Chemistry Lecture #84: Factors Affecting Reaction Rate

There are several factors that affect the rate of a chemical reaction. These factors include the nature of the reactants, concentration, surface area, temperature and catalysts.

Nature of the Reactants

Some types of chemical reactions are just faster or slower than others. I'll list some general conditions that predispose a reaction to be fast or slow. These conditions won't guarantee that a reaction will be fast or slow. They are general trends that occur most of the time, but not all of the time.

- Gases tend to react faster than solids or liquids. In order for a reaction to occur, particles must be separated from each other and moving with sufficient speed. In the gaseous state, particles are already far apart and moving rapidly.
- Ionic compounds will react faster with each other if they are dissolved in water. In the solid state, ions are tightly bound to each other and are not moving from place to place. Dissolved in water, ionic compounds separate into ions, which float freely and collide with each other more easily.
- Reactions between ions tend to be faster than reactions between molecules. Reactions between molecules often involve the transfer of electrons, and the rearrangement of atoms and bonds from one location to another. These processes increase the reaction time. On the other hand, reactions between ions simply involve a positive charge being attracted to a negative charge.

- Stronger bonds between atoms increases the reaction time. For example, single bonds are weaker than double bonds. A reaction that requires the breaking of single bonds in a molecule will proceed faster than a reaction that requires the breaking of double bonds.
- A reaction that requires the breaking of many bonds will be slower than a reaction where fewer bonds need to be broken. Consequently, smaller molecules will react faster than larger molecules since larger molecules have more atoms which requires more bonds to hold the atoms together.

Concentration

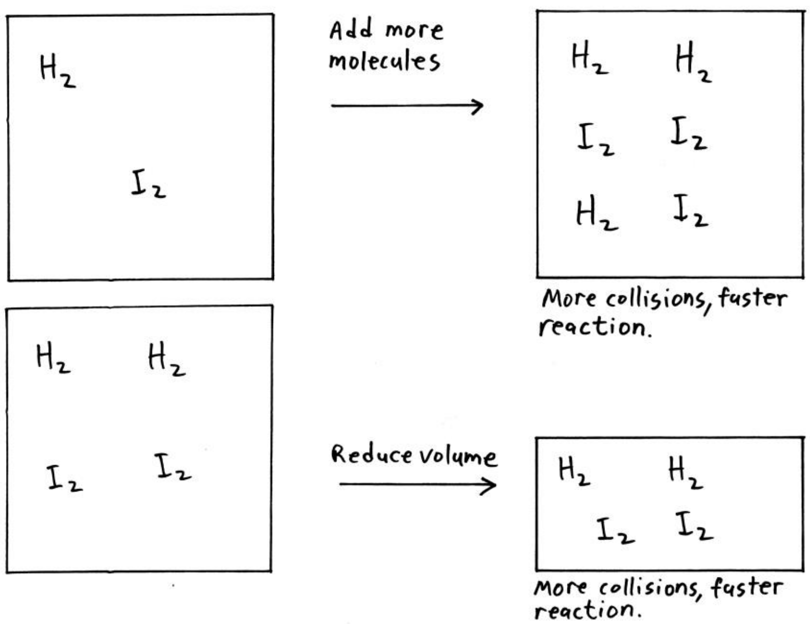
Remember that concentration is expressed in moles/liter. It's the number of moles or particles in a container of a certain volume.

Suppose we have hydrogen and iodine gas in a closed container. As the gas molecules float around, they collide with each other, and occasionally they will collide with enough energy to react and form hydrogen iodide.

If we add more hydrogen and iodine to the container, we've increased the concentration. At higher concentration, there will be more collisions between the molecules. If there are more collisions, the reaction will occur more rapidly. Thus, reactions are faster at higher concentrations.

The other way to increase the concentration is to reduce the volume of the container. This increases the pressure in the container. Since there is less space in the container, collisions between molecules are more likely to occur, which increases the reaction rate.

$H_2 (g) + I_2 (g) \rightarrow 2HI (g)$



Increasing concentration Increases Reaction Rate.

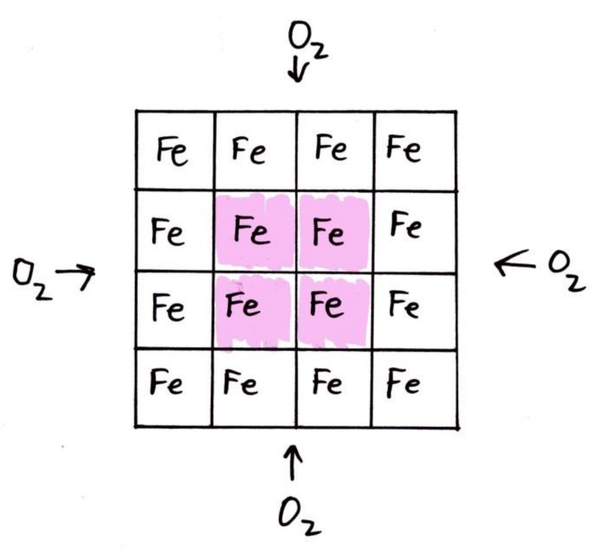
Surface Area

If a reaction involves a solid reacting with another substance, the reaction rate can be sped up by increasing the surface area of the solid. One way to increase the surface area of a solid is to break up the solid into smaller pieces. Breaking apart the solid will create more surfaces and thus expose more molecules of the solid to other reactant molecules.

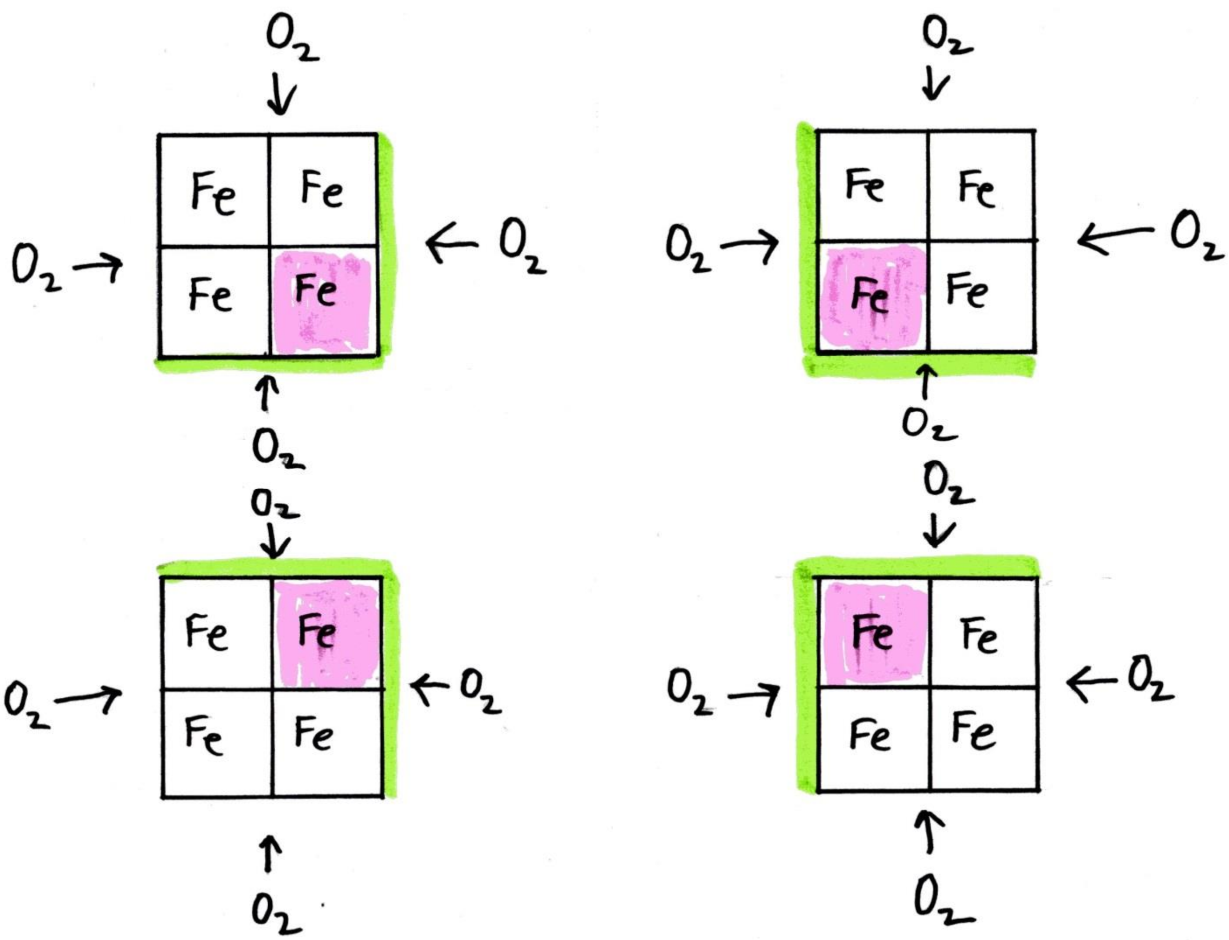
For example, solid Fe reacts with gaseous O_2 to create Fe_2O_3

$$4Fe\ (s) + 3O_2\ (g) \rightarrow 2Fe_2O_3\ (s)$$

Below is a 2-dimensional diagram of oxygen molecules surrounding a solid piece of iron. Oxygen can collide with four surfaces. The Fe atoms highlighted in pink are below the surface of the block of iron. Oxygen molecules are unable to react with these iron atoms.



If we break the block of iron into four pieces, we increase the surface area of the solid and expose more Fe atoms to oxygen. Oxygen can now collide with eight new surfaces (highlighted in green). The Fe atoms highlighted in pink can now react with oxygen.



Since there are now more collisions between Fe and O_2, the reaction will occur more rapidly. Thus, increasing the surface area of the solid increases the reaction rate.

Temperature

At higher temperatures, a chemical reaction will be faster. Remember that temperature is a measure of the average kinetic energy of atoms or molecules. A higher temperature means that there are more particles that are moving faster. If atoms and molecules are moving faster, there will be more collisions, which will increase the reaction rate.

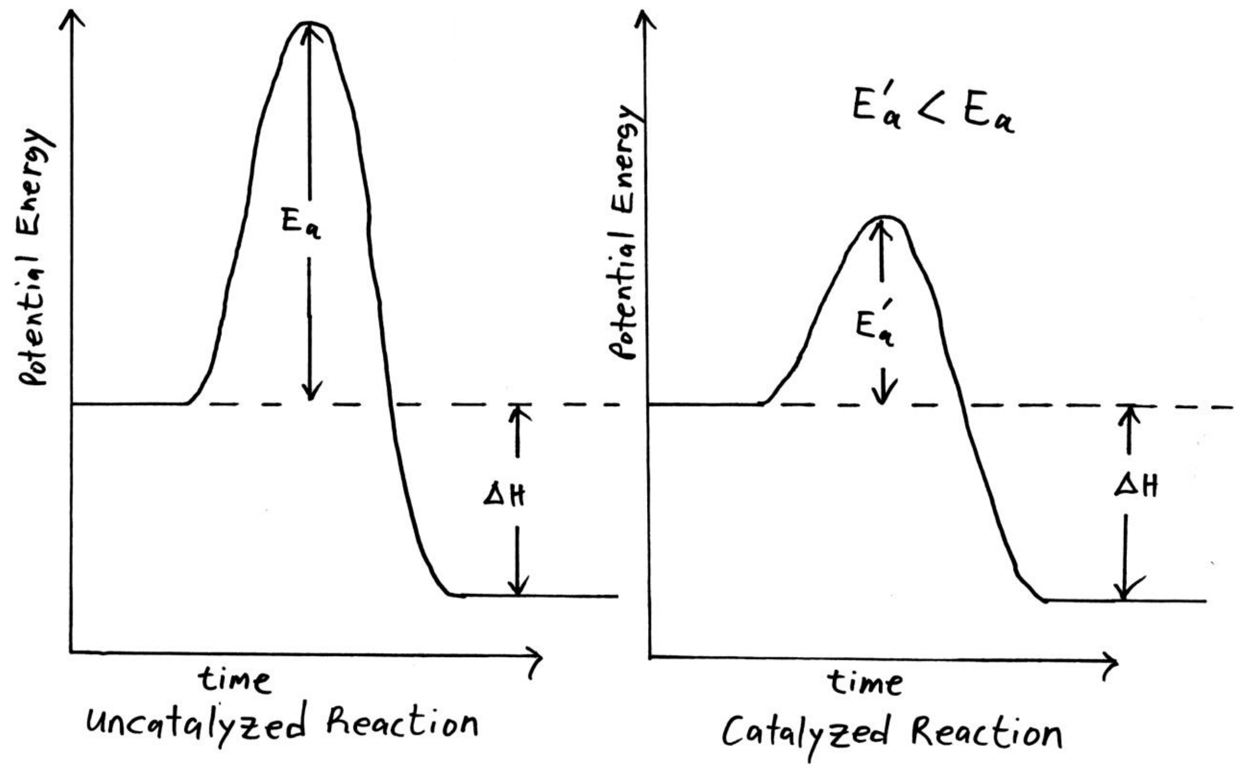
In addition, if the particles are moving faster, the collisions between particles will be more powerful. Old bonds are more likely to break, which allows new bonds to form. Thus, at higher temperatures, more particles will have sufficient activation energy (E_a) for a reaction to occur.

Catalysts

A catalyst is a substance that makes a chemical reaction go faster. A catalyst interacts with the reactants, but is not altered or destroyed in the interaction. After the reaction, the catalyst emerges intact, and can once again interact with reactants to speed the reaction.

Catalysts speed the rate of reactions by lowering the E_a.

Below is a potential energy diagram of a reaction without a catalyst, and with a catalyst.



These graphs both show the same chemical reaction. The only difference is that with a catalyst, it takes less energy to initiate the reaction and get it started. The activation energy of the catalyzed reaction is less than the activation energy of the uncatalyzed reaction (or $E_a' < E_a$).

Catalysts lower the activation energy of a reaction by partially or completely breaking the bonds of the reactants.

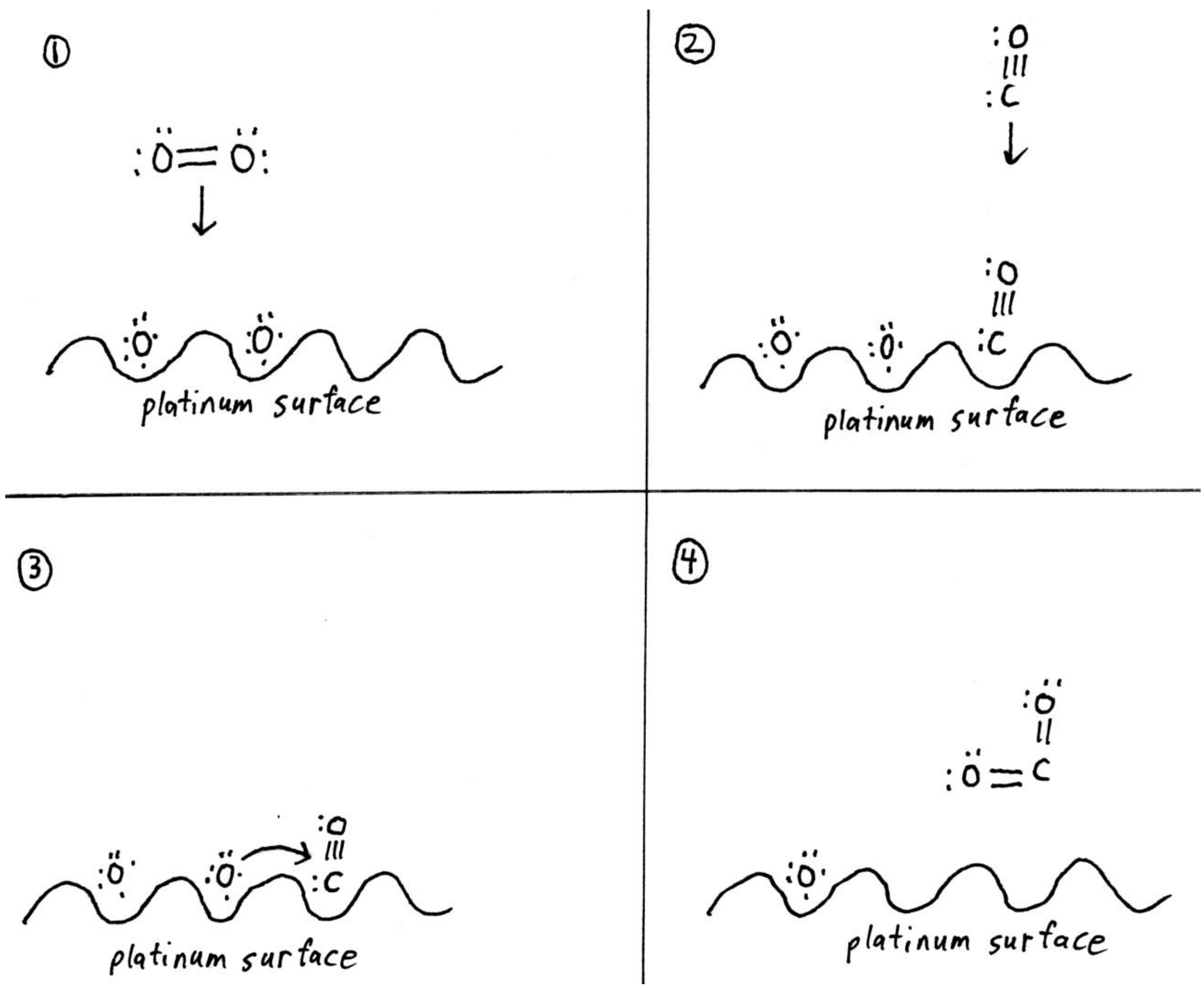
For example, carbon monoxide can be converted into carbon dioxide, but the reaction is very slow.

$2CO\,(g) + O_2\,(g) \rightarrow 2CO_2\,(g)$ slow

But if CO and O_2 are exposed to platinum (Pt), the reaction occurs more quickly.

$2CO\,(g) + O_2\,(g) \xrightarrow{Pt} 2CO_2\,(g)$ faster

Platinum makes the reaction faster by breaking the bonds between the oxygen atoms. The 4 pictures below show the process of the reaction.



In the first picture, an oxygen molecule lands on the surface of platinum. The oxygen atoms are attracted to the surface of platinum - a partial bond is formed between the platinum surface and the oxygen atoms. This bond is strong enough to break the bonds between the oxygen atoms.

In the second picture, a carbon monoxide molecule attaches itself to the surface of the platinum.

The oxygen atoms are capable of moving across the surface of platinum. The third picture shows an oxygen atom migrating toward the carbon monoxide molecule. It makes contact with the molecule, bonds to it, and forms carbon dioxide.

Carbon dioxide is a more stable molecule than carbon monoxide, so it is no longer attracted to the surface of platinum. It leaves the surface.

Platinum acts as a heterogeneous catalyst in this reaction. A heterogeneous catalyst is in a different physical state from the reactants. In the above reaction, oxygen and carbon monoxide are gases, while platinum is a solid.

A homogeneous catalyst is in the same physical state as the reactants. For example, a sugar cube ($C_{12}H_{22}O_{11}$) can be set on fire and undergo combustion if it is covered with ashes from a burned piece of paper.

$$C_{12}H_{22}O_{11}\ (s) + 12\ O_2\ (g) \xrightarrow{\text{ashes}} 12CO_2\ (g) + 11\ H_2O\ (g)$$

It is very difficult to light a sugar cube on fire. If you hold a flame to a sugar cube, the cube just melts. But if you cover the cube with ashes before attempting to light it, the cube will catch on fire and produce a pretty, blue colored flame. The ashes contain solid metal salts such as sodium carbonate and calcium carbonate. These compounds act as catalysts to promote combustion. Since the sugar and the carbonates are both solids, the ash acts as a homogeneous catalyst.