# Chapter 8 BASIC ELECTRICITY



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# **Chapter 8**

# **Basic Electricity**

# Introduction

Our objective for this Chapter is to make you feel more comfortable with electricity and to give you the information you need to service and troubleshoot electrical devices.

The easiest way to learn about electricity is to define the words used to describe electricity and its properties. Let's start with the word *electricity*. Electricity is an

Electrical safety

Electricity can be dangerous. It can create three hazards: fire, skin burns, and shock. Shock can cause muscle spasms, unconsciousness and even death.

Proper installation of all electrical equipment is essential. The National Electrical Code<sup>®</sup> sets the standards. Local communities can make this code law, and in addition, they can make their own codes even more restrictive.

A common and dangerous practice is testing the ignition transformer with a screwdriver. The transformer is putting out 10,000 volts and can give you a dangerous and serious shock.

Electric energy needs a pathway from the source and back to the source. If you do your job, this pathway is our electric circuit. almost magical way to take the potential energy locked up in coal, natural gas, oil, waterfalls, and even inside atoms—move that energy great distances—and ultimately have it do useful work for us.

Any source of electricity must get the energy from somewhere. The battery gets energy from a chemical reaction. The generator gets energy from the work done turning the shaft. The work it does for

But any wet object has enough minerals in the water to provide an alternate pathway. The human body is over 50% water, and when the skin is damp it will provide a good pathway back to the source if there is not an easier one. Never allow your body to be that pathway! Always consider all electrical components to be energized until you test and prove they are not.

When you are working on electricity, remove all metal objects such as watches and jewelry from your hands and wrists. Until you are absolutely sure a circuit is shut off, only use one hand—keep the other in your pocket. This prevents the electric pathway from going from one hand to the other hand through your heart. Be sure to replace any damaged or frayed wires, protect wires from touching moving equipment, and keep them clear of walkways. Oilheat is to power our motors that pump oil and water, make the spark needed for ignition; and automatically control the entire heating process.

Electrical current flows through wires, switches, and transformers to our heating appliances.

The force that pushes the current through the wire is called *Voltage*, which is measured in *Volts*. The amount of current

flowing through the wire is called *Amperage* or *Current*, which is measured in *Amps*. The *Resistance* to this flow is measured in *Ohms*. The power used to run our motors and create spark is measured in *Watts*.

To better understand these important words, it might be helpful to compare electricity to the flow of water in a pipe.

# **Volts**

No Pressure

High Pressure

Voltage is like water pressure (pounds per square inch), and like water pressure, does not need an actual flow. Regardless of the faucet being open or closed, there is still water pressure in the pipe. Likewise, there are volts at an electrical outlet even though nothing is plugged into that outlet and there is no flow. Of course, the potential for flow is there and that is why volts are referred to as electric potential; it could flow if the conditions were right even though it is not flowing now.

Voltage is the force created by the power source (the battery, transformer, or generator). This is called the electromotive force (EMF).

When water comes out of a faucet, it flows under pressure. But when that water drains out of the sink, it has no pressure except gravity. Voltage is the same. As voltage pushes the electricity through the wires, it keeps it under pressure.

Once the electricity has finished doing its work (turning a motor, making a spark), it returns to where it came from under no pressure. The voltage is all "used up". Therefore, voltage supplied to the circuit is voltage *used by* the circuit.

### Amps = water flow

Amperes, or amps for short, are a way of expressing the amount of electricity flowing through the wire, the rate of flow (current). They are like the gallons per hour flow of water through a pipe. Figure 8-1.

The voltage is like the force of the water in the pipe and the amps are like the amount of water flowing out of the faucet.

### Ohms = resistance to flow

As water flows through a pipe, it encounters *resistance* to the flow depending upon the physical characteristics of the pipe. How much water flows through the pipe, at any given amount of water pressure, is affected by the size of the pipe and even the smoothness of the inner walls.

Amps also meet resistance from insulation, motors, circuits or anything that restricts the free flow of electricity. This resistance to the flow of Amps is called *Ohms*.

# Resistance to flow makes friction and friction makes heat

Resistance to flow, whether it is water or electricity, creates friction, and friction converts energy to heat. Electricity faces much resistance trying to fight its way through wiring, and it creates a lot of heat doing it. The greater the resistance to flow in the wire, the more heat is produced. This isn't all bad. The heat can be used to make

Figure 8-1: Water analogy electric heaters for toasters, electric water heaters, and electric baseboard heat. This heat can also be used to make heat anticipators in thermostats and safety timers in primary controls.

### What's a watt?

Watts are the power consumed by an electrical circuit. One amp (remember, that's the amount of flow) driven by one volt (the amount of pressure) through a circuit equals one watt of power, see Figure 8-2. This work can also be called *horse-power*. One horsepower equals 746 watts.



If a circuit using one watt operates for an hour, this called a *watt-hour*. Sometimes, AC power is called *volt-amps* (VA) or *apparent power*. As current or voltage increases in a circuit, the power consumption and work done also increases. Every electrical device needs a certain amount of power, so it is given a power rating based on it being supplied with a specific number of volts and amps. If the right amount is not supplied, it changes the device's power consumption and performance.

> Did you know? Electric company bills are based upon kilowatts per hour, kwh. A kilowatt is 1,000 watts.

### The math

Volts, amps, ohms and watts are all related to each other. If you change one, you change the others, too. These relationships are described by two math formulas:

volts = amps times ohms

and watts = volts times amps

Remember, if one changes, it affects the others.

### Conductors

Some materials offer very little resistance to the flow of electricity; these materials are called conductors. Most metals are good conductors. Gold, silver, copper, and aluminum are very good conductors. That's why wires are made out of metal. Also, some switches are made out of mercury (a liquid metal).

Wires are the conductors; they are very much like pipes for water. In a water pipe, not only does the pipe material affect the resistance to flow, the size of the pipe or wire also determines how much resistance to the flow there is. A fat wire, like a fat pipe, offers less resistance than a skinny one, and a short wire offers less resistance than a long one. In electricity, temperature is important, too. Cold conductors offer less resistance than hot ones. Force is needed to overcome this resistance. Remember, in water, the force is called pressure (pounds per square inch), and in electricity, the force is measured in volts.

### Insulators

Many materials offer a lot of resistance to the flow of electricity, these materials are called *insulators*. Air, glass, porcelain, plastic, and rubber are all good insulators. They stop the flow of electricity. These Figure 8-3: Water circuit

High

Current (flow)

is the same in all parts of the

circuit

materials are used to contain or control the flow of electricity along a conductor, such as a copper wire. Because air is a good insulator, the resistance of the air stops the electricity at the end of a wire like a wooden o Pressure plug stuck in the end of a pipe. If enough water pressure is put on that plug it will pop out and the water

will flow. If enough electric pressure (volts) are put against the insulating air it, becomes a conductor and lets the electricity flow in the form of a spark. A ten thousand volt transformer can make electricity jump across the air space between the ignition electrodes in an oilburner. This creates the "spark" that ignites the oil.

### Loads

A *load* is a device that converts electrical energy to some other form of energy in order to do work. A load also creates resistance that opposes electrical flow. Here is an example: a light bulb converts electric energy to heat and light because the filament resists the flow of electricity, getting so hot it actually glows. Another example: a motor changes electric energy into mechanical energy.

Some of the loads found in oil burner circuits are:

- *Motors*—in the burner, circulator, fan, power venter, humidifier
- *Electromagnetic coils*—in relays, solenoid valves
- Transformers—in ignition and control
- *Heaters*—in the primary control safety switch, thermostat heat anticipator

# **Electrical circuits**

The most important thing to understand about electricity is the electric circuit. Electricity has to flow from a source out into the circuit and back to the source. Figure 8-3.

A typical circuit, then, has a conductor that carries the electric current from the source, through a switch, to a load—and back to the source. Current flows only in a complete circuit. However, the energy it gains in the electromotive force (measured in volts) from the power source is lost in the resistances (ohms) it encounters in the circuit. The switch is a device that interrupts the circuit. When it is open, electricity can't flow. When closed, the circuit is complete and the flow continues. See Figure 8-4.

### Figure 8-4: Open and closed switches



A complete circuit should always include a load of some sort. If you just run a conductor from the source back to the source without going through a load, you have a *short circuit*. Since there is no resistance to slow up the electrical current, the amps just keep going higher and higher. This increases the heat build-up from the resistance in the conductor until it gets so hot it starts a fire.

Fuses or circuit breakers are installed in the circuit to prevent this from happening. Circuit breakers are automatic switches that cut off the current if it starts to reach dangerous levels. Figure 8-5.

The primary resistance to flow in a circuit is the thing doing the work, the "load". It converts the electrical energy into another from of energy. However, the conductor can also restrict the flow, especially if it is undersized, too hot, or too long.

Resistance (ohms) opposes flow. Voltage



overcomes resistance to create flow. Any change in ohms will cause the opposite change in amps because volts from the power source are relatively constant. An increase in ohms reduces amps. A decrease in ohms increases amps. Increasing volts increases amps, this is called *Ohms Law*, Figure 8-6. It states: *"It takes 1 volt to push 1 amp through 1 ohm."*  Figure 8-5: Fuse or circut breaker protects the circut



### **Series Circuit**

A series circuit is one where there is only one path for the electric current through the loads. Remember the old Christmas tree lights (each light is a load) where, if one burned out, they all went out? That was a classic series circuit. Aside from the problem of losing one load and shutting off all the rest, the other drawback to a series circuit is that each load steals electricity from the other loads.

In a series circuit, the power is delivered in the greatest quantity to the point of



largest resistance. This is why poor connections in a circuit, where the resistance is high, tend to overheat.

Since voltage applied to a circuit is voltage used by that circuit, more than one load in the same pathway will share the supply voltage. Loads in the same pathway reduce the voltage to each load as well as the current through the entire circuit. The volts drop as they go from load to load. The current flow (amps) is affected by both the volts and the total ohms of the circuit, and is the same in all parts of the circuit.

To review, in a series circuit the total resistance (ohms) is equal to the ohms of all the individual conductors, switches, and loads present in the circuit. The current flowing (amps) in all parts of the circuit is the same. By adding all the voltage drops of all the loads together it equals the applied voltage (volts from the source). Figures 8-7 and 8-8.

# **Parallel circuit**

A parallel circuit has separate branches for each load. This way, if one load burns out, it will not affect the other loads. Also, all the loads receive the same voltage.

The loads are parallel to each other. In a parallel circuit, some of the loads and not others can be turned on. For example, the burner motor and the ignition can run separately, so the spark can be shut off once flame is established.

In a house circuit, all the lamps and appliances are wired in parallel. This way each can be turned on and off separately. See Figures 8-9B and 8-10B.

The resistance of the load in each branch circuit determines the current (amps) delivered to that branch. The current in the common lines is equal to the current flowing in the branch circuits served by that section of the common line. Unlike in a series circuit, the current may vary in different parts of a parallel circuit.

As the number of branch circuits increases, the total current draw increases. If you plug too many appliances into an extension cord the amp rating of the wire might be exceeded. The wire will get hot. The overloaded circuit could cause a fire.

Overloaded circuits also decrease the voltage to all the loads. As the wire heats up, its resistance increases. The wire starts acting like a load in series with the other loads, and starts stealing electricity from all the loads in the circuit. This is why the oilburner should be wired with its own individual circuits, not sharing the circuit with any other loads.

# **Combination circuit**

Oilheating systems use what is called a combination circuit. The switches and limit controls are in series with the primary control. If any one of them opens, the electric current to all the loads stops. All loads are wired parallel to each other to allow individual component control and to ensure full voltage is supplied to each load.

### Safe capacity for 120 volt circuits

To be sure you will not overload a circuit, check the amps needed for each of the loads connected to the circuit. This information is on the label of the load. Add up all the watts to be sure they are within the safe capacity. The rated *ampacity* of controls, switches, and conductors must be followed.

# AC/DC

Electric current is either direct current (DC) or alternating current (AC). Direct current typically comes from a battery. It



only flows in one direction, from the negative side of the battery through the circuit to the positive side. Alternating current is what the electric company supplies. It changes direction, flowing back and forth in the wire. Each back and forth change is called a cycle. In North America, the electricity cycles 60 times a second, 120 changes of direction.

The current delivers power to the load no matter which way it is flowing. The voltage goes from and returns to zero 120 times a second. A light bulb in an AC circuit glows dim and bright in just this rhythm.

In a DC system, there are two kinds of electrical charges—positive and negative. Positive is also referred to as "hot" and negative as "neutral". In an AC system, the switched line is referred to as "hot" (H) or L1 and the unswitched side is referred to as "neutral" (N) or L2. (Be careful: L2 is also labeled as the second hot leg in most electric distribution panels. The L2 referred to here is the neutral wire.)

Separating electricity into two wires is called polarization. It is a way of making sure the electricity goes where it is wanted. You have probably noticed that most small appliances have a wide blade and a thin blade on their plug. There is only one way you can plug these things in. This way the appliance's switch will control the hot wire, not the neutral wire allowing for a safe shut-off of current. If polarization is reversed in heating systems, some controls will appear to function normally, but the limit control will be interrupting the neutral. This is dangerous.

Figure 8-11: L1 and L2 point to the power source



### Wiring diagrams

Wiring diagrams are sort of like road maps or blueprints that show us how a circuit is designed. To install or service electrical equipment, you must be able to read the wiring diagram.

One of the confusing things about wiring diagrams is that a complete circuit is always needed, and then the diagram starts right out with a big space between the two wires feeding the circuit. These two wires are labeled + (positive or hot) and - (negative or neutral), or as mentioned previously, they are now called L1 and L2 (line 1 and 2). All three names mean the same thing. When you see these labels, it means there is a complete circuit—without actually drawing it.

If you follow L1 and L2 off to the left off the page, they go back to the circuit breaker, the main breaker, and all the way to the big transformer hanging on the pole in front of the building. From there they go all the way back to the power plant. Just remember, the arrows on L1 and L2 are pointing at the power plant, and they represent a complete circuit. Figure 8-11.

L1 is the electrically charged line that causes electrical flow and L2 is the return line home. The direction of flow is from L1 to L2—from charged to uncharged pressurized to unpressurized.

### **Wires**

Wire comes in many different sizes. Wire sizes run from 0000 (4 naught, the largest) to 40 (the smallest); the lower the number, the fatter the wire. To size a wire, consider the maximum voltage rating of the wire and the amperage draw of all the loads in the circuit.

The number of wires bundled together in the wire sheathing (insulating jacket) is printed on the sheathing after the wire gauge number (14/2 and 14/3). Only insulated wires are counted, so 14/2 has a black, white, and a bare ground wire which is not insulated and therefore not in the count. 14/3 has an added red wire. Thermostat cables can have from two to seven wires in them, depending on the added functions of the thermostat (air conditioning, humidifier, and fan functions.)

To make identification easier, the colorcoding of the wire insulation is standardized.

The spot where wires are joined together or hooked to a control is the weakest link in a circuit. Be very careful when making these connections. All connections must be in a junction box or protected control box with clamps at the entrance and exit to be sure stress is not placed on connections if the wires are pulled.

If exposed to high heat or humidity, connections may become dirty or corroded. Always check exposed connectors (like the terminal block on primary controls), and always seal hidden connections with electrical tape. Copper wire is recommended for all oilburner wiring and is required in some cases.

# **Armored cable**

Any wiring around an oil-powered appliance should be protected by either flexible metal conduit or armored cable. There are two kinds of armored cable: BX and MC.

BX has no ground wire. Its metal sheathing serves as the ground. Some people mistake the thin metal bonding strip in the cable for a ground wire. The strip is easily broken and is used only to make a conductive connection to a metal junction box. Older BX used heavy steel sheathing. Aluminum is now used because it is lighter, easier to cut, and is a better conductor. MC cable is like BX, but with a green insulated grounding wire. Most codes require MC instead of BX for a sure ground.

Flexible metal conduit has no conductors installed in it. The National Electrical Code<sup>®</sup> specifies how it can be used and how many conductors may be installed in the conduit.

# **Switches**

Switches are used to stop the flow of electricity. It is a simple idea; just cut the conductor and put an insulator (air) between the two cut pieces of the conductor.

A switch is like a drawbridge installed in the middle of a race course. Imagine what would happen if during a race, you suddenly opened the drawbridge, leaving a big hole in the track. All the cars would stop; there would be no more current flow. Thanks to the car brakes, the resistance would be very high but there would still be voltage. The cars would still have all that

### Did You Know?

When the switch is open, the electricity flows out of the power source to the open switch. It can go no farther. In a fraction of a second, the potential on the power side of the switch reaches the same as the potential from the power source. and there is no further flow of electricity. At the same time, the potential on the other side of the switch reaches the level from the other side of the power source, and there is no current. When we close the switch, the negative charge instantly goes to the positive potential on the other side and electricity flows through the circuit.

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Figure 8-12: Switching arrangements (various setups)

power available from the engines even if they were not using it.

Electric switches open to stop the flow of electricity just like the drawbridge opens to stop the flow of traffic. Switches can be manually or automatically operated.

For a switch to safely control a load on a typical oilheat system, it must be located in the source or hot line (L1), never in the neutral line! Switches in the neutral line can turn the load on and off but will not allow work to be done on the load without the risk of electric shock.

There are many different kinds of switches. The most common switch is a single pole, single throw switch, or SPST for short. They are either on or off. This is a swinging gate (or drawbridge) that can make an air break in a conductor when it is open and connect the break when it is closed. A SPST switch turns everything in a single circuit on and off. There can be many SPST switches in one hot line. Another type of switch is a single pole double throw switch, or SPDT. This switch is used to turn the electricity on or off in one or the other of two separate circuits. This would be like a Y intersection. You can decide to drive on one road or the other. Some heat/cool thermostats have SPDT switches.

Double pole single throw (DPST) switches can make or break two separate circuits at the same time. The two circuits being switched can be off the same voltage or different voltages. This would be like a drawbridge that had a street and a railroad track on it. The main breaker at the electric panel is a DPST.

Double Pole Double Throw (DPDT) switches re-direct the power of two separate supply lines to two different circuits. See Figures 8-12.

The contacts of automatically operated switches in wiring diagrams are shown in their normal (at rest) position when the unit is not operating. Contacts on automatically operated switches are classified as normally open (NO) or normally closed (NC). The determination is made by the position of the contacts when the device is either not energized or not sensing the condition it is designed to sense.

Manual switches are operated by hand. Examples of manual switches in oilburner circuits are the stair switch, the on/off switch at the burner, the manual/auto fan and thermostat switches and the reset button on the primary control and motor. The reset button is an example of a manual switch that also is switched automatically.

Automatic sensing switches respond to a change in conditions such as: temperature, pressure, flow, liquid level, light and humidity.

Some switches open when the temperature, pressure, light, or liquid level rises and some open when one of these things falls. If the switch "makes" (closes) on fall, this is called "makes on fall" or "breaks (opens) on rise." If a switch opens as a result of a rise in the sensed condition, this is called a direct acting (DA) switch. If it opens on fall in the sensed condition, it is a reverse acting (RA) switch.

Heat-only thermostats and high limits are direct acting switches since they open on the rise in temperature. Cooling thermostats, fan off switches in fan-limit controls, low-water cutoffs, and reverse acting aquastats are reverse acting because they open on the fall of the sensed condition.

# Timers-bimetals & warp switches

As you will learn in the primary control chapter, one of the things an oilburner circuit must do is shut itself off on "safety" in case flame is not established after the burner has been energized.

In many of these controls, there is a timer switch that uses small electrical heaters in combination with bimetals. Figures 8-13 and 8-14 shows how it works.

A bimetal is composed of two different strips of metal fused together. One end of the strip is secured and a small electric heater is placed under it. As it heats up, the two metals expand at different speeds. The Figure 8-13: Warp switch, often used as a safety switch in controls

Firgure 8-14: Warp switch locking burner out on safety



### Figure 8-14





#### Figure 8-15: Electromagnet

one closer to the heater expands faster. Since the two pieces of metal are fused together and they are secured on one end, the quickly expanding piece of metal bends away from the heat and makes the strip warp. This is why it is called a warp switch.

As you can see in the illustration, as the bimetal warps, it releases the movable contact and the spring on the movable contact opens the circuit. This puts the oilburner on 'safe' and stops the flow of electricity to the heater, see Figure 8-15. The only way to close this switch again is to wait for the bimetal to cool and warp back and then someone must push the 'reset' button to reset the moveable contact under the lip of the bimetal.

# Electricity and magnetism

Electromagnetism describes the relationship between electricity and magnetism. If you move a wire in a magnetic field, you generate voltage if that wire is part of a complete electrical circuit. The generated voltage will cause electric current to flow



Two factors affect the strength of an electromagnet:

- 1. The intensity of the current in the coil.
- 2. The number of turns of wire in the coil.

Electromagnets are rated in amp-turns.

### **Solenoid valves**

To make a solenoid valve, an iron bar is placed into the center of a coil of wire and electricity is sent through the wire. The electromagnetic force will pull and hold the bar in the center of the coil. If a spring is attached to the iron bar (or valve stem), it returns to its original position when the electricity is shut off. If a valve seat is put on the end of the valve stem you have an electrically operated valve. Figure 8-16.

### **Relay switches**

Relays are electromagnetic switches found in primary controls, operating controls, and switching relays that use electromagnets to open and close. To create a magnetic field, wrap a coil of wire around a metal core. The magnetic field magnetizes the core and this electric



Figure 8-16: Solenoid valve



magnet is used to open or close a switch that is held in its normal position by a spring, see Figure 8-17.

The nice thing about this kind of automatic switch is that low voltage wiring can be used for the electric magnet and the switch that sends electricity through the coil that can make or break a line voltage switch. When the low voltage remote switch (thermostat) opens, the magnetism immediately stops and the spring quickly returns the switch to its normal position. This snap action reduces arcing as the switch opens or closes.

The biggest problem with relays is the contacts. Dirty or corroded contacts add resistance to the circuit, resulting in reduced voltage to the load, which can create arcing that shortens the life of the contacts. The good news is that most new relays are enclosed in plastic to keep them clean. A properly working relay will not cause any voltage drop when closed.

Relays are represented in wiring diagrams as the coil of wire and the switch. The coil is usually energized by low voltage. The switch can control either a high or low voltage circuit. The working limit of the switch is determined by the amperage draw of the circuit it is controlling. Many relays are single pole double throw switches, so you might have a low voltage switch and a line voltage switch. The way to keep track of all this is to label the coil with a number and a letter like 1K. Then label the switch contacts controlled by that coil 1K1 and 1K2.

### **Transformers**

Transformers use electric power at one voltage to produce an almost equal power at another voltage. In our industry transformers operate on alternating current (AC); they are made of an iron core with two separate wire coils wrapped around two sides. The coil where the electricity goes in is the primary coil, and the coil where the electricity comes out is the secondary coil. Figure 8-18.

Thanks to AC, the electric field in the primary coil pulses back and forth, causing the magnetic field it creates to pulse back Figure 8-17: Simple relay and forth in the iron core causing the north and south poles to switch back and forth. This pulsating magnet field creates a pulsing electric field in the secondary coil.

Step-down transformers have more primary coils than secondary and reduce voltage. Step up transformers have more coils in the secondary coil and increase voltage. There is no electrical connection between the primary and secondary coils. The only connection between the two is the magnetic field.

When voltage is applied to the primary coil, a magnetic field is generated which creates voltage in the secondary coil. The amount of voltage generated in the secondary coil is determined by the ratio of coils between the primary and secondary coils.

Transformers are very efficient and can provide as much as 90% of the energy put into the primary side to the secondary side. The small energy loss is due to the heating of the wires in the coils.

# Why are transformers and solenoids loads?

The greater the current, the greater the magnetic field around the conductor. The

IRON CORE Primary Secondary magnetic field limits current flow by pushing back against the source voltage.

Remember, current is not only caused by voltage from the power source, it is caused by any electromotive force that acts upon the conductor. As the electricity goes through the coil of wire in the transformer or solenoid, it creates a magnetic field that resists the flow of electricity. It becomes a load. This is called this "back emf" because it counteracts the voltage (electromotive force) from the power source.

### **Motors**

Motors turn electrical energy into mechanical energy.

If a permanent magnet is mounted on an axle and placed between the opposite poles of two fixed magnets, the magnet on the axle will spin until its north pole faces the south pole of the fixed magnet, and its south faces north. (Like poles repel each other, opposites attract.)

If you could reverse the poles of the fixed magnets just as the rotating magnet was coming to a stop, it would force it to turn another half circle until the opposite poles lined up again. Figure 8-19.

If you make the fixed magnets electromagnets every time the alternating current in the electromagnet changes direction the poles in the magnet flip (north becomes south and south becomes north) driving the rotating magnet around again. It will keep turning as long as the current in the fixed magnets keep flipping. The fixed (stationary) electromagnets are called the stator, and the rotating magnet the rotor.

### **Measuring electricity**

Since electricity can not be seen (except for sparks), testing and measuring devices are needed in order to properly troubleshoot heating and air conditioning systems.

Figure 8-18: Basic design used in an iron core transformer To measure voltage (volts), amps (current), and ohms (resistance), you can buy a device called a multimeter that lets you test all three. Your meter will come with directions on how to use it. Read and follow those directions.

### Using a multimeter

The handiest device for electric testing is the multimeter mentioned above. It can measure voltage, current and resistance. You can buy analog meters that use a swinging needle to give you continuously varying readings, or a digital meter that gives readings with discrete numbers on a screen. Digital meters are easier to read and don't need to be "zeroed out" before use.

If you are reading a stable DC or AC voltage or current, a digital meter is a good thing. If you are measuring a slowly, varying current or voltage, a digital meter could be constantly refreshing itself, making the display very hard to follow.

Before you can use your meter, you must decide what you want to measure (i.e. voltage, current or resistance) and what reading (range of value) you expect to get. This way, you can pick which function to use and which scale setting within that function. To prevent damage to the meter, do this before connecting the meter. Switching the function selection dial while attached to a live circuit could damage your meter. Always disconnect the test leads or shut off the circuit before changing the selection dial.

Each function has a maximum and minimum range. Exceeding the maximum is dangerous to you and the meter. The closer you are to the middle range, the more accurate your reading will be. Pick the range on the multi-position rotary switch that gives you the most accurate reading while not exceeding the maximum for the range. If you are not sure, always start with the highest range and work your way down.

Read your meter's instructions to determine what the symbols on the dial mean. The black lead should always be connected to the COM (common plug) jack. The position of the red lead varies

Figure 8-19: Arrangements of magnets to create motion



with the different functions based on the symbols marked on your meter.

- Be careful how you treat your meter
- Protect it from moisture and high temperatures
- Replace worn or cracked test leads
- When not in use store it in its case
- Check the battery for corrosion
- Remove the batteries for long storage periods
- Do calibration checks against known volts, amps, and ohms regularly

### Measuring voltage

A voltmeter is used to measure the difference in electric pressure between two points. Since a load creates a difference in electric pressure (or force) as it does work,



the pressure is relative; that is, one point must be measured against another.

Electrical charge flowing from any power source is at a high energy level; when it returns from the circuit, its energy is low. The power source's job is to boost the energy level of the charge. The voltmeter measures this change in charge (the difference in energy level) through the circuit.

Somewhere in the circuit, the energy of the flowing charge is converted into other forms by the load. When a light bulb is lit, the electric energy becomes heat and light. To measure this conversion of energy (change in charge), use a voltmeter. Figure 8-20.

Remember, "Voltage applied is voltage used." Whatever voltage is applied to a circuit will be used up by that circuit. This is why measuring voltage is the best way to find out if a circuit is working properly.

A voltmeter allows very little current to go through it. It has very high resistance, so it has almost no effect on the circuit being measured. When you connect the leads from the voltmeter to two different points in the circuit, it measures the difference in potential (volts) between those points. It tells you how much energy is being used between the points where the two leads are touching the circuit.

To measure voltage, touch the one of the voltmeter's leads to each of the two wires on either side of the load. This will measure the voltage drop of that load. Voltage drop is the amount of electrical energy that is being converted by that load. If you touched the meter leads to L1 and L2, you would measure the voltage step-up from the energy source.

There will be no voltage drop across a closed switch. The pressure drop across an

# Figure 8-20

open switch will be the applied pressure of the power source.

A voltmeter measures the difference in electrical pressure or the potential difference in emf between two points in contact with the test leads. Voltmeters are used in parallel to whatever is being tested.

The two things to remember when testing for voltage on a live circuit are: There has to be resistance between the two points being measured and there must be a complete circuit to make a zero reading mean something.

### **Measuring current**

An ammeter measures the rate at which the electric current flows from the power source, through the wire and load, and back to the source.

There are two kinds of ammeters; in-line and clamp-on. In-line ammeters are not commonly used by service technicians in our industry. They are primarily used during bench testing.

The clamp-on ammeter is easy to use. It uses electromagnetic induction. Whenever electricity flows through a wire, it creates a magnetic field around that wire. The clamp-on ammeter converts the strength of the magnetic field into a current reading.

To use a clamp-on ammeter, first pick the correct scale (when in doubt start high) then open the jaws of the meter, insert one line between the jaws, close the jaws and take a reading. This meter can be used safely on a live circuit without disconnecting the power since the magnetic field is not affected by the wire's insulation. See Figures 8-21 and 8-22.

Clamp over one line at a time because the magnetic fields from each wire cancel each other out. If you placed both the hot



and neutral lines between the jaws you would get a zero reading even if there was current flowing in the wires. You can test either the hot or neutral line, but not both at the same time. Since AC and DC currents create different magnetic fields, be sure to set your meter for the current you are measuring.

If the current you are measuring is too low for your meter to read accurately, you can loop the wire around the jaws several times to increase sensitivity. Just divide the reading by the number of loops. Ten loops is an easy number to use. Figure 8-21: Clamp-on ammeter

Figure 8-22



To understand what your ammeter is measuring, you should know:

- The type of circuit
- The design ampacity (current carrying capacity) of the components
- The design current draw of the loads.

The design ampacity is usually marked on each component and must be higher than the amp rating of the fuse protecting that component. For example, a 15-amp fuse should protect components exposed to 120 VAC.

The design current draw of a load is usually listed on the rating plate. The listed design current draw, in amps, is for steadystate normal operation. On start-up and under increased motor load, there is a higher required torque and a slower operating speed, the motor current will be higher.

The surge current draw on initial startup of a motor may be four or five times its normal current draw. Sometimes the surge current draw is also listed on the rating plate.

If a burner motor bearings are dry, or the oil pump has rust in its gear set, the motor

Figure 8-23: Ohmmeter readings



will not be able to function normally and the current draw might be less than the listed rating.

### **Measuring resistance**

The ohmmeter is used to measure resistance. It measures the resistance between two points. It can measure just one load or a whole circuit.

The ohmmeter has its own electric source (a battery). Since it provides its own power, disconnect the circuit or device to be tested from the power source. It measures the resistance between two points by applying a steady voltage from the meter's battery to a de-energized circuit or device. Figure 8-23.

You can use the ohmmeter to see if theres is a complete circuit. This measurement is called *continuity*. If you touch one ohmmeter lead to a wire disconnected from the power source going into a circuit and, at the same time, touch one of the leads to the wire coming out of the circuit and there is no current returning to the meter, it means the pathway between the two wires is broken.

The ohmmeter will read infinite resistance and there is no continuity. If, on the other hand, 1 amp of current returns for every volt applied to the circuit, there is no resistance. The ohmmeter will read zero. This is a short circuit. Any reading between zero and infinite is the resistance to flow for the circuit measured.

Unlike the voltmeter and ammeter, the ohmmeter must never be connected to a live circuit. It supplies its own power from its battery, and it will be damaged if outside current goes through it.

To use the ohmmeter, disconnect the power supply and isolate the line or device

being tested from other paths back to the source. Do this in case there is a capacitor (a device that stores electricity) in the circuit.

The ohmmeter must be zero adjusted before every test. Just touch the two test leads together creating a short circuit with zero resistance and use the zero adjustment dial. Most digital meters automatically zero adjust. If your meter will not read zero, the battery is too weak and must be replaced.

To test for resistance, disconnect L1 and L2 (H and N wires) from the power source and touch the two leads on either side of the component to be tested. If there is no resistance the reading will be zero. If there is no connection between the two points the resistance will be infinity. The digital meter will read OL (overload). A reading between zero and the maximum scale setting is the resistance between the connected points.

Not only must you isolate the circuit to be tested from the source, it must also be isolated from the rest of the circuit. Otherwise, you will get a false reading from the resistance of another load in a branch parallel circuit. Figure 8-24.

### **Electrical safety**

Electricity can be dangerous. It can create three hazards: fire, skin burns, and shock. Shock can cause muscle spasms, unconsciousness and even death.

Proper installation of all electrical equipment is essential. The National Electric Code<sup>®</sup> sets the standards. Local communities can make this code law, and in addition, they can make their own codes even more restrictive.

A common, but dangerous practice, is testing the oilburner ignition transformer with a screwdriver. The transformer is



putting out 10,000 volts and that can give you a dangerous and serious shock. Always use proper test equipment.

Be sure to verify that all capacitors are fully discharged before touching or working on them. To safely discharge a capacitor you will need a 20,000 ohm 5 watt resistor, two insulated screwdrivers and two jumper wires with alligator clips on both ends. Figure 8-25. Connect one jumper wire clip to one wire of the resistor and clip the other jumper wire to the other resistor wire. Connect the clips on the Figure 8-24: Common ohmmeter reading error, isolate the load to be tested

Figure 8-25: Safely discharging a capacitor



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The lower the wire number, the bigger the wire and the more amps it can carry. opposite ends of both jumper wires to different screwdrivers, hold the handles of the screwdrivers and touch the blades to opposite terminals of the capacitor.

Electric energy needs a pathway from the source and back to the source. If you do your job, this

pathway is our electric circuit.

Any wet object has enough minerals in the water to provide an alternate pathway. The human body is over 50% water, and when the skin is damp it will provide a good pathway back to the source if there is not an easier one. Never allow your body to be that pathway! Always consider all electrical components to be energized until you test and prove they are not. When you are working on electricity, remove all metal objects such as watches and jewelry from your hands and wrists. Until you are absolutely sure a circuit is shut off, only use one hand—keep the other in your pocket. This prevents the electric pathway from going from one hand to the other hand through your heart. Be sure to replace any damaged or frayed wires, protect wires from touching moving equipment, and keep them clear of walkways.

### Fire

Every wire has resistance and converts some electrical energy into heat. When current flows, the wire warms up and keeps getting hotter until it reaches steady state where the heat it loses to its surroundings equals the heat being created. If there is too much current being drawn by the loads in a circuit, the steady state temperature of the

### **Multimeter Tips**

#### Voltmeter:

Touch one lead from the meter to one side of the load or circuit to be tested and one to the other so the meter is parallel to what you are testing. This test is done on a live circuit. The reading is the difference in voltage from the spot where one lead is touching to the spot where the other is touching.

#### Ammeter:

Now, energize the circuit and the meter will tell you the amps traveling to that load or circuit. The clamp on ammeter is much easier and less intrusive to use. Close the clamp around the single wire you wish to test while the circuit is energized and it will tell you the amps flowing through that wire. The meter will read the amps through the wire cover, so this test need not be done on bare wire.

#### Ohmmeter:

Disconnect the hot and neutral wires from the power source and discharge any capacitors that may be in the circuit to be tested. The ohmmeter supplies its own power. Touch the leads from the meter to the wires you have disconnected from the power source and the meter will show the resistance of that circuit or load.

wire may be dangerously hot, creating a fire. This is called an overloaded circuit.

#### Common causes of overloads are:

- Too many devices on the circuit
- Devices working harder than they are supposed to
- Damaged or worn out devices
- Current surge when a motor starts

A short circuit causes a sudden excessive draw well beyond the capacity of the circuit. It happens if the resistance of the loads is removed, or there is a direct unrestricted current flow to ground, conductors touching grounded metal, or the source conductor is touching neutral.

### **Fuses and circuit breakers**

To protect against any circuit carrying too much current, every circuit needs a fuse or circuit breaker. It is wired in series so all the current in the circuit goes through it. These are automatic switches that open if the current goes higher than their rating.

Fuses are one time only devices. When they blow, they must be replaced. Circuit breakers can be reset and used repeatedly. Never used an oversized fuse or circuit breaker; this defeats the purpose of the fuse or breaker and may create a dangerous situation. You should find out *why* the circuit is drawing too many amps, causing the fuse or breaker to open.

### **Shock protection**

The electric shock from a 120-volt circuit is dangerous and can be fatal. A shock occurs when a person becomes part of an electric circuit. The severity of shock depends upon:

- · Amount of current
- Type of voltage (AC or DC)
- The path the electricity takes through the body
- Amount of voltage
- Time duration of the shock
- Condition of the skin

To protect from shock, electricity must be kept in the wire. Install the circuits so that in case the electricity escapes, it does no harm.

A shock is when an electric current passes through the body, causing spastic contraction of muscles. If it goes through the heart, it may kill.

Shocks happen when you touch a wire carrying lots of volts and some other part of your body is touching something at ground potential. Bare feet, especially when wet, are very dangerous. A dry human body is pretty resistant to electric flow, but a sweaty or otherwise wet one is a very good conductor. Rubber soled shoes insulate your body from ground and prevent the formation of a complete circuit.

Good insulation keeps the electricity inside the wire, but insulation may crack with age or high temperature and may also wear off if it is touching a moving part. So even if it was wired right at first, with age it may go bad and let electricity leak out, presenting a shock hazard.

To be sure that the electricity has an easy way to get home without going through you, install a ground fault protection system (GFI- Ground Fault Interrupter). Grounding provides a direct low resistance path from the circuit to ground. For example, suppose the insulation on the wire inside a burner motor cracks and the wire is touching the motor case. If you kneel down on a damp floor to work on the burner and you touch the motor with your hand, the current could flow through your body into the floor, and over to the ground rod from the house service—a complete circuit. This is a dangerous situation. To stop this from happening, run a ground (bare copper or green) wire from the burner back to the ground rod.

This pathway will offer much less resistance to the electricity than your body and the cellar floor and the current will go that way. Electricity is lazy; it will always go the easiest way, the path of least resistance. Figure 8-26.

All electric codes including the NEC— National Electrical Code<sup>®</sup>—call for careful grounding. Connections from one wire to another must be enclosed in insulation. Every switch, outlet, and appliance must be protected. All these devices should be connected to each other by grounding wires connected to a rod driven 10 feet into the earth. The ground wire is the third prong on plug-in devices.

To protect us, the ground wire must go from the load back to the panel without any breaks. The best way to check this is to touch one lead from your voltmeter to the either the hot or neutral wire and one to the ground wire. If the ground is good you will get the same reading as you would from hot to neutral.

# Stay on the lookout for potential problems

When troubleshooting a circuit, electric junction boxes often must be opened. This can be dangerous. Sometimes wires from more than one circuit might be hiding in a box. If you can, try to trace all the wires going into the box to see if more than one goes back to the service panel. The goal is to shut off all the electric wires going to that box before removing the cover.

If this is not possible then treat the wires in the box as if they were hot. While holding the cover plate, use an insulated screwdriver to carefully loosen the screws and ease off the plate. To test for power, use only one hand to gently pull out the wires so all connections are at least an inch apart. Unscrew the wire nuts and use your meter to test for voltage.

# Watch out for overcrowded junction boxes

Too many wires jammed into too small a box can cause shorts.

• Check for old and cracked insulation.

• Confirm polarization. White wires go to silver terminals. Black goes to brass. Be sure there is only one wire hooked to each terminal.

• Check armored cable connectors. The cut end of the metal cable can be sharp. To prevent the wire insulation from being cut be sure protective plastic bushings are installed at the cable ends.

### Safety tips

The Occupational Safety and Health Administration's (OSHA) electric safety regulations require that anyone doing electrical repairs must receive safety training. They also require that employers must adopt safe electrical work practices and that a lock out tag out must be used for hard-wired equipment that is de-energized.

The key to safety is to know the dangers of electricity and how to avoid hazards.

#### Figure 8-26



grounding wire has been installed from the frame of the motor to ground. Even though the winding is accidentally grounded to the frame, as prepresented by G, there is no shock hazard.



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### The following are some safety tips:

• Shut off the power!

• Stay focused! Even after turning off the power, work as if the wires are live.

• Post a sign on the electric panel and remote switch so no one will turn on the power while you are working on the circuit.

• Always check to be sure that the equipment being used is grounded.

• Always use insulated tools and be sure the insulation is in good condition. Use electrical tape on wire nuts and connections for added protection.

• Water on the floor is a good conductor—when working in wet areas, be sure to use protective equipment like rubber-soled shoes.

• Do not overload electrical circuits.

• Use extra caution with extension cords. Their insulation can be cut, and they can be overloaded leading to increased danger.

• Inspect heating equipment before starting repair to be sure it is de-energized.

• When inspecting a circuit, keep one hand in your pocket to prevent hand-to-hand shock.

### Lock out tag out

This procedure is used to be sure that no one turns on a switch and energizes electrical equipment while you are working on it. Use a tag or lock connected to the switch or circuit breaker to let other people know you turned it off on purpose and you want it to stay off. The only person who



should remove locks and tags is the person who put them there.

To do a lock out tag to OSHA's satisfaction, a lockout device and tag stating not to remove the lock should be placed over the circuit breaker, fuse box, or switch that will prevent a person from energizing the circuit.

It is difficult to put a lock on a stair switch. As an alternative to locking out a piece of equipment, tag outs can be used if it will provide an equivalent level of safety.

OSHA indicates that shutting off the equipment in two places will provide such equivalence. For example, if you shut off the circuit breaker and emergency switch at the top of the stairs and stick a note on both of them you have met the requirement. Obviously this procedure is very important if the circuit breaker and remote switch are in different rooms than the equipment you are working on. You do not want some helpful person thinking they found the problem with the heater and turning on the breaker in the other room while you are hooking the black wire from the primary control to the L1 wire.

### **Practical tips**

### Splicing wires

To splice wires first strip the wires with a wire-stripping tool. (Don't use a knife; it might nick the wire, reducing its electric carrying capacity.) Slip the wire into the correct hole in the stripper, squeeze, twist, and pull off the insulation.

Next hold the stripped wires together and grab the ends with lineman's pliers. Twist clockwise, making sure all wires turn. Twist them together like a candy cane into a neat looking spiral. Now snip off the



end leaving enough exposed metal so the wire nut will just cover it. (About a half inch is good.) Now slip on an appropriately rated wire nut as far as it will go and turn it clockwise until tight, Figure 8-27. Finally wrap electrical tape around

the bottom of the nut and wires.

#### Hooking wires to a terminal

Before you start, many devices come with the terminal screws unscrewed. Screw in any terminal screws for terminals you are not going to use. Now you are ready to hook up your wires.

Strip about three quarters of an inch of insulation from the wire end. Then using long nose pliers grab the wire just above the insulation and bend it back at about a 45-degree angle. Move the pliers up about a quarter inch from the insulation and bend again in the opposite direction about 90 degrees to start a loop. Now move the pliers another quarter inch and bend the wire into a question mark"?". Leave an opening in the end just big enough for the terminal screw. (You can buy a wirebending screwdriver to make this job easier.) Figure 8-28.

Figure 8-28. Make sure the terminal screw is unscrewed far enough, and then slip the loop over the screw threads, with the loop running clockwise. Use the long nose pliers to squeeze the loop around the terminal,

You should never attach two or more wires to one terminal screw. To make a multiple connection, make a "pigtail" wire by cutting a six-inch length of wire, strip both ends, splice the multiple wires to one end, and then attach the other end to the terminal screw.

# Armored cable

and then tighten the screw.

To cut armored cable, bend it about one foot from the end and squeeze the bend until the armor breaks apart slightly. If you have trouble, use a pair of channellocks to squeeze the wire. Figure 8-29.



Figure 8-28: Strap and wrap wire Grasp the cable firmly on each side of the break and twist the waste end clockwise until the armor comes apart enough for you to slip in cutters. If you have trouble doing this with your hands, use two pairs of pliers.

Cut through one rib of the armor with a pair of side-cutting pliers. Slide the waste armor off the wires. Remove the paper wrapping and plastic strips. Leave the thin metal bonding strip alone. Use side-cut pliers to trim away pointed ends of the sheathing that could nick a wire.

The next step is to slip the plastic bushing over the wires. Slide it down into the armor so it protects the wires from the sharp edges of the armor. If there is a bonding strip, cut it to about two inches and wrap it over the bushing and around the armor to ensure conductive contact between the armor and the box.

Option: If you plan to do a great deal of wiring, you might want to buy an armored wire cutter to speed up this job. Now attach the clamp (connector) to the cable. Remove the lock nut from the armor cable clamp and slide the clamp down over the bushing as far as it will go. Then tighten the screw.

Finally remove the knockout from the junction box, and poke the wire and connector into the hole. Slide the locknut over the wires, and thread it onto the cable clamp. Use a hammer and screwdriver to tap the locknut tight.



#### **Basic Concepts about Electric Circuits**

• Electricity must have a complete path from an electrical source through a load and back to the source.

• Conductors offer less resistance to electric current than insulators.

• Voltage is the electrical pressure difference between two points in a circuit that causes electricity to flow.

• Current is the rate of flow as measured in amps.

• Resistance is the opposition to flow measured in ohms or pressure drop.

• A load offers resistance to an electrical current. It determines the current draw for any voltage applied.

• The load will only draw enough current to overcome that resistance.

· Voltage applied is voltage consumed.

 It takes one volt to push one amp through one ohm.



### In case you are interested

In this chapter we have talked about what electricity does. We have not really covered what it is. That is because electricity can be confusing. However, some of you might be wondering what electricity actually is. So for those brave souls who want to know more, read on. If you are already hopelessly confused, you can stop reading now.

Everything contains electrically charged particles, both positive and negative. These particles make up the atoms that are the building blocks for everything in the universe. Atoms are really, really small. It would take several million of them, lined up, to reach across the dot at the end of this sentence. Each atom is electrically neutral because it contains equal amounts of positive and negative charge.

The positive charge of an atom is in the center, called the nucleus. The nucleus is made of protons that have a positive charge and neutrons that have no charge. The number of protons determines what kind of material the atom is. For example, hydrogen has one proton, and oxygen has eight.

Circling around the outside of the nucleus are electrons. They are sort of like planets circling around the sun. As in the solar system, there is a lot of empty space. The nucleus is like a marble sitting in the middle of a football field. Some of the electrons are at the back of the end zone. The electrons have almost no mass, but they carry a negative charge equal to the positive charge of the proton. So a neutral atom has as many electrons in the space surrounding the nucleus as it has protons inside it. The electrons are held close to the nucleus by the electric force of attraction between opposite charges.

In different kinds of atoms, the electrons farthest from the nucleus may be bound strongly or weakly. The ones that allow their electrons to escape easily are called conductors. The atoms that hang on tight to their electrons are insulators.

The flow of free electrons in a conductor is what we call electric current. If you throw a switch to turn on a lamp five feet away, it takes 40 minutes for the little electrons to fight their way through the conductor from the switch to the lamp. What turns on the lamp right away is a pulse, each electron pushing those ahead of it until the pulse reaches the lamp. The pulse travels almost at the speed of light.

If you are feeding the lamp with AC, it is not a pulse that travels but a wave. Each electron vibrates back and forth, passing its energy along to the next, just like molecules of air passing a sound wave or water in the ocean passing a wave.

