TEACHER'S GUIDE

SCIENCE KEY CONCEPTS SERIES: CHEMISTRY

APPLIED CHEMISTRY

15 minutes, Video

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FOR USE IN: Chemistry
LEVEL: Grades 9-12
EDUCATIONAL ADVISOR: Dr. O. Roger Anderson, Columbia University: Professor Natural Sciences, Teachers College; Senior Research Scientist, Lamont-Doherty Earth Observatory
TEACHER'S GUIDE WRITER: Dr. Julie B.Ealy, Assistant Professor of Chemistry at Pennsylvania State University, Berks-Lehigh Valley.
EDUCATIONAL OBJECTIVES:
To help the student understand these 3 key concepts about applied chemistry:

⇒ 1. Ammonia and Fertilizer
⇒ 2. Plastics and Polymerization
⇒ 3. Sulfur and Sulfuric Acid

Note: Each concept runs 5 minutes, and is separately titled. To play only Concepts #2 or #3, simply fast forward until you see its title.

BACKGROUND INFORMATION:
In this video applications of chemistry are represented such as: the use of ammonia in the making of fertilizer, plastics and an example of how polystyrene is synthesized from the polymerization of styrene units, and the synthesis of sulfuric acid. All three processes represent applications of chemistry on an industrial level. For example, in 1997 the following was produced: 16.52 billion pounds of ammonium nitrate, the main constituent of fertilizer, and 18 billion pounds of nitric acid, which is utilized in the synthesis of fertilizer. The synthesis of polystyrene results in 3.3 million tons produced per year in the United States.

The use of catalysts in the production of ammonium nitrate and sulfuric acid are very important. Reactions are often favored thermodynamically at room temperature. That is, the equilibrium constant for the reaction, which is an indication of the formation of products, is much greater than one. The problem is that the reaction does not occur very fast at room temperature. The reaction, therefore, is not favored kinetically. Catalysts help to increase the rate of a reaction by providing an alternative pathway. Overall, a catalyst lowers the activation barrier for a reaction so that less energy is needed to break reactant bonds in order to initiate the reaction. Therefore, the reaction takes less time because more molecules possess the needed minimum energy necessary for a reaction.

CONTENT

This program looks at the making of fertilizers from nitrogen and hydrogen, polystyrene from crude oil and sulfuric acid from sulfur. Each process is shown in the laboratory, along with the facilities used to carry it out on an industrial level. Computer graphics illustrate and animate explanations of the principles and dynamic processes involved.

Ammonia and Fertilizers Fertilizers increase the nitrogen content of the soil and crop production. They are made from ammonium nitrate, which is itself made from ammonia gas and nitric acid. Ammonia is made from nitrogen and hydrogen mixed under pressure. $N2 + 3H2 ? 2NH3$

Computer animation shows how the molecular structures reverse back and forth in this reaction. In industry, this reaction takes place in a pressurized tower using an iron catalyst at 450°C, at a pressure 200 times greater than atmospheric pressure. It is called the Haber-Bosch process. Nitric acid is produced in several stages. Firstly, ammonia is oxidized with a platinum catalyst to form nitrogen monoxide. 4NH3 + 5O2 ? 4NO + 6H2O Nitrogen monoxide is further oxidized to form nitrogen dioxide, a brown gas. When water is added, the gas goes clear as nitric acid is formed. 4NO2 + O2 + 2H2O ? 4HNO3 Ammonium nitrate is made by adding ammonia to the nitric acid.: HNO3 + NH3 ? NH4NO3

Plastics and Polymerization The raw materials for making plastics are made from crude oil. The first stage is 'cracking' the molecules. In the laboratory, cracking is demonstrated with liquid paraffin, a derivative of crude oil. Liquid paraffin consists of chains of 20 or more carbon atoms joined with single bonds. Such chains are called alkanes. To crack them, paraffin is poured onto glass wool and heated with a ceramic catalyst. The colorless gas given off contains alkenes, which are shorter carbon chains and have a double carbon bond. Alkenes turn brown bromine water colorless. The alkenes are monomers or building blocks of polymers. Polystyrene is made from monomers called styrenes. If the styrenes are heated in a water bath over a few hours, they bond into the polymer, polystyrene. The molecular structure of this is shown.

Sulfur and Sulfuric Acid Sulfur is extracted from rocks. When it is heated in air it burns, with a characteristic blue flame, and forms sulfur dioxide. S + O2 ? SO2 The next stage is to further oxidize the sulfur dioxide to sulfur trioxide. This is done at 450°C, with a catalyst, and must be carefully controlled to stop the reaction reversing completely. 2SO2 + O2 ? 2SO3 Sulfur trioxide plus water, in a sulfuric acid solution, makes more sulfuric acid. SO3 + H2O ? H2SO4 Sulfuric acid is widely used in industry. One of its properties is its ability to absorb water. This is seen when it is added to sugar. Water is absorbed from the sugar and released as steam, leaving pure carbon.

AFTER SHOWING THE VIDEO:

Ammonia and Fertilizers Ammonia, NH_3, is one of the two chemicals needed in the synthesis of ammonium nitrate, NH_4NO_3. The equation for the formation of ammonia is $N_2(g) + 3H_2(g) <==> 2NH_3(g)$ $\Delta H = -92$ kJ/mole The value of ΔH is negative which indicates that this reaction is exothermic. Overall, more heat energy is released when product bonds are formed than is needed to break reactant bonds.The equilibrium expression and equilibrium constant for the reaction are

$$K_c = \frac{[NH_3]^2}{[N_2]\ [H_2]^3} = 3.6 \times 10^8 \text{ at } 25^oC$$

The large K_c value indicates the relationship between the concentration of the products divided by the concentration of the reactants, taking into account the number of moles of each species in the balanced equation. Unfortunately, though the value is very large which indicates that the reaction is thermodynamically favored at room temperature, the reaction is very slow, that is, it is not favored kinetically.

So why not just increase the temperature. Does that not make a reaction go faster? Yes, it does, but in this case an increase in temperature causes the reverse reaction to take place (Note the double arrows. They indicate a reversible reaction.) More nitrogen and hydrogen are produced, not ammonia. This is related to the fact that the reaction is overall exothermic. Increasing the temperature of an exothermic reaction favors the production of reactants, not products. In fact the value of K_c drops from 650 to 0.5 when the temperature is increased from 209^{o}C to 467^{o}C. This indicates that the value of the denominator (the reactants) in the K_c expression has increased significantly. To help increase the rate of the reaction, a catalyst of iron, a transition metal, is added. A higher yield of ammonia can be produced faster and at a lower temperature.

In addition to a catalyst, the pressure on the reactant molecules is increased. An increase in pressure favors the side of a reaction equation where there are fewer moles of gas molecules. In equation 1, there are 4 moles of gas on the left (reactants) and only 2 moles of gas on the right (products). This is why the reaction takes place in a pressurized tower. An indication of the benefit of increased pressure is shown by the following

information	Moles % of NH_3 at 209^oC		
Pressure	10 atm	100 atm	1000 atm
K_c	51	82	98

Note the increase in the value of the equilibrium constant when the pressure is increased. This is indicative of more products. Temperature and pressure have to be adjusted carefully to obtain the highest yield of ammonia. The other chemical needed to make ammonium nitrate is nitric acid, HNO_3. Nitrogen monoxide, NO, is recycled to be used again in the reaction. Note, again, that a catalyst is needed. Iron was used in the production of ammonia and platinum is used in equation 2, one of the reactions, which contributes to the production of nitric acid.

Nitrogen monoxide reacts with oxygen As demonstrated in the video, nitrogen monoxide is a colorless gas, but in the presence of oxygen it forms brown nitrogen dioxide, NO_2, gas. Equation 4 is the final reaction in the production of nitric acid. If nitrogen monoxide was released into the atmosphere this could ultimately lead to the production of acid rain.

Aqueous ammonia reacts with nitric acid Ammonium nitrate, NH_4NO_3 is finally produced when aqueous ammonia and nitric acid are mixed according to the following NH_3 (aq) + HNO_3 (aq) ==> NH_4NO_3 (s) The vapors from the two solutions react to form white ammonium nitrate which is observed as a white cloud in the air.

Plastics and Polymerization

Paraffin, which can be represented generally by the formula $C_{25}H_{52}$, is better known as candle wax. Paraffin is one of the products from the cracking of crude oil in which long chain molecules are broken down into shorter molecules. Candle wax is an alkane, a hydrocarbon made up of hydrogen and carbon atoms. All the atoms are bonded with single covalent bonds. A covalent bond is a force of attraction between negatively charged electrons and the positive nuclei of two atoms. A single bond would represent a pair of electrons. The basic formula for an alkane is C_nH_{2n+n}. In paraffin, n = 25 for 25 carbon atoms and 2n + n = 52 for 52 hydrogen atoms.

When paraffin is cracked, two possible products could be $C_{13}H_{28}$ and $C_{12}H_{24}$. The second of the two products is an alkene. Alkenes have the general formula, C_nH_{2n}. Here n = 12 carbon atoms and 2n = 24 hydrogen atoms. Hydrocarbons with this general formula have at least one double covalent bond in the structure. A double bond would have two pairs of electrons. A reaction that is indicative of the presence of an alkene is one in which red liquid bromine becomes colorless. When bromine reacts with an alkene, the carbon-carbon double bond is broken and the two bromine atoms of the bromine molecule participate in an addition reaction with the alkene. An alkyl halide results where there are all single bonds and, therefore, there is no more red bromine liquid. The alkyl halide is saturated with all single bonds. An example using the simplest alkene, ethylene, C_2H_4 is $CH_2 = CH_2$ + Br_2 ==> $BrCH_2CH_2Br$

If bromine atoms were counted as "hydrogen atoms", the formula of the alkyl halide would fit the general formula for an alkane, C_2H_{2n+n}.

Identical alkene molecules are the basic monomeric units of plastics. They join together to form long chains called polymers. These polymers are the plastics with which we are familiar and that have made our lives so much easier.

The polymerization of styrene, the monomeric unit of polystyrene, is called an addition polymerization where units of styrene add onto each other. The initiator for the reaction is often benzoyl peroxide, $C_6H_5CO\text{-}O\text{-}O\text{-}COC_6H_5$.

Sulfur and Sulfuric Acid

Sulfur occurs most often as S_8 molecules. The sulfurs are bonded to each other with single S-S bonds in an 8-membered puckered ring structure. As sulfur is heated the ring structure breaks apart into chains that are bonded with S-S bonds. Continued heating breaks the chains into smaller chains. Above 444^oC the sulfur boils to give off a vapor.

Reproduction note: Reaction of sulfuric acid with sugar Sulfuric acid can act as a dehydrating agent that removes water from another substance, such as sucrose, $C_{12}H_{22}O_{11}$. When H_2O is removed as steam, the resulting product is mostly black, crusty carbon. The reaction, overall, is exothermic and produces a large amount of heat energy. It would be far too hot to touch as would be evident from the steam that is generated.

EXPLORING AND INVESTIGATING

1. Catalytic converters are used in automobile exhaust systems. What are the catalysts in the converter? What are the two substances for which they act as catalysts?
2. Iron is a transition metal and often acts as a catalyst. What are other transition metal catalysts?
3. Research the life of Fritz Haber.
4. Nitrogen participates in the nitrogen cycle. Explain the purpose of the nitrogen cycle.
5. All of the chemicals in the Ostwald process for making nitric acid are molecular. Molecular substances do not conduct a current. What is unique about nitric acid in this respect, and why?
6. Explain why platinum is a good metal for jewelry.
7. What are three other products that result from the cracking process of crude oil? Give both their name and formula.
8. What are some of the practical uses of polystyrene? Polystyrene can be described as thermoplastic. Explain what thermoplastic means.
9. Starch, as found in foods such as potatoes and bread, is a polymer. What are the monomeric units of starch? What is the general formula for starch?
10. Disposal of plastics is a major environmental problem. Find out what your community does to help with this problem.
11. Research the topic of acid rain. What nonmetal oxides + water are responsible for acid rain?
Where do the nonmetal oxides come from that contribute to acid rain?
12. Coal is mostly carbon. Research the different grades of coal and their fuel efficiency.

BENCHMARK MEDIA 569 NORTH STATE ROAD, BRIARCLIFF MANOR, NY 10510
TEL: 914/762-3838, 1/800-438-5564 FAX: 914/762-3895 E-MAIL: benchmedia@aol.com