Collision Theory

To explain why chemical reactions occur, chemists have proposed a model, known as **collision theory**, which states that molecules must collide in order to react. These collisions can involve one particle and a container wall, or two particles colliding with each other. A few reactions involve three-body collisions, but these are rare. No cases of four-body collisions are known.

In any chemical reaction, the number of collisions among the particles of reactants has a direct impact on the rate of the reaction. If there were no collisions, there would be no reaction. However, there can also be billions of collisions and still no reaction. This is because not all collisions are effective in leading to the production of products.

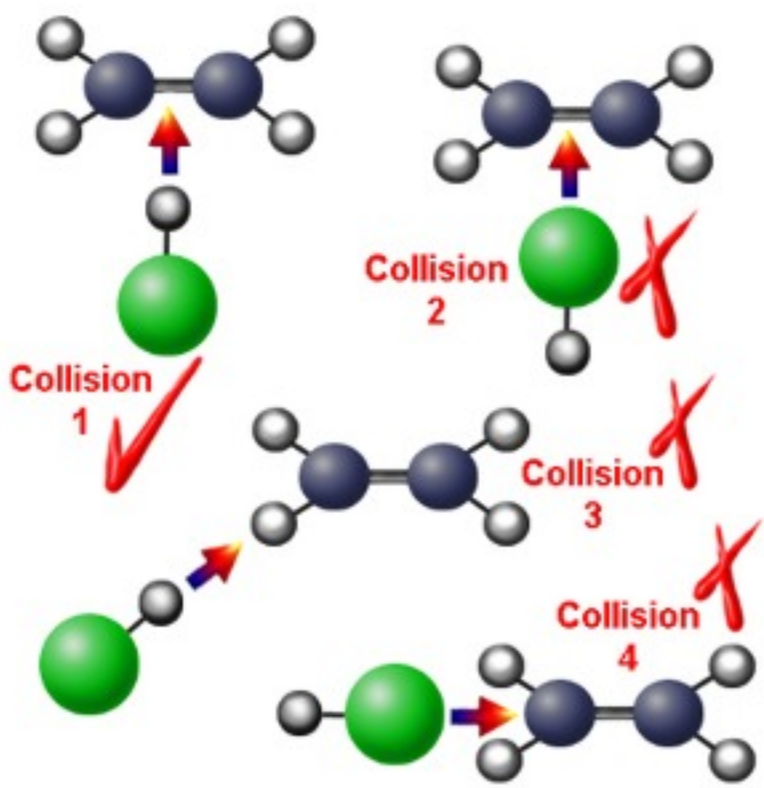
A collision is an **effective collision** if it leads to the formation of products. A collision that does not lead to the formation of products is an **ineffective collision**.

If every collision led to a reaction, all chemical reactions would have rates hundreds of times faster than they actually are. For example, in a mixture of H_2 and I_2, each molecule collides about 10 billion times per second. If every collision resulted in the formation of HI, the reaction would be over in a fraction of a second. Instead, the reaction proceeds quite slowly because only about 1 in every ten trillion collisions is effective.

There are two factors that determine whether or not a collision is effective — the orientation of the colliding particles, and the energy of the colliding particles.

Orientation

For a reaction to occur, the particles must be oriented in a favorable position that allows the bonds to break and atoms to rearrange. Otherwise, the colliding molecules simply bounce off one another.



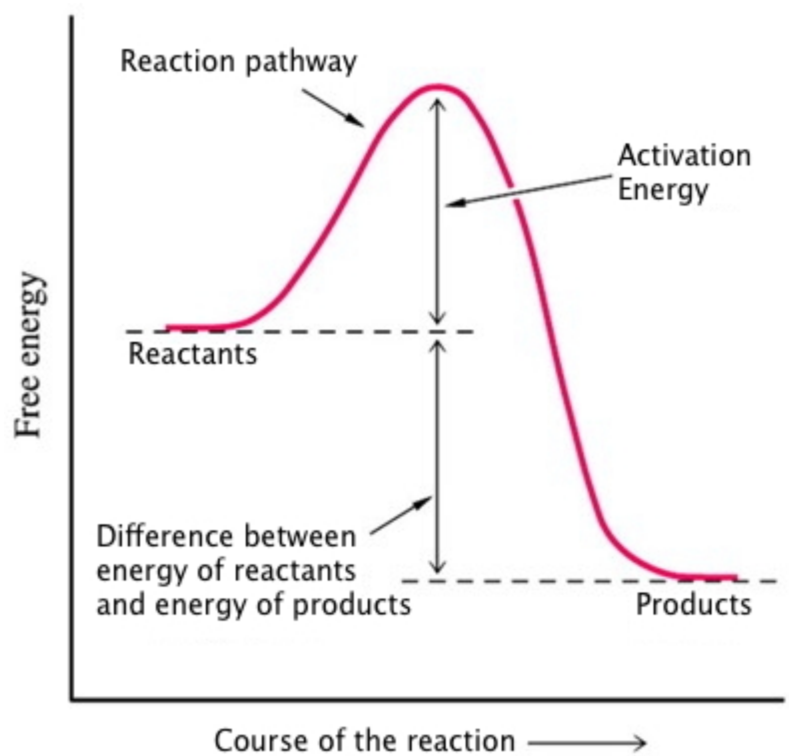
Some collision orientations can lead to reaction, while others do not.

Energy

According to collision theory, energy is required to break the bonds that hold reactants together. The energy for this purpose comes from the kinetic energy of the reacting particles, which is determined by their mass and speed. The more massive the particle or the faster its speed, the greater its kinetic energy.

In 1888, Svante Arrhenius proposed that particles must possess a certain minimum amount of kinetic energy in order to react. He likened this to a boulder being pushed up and over a bump before rolling down a hill. It requires energy to get the boulder over the bump, but once it is over it rolls down the hill quite easily.

Energy diagrams are used to show the changes in energy that occur during a chemical reaction. A typical energy diagram is shown below.



Notice that the shape of the energy diagram is similar to the shape of a hill. Here you can see that the energy of the reactants must be raised to the top of the energy barrier before it can drop to a lower level. The difference between the energy at the peak and the energy of the reactants is called the **activation energy**. The activation energy is the energy needed to start the reaction. When particles collide with enough energy — at least equal to the activation energy — existing bonds may be broken and new bonds can form.

Activated Complex

There is an extremely brief interval of bond disruption and bond formation known as a **transition state**. During the transition state, the reactants form a short-lived complex that is neither reactant nor product, but has characteristics of both. This transitional structure is called an **activated complex**.

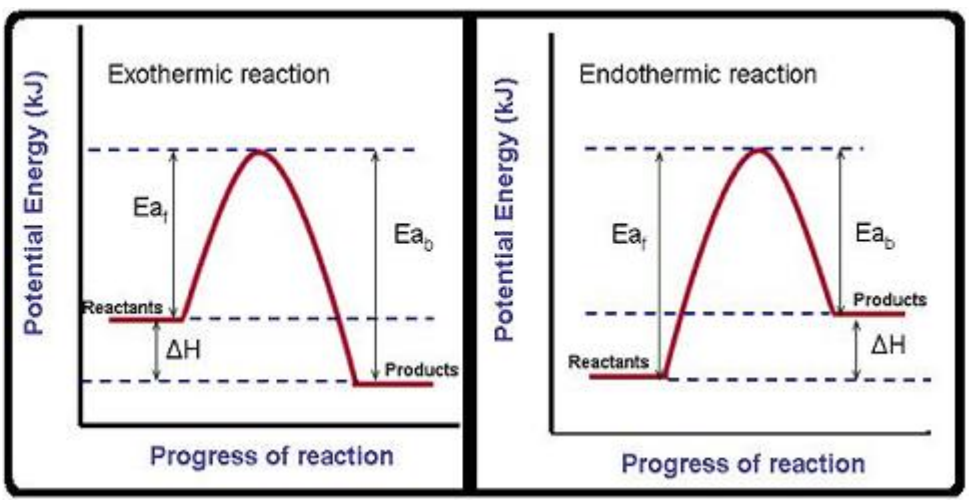
The activated complex exists along the reaction pathway at the point where the energy is greatest — at the peak indicated by the activation energy. The **activation energy**, E_a, is the energy required to achieve the transition state and form the activated complex.

Every reaction has its own activation energy. The higher the activation energy, the smaller the number of collisions with enough energy to react, and the slower the reaction rate.

Endothermic and Exothermic Reactions

A reaction is said to be **endothermic** when the energy of the product(s) is greater than that of the reactants. Such a reaction will absorb heat energy from its surroundings.

A reaction is said to be **exothermic** when the energy of the product(s) is less than that of the reactants. Such a reaction will release heat energy into its surroundings.



Enthalpy (ΔH) is a measure of the amount of heat absorbed or released during a chemical reaction. It is calculated by subtracting the energy of the reactants from the energy of the products.

$$\Delta H = H_{products} - H_{reactants}$$

Factors that Affect Reaction Rate

There are five general factors that affect the rate of a reaction: nature of reactants, temperature, concentration, surface area, and catalysts. The effect of each can be understood in terms of collision theory.

Nature of the Reactants

The rate of a reaction depends on the reactants involved and the complexity of the bonds that have to be broken and formed.

Reactants whose particles are held together by strong forces will require more energy in order to react. Reactions in which there are only small rearrangements of atoms necessary are usually faster. Reactions with many covalent bonds to be broken are usually slower.

The state of a reactant can also have a considerable effect on reaction rate. According to the kinetic theory of matter, the particles in gases move more freely and rapidly than those in liquids, which are moving more freely and rapidly than those in solids. Since collisions occur more often and with higher energy as motion increases, you should expect reaction rates to be fastest among gases and slowest among solids.

Temperature

Increasing the temperature of the reactants in a chemical reaction will increase their average kinetic energy. The faster the molecules are moving, the more frequently they will collide. In addition, they will be more likely to have enough energy to produce effective collisions. Thus, increasing the temperature of the reactants should increase the rate of the reaction.

Concentration

Increasing the concentration of the reactants in a chemical reaction will increase the number of collisions that occur. Since there are more collisions taking place, the likelihood of an effective collision increases. Thus, increasing the concentration of the reactants should increase the rate of the reaction.

Note: This explains why reactions tend to slow down as they proceed. As the reaction proceeds, reactant concentration decreases, resulting in a decreased reaction rate.

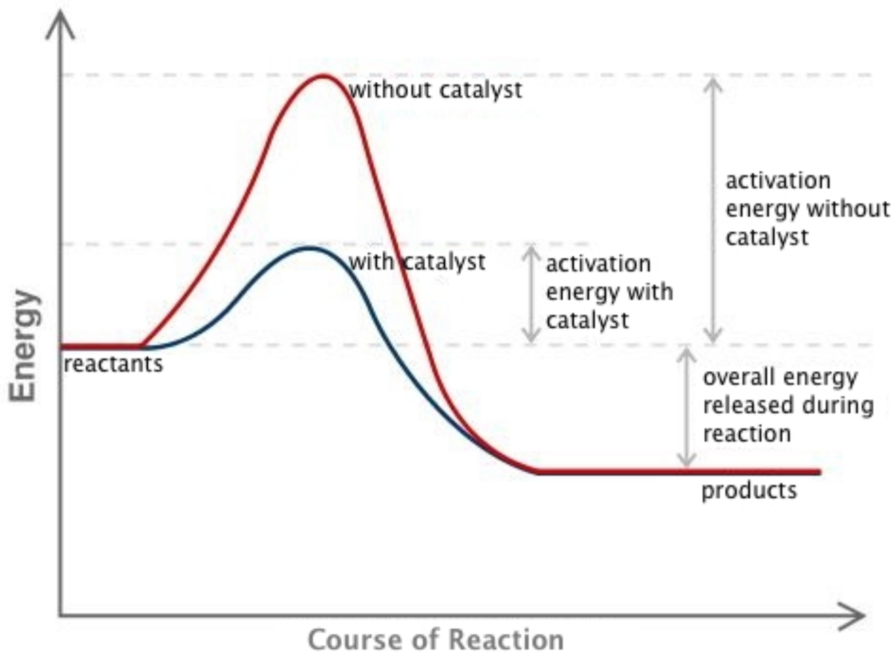
Surface Area

The larger the surface area of a reactant, the greater the number of particles that are exposed for reaction. In other words, the larger surface area increases the frequency at which particles collide. If particles collide more often, the chances of an effective collision increase. Thus, increasing the surface area of the reactants should increase the rate of the reaction.

Catalysts

A **catalyst** is a substance that increases the rate of a reaction, without itself being used up in the reaction. Catalysts work by reducing the activation energy needed for the reaction to take place. Since less energy is needed, more collision will have enough energy to react.

The energy diagram below illustrates the effect that a catalyst has on a reaction.



Note: There is also a substance called an **inhibitor** that reduces the rate of a reaction, without itself being used up in the reaction.

Worksheet

1. What does the reaction rate indicate about a particular chemical reaction?

2. According to the collision theory, what must happen for two molecules to react?

3. How would the rate of the reaction $2H_2(g)+O_2(g)\rightarrow 2H_2O(g)$ stated as the consumption of hydrogen compare with the rate stated as the consumption of oxygen?

4. How do temperature, concentration, and surface area affect the rate of a chemical reaction?

5. How does the collision model explain the effect of concentration on reaction rate?

6. How does the activation energy of an un-catalyzed reaction compare with that of a catalyzed reaction?

7. What does the activation energy for a chemical reaction represent?

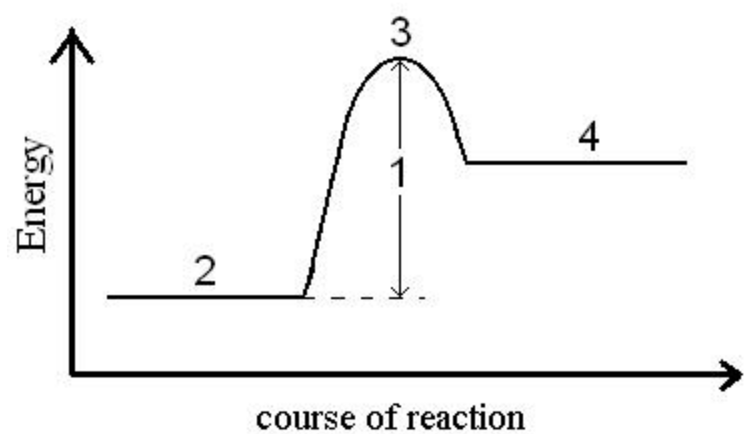
8. Suppose two molecules that can react collide. Under what circumstances do the colliding molecules not react?

9. If $A\rightarrow B$ is exothermic, how does the activation energy for the forward reaction compare with the activation energy for the reverse reaction ($A\leftarrow B$)?

10. Explain how a catalyst affects the activation energy for a chemical reaction.

11. On the accompanying energy level diagram, match the appropriate number with the quantity it represents.

    a) reactants
    b) activated complex
    c) products
    d) activation energy



12. ΔH for a reaction is negative. Which has more energy, the products or the reactants? Is the reaction endothermic or exothermic?