PROJECT

Basic Electricity Part 1

A new series covering the theory and practice of the basics.

Ron C. Johnson

Are you a newcomer to this fascinating area of electronics? maybe you are an avid hobbyist with a basic knowledge of the subject but you would like to know more about the theory behind the circuits you are building. Perhaps you have worked around the fringes of electronics for some time and would like some of the technical background you are missing.

If so, this series on basic electricity and electronics will serve to fill in the blanks in your knowledge. If you are already familiar with some areas they can be a review to sharpen your skills.

Electronics, like other areas of applied science, is heavily reliant on mathematics in dealing with the relationships involved. In this series we will attempt to minimize the amount of mathematics and give an overview of the subject in a qualitative way. Unfortunately, for those of us who do not get a thrill out of number crunching, we will not be able to avoid it altogether. Hopefully, we can sneak it in a little at a time in a way that supports the concepts without forcing us to become human calculators.

Back to the Basics

Those of you who have had high school physics and chemistry can now drag out your old text books and blow the dust off them. We are going to enter the sub-atomic world to look around at the nature of charged particles.

Don't worry, it won't hurt a bit.

Why do we call copper, nickel, gold, etc., *conductors* while other materials are called *insulators*? What is a *semi*conductor anyway? What makes current flow in a conductor and what really is *current*? Why is the sky blue?

Well, except for that last one, we'll try to answer these and a few other questions here.

If you are somewhat familiar with the structure of the atom you know that it is made up of a nucleus with some electrons orbiting around it (Figure 1). The nucleus of an atom is made up of protons and neutrons basically, of which the neutrons have no charge and the protons are positively charged. The electrons, on the other hand, are negatively charged and spin around the nucleus in "shells", or energy levels. They are held in place by a balance of their attraction to the nucleus and their centrifugal force.

All the elements have different atomic structures with varying numbers of protons and electrons. It so happens, though, that some materials have an incomplete set of electrons in their outermost shell. This makes the remaining ones easier to remove by adding a little extra energy to that material (heat or some other force). Add that energy and "presto" we have free electrons floating around in the material. A material which has lots of free electrons is called a *conductor* because it can easily carry the flow of electrons through it.

An *insulator*, on the other hand, is a material in which the atomic structure is very stable. Because the outermost shells in these materials are filled with the correct number of electrons it would take considerable force to remove any electrons from their orbits. Therefore current will not easily flow in these materials.

Semiconductors are initially similar to insulators in that they have their outermost shells filled. However, by careful addition of impurities to these materials we can control the presence of some free electrons, and using a voltage or current, control how well they conduct. More about this in a later segment.

Now we have materials which will carry free electrons through them and we have materials which will not. What can we do with them?

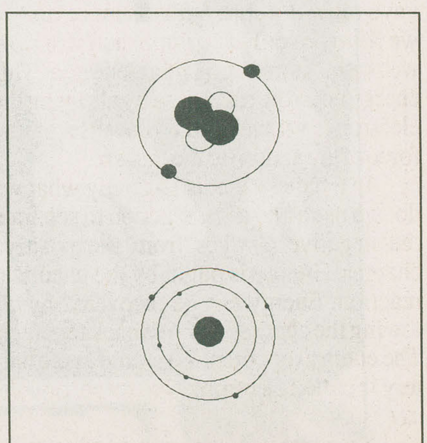

Fig. 1. Typical atomic structure with electrons orbiting the nucleus.

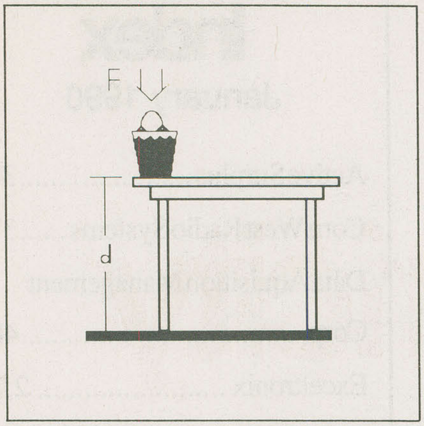

Fig. 2. Potential energy is stored by lifting the pail from floor to table.

Let's look further into the matter.

Work and Energy

In asking what can we do with them, what we are really asking is: How can we do some work with these materials?

If you remember your high school physics you will recall that work is accomplished if you move a force through a distance. You can build up potential energy (stored work) if you put energy into a system. For example, if you lift a pail of water from the floor and place it on a table you have operated a force (against gravity) through a distance (from floor to table) (Figure 2). Once there, it has stored potential energy which can be recovered by lowering the pail back to the floor. What has that got to do with electricity?

Well, think about the charges in the atoms we talked about earlier. We know that the negative electrons are attracted to the positive protons. That attraction is a *force*. If we move the electron farther away from the proton it will require a force against the attraction to do so. We will have moved it through a distance and so we have not only accomplished work but we have stored potential energy. This energy could be recovered by allowing the electron to travel back (because of the force of attraction) to the proton.

In a battery that is basically what we do: we use a chemical reaction to separate the negative charges from the positive charges. Energy is put in by the chemical reaction. Energy can be recovered by allowing the charges to move back together. The energy (or potential) stored in the battery is called electromotive force, or *voltage*.

Now we connect our conductor, a copper wire, between the two connections on a battery (Figure 3). The chemical reaction in the battery has produced a potential which causes electrons to flow through the wire to the other post of the battery. (The post which has the abundance of negative charges is called the negative post, while the post which has the abundance of positive charges is the positive post.) We notice that the copper wire becomes very hot and even starts to glow. Why should this be happening?

The fact is that even copper, an excellent conductor, is not a perfect conductor. As the electrons are pushed along the wire by the electromotive force they have a tendency to bump into atoms and other free electrons. As they do so, some of the energy used to move them through the wire is converted into heat energy and light energy. The extent to which a conductor opposes the flow of electrons is called *resistance* and is determined by the kind of material, its length, and cross-sectional area. The rate of the flow of electrons (charge per second) is called the *current*.

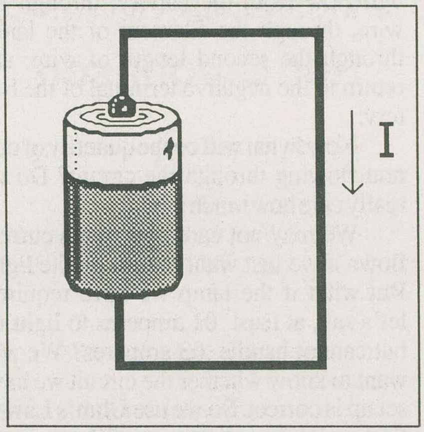

Fig. 3. A typical D cell with current flowing through the conductor connecting the terminals.

Now the confusion. Even though we know that it is the electrons which flow through the wire (because they are the mobile charge and a much lower mass than protons), in electronics it is conventional to think of current as flowing from the positive terminal of a battery or other power source, to the negative terminal. This is called *conventional current flow* and is more rooted in history than in physics.

So now we have electromotive force, or voltage, current, and resistance. How do these actually relate?

Ohm Sweet Ohm

Here is where we will sneak in a little math. The relationship between voltage, current and resistance is called *Ohm's Law*, and is expressed as follows:

$$E = I \times R$$

where E is electromotive force or voltage in volts, I is current in amperes, and R is resistance in ohms.

(Note that when we talk about electromotive force or voltage supplied by a battery or power source the symbol is E, whereas when we talk about a voltage drop across a resistance we symbolize voltage with V.)

Ohm's Law is the basic mathematical building block of electricity and as such is something we need to remember to understand what is going in electrical and electronic circuits. Let's use an analogy to help understand the relationships here.

Remember we talked about lifting the pail of water to the top of a table and in so doing storing energy there (Figure 4). The potential energy in that pail of water is like voltage. There is a force, created by gravity, which is exerted on the water. At this point the water cannot go anywhere. Now let's put a valve into the side of the pail near the bottom and another pail on the floor below it (no need to be sloppy here). When we open the valve part way the water runs out of the top pail into the bottom pail at a rate determined by how much we have opened the valve. The restriction of the valve is analogous to resistance. The rate of the flow of the water is similar to current (which is the rate of flow of charged particles or electrons). We will see in future issues how the pail at the bottom can be compared to a capacitor storing charge.

The difference between the water analogy and electricity is that in electric circuits we have just that — *circuits*, or

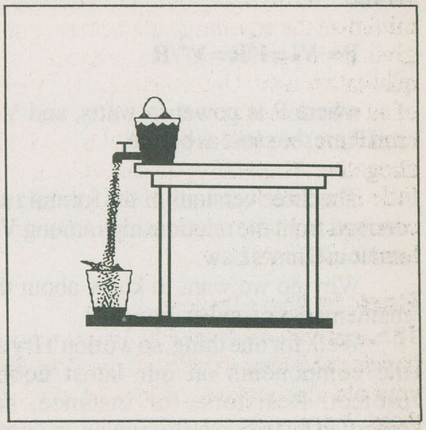

Fig. 4. Water pressure (due to potential energy forces water to flow. The valve restricts the rate of flow.

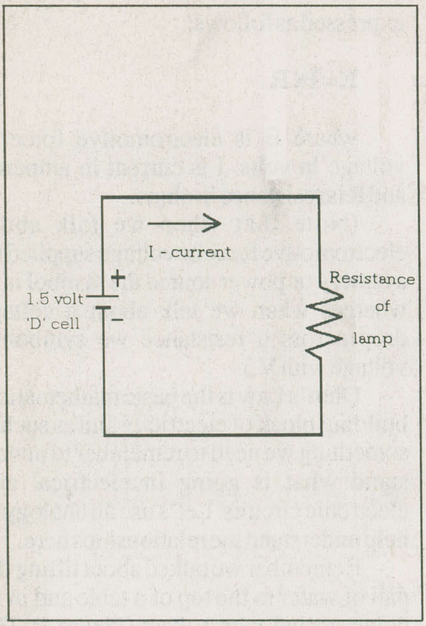

Fig.5. A simple electrical circuit.

circles. Current always flows in complete loops from the positive terminal of the power source, through a resistance or energy converter of some kind, back to the negative terminal of the source. (Remember we are talking about conventional current flow.)

Power

The other mathematical relationship we should look at in this issue is *power*. We said that in connecting our copper wire from the positive post to the negative post of the battery that current flowed and the wire became hot and glowed. In doing so we have converted electrical energy into thermal energy and radiant energy dissipating power in the process. We can determine the power dissipated by the formula:

$$P = VI = I^2R = V^2/R$$

where P is power in watts, and V, I and R are the same as before.

The three versions of the formula are derived from the relationships among V, I and R in Ohm's Law.

Why do we want to know about the mathematics of power, you say?

Well, for one thing, so we don't fry all the components on our latest hobby project. Resistors, for instance, are specified by their resistive value, in ohms, but also have a maximum power they can dissipate before they go up in smoke. We have to be able to tell if we are subjecting them to too much voltage and current unless we plan on making toast out of our projects.

The Real Thing

Finally, let's put this all together in an actual electric circuit and see how it works. In fact, if you want you can set this up and check it out yourself.

In Figure 5 we have a simple electric circuit consisting of a battery (the power source), and incandescent lamp (the resistance, or energy converter), and wire connecting them (the current path). The battery we are using is a standard D cell (used in flashlights, etc.) which has electromotive force of 1.5 volts. The incandescent lamp has an internal filament resistance of 100 ohms.

As the circuit is constructed current will flow from the battery, through the wire, through the filament of the lamp, through the second length of wire, and return to the negative terminal of the battery.

Now, what will be the quantity of current flowing through the circuit? Do we really care how much it is?

We may not care how much current flows if we just want to turn on the light. But what if the lamp we have requires, let's say, at least .01 amperes to light up but cannot handle .03 amperes? We will want to know whether the circuit we have set up is correct. So we use Ohm's Law to find out how much current will be present:

$$V = I \times R$$

so $I = V/R = 1.5$ volts/ 100 ohms = .015 amperes

This is within the range specified so the circuit will work properly.

We can also determine how much power the circuit is dissipating by using the power formula:

$$P = V \times I$$

= 1.5 volts x .015 amperes = .0225 watts

These are the basic, but vital, aspects of electric circuits. Everything else builds from here. And it gets more practical and interesting.

Next month we will take a look at series and parallel circuits, switches and fuses, power sources, and lots of other interesting things.

Hope you'll get a charge out of it. ■