TEACHER'S GUIDE
SCIENCE KEY CONCEPTS SERIES: CHEMISTRY

REACTIONS AND ENERGY CHANGES

15 minutes, Video

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FOR USE IN: Chemistry
LEVEL: Grades 9-12
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EDUCATIONAL OBJECTIVES:

To help the student understand these 3 key concepts about reactions and energy changes:

- ⇒ **1. Exothermic and Endothermic Reactions**
- ⇒ **2. Reaction Rates: Temperature and Concentration**
- ⇒ **3. Catalysts**

BACKGROUND INFORMATION:

There are many different forms of energy such as light, sound, heat, and nuclear. Light is observed in lightsticks, sound is heard when a gas is produced in a chemical reaction, heat is felt when a hot pack is utilized for an injury, and there would be evidence of nuclear energy when a radioactive element spontaneously emitted radiation. It always takes energy to break molecular reactant bonds and energy is always released when product bonds are formed. The overall relationship between these two processes determines whether the reaction will be considered exothermic or endothermic.

Potential energy is stored in the bonds that connect the atoms in compounds. That potential energy can be released in different forms when compounds undergo a chemical reaction. The combustion of burning fuels or the metabolism of food illustrates that potential energy is stored in the bonds of the fuel and food. The release of energy permits a vehicle to run and our bodies to participate in various activities such as swimming or riding a bike.

The rate at which a reaction occurs is influenced by different factors. If the concentration or temperature is increased or decreased, the reaction will occur faster or slower, respectively. A catalyst can also be added. It can speed up the reaction so that products are produced faster and subsequently reactants are produced faster if the reaction is reversible. Catalysts provide alternative pathways so that the activation barrier is lowered and products can be produced faster.

CONTENT OF THE VIDEO

Note: Each concept runs 5 minutes, and is separately titled - visually indexed. To play only Concepts #2 or #3, simply fast forward until you see its title. **The video demonstrates a variety of exothermic and endothermic reactions In addition, it shows with computer animation what happens at the molecular level; how energy is released or used up when molecular bonds are broken and reformed during these reactions. Animation also explains how changing the temperature or concentration of chemicals affects the rate of a reaction. Catalysts also affect reaction rates, and several reaction demonstrations show that the catalysts themselves are not used up or changed during these reactions; and that different catalysts have different degrees of effectiveness in speeding up the reaction rate.**

Exothermic and Endothermic Reactions **This starts with a collage of exothermic reactions giving out energy as light, heat, sound and electricity. Another exothermic reaction, sodium hydroxide added to sulfuric acid, is viewed through a thermal imager. The temperature of the solution rises from 24.4°C to 52.4°C. An endothermic reaction, adding barium hydroxide to ammonium thiocyanate, results in a temperature reduction from 19.1°C to -11.6°C. When hydrogen and oxygen in a balloon are ignited, energy is given out and water is formed. Computer animation shows how some energy is used up in initiating a chain reaction which breaks the hydrogen and oxygen molecular bonds, but the energy released when the hydrogen and oxygen bonds are broken, is a much greater quantity than that needed to form the product water molecule bonds – and so energy is given off, an exothermic reaction. (Question) What happens in an endothermic reaction? (Answer) More energy is used to form the new molecular bonds than was released by breaking up the former molecular bonds, and so heat energy is drawn from**

the surroundings and the temperature drops **Reaction Rates** **Reaction rates are measured by the rate for which the products are formed. When hydrochloric acid and sodium thiosulphate are mixed, light meters measure the decrease in light through the solution as sulfur is formed, while the time taken is recorded. Data loggers record the light levels and are connected to a computer, which plots graphs of the reaction rate. This is repeated using a different concentration of HCL. Computer animation shows how increasing concentration increases the collision of molecules and so speeds up a reaction. (Question) If you decrease the concentration of HCL, what do you think will happen? (Answer) The collision of the molecules will decrease and the rate of reaction will slow down. Further experiments show the effect of raising or lowering temperature on reaction rates. (Question) How might increasing or decreasing the temperature affect the number of successful collisions? (Answer) Increasing the temperature would increase the kinetic energy of the molecules and so increase the number of collisions and successful collisions in a given amount of time. The reverse would happen when decreasing the temperature.** **Catalysts** **Hydrogen peroxide decomposes slowly to water and oxygen. An experiment is carried out to see the effect of catalysts: iron oxide, lead dioxide and manganese dioxide, on hydrogen peroxide decomposition. Catalysts are specific to a reaction and do not get used up in a reaction. This is investigated through the thermal decomposition of potassium chlorate, which produces oxygen, using copper oxide as the catalyst. 0.25g of copper oxide is used and at the end of the reaction, the weight of the filter paper will change from 0.83g to 1.07g after it has filtered out the catalyst during the reaction. (Question) How much of the catalyst has been recovered? (Answer) 0.24g of the catalyst has been recovered. (Question) If it is true that catalysts are not used up in a reaction, then how do you account for the missing 0.01g of catalyst?**

AFTER SHOWING THE VIDEO:

The first reaction shown in the video was 2 NaOH (aq) + H_2SO_4 (aq) ===> Na_2SO_4 (aq) + 2 HOH + Energy (1)
The energy term on the right, or product side of the reaction, indicates that the reaction is exothermic. This means that overall more energy was released in the formation of the product bonds than was needed to break the bonds of the reactants. As a reminder, it always takes energy to break reactant bonds and energy is always released when product bonds are formed.

ALTERNATIVE "The first reaction shown in the video was 2 NaOH (aq) + H2SO4 (aq) ===> (1) Na2SO4 (aq) + 2 HOH + Energy (1)
***The energy term on the right, or product side of the reaction, indicates that the reaction is exothermic. This means that overall more energy was released in the formation of the product bonds than the combined energy that was needed to break the bonds of the reactants, plus that contained in the bonds broken. As a reminder, it always takes energy to break reactant bonds and energy is either released or absorbed when product bonds are formed*"**

The minimum amount of energy needed to break the reactant bonds is called the activation energy. Reactions that are exothermic give off heat energy. The reaction vessel would feel warmer if touched. When reactions are exothermic, the production of products is favored. In more chemistry terms, the reaction is thermodynamically favored.

The next reaction was: $Ba(OH)_2 \cdot 8H_2O$ (s) + 2 NH_4SCN (s) ===> $Ba(SCN)_2$ (s) + 2 NH_3 (g) + 10 H_2O (l) (2)
The reaction between barium hydroxide octahydrate and ammonium thiocyanate is endothermic. In the reaction more energy overall is needed to break reactant bonds than is released when product bonds are formed.

ALTERNATIVE *"The reaction between barium hydroxide octahydrate and ammonium thiocyanate is endothermic. In the reaction more combined energy overall is needed to break reactant bonds plus that contained in the bonds broken, than is released when product bonds are formed"*

A reaction vessel would feel cooler if it was touched. Reactions that are endothermic are NOT thermodynamically favored so there has to be a reason why the reaction occurs that would favor the production of products. In reaction 2, three (sum of the coefficients) moles of reactants form thirteen moles of products. Also, both of the reactants are solids, whereas the products are solid and also gaseous ammonia and liquid water. When there is an increase in the number of moles of products or a change in state from solid to liquid and gas molecules, the production of products is favored. Either an increase in the number of particles or a change in state from solid to liquid or liquid to gas, increases the entropy of a system and this favors an increase in the spontaneity of a reaction. Entropy is a measure of the number of different ways a system can be arranged. The number of ways it can be arranged has increased. Though the reaction is endothermic and that does not favor spontaneity, the increase in entropy does.
The next two reactions were the formation and decomposition of water.

$2 H_2 (g) + O_2 (g) ===> 2 H_2O (g) + Energy$ (3)

$Energy + 2 H_2O (l) ===> 2 H_2 (g) + O_2 (g)$ (4)

When hydrogen and oxygen chemically combine to produce water, the reaction is exothermic. The reverse of the reaction, the decomposition of water with the aid of electricity, is endothermic. The numerical value of the energy term is the same in both cases and this is true for all chemical reactions though the numerical value differs from one reaction to the next.

The next reaction involved the formation of colloidal sulfur.

$2 HCl (aq) + Na_2S2O3 (aq) ===> 2 NaCl (aq) + H_2O (l) + SO_2 (g) + S (s)$ (5)

Colloidal sulfur forms as a result of the reaction between hydrochloric acid and sodium thiosulfate. The sulfur scatters light as it is being formed. As more and more colloidal sulfur is formed the reaction solution becomes cloudier and less light is able to pass through. A colloid is a mixture in which the solute-like particles are suspended in a solvent-like phase. The particles are small enough that they do not settle because of Brownian motions, but large enough to scatter light.

In the starch-iodine reaction, a solution of starch was mixed with a second solution of iodine, I_2, and potassium iodide, KI. Starch is composed of gluco-pyranose units, $C_6H_{12}O_6$, linked together in an overlapping spiral-like structure with a central cavity. A starch-iodide complex forms between the starch and a pentaiodide anion, I_5^-, with the anion inside the coiled starch molecule. This complex is responsible for the blue-black color.

When the temperature of a reaction increases, the ions or molecules participating in the reaction move faster, that is, they possess more kinetic energy. With greater kinetic energy, they collide more often and the possibility of a reaction occurring also increases. This means that there is a greater possibility that products will be formed. Of course if the temperature was decreased, there would be fewer collisions and less of a chance of product formation.

A general rule of thumb is that for each 10°C increase in temperature the rate of a reaction doubles. This means if a reaction takes 21 seconds at 25°C, it will take ½ that amount of time at 35°C, as in the video. Since the reaction took ½ the time, the rate of the reaction doubled. If the temperature was decreased to 15°C, the time for the reaction would be approximately 42 seconds, that is, the reaction would take twice as long as at 25°C.

The decomposition of hydrogen peroxide occurs by the following equation.

$2 H_2O_2 (aq) ===> 2 H_2O (g) + O_2 (g)$ (6)

Gases are produced in this reaction. The addition of the detergent provided a suitable phase for formation of foam as the gas was evolved. Hydrogen peroxide, H_2O_2, will decompose without the aid of a catalyst though it will occur very slowly. A catalyst lowers the activation barrier of a reaction so that less energy is needed to break reactant bonds in order to initiate a reaction. Therefore, the reaction takes less time because more molecules possess the needed minimum energy necessary for a reaction. Transition metals are often catalysts. Iron and manganese are transition metals, though lead is not.

A solution of sodium potassium tartrate, $NaKC_4H_4O_6$, is reacted with hydrogen peroxide in the presence of a catalyst of cobalt (II) chloride, $CoCl_2$. Only the species that participate in the reaction are shown in the following equation.

$C_4H_4O_6^{2-} (aq) + 5 H_2O_2 (aq) \overset{Co^{2+}}{===>} 4 CO_2 (g) + 2 OH^- (aq) + 6 H_2O (l)$ (7)

Cobalt is also a transition metal. In addition to cobalt (II) ions as a catalyst, iron (II) and copper (II) will also catalyze the reaction. The green complex that forms is an intermediate in the reaction and the complex is cobalt (II) tartrate, $CoC_4H_4O_6$. The return of the pink color of Co^{2+} ions indicates that the cobalt (II) catalyst was not used up in the reaction

In the next reaction copper (II) oxide acts as a catalyst for the decomposition of potassium chlorate, $KClO_3$.

$2 KClO_3 (s) \overset{Cu^{2+}, Heat}{===>} 2 KCl (s) + 3 O_2 (g)$ (8)

Oxygen gas is generated in the reaction. When a glowing splint is placed in a test tube of pure oxygen, the splint will burst into flames. The presence of a catalyst again enables a reaction to take place more rapidly. Copper (II) oxide is the catalyst and is black in color. Because it is a catalyst, it remains unchanged.

QUESTIONS IN THE VIDEO

1.Why does an endothermic reaction absorb heat, but an exothermic reaction releases heat?

This question is probably best answered with a small chart. The numbers have been made up to illustrate the relationship of the energy that is needed to break reactant bonds and the energy released to form product bonds.

Energy	***Exothermic***	***Endothermic***
Energy needed	***+ 20 kJ***	***+ 20 kJ***
Energy released	***- 10 kJ***	***- 50 kJ***
Overall energy	***+ 10 kJ***	***- 30 kJ***

2.What do you think would happen if the concentration of hydrochloric acid were lower than 1 molar in the reaction of the formation of colloidal sulfur? If the concentration of HCl (aq) was 0.5 molar instead of 1 molar, the curve produced as a graph would be less steep. This would indicate that the reaction occurred more slowly. Since there are not as many species in solution to react, there will be fewer collisions and not as much colloidal sulfur will be formed.

3.When the filter paper was weighed after the decomposition of potassium chlorate, why was the mass 0.01 grams less than it should have been? The insoluble copper (II) oxide catalyst was recovered after the reaction was over, but it appeared that 0.01 grams of catalyst had been used up and catalysts do not get used up in a reaction. The 0.01 grams was probably due to experimental error since the 0.01 place in the decimal amount of catalyst was uncertain.

EXPLORING AND INVESTIGATING

1. What caused the Hindenburg dirigible to explode? What changes were made in the gases utilized in balloons after the explosion?
2. What are other examples of colloidal suspensions?
3. Research the chemicals that are used in hot packs and how they work.
4. Research the chemicals that are used in cold packs and how they work.
5. Explain why it is important to refrigerate foods, especially in the summer time.
6. Provide several examples where a catalyst is involved in the digestion of foods. What is the general name given to catalysts that aid in the digestion of food? Explain what would happen if there were no catalysts available for food digestion.

Caution: observe all safety regulations of your school when doing experiments in the laboratory. Check with the appropriate officer in your school before doing these experiments.

Further Information on the Internet

Charles Hall: A historical account of the development by Charles M Hall of a method for the electrolytic extraction of aluminum. (Level: student) http://chemserver.chem.oberlin.edu/CharlesMartinHall.html

Copper: Information produced by the Copper Development Association of North America, which contains teaching resources about the refining of copper and the commercial production of copper and its alloys. (Level: student and teacher) http://www.copper.org/general/homepage.htm

Electrolytic processes: Provides an overview of the application of electrolytic processes in the production and refining of metals. (Level: teacher) http://www.chem.ualberta.ca/courses/plambeck/p102/p02113.htm

Galvanizing: The home page of the metal finishing industry. Includes FAQs, which provide support materials for teaching about galvanizing and other electrochemical processes used in the production of metals. (Level: student and teacher) http://www.finishing.com/Home/about.html

Tin plate: some descriptive information about the commercial importance of tin and the processes involved in tin plate production. (Level: student) http://me.mit.edu/2.01/Taxonomy/html/Materials.html

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