FACTORS THAT AFFECT REACTION RATES

1. Nature of Reactants
2. Surface Area of Solid Reactants
3. Concentration of Reactants
4. Temperature of Reaction System
5. Presence of a Catalyst

1. Nature of Reactants

Some generalizations:

a) State of Matter

(i) Gases tend to react faster than aqueous solutions, liquids or solids

eg. $CH_{4(g)} + 2\ O_{2(g)} \rightarrow CO_{2(g)} + 2\ H_2O_{(g)}$ ***fast***

$C_{25}H_{52(s)} + 38\ O_{2(g)} \rightarrow 25\ CO_{2(g)} + 26\ H_2O_{(g)}$ ***slow***

- It takes energy to separate particles from each other. In order to burn candle wax, the solid wax has to be melted and then vaporized before it reacts with oxygen.
- Methane gas is already in the gaseous state so it burns faster than wax.

(ii) Simple aqueous ions react almost instantaneously

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

$Pb(NO_3)_{(aq)} + 2\ KI_{(aq)} \rightarrow PbI_{2(s)} + 2\ KNO_{3(aq)}$ ***fast***

- Solid lead(II) nitrate will react with solid potassium iodide, but the reaction is very, very slow. That's because the ionic bonding in each reactant is strong and the ions in each compound are hard to separate from each other.
- When aqueous solutions of these compounds are mixed, the formation of lead(II) iodide is rapid. In aqueous solutions, the ions of each compound are dissociated. When the two solutions are mixed together, all that is required for a reaction to occur is contact between the lead(II) ions and the iodide ions.

  Net Ionic equation for actual reaction: $Pb^{2+}_{(aq)} + 2\ I^-_{(aq)} \rightarrow PbI_{2(s)}$

b) Bond Type

- Reactions involving ionic species tend to proceed faster than reactions involving molecular compounds (covalent bonds are stronger)

eg. $2\ CO_{(g)} + O_{2(g)} \rightarrow 2\ CO_{2(g)}$ ***very slow***

$5\ Fe^{2+}_{(aq)} + MnO_4^-{}_{(aq)} + 8\ H^+_{(aq)} \rightarrow 5\ Fe^{3+}_{(aq)} + Mn^{2+}_{(aq)} + 4\ H_2O_{(l)}$

very fast

c) Bond Strength

- Reactions involving the breaking of weaker bonds proceed faster than reactions involving the breaking of stronger bonds.

eg. $2\ C_2H_{6(g)} + 7\ O_{2(g)} \rightarrow 4\ CO_{2(g)} + 6\ H_2O_{(g)}$ ***very, very fast***

$2\ C_2H_{4(g)} + 6\ O_{2(g)} \rightarrow 4\ CO_{2(g)} + 4\ H_2O_{(g)}$ ***very fast***

- The double carbon to carbon bonds in ethene ($C_2H_{4(g)}$) are stronger than single C-C bonds in ethane ($C_2H_{6(g)}$).

d) Number of Bonds / Molecular Size

- Reactions involving the breaking of fewer bonds per reactant proceed faster than those involving the breaking of a larger number of bonds per reactant.

eg. $C_5H_{12(l)} + 8\ O_{2(g)} \rightarrow 5\ CO_{2(g)} + 6\ H_2O_{(g)}$ ***very fast***

$C_2H_{6(g)\ (l)} + 14\ O_{2(g)} \rightarrow 9\ CO_{2(g)} + 10\ H_2O_{(g)}$ ***fast***

- Nonane (C_2H_6) burns more slowly than pentane (C_5H_{12}) because there are more bonds to be broken per molecule of nonane than there are per molecule of pentane. Nonane is a larger molecule.

e) Strength of Acid

- Strong acids which are completely ionized in solution react faster than weak acids which are only partially ionized in solution
- There are 6 strong acids: $HCl_{(aq)}$, $HBr_{(aq)}$, $HI_{(aq)}$, $H_2SO_{4(aq)}$, $HNO_{3(aq)}$, $HClO_{4(aq)}$
- All other acids are considered to be weak acids

eg. $2\ HCl_{(aq)} + Zn_{(s)} \rightarrow H_{2(g)} + ZnCl_{2(aq)}$ ***very fast***

$2\ CH_3COOH_{(aq)} + Zn_{(s)} \rightarrow H_{2(g)} + Zn(CH_3COO)_{2(aq)}$ ***fast***

- HCl is completely ionized which means all of the HCl molecules form aqueous H^+ and Cl^- ions when dissolved in water
- CH_3COOH is only partially ionized which means that only some of the molecules form ions when dissolved in water

f) Reactivity of Metal

- Metals with low electronegativity react faster than metals with higher electronegativity because the lower the value the more easily a metal will give up electrons. When metals lose electrons they form ions.

eg. $2\ Li_{(s)} + 2\ HOH_{(l)} \rightarrow H_{2(g)} + 2\ LiOH_{(aq)}$ ***fast***

$2\ K_{(s)} + 2\ HOH_{(l)} \rightarrow H_{2(g)} + 2\ KOH_{(aq)}$ ***very fast***

- Electronegativity values: Li = 1.0 K = 0.8

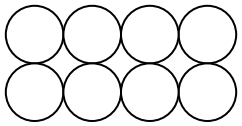
2. Surface Area of Solid Reactants

- An increase in the exposed matter of a solid reactant increases the reaction rate

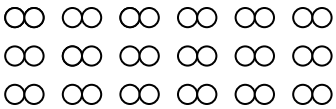
- Explained by the *Collision Theory*
  - The greater the surface area the better the chance of collision. The more collisions per unit of time, the faster the reaction.

  - That's why many solids are powdered using a mortar and pestle before being used in a reaction.

- Examples of reactions where surface area is important are:
  - active metals with acids, e.g. HCl with zinc
  - coal dust with oxygen gas
  - grain dust with oxygen gas



A lump of solid (1.0g)



Powdered solid (1.0g)

3. Concentration of Reactants

- An increase in the concentration in one or more of the reactants will increase the reaction rate (as long as the reactant is in the rate-determining step).

- Explained by the *Collision Theory*
  - An increase in the number of particles in a given volume of space (mol/L) will result in a better chance of collision. The more collisions per unit of time, the faster the reaction.

eg. $2\ HCl_{(aq)} + Zn_{(s)} \rightarrow H_{2(g)} + ZnCl_{2(aq)}$

  - 2.00 g of Zinc will react faster in 6.00 mol/L HCl than the same mass of Zinc in 2.00 mol/L HCl

- To change the concentration of an aqueous species:
  - more solute can be added to make the solution more concentrated
  - more solvent can be added to make the solution more dilute (less concentrated)

- To change the concentration of a gas:
  - Adding more gas to a fixed volume or increasing the pressure by decreasing the volume of the container will increase the concentration.
  - Removing some gas from a fixed volume or decreasing the pressure by increasing the volume of the container will decrease the concentration

4. Temperature of the Reaction System

- In general, as temperature increases, reaction rate increases.

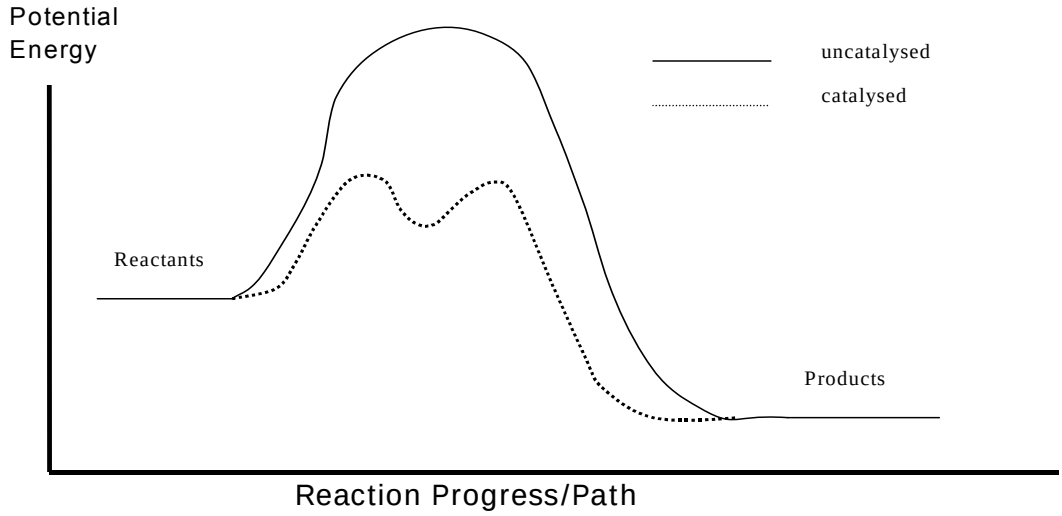
- Explained by the *Kinetic Molecular Theory and the Collision Theory*
  - At higher temperatures, particles have greater kinetic energy so they are moving faster
  - Particles will thus collide more frequently and with greater intensity. Therefore more particles will overcome the activation energy barrier to form products.

5. Catalyst

- A catalyst is a substance that speeds up the reaction rate without being used up in the process. (Therefore it can be regenerated and used again)

- It provides a new pathway (reaction mechanism) to form products, one that requires less energy
  - It lowers the activation energy for the reaction, therefore more particles have the required energy to overcome the activation energy barrier and form products

- The effect of adding a catalyst on a reaction can be demonstrated on a Potential Energy Diagram:



Note: Increasing the temperature, concentration or surface area has **no** effect on activation energy. Only a catalyst can lower E_A.

REACTION KINETICS WORKSHEET #2

1. At room temperature, the reaction $Mg^{2+}_{(aq)} + 2\ Br^{-}_{(aq)} \rightarrow MgBr_{2(s)}$ proceeds quickly, while the combustion of propane, $C_3H_{8(g)}$ is extremely slow.

   a) Suggest reasons for the difference in rates.

   b) How might the second reaction be speeded up?

2. Explain each of the following observations:

   a) Aluminum metal is used on the exterior of buildings and in making screen doors, yet a bottle of aluminum powder is labeled “flammable”.

   b) Food kept in a refrigerator does not spoil as rapidly as the same food left on the kitchen counter.

   c) Fuels burn more rapidly in pure oxygen than in the air.

3. Iron(II)sulfide reacts with dilute hydrochloric acid according to the following equation:

$$FeS_{(s)} + 2\ HCl_{(aq)} \rightarrow FeCl_{2(aq)} + H_2S_{(g)}$$

   a) List 4 changes that could be made to the reaction system in order to increase the reaction rate.

   b) Suggest experimental techniques that could be used to monitor the reaction rate.

4. Cane sugar (sucrose) can be hydrolyzed to produce 2 hexose molecules. This reaction is very slow.

$$C_{12}H_{22}O_{11(s)} + H_2O_{(l)} \rightarrow C_6H_{12}O_{11(aq)} + C_6H_{12}O_{11(aq)}$$

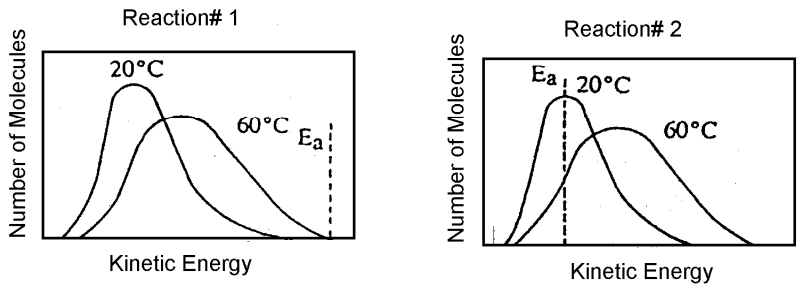
   If sulfuric acid is added to the reactants, the reaction is much faster. What is the role of the acid? Explain how it works.

5. For each pair of reactants identify which has the greater activation energy and explain your choice.

   a) A 1 cm cube of Fe reacting with 20 mL 1.0 mol/L HCl producing hydrogen gas at a rate of 1mL/s or a cube of Mg reacting with 20 mL of 1.0 mol/L HCl producing hydrogen gas at a rate of 5 mL/s.

   b) A cube of Fe reacting with 20 mL 1.0 mol/L HCl or powdered Fe, having the same mass, reacting with 20 mL 1.0 mol/L HCl.

6. The rates of 2 different reactions are compared at two different temperatures. The diagrams shown below indicate the distribution of kinetic energies possessed by the reactant molecules at both temperatures and the activation energy requirements for each reaction.



   a) Predict which reaction will be faster at room temperature. Explain your choice.

   b) When the temperature is increased to 60°C what will happen to the rate of Reaction 1 and of Reaction 2? Explain.

   c) In which reaction(s) does the activation energy requirement change when the temperature is increased? Explain.

7. Two pieces of evidence relating to the behavior of gases support the Kinetic Molecular Theory ie. pressure and diffusion. Explain.