Basic Electricity

Basic Automotive Electricity

Electricity is a big mystery to you, eh! You've tried to learn something about it but they throw a set of formulas at you and never bother to tell you why? Or where you'd use them? Not sure which meter to pick up to see why that blower motor, starter, or alternator you just installed doesn't work right? We want to help.

This article is intended to present the basic operation of components and circuits from a practical standpoint without going into the theory that bogs down most of us when we try to study and understand electricity. In order to intelligently diagnose *most* electrical system problems we really don't need to know that theory. Yes, there are times when solving circuit problems requires a deeper study and understanding of circuit analysis than we'll give here. But we hope that after using the basics for a while, you'll be encouraged to study electricity a little deeper.

Electrical Current

We can think of the flow of electrical current in the same way as we think of the flow of water. We say that water flows in a current down the stream. In the same way, we say that electrical current flows through a wire or cable.

If we put a paddle wheel in the stream so that the current of water can turn the wheel, the flow of water current can be made to do some work. If we put an adjustable gate upstream of the paddle wheel (before the current gets to the wheel) we can control the amount of water that gets to the wheel. Therefore, we can adjust the amount of work that gets done in a certain period of time. Of course the more water that flows, the more work that gets done.

Electrical current flows along a wire in the same way. And the greater the job that needs to be done, the greater the current we need. Then we can think of the size of wire carrying the electrical current as the width of the stream carrying the water current. The more current we need, the bigger the wire needs to be.

We say that electrical current flows from the *positive* terminal of a battery to the negative because Ben Franklin said so. He really didn't know. He took a guess. After all, he had a 50/50 chance of being right. It had to be one way or the other. Many years later when scientists were able to measure it in the laboratory, they found old Ben was wrong.

But by that time so much had been done and written about electricity that most people continued to think about it in Franklin's way. And for most practical purposes that's okay, especially on the automobile. So now we say that Ben's way is conventional current flow. We say that flow from negative to positive is actual or true current flow. Conventional flow is the easier way to think about it and is used by almost everybody. Of course, we'll use it here and say that current flows from positive (+) to negative (−).

Whether it's water or electricity, there are four characteristics concerning the ability of the flow to do work.

- The amount of current flowing.
- The force of pressure behind the current.
- The impedance or resistance the current encounters along its path.
- The amount of work that gets done.

As technicians, we don't design electrical circuits. We maintain and repair them after we find the fault. To find the fault, we must measure one or more of these characteristics. There is a certain amount of confusion among us about the terms—the words used to describe the characteristics. So the first thing to do is to come to an understanding on the terms.

DC, Direct Current

Figure 1

With direct current flowing through a wire, one end is always positive, the other end is always negative. Conventional current flow is from positive to negative.

Measurement Terms

The amount of water flowing, whether in a stream or in a pipe, is measured in G.P.M., Gallons Per Minute. The amount of electrical current flowing is measured in amperes, amps for short. How much current is flowing? So many amps. And the number of amps flowing depends on the job that needs to be done. A big job like cranking may take 200 amps. A small job like lighting the instrument panel may take one or two amps.

The water gets its pressure from gravity, by falling down a hillside or even falling through a small incline in the river or stream. Water pressure is measured in P.S.I., Pounds per Square Inch. Because electrons are too light to be affected by gravity, electrical pressure has to be developed through chemical means (the battery) or electro-magnetic means (the generator or alternator). Electrical pressure is measured in volts. So, voltage is electrical pressure.

Can there be voltage without current? From a practical standpoint, yes. Putting a voltmeter across a battery that is not connected to anything else will indicate 12 volts even though no current is flowing, except a very small current needed to operate the meter. If we connect the voltmeter to the hot side of a burned-out lamp bulb, we'll read a voltage even though no current is flowing through the bulb.

Electrical current does not have an easy time flowing along a wire. Current always encounters some resistance. That resistance is measured in ohms. Every wire has some resistance: the actual amount depends upon the diameter and the length of the wire. A coil or a motor winding may have many turns of small wire. The long length and small diameter of this wire will have a high resistance, maybe up to several thousand ohms. The heavy, large diameter cable from the battery to the starter will have a very small resistance, a fraction of an ohm.

We use resistance to determine if a winding or coil is partially shorted, that is, the wire's insulation is burned somewhere deep in the coil. The bare wire of one turn is touching the bare wire of another turn, or touching the metal case.

Resistance measurements are also used to determine the condition of resistors in the system that are intended to hold back the current, such as to dim panel lights or reduce blower motor speeds.

One more term we need to use from time to time is watts. This is the amount of power being used. It also designates the amount of electrical power that is—or can be—supplied by a power source like the battery and alternator. For a period of time watts was used to designate battery capacity.

Watts is power. Watts equals volts multiplied by the amps. For example, if the current going to a headlight lamp is 4 amps and the voltage is 12, $4 \times 12 = 48$ watts. 48 watts is the power being drawn by the lamp.

Kinds of Current—AC vs. DC

There are two kinds of electrical current, DC (direct current), and AC (alternating current). What's the difference and why do we care?

Direct current is current that flows in only one direction, from positive to negative. With DC flowing through a wire, one end of the wire will always be positive, the other will always be negative. It's the kind of current we get from a battery, pure DC.

AC, however, is current that goes back and forth in the wire, first going in one direction (above zero volts) and then in the opposite direction (below zero volts).

AC, Alternating Current

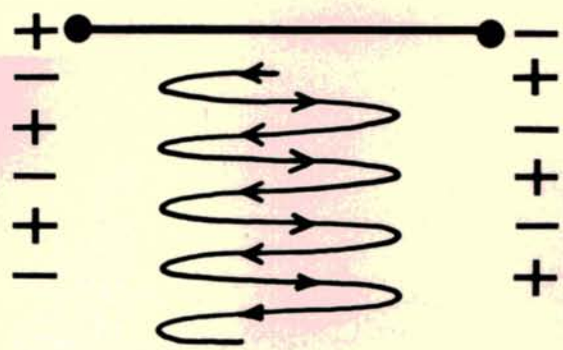

Figure 2

With alternating current flowing through a wire, the ends of the wire are reversing (alternating) their polarity.

How fast does the current go back and forth? That depends on the speed of the machine—the generator or alternator—that is producing the current. Current produced by rotating machines is always AC. For example, the generators that produce the 110/220 volt electricity for our homes and shops are highly regulated in speed to produce 60 hertz. This means that in one second, the current makes 60 complete cycles from positive to negative and back to positive. We say that the frequency is 60 Hz (short for hertz). Actually, that's a pretty low frequency. We'll talk about some higher frequencies later.

Automotive electrical systems are DC, mainly because the battery is an important part of the system. A battery is strictly a direct-current device. But the current generated by the automotive generator and alternator is AC, which means that the outputs of those machines must be rectified, that is, changed to DC. This is done by the commutator in the generator and by diodes in the alternator.

The terms we have used above are the formal, textbook words. In practice, other terms and phrases are often used to describe electrical measurements. Let's clarify some of these regarding current.

You might get the question: "How much current is the starter drawing?" The textbook answer is "X amps." But the question might also be stated as:

- What is the starter's current draw?
- What is the starter's amp draw?
- What is the starter's amperage draw?

For the amount of current going out of the battery, the question might be:

• What is the battery drain?
• What is the battery load?
• What is the amperage drain?

The amount of current (amps) needed to supply the entire system with everything turned on is said to be the system load.

If an alternator is designed to produce 70 amps, we say that its current rating is 70 amps, or that its amperage is 70 amps.

Circuit Elements

Wire

Wire does nothing but carry current between or among the active circuit elements. But it must be big enough in diameter to carry the current required by the device it is connected to. The necessary length of the wire also has an affect on the minimum diameter.

Wire is specified in AWG (American Wire Gauge) sizes. The smaller the AWG number (called the gauge number), the larger the diameter of the wire. In auto work there is a tendency to call the larger sizes of wire *cable*—even though the wire may not be cable according to that word's definition. For example, the battery cable is #6 or #8 gauge on most 12-volt systems in order to carry heavy power. Moderate power from the alternator is carried by 10- or 12-gauge wire, and lower power in other circuits is carried by 18-gauge wire.

Is there anything special about automobile wire? For one thing, it must be stranded, which means the entire wire is not solid, but is made up of several strands of smaller wire. This makes the wire flexible and able to withstand the vibration of the automobile. Solid wire crystallizes and cracks at the fixed mounting points very quickly. Therefore, solid wire must not be used. The solid wire used in buildings is not flexible enough for automotive work. The insulation must also be able to resist the high temperatures of the engine compartment and resist wear-through by abrasion.

Resistors

A resistor is an element placed in a circuit for the specific purpose of reducing voltage. Any resistor is designed to have a certain specific resistance value in ohms. It may be in the form of a wire of a resistive material. Such a wire is often used in the primary ignition circuit between the ignition switch and the primary terminal of the coil to reduce the voltage at the coil to about eight volts. Some cars use a wire-wound resistor to do the same job. Again, the wire used here is made of a special resistive material. Some of these are called ballast resistors, but not every wire-wound resistor is a ballast resistor.

The circuit of the heater/air conditioner blower motor uses a couple of heavy wire-wound resistors. Consider the blower control that has a three position switch. In the low-speed position, the switch will contact the end of a series of two resistors. With the two resistors in the line, the voltage to the motor will be low and the motor will run slowly. At the medium position, the switch will only contact the end of the first resistor. With only one resistor in the line, the motor will run at medium speed. At high speed, the switch will cut out the last resistor, allowing full voltage to the motor. Then the motor will run at full speed.

The most common resistor is the carbon resistor made of a rod containing a certain amount of carbon needed to get a specific resistance value. These are usually found in radio and electronic circuits. You don't usually see these around the automobile.

All resistors change their ohmic value to some small extent with heat. The amount of change is taken into consideration in the design of the circuit. However, there is a special type of resistor in which the ohmic value varies with temperature in a very predictable and repeatable way. It's called a thermistor. A thermistor is used on the auto most often as a temperature sensor feeding temperature information—usually coolant temperature—to the computer. As the temperature changes, the thermistor's resistance (ohmic) value changes, and so the voltage going to the computer changes. The computer reacts to this voltage, along with signals from other sensors, to adjust the engine timing and fuel mixture.

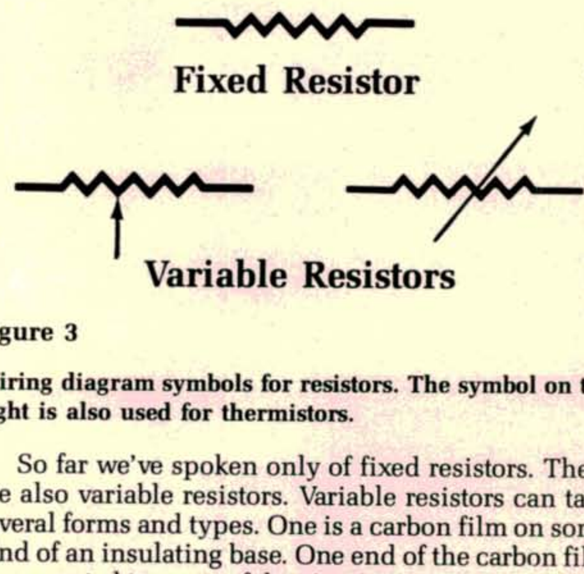

Figure 3

Wiring diagram symbols for resistors. The symbol on the right is also used for thermistors.

So far we've spoken only of fixed resistors. There are also variable resistors. Variable resistors can take several forms and types. One is a carbon film on some kind of an insulating base. One end of the carbon film is connected to a part of the circuit. A contacting wiper that can ride from one end of the film to the other is connected to the other part of the circuit. As the wiper moves across the carbon, the resistance is varied. Volume controls of radios are this type.

Another kind of variable resistor is the wire-wound type called a rheostat. A coil of resistance wire is wound around an insulating board or rod. A contacting wiper is arranged so it can move from one turn to the next, again varying the resistance. On the car, this type of variable resistor is found in the rotating part of the headlight switch to control the intensity of the dashboard panel lights. The TPS (throttle position switch) found on computer-controlled carburetor systems is another example of a variable resistor or rheostat.

Small rheostats are sometimes called potentiometers.

The electrical symbols that are used in wiring diagrams to identify fixed resistors and variable resistors are shown in Fig. 3.

Lamp Bulbs

Lamp bulbs are so common that they seem hardly worth talking about. However, a couple of points should be made. The light is produced by pushing current through the resistance of a fine wire called a filament. The filament gets hot enough to glow brightly. This white heat would burn the filament very quickly if the filament were in air, so the glass bulb is evacuated, leaving the filament in a vacuum. The point to be made here is that the resistance of a cold filament is very low. This suggests that even a small lamp would draw a heavy current when connected to a battery. In reality, the lamp does not draw much current except for the instant when the switch is closed. As soon as the filament heats up, its resistance rises drastically and the lamp actually draws only moderate or low current. Of course, the amount of current the lamp actually draws depends on how much work it does, that is, how much light it produces.

Circuit Operation

There are a few more circuit elements we need to talk about. But first, let's take a break and look at the operation of a simple but typical circuit containing the elements we've already covered.

Let's wire up a lamp bulb to a 12-volt battery. Let's include a switch so we can turn the lamp off and on as shown in Fig. 4. We'll arrange a series circuit composed of the battery, the switch, a lamp, and wires that connect these parts together. In a series circuit, the current flows progressively through each component of the circuit. So when we close the switch in our cir-

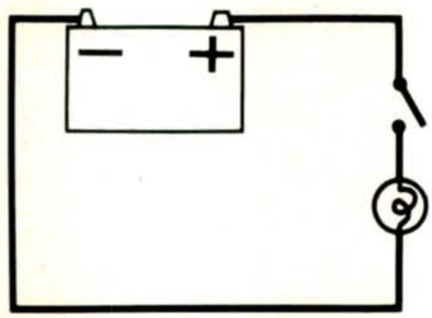

Figure 4

A simple series circuit of a battery, a switch, and a lamp bulb.

cuit, the current will flow from the positive post of the battery, through the closed switch, then through the lamp, to the negative post of the battery, through the battery, and start the trip all over again. As long as the circuit is complete, the current keeps flowing through this loop, through the loop, through the loop—until the switch is opened, the lamp burns out, or one of the wires breaks.

What happens to the current as it keeps making the circuit? What happens to the voltage? Well first of all, we've got to know what the current and voltage are. The voltage is easy. The circuit is powered by a 12-volt battery. How much current is flowing out of the battery and into the circuit? That same question might also be worded:

- What's the drain on the battery?
- What's the battery load?
- What's the amperage of the circuit?

The size of the lamp determines the amperage of the circuit. Let's say the lamp draws two amps. Then two amps will flow out of the battery, loop their way through the circuit, and flow back into the battery again.

What happens to that current? Does it just dissipate as it flows through the light bulb? Does the current just burn up?

In almost every treatise on basic electricity, there's a discussion of a basic law called Ohm's Law. Ohm's Law defines the relationship among amps, volts, and resistance. But this writer thinks that another law is even more important to us here. That law is called Kirchoff's Current Law and the law states: in a closed electrical circuit, all of the current leaving a point must return to that point. Not only is Kirchoff's Law vital to your understanding of circuits, it's also essential to your troubleshooting of circuits!

So what does this law mean to us and to the circuits we've been discussing here? It means that whatever current leaves the positive post of the battery must get back to the positive post. How does it do that? After it flows through the switch and the lamp, it'll continue on through the return wire to the negative post, through the plates and electrolyte of the battery and back to the positive post. It means that the same current (amps) is flowing in every element of the circuit. It further means that the current (amps) is the same in every part of a series circuit, so that the two amps flowing out of the battery flows through the switch, the lamp, and all connecting wires including the return line. This has further implications you must remember:

- A measurement of current can be made in *any* part of the circuit.
- Any weakness in the return line such as loose and dirty connections, undersize wires, etc., are just as important as weaknesses in the hot line are!

Well, what does happen to the electrical energy as it passes through the lamp? Something's gotta be given up or we'd have perpetual motion within the circuit! What happens is that the *voltage* drops as the electricity flows through the light bulb. This means some voltage is lost going through the bulb. When the current reaches the battery again, it gets pumped back up to 12 volts as it flows from negative to positive.

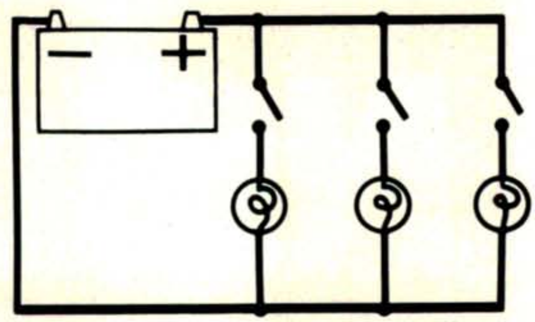

Figure 5

A parallel circuit of 3 series circuits. Each lamp is in series with its own switch.

Now let's add some more lamp bulbs to the battery, with a switch for each lamp as shown in Fig. 5. Notice here that there are three individual circuits. Notice that each lamp can be turned on independently of the others. These are called parallel circuits. One end of each of the circuits is connected to the "hot" (positive) line from the battery, and the other end of the circuit is connected to the "return" (negative) line to the battery. In the wiring diagram, the circuits form

Total Approx. Circuit Amperes	Total Circuit Watts	Total Candle Power	Wire Gage (For Length in Feet)											
12V	12V	12V	3′	5′	7′	10′	15′	20′	25′	30′	40′	50′	75′	100′
1.0	12	6	18	18	18	18	18	18	18	18	18	18	18	18
1.5		10	18	18	18	18	18	18	18	18	18	18	18	18
2	24	16	18	18	18	18	18	18	18	18	18	18	16	16
3		24	18	18	18	18	18	18	18	18	18	18	14	14
4	48	30	18	18	18	18	18	18	18	18	16	16	12	12
5		40	18	18	18	18	18	18	18	18	16	14	12	12
6	72	50	18	18	18	18	18	18	16	16	16	14	12	10
7		60	18	18	18	18	18	18	16	16	14	14	10	10
8	96	70	18	18	18	18	18	16	16	16	14	12	10	10
10	120	80	18	18	18	18	16	16	16	14	12	12	10	10
11		90	18	18	18	18	16	16	14	14	12	12	10	8
12	144	100	18	18	18	18	16	16	14	14	12	12	10	8
15		120	18	18	18	18	14	14	12	12	12	10	8	8
18	216	140	18	18	16	16	14	14	12	12	10	10	8	8
20	240	160	18	18	16	16	14	12	10	10	10	10	8	6
22	264	180	18	18	16	16	12	12	10	10	10	8	6	6
24	288	200	18	18	16	16	12	12	10	10	10	8	6	6
30			18	16	16	14	10	10	10	10	10	6	4	4
40			18	16	14	12	10	10	8	8	6	6	4	2
50			16	14	12	12	10	10	8	8	6	6	2	2
100			12	12	10	10	6	6	4	4	4	2	1	1/0
150			10	10	8	8	4	4	2	2	2	1	2/0	2/0
200			10	8	8	6	4	4	2	2	1	1/0	4/0	4/0

- **Calculate the wire length of the circuit including the ground or return circuit wire if one is used.**
- **Determine the total circuit load in amps, watts, or candlepower, and choose the appropriate column.**
- **Move to the column showing the length of the entire wire circuit. Select the proper wire gauge.**
- **Use a wire two sizes larger for 6 volt applications. (If you need 16 for 12 volt, use 14 for 6 volt.)**

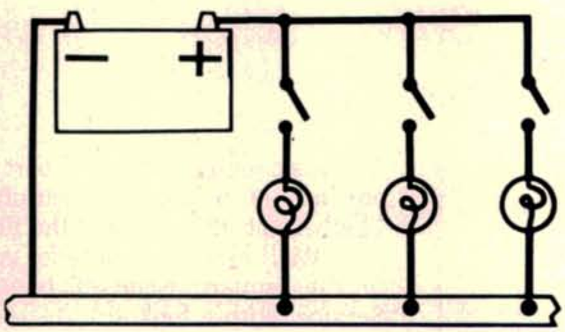

Figure 6

On the vehicle the frame, engine, and sheet metal are all connected together via straps and bolts to become the negative bus called *ground*.

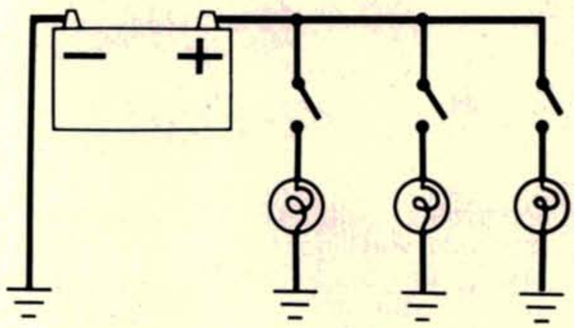

Figure 7

Ground connection to the chassis is symbolized by the triangular shape of three lines.

a ladder, with the rails being the positive and negative lines, and the rungs being the three individual series circuits. So we say that each of the circuits is in parallel with the others. Another way of describing these parallel circuits is to say that each circuit is *across* the others. Take a moment and compare Fig. 5 with Fig. 4. See how we have stacked up or hooked up three separate *series* circuits to form three circuits in parallel with each other? Please re-read what we just told you. Re-read it until you understand it!

Each lamp is the same size, so each circuit will draw two amps. When all three switches are closed, the total amount of current drawn from the battery will be six amps. The total amount of current returning to the battery's negative post will be six amps.

The diagram of Fig. 6 shows the second end of each circuit connected to a negative bus. On a car, the negative bus is the frame, the sheet metal, and the engine block. These three are connected together by cables, straps, or bolts to form the negative bus. We call this bus ground. Ground is symbolized on wiring diagrams by the triangle of three lines as shown in Fig. 7.

Let's modify the third circuit so that the brightness of the lamp can be adjusted. We'll insert a rheostat between the switch and the lamp. You can see that the rheostat is in series with the switch and the lamp. The symbol shown on the diagram is the same one found on wiring diagrams. With the sliding contact at the beginning of the resistance wire, there is no resistance in the circuit. Therefore, the lamp will shine at full brightness. With the slider at the other end of the wire winding, there will be the full resistance of the rheostat in the circuit. Then the lamp will shine at its dimmest. This is exactly the circuit found in the panel lamp dimming portion of the auto's light switch.

What happens to the voltage in this kind of a situation? Part of the 12 volts will be dropped across the resistance of the rheostat and the remainder of the voltage will be dropped across the resistance of the lamp. How this will be divided up, of course, depends on how far we turn the rheostat.

WAIT . . . There's more

This concludes the first part of our article on basic electricity. That's right, this was just the first part. We'll have even more for you in the January issue of *Import Service*, with a look at:

- Short circuits
- Current measurement
- Voltage measurement
- A closer look at individual system components.

So stop back next month as our look at electricity moves from basic theory to some more concrete applications in the real world.