Experiment 12: Building a Conductivity Detector and Testing for Ions

and

Experiment 22: Chemical Reactions and Electricity

Prelab Lecture
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What are these labs about?

The common thread of these two labs is ions. Ions are any atomic or molecular species that is either positively or negatively charged. Common examples of atomic ions are Na^+, K^+ and Cl^-. Common examples of molecular ions are NO_3^-, SO_4^{-2}, and NH_4^+.

Why are ions important?

Ions are critical in biological systems, in part because of the origins of life in the earth's oceans. For example, Na and K ions are critical nutrients in relatively high concentrations, and oxygen transport is dependent on small concentrations of iron. Zinc and copper ions are others that are required in small concentrations.

However, many ions have similar chemistry. If the wrong ion was present in water, it could replace one of these essential nutrients. The chemistry would be similar enough to allow it to take the place of the proper ion in your cells, but different enough to injure your health. For this reason ions are significant pollutants in water, and their detection is important.

In addition, there is a branch of chemistry involving ions called electrochemistry that is commercially important and is important in environmental technology. Chemistry of ions is central to electrical generation in batteries, and in hydrogen fuel cells, the most environmentally friendly technology proposed for operating cars in the future. (They are already used as power sources in space.) In addition, the process proposed to generate the hydrogen, electrolysis of water, is another example of electrochemistry.

We will explore both electrochemistry and the detection of ions today. Let's talk more about detection of ions first.

OK, how do ions get in water?

There are two ways. One is by the dissolution of ionic compounds. Ionic compounds consist of two types of ions, cations, which have positive charges, and anions, which have negative charges. The balance between positive and negative charges has to be such that the total charge for the compound adds up to zero. When ionic compounds dissolve in water, the cations and anions are separated from each other in a process called hydration. Therefore a solution of an ionic compound in water consists of cations surrounded by water, and anions surrounded by water, but just as the ionic compounds had charges that added up to zero, the solution of these compounds also has charges that add up to zero. The requirement that the charges have to add up to zero is called electroneutrality.

The other way that ions can get in water is through chemical reactions that generate ions. The electrochemical reactions that we'll study in the second half of today's lab are some of these reactions. However, it is very important to note that these reactions also must result in equal number of positive and negative charges. Both cations and anions must be formed.

How can they be detected?

The easiest way to detect the presence of ions is using an electrical circuit to check to see if they conduct electricity. The reason this works is that electrical currents, which are flows of charge, can be flows of electrons OR flows of ions. Since ions dissolved in water can move, they can conduct electricity. We'll be building a detector that will light up when ions are present and complete an electrical circuit.

Once we build the detector what will we do with it?

You'll test deionized water, tap water, salt water, sodium hydroxide solution (NaOH), hydrochloric acid, sugar in water, ethanol in water, and then you'll pick five substances outside of lab to study. In each case you'll be looking to see if ions are present.

In addition, you'll be doing some experiments to test the sensitivity of your detector.

What do you mean by sensitivity?

We mean the lowest concentration that will cause your LED to light up.

Are there any tips for this part of the experiment?

1. When soldering, instead of using a match to melt the solder, use one of the birthday candles we have available.
2. It helps if one partner holds the two wires together and the other melts the solder. Make sure that the solder doesn't just melt and form a droplet, but flows smoothly between the wires being connected.
3. Don't immerse your alligator clips directly into the solution. Straighten out a paperclip and cut it in half, and use the two pieces as wires to dip into your solutions. Clean off the wires in between measurements.
4. Don't forget to test 5 additional liquids after you leave lab.

Now let's turn to our study of electrochemical reactions.

Why is electricity important in chemistry?

There are two reasons. First, some chemical reactions can generate electricity. The setups by which they do this are called either galvanic cells, or voltaic cells. (The difference is nationalistic – the French discoverer of the cells, was M. Galvin, and the Italian Sr. Volta). The batteries we use to power so many of our devices (I-Pods, Ipads, cell-phones) are simply a series of these cells strung together.

In addition, it is possible to use electricity as a way to start a chemical reaction. This is called electrolysis. A common example of this is electroplating, a process by which metal ions are forcibly converted to solid metal by application of an electric current. Gold and silver plated jewelry is manufactured by this process. Electrolysis is also important is such critical industrial processes as the purification of aluminum from its ore.

A more environmentally significant use of electrolysis is in using electricity to split water into hydrogen and oxygen. This would provide a source of hydrogen gas to use in fuel cells, one of the environmentally friendliest means of generating electricity, since the product of the reaction is water.

How can chemical reactions generate electricity?

The fundamental reason this is possible is because of the existence of oxidation and reduction reactions, in which electrons are transferred from one atom or molecule to another.

An example is the reduction of copper ions by zinc metal,

$$Zn(s) + Cu^{+2}(aq) \rightarrow Zn^{+2}(aq) + Cu(s).$$

Where are the electrons? I don't see any electrons in the equation.

This is because in order to make sure that we don't build up an excess of either positive or negative charges the exact number of electrons given off by one atom have to equal the number of electrons absorbed by the other atom. Therefore there is no NET buildup of electrons in such a reaction. To see this we divide the reaction into two reactions, one for Zn and one for Cu. Since we're dividing the reactions in half we call the two reactions "half-reactions".

What are the half reactions in this case?

The half reaction for the Zn is

$$Zn(s) \rightarrow Zn^{+2}(aq) + 2e^{-}$$

Notice two things about this half reaction. First, notice that this half reaction tells us that the neutral zinc is giving up two electrons. (The technical name for this is oxidation.)

Second notice that the total charge on each side of the reaction is the same, zero on the left side and zero (2 + -2) on the right side.

The half reaction for the copper is

$$Cu^{+2}(aq) + 2e^{-} \rightarrow Cu(s).$$

Notice first that two electrons are absorbed by the copper ion in this reaction. Notice that the number of electrons given up by the Zn matches the number of electrons absorbed by the Cu.

In this way of writing the reaction, it's apparent that electrons are transferred, and therefore that there is a flow of electricity.

Can a flow of electrons be measured if the two metals and two ionic solutions are mixed together in one container?

No, the reaction will occur, and electrons will flow from the Zn to the Cu^{+2} atoms, but we won't be able to measure the flow of electrons, or the voltage of the reaction.

Voltage? What's a voltage?

For electrical reactions, the voltage is a measure of the energy that is released. The higher the voltage the more energy there is. A positive voltage means that products will be produced spontaneously.

What does a negative voltage mean?

It means that in order to produce products, we need to provide electricity with enough voltage that the total voltage (reaction voltage + voltage of the battery) is positive. When we force a reaction to occur this way it's called electrolysis.

So how do we measure the voltage?

We set up an apparatus, called a voltaic cell, in which the half reactions are separated. A voltaic cell looks like this schematically:

In one beaker, we have a solution of Zn^{+2} and an electrode (piece of metal or graphite that conducts electricity). In this case our electrode is Zn(s). In the other beaker, we have a solution of Cu^{+2} and a Cu electrode. We connect them with a wire, and a device to measure voltage, called a voltmeter. This setup allows the Zn(s) to give up electrons, and pass them through the wire so that the Cu+2 can absorb them. The voltmeter measures the voltage.

So this is all you need for a galvanic cell?

No, there's still a problem. As the reaction occurs, the Zn side loses electrons, and the Cu side gains them. This means that as the reaction proceeds, the Zn side gets progressively more positive and the Cu side gets progressively more negative. This violates the requirement we mentioned earlier that all solutions must stay neutral.

How do we keep the two solutions neutral?

We use a device called a salt bridge. The salt bridge allows ions to flow from one beaker to the other (or one half cell to the other) in order to keep the solutions neutral. Without the salt bridge you typically can't measure any voltage at all. Essentially what is occurring is that an electrical circuit is formed in which electrons flow from one half-cell to the other, and ions flow in the opposite direction.

So what are we doing in this experiment?

You'll create three galvanic cells on a piece of filter paper and measure the voltages of the reactions.

Then you'll perform electrolysis, first on water, and then on a solution of potassium iodide.

Are there any tips for this part of the experiment?

1. When doing the Galvanic Cell part of the experiment, make sure that your watch glass is upside down (so that the glass slopes downward).
2. The drops from our droppers are large so only one drop is necessary to put onto the circles.
3. When you measure the voltage, you may get a negative voltage. If you do, simply reverse the electrodes on your voltmeter. Make sure that you record which metal the red electrode is touching when the positive voltage is observed. This is important because under those circumstances, the red electrode is touching the half cell that is absorbing the electrons. (I.e. the electrons flow from the metal that the black electrode is touching to the solution that the red electrode is in contact with).

4. Before you add the phenolphthalein in the KI electrolysis, make sure that you give yourself the opportunity to observe any color changes. The phenolphthalein may mask any such color changes.
5. When you add the phenolphthalein for the electrolysis of KI, add only one drop by each electrode, and put it very close to the electrode. Observe the effect near one electrode before you put the drop by the other.

Lab report:

For Experiment 12, fill in the data sheets on pages 85 and 86. In addition, you'll need to answer the questions on page 84.

For Experiment 22, fill in the data sheet on page 155 and 156, and answer the questions on pages 153 and 154. There are a lot of these so don't wait until the last minute. Note that we are not constructing a citrus cell.

Honor Stuff:

All the material for the two experiments can be done collaboratively by you and your partner or partners.