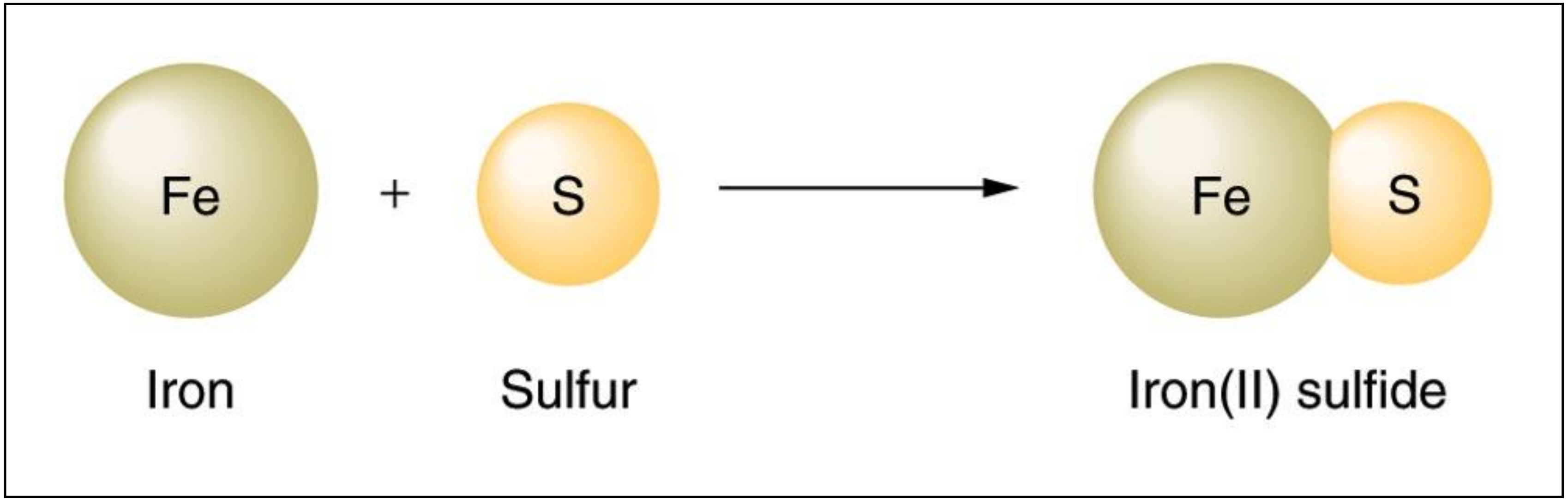
Balancing Equations – *Confidence Exercise*

- $NaN_3(s) \rightarrow Na(s) + N_2(g)$
  - This is an unbalanced reaction.
- $2\ NaN_3(s) \rightarrow Na(s) + 3\ N_2(g)$
  - Nitrogen is now balanced (6 on each side).
- $2\ NaN_3(s) \rightarrow 2\ Na(s) + 3\ N_2(g)$
  - Both nitrogen and sodium are balanced.

- This reaction shows how car air bags inflate by the electrical ignition of sodium azide (NaN_3) to produce nitrogen gas (N_2). *Interesting but Not Important*

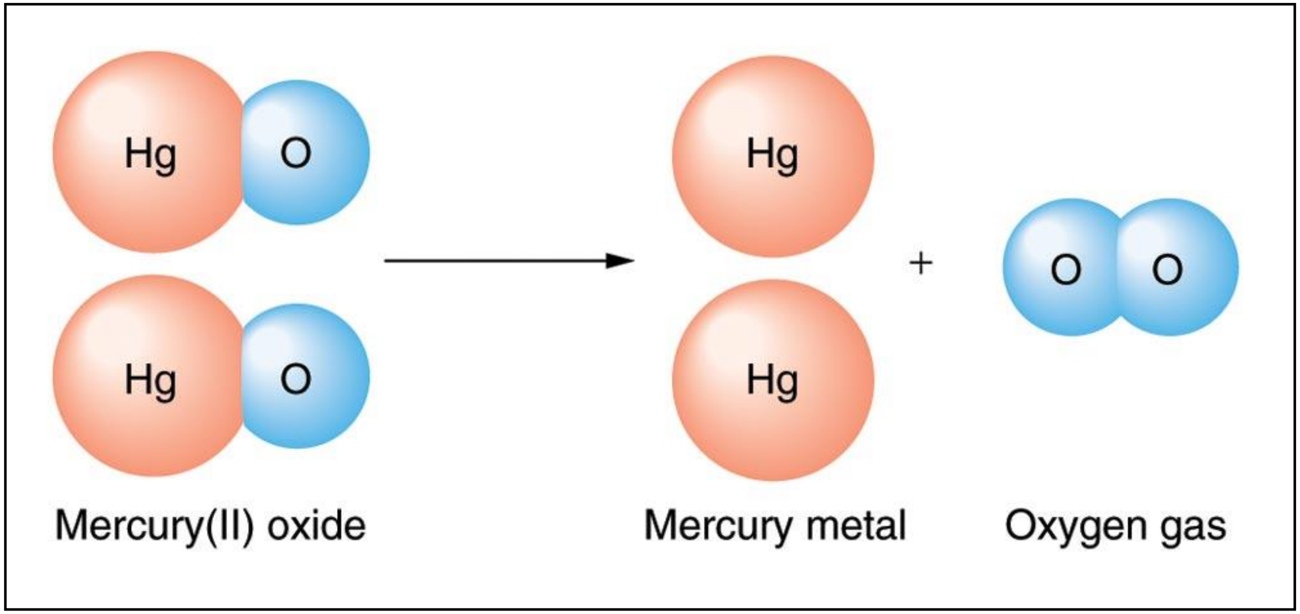
Type of RXN - Combination Reactions

- Combination Reaction – at least two reactants combine to form one product
  - $A + B \rightarrow AB$



Type of RXN - DecompositionReaction

- Decomposition Reaction – only one reactant is present and it breaks into two or more products
  - $AB \rightarrow A + B$



Chemical Reactions – A Change in Energy

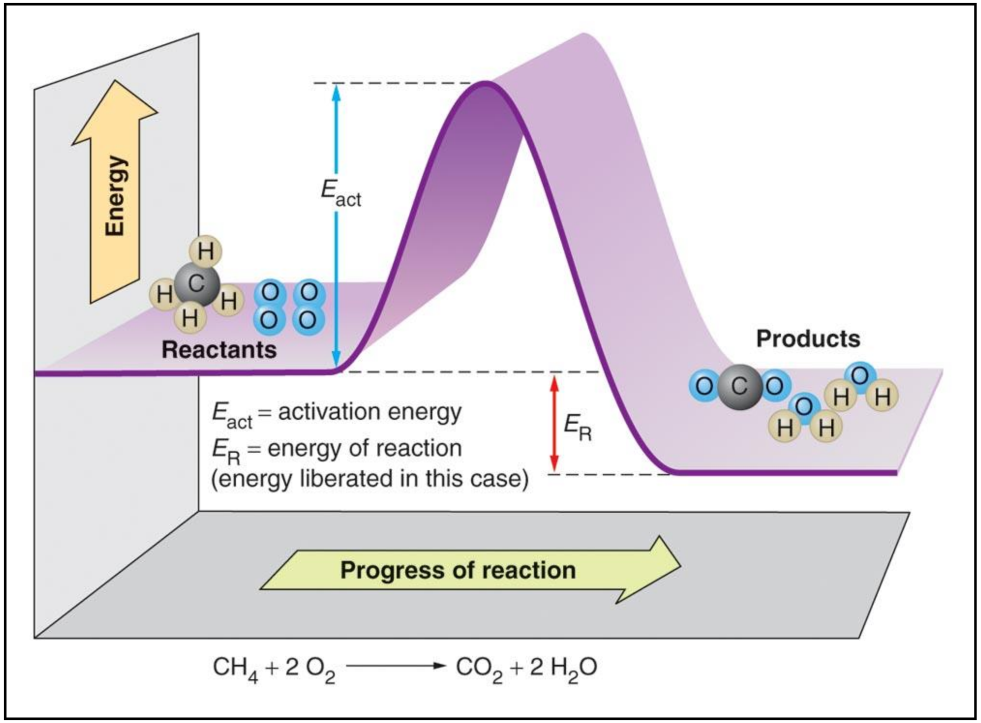
- During a chemical reaction, some chemical bonds are broken and other bonds are formed
- The different bonding energies of the reactants and products result in a change in energy
- In order to break bonds, energy must be absorbed
- When new bonds are formed, energy is released
- Energy from a chemical reaction is released or absorbed in the form of light, heat, electrical energy, or sound

Exothermic Reactions

- Exothermic reaction – a chemical reaction that results in a net release of energy to the surroundings
- Example: The burning of methane
- $CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$ + *energy (usually heat)*
- Bonding energy in the products is less than bonding energy in the reactants
    - therefore, energy is released

Exothermic Reactions (downhill)

- Net release of energy (E_R) – the bonds in the products have less total energy than the bonds in the reactants

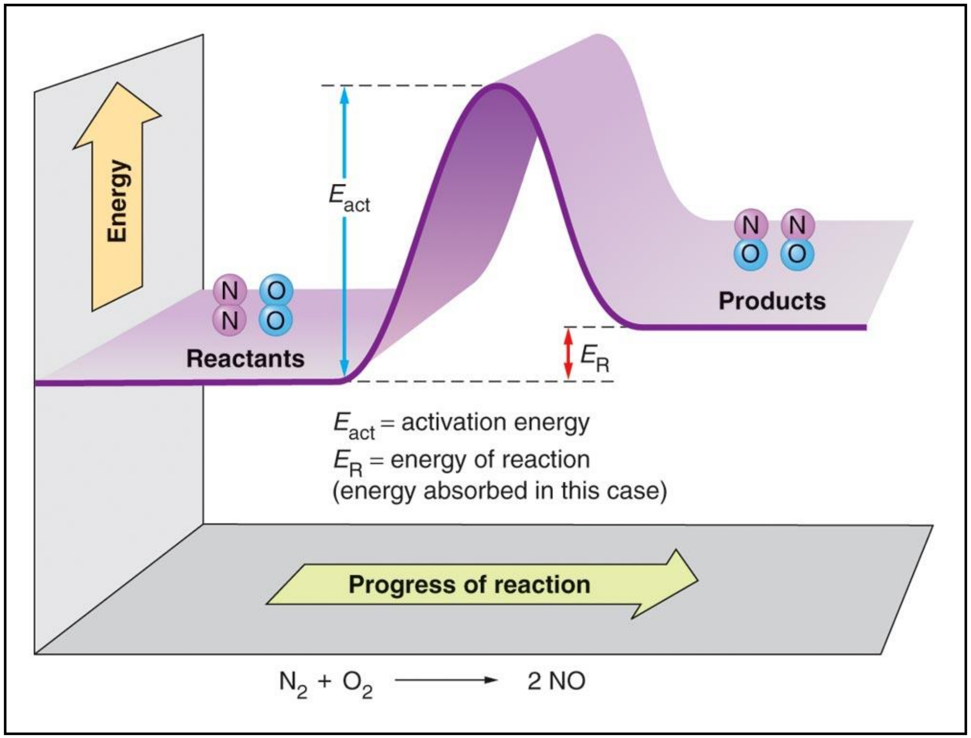


Endothermic Reactions

- Endothermic reaction – a chemical reaction that results in a net absorption of energy from the surroundings
- *Example*: $3\ O_2 + \textit{energy} \rightarrow 2\ O_3$
- Bonding energy in the reactants is less than bonding energy in the products
  - Although energy is released when the ozone bonds are formed, the amount is less than is absorbed in breaking the oxygen molecule bonds
  - therefore energy is absorbed

Endothermic Reactions - uphill

- Net absorption of energy (E_R) – the bonds in the reactants have less total energy than the bonds in the products   end 9 am 9/19 W



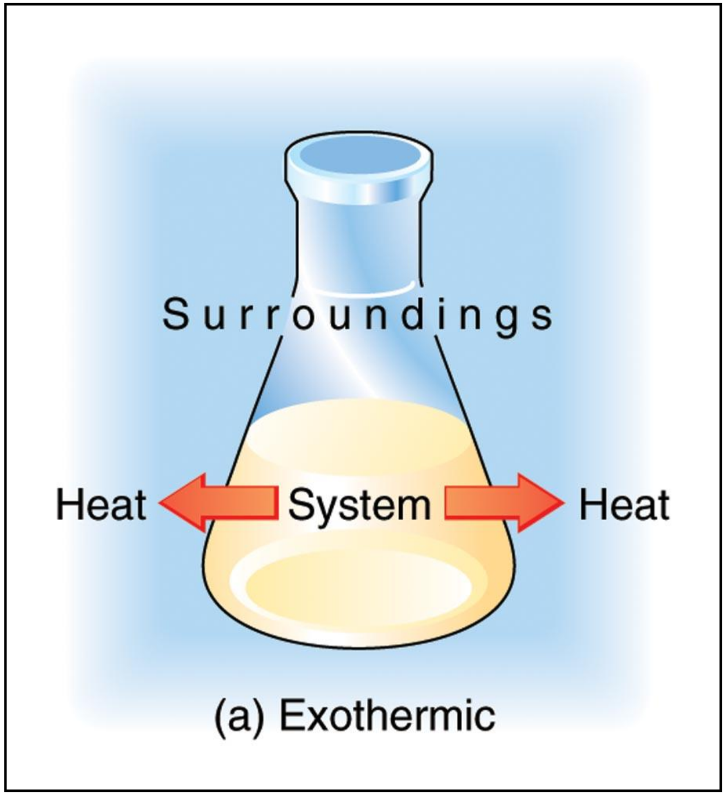
Activation Energy

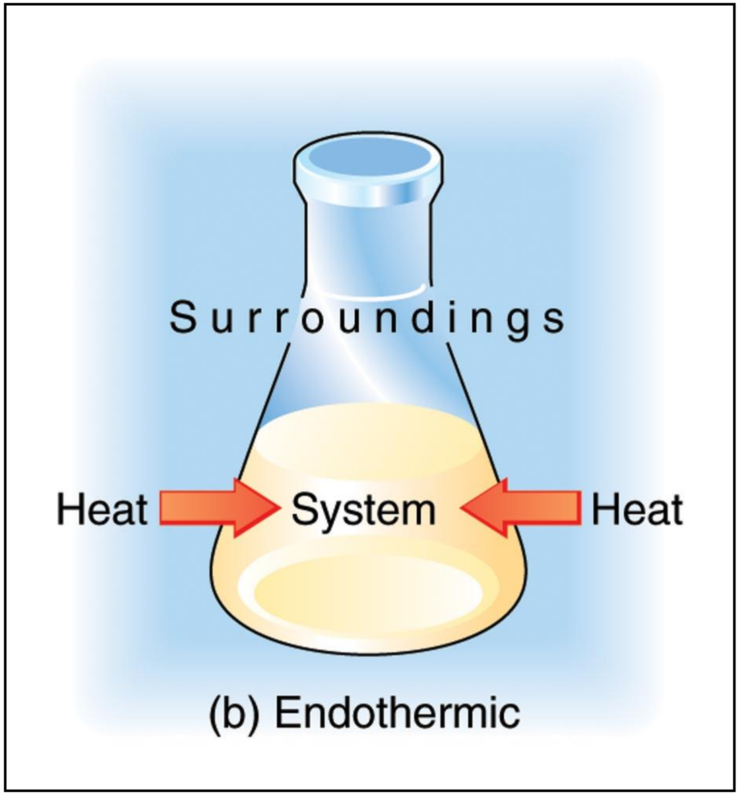
- Activation energy (E_{act}) – the energy necessary to start a chemical reaction (energy to get over the hill)
- In order to burn methane, one must provide an initial spark to break the "first" C—H and O—O bonds
  - After the initial bonds are broken, the energy released breaks the bonds of still more CH_4 and O_2, continuously giving off energy as heat and light
- E_{act} – the minimum kinetic energy that colliding molecules must possess to react chemically

Activation Energy

The activation energy required for a common match is acquired through friction (heat)

Heat Flow in Exothermic and Endothermic Reactions





<u>Exothermic</u> – vessel heats up as heat flows to surroundings RXN feels hot

<u>Endothermic</u> – vessel cools off as heat flows in from surroundings, RXN feels cold

Explosive & Combustive Reactions

- Explosion – occurs when an exothermic chemical reaction liberates energy almost instantaneously really fast exothermic chemical reaction
- Combustion reaction – a substance reacts with oxygen by bursting into flames and forming an oxide (exothermic reaction)
  - Burning of natural gas, coal, paper, wood
  - It is slower than an explosion

Hydrocarbon Combustion

- All C-H compounds (hydrocarbons) and C-H-O compounds produce energy when they react with oxygen
  - Exothermic chemical reactions
  - Give off CO_2 and H_2O when combustion is complete

Complete Hydrocarbon Combustion – *Example*

- *One of the components of gasoline is the hydrocarbon named heptane, C_7H_{16}. Write the balanced equation for its complete combustion.*
- Write heptane plus oxygen w/ reaction arrow
- $C_7H_{16} + O_2 \rightarrow$
- The products are **always CO_2 & H_2O**. (for **every** hydrocarbon)
- $C_7H_{16} + O_2 \rightarrow CO_2 + H_2O$
- Balance equation
- $\mathbf{C_7H_{16} + 11\ O_2 \rightarrow 7\ CO_2 + 8\ H_2O}$

Complete Hydrocarbon Combustion – *Confidence Exercise*

- *Write and balance the equation for the complete combustion of the hydrocarbon propane, C_3H_8 , a common fuel gas.*
- Write propane plus oxygen w/ reaction arrow
- $C_3H_8 + O_2 \rightarrow$
- The products are **always CO_2 & H_2O** for **every** hydrocarbon
- $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$
- Balance equation
- $\mathbf{C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O}$

Incomplete Combustion of Heptane

- With **insufficient time or oxygen** heptane does not completely combust, resulting in the following chemical reaction:
- $C_7H_{16} + 9\ O_2 \rightarrow 4\ CO_2 + 2\ CO + C + 8\ H_2O$
- In many cases this incomplete combustion can be seen in the dark exhaust gases given off by some automobiles
  - Note that sooty black carbon (C) and poisonous carbon monoxide (CO) are also products of **incomplete hydrocarbon combustion**

End class 9/21   11 am class

Rate of Reaction

- How fast a reaction proceeds (rate of reaction) depends on 3 variables:
  1) Temperature of the reactants
  2) Concentration of the reactants
  3) Catalyst Presence

Temperature Affects Rate of Reaction

- Recall that temperature is the average kinetic energy of the molecules
- For chemical reactions to proceed, the reacting molecules must collide with enough kinetic energy to break bonds (E_{act}) (enough energy to go over the energy hill)
- Increased kinetic energy (**higher temperature**) of the reacting molecules results in more abundant and more violent molecular collisions; therefore, the rate of reaction increases

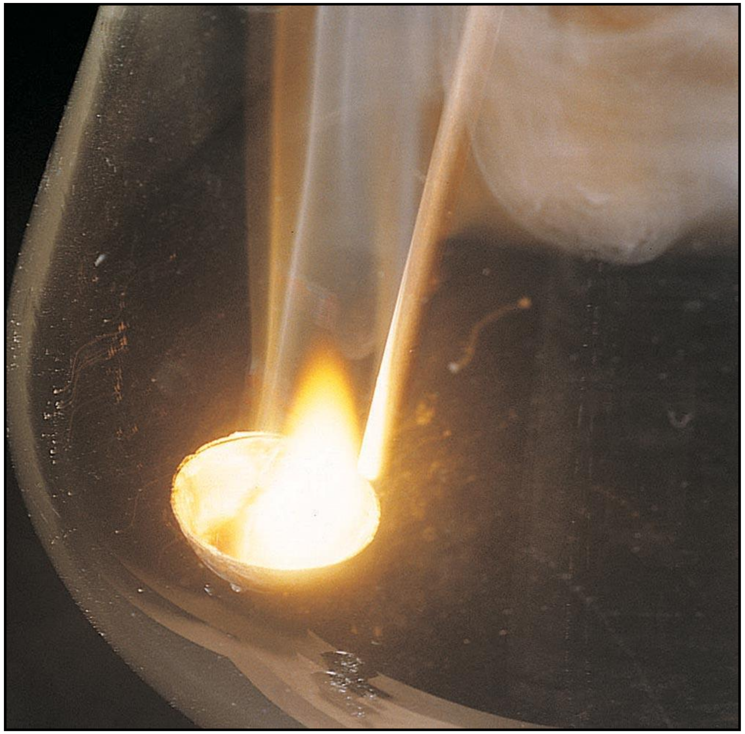
Concentration Affects Rate of Reaction

- Generally, higher the concentration of the reactants the faster the rate of the reaction.
- A higher concentration of reactants results in more molecular collisions and a faster reaction rate

- In pure oxygen (100%) a normal cigarette will actually burst into flames *don't need to know*
    - Recall that typical air has only about 21% oxygen

Concentration Affects Rate of Reaction

Phosphorus burning in pure oxygen (left) vs. 21% oxygen (right)



higher concentration *vs* *lower concentration*

faster *slower*

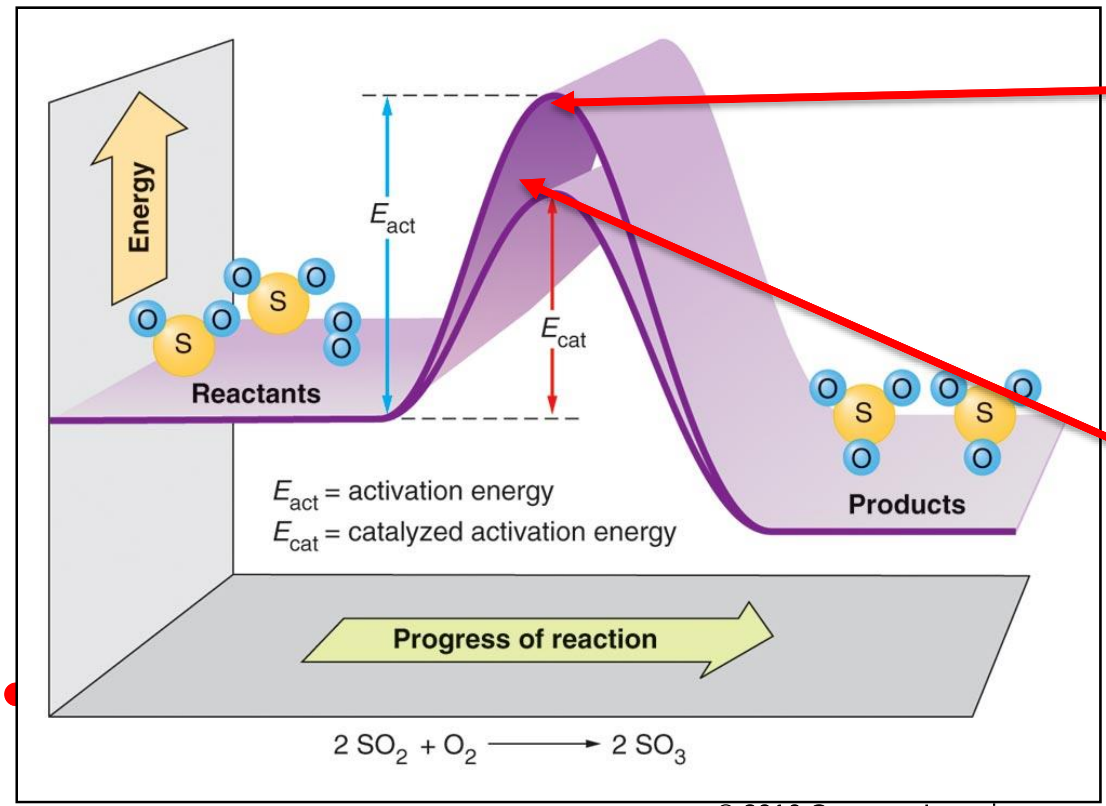
Catalysts Affects the Rate of Reaction

- Catalyst – a substance that increases the rate of reaction, but is not consumed in the reaction

- Some catalysts provide a surface to aid in concentrating the reactants. *don't need to know*
- Most catalysts provide a new reaction pathway that has a lower activation energy
- Although not consumed, the catalyst usually forms an intermediate "product" that takes part in the process and then decomposes back to its original form

Catalysts

- Generally provides a new reaction pathway with a lower activation energy requirement end 9/219am



without catalyst higher hill

with catalyst lower hill

Catalysts affects the Rate of Reaction – *Another Example*

- The decomposition of H_2O_2 at room temperature is very slow.
- $2\ H_2O_2 \rightarrow 2\ H_2O + O_2$ *(slow)* *without catalyst*
- When a small amount MnO_2 is added to the H_2O_2 the reaction proceeds rapidly.

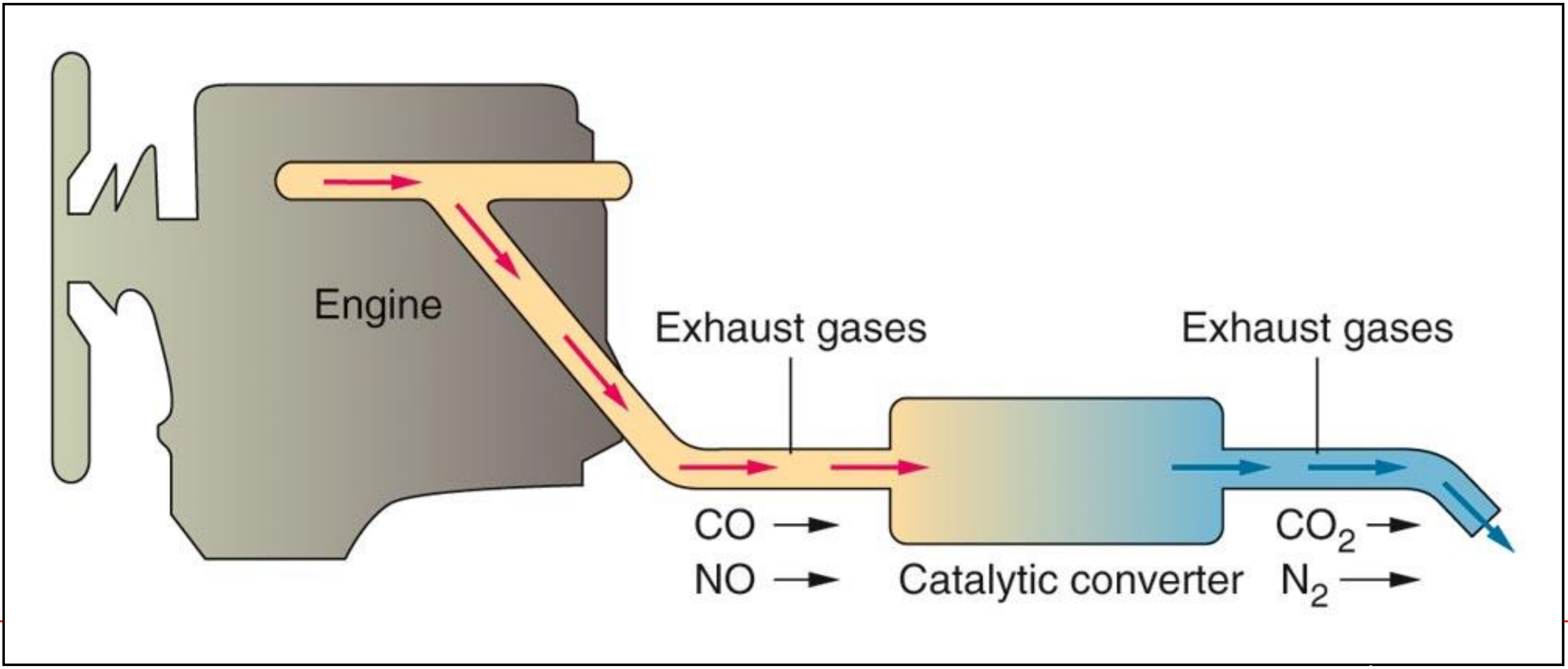
- $2\ H_2O_2 \xrightarrow{MnO_2} 2\ H_2O + O_2$ (fast) with catalyst
  - Catalyst is signified by placing it over the reaction arrow.

Automotive Catalytic Converter

- Beads of Pt, Rh, or Pd serve as catalysts to quickly convert noxious CO and NO into CO_2 and N_2

End class 9/24/18 Monday 11 am class

don't need to know entire slide – interesting though



Enzymes

- In the biological world, living organisms also use biological catalysts
  - They are called enzymes
- These enzymes control various physiologic reactions.
- For example, milk sugar (lactose) is broken down in a reaction catalyzed by the enzyme lactase
- Individuals who are “lactose intolerant” have a deficiency of lactase

Acids and Bases

<u>Acids</u>: produces hydrogen ion (H+) or hydronium ion (H_3O^+) in water

<u>Bases</u>: produces hydroxide ion (OH^-) in water

(Arrhenus Definition)

Acid

- Dissolved in water, an acid:
  - Conducts electricity
  - Litmus dye → blue to red (don't memorize color)
  - Sour taste (Never taste an acid!)
  - Reacts with and neutralizes a base
  - Reacts with active metals, give off H_2 gas

Base

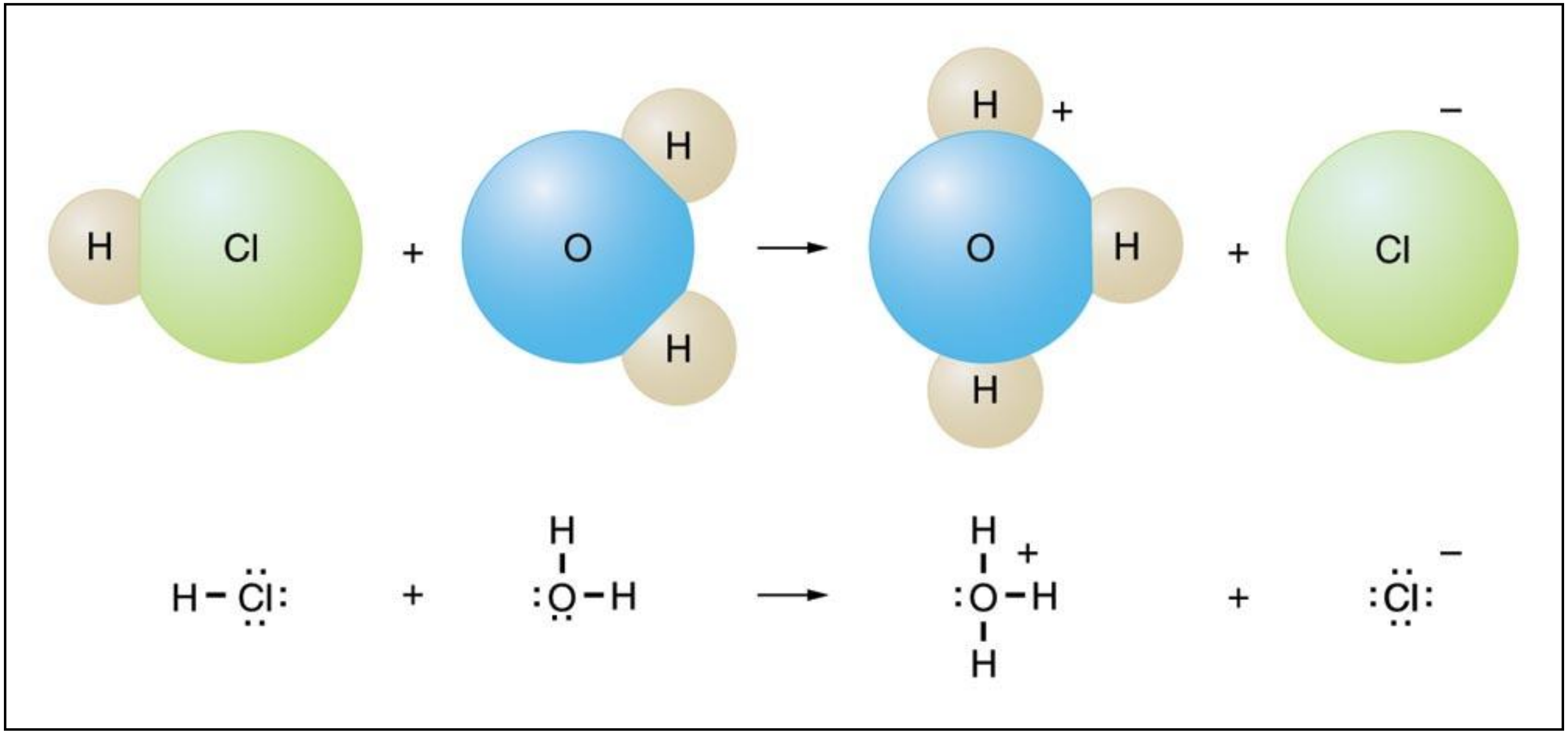
- Dissolved in water, a base:
  - Conducts electricity
  - Litmus dye → red to blue (don't memorize color)
  - Reacts with and neutralizes an acid

An Arrhenius Acid

- As the HCl molecule disassociates in water
- HCl + H_2O → H_3O^+ + Cl^-
  - The H_3O^+ is called the hydronium ion

- Arrhenius acid is a substance that produces hydrogen ions, H^+ (or hydronium ions, H_3O^+), in water

HCl Reacts with H_2O – Forming Hydronium Ions (H_3O^+) and Chlorine Ions ($Cl^–$)



Lewis Acid/Base

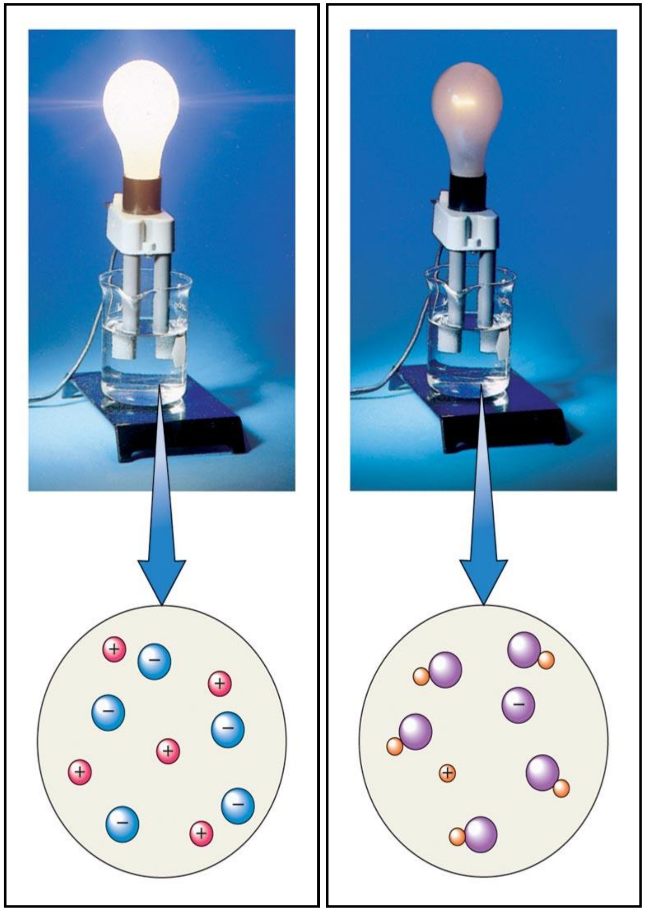
- A Lewis acid is any species that *accepts* lone pair electrons
- A Lewis base is any species that *donates* lone pair electrons
- Water need not be the solvent; however, we limit the discussion to water

Strong & Weak Acids

- An strong acid ionizes completely in solution
- Strong acids include HCl, HNO_3, H_2SO_4
  - All three of these in water ionize virtually completely
- Weak acids do not ionize completely in solution
  - At equilibrium, only a small fraction of the molecules disassociate to form H_3O^+
- Acetic acid, $HC_2H_3O_2$ (vinegar), is a common weak acid

- Memorize strong and weak acid shown on this slide.

Strong Acids Ionize More Completely



- Conduct electricity better
- Bulb glows brightly

Dynamic Equilibrium

- $HC_2H_3O_2 + H_2O \rightleftharpoons H_3O^+ + C_2H_3O_2$

- A double arrow may be used if the reverse reaction is significant
- When two ’competing’ reactions are occurring at the same time, the system is in ***dynamic equilibrium***
- In the case above, only a small fraction of the acetic acid molecules dissociates

Acids Are Very Useful Compounds

- Sulfuric acid has a number of different industrial uses
- Refining petroleum, processing steel, fertilizers
- Dilute HCl helps digest food in the stomach
- Citric acid ($H_3C_6H_5O_7$) in citrus fruits
- Carbonic (H_2CO_3) and phosphoric (H_3PO_4) acids in soft drinks
- Acetic acid ($HC_2H_3O_2$) in vinegar

- *Info only – do not need to know for exam. End class 9/26 9 am*

An Arrhenius Base

- When pure sodium hydroxide (NaOH) is added to water, it dissolves releasing Na^{+} and OH^{-}
- The base properties of NaOH are due to the hydroxide ions (OH^{-})
- Therefore an Arrhenius base is a substance that produces hydroxide ions (OH^{-})

An Arrhenius Base

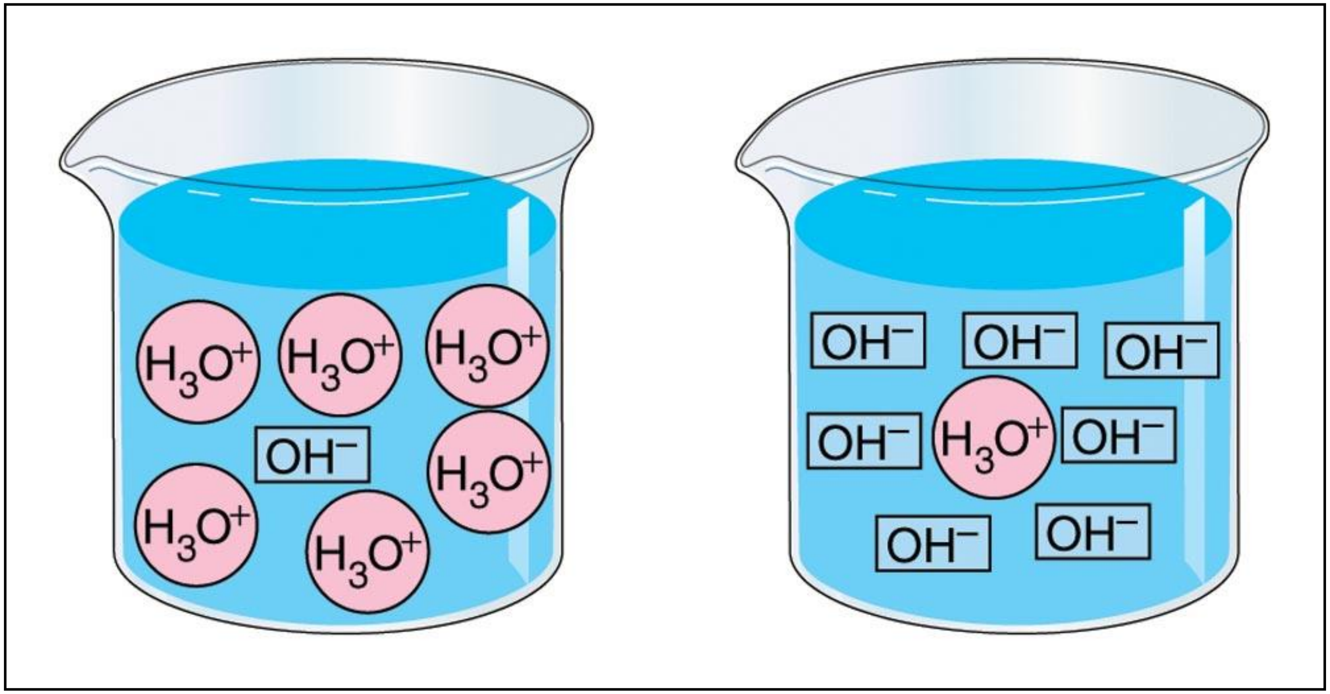
- Ammonia (NH_3) is also considered a base even though it does not contain OH^-
- In water ammonia reacts with H_2O to form OH^-
- $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$
- Common household bases include Drano ($NaOH$) and Windex (NH_3)

Water

- Water will slightly ionize by itself
- $H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$
- Therefore all aqueous solutions have both the hydronium ion (H_3O^+) and the hydroxide ion (OH^-)
- For pure water the concentrations of H_3O^+ and OH^- are equal, and therefore neutral
- An acidic solution has more H_3O^+
- A basic solution has more OH^-

Acidic and Basic Solutions

Acidic solution – higher concentration of H_3O^+
Basic solution – higher concentration of OH^-



Acidic Solution Basic Solution

pH – “power of hydrogen”

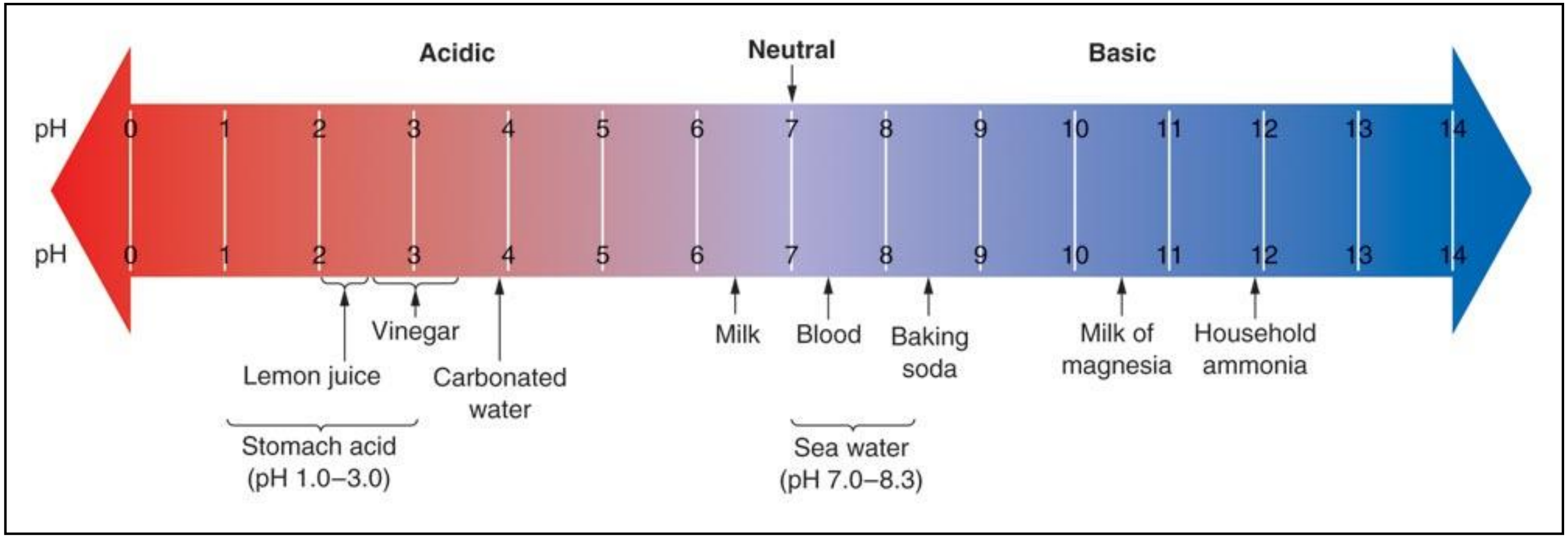
- The relative acidity or basicity of a solution is commonly designated by citing the pH
- The pH of a solution is a logarithmic measure of the concentration of the hydrogen ion

$$pH = -\log [H^+]$$

(higher pH more basic, lower pH more acidic)

The pH Scale

A solution with a pH of 7 is neutral, a solution with a pH less than 7 is acidic, and a solution with a pH greater than 7 is basic (memorize this)



The pH Scale

- Most body fluids of a healthy person must remain in a very narrow range on the pH scale
- Thus the pH of different body fluids may be used as a diagnostic measure
  - The pH of blood should be between 7.35 – 7.45
  - Don’t need to know this slide for exam.

Acid-Base Reaction

- When an acid is brought in contact with a base its characteristic properties disappear
  - And vice versa

- An acid and a hydroxide base react to produce water and a salt
- A salt is an ionic compound composed of any cation except H^+ and any anion except OH^-
  - Examples of salt include, KCl, $Ca_3(PO_4)_2$, $CuSO_4 \cdot 5H_2O$, $CaSO_4 \cdot 2H_2O$

Acid-Base Reaction – *Example*

- *Write a balanced equation for stomach acid HCl and milk of magnesia $Mg(OH)_2$*

- $HCl + Mg(OH)_2 \rightarrow H\ O\ H + MgCl_2$
- acid base water a salt

Exchange partners in reaction products.

- Balance the equation, using Mg^{2+}
- $\mathbf{2\ HCl + Mg(OH)_2 \rightarrow 2\ H_2O + MgCl_2}$

Acid-Base Reaction – *Confidence Exercise*

- *Write a balanced equation for stomach acid HCl and aluminum hydroxide (Di-Gel) $Al(OH)_3$*
- HCl is an acid and $Al(OH)_3$ is a base
- ∴ we know the water and a salt is produced
- $HCl + Al(OH)_3 \rightarrow H_2O$ + a salt
- Determine the salt from the given reactants
- $HCl + Al(OH)_3 \rightarrow$ H O H + $AlCl_3$
- Balance the equation, using Al^{3+}
- **$3\ HCl + Al(OH)_3 \rightarrow 3\ H_2O + AlCl_3$**
- **End class 9/26/18**