training chart manual

SECTION a

FUNDAMENTALS OF ELECTRICITY AND MAGNETISM

Delco Remy

Delco Remy

SECTION a

table of contents

3

introduction

This manual covers the Fundamentals of Electricity and Magnetism, and is basic to all of the other manuals in the Delco-Remy series of training publications. Because it is basic, it is probably the most important manual in the entire training series.

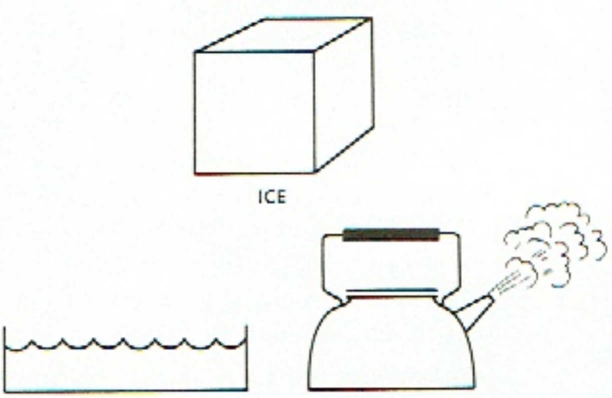
The subject of Fundamentals is the foundation upon which the study of electrical equipment is based. Whether the unit is a generator, an ignition coil, or a transistor regulator, the same basic principles contained in this manual apply equally well to all types of electrical equipment.

The student or service technician who wants to progress in his chosen field soon recognizes the paramount importance of a good knowledge of electrical fundamentals. This manual covers these fundamental principles of electricity and magnetism, and has been prepared for the student and technician who want a solid foundation upon which to build their knowledge of automotive-type electrical equipment.

composition of matter

The practical use of electricity has been known to man for over one hundred years. Electricity consists of the movement of **electrons** in a conductor. In order to understand what an electron is and how it behaves, let's look briefly at the composition of **matter.**

Matter is anything which has mass and occupies space, and therefore is literally everything in the universe except the complete voids that exist between the sun, stars, and planets. Matter may be in the form of a solid, a liquid, or a gas (vapor). Thus, ice, water, and steam are examples of matter in all three forms.

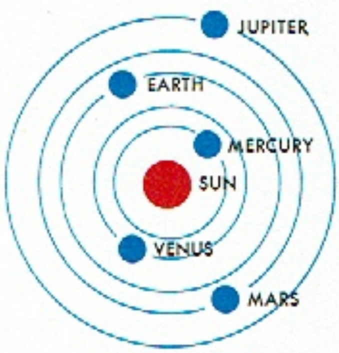


All matter is composed of chemical building blocks called **elements.** Nature has provided 92 elements which combine in countless different combinations to form the different kinds of matter found on Earth.

Two of the more common and plentiful elements are hydrogen and oxygen. When these two gases are chemically combined, the result is water. Two other common elements in large supply are sodium and chlorine, which can combine chemically to form salt. An element which is valuable because of its limited supply is gold. Although chemical combinations of elements comprise most forms of matter, it should be recognized that matter also includes the elements themselves.

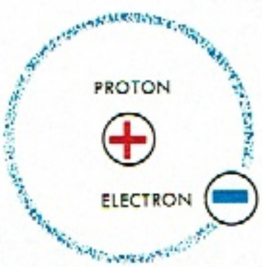
Now that we have seen that all matter is composed of elements, let's look at some of the better-known elements, break them down into their component parts, and see how the electron fits into the picture.

The smallest particle into which an element can be divided and still retain its characteristic as an element is the **atom.** An atom is so small that it cannot be seen even with the most powerful microscopes. There are 92 different known atoms in Nature, one for each of the 92 natural elements.

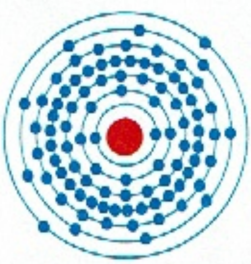


SOLAR SYSTEM

An atom is constructed much like our solar system, in which the sun is the center or core and the planets revolve in orbits about the sun. In the atom, the center or core is composed of particles called **protons,** and the "planets" which revolve around the core are called **electrons.** In our study of electricity, we shall see that protons and electrons are of paramount importance.



HYDROGEN ATOM



URANIUM ATOM

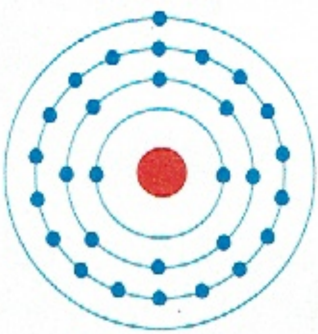
The simplest element known is hydrogen. Its atom can be represented by a single electron in orbit about the core containing one proton. The most complex element is uranium. It has 92 protons in its core and 92 electrons in orbit about the core. Between these two are the remaining elements, each having an atomic

5

structure that differs from its two neighbors by one proton and one electron.

Each element can be listed according to its **atomic number.** The atomic number is simply the number of protons in the core of an element. Thus, the atomic number of hydrogen is one and of uranium is 92. The atomic number of copper is 29 and its two neighbors are nickel and zinc, which have atomic numbers of 28 and 30, respectively.

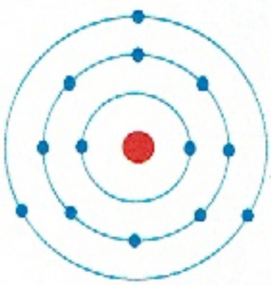
The element copper is widely used in electrical equipment because it is a very good conductor of electricity. The copper atom contains 29 protons and 29 electrons. The 29 protons are concentrated in the core, and the 29 electrons are distributed in four separate shells or rings, with each shell or ring being a different distance from the core. Each electron follows its own individual path as it orbits about the core, but the two electrons in the first ring remain at the same distance from the core, the eight electrons in the second more distant ring occupy the same distance from the core, and the 18 electrons in the third ring or shell remain at the same distance from the core. The fourth ring is the farthest from the core, and it contains only one electron.



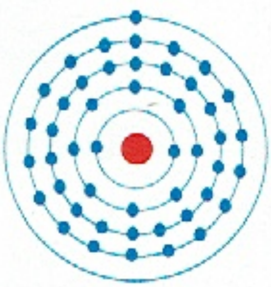
COPPER ATOM

Elements containing less than four electrons in the outer ring are generally classified as good conductors of electricity, with the degree of conductivity varying between elements, and elements containing more than four electrons are not good conductors and are called insulators. The reasons for this type of electrical characteristic will be explained in a following section. Elements containing four electrons in their outer ring are generally classified as semi-conductors, and this subject is covered in Delco-Remy Training Chart Manual DR-5133J.

Two elements other than copper commonly used as conductors are aluminum and silver. Note that both have less than four electrons in their outer rings, aluminum having three and silver one. Also note that the electrons occupy three rings in aluminum and five rings in silver. Although silver is the best conductor of all the 92 elements, copper is more widely used because of its plentiful supply, and because of economic factors relating to cost.



ALUMINUM ATOM



SILVER ATOM

Our study of the composition of matter relating to the structure of the atom can be summarized in the following statements:

A. The atom consists of electrons in orbit about a core containing protons.

B. Each atom contains an equal number of protons and electrons.

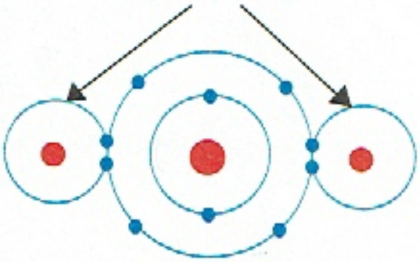
C. The electrons occupy shells or rings which are at different distances from the core.

D. The number of electrons in the outer ring determines to a great extent the electrical characteristics of an element.

E. There are 92 different kinds of atoms, one for each of the 92 natural elements.

F. It is the difference in atomic structure that causes the 92 elements to be different.

Of additional interest is the method by which different elements combine chemically to form **compounds.** The smallest particle to which a compound can be divided and still retain its characteristics is called a **molecule.** A molecule of water, for example, is composed of a chemical combination of two atoms of hydrogen and one atom of oxygen. The chemical symbol for water is H_2O.



MOLECULE OF WATER

The **valence** of an element is defined as the capacity of an atom of the element to combine with other atoms to form a molecule. Note that in chemical combinations the outer-ring electron, or electrons, of one atom occupies the same ring as the outer-ring electron or electrons of the other atom. It is the tendency of every atom to **complete** its outer ring by effectively having the maximum allowable number of electrons in its outer ring. Consider the molecule of water as an example.

Before combining into water, the hydrogen atom has one electron and the oxygen atom six electrons in their outer rings. In order for the outer rings to be **complete,** the hydrogen atom requires two electrons, and the oxygen atom eight electrons. The hydrogen atom, therefore, has a valence of one, and the oxygen atom a valence of two. When chemically combined to form a molecule of water, each of the hydrogen atoms effectively has two electrons, and the oxygen atom effectively has eight electrons in their outer rings. The outer rings are therefore complete, and it is this tendency of atoms to complete their outer rings that causes the various elements to form chemical compounds.

Although chemical combinations are of interest in a study of the composition of matter, our primary concern in electricity is limited to the protons and electrons that comprise an atom. In the next section, we will answer the question "What Is Electricity?" and will see that the proton and electron play a predominant part in this story.

what is electricity?

In the previous section, we learned that an atom contains particles called protons and electrons. The proton is said to have a **positive charge,** and the electron a **negative charge.** The word charge implies a **potential force,** and in an atom the protons exert an attractive force on the electrons to hold them in their orbits. Since the positive charge of a proton is equal in magnitude to the negative charge of an electron, the atom is electrically neutral. This neutrality can be altered, however, if some means can be found to cause a quantity of electrons to leave their atoms and congregate in a certain area, leaving behind atoms which are deficient in their normal number of electrons.

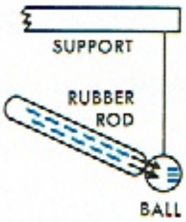
A collection of electrons represents a negative charge. Atoms that are deficient in electrons have more protons than electrons and therefore have a positive charge. Negative charges are indicated by the dash line (−) symbol, and positive charges by the plus (+) sign. A simple experiment can be performed to show that a force does exist between negative and positive charges.

To perform the experiment, a rubber rod and a piece of wool, a glass rod and a piece of silk, and a pith ball suspended from a support with a cotton thread are needed.

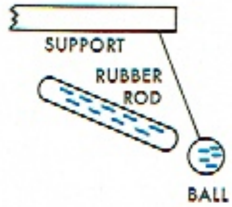
When the rubber rod is rubbed with wool, electrons will be physically removed from the wool and will collect upon the rubber rod. The wool will be positively charged, because its atoms have a deficiency of electrons. The rubber rod will have a negative charge, because it has an excess or surplus of electrons.

When the rubber rod is touched to the ball and then removed, some of the excess electrons will move from the rod to the ball. The ball will become negatively charged, and the rod will retain a portion of its negative charge. Now when the rod is moved towards the ball again, the ball will swing away from the rod, illustrating the fact that a force of repulsion exists between the negatively charged ball and negatively charged rod. From this experiment, we may conclude that **like charges repel.** In this case the charges are negative;

however, the same result occurs when the charges are positive as will now be seen.

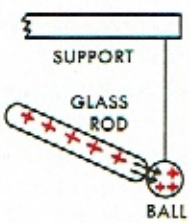


ROD CHARGES BALL

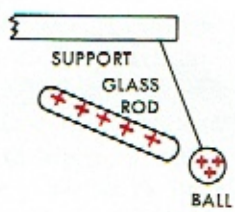


LIKE CHARGES REPEL

If a glass rod is rubbed with silk, electrons leave the rod and accumulate on the silk. The rod is positively charged, since some of its atoms have a deficiency of electrons. When the rod is touched to the ball and then quickly removed, electrons will leave the ball and collect on the rod. The rod will remain positively charged (although to a lesser degree), and the ball will become positively charged. As the rod is moved toward the ball again, the ball will swing away from the rod, again illustrating the fact that **like charges repel.**

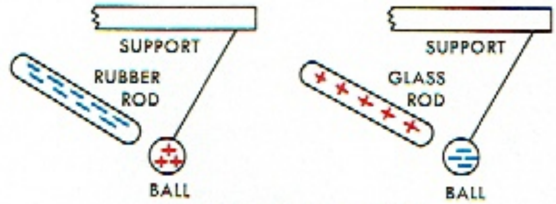


ROD CHARGES BALL



LIKE CHARGES REPEL

A negatively charged rod moved toward a positively charged ball, and a positively charged rod moved toward a negatively charged ball, will cause the ball to move toward the rod. This leads us to conclude that there is a force of attraction between unlike charges. We can, therefore, say that **unlike charges attract.**



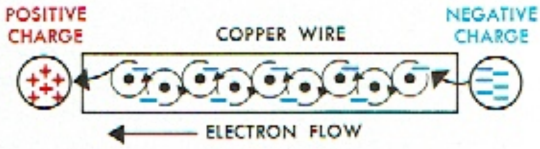
UNLIKE CHARGES ATTRACT

This experiment involves **static electricity**, since the positive and negative charges after accumulating on the rod and ball are stationary. Three very important observations can be made from this experiment.

1. Electrons can be made to leave their atoms in some materials.
2. Some kind of force, such as friction, is needed to cause an electron to leave its atom.
3. Like charges repel and unlike charges attract.

Now, let's look at what happens in a copper wire when a negative charge and a positive charge are located at the ends of the wire. How these charges are obtained will be explained later on; for the moment assume that these charges do exist and that the magnitude of the charges remains unchanged.

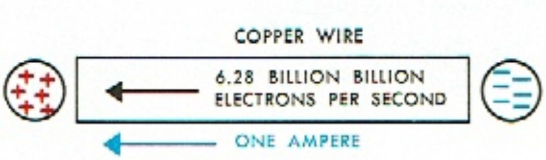
The copper wire, of course, contains countless billions of electrons and atoms, but we will illustrate only a few of these atoms, and will show only the single electron in the outer ring. An electron in an atom near the positive end of the wire will be attracted toward the positive charge, and it will leave its atom. This atom, then, becomes positively charged, because it is deficient one electron, and it will exert an attractive force on the outer-ring electron in a neighbor atom. The neighbor atom will give up its electron to the first atom, and at the same time collect an electron from another neighbor atom. The net result is a movement of electrons through the wire, with the negative charge at the other end of the wire providing a repelling force equal to the



attractive force provided by the positive charge. Although the movement of electrons is not in one direction only, but rather is a haphazard drifting of electrons from one atom to another, the net effect is a drift of electrons from the negatively charged end to the positively charged end of the wire. It is important to observe that the movement or flow of electrons will continue for as long as the positive and negative charges are maintained at the ends of the wire. This continuous flow of electrons in a conducting material, such as a copper wire, is called dynamic electricity, and leads us to this general definition: ELECTRICITY IS THE FLOW OF ELECTRONS FROM ATOM TO ATOM IN A CONDUCTOR.

current

The flow of electrons through a conductor is called current, and is measured in amperes. The electric current is one ampere when 6.28 billion billion electrons pass a certain point in a conductor in one second. Thus, current is the rate of electron flow and is measured in amperes or electrons per second. An analogy is the flow of water in a pipe measured in gallons per minute.



voltage

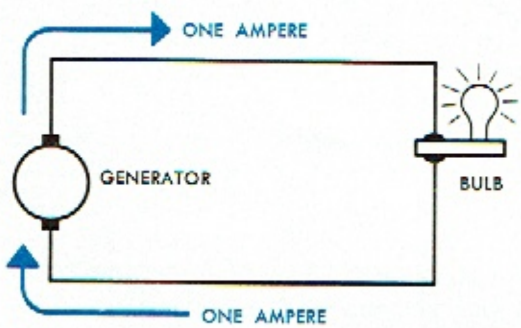
In our previous discussions, we considered a copper wire with a positive charge at one end and a negative charge at the other end, and observed that a current would flow through the wire for as long as the charges are maintained at the wire ends. The charges at the wire ends are said to possess potential energy, because they have the ability to perform work by causing electrons to move through the wire due to their forces of attraction and repulsion. The potential energy at these two points (the wire ends) is often referred to simply as potential, and the difference in potentials is called the potential difference. The potential difference in turn, is called the voltage or electromotive force (emf), and the unit of measure is the volt.

There are many ways to produce voltage, including friction, chemical energy, and mechanical energy. The rubbing of the glass rod with silk explained in a previous section is an example of voltage produced by friction. The storage battery, composed of lead plates immersed in a solution of sulfuric acid, produces voltage by chemical means. A generator is an example of a way to produce voltage by mechanical means.

The concept of voltage is sometimes difficult to understand, but the following two analogies are often helpful. Voltage is like a stretched rubber band, or a spring that has been compressed — all three represent **potential** energy, or the ability to do work. The storage battery, for example, may have a potential of 12 volts between its terminal posts, and this potential exists even though no current-consuming devices are connected to the posts. Similarly, the voltage of house wiring may be 110 volts, and this voltage is present even though no household appliances are being used. The voltage "stands by" to expend its potential energy whenever current-consuming devices are connected to the voltage. Thus, voltage can exist without current, but current cannot exist without voltage.

Voltage, therefore, is produced between two points when a positive charge exists at one point and a negative charge exists at the other point. The greater the deficiency of electrons at the positive potential and the greater the excess of electrons at the negative potential, the greater will be the voltage.

A generator or a battery can be looked upon as an electron pump. The generator, for example, will supply a continuous flow of electrons (current) through a light bulb that is connected to the generator. The movement of electrons is continuous; that is, if one ampere of current is leaving the generator, one ampere is entering at the other terminal to maintain a constant current flow.



interesting sidelights

Man in his use of voltage and current limits his endeavors to values that can be controlled. Nature, however, often puts on a show in the form of an electrical storm where the voltage and current "get out of control." The voltage between the earth and a storm cloud may be over one million volts before lightning strikes. When lightning does occur, this tremendous potential energy (voltage) is released in a current discharge that may consist of millions of amperes. The destructive effects of the release of this much energy are well known.

Another illustration to point out the tremendous force that can exist between a negative potential and a positive potential is to consider one pound of electrons to be concentrated at the North Pole on the Earth, and a similar deficiency of electrons to be present at the Earth's South Pole. Such a condition would never exist, but if it did, the force of attraction between the two would be approximately 4,000,000,000,000,000 tons, or four quadrillion tons.

resistance

All conductors offer some measure of resistance to the flow of current. The resistance results primarily from two factors. One factor is that each atom resists the removal of an electron due to the attraction exerted on the electron by the protons in the core. The other factor involves the countless collisions that occur between electrons and atoms as the electrons move through the conductor. These collisions create resistance, and cause heat to appear in any conductor through which a current is flowing.

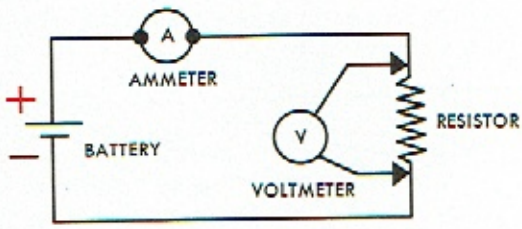
COPPER WIRE

RESISTANCE AND CURRENT
CREATE HEAT

The basic unit of resistance is the ohm, and is defined as the resistance that will allow one ampere to flow when the potential is one volt. This is an expression of Ohm's Law, which is covered in the next section. Resistance is often indicated by the symbol Ω; thus 5 Ω means five ohms.

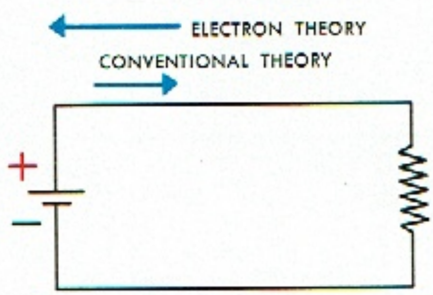
Ohm's law and electrical circuits

A simple electrical circuit consists of a resistor connected to a source of voltage by conductors. The resistor may be a light bulb or any other type of device having resistance. The voltage source may be a battery or generator, and the conductors usually are copper wire.



In an electrical circuit, an ammeter can be used to measure the current, and a voltmeter may be connected across any two points in the circuit to measure the potential difference, or voltage, between the two points. Ammeters and voltmeters will be covered in more detail in a following section.

There are two means of describing current flow in a circuit. The **conventional theory** arbitrarily chose the direction of current flow to be from the positive terminal of the voltage source, through the external circuit, and then back to the negative terminal of the source. The subsequent discovery of the electron in 1897 led to the **electron theory** of current flow, which is from the negative terminal, through the external circuit, and than back to the positive terminal of the source — just the opposite of the conventional theory. Since either theory can be used, and since the conventional theory is widely used in industry, the conventional theory, from positive to negative, will be used in this manual.



Ohm's Law expresses the relationship between the current (I), the voltage (E), and the resistance (R) in a circuit. Ohm's Law can be expressed in three different ways, and can be applied to the entire circuit or to any part of a circuit. When any two factors are known, the third unknown factor can be calculated from Ohm's Law.

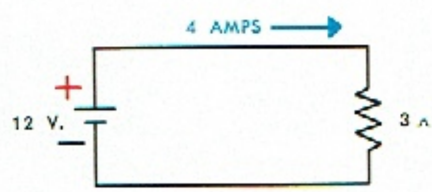
$$I = \frac{E}{R} \qquad \text{AMPERES} = \frac{\text{VOLTS}}{\text{OHMS}}$$

$$E = IR \qquad \text{VOLTS} = \text{AMPERES} \times \text{OHMS}$$

$$R = \frac{E}{I} \qquad \text{OHMS} = \frac{\text{VOLTS}}{\text{AMPERES}}$$

series circuits

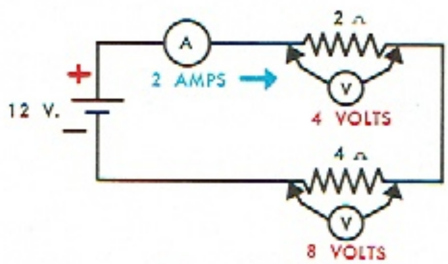
A simple series circuit may consist of a three-ohm (3 Ω) resistor connected to a 12-volt battery. The current can be determined from



Ohm's Law, where $I = \frac{E}{R} = \frac{12}{3} = 4$ amperes, or 4 amps.

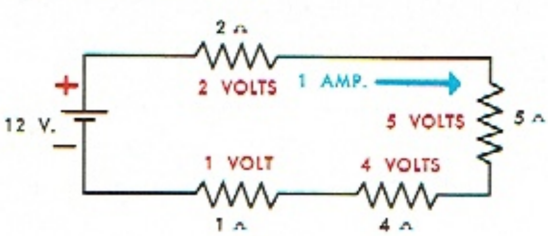
Another series circuit may contain a two-ohm resistor and a four-ohm resistor connected to a 12-volt battery. The word "series" is given to a circuit in which all the current that flows through one resistor also flows through the other resistors. It can be seen that this would hold true for this circuit. In a series circuit, the total circuit resistance is equal to the sum of all the individual resistors. In this circuit, the total circuit resistance is $4 + 2 = 6$ ohms. The current from Ohm's Law is

$$I = \frac{E}{R} = \frac{12}{6} = 2 \text{ amperes.}$$



Ohm's Law applied to the two-ohm resistor can be used to give the voltage across the two-ohm resistor; thus, $E = IR = 2 \times 2 = 4$ volts. For the four-ohm resistor, $E = 2 \times 4 = 8$ volts. These values are called the **voltage drops,** and the sum of all voltage drops in the circuit must equal the source voltage, or $4 + 8 = 12$ volts.

An ammeter connected in this circuit will read two amperes, and a voltmeter connected across each of the resistors will read four volts and eight volts, as illustrated.



Another circuit containing four resistors in series is illustrated. The total circuit resistance is 12 ohms and the current is one ampere, with the voltage drops across each resistor as shown.

The series circuit is characterized by the following three facts:

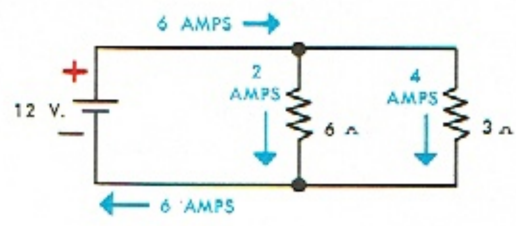
1. The current through each resistor is the same.
2. The voltage drops across each resistor will be different if the resistance values are different.
3. The sum of the voltage drops equals the source voltage.

parallel circuits

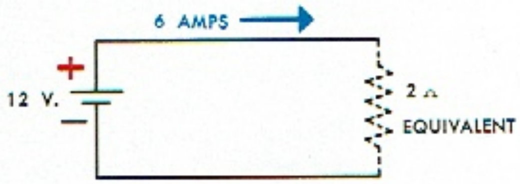
A parallel circuit is characterized by the following three facts:

1. The voltage across each resistor is the same.
2. The current through each resistor will be different if the resistance values are different.
3. The sum of the separate currents equals the total circuit current.

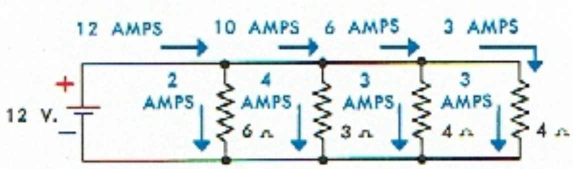
Consider a circuit in which a six-ohm and a three-ohm resistor are connected to a 12-volt battery. The resistors are in parallel with each other, since the battery voltage (12 volts) appears across each resistor. The current through each resistor, often called a branch of the circuit, can be determined from Ohm's Law. For the six-ohm resistor, $I = \frac{E}{R} = \frac{12}{6} = 2$ amperes, or 2 amps. For the three-ohm resistor, $I = \frac{12}{3} = 4$ amps. The total circuit current supplied by the battery is $2 + 4 = 6$ amperes.

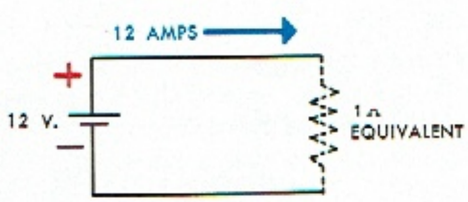


The **equivalent resistance** of the entire circuit has to be two ohms, since $R = \frac{E}{I} = \frac{12}{6} = 2$ ohms. This value for any two resistors in parallel is equal to the product divided by the sum, or in this case $\frac{6 \times 3}{6 + 3} = \frac{18}{9}$ $= 2$ ohms.



A circuit containing four resistors in parallel is illustrated. The branch currents are $I = \frac{E}{R}$ $= \frac{12}{6} = 2$ amps, $\frac{12}{3} = 4$ amps, and $\frac{12}{4} =$ 3 amps, and $\frac{12}{4} = 3$ amps. The total battery current is $2 + 4 + 3 + 3 = 12$ amperes. The equivalent circuit resistance has to be one ohm, since $R = \frac{E}{I} = \frac{12}{12} = 1$ ohm. This resistance value is obtained as follows: the six and three-ohm resistors are equivalent to two ohms ($\frac{6 \times 3}{6 + 3} = 2$ ohms), the two four-ohm resistors are equivalent to two ohms ($\frac{4 \times 4}{4 + 4}$ $= 2$ ohms), the two-ohm equivalent resistor in parallel with another two-ohm equivalent resistor is equivalent to one ohm ($\frac{2 \times 2}{2 + 2}$ $= 1$ ohm).

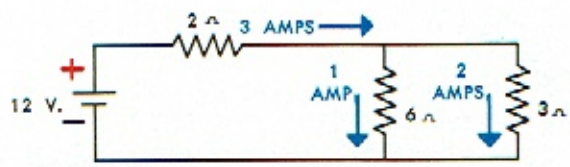


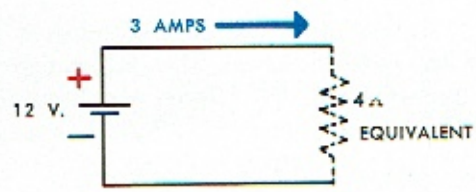


· series-parallel circuits

A series-parallel circuit is illustrated. Note that the six- and three-ohm resistors are in parallel with each other, and together are in series with the two-ohm resistor.

The total current in this circuit is equal to the total voltage divided by the total resistance. The total resistance can be determined as follows: Since as explained above, the six- and three-ohm resistors are equivalent to a two-ohm resistor ($\frac{6 \times 3}{6 + 3} = 2$), this equivalent two-ohm resistor added to the other two-ohm resistor gives an equivalent circuit resistance of four ohms ($2 + 2 = 4$ ohms). An equivalent circuit is shown. The total current, therefore, is $I = \frac{12}{4} = 3$ amperes.





With three amperes flowing through the two-ohm resistor connected nearest to the battery, the voltage drop across this resistor is $E = IR$ $= 3 \times 2 = 6$ volts, leaving six volts across the six- and three-ohm resistors. The current through the six-ohm resistor is $I = \frac{E}{R} = \frac{6}{6}$ $= 1$ ampere, and through the three-ohm resistor is $I = \frac{6}{3} = 2$ amperes. The sum of these two current values must equal the total circuit current or $1 + 2 = 3$ amperes.

Another series-parallel circuit is illustrated. The equivalent circuit resistance can be calculated as follows: $\frac{12 \times 4}{12 + 4} = \frac{48}{16} = 3$ ohms; $\frac{4 \times 4}{4 + 4} = \frac{16}{8} = 2$ ohms; these two values added to the one-ohm resistor give an equiv-