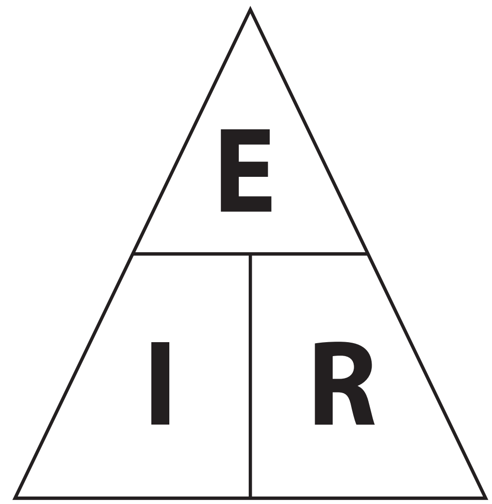
Ohm's Law



$$R = E \div I$$
$$I = E \div R$$
$$E = I \times R$$

$$P\ (\text{watts}) = E\ (\text{volts}) \times I\ (\text{amps})$$
$$Q\ (\text{energy}) = P\ (\text{watts}) \times t\ (\text{hours})$$

This common representation of Ohm's Law aids in remembering the position of the variables in the formula. E is voltage in volts. I is current in amps. R is resistance in ohms.

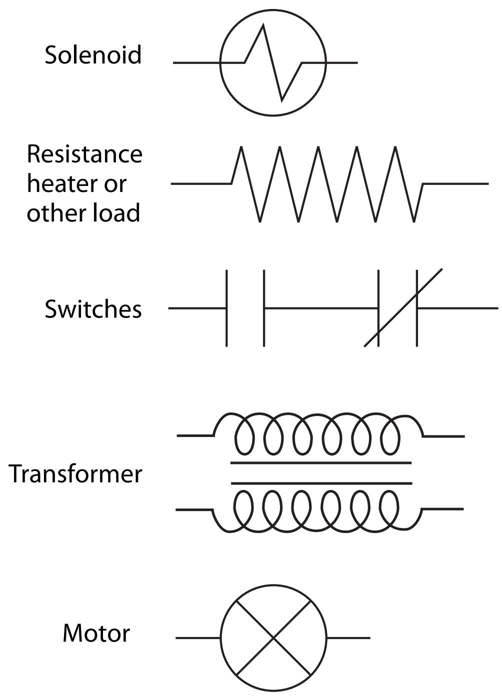
Electric Circuits and Devices

Electrical principles are presented next because electricity is so important to home energy use. Electricity is the most refined and versatile form of energy. It can be converted into light, heat, or motion. Electricity heats homes, spins motors, lights lamps, cooks, and entertains. Electric circuits providing heat, light, or motion are called *power circuits*. Electricity also regulates most energy-using devices — furnaces, water heaters, and major appliances — using *control circuits.*

An electrical generator pushes electrons through a metal wire, imparting them with electrical energy. Whenever an abundance of electrical energy exists in one area along with a relative lack of electrical energy in another, *voltage* (also called *potential difference*) exists between the two areas. Electricity flows from electrically charged areas to electrically neutral areas. The earth is electrically neutral and is used for the neutral part of circuits.

Most electrical generators are turned by rotating machines called turbines. A turbine is turned by pressurized steam, flowing water, or wind. Heat for the steam turbine comes from the combustion of oil, gas, coal, or thermonuclear reaction.

Electrical Symbols



These are common symbols used in electrical circuit diagrams.

An electric *circuit* consists of three essential parts: a source of electricity; a *path* for the electricity to flow; and a *load*, a device that uses electricity. Most circuits also have a *switch* to start and stop the flow of electricity. The switch creates an air gap in the hot wire of the circuit. We say that a switch is *open* if it is creating an air gap and stopping electricity, and *closed* if it is connecting the circuit.

Electrical Principles

The flow of electricity is described by a well-known formula called Ohm's Law — E (voltage) = I (current) x R (resistance). E stands for *electromotive force*, but is better known as voltage. *Voltage*, expressed in volts, measures the electrical pressure. *Amperes*, or amps, measures current — the flow of electrons. And resistance describes the circuit's opposition to current in units called *ohms.*

Current in amps multiplied by voltage in volts equals the power of the circuit in watts. And watts multiplied by time, in hours, equals watt-hours of energy. This simple relationship between current, voltage, power, and energy is true for electric-resistance devices like heaters and incandescent lights. However, actual energy consumption for motors, transformers, and other devices with coils is less than amperage times voltage because of an effect known as reactance, which is beyond the scope of this discussion.

Series Versus Parallel Circuits

Series circuits form a single looping path from the source to the load and back to the source. The electrical current is the same in all parts of the circuit. Series circuits control heating systems and simple appliances.

Several switches placed in series allow any of these switches to interrupt electrical current to the load. Therefore, a series control circuit can decide that both safety and necessity are present before connecting the load. Both the safety switch and control switch must be closed for electricity to flow to the load.

Parallel circuits form ladder rungs between the hot and neutral wires. In home wiring, each rung is a light, outlet, or appliance. In parallel circuits, voltage is the same on all rungs.

Several switches placed in parallel circuits allow any of these switches to connect a load. Heating and cooling systems often use parallel switches to start the blower — one switch for heating and one for cooling.

Control Circuits

Control circuits are often low-voltage circuits using transformers to step down the voltage. This lower voltage is safer for remote controls and requires smaller and less expensive switches, wiring, and control components. Newer appliances have electronic controls that use even less power than traditional low-voltage control circuits.

A control circuit employs a *controller*, like a thermostat, with a *sensing device*, like a bimetal spring or thermistor to control electric power to a *final control element*, like a gas valve, oil burner, fan, or pump. Controllers and sensing devices may be the traditional electromechanical or the newer electronic types.

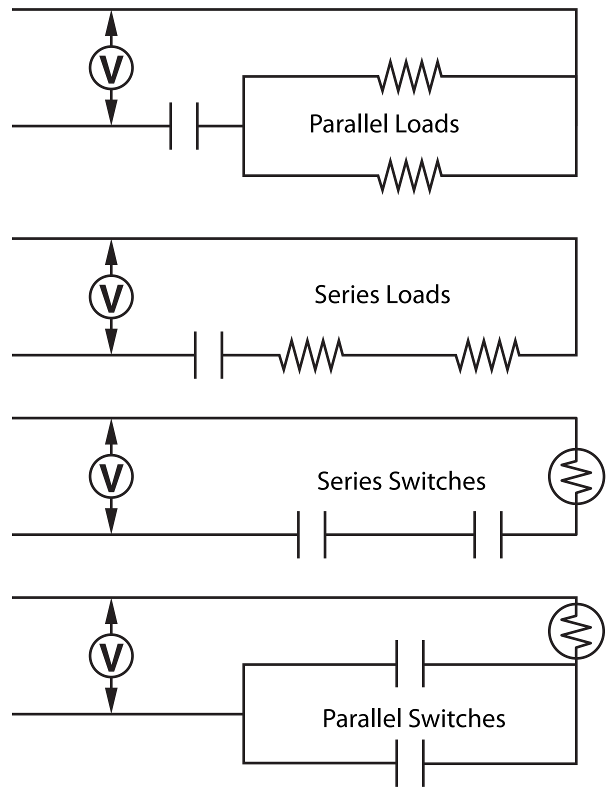
Transformers and Power Supplies

A *transformer* is a device that transforms or changes voltage from one circuit to another. Power companies use high voltage to transport electricity over long distances to reduce line losses, and then step voltage down with transformers to make it safe for local customers.

Step-down transformers within the home reduce voltage from around 115 volts to 24 volts for controlling heating and cooling systems. This lower voltage is safer and more convenient for installing the thermostat without having to run sheathed cable. Dedicated 24-volt controls provide more precise control of energy systems than their 115-volt counterparts.

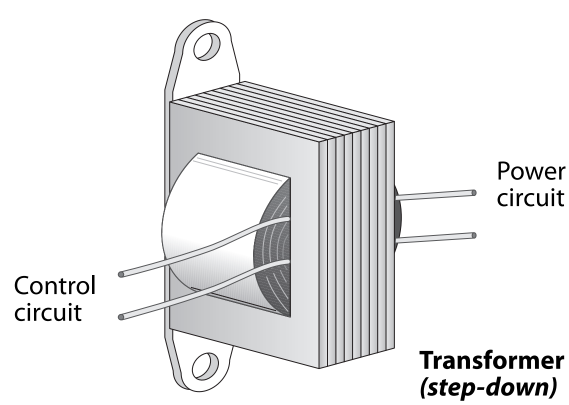
Electronic controls allow even more precise control than low-voltage electromechanical controls. An electronic power supply acts like a transformer to reduce voltages to levels required by the electronic sensing devices and microprocessors. A microprocessor is an electronic brain that can make decisions about control based on a number of inputs.

Types of Electric Circuits



These are the four possibilities for the arrangement of loads and switches in electric circuits.

Transformers

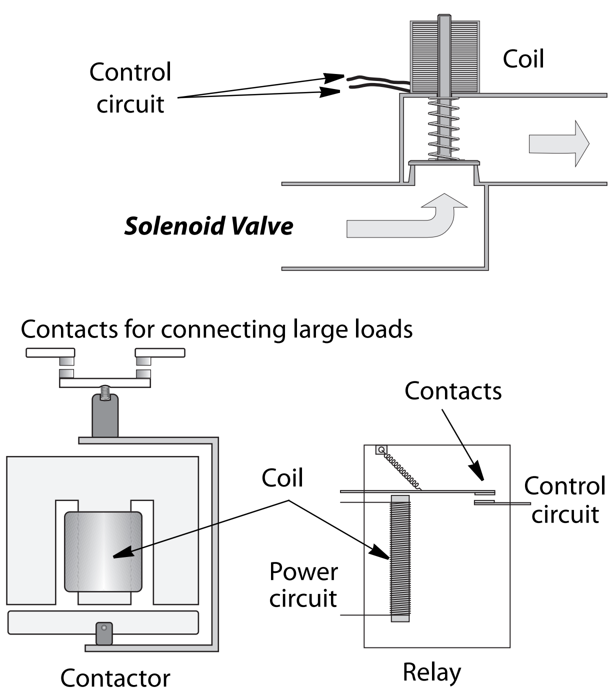


The transformer powers the control circuit to operate a relay for a solenoid valve via a thermostat, aquastat, or limit switch.

Solenoids

A wire coiled around an iron bar will magnetize it, causing it to move when electricity flows through the coil. This principle is called *solenoid action* and is used to open and close solenoid valves and switches called *relays* and *contactors*. An example of a solenoid valve is the automatic gas valve on a gas furnace. Relays are powered by the control circuit. Relays connect and disconnect loads like solenoids and small motors in the power circuit. Larger motors and electric heating elements require sturdier automatic switches called contactors.

Types of Solenoids



Solenoids can operate a switch, like a relay or contactor, or final control element, like a gas valve.

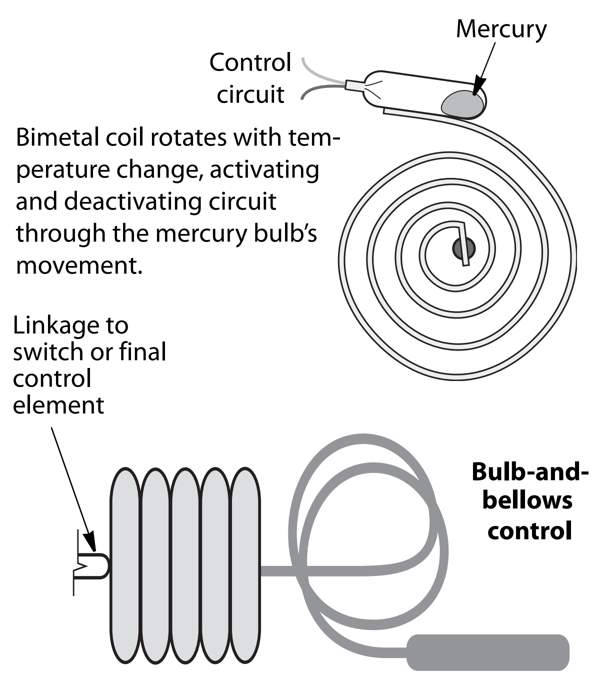
Temperature-sensitive Elements

Bimetal elements or bulb-and-bellows elements move electrical contacts or a valve stem in response to temperature changes. The most common devices using temperature-sensitive elements are thermostats and *limits*. Limits are safety switches that interrupt power if temperatures get too high.

Bimetal elements are temperature-sensitive metal coils and strips. A thermostat uses a bimetal element to turn the heating system on and off. The bimetal element is two thin metal pieces with different rates of expansion bonded together. It bends, rotates, or snaps inside out as the temperature changes. This motion is used to move a switch's contacts or a final control element.

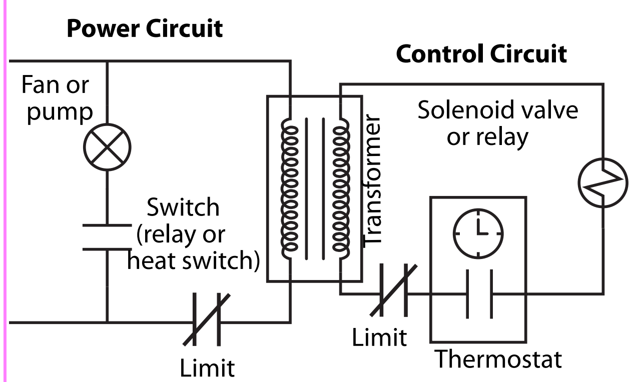
Bulb-and-bellows controls use the variation in volume of a liquid or gas to move electrical contacts or a final control element.

Electromechanical Heat Sensor



A bimetal coil or bulb-and-bellows mechanism can operate an electrical switch or a final control element like a gas valve.

Simple Heating Control Circuit



The transformer is a load in the power circuit and the source of electricity for the control circuit.

Variable Resistors

Variable resistance elements are a part of many electromechanical and electronic control systems. When electricity flows through an electric resistance wire, the electricity is converted to heat. This principle is used by tiny electric resistance heaters that are part of various control devices. Thermostats and electric furnace controls have small resistance heaters combined with their bimetal operators that serve as timers.

Copper wire coiled on a bobbin is also used to sense temperature because the wire's resistance varies significantly with temperature. Variable resistors, called *potentiometers*, are used to tune electronic circuits. Variable electronic resistors are discussed in the next section.

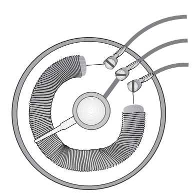
See "Heating Comfort Controls" on page 158 and "Electric Furnaces" on page 180.

Electronic Sensing and Control Devices

Electronic sensors and control devices are part of many sophisticated modern control systems. The most common electronic sensors found in residential control systems are *thermistors* and *photoresistors*. Thermistors sense changes in temperature and photoresistors sense changes in light level. A small sensing current runs from an electronic power supply to a *transistor* through a thermistor, photoresistor, or other electronic sensor, which serves as an automatic switch to activate or deactivate the transistor. The transistor works like a relay to start a burner, compressor, fan, or pump.

A microprocessor can store information entered by the user or collected from sensors for deciding how to operate the system. Electronic control systems are used on many modern heating systems, multifamily lighting and domestic hot water systems, sprinkling systems, and security systems.

Electronic Control Components

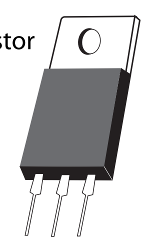


Circuit A
Common
Circuit B

Potentiometer

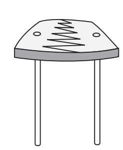
Potentiometer varies resistance in two circuits by adjusting a knob. Wound resistors like this one are also combined with bimetal elements and used as timers.

Transistor

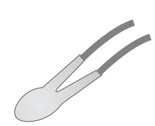


C E B

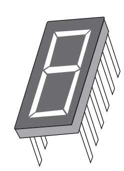
Transistors work like relays. A small current flowing from "C" to "B" allows a much larger current to flow from "E" to "B".



Photoresistor



Thermistor



Light-emitting diode number displays

Light-emitting diode indicator light

It's helpful to understand the functioning of components of electronic control systems.