DEMONSTRATION 1

CHEMICAL REACTIONS

A chemical reaction or a chemical change is defined as the conversion of one or more substances into one or more other substances. Such a change is exemplified by the conversion of iron and oxygen into iron rust. The study of chemical reactions constitutes a large part of the study of chemistry. This demonstration will illustrate typical phenomena associated with such reactions.

Procedure

A. Two colorless solutions (denoted A and B) are mixed by adding A to B with stirring. Note evidence for any chemical reaction.

More solution A is added to the mixture. Observe the results.

The procedure is repeated except that solution B is added to solution A, initially, followed by addition of more solution B. Compare the results for the two procedures.

Now the resulting two solutions are mixed. Are the two solutions the same? Explain your answer.

B. The apparatus shown in Figure 1, which contains the same solutions used in part A, is weighed. The solutions are mixed and the apparatus weighed again. What do the results indicate about chemical reactions?

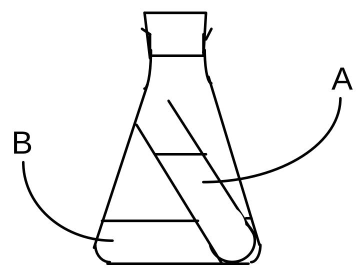


Figure 1

C. The instructor will show you a solid compound. What are its apparent properties?

The instructor will also show you a liquid compound. What are its apparent properties?

A finely ground sample of the above mentioned solid compound is treated with a few drops of the liquid. Note evidence for chemical reaction.

The resulting residue is added to a colorless aqueous solution. Note the results.

The original solid compound is treated the same way.

What do your observations indicate?

DEMONSTRATION 2

BOYLE'S LAW

The object of this demonstration is to verify Boyle's Law which states that at constant temperature the volume of a gas varies inversely with pressure. According to this law, if the initial volume of a contained gas is V_1 at the pressure P_1 and the volume is changed to V_2 with the pressure changing to P_2 , the relationship between the two volumes and the two pressures will be as follows if the temperature is held constant.

$$\frac{V_1}{V_2} = \frac{P_2}{P_1} \qquad (1)$$

In this demonstration the volume and pressure of a gas, namely air, contained in a cylinder are measured (V_1 and P_1). The volume of air is then decreased by addition of a liquid, and the volume and pressure of the air under the new conditions (V_2 and P_2) are measured. The ratios P_2/P_1 and V_1/V_2 are compared to test if equation (1) holds.

Procedure

The apparatus shown in Figure 1 is used. A reservoir is connected to the cylinder so that a nonvolatile liquid may be introduced. A mercury manometer is also connected to the cylinder so that the pressure of the gas may be measured.

The initial volume of air in the cylinder (V_1) is simply the volume of the cylinder. How can this be determined?

The initial pressure of air in the cylinder is atmospheric pressure (P_1) which can be measured using a barometer.

In order to decrease the volume of air, the liquid is allowed to flow into the cylinder from the reservoir, and the volume of air decreases by an amount equal to the volume of liquid added. The addition of liquid is contained until no more liquid flows into the cylinder. At this point the pressure change is measured with the manometer. The final pressure P_2 is computed from the barometric pressure and the manometer reading. How can the final volume of gas in the bottle, V_2, be measured?

Do the results prove Boyle's Law?

P_1 .... ______

manometer reading after
addition of liquid .... ______

P_2 .... ______

$\frac{P2}{P1}$ .... ______

volume of liquid added ...... ______

V_1 .... ______

V_2 .... ______

$\frac{V1}{V2}$ .... ______

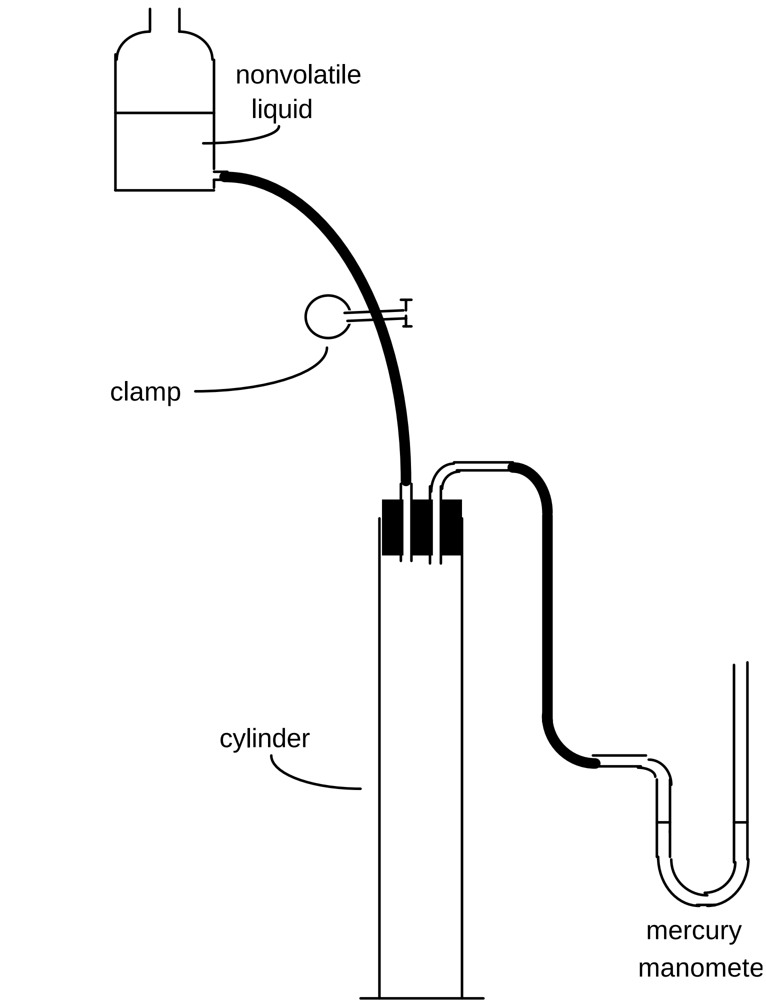


Figure 1

DEMONSTRATION 3

COLLOIDS

Colloids or colloidal dispersions are mixtures in which particles (or droplets, or bubbles) of one medium having diameters of 10^{-4} - 10^{-6} mm are suspended in another medium. If the particles are smaller than 10^{-6} mm in diameter the mixture exhibits the properties of a true solution and is not considered to be a colloid. If the particles are larger than 10^{-4} mm in diameter, the mixture is not colloidal but heterogeneous.

There are many common examples of colloids. Some of these are smoke in which small solid particles are dispersed in air and clouds and fog in which small water droplets are dispersed in air (Figure 1).

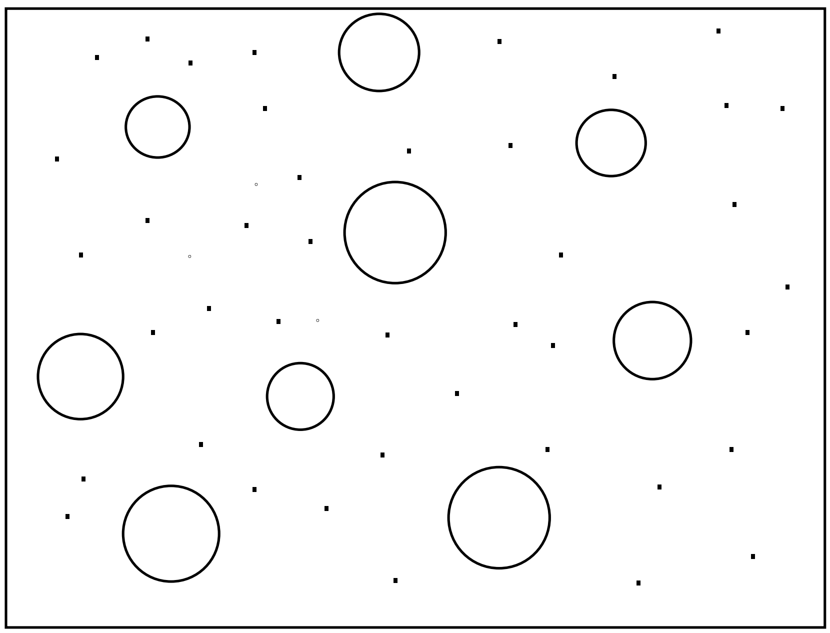


Figure 1 - Clouds and fog : droplets of water dispersed in air (Water droplets are represented by the circles, and air molecules are represented by dots.)

Mayonnaise is a colloidal dispersion in which droplets of one liquid (salad oil) are dispersed throughout another liquid (vinegar). Another colloidal dispersion of this type is hand lotion. We can also have colloidal dispersions consisting of liquid droplets dispersed in a gas and liquid droplets dispersed in a solid. Fog and clouds exemplify the former, and butter is an example of the latter. In fog and clouds, tiny droplets of water are dispersed in air, as mentioned above, and in butter, tiny droplets of water are dispersed in butter fat.

There are many examples of colloids in which particles of solids are dispersed in other media: other solids, liquids and gases. An example of the first type is the rubber of a tire in which particles of carbon black are dispersed in rubber. Rubber is a white material and the color of tire rubber is due to the carbon black particles. Examples of the second is muddy river water in which tiny particles of silt are dispersed in water, and an oil based paint in which particles of color pigment are dispersed in an oil base. An important example of a colloid in which solid particles are dispersed in a gas is smoke.

There are also many examples of colloids in which tiny bubbles of gases are dispersed in liquid and solid media. There are no examples of colloids consisting of mixtures of gases, however, since such mixtures are uniform mixtures of molecules and are , therefore, solutions. Examples of colloids consisting of tiny bubbles of gases dispersed in liquids are foams such as whipped cream and shaving cream, and an example of a colloid consisting of tiny bubbles of a gas dispersed in a solid is cloudy ice. The cloudiness is due to the presence of tiny bubbles of air trapped in the ice crystal.

In this demonstration colloids will be prepared and some of the properties of these will be observed.

Procedure

A. A solution of aluminum sulfate is mixed with a solution of sodium bicarbonate. What reaction is responsible for the results?

The procedure is repeated except that a detergent is added to the aluminum sulfate solution first. Account for any different behavior.

Is the mixture a colloid? If so, what kind of colloid is it?

B. A solution of sodium thiosulfate, $Na_2S_2O_3$, is placed in the path of a beam of light which subsequently strikes a white screen. Sulfuric acid is added resulting in the slow production of colloidal sulfur. Observe the solution as this occurs as well as the screen. Account for the results.

DEMONSTRATION 4

WATER PURIFICATION: REMOVAL OF DISSOLVED SALTS

There is an abundance of water in nearly all regions of the world including arid regions like the Tularosa basin where White Sands National Monument is located. In the Tularosa basin the water table is only a few feet below ground level and extends several thousand feet in depth to bed rock. Even though there is an abundance of water in the world most of it is unusable for most purposes due to impurities like dissolved salts. For example, the water of the Tularosa basin is saturated with gypsum (calcium sulfate). Even fresh water, which is suitable for domestic uses, contains some dissolved salts so that it cannot be used for laboratory purposes.

Two of the most important methods of removing salts to improve water quality are distillation and ion exchange. The former method takes advantage of the property that salts are essentially nonvolatile and the later uses the fact that salts are made up of ions.

In this demonstration both techniques of salt removal will be observed.

Procedure

A. <u>Distillation</u>

The distillation apparatus shown in Figure 1 is assembled on the demonstration bench. Some water containing potassium permanganate, which is a salt, is placed in the distillation flask. What is responsible for the color of the solution?

The solution is boiled, and cold water is circulated through the condenser. Note evidence that the liquid in the receiver is free of potassium permanganate.

B. <u>Ion Exchange</u>

Two ion exchange columns are set up as shown in Figure 2.

These columns contain small beads of polymeric materials (see Demonstration 15) known as ion exchange resins. These beads are insoluble in water but are porous so that water can move through them. Along the polymeric chains of ion exchange resins are groups of atoms which are either ionic or ionizable. The resin in the top column contains strongly acidic groups known as sulfonic acid groups which readily ionize to yield hydrogen ions (H^+). A portion of the structure is depicted in Figure 3.

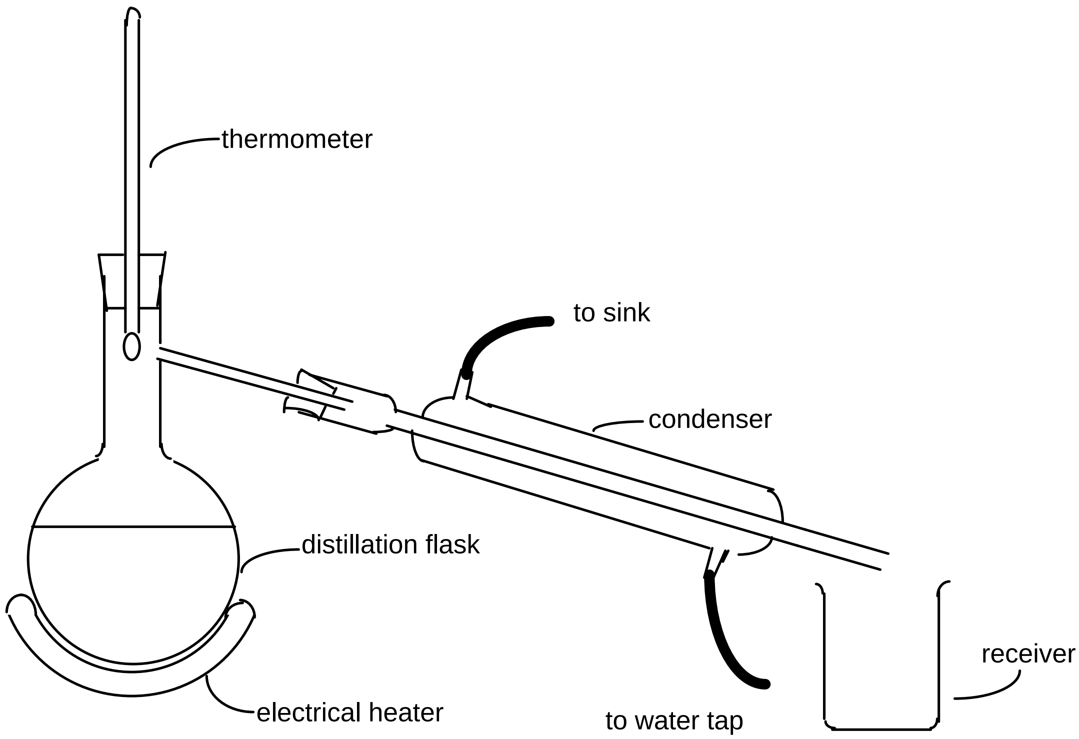


Figure 1. Distillation Apparatus

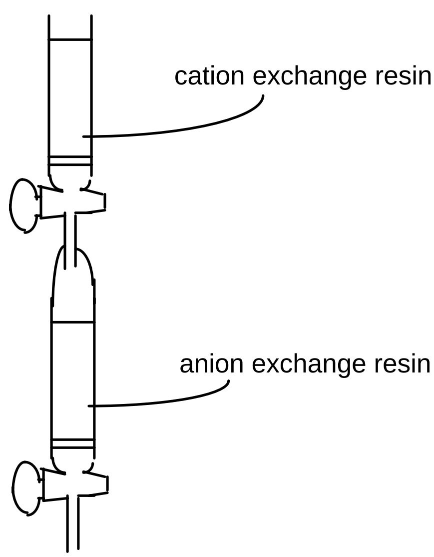


Figure 2. Ion Exchange Columns

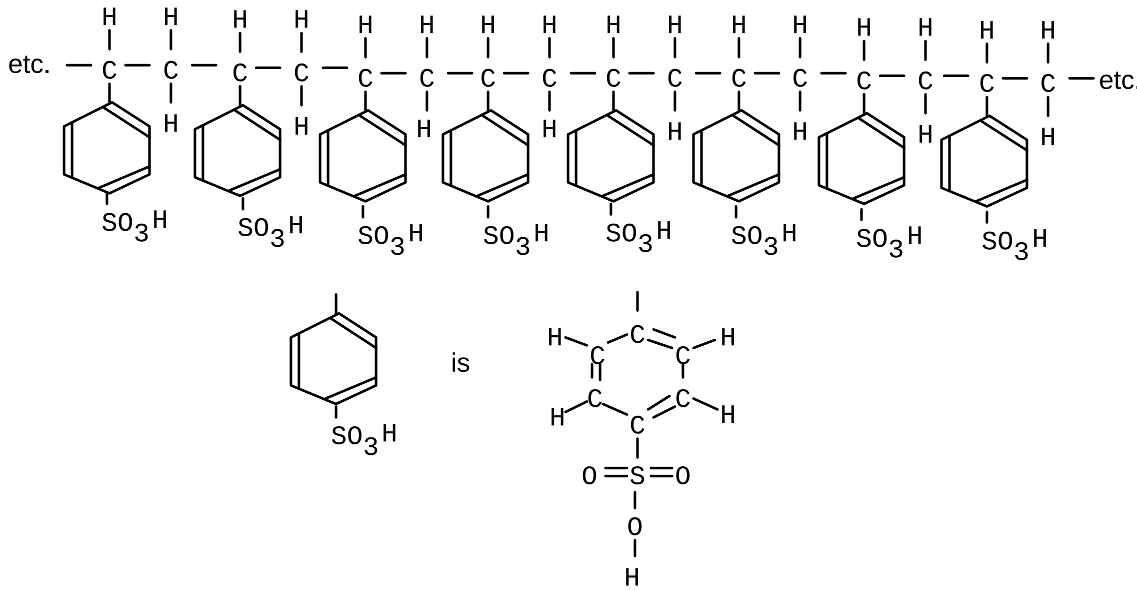
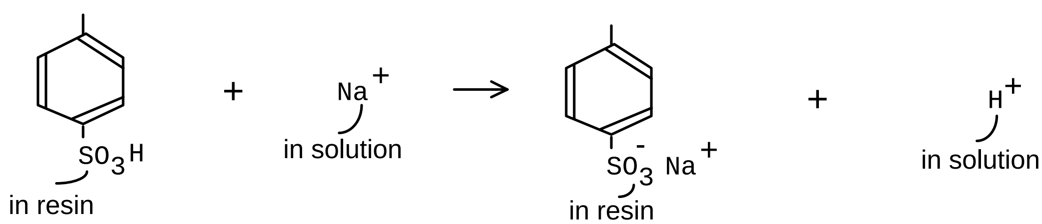


Figure 3. Structure of a Cation Exchange Resin

If an aqueous solution containing a dissolved salt comes in contact with such a resin, the positive ions (cations) of the salt readily replace H^+ ions and become absorbed in the resin. The H^+ ions are released to the solution. The process is depicted below for the reaction of one sodium ion in solution with one sulfonic acid group of the resin.



The process is termed ion exchange, and the resin is called a cation exchange resin.

The resin in the lower column contains positively charged groups known as organic ammonium groups. Associated with these groups are negative ions (anions) which in the case of the lower column are hydroxide ions (OH^-). The structure is depicted in Figure 4.

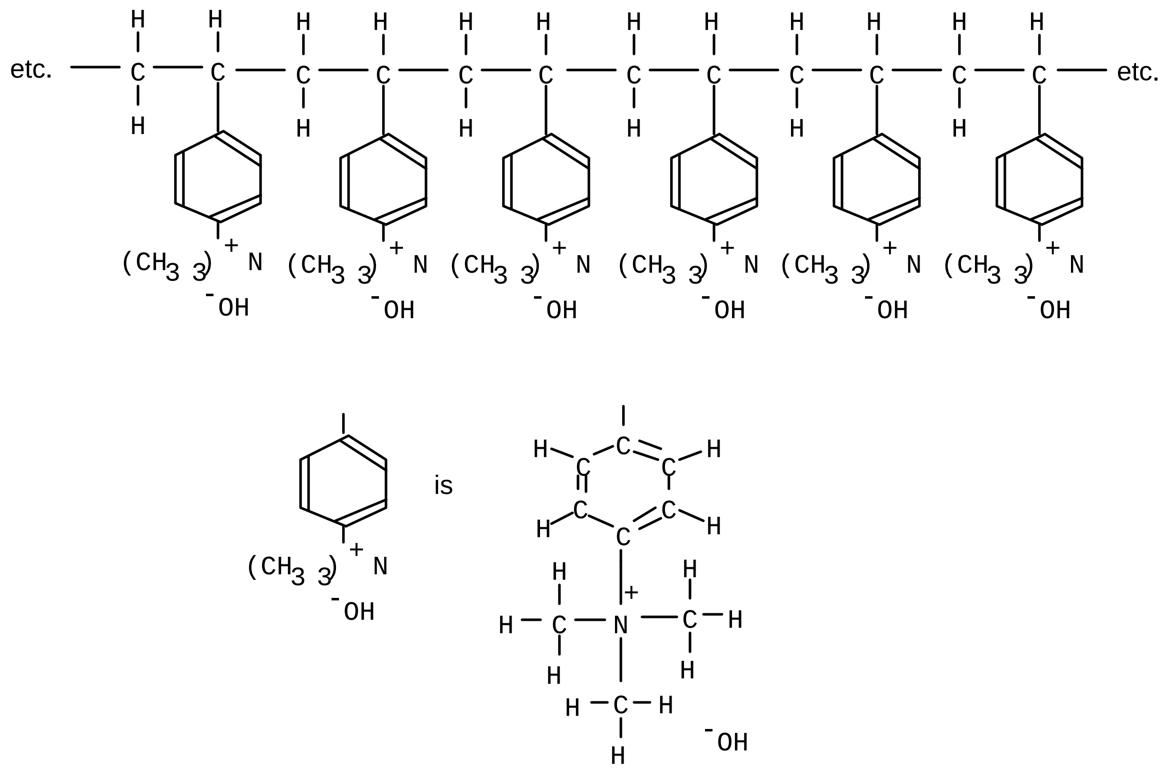
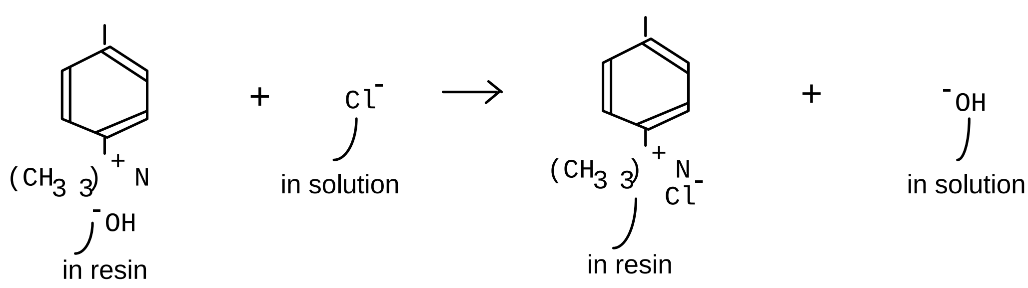


Figure 4. Structure of an Anion Exchange Resin

When a solution containing a dissolved salt comes in contact with such a resin the anions of the salt replace OH^- ions. The process is depicted below for the reaction of one chloride ion in solution with one ammonium group of the resin.



Thus, the anions of the salt are absorbed in the resin, and the OH^- ions of the resin are released to the solution. Such a resin is called an anion exchange resin.

If a solution of sodium chloride in water is poured through the two columns the sodium ions, Na^+, in solution are replaced by hydrogen ions, H^+, in the upper column and the chloride ions, Cl^-, in solution are replaced by hydroxide ions, OH^-, in the lower column. The hydrogen ions from the upper column combine with the hydroxide ions in the lower column to produce water

$$H^{+} \quad + \quad OH^{-} \quad \rightarrow \quad H_2O$$

so that the ions of sodium chloride are retained in the two columns and pure water exits the lower column.

A solution containing green cations and purple anions is to be passed through the two columns. Predict where these ions should be retained and observe the results as the instructor introduces the solution into the columns.

Record your observations. Are they in agreement with your predictions?

List advantages and disadvantages of the two methods of salt removal.

DEMONSTRATION 5

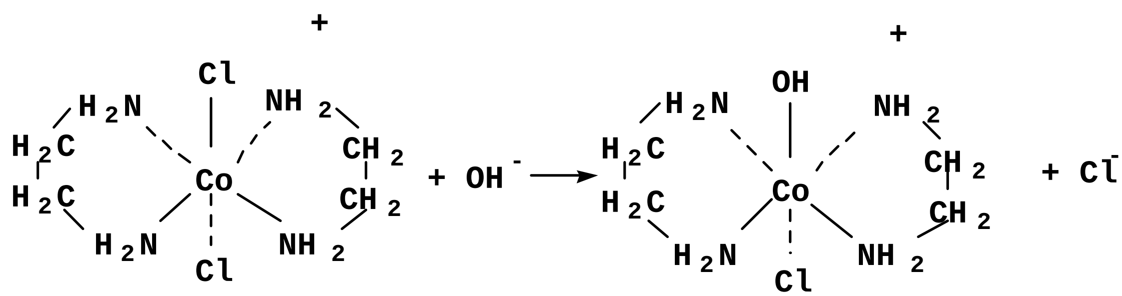
CHEMICAL KINETICS

Chemical kinetics is that branch of chemistry which is concerned with the rates of chemical reactions and the factors which determine these rates. The principal factors which determine the rate of reaction are 1) the nature of the reactants, 2) temperature, and 3) concentrations of substances involved in the reaction.

In this demonstration the effect of temperature and concentration of reactants upon the rate of a reaction will be illustrated.

Procedure

The reaction to be examined is the reaction of a green coordination complex with hydroxide ion, OH^-, to form a red corrdination complex and chloride ion.



green red

The instructor will show you the reactant complex. What are its physical properties.

Examine what happens when an aqueous solution of this complex is treated with sodium hydroxide solution. What are the properties of the product complex in solution?

The instructor has three solutions with different concentrations of hydroxide: solution 1 with a very low concentration, solution 2 with a hydroxide concentration 10 time that of solution 1, and solution 3 with a high hydroxide concentration 100,000 time that of solution 1.   Note what happens when the reactant complex is added to these solutions. What can you say about the dependence of the rate of reaction upon the concentration of hydroxide?

The instructor has three samples of the solution 1: one in ice, another at room temperature and the third in boiling water. Note what happens when the reactant complex is added to these solutions. What is the effect of temperature upon the rate of reaction.

DEMONSTRATION 6

CHEMICAL EQUILIBRIUM AND LE CHATELIER'S PRINCIPLE

Consider a hypothetical chemical reaction represented by

A + B · C + D

and suppose that the products above (C and D) can also react to yield the reactants, i.e.,

C + D · A + B

Such reactions are said to reversible and are denoted

A + B ⁄ C + D

There are many chemical reactions of this type.

Considering our hypothetical example again, if we initiate the reaction by mixing A and B, then as the reaction proceeds, the amounts of A and B in the reaction mixture decrease while the amounts of C and D increase. But as the amounts of C and D increase, the rate of conversion back into A and B also increases so that ultimately the rate at which A and B are reacting to yield C and D equals the rate of which C and D are reacting to yield A and B. At this point there is no further change in the relative amounts of all four species, A, B, C and D and the reaction is said to be at equilibrium.

Once a state of equilibrium has been reached, the equilibrium will be maintained indefinitely unless the conditions under which the equilibrium exists are altered. If the conditions are changed the system will no longer be at equilibrium; however, under the new conditions, in time a new equilibrium will be attained. Le Chatelier's Principle pertains to how an equilibrium will be affected when conditions are altered. It states that if the conditions are changed, the equilibrium will change so as to tend to restore the original conditions. Let us see how that principle operates by considering the above hypothetical case again:

A + B ⁄ C + D

Suppose the system is at equilibrium and we add more A to the mixture. We have altered the conditions and equilibrium is disrupted. According to Le Chatelier's Principle, adding more A should favor the forward reaction since this reaction would tend to restore the original conditions by removing A. As a result, at the new equilibrium, the amounts of C and D will be increased relative to the original equilibrium and the amount of B will be decreased. We say that the equilibrium has been shifted toward products. Similarly, if we add more of one of the products the equilibrium will be shifted toward reactants.

An equilibrium can be changed by a change in temperature also. Let us examine how Le Chatelier's Principle applies to this situation. In general, chemical reactions either give off heat or absorb heat. Reactions of the former type are called exothermic while reactions of the latter type are called endothermic. Exothermic reactions heat the reaction mixture and the surroundings. For the case of reversible reactions, if the forward reaction is exothermic, the reverse reaction is endothermic, and <u>vice versa</u>. When a reversible reaction is at equilibrium the heat given off by the exothermic reaction equals that being absorbed by the endothermic reaction so that no net heating nor cooling occurs, and therefore, no change in temperature results.

Now suppose that a reaction mixture at equilibrium is cooled by some means. Le Chatelier's Principle tells us that the equilibrium will change in such a way as to resist the cooling; that is, lowering the temperature will shift the equilibrium in the exothermic direction. Let us illustrate this by using our hypothetical example again:

$$\mathbf{A + B \rightleftharpoons C + D}$$

Assume that the forward reaction is exothermic. Cooling the system will shift the equilibrium in the forward direction, and accordingly the amounts of C and D will increase while the amounts of A and B will decrease. On the other hand, warming the system will cause a shift in the endothermic direction and the relative amounts of A and B will increase as the amounts of C and D decrease.

In this demonstration several chemical equilibria will be observed and Le Chatelier's Principle will be illustrated.

Procedure

A. The instructor will show you an aqueous solution of cobalt (II) chloride. What species are in solution?

What species is responsible for the beautiful color of the solution?

B. Observe what happens when concentrated hydrochloric acid is added to the solution. What chemical reaction is responsible for the observations?

C. What happens when more water is added to the mixture?

What do your observations indicate?

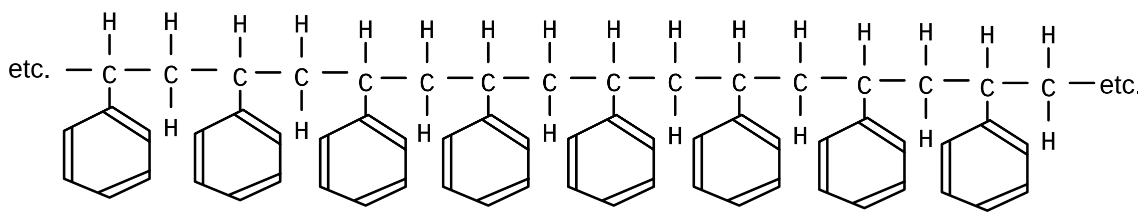
D. Note and explain what happens when more hydrochloric acid is added.

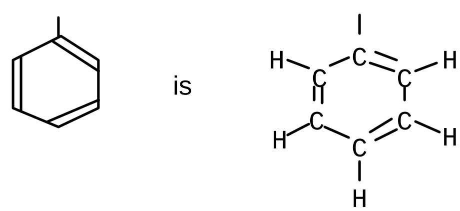
E. Examine another solution of cobalt (II) chloride. Observe the solution when it is first heated and subsequently cooled. Interpret your observations.

DEMONSTRATION 7

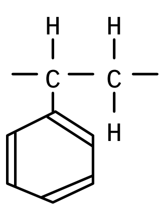
POLYMERS

All the plastics and fibers we encounter in our everyday lives are polymers consisting of large molecules made up of repeating structural units. An example of a polymer is polystyrene which is the material from styrofoam is made (the ion exchange resins described in Demonstration 14 are also made from polystyrene). Polystyrene has a structure a portion of which is shown below.





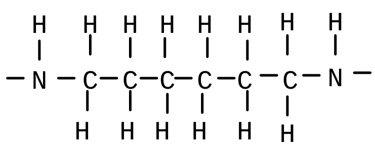
The repeating structural unit in this polymer is as follows,

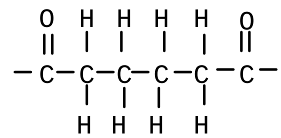


and the number of these structural units in a single molecule may exceed 6000 giving a molecular weight of approximately 600,000.

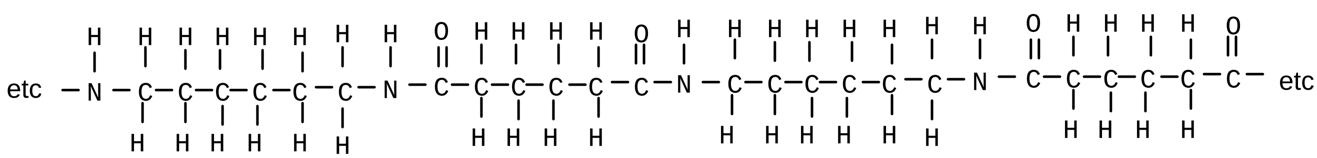
Other polymers include the natural fibers cotton, wool and silk and the synthetic fibers polyester and nylon. Familiar polymeric plastics include PVC (used to make plastic pipe and credit cards), polyethylene (used to make trash bags and soft plastic bottles), ABS plastic (used to make telephone cases and appliance cases) and rubber.

In this demonstration nylon will be synthesized. There are several types of nylon two of which are designated nylon-66 and nylon 6,10. Nylon 66, the type of nylon used to make women's hose, consists of molecules with the two structural units shownas follows.

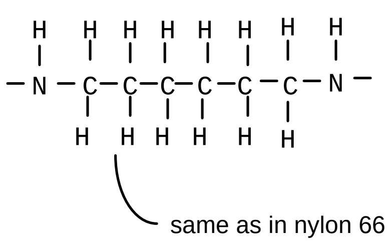


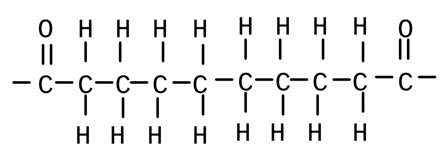


These two structural units alternate in the structure of the polymeric molecules of nylon-66 as depicted as follows.



Nylon-6,10, which is used to make nylon gears, bushings and combs is similar in structure to nylon 66 with the difference being that one of the structural units has 10 carbon atoms in it rather than 6. The two structural units for nylon-6,10 are shown below.



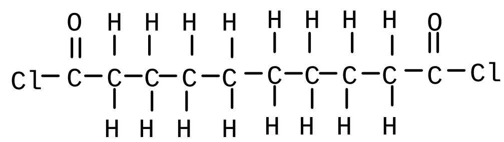


Note that the number designations for nylon-66 and nylon-6,10 refer to the number of carbon atoms in the respective structural units.

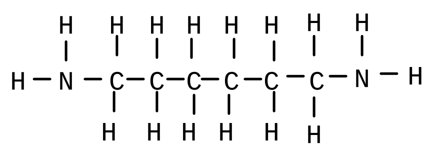
In this demonstration we will show how chemical reactions can be used to link up small molecules (containing the structural units) to yield polymeric species. The synthesis of nylon will be used for this purpose.

Procedure

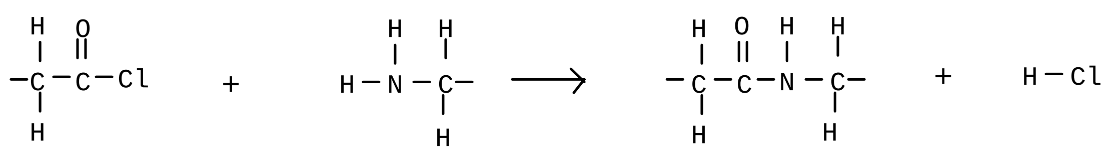
The instructor has prepared solutions of sebacoyl chloride,



in hexane and hexamethylenediamine,



in water. Note that a sebacoyl chloride molecule contains one of the structural units in nylon-6,10 and that a hexamethylenediamine molecule contains the other. Sebacoyl chloride is an example of a class of compounds called acid chlorides and hexamethylenediamine is an example of another class of compounds called amines Acid chlorides react with amines according to the following equation.



part of acid chloride molecule

part of amine molecule

The nitrogen atom of the amine displaces the chlorine atom of the acid chloride producing a type of compound known as an amide. The displaced chlorine atom ends up in hydrogen chloride.   Show how this type of reaction should link the structural units in sebacoyl chloride and hexamethylenediamine to form nylon-6,10.

Water and hexane are immiseble. Some of the hexamethylenediamine aqueous solution is poured into a small beaker and some of the sebacoyl chloride hexane solution is poured upon the other solution. Note the formation of two layers as the less dense hexane solution floats upon the more dense water solution. Note what happens at the interface between the two layers. What reaction has occurred?

Observe what happens when the material is drawn out of the beaker. What is the material?