Two for the price of one!

Drag racing is a sport where two cars start from a dead stop and drive as fast as they can down a quarter-mile strip. At the end of the strip are timers that determine both elapsed time (how long did it take for them to cover the quarter mile) and top speed (how fast were they going as they went through the timer chute). Both pieces of data are important. One car may accelerate faster and get ahead that way, while the other care may be slower off the line, but can get up to a higher top speed at the end of the run.

Chemical Reaction Rate

Chemical reactions vary widely in the speeds with which they occur. Some reactions occur very quickly. If a lighted match is brought in contact with lighter fluid or another flammable liquid, it erupts into flame instantly and burns fast. Other reactions occur very slowly. A container of milk in the refrigerator will be good to drink for weeks before it begins to turn sour. Millions of years were required for dead plants under Earth’s surface to accumulate and eventually turn into fossil fuels such as coal and oil.

Chemists need to be concerned with the rates at which chemical reactions occur. Rate is another word for speed. If a sprinter takes 11.0 s to run a 100 m dash, his rate or speed is given by the distance traveled divided by the time.

\[
\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{100 \text{ m}}{11.0 \text{ s}} = 9.09 \text{ m/s}
\]

The sprinter’s average running rate for the race is 9.09 m/s. We say that it is his average rate because he did not run at that speed for the entire race. At the very beginning of the race, while coming from a standstill, his rate must be slower until he is able to get up to his top speed. His top speed must then be greater than 9.09 m/s so that taken over the entire race, the average ends up at 9.09 m/s.

Chemical reactions can’t be measured in units of meters per second, as that would not make any sense. A reaction rate is the change in concentration of a reactant or product with time. Suppose that a simple reaction were to take place in which a 1.00 M aqueous solution of substance \( A \) was converted to substance \( B \).

\[
A(aq) \rightarrow B(aq)
\]
Suppose that after 20.0 seconds, the concentration of $A$ had dropped from 1.00 M to 0.72 M as $A$ was slowly being converted to $B$. We can express the rate of this reaction as the change in concentration of $A$ divided by the time.

$$\text{rate} = -\frac{\Delta [A]}{\Delta t} = -\frac{[A]_{\text{final}} - [A]_{\text{initial}}}{\Delta t}$$

A bracket around a symbol or formula means the concentration in molarity of that substance. The change in concentration of $A$ is its final concentration minus its initial concentration. Because the concentration of $A$ is decreasing over time, the negative sign is used. Thus, the rate for the reaction is positive and the units are molarity per second or M/s.

$$\text{rate} = -\frac{0.72 \text{ M} - 1.00 \text{ M}}{20.0 \text{ s}} = -\frac{-0.28 \text{ M}}{20.0 \text{ s}} = 0.014 \text{ M/s}$$

The molarity of $A$ decreases by an average rate of 0.014 M every second. In summary, the rate of a chemical reaction is measured by the change in concentration over time for a reactant or product. The unit of measurement for a reaction rate is molarity per second (M/s).

**Summary**

- The reaction rate indicates how fast the reaction proceeds.

**Practice**

**Questions**

Read the material at the link below and answer the following questions:

[http://chemwiki.ucdavis.edu/Physical_Chemistry/Kinetics/Reaction_Rates/The_Rate_of_a_Chemical_Reaction](http://chemwiki.ucdavis.edu/Physical_Chemistry/Kinetics/Reaction_Rates/The_Rate_of_a_Chemical_Reaction)

1. Why is the rate of disappearance a negative value?
2. What is the average rate of reaction?
3. What is the instantaneous rate of reaction?

**Review**

**Questions**

1. What is another word for rate?
2. What does $[ ]$ stand for?
3. What are the units of reaction rate?
Activation Energy

How do fireworks light up the sky?

The sight of fireworks exploding across the night sky is always exciting. These materials, invented hundreds of years ago, can be dangerous if not handled properly. The chemicals do not react until the fuse burns down and heat is applied to the system. Then the rocket is launched and explodes high in the sky.

Activation Energy

Calcium metal stored in an argon atmosphere.

Why do some chemical reactions occur readily while others require input of heat in order to take place? If we mix metallic sodium with water, a reaction occurs immediately, releasing a great deal of heat (enough to ignite the hydrogen gas that is formed). Group II metals, such as calcium, react at a much slower rate. Unlike the extremely vigorous reaction with sodium, the reaction with calcium is slow enough that we can trap the hydrogen gas released.

Supplying reactant particles with energy causes the bonds between the atoms to vibrate with a greater frequency. This increase in vibrational energy makes a chemical bond more likely to break and a chemical reaction more likely to occur when those particles collide with other particles. The activation energy for a reaction is the minimum energy that colliding particles must have in order to undergo a reaction. Some reactions occur readily at room temperature because the reacting particles already have the requisite activation energy at that temperature. Other reactions only occur when heated because the particles do not have enough energy unless an external source of heat provides the particles with more kinetic energy.
Summary

- Activation energy is defined for a chemical reaction.

Practice
Questions

Watch the video at the link below and answer the questions:

http://www.youtube.com/watch?v=u_1uLP30uxY

1. Does magnesium react with water at room temperature?
2. How did the speaker get magnesium to react with water?
3. What is one product of this reaction?

Review
Questions

1. Does sodium react faster or slower with water than calcium does?
2. How does vibrational energy contribute to a reaction?
3. Before some molecules react, what has to happen?
Oops!

Car damage can be very expensive, especially if the person hitting your car does not have insurance. Many people have had the experience of backing up while parallel parking and hearing that “bump”. Fortunately, there is often no damage because the cars were not going fast enough. But every once in a while there is a rearrangement of the body parts of a car when it is hit with sufficient speed. Then things need to be fixed.

Collision Theory

The behavior of the atoms, molecules, or ions that comprise the reactants is responsible for the rates of a given chemical reaction. Collision theory is a set of principles that states that the reacting particles can form products when they collide with one another provided those collisions have enough kinetic energy and the correct orientation. Particles that lack the necessary kinetic energy may collide, but the particles will simply bounce off one another unchanged. The figure below illustrates the difference. In the first collision, the particles bounce off one another and no rearrangement of atoms has occurred. The second collision occurs with greater kinetic energy, and so the bond between the two red atoms breaks. One red atom bonds with the other molecule as one product, while the single red atom is the other product. The first collision is called an ineffective collision, while the second collision is called an effective collision.

An ineffective collision (A) is one that does not result in product formation. An effective collision (B) is one in which chemical bonds are broken and a product is formed.

Summary

- Collision theory explains how materials can collide and become new materials.

Practice
Questions

Watch the video at the link below and answer the following questions:

http://www.youtube.com/watch?v=4n_hKAA87nM

1. What were the reactants?
2. What was the product?
3. What did the match do?

Review

Questions

1. How does a chemical reaction occur?
2. What are two requirements for collision to form a product?
3. Two molecules collide and then bounce off of one another. What kind of collision is that?

Explore More

Sign in to explore more, including practice questions and solutions for Collision Theory.
Potential Energy Diagrams
What was Sisyphus’s punishment?

Sisyphus was a mythological being who had been a very evil king. As a punishment, he was supposed to roll a large stone up to the top of a long hill. A spell had been placed on the stone so that it would roll back down before reaching the top, never to complete the task. Sisyphus was condemned to an eternity of trying to get to the top of the hill, but never succeeding.

Potential Energy Diagrams

The energy changes that occur during a chemical reaction can be shown in a diagram called a potential energy diagram, or sometimes called a reaction progress curve. A potential energy diagram shows the change in potential energy of a system as reactants are converted into products. The Figure below shows basic potential energy diagrams for an endothermic (A) and an exothermic (B) reaction. Recall that the enthalpy change ($\Delta H$) is positive for an endothermic reaction and negative for an exothermic reaction. This can be seen in the potential energy diagrams. The total potential energy of the system increases for the endothermic reaction as the system absorbs energy from the surroundings. The total potential energy of the system decreases for the exothermic reaction as the system releases energy to the surroundings.

A potential energy diagram shows the total potential energy of a reacting system as the reaction proceeds. (A) In an endothermic reaction, the energy of the products is greater than the energy of the reactants and $\Delta H$ is positive. (B) In an exothermic reaction, the energy of the products is lower than the energy of the reactants and $\Delta H$ is negative.
The activation energy for a reaction is illustrated in the potential energy diagram by the height of the hill between the reactants and the products. For this reason, the activation energy of a reaction is sometimes referred to as the activation energy barrier. Reacting particles must have enough energy so that when they collide they can overcome that barrier (see Figure below).

The activation energy ($E_a$) of a reaction is the barrier that must be overcome for the reactants to be able to become products. (A) The activation energy is low, meaning that the reaction is likely to be fast. (B) The activation energy is high, meaning that the reaction is likely to be slow.

Summary

- Potential energy diagrams for endothermic and exothermic reactions are described.
- Diagrams of activation energy and reaction progress are given.

Practice

Do problems 1-9 at the following link:

http://www-pvhs.stjohns.k12.fl.us/teachers/veatchd/12F0088C-0118C716.63/potential%20energy%20diagram%20worksheet.pdf

Review

Questions

1. In an endothermic reaction, is the potential energy of the products higher or lower than the potential energy of the reactants?
2. In an exothermic reaction, is the potential energy of the products higher or lower than the potential energy of the reactants?
3. What does activation energy tell us?
What are the chances of a fender-bender on the highway?

Driving on a crowded freeway can get exciting. Lots of cars, drivers who aren’t paying attention, people who speed, people who drive too slow – the chances of a collision are rather high. A lot of cars in a particular amount of space equals a high car concentration and many opportunities for unwanted connections with other cars.
Activated Complex

Reactant particles sometimes collide with one other and yet remain unchanged by the collision. Other times, the collision leads to the formation of products. The state of the particles that is in between the reactants and products is called the activated complex. An activated complex is an unstable arrangement of atoms that exists momentarily at the peak of the activation energy barrier. Because of its high energy, the activated complex exists for an extremely short period of time (about $10^{-13}$ s). There is equal likelihood that the activated complex either reforms the original reactants or goes on to form products. The Figure below shows the formation of a possible activated complex between colliding hydrogen and oxygen molecules. Because of their unstable nature and brief existence, very little is known about the exact structures of many activated complexes.

![Activated Complex Diagram](image)

An activated complex is a short-lived state in which the colliding particles are at the peak of the potential energy curve.

Summary

- The role of the activated complex in reactions is described.

Practice

Questions

Watch the video at the link below and answer the following questions:

http://www.youtube.com/watch?v=rl50M-wNVcs

1. What were the reactants?
2. What colors were the reactants?
3. What color was the activated complex?
4. What were the structures of the products?
5. What color was the final solution?

Review

Questions

1. Do all collisions of reactant particles lead to products?
2. How long does the activated complex usually last?
3. How does this compare with the activated complex in the video you watched?
Factors Affecting Reaction Rates

By their nature, some reactions occur very quickly, while others are very slow. However, certain changes in the reacting conditions can have an effect on the rate of a given chemical reaction. Collision theory can be utilized to explain these rate effects.

Concentration

An increase in the concentration of one or more reacting substances results in an increase in the rate of reaction. When more particles are present in a given amount of space, a greater number of collisions will naturally occur between those particles. Since the rate of a reaction is dependent on the number of collisions occurring between reactants, the rate increases as the concentration increases.

Pressure

When the pressure of a gas is increased its particles are forced closer together, decreasing in the process the amount of empty space between the particles. Therefore, an increase in the pressure of a gas is also an increase in the concentration of the gas. For gaseous reactions, an increase in pressure increases the rate of reaction for the same reasons as described for an increase in concentration. Higher gas pressure leads to a greater number of collisions between reacting particles.

Surface Area

A large log placed in a fire will burn relatively slowly. If the same mass of wood were added to the fire in the form of small twigs, they would burn much more quickly. This is because the twigs provide a greater surface area than the log does. An increase in the surface area of a reactant increases the rate of a reaction. Surface area is larger when a given amount of a solid is present as smaller particles. A powdered reactant has a greater surface area than the same reactant as a solid chunk. In order to increase the surface area of a substance, it may be ground into smaller particles or dissolved into a liquid. In solution, the dissolved particles are separated from each other and will react more quickly with other reactants.

Temperature

Raising the temperature of a chemical reaction usually results in a higher rate of reaction. When the reactant particles are heated, they move faster and faster. This results in a greater frequency of collisions. A more important effect of the temperature increase is that the collisions occur with a greater force and are thus more likely to surmount the activation energy barrier and go on to form products. Increasing the temperature of a reaction increases the number of effective collisions between reacting particles, so the reaction rate increases.

Summary

- Factors affecting reaction rate are:
  - concentration of reactants
  - pressure (if gas)
  - surface area
  - temperature
Practice

Questions

Watch the video at the link below and answer the following questions:

http://www.youtube.com/watch?v=UWkzSHaxZE

1. What factor was demonstrated by adding oxygen to the fire?
2. What was shown with the aluminum powder?
3. What factor was mentioned, but not demonstrated?

Review

Questions

1. How does an increase in concentration of reactant increase rate?
2. Why would rates increase with a larger surface area of reactants?
3. What effect does temperature have on reaction rate?

Explore More

Sign in to explore more, including practice questions and solutions for Factors Affecting Reaction Rate.