Experiment 18: pH Measurements of Common Substances

and

Experiment 17: Reactions of Acids with Common Substances

Prelab Lecture

What is this lab about?

You mean what ARE THESE labs about?

Ok, so what are THESE labs about?

Mostly they are about acid rain.

How do they relate to acid rain?

In two ways (which is appropriate since we're doing two experiments). First, acid rain, which is rain containing a higher concentration of H^+ than is normal, is often reported in terms of lower than normal pHs. In Experiment 18, we'll be exploring the pH's of various substances – first to establish experimentally the relation between pH and the concentration of acid or base, and second to determine the pH's of various liquids, including local rainwater and water from Westhampton lake.

Second, one of the reasons that people are concerned with acid rain is its potential for destruction. It can damage living things. Most of you are aware that fish can be killed as a result of acid rain, but it also has the potential to damage forests and other plant life. In Germany, the Black Forest has been severely damaged by acid rain. It can also damage man made things like buildings and statuary. As an example Michelangelo's David was moved indoors because it was slowly being eaten away by acid rain. In the second part of the experiment, you'll be observing the effect of four different acid samples on marble, four different metals, and on egg white.

What is pH?

pH is a measure of the concentration of H^+ in water. It is defined as

$$pH = -\log\left[H^+\right],$$

where the brackets indicate concentration.

(Note that on your calculators there are two keys for calculating logarithms, the Ln key and the Log key. For pH calculations it is very important that you only use the LOG key).

Because of this definition, the pH of a liquid decreases by one if the concentration of acid increases by a factor of 10.

If I know the pH of a liquid, can I figure out the concentration of H^+?

Yes. You raise 10 to the power of the negative pH, i.e.,

$$\left[H^+\right] = 10^{-pH}$$

Where does H^+ in water come from?

There are two sources. One is from splitting water itself into an acidic and basic component according to the reaction

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$$

where the double arrow indicates that the reaction can go in either direction, i.e., that either water can split up into H^+ and OH^- or that H^+ and OH^- can react with each other to make water. At room temperature this reaction contributes only 10^{-7} moles of acid/per liter of water, a very small concentration of acid. (10^{-7} is one ten millionth).

The other source of H^+ in water is when an acid is put into water.

What's an acid?

The oldest definition of an acid still in use is due to Svante Arrhenius, a Swedish physical chemist. According to Arrhenius, an acid is a compound which produces H^+ when dissolved in water. Thus when an acid HA, is dissolved in water, the following reaction occurs:

$$HA \rightleftharpoons H^+(aq) + A^-(aq)$$

Since all of our samples in this experiment will contain water, this simple definition is all we need.

You can see from this reaction that adding acid to water increases the concentration of H+, and therefore decreases the pH.

What happens to the hydroxide ion, OH-, when the acid is added?

Some of it is consumed by reacting with the H+. However, because of the tendency of water to split into H+ and OH-, there will always be some OH- present.

I've heard of bases, too. What are they?

The simplest definition of a base is also due to Arrhenius. According to Arrhenius, a base is a compound that produces hydroxide ion when dissolved in water. Metal hydroxides are common Arrhenius bases. For example, when sodium hydroxide dissolves in water, the following occurs:

$$NaOH(aq) \rightleftharpoons Na^{+}(aq) + OH^{-}(aq)$$

Is there something like a pH for bases?

Yes. It's called a pOH. It's defined by

$$pOH = -\log\left[OH^{-}\right]$$

Is there any other way to define an Arrhenius base?

Yes, it is possible to define an Arrhenius base by what happens when it reacts with an Arrhenius acid. According to this functional definition, an Arrhenius base reacts with an Arrhenius acid to form water and a salt.

The classic example of this is when aqueous solutions of sodium hydroxide and hydrochloric acid are mixed:

$$NaOH(aq) + HCl(aq) \rightleftharpoons H_2O(l) + NaCl(aq)$$

Acids consume bases. Bases consume acids. Is there any relation between the amount of acid and the amount of base in water?

Yes. The relation is

$$\left[H^{+}\right]\left[OH^{-}\right] = 10^{-14}$$

This implies that if you know either the concentration of H+ or OH- in water, you can figure out the concentration of the other:

$$\left[H^{+}\right] = \frac{10^{-14}}{\left[OH^{-}\right]} \quad \text{and} \quad \left[OH^{-}\right] = \frac{10^{-14}}{\left[H^{+}\right]}$$

Does this mean that there is a relation between the pH and pOH?

Yes, and it's quite simple. It is

$$pH + pOH = 14$$

How will we measure the pH of a sample?
We'll use a device called a pH meter. After proper calibration, dipping the tip of a pH meter into a liquid measures the pH and allows it to be read directly from the meter.

How does it work?

The pH meter essentially creates a galvanic cell like one of the ones you created last week. In this case H^+ is one of the reactants. The principle on which the pH meter is based is that the voltage that is produced depends not just on the identity of the reactants in the electrochemical cell, but on their concentration. In other words, as the concentration of H^+ changes the voltage changes. A graph of voltage vs pH is measured, and is programmed into the meter, so that when a certain voltage is produced, the appropriate pH appears on the readout.

How do I calibrate the pH meter?

Do the following steps:

1. On the pH meter, press the CAL button. 7-4 will show up.
2. Press yes. 7 will show up.
3. Take the cap off the pH meter. Rinse with distilled water into a beaker and then very gently dry with a Kimwipe. Insert into a 30 ml beaker with enough pH 7 buffer in it to completely cover the bulb of the pH meter.
4. Wait until the readings steady and the word ready lights up, and then press yes.
5. The number 4 will light up.
6. Empty rinse and dry your 30 ml beaker. Fill it with enough pH 4 buffer to completely immerse the bulb of the meter.
7. Rinse the bulb of the meter with distilled water and gently dry, then immerse the bulb in the pH 4 buffer.
8. Wait until the readings steady and the word ready lights up. Press yes. Calibration is complete.

Are there any other tips I need for this part of the experiment?

1. Always carefully rinse and dry the bulb of the pH meter between samples.
2. Handle the bulb of the pH meter very gently, as it is made of VERY thin glass.
3. Be very careful when working with the drain cleaner as it is very nasty stuff. Very bad for your skin, very bad for your clothing.
4. Omit part V of the experiment.
5. Don't forget to predict the pH of the first three solutions before you measure them.

So now, we know how to measure pH, and how to figure out if we have acid rain. What are we doing in the second part of the experiment?

We're going to look at three different kinds of acid, nitric acid, HNO_3; sulfuric acid, H_2SO_4; and hydrochloric acid, HCl, to see how they react with some common materials –

marble, a mineral; zinc, copper, paperclip and aluminum, four metals; and with egg white. It's for the purpose of understanding what acid rain can do.

What kind of reactions do acids generally do?

The most important reaction of acids is neutralization, in which the acid reacts with a base to provide a salt and water, as we showed earlier.

A special case of neutralization is the reaction of acid with carbonate ion, CO_3^{-2}, in which the products are water, carbon dioxide and a salt. For example, :

$$2HCl(aq) + Na_2CO_3(aq) \rightleftharpoons H_2O(l) + CO_2(g) + 2NaCl(aq)$$

A second reaction that we saw in detail two weeks ago is an oxidation-reduction reaction with metals, to produce hydrogen gas and metal cations, for example:

$$2HCl(aq) + Ni(s) \rightleftharpoons H_2(g) + NiCl_2(aq)$$

With proteins, the acid can do something called denaturation. Denaturation changes the away the protein folds in on itself away from the natural folding (hence the name denaturation), when the pH of the solution moves away from the narrow range of physiological pH's (from about pH 6.5 to pH 7.5).

I can understand why the neutralization reactions and the redox reactions matter, but why is denaturation important?

The function of a protein depends on the nature of its folding. If you change the folding, you can either permanently or temporarily stop the protein from functioning the way it should.

Why do we use sulfuric acid twice?

The two sulfuric acid samples are 6.0 M, which is very concentrated, and 0.6 M, 10 times less concentrated. The reason that we use both concentrations is that 6.0 M is much more concentrated than acid rain. (So for that matter is 0.6 M) By looking at two different concentrations of acid, we can see whether the effect of changing the concentration is to change the reaction which occurs or simply to change the speed of the reaction.

Are there any experimental pointers for this part of the lab?

1. Remember that all of your nitric acid – metal reactions need to be done in the hood.
2. Wear your safety glasses! Some of these reactions spatter.
3. Only the aluminum pieces can be sanded. The rest need to be used as is.
4. Be patient. Some of the reactions take several minutes to develop. However, don't wait the full time for a given sample before going on to the next sample.

Wait a minute, make your observations, and then periodically check to see if there are any new changes while working on the other samples.

5. Because paper clips are iron with a coating of nickel, you'll see two different reactions. Be careful to look for both reactions, and make observations for both.
6. When filling the wells 20 drops of the HCl, and both H_2SO_4 solutions are fine. However, the drops from the HNO_3 dispenser are larger, and 12 drops are sufficient.
7. Some of the metal pieces will float on top of the acids. If they do, use your glass rods to push them gently down into the liquid. Remember to rinse the glass rod off between samples.

What goes into the lab reports?

As usual, fill in both data sheets, on pages 125, 126, 131 and 132, and answer questions 1-9 (omit the incredibly stupid question 10) on page 123 and questions 1-3 on page 130, as well as the questions on the data sheets.

Honor stuff:

All work can be done collaboratively with your lab partner.