When we are not sure,
we are alive.
--Graham Greene

Reactions of Acids

Acids are *electrolytes*, i.e., their solutions contain ions. The presence of hydrogen ions, H^+ (sometimes written as hydronium ions, H_3O^+) indicates an acid. This is the simplest possible definition of acids that has anything to do with the actual chemistry behind their behavior. Your text gives what are called "operational definitions" for acids which simply describe some of their more obvious properties.

Acids react with many elements (principally metals) and many types of compounds--too many to look at in a single experiment. In this exploration you will observe the following kinds of acid reactions:

- with bases
- with metal oxides
- with metal carbonates
- with metals

Bases are also electrolytes which can generally be recognized the presence of hydroxide ion (OH^-) in their formulas (ammonia, NH_3, is an important exception). They react with acids to produce water and another type of electrolyte compound called a *salt*. This kind of reaction is called **neutralization**. Neutralization reactions can be followed in a variety of ways. Certain dyes are sensitive to the amount of acid or base in a solution and will change color as the amount of either changes. These dyes are known as *indicators*. Also, a quantity called the *pH* changes during a neutralization reaction. We will have more to say about pH later in the year. In this experiment you will use indicators to investigate the neutralization process.

Metal oxides and carbonates are compounds which exhibit some basic behaviors in water solution. So it should not be surprising that they will also react with acids. Metal oxides may be considered as "bases without water" or *basic anhydrides*. For example, if H_2O is removed from the formula $Ca(OH)_2$, the result is CaO. Such compounds react with acids in the same way as bases, producing water and a salt.

Metal carbonates are the products of the reaction of metal oxides with carbon dioxide, e.g.,

$$CaO + CO_2 \rightarrow CaCO_3$$

When an acid comes in contact with a metal carbonate, water and a salt are produced along with carbon dioxide gas.

The behavior of these two types of compounds with acids is important because of the use of both in building and sculptural materials around the world. The increasing acidity of rain in many developed areas poses a problem for these materials as you will see.

Finally, many metals react with acids. This is actually another type of chemical reaction known as "redox" (short for oxidation and reduction) which we will look at in more detail in the next experiment. For most metals the products of the reaction are hydrogen gas and a salt. This is a classic "displacement" reaction. However, the noble metals (Cu, Ag, etc.) are not attacked by all acids and when they do react, the products typically do not include hydrogen gas. Just as acid rain is a concern with respect to oxide and carbonate based building materials, ornamental and structural metals are affected as well.

Preparing to experiment

You will be provided with the following materials:

1. phenolphthalein indicator
2. bromthymol blue indicator
3. neutral litmus paper
4. solutions of hydrochloric acid, sulfuric acid, sodium hydroxide, and a mixture of equal parts hydrochloric acid and sodium hydroxide
   [these solutions are of equal concentration, i.e., one drop of each contains the same amount of HCl, H_2SO_4 or NaOH in moles]
5. more concentrated solutions of HCl, H_2SO_4, and HNO_3
6. samples of the following metals: Zn, Cu, Fe, Al
7. samples of CaO, $CaCO_3$ (marble chips)
8. boiled distilled water
9. 24 well microplate
10. 24/96 well combination microplate

Design an experiment to determine the color of each indicator (and litmus paper) when exposed to an acid, a base, boiled distilled water, and a mixture of equal volumes of acid and base. [*hint:* use 1-2 drops of each substance and one drop of indicator in one of the small wells on the plate--you only need to try one of the acids]

[continued on next page]

Design an experiment to predict the ratio between HCl and NaOH in a reaction and also between H_2SO_4 and NaOH. [*hints*: both liquid indicators change color at approximately "neutral"; start each experiment with about 50 drops of NaOH in one of the large wells on the plate]

Design an experiment to test the reactions of the three more concentrated acid solutions with the metals, oxide and carbonate sample [*hint:* use the 24-well plate---do the nitric acid last and *in the fume hood*--you may leave your plate there when you are finished observing]

Pre-lab take-home quiz

Answer these questions on a separate piece of paper to be turned in on the day you do this experiment.

1. Describe the difference in products when HCl reacts with Mg metal, MgO and $MgCO_3$.

2. One solution contains H_2SO_4 and another contains HNO_3. If each has equal moles of the respective acid present, which solution contains more H^+ ions?

3. Acids are described as strong or weak depending on whether they are strong or weak electrolytes, i.e., whether they break up completely into ions or only partly. HCl is a strong acid. Nitrous acid (HNO_2) is weak. In solutions with equal concentrations of these acids, which would have more free H^+ ions present?

Technique

1. Indicator papers

Many indicators can be used in a more "portable" form by applying the dye to paper and allowing it to dry. The color changes in acid or base solution remain the same. To correctly use an indicator strip you should place a drop of the solution to be tested (either with a dropper or the end of a stirring rod) on the paper. DO NOT dip the paper into the solution.

2. Using boiled water in acid/base experiments

We generally use *distilled* water in experiments because it has been purified (by boiling the water and collecting the condensed steam) so that the majority of ions have been removed. However, distilled water stored in plastic bottles and allowed to stand for any period of time gradually collects CO_2 from the atmosphere, just as bodies of fresh and salt water do in the environment outside the lab. The following reactions then take place:

$$H_2O + CO_2 \rightarrow H_2CO_3$$

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

The presence of H^+ ions (even in small amounts) makes the water slightly acidic. This may result in spurious results. Boiling the distilled water drives out the CO_2 (most gases are *less* soluble in liquids at higher temperatures--in contrast to most solids) and ensures better results. Be sure not to leave the boiled water containers uncapped for any long period of time.

3. Titration

When solutions containing substances that react are compared with regard to concentration, the process is called *titration*. Sometimes the solution mixture signals when the titration is complete by changing color. Often--as in this experiment--another substance is added (an indicator) to show when the reaction is finished. This is generally the case for acid-base reactions since most acids and bases are colorless and react to form colorless products.

Very accurate titrations are done with a device called a *buret* which you will use in later experiments. But the general technique is the same regardless of whether you use expensive glassware or a simple dropper. You must measure the initial volume of one solution and then add the other until the reaction is complete. The added volume of the second solution is then compared to the original volume to determine the ratio between the reactants. In this experiment this comparison is simplified by the fact that the solutions are of equal concentration, but it is possible to use different concentrations and even solids!

Rather than use a buret, you will use a pulled beral pipet. These disposable plastic pipets have thin stems which can be made even thinner by gently pulling on the plastic. This process draws the stem into a fine tip which gives a more reproducible drop size, **if the dropper is held vertically**. To get an accurate result, you will need to use a reasonable number of drops (50 is not too many--more is better). Since the plastic material the droppers is made from is non-wetting, you can use the same pipet to deliver all of the solutions. That way all your drops will be created equal if you are careful. Just be sure to rinse the pipet thoroughly with distilled water between solutions--and *stir* during the reaction. Oh, and don't forget to add a drop of indicator before you begin titrating!

The chemicals

Phenolphthalein is a white powder, a complex hydrocarbon derivative that was used in laxatives (once in Ex-Lax™). It also functions very well as an acid/base indicator for most titrations except those involving ammonia. It is very sensitive to CO_2 (which can dissolve in water to a small extent) and for very accurate determinations all water for solutions must be boiled to expel CO_2. For titrations it is used in a 1% ethanol solution. It is practically insoluble in water.

Bromthymol Blue is another very complex hydrocarbon molecule that is useful as an acid/base indicator. Like phenolphthalein it is not very soluble in water and an alcoholic solution is used (1% in 50% alcohol)

Sodium hydroxide is commonly known as lye or caustic soda. It is a very hygroscopic white solid (absorbs water from the air rapidly) and also absorbs CO_2. It is very corrosive to vegetable and animal matter and aluminum metal, especially in the presence of moisture. Dissolving NaOH in water generates considerable heat.

Besides its use in the laboratory, sodium hydroxide is used in commercial drain cleaner preparations, to treat cellulose in the manufacture of rayon and cellophane and in the manufacture of some soaps. It is corrosive to all tissues and can be detected on skin by the "slimy" feeling associated with bases. It should be rinsed off thoroughly upon contact. It can damage delicate eye tissues and cause blindness.

Hydrochloric acid is also known as muriatic acid. It is the same liquid acid that is often used in controlling the pH of swimming pool water. It is sometimes colored yellow by iron impurities, traces of chlorine and organic matter. Reagent grade HCl contains about 38% hydrogen chloride gas, close to the limit of its solubility at room temperature.

Hydrochloric acid in concentrated form has the sharp, choking odor of hydrogen chloride. It is used in the production of other chlorides and in refining some ores (tin and tantalum), cleaning metal products, removing scale from boilers and heat-exchange equipment, and as an important laboratory reagent (often in diluted form).

Concentrated solutions cause severe burns; permanent visual damage may occur. Inhalation causes coughing, choking; inflammation and ulceration of the respiratory tract may occur. Ingestion can be fatal.

Sulfuric acid is a clear, colorless oily liquid in concentrated form (98%). It is highly corrosive and has a high affinity for water, abstracting it from wood, paper, sugar, etc., leaving a carbon residue behind. Dilution of concentrated sulfuric acid generates a tremendous amount of heat. Here in the lab your instructors prepare the dilute sulfuric acid you use by pouring the concentrated acid slowly over ICE while stirring! Even so, the resulting solution is very warm. As with all acid dilutions, acid is added to water, not the reverse, since the heat generated can boil the water at the point of contact and cause spattering.

Sulfuric acid is used to make fertilizers, explosives, dyes, parchment paper, and glue. It is used, in concentrated form, in automobile batteries as the electrolyte. It is corrosive to all body tissues and contact with eyes may result in total blindness. Ingestion may cause death. Frequent skin contact with dilute solutions may cause dermatitis.

Nitric acid has been called "aqua fortis" (strong water). It is generally produced by the oxidation of ammonia followed by reaction of the gaseous products with water. When pure it is a colorless liquid that fumes in air with a characteristic choking odor. "Concentrated" nitric acid is a water solution containing 70% HNO_3. Even dilute solutions will stain woolen fabrics and animal tissue yellow. It is a very strong oxidizing agent, reacting violently with most organic matter.

Nitric acid is used in the manufacture of fertilizers, dye intermediates and explosives.

Calcium oxide (also called lime or quicklime) is produced commercially by heating limestone (principally $CaCO_3$) . It readily absorbs CO_2 and H_2O from the air. Soluble in water, it forms $Ca(OH)_2$, liberating much heat.

Calcium oxide is used in the manufacture of bricks, plaster, mortar, stucco and other building materials, as well as in the processing of steel, the manufacture of glass and paper, the production of Na_2CO_3, dehairing hides, clarification of cane and sugar beet juices, in fungicides and insecticides and in water and sewage treatment (whew!).

Calcium carbonate is generally produced from limestone but exists in a variety of forms naturally, including the mineral calcite (crystals notes for the double refraction properties), chalk and marble. It is used in the manufacture of paint, rubber, plastics, paper, ceramics, inks and cosmetics; as a filler it is found in matches, adhesives, pencils, crayons and linoleum. It is sometimes used to reduce the acidity of wines.

Copper makes up about 0.01% of the earth's crust. It is one of the earliest known metals and is known for its unique reddish color when pure. However it becomes dull when exposed to air, forming oxides of copper, and in moist air becomes coated with green copper carbonate (this is part of the patina that appears on old copper or copper alloy exposed to the elements--like the Statue of Liberty). It is very slowly attacked by dilute hydrochloric acid and sulfuric acid, while nitric acid can readily dissolve it. It also slowly dissolves in aqueous ammonia.

Copper is used in the manufacture of bronzes (copper + tin) and brasses (copper + zinc), and is used extensively in electrical conductors (wires, printed circuits, etc.). Of course copper also makes up a percentage of nearly all U.S. coins minted today.

Copper itself probably has little or no toxicity, but some of its compounds can be quite hazardous.

Iron occurs to the extent of about 5% in the earth's crust. As a refined metal it has been known for centuries. When pure it is silvery white or gray, hard, malleable and slightly magnetic. Stable in dry air, it readily oxidizes (rusts) in moist air. Its chief uses are as a structural alloying agent (in steels) and in the manufacture of some permanent and electromagnets.

Aluminum is a white, malleable metal with a somewhat bluish tint. It can take a high polish in dry air but oxidizes superficially in the presence of moisture. As a pure metal or in alloys, aluminum is used in aircraft, cooking utensils, electrical apparatus and even in some dental alloys. Powdered aluminum is found in some fireworks, explosives and aluminum paints.

Analysis

These questions should be answered in your laboratory notebook following your observations and data.

1. What color is phenolphthalein in acid, base, and neutral solutions?

2. Same question as #1, but for bromthymol blue.

3. Same question as #1, but for litmus.

4. Write the balanced *molecular* equation for the reactions between HCl and NaOH. Do the same for H_2SO_4 and NaOH.

5. Write balanced *net-ionic* reactions for the processes in #4.

6. Use your titration data to show that the ratio between HCl and NaOH matches the one shown in your reaction written for #4. Do the same for H_2SO_4 and NaOH.

7. Which indicator did you choose for your titrations and why?

8. What visual evidence is there for the reaction of the acids with CaO? With $CaCO_3$? Choose <u>one</u> acid and write balanced *molecular* reactions for that acid with the two compounds.

9. Write balanced *net-ionic* reactions for the processes in #9.

10. What visual evidence is there that nitric acid does not react with metals in the same way as hydrochloric or sulfuric acid? Choose <u>one</u> metal and <u>one</u> acid (*not* nitric) and write a balanced *molecular* reaction for what happened when they were combined.

11. Write a balanced *net-ionic* reaction for the process in #10.