lines of flux, by making the magnet stronger or by moving the conductor through the lines faster.

2. Chemical

In the chemical make-up of materials, there can exist an imbalance of electrons and protons. If a material having an excess of electrons is connected by a conductor to a material having a deficiency, electrons will be forced through the conductor.

For example, if a piece of aluminum and a piece of copper are immersed in a solution of hydrochloric acid and water, and the two pieces of metal are connected by a piece of wire, electrons will leave the aluminum and flow to the copper. The electrons which leave the aluminum are replaced by the negative chlorine ions from the acid. When the chlorine combines with the aluminum, it eats away part of the metal and forms a gray powdery material on the surface. Positive hydrogen ions will be attracted to the copper where they are neutralized by the electrons that came from the aluminum, and bubble to the surface as free hydrogen gas.

3. Thermal (Heat)

When certain combinations of wire, such as iron and constantan or chromel and alumel, are joined into a loop with two junctions, a thermocouple is formed. An electrical current will flow through the wires when there is a *difference* in the temperature of the two junctions. A cylinder head temperature measuring system has one junction held tight against the engine cylinder head by a spark plug (the hot junction), while the other junction is in the relatively constant temperature of the instrument panel (the cold junction).

4. Pressure

Crystalline material such as quartz has the characteristic that when it is bent or deformed by a mechanical force, an excess of electrons will accumulate on one surface, leaving the opposite surface with a deficiency. This is known as the piezoelectric effect and is made use of in crystal microphones and phonograph pickups. And the fact that this interchange between mechanical and electrical energy is reversible makes crystals useful for producing alternating current for radio transmitters. A piece of crystal has only one natural frequency at which it will vibrate, and if it is

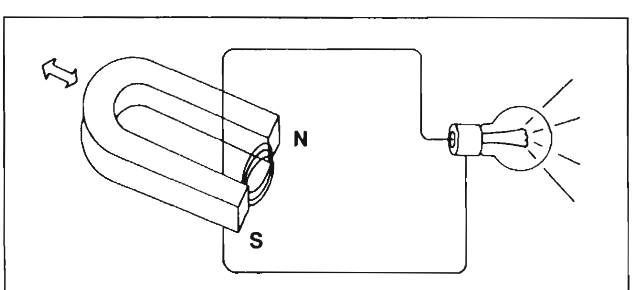

***Figure 1-29.** The amount of electricity generated by electromagnetic induction is determined by the rate at which the conductor cuts through lines of magnetic flux.*

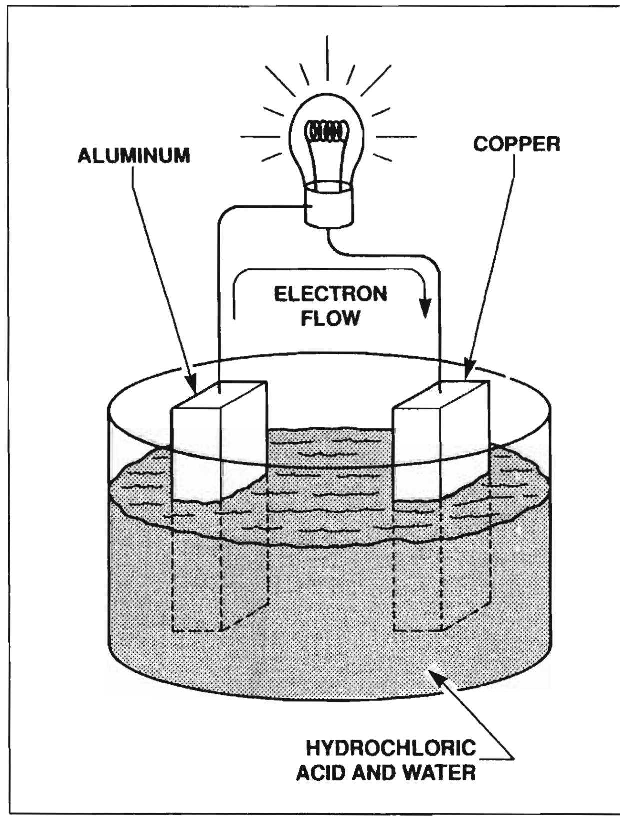

***Figure 1-30.** Electrons will flow between two dissimilar metals when they are connected by a conductor and are both immersed in an electrolyte.*

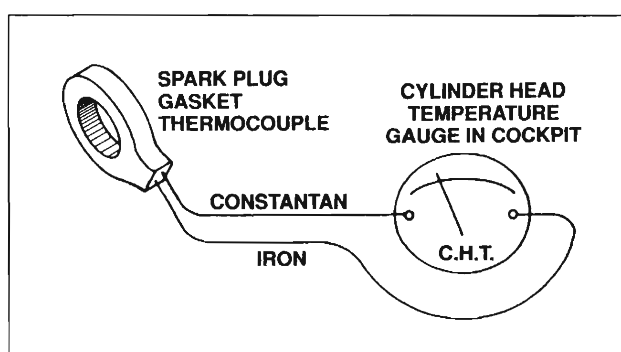

***Figure 1-31.** Electrons will flow in a thermocouple made of certain dissimilar metals when there is a temperature difference between the two junctions.*

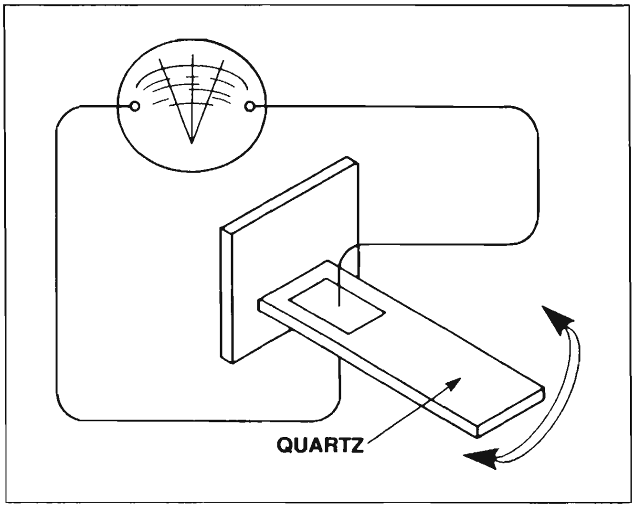

Figure 1-32. An electrical potential difference will be built up across the faces of certain crystalline materials when they are bent or otherwise subjected to mechanical pressure.

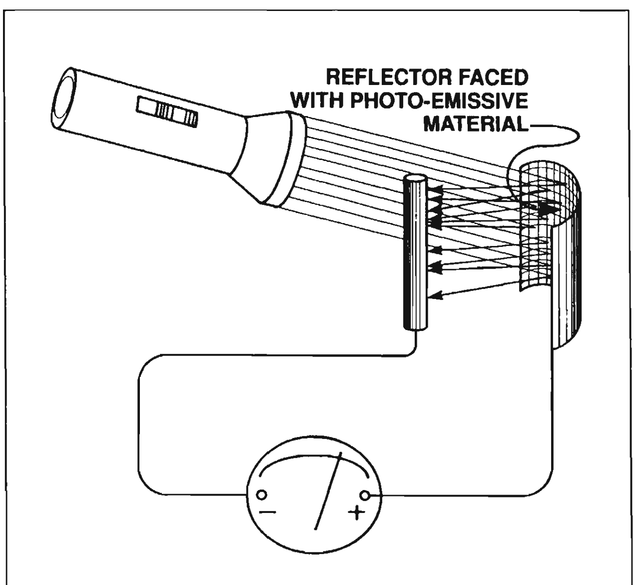

Figure 1-33. A photoemissive material will emit electrons when it is struck by light.

excited by pulses of electrical energy, it will vibrate at this frequency. As it vibrates, it produces between its faces an alternating voltage having an accurate frequency.

5. Light

Light is a form of energy. When it strikes certain photoemissive materials such as selenium, it imparts enough energy to the atoms that electrons are discharged from their bonds and are free to flow in a circuit and do work.

Switches may be controlled by light-sensitive devices to turn airport lights on at dusk and off at dawn, and sensitive light measuring meters are used in photography to determine the amount of light available, so that the proper exposure can be made.

6. Friction

Although not a practical method of producing electricity for power, friction between two materials can produce static electricity. Static electricity and electrostatic fields were discussed in an earlier section of this manual. The technician needs to be aware of the ease with which static electricity can be produced, and with methods for its control or elimination, as many electrostatic-discharge-sensitive (ESDS) devices are used in electronics equipment aboard many modern aircraft.

G. Current Electricity and Ohm's Law

1. Ohm's Law

In our study this far, we have seen that a concentration of electrons will produce an electrical pressure that will force electrons to flow through a circuit. And by assigning values to the pressure, flow, and opposition, we can understand the relationship that exists between them, and can accurately predict what will happen in a circuit under any given set of conditions.

It was the German scientist George Simon Ohm who proved the relationship between these values, and in 1826 he published his findings. Ohm's law is the basic statement which says in effect that the current that flows in a circuit is directly proportional to the voltage (pressure) that causes it, and inversely proportional to the resistance (opposition) in the circuit. The units we use make this relationship easy to see: one volt of pressure will cause one ampere of current to flow in a circuit whose resistance is one ohm.

For ease of handling these terms in formulas, voltage is represented by the letter E, current by the letter I, and resistance by the letter R. A statement of Ohm's law in the form of a formula is, therefore, $E = I \times R$. If we want to find the current, we use the formula $I = E/R$, and resistance may be found by the formula $R = E/I$.

Power in an electrical circuit is measured in watts, and one watt is the amount of power used in a circuit when one amp of current flows under a pressure of one volt.

The relationship between voltage, current, resistance, and power is such that any one value may be found when any two of the others are known. One easy way to find the correct formula is to use a series of divided circles representing the symbols in the formula. In figure 1-34, we see that the voltage in the circuit is equal to the product of the current and the resistance ($E = I \times R$). The top half of the circle is equal to the bottom half. We also know that the current may be found by dividing the voltage by the resistance ($I = E/R$), and the resistance is equal to the voltage divided by the current ($R = E/I$).

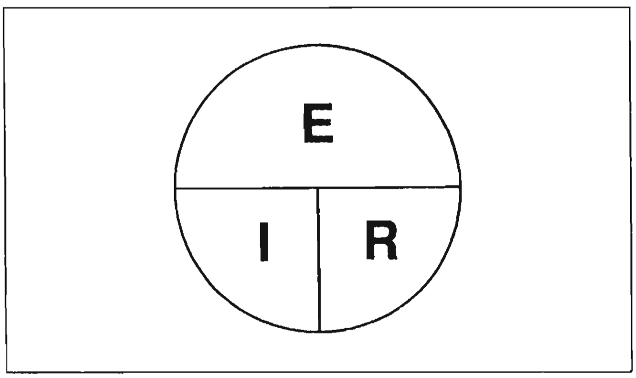

Figure 1-34. The relationship between voltage, current, and resistance.

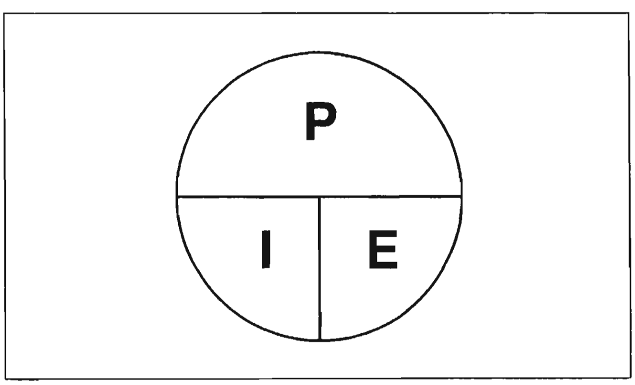

Figure 1-35. The relationship between power, current, and voltage.

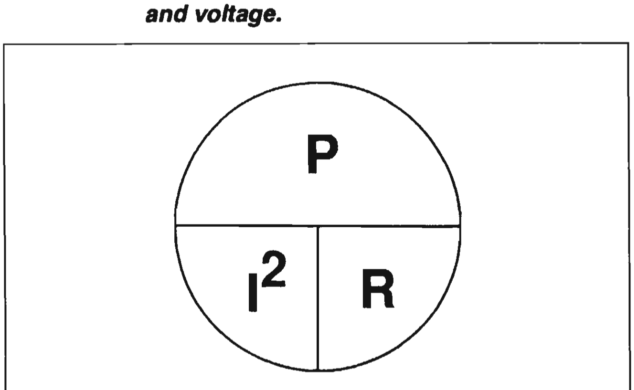

Figure 1-36. The relationship between power, current, and resistance.

The same relationship may be found between power, current, and voltage. We know that power is equal to voltage times current ($P = I \times E$). Figure 1-35 shows us an easy way to find current by dividing power by voltage ($I = P/E$), and to find the voltage by dividing power by the current ($E = P/I$).

The other six relationships are just as easy to find when we use the circles of figures 1-36 and 1-37. In figure 1-36, we find that $P = I^2 \times R$, and $R = P/I^2$. Now we have one very small problem, $I^2 = P/R$, but we want I, not I^2, so we must take the square root of both sides of the equation. When we do this, we end up with $I = \sqrt{P/R}$.

Figure 1-37 works in the same way with $E^2 = P \times R$. To find E, we must take the square root of both sides. When we do, we get $E = \sqrt{PR}$. The other relationships give us $P = E^2/R$ and $R = E^2/P$.

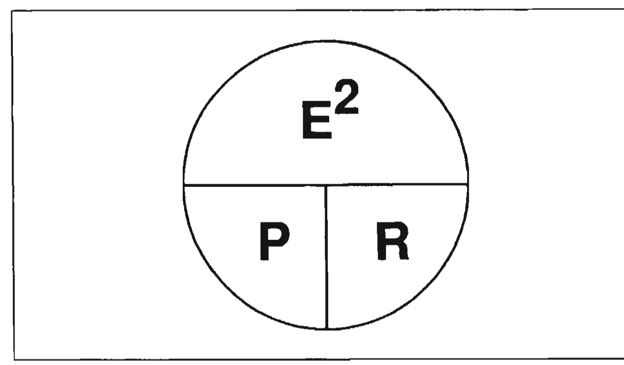

Figure 1-37. The relationship between voltage, power, and resistance.

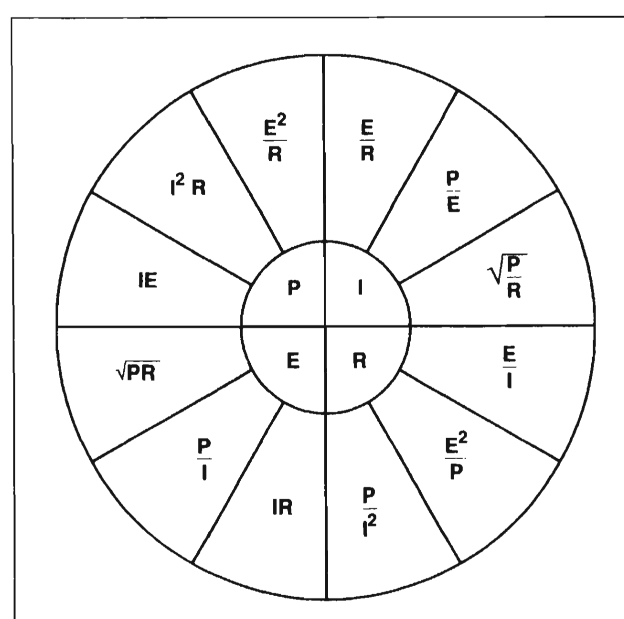

Figure 1-38. Summary of basic equations using the volt, ampere, ohm, and watt.

2. Mechanical Power in Electrical Circuits

Power, as we remember from basic physics, is the time-rate of doing work, and the practical unit of measurement is the horsepower which is the amount of power required to do 33,000 foot-pounds of work in one minute, or its equivalent of 550 foot-pounds of work in one second. A constant allows us to relate electrical power to mechanical power. The electrical equivalent of one horsepower is 746 watts.

If we have a 24-volt electric hoist, we can find the amount of current needed to raise a 1,000-lb. load 6′ in 30 seconds.

$$1{,}000 \times 6 = 6{,}000 \text{ foot-pounds}$$

$$\frac{6{,}000}{30} = 200 \text{ foot-pounds per second}$$

$$\frac{200}{550} = 0.364 \text{ HP}$$

$$746 \times 0.364 = 271.5 \text{ watts}$$

$$I = \frac{P}{E} = \frac{271.5}{24} = 11.31 \text{ amps}$$

3. Heat in Electrical Circuits

In circuits where mechanical work is not actually being done, power is still a very important consideration. For example, if you install a resistor in a light circuit to drop the voltage from 12 volts down to three, for a light bulb that requires 150 milliamps, you must find the resistance in ohms and the power in watts, this resistor must dissipate.

To solve this problem, we must first find the voltage to be dropped:

$$E = 12 - 3 = 9 \text{ volts}$$

Find the resistance required:

$$R = E/I = 9/0.15 = 60 \text{ ohms}$$

Find the power dissipated in the resistor:

$$P = I^2 \times R = 0.15^2 \times 60 = 1.35 \text{ watts}$$

The resistor will only have to 1.35 watts, but for practical purposes, you will most probably use a two-watt resistor.

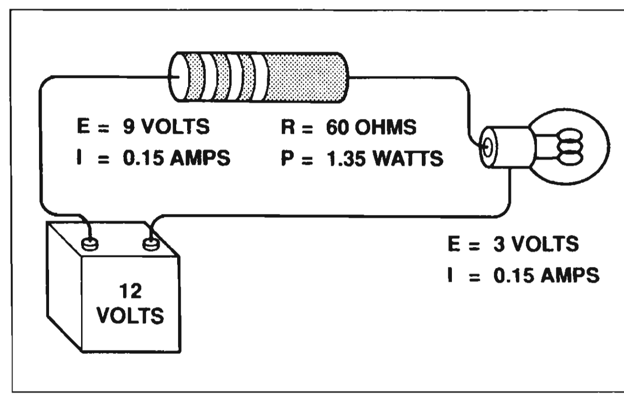

Figure 1-39. Determining the characteristics of a resistor needed to drop voltage in a circuit.

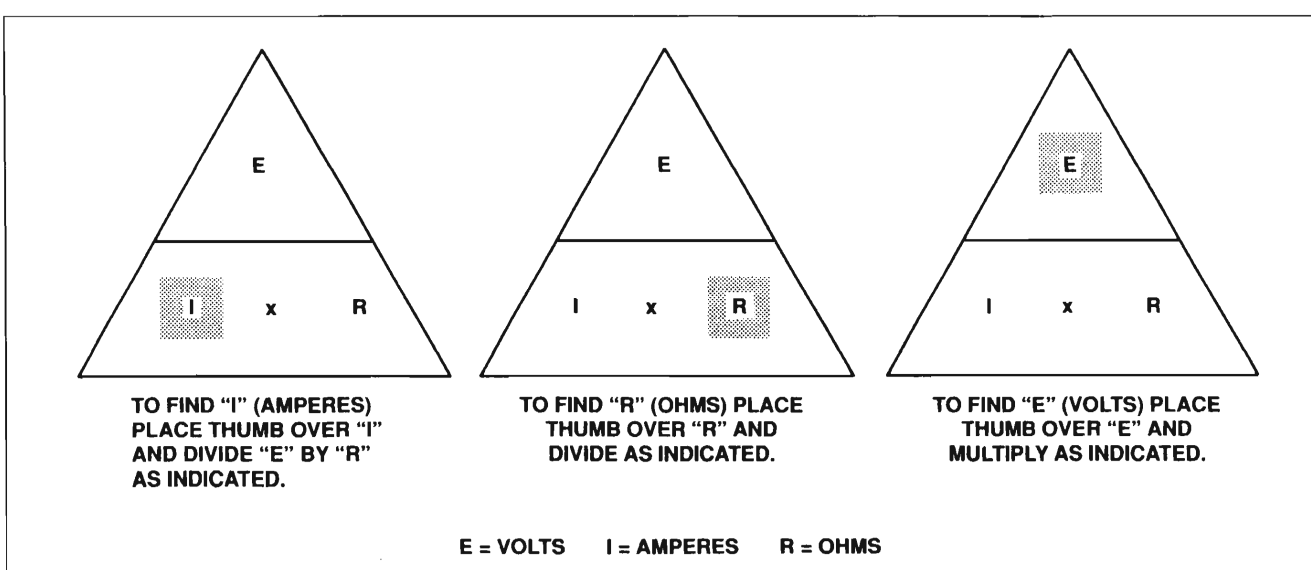

Figure 1-40. Ohm's law relationships.

H. Circuit Elements

All complete electrical circuits consist of at least a minimum of a source of electrical energy, a load device to use the electrical energy produced by the source, and conductors to connect the source to the load or loads in the circuit. These circuit elements do not comprise a practical electrical circuit, however. In order to make a circuit practical, a control device, such as a switch, must be placed in the circuit to allow the loads to be easily and safely energized and de-energized. Some type of protection must be provided for the circuit wiring, in the form of fuses or circuit breakers, to stop current in the event of an overload or other circuit malfunction.

The source may be a battery, a generator, or other apparatus that converts some form of energy into electricity, and these are discussed in the appropriate section of the text. The load may be anything that converts electrical energy into mechanical or chemical energy, or into heat or light. These devices will be discussed in the appropriate section. Here, we are primarily concerned with the conductors used to join the source and the load, and components used to control the flow of current and protect the circuit from damage due to shorts.

1. Conductors

The purpose of a conductor is to provide a path for the electrons to flow from the source, through the load, back to the source. It must do this with the minimum of resistance, but other factors must also be taken into consideration, so the choice of a conductor is often a compromise.

Most aircraft electrical systems are of the single-wire type, meaning that the aircraft structure itself provides the path through which the current returns from the load to the source. A great deal of weight is saved by using this type of system, but it is extremely important that a good connection capable of carrying all of the current is provided between the aircraft structure and the battery, generator, and all of the devices using the current.

The resistance of a conductor is affected by two things: its physical characteristics and its dimensions.

a. Physical Characteristics

1) Resistivity

For most practical aircraft circuits, we use two types of conductors, copper and aluminum. Copper wire has only about two-thirds of the resistance of the equivalent gage of aluminum wire, and is the one most generally used. But for applications requiring a great deal of current, aluminum wire is often used. Its resistivity is higher than that of copper, and a larger conductor is needed, but since aluminum weighs so much less than copper, a great deal of weight may be saved by its use.

2) Temperature

Most metals have what is known as a positive temperature coefficient of resistance. This means that the resistance of the material will increase as its temperature increases. This characteristic is used in some temperature measuring instruments where the resistance change in a piece of wire is used to measure temperature. For practical purposes, however, both copper and aluminum have such a small change in resistance with temperature over the temperature range encountered in flight that it is normally not considered to be a problem.

b. Dimensions

1) Length

For most common conductors, the resistance will vary directly with length. That is, as length increases for a given specific conductor, its resistance will increase.

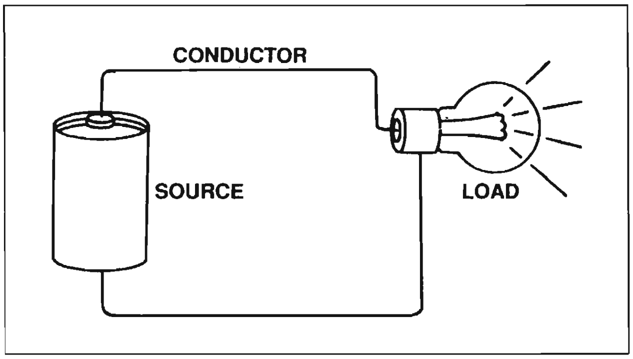

Figure 1-41. All complete circuits must have a source of electrical energy, a load to use the energy, and conductors to join the source and the load.

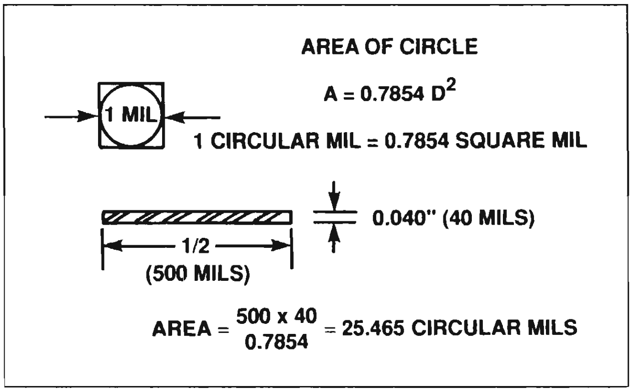

Figure 1-42. Relationship between circular mils and square mils.