Course SS103

Electrical Fundamentals

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1. Introduction to Electricity

The importance of electricity in our modern society is often taken for granted. Without electricity, the heating, cooling, and refrigeration industries would never have advanced beyond ice, saw dust, and the wooden locker.

This industry relies on electricity to power and control the components that maintain comfort in our homes and offices. It is for this reason that service technicians need to understand the principles of electricity and be able to troubleshoot these circuits.

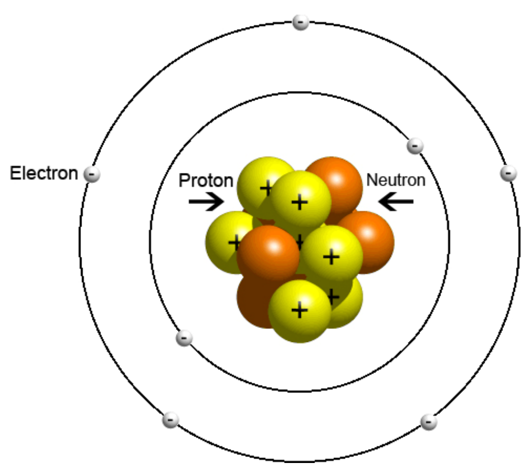
To begin the study, we'll start with atomic structure.

1.1. Atomic Theory of Matter and Electricity

All matter in the universe is composed of elements. To date, over 100 elements have been found in our universe. To break down the elements, we must look at the atom, which is the smallest particle of an element that can exist alone or in combination with others.

The center of an atom is the core or nucleus. The nucleus is composed of protons, which are positively charged particles, and neutrons, which are neither positively nor negatively charged. Atoms of the same element always have the same number of protons (called the atomic number), but the number of neutrons can vary with different atoms of the element. Atoms than contain a different number of protons and neutrons are called isotopes of the element.

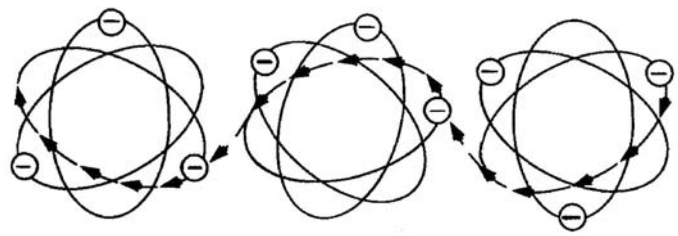
The other part of the atom is composed of electrons, negatively charged, which orbit the nucleus, very much like our moon orbits the earth.



Usually atoms have an equal number of protons and electrons. When this is true, the atom is considered electrically neutral. Under certain conditions, however, either gaining or losing an electron can unbalance an atom. When this occurs an atom can become either negatively or positively charged.

Metal's atomic structure has electrons that can easily be "knocked out of their orbits" around the nucleus. These free electrons and the materials (metals) are called conductors. When an atom loses its electrons, it becomes unbalanced and contains a positive charge. When this occurs the atom can easily attract and acquire additional electrons; this makes the atom negatively charged.

When this alternating state of positively then negatively charged particles exists, electrons can flow between the two opposing atoms. This flow of electrons is electrical energy or electricity.



1.2. How Electricity Is Produced

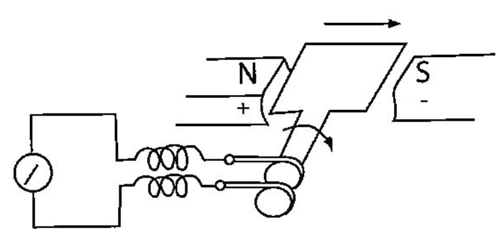
The movement of electrons or, as we refer to it, a "flow of electrons" is accomplished in several ways. The means most commonly related to HVAC will be discussed here.

1.2.1. Chemical

A battery produces a flow of electrons by a chemical reaction between two electrodes within the battery. Electrodes by definition are "solid conductors through which an electric current can pass." One electrode in a battery "gives up" the electrons whereas the other electrode "collects" the electrons. The electrodes are constructed of dissimilar metals. When encased within an electrolyte, such as an acid or paste, electricity is produced by the chemical reactions of the electrolyte and conductors. Batteries produce Direct Current (DC), which is electron flow in one direction only.

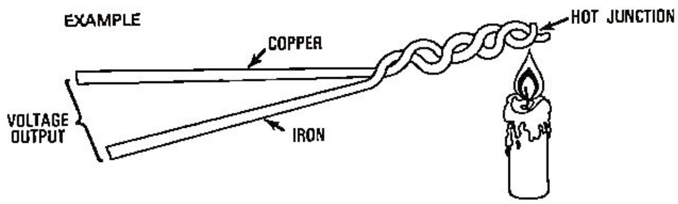
1.2.2. Magnetic Induction or Electricity by Magnetism

Magnetic Induction is the most widely used form of electricity generation. This is accomplished by rotating magnets within a coil of wire, whereby the lines of force within the coil cause an alternating current (AC) to flow within the wire. These magnets break the lines of force within the coils of wire and induce alternating current (AC) to be produced. This method of electrical generation is what powers our homes, our offices, and the heating and air conditioning equipment that maintains our comfort.

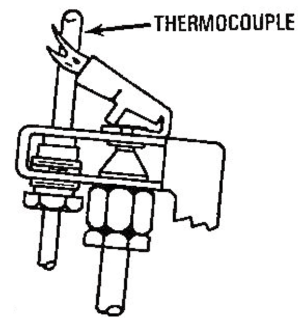


1.2.3. Heat

If two dissimilar metals are joined together at one end and their junction is heated, a small amount of voltage will be produced.



The heat from the pilot flame is the source of heat that causes the thermocouple to create a small amount of DC voltage. This DC voltage of approximately 30 mv (millivolts) energizes the small coil in the gas valve (pilot valve), holding the pilot valve open to allow gas to flow. If the flame for any reason is blown out, the heat will be removed from the thermocouple, causing the pilot valve to close.



1.3. Conductors and Insulators of Electricity

The movement of free electrons from one atom to another is facilitated by the characteristics of a good conductor. Most metals are conductors of electricity, but all metals do not conduct electricity equally. Metals that are good electrical conductors are copper, aluminum, and silver. Copper is most widely used because of its lower cost. Silver is a better conducting metal but is most often used only on the surface of contacts in switching devices such as relays or motor starters (contactors) because of its much higher cost.

Insulators are materials that do not easily give up or "take-on" free electrons. Examples of insulators are glass and rubber. How well any insulator works is directly dependent upon the strength of the electrical potential applied—in other words, how high the voltage value is.

No matter how good an insulator is, certain conditions can exist whereby an insulator will fail. If the electrical potential exceeds the insulating characteristics of the insulator or the amount of current exceeds the rating of the conductor, the insulator will fail due to high pressure or high heat, respectively.

The importance of conductors and insulators cannot be understated. Without good conductors or insulators, the circuits necessary to operate and control the components of an HVAC system could not exist.

1.4. Electric Potential (Voltage)

Voltage (represented with the symbol "E") is the pressure behind electron flow. Naturally if there is no pressure, there is no reason for electrons to move. The volt measures the pressure of electricity. Keep in mind that pressure alone does not indicate the total amount of energy being used. Just as with a water pipe, you can have pressure without flow when it is turned off.

Everyone has experienced a drop in water pressure when additional faucets are opened. The same concept can be applied with electricity when the demand of usage exceeds the capabilities of the incoming supply. Sometimes when a large load starts, the lights will dim for a second. The pressure (voltage) of electricity is dropping when this occurs. Systems that run on a higher voltage level have the capability of using more total energy because of the higher pressure, but the usage is determined by the load doing the work.

1.5. Current Flow (Amperage)

Amperage (represented with the symbol "I") measures the flow of electrons and is referred to as current. In order for the current to flow, there must be a complete path from the power source to the load and back. These pathways for electricity are called circuits.

There are two types of electrical current: Direct Current (DC) and Alternating Current (AC).

- **Direct current** is the flow of electrons in one direction. Outside the source, direct current flows from the negative potential to the positive potential. Direct current is seldom used in powering HVAC equipment; it is, however, used in control or sensing circuits.

- **Alternating current** flows in two directions. It flows back and forth between the source and the load, changing directions 60 times a second in domestic applications. This change in direction is referred to as frequency and is measured in hertz.

The current in both direct and alternating circuits is measured in amperes (represented by the symbol "A"). Amperes are measured with an ammeter. In small amounts, amperes are measured in either microamps (millionths of an amp) or milliamps (thousandths of an amp). In larger amounts amperes are measured in kiloamps (thousands of amps).

- 1microamp (μ) = 0.000001
- 1 milliampere (m) = 0.001
- 1 kiloamp (k) = 1000

The importance of measuring amperes is to help the technician in determining the correct operation of the equipment being serviced. All electrical devices, when energized, draw electric current. These electrical devices require a certain amount of current. When we compare actual current draw to rated current draw, a determination can be made as to the health and load of the electrical component.

1.6. Resistance (Opposition to Current Flow)

Resistance (symbol "R") is the opposition to current flow and is measured by the "Ohm." Like a long water pipe, there is some resistance in the conductors of electricity. If you run an extension cord down the street to a neighbor's home, there will be some pressure drop (voltage drop) when you energize a large electric load. This voltage drop is due to the resistance in the wire. As long as the pathway (wire) is sized correctly, there should only be a minimal voltage drop.

1.7. Wattage (Electric Power)

Wattage (symbol "W" or "P") is the measurement of electric power, which is the rate at which electrons do work. One watt is equal to the power generated by one ampere of current driven by one volt. The total power consumed is measured by the watt. Electricity is sold to the consumer by the kilowatt hour (1000 watts).

There are two formulas you need to remember relevant to wattage:

- 1 Watt = 3.413 BTUHs of heat
- 1 Horsepower = 746 watts

1.8. Ohm's Law

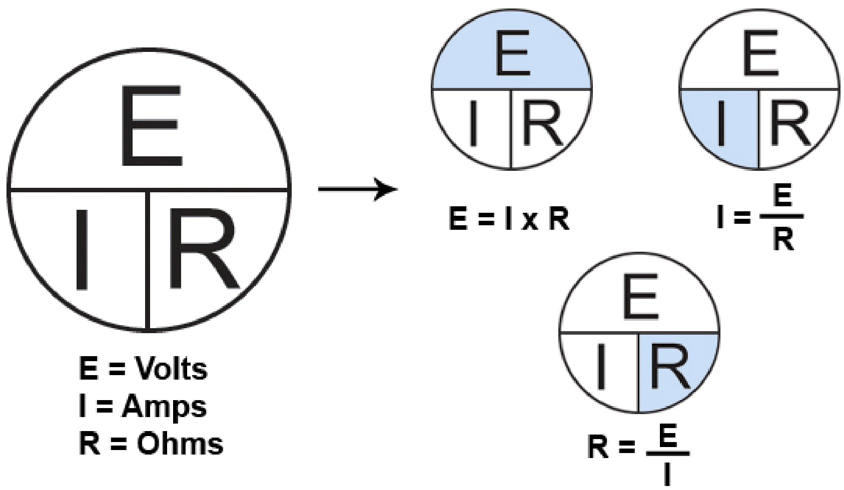
Ohm's Law shows the mathematical relationship between **voltage**, **current**, and **resistance**. In order for you, the technician, to use a current measurement to help in determining the "health" of an electrical component (in the previous section), you must have a formula for determining how much current can be measured in a circuit when a voltage is applied to a known resistance. Ohm's Law does this for you.

The key to using Ohm's Law is knowing any two of the three elements. When voltage and resistance are known, current can be found. Likewise, when current and resistance(s) are known, voltage can be determined for a circuit or voltage drop across a component in a circuit.

Ohm’s law is expressed with the following formula:

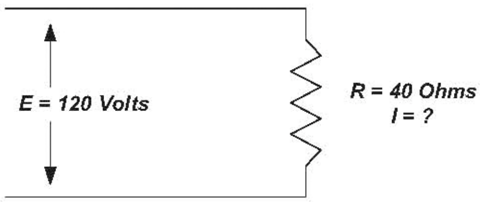
$$I = E / R$$

(current = voltage / resistance)



Example 1

What is the current in the depicted circuit?



1) When finding current use: ***I = E / R***

2) Determine the applied voltage from the diagram.

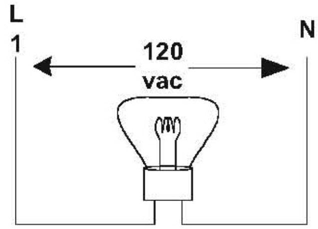
3) Determine the resistance of the single resistor load in the circuit.

4) Divide voltage by resistance using the formula. ***I = 120 / 40***

5) The answer is: ***I = 3 amps***

Example 2

What is the resistance of a bulb with 120 volts and the measured current is .80 amps?



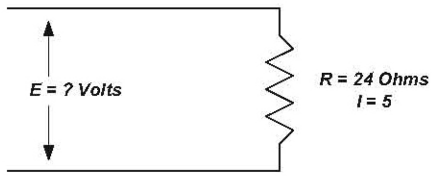
1) When finding resistance use: ***R = E / I***

2) Take the 120 volts and divide it by .80 amps: ***R = 120 / .80***

3) The answer is: ***R = 150 Ohms***

Example 3

How much voltage is supplied to the depicted circuit?



1) When solving for voltage use: ***E = I x R***

2) Determine the measured current from the diagram: ***I = 5***

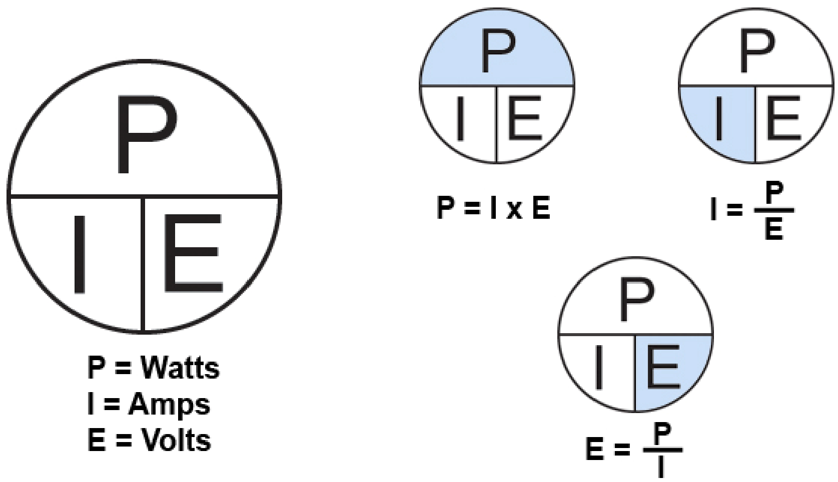
3) Determine the measured resistance of the single resistor load: ***R = 24***

4) Multiply current (I) x resistance (R): ***E = 5 x 24***

5) The answer is: ***E = 120 volts***

1.9. Watt's Law

Electric power is the rate at which electron flow does work. Electric power (watts) can be calculated by using the Watt's Law formula. This formula, ***P = I x E***, allows the technician to determine wattage or electric power by measuring current in the circuit and applied line voltage. Taking the formula, you multiply current times voltage, and electric power or wattage is determined.



In HVAC, resistive heaters and motors consume power. To measure their power, we must use conversions. One horsepower is equal to 746 watts. One watt is equal to 3.413 BTUH (BTUs per Hour).

To convert watts to BTUs, we must use Watt's Law and the conversion. Here's an example: Two heating elements each receive 240 VAC. The total current measured on both elements is 41.5 amperes. Using PIE we calculate watts.

1) P = I x E

2) P = 41.5 x 240

3) P = 9960

4) BTUs = P x 3.413

5) BTUs = 9960 x 3.413

6) BTUs = 33993

Two additional formulas in Ohm's Law use reciprocals to calculate electric power. Watts (P) can be found by squaring the measured voltage and dividing it by the measured resistance. The other method allows you to square the measured current and multiply it by the measured resistance. These two formulas are shown below.

- $P = E^2 / R$
- $P = I^2 x R$

The following examples will show you how to use the PIE formula and the two reciprocal power calculating formulas.

Example 1

How many amperes of current will be measured on a 5000-watt element with 240 VAC applied?

1) When solving for current, you choose: $I = P / E$
2) Take the 5000 watts and divide it by 240 volts: **5000 / 240**
3) The answer is: ***I*** **= 20.83 amperes**

Example 2

How many volts are applied to a circuit with a rated 7500-watt element and measured current of 31.5 amperes?

1) When solving for E (Volts) choose: $E = P / I$
2) Take the rated 7500 watts and divide it by the amperes: **7500 / 31.5**
3) The answer is: ***E*** **= 240 volts**

Example 3

How many watts of power are produced with 240 volts and an 11.5 resistive element?

1) When solving for P (Watts) and only voltage and resistance are known, choose the formula: ***$P = E^2 / R$***

2) Take the rated voltage of 240 and square it: **240 x 240 = 57,600**

3) Divided the product of 2402 by the resistance of 11.5 ohms: **57,600 / 11.5 = 5008**

4) The answer is: ***P*** **= 5008 watts of power**

Example 4

How many watts of power are produced when measured current is 25 amperes and measured resistance is 9.6 ohms?

1) When solving for P and current and resistance are known, choose the formula: ***$P = I^2 x R$***

2) Square the current: ***I^2*** **= 25 x 25 = 625**

3) Multiple the product of ***I^2*** by the resistance = **625 x 9.6 = 6000**

4) The answer is: ***P*** **= 6000 watts of power**

1.10. Review

Electricity is literally the driving force of the heating and cooling industry. To understand electricity, we looked at its foundation. All elements are made up of atoms. An atom's core, or nucleus, is composed of neutrons and protons. Orbiting these atoms are the electrons. When the electrons and protons are in equal number, an atom is said to carry a neutral charge. It is when an atom loses or gains electrons that the atom becomes either positively or negatively charged. The law of charges states that like charges repel and unlike charges attract. Examples of like charges repelling are represented by a (+) and (+) or a (-) and a (-). Unlike charges would be rated as a (+) and a (-) charge attracting the other. Metals can be made to attract these unlike charges. As a result, current can be made to flow.

We also learned that electricity can be produced chemically within a battery. Voltage produced by a battery is direct current, which is current that flows in one direction only from a negative potential to a positive potential. Electricity can also be produced by rotating magnets within coils of wire. This method creates an alternating current. In the USA and Canada, electricity is generated at a frequency of 60 Hertz; that is, current within a circuit changes direction 60 times per second. In the residential and light commercial HVAC industry, we use alternating current in values of 24 VAC, 120 VAC, and 240 VAC. Last, we saw that electricity can be produced through applying heat to a junction of two dissimilar metals. These devices are referred to as thermocouples. They produce electricity in the millivolts range, which is thousandths of a volt DC.

In the section covering conductors and insulators, we learned which metals were good conductors of electrons. We saw that copper was used for its good conductivity and low cost. We also saw that silver was a better conductor, but because of its much higher cost is used on a limited basis. We learned the characteristics of a good insulator. Typically rubber and glass are used to insulate the conductors that are used in electrical wiring and electrical circuits.

Finally we learned about four factors that are present in any circuit. These factors are:

1) Electromotive force, which is the pressure of voltage.

2) Current is the movement of electrons, measured in amperes.

3) Resistance is the opposing force to current flow in an electrical circuit. All loads, such as motors and elements, have some resistance. Resistance is measured in ohms.

4) Power was the rate at which the electrons do work. It is measured in watts.

Ohm's Law pulled the four factors together by showing the mathematical relationship of these factors and how easily a service technician can apply it.

1.11. Review Questions

1) What is the smallest particle of an element that can exist alone or in combination?

    a) Atom
    b) Electron
    c) Proton
    d) Neutron

2) The movement of free _________ is the basis for electrical current flow.

    a) Atoms
    b) Electrons
    c) Protons
    d) Neutrons

3) Which metals are commonly used in electrical circuits?

    a) Copper
    b) Aluminum
    c) Silver
    d) All the above

4) Insulators are materials that do not easily give up or "take on" free electrons. Which materials below are good insulators?

    a) Silica
    b) Glass
    c) Rubber
    d) Both b & c

5) Electricity can be produced in which of the following methods?

a) Heat

b) Magnetic Induction

c) Chemical

d) All the above

6) _________ current flows in one direction only. It flows outside the voltage source from a _________ potential to a _________ potential.

a) Direct, Positive, Negative

b) Alternating, Negative, Positive

c) Direct, Negative, Positive

d) Alternating, Positive, Negative

7) Electromotive force is the "pressure" behind the flow of electrical current. It is measured in __________.

a) Current

b) Resistance

c) Volts

d) Watts

8) The flow of Electrons in an electrical circuit is measured in _________.

a) Current

b) Resistance

c) Volts

d) Watts

9) The opposition to electrical current flow is measured in ___________.

   a) Current

   b) Resistance

   c) Volts

   d) Watts

10) Electric Power is the rate at which electron flow does work. The amount of work done is measured in ___________.

   a) Current

   b) Resistance

   c) Volts

   d) Watts

11) Ohm's Law shows the mathematical relationship between voltage, current, and resistance. Which of the following formulas apply to Ohm's Law?

   a) I = E / R

   b) R = E / I

   c) E = I x R

   d) All the above

12) Watt's Law shows the mathematical relation between wattage, current, and voltage. Which of the following formulas apply to Watt's Law?

   a) P = I x E

   b) I = E / R

   c) E = I x R

   d) All the above

13) How many amperes will be measured on a circuit with a 5000-watt heater with 235 volts applied?

a) 15

b) 21

c) 1,175,000

d) 11.045

14) What is the applied voltage on an electric heater that is drawing 24 amperes of measured current and has a resistance of 10 ohms?

a) 120 volts

b) 240 volts

c) 2.4 volts

d) 24 volts

15) How many watts of power are produced with 240 volts applied to a 7.75-ohm heater?

a) 30.96

b) 1860

c) .032

d) 7432

16) How many BTUs of heat can be produced from 10,000 watts of heater power with 235 volts applied?

a) 42.5

b) 3.413

c) 34,130

d) 5.52

2. Electrical Circuits

The knowledge of electrical circuitry in all heating and cooling systems is critically important to the technicians who install and service comfort equipment. Air handlers, condensers, heat pumps, and gas heating units all contain various types of circuits, each designed to do a specific job. The two most important kinds of circuits found in comfort equipment are the series circuit and the parallel circuit.

- **Series circuits** are electrical circuits with only one path for current to flow. They are often used for devices that are either control or safety oriented. An example would be a safety switch that opens when heat exceeds its rating, turning off the component(s) that generate the heat.

- **Parallel circuits** have more than one path for current to flow. Each branch of the parallel circuit receives source voltage. Each branch has a load that performs a specific task. For example, the condenser fan motor and compressor in a condensing unit both receive source voltage, and each has a specific task.

- **Series-Parallel circuits** combine these two types of circuits. These combination circuits are usually comprised of a switch or switches wired in series with two or more parallel circuits. When the switch opens, the components are disconnected. An example would be the contactor wired in series with the condenser fan motor and compressor that are wired parallel.

As a service technician, you must understand the circuits of comfort equipment in order to install and service this equipment. In the next section, we will take a closer look at the make-up of electrical circuits.

2.1. Electrical Circuit Basics

What is an electric circuit? An electric circuit combines source voltage, a load (such as a motor or element), and connecting wire to make a path of current flow.

- **Closed Circuit:** When the circuit is complete and current can flow from the source through the connecting wiring, to the load, and return to the source, it is said to be a "closed circuit," allowing work to be done.

- **Open Circuit:** When that same current path is broken or interrupted and no current can flow, it is referred to as an "open circuit," and work cannot be done.

When the attached loads of these circuits are fan motors, compressors, and heating elements, the HVAC equipment can cool or heat the air. When we combine automatic switches powered by low voltage, such as thermostats, we can control the sequence of operations to make the comfort equipment "stand alone."

2.2. Source Voltage

Source voltage is the supply voltage that is wired to the cooling or heating appliance. In the residential heating and cooling industry, we usually use 120 VAC (*Volts Alternating Current*) for gas heating and 240 VAC for air conditioners, air handlers, and heat pumps.

2.2.1. 120 Volt Circuits

How do we get 120 volts to a gas heating product? From the home electrical panel, where either fuses or circuit breakers are installed, we bring three wires to the receptacle.

- The black wire is electrically "hot" and is attached to the load side of the fuse or circuit breaker.
- The white wire is attached to neutral terminal buss in the service panel.
- The green wire is the ground wire. We attach the green wire to the ground terminal buss in the home service panel.

At the receptacle we attach the wires accordingly.

- The black (hot) wire is attached to the short vertical terminal of the receptacle.
- The white (neutral) wire is attached to the long vertical terminal of the receptacle.
- The green (ground) wire is attached to the green ground screw, which is the bottom, round hole in the 15 amp receptacle.

2.2.2. 240 Volt Circuits

When wiring 240 volts to an air conditioner or other 240 VAC component of an air conditioning system, three wires are also run from the home electrical panel to the 240 volt service panel for the air conditioning component.

Typically, this is how it is wired:

- A red (hot) wire is run from the L1 side of a dual, 240 volt circuit breaker.
- A black (hot) wire is run from the L2 side of the dual, 240 volt circuit breaker.
- A green (ground) wire is run from the Ground Terminal Buss.

At the service disconnect panel for the 240 VAC air conditioning components, the opposite ends of the three wires are wired.

- The red (hot) wire attaches to the L1 line side of the disconnect switch.
- The black (hot) wire attaches to the L2 line side of the disconnect switch.
- The green (ground) wire is attached to ground lug in the service disconnect panel.

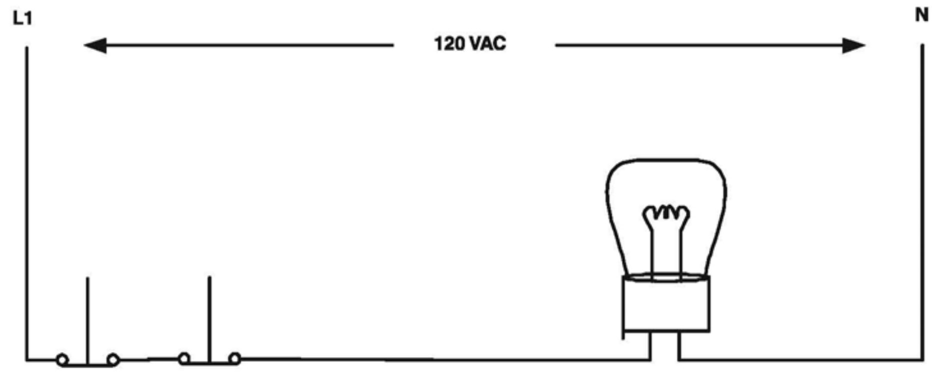
When the installer attaches the electrical wires from the 240 VAC air conditioning component, he or she will attach the red wire to the red wire load terminal, the black wire to black wire load terminal, and the ground wire to the ground terminal Buss in the Disconnect Panel.

Although in 240 volt systems the wiring is usually connected as previously listed, line 1 and line 2 are interchangeable. Many times, 240 volt circuits use the same color wire and no attempt is made to identify line 1 from line 2.

2.3. Series Circuits

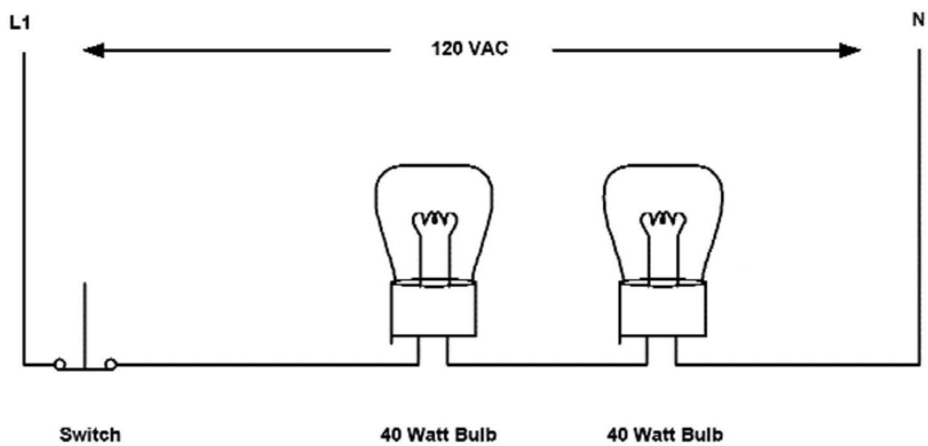
The easiest circuit to understand is the series circuit. Within a series circuit, there is only one current path, meaning that the current within that circuit must pass through each component of that circuit for it to function. The series circuit is often used to control one or more loads by wiring switches or controls in series with the loads.

The diagram below shows a typical series circuit with two switches wired in series, controlling the load. If either switch opens, the current path to the load will be interrupted and the circuit will be de-energized. In circuits with series controls, all of the switches must be closed for the load to operate.



Series Switches Controlling One Load

In addition to having one or more switches wired in series with a load, two or more loads can be wired in series as well. When this occurs, both loads will be sharing total supply voltage, based upon the resistance of each of the loads. If the resistance in each load is the same, then the voltage will be divided equally. If the resistance of one load is considerably higher than the resistance of the second load, the load with the higher resistance will receive the higher voltage across that load. Example: If one of the loads has half of the total circuit resistance, it will receive half of the total circuit voltage.



Series Loads of Equal Wattage and Resistance

2.3.1. The Rules for Series Circuits

When two or more resistive loads are wired in series, there are "Rules to Remember." The **Rules for Series Circuits** are:

1) The current remains the same throughout the series circuit.

2) The voltage will be divided in proportion to the resistance of each load.

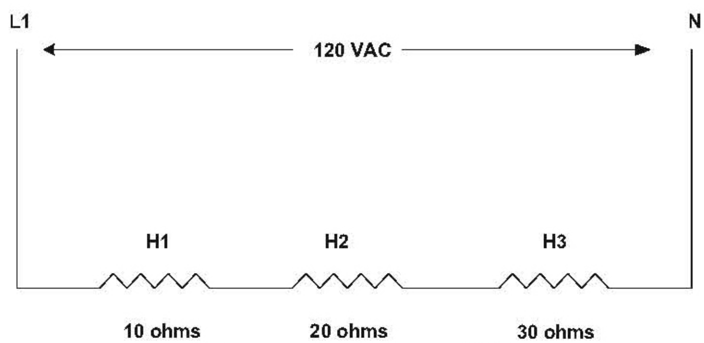
3) If any of the series loads fail (opens), all loads will stop working.

4) Total resistance of the series circuit will be the sum of all resistances in the series circuit.

5) The sum of the voltage drops across each resistive load is equal to applied or source voltage.

2.3.2. Calculating Current, Resistance, and Voltage in a Series Circuit

In the diagram below we have three resistive heaters wired in series. Each of the heaters has different resistance values. When voltage is applied, remembering Rule 2 above, the voltage will be divided in proportion to the resistance. The amount of voltage across each heater will be different. This voltage is referred to as a voltage drop. A voltage drop is the voltage used in the process of moving the current through that part of the series circuit.



Series Loads of Unequal Values

Each heater consuming part of the voltage causes a voltage drop to the other heaters.

In the diagram above, let's calculate the voltage drops across each heater.

- Step 1:
  To determine voltage drop, you can use Ohm's Law. Ohm's law states that voltage equals current times the resistance. The formula is: $E = I \times R$

- Step 2:
  Determine the total resistance in the circuit. Rule 4 reminds us that total resistance in a series circuit can be found by adding. Therefore, $R_1 + R_2 + R_3 = R_T$

- Step 3:
  Substituting the resistance values of the three heaters, we add: **10 + 20 + 30 = 60 Ohms**

- Step 4:
  To determine current flow in the circuit, we have to use Ohm's Law again. To solve for current, the formula is: $I = E/R$

- Step 5:
  Using the formula: **I = 120 / 60 = 2**

- Step 6:
  Now that we have determined total current, we can find the voltage drop across each resistance by using the formula: ***E = I x R***

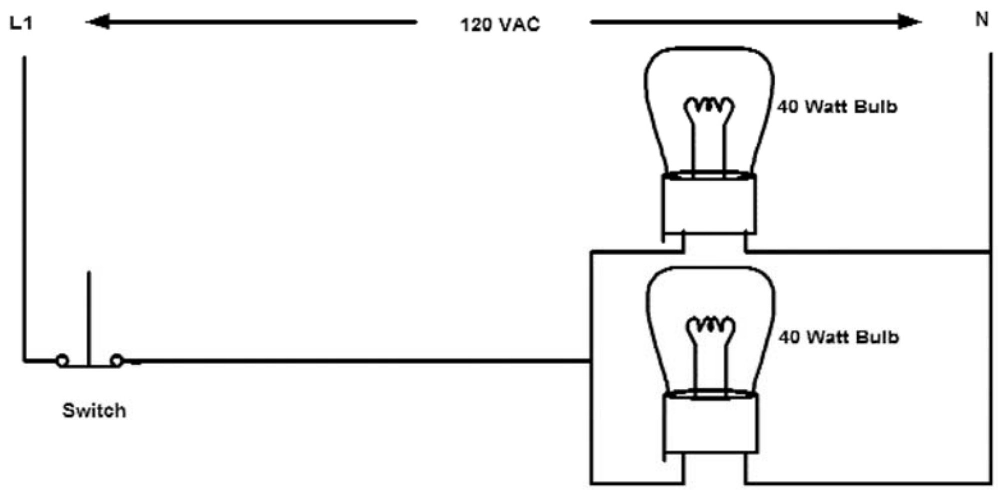
- Step 7:
  The voltage drop across H1 (Heater 1) is: $\mathbf{E_{H1} = I \times R_{H1}}$
  Substituting 2 for the current and 10 for resistance of Heater 1, we can solve for
  $\mathbf{E_{H1}}$ **= 2 x 10 = 20 volts dropped across** $\mathbf{H_1}$

- Step 8:
  Doing the same for $\mathbf{H_2}$ (Heater 2) and $\mathbf{H_3}$ (Heater 3), we find:
  $\mathbf{E_{H2}}$ **= 2 x 20 = 40 volts dropped across** $\mathbf{H_2}$
  $\mathbf{E_{H3}}$ **= 2 x 30 = 60 volts dropped across** $\mathbf{H_3}$

- Step 9:
  When we add the voltage drops, Rule 5 applies: **20 + 40 + 60 = 120**
  The sum of the voltage drops equals source voltage.

2.4. Parallel Circuits

In the introduction to Electrical Circuits, we stated, "Parallel circuits have more than one current path." As we discussed in the introduction, the majority of electrical components in a heating or cooling product are arranged in parallel so that each component will receive source voltage. In the following example, both loads receive the source voltage of 120 VAC and are thus wired in parallel. The total amperage is the sum of amps in each load circuit.



Remember: *In order for the loads in heating and cooling products to receive source voltage of either 120 or 240 VAC, they must be wired in parallel!*

2.4.1. The Rules for Parallel Circuits

When two or more resistive or inductive loads are wired in parallel, these are the "Rules to Remember."

1) All loads receive full line voltage (source voltage).

2) The total amperes in the circuit are the sum of the individual amperes measured in each branch of the parallel circuits.

3) Each load operates independently of the others. If one load fails, the others will continue to work.

4) Total resistance of all branches in parallel is less than the smallest branch's resistance. (*Total resistance is less than the least!*)

2.4.2. Calculating Current, Resistance, and Voltage in a Parallel Circuit

Since all loads receive line voltage, calculating voltage is not necessary in parallel circuits. Amperes are determined by the applied voltage divided by the loads' resistance. Total amperes are the sum of the amperes measured in each branch. The only element that requires calculation is total resistance.

As resistances are added in parallel, the total resistance for the parallel circuits decreases. The following is a formula for determining total resistance of two resistances in parallel.

The formula is:

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

Remember: *Total resistance in a parallel circuit cannot be determined by adding their values. Total resistance must be calculated!*

When more than two resistances are in parallel, another formula applies. The reciprocal formula states: "Total resistance is equal to the sum of the reciprocals[2] of all resistances."

This formula is:

$$R_T = 1/R_1 + 1/R_2 + 1/R_3$$

When adding reciprocals, you must find a common denominator[3] for all numbers. Once this is found, the fraction must be converted to the common denominator. Once the fractions with common denominators are added, you must invert and divide the new fraction to get total resistance.

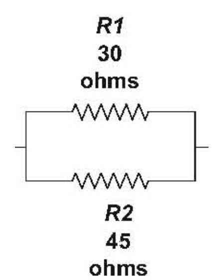
[2] *The reciprocal of a number is one divided by that number (for example, for the number* ***x****, its reciprocal is* ***1/x****).*

[3] *The denominator is the "bottom" number (for example, in* ***1/x****, the denominator is* ***x****).*

Let's apply this new information to some examples.

<u>**Example 1**</u>

Find the total resistance in this diagram.



1) Since there are only 2 resistances in parallel we can use the formula:

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

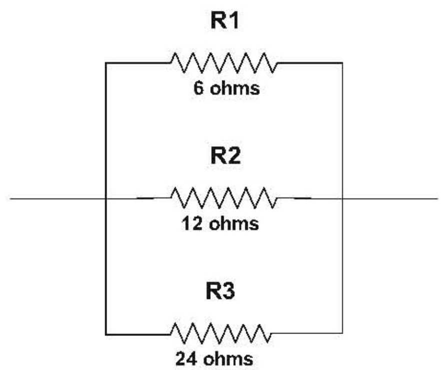
2) Looking at the diagram, we see the following values: $\mathbf{R_T = 30, R = 45}$

3) Substitute the values in the formula:

$$R_T = \frac{30 \times 45}{30 + 45} = \frac{1350}{75} = 18$$

Example 2

Find the total resistance in a parallel circuit with 3 resistances. The first branch has 6 ohms, the second branch has 12 ohms, and the third branch has 24 ohms.



1) Choose the formula of reciprocals. The formula is:

   $\mathbf{R_T = 1/R_1 + 1/R_2 + 1/R_3}$

2) Substitute the R values from the description above.

   $\mathbf{R_T = 1/6 + 1/12 + 1/24}$

3) Find a common denominator for the 3 resistance values. The number is 24.

4) How many times will 6 go into 24? Answer is 4 = 4/24

   How many times will 12 go into 24? Answer is 2 = 2/24

   How many times will 24 go into 24? Answer is 1 = 1/24

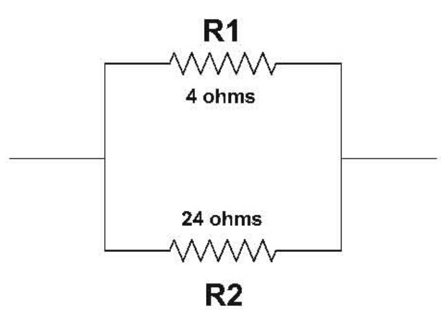
5) Add the following: 4/24 + 2/24 + 1/24 = 7/24

6) Invert the fraction and divide. 7/24 becomes 24/7

7) $\mathbf{R_T = 24/7 = 3.428}$

Example 3

Can you find total resistance in Example 2 while using the formula for two resistances in parallel? Yes, you can!



1) Find the resistance of R_1 and R_2.

   $$R_T = \frac{6 \times 12}{6 + 12} = \frac{72}{18} = 4$$

2) The effective value of R1 and R2 now becomes 4. When we redraw the diagram, it shows two resistances in parallel. One is 4 and the other is 24.

3) Find the value of 4 and 24.

$$\mathbf{R_T = \frac{4 \times 24}{4 + 24} = \frac{96}{28} = 3.428}$$

2.5. Series-Parallel or Combination Circuits

When we use combination circuits as control circuits, there will be one or more switches wired in series, with two or more loads wired parallel.

We have two switches that must be closed before 120 volts is applied to the two loads wired in parallel. If either switch opens, both loads stop functioning. With both switches closed, if the top load failed to open, the bottom load would continue to receive 120 volts and it would continue to operate independently.

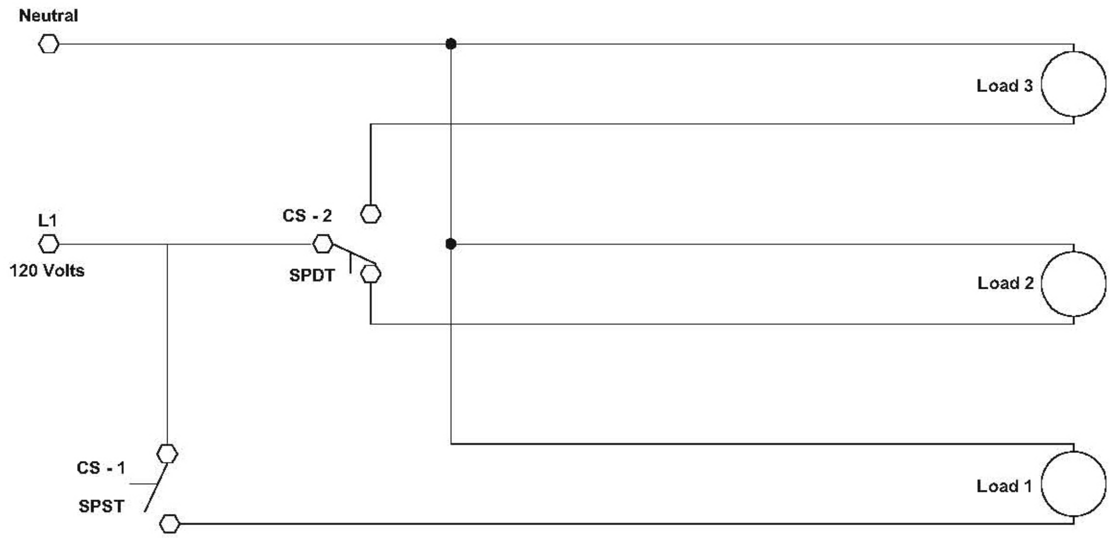
2.6. Wiring Diagrams

A wiring diagram is a pictorial representation of an electro-mechanical appliance. Wiring diagrams are either depicted as a schematic (pictorial) or a ladder-wiring diagram. Each diagram has its own advantages, but they both "say" the same thing. There are also diagrams that are a combination of both, which could be called "cross breed" diagrams.

Regardless of which type of diagram is used, one thing is for certain: Until the technician understands both types of diagrams, he will come up "short" when it comes to electricity.

2.6.1. The Schematic (Pictorial) Diagram:

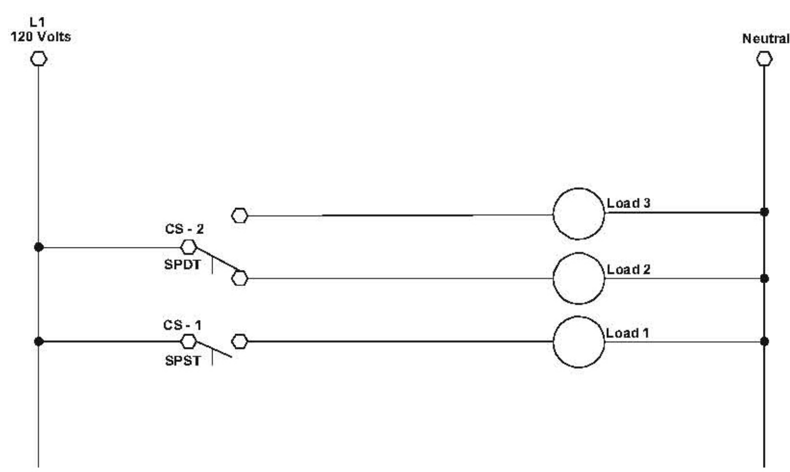
The schematic diagram shows each electrical component placed on a diagram with the wiring arranged around its location. All of the wiring, whether low voltage or high voltage, connects the components. The biggest shortcoming of wiring schematics is they do not clearly depict the operational sequence of each circuit or which parts of the components are low voltage and which are high voltage. The real value of a schematic is showing the technician the entire component and where the wires are connected, just like a road map shows a traveler where to go.



2.6.2. The Ladder Diagram

The ladder diagram, sometimes called a "straight line" diagram, gets its name from the way it looks. In a ladder diagram, each circuit is depicted as a separate rung on a ladder laid out in a straight line. The advantage of this type of diagram is that each circuit is illustrated individually and is easy to follow. For the technician, the ladder diagram is the one that offers the most useable information for understanding the sequence of operation and troubleshooting electrical problems. The disadvantage of this type of diagram is that components with multiple circuits are not shown as one physical piece, and they are not arranged in a straight manner.

The following ladder diagram has the same components and function as the previous pictorial diagram shown in the "straight line" format.



2.6.3. Reading the Wiring Diagram

Reading diagrams is a matter of taking each circuit and following it from one side of the line to the other. Remember, it is always best to start at Line 1 and work your way through the switches and components to Line 2.

In these diagrams, the switches are manually operated and work independently from each other.

- When CS-1 (SPST) is closed, it will activate Load 1.
- When CS-2 (SPDT) is in its normal position, Load 2 is activated.
- When CS-2 is flipped, Load 2 will turn off and Load 3 will be activated.

With the circuit is powered up and the switches are in their normal position, you would expect to see Load 2 "On" and Loads 1 and 3 "Off."

2.7. Review

Electrical circuitry in heating and cooling products is comprised of the two most common types of circuits. They are series circuits and parallel circuits.

Electrical circuits must have a voltage source, connecting wiring, loads (such as motors and heating elements to do work), and switches to control the sequence of operation.

When an electrical circuit has the components mentioned above and the switch is closed, electrical current can flow. This completed path is referred to as a closed circuit. When the same current path is broken by either a switch opening or a wire breaking, current cannot flow. This is referred to as an open circuit.

Series circuits are usually control circuits. They have only a path of current flow. If more than one load is wired in series, the applied voltage is divided in proportion to the resistance of each load. (Review the "Rules to Remember" for series circuits.)

Parallel circuits have more than one current path. The majority of electrical components in a heating or cooling product that do work are arranged so that each component will receive source voltage. When resistances are wired parallel, their total resistance is less than the smallest resistance. (Review the "Rules to Remember" for parallel circuits.)

Combination circuits are the joining of both a series and a parallel circuit. These combination circuits are often called series-parallel circuits. When we wire a switch or switches in series with two or more parallel loads, the parallel loads will operate independently as long as the series switches are closed.

2.8. Review Questions

1) Which type of circuit is often referred to as a control circuit?

   a) Series Circuit

   b) Parallel Circuit

   c) Series-Parallel Circuit

   d) High Voltage Circuit

2) When two loads are wired to receive the same voltage, they are wired in:

   a) Series

   b) Parallel

   c) Series-Parallel

   d) None of the above

3) A closed circuit is defined as a circuit in which current can flow from source voltage through the connecting wiring and switches, to the load, and return to the source.

   a) True

   b) False

4) Source Voltage is defined as the supply voltage, usually 120 VAC for gas heating and 240 for air conditioners and heat pumps, which is wired to the cooling or heating appliance.

   a) True

   b) False

5) In a Series Circuit, voltage can be _______ ___________ across each load.

   a) Divided Proportionally (Unequally)

   b) Divided Equally

   c) Both a & b

   d) None of the above

6) What is the formula for calculating voltage drop in a series circuit?

   a) $E = W_2 \times R$

   b) E = P/ I

   c) E = I x R

   d) $E = R_2 \times I$

7) What is the total resistance for a 30, 40, and 50 ohm resistors wired in series?

   a) 20

   b) 55

   c) 100

   d) 120

8) If 120 VAC is applied to the three resistors in question 7, what is the total current draw?

   a) 6

   b) 2.18

   c) 1.2

   d) 1

9) What will be the voltage drop across each of the 3 resistors in questions 7 and 8?

   a) 30, 40, 50

   b) 120, 120, 120

   c) 40, 40, 40

   d) 60, 60, 60

10) In a 240 VAC condensing unit with a compressor and condenser fan motor wired parallel, how many volts will be applied and measured across the compressor and condenser fan motor?

a) 120

b) 240

c) 24

d) 60

11) In a parallel circuit, total resistance of all the loads is always:

a) Added

b) Subtracted

c) Less than the smallest

d) More than the largest

12) What is the total resistance of a 30 ohm and a 50 ohm resistor wired in parallel?

a) 80 ohms

b) 40 ohms

c) 20.50 ohms

d) 18.75 ohms

13) What is the total resistance of a 30 ohm, 40 ohm, and 50 ohm resistor wired in parallel?

a) 120 ohms

b) 60 ohms

c) 12.76 ohms

d) 20.50 ohms

14) The _________ diagram offers the most useable information for understanding the sequence of operation and troubleshooting of electrical problems.

a) Schematic

b) Parallel

c) Series

d) Ladder

3. Switches

Switches are control devices that are wired "in series" with the loads. There are many different types of switches. Push button, limit, pressure, air flow, thermostats, and liquid level switches are just a few. While some switches are manually operated, others are automatically operated or operated by the influence of a magnetic coil, like the contactor or relay. The following terms will be helpful in identifying the type of switch used and its action.

- **Normally Open:** This describes the position of the contacts as "open" in its de-energized or normal position. These switches allow current to flow when they are activated. A normally open switch is always identified as such, although it may or may not be open any given point. This means that when a normally open switch is energized, it actually closes, but it still carries the name of a normally open switch. It does not lose its identity. The proper way to express this action is "the normally open switch has closed."

- **Normally Closed:** This describes the position of the contacts as "closed" in its de-energized or normal position. These switches conduct a path for current until they are flipped on or energized. These switches break current flow when they are activated. The proper way to express this action is "the normally closed switch has opened."

- **Poles:** This describes the number of contacts that the switch has. Each pole has its own path or terminal feeding the switch.

- **Throw:** This describes how many operating positions the switch has. Each throw has its own path or terminal leaving the switch.

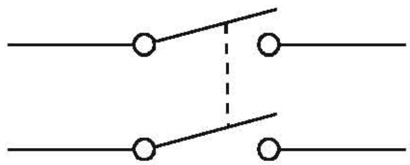
3.1. Single Pole, Single Throw (S.P.S.T.) Switch

The name tells you that there is one pole and one throw. This switch has one path in, one path out, and a single action.

S.P.S.T.
Switch

3.2. Double Pole, Single Throw (D.P.S.T.) Switch

This switch has two poles but has only one throw. This switch can control two separate circuits at the same time. It's the same as having two S.P.S.T. switches combined with one action.

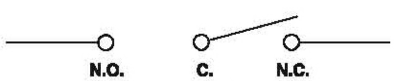


D.P.S.T.
Switch

3.3. Single Pole, Double Throw (S.P.D.T.) Switch

This switch only has one path in (single pole) but has two paths out (double throw). This means the switch can be made to one circuit or the other but not to both at the same time.

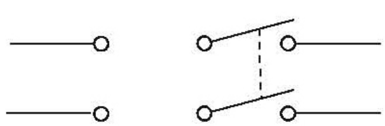
- **Common (C):** Common is referred to as the "pivot point" of the switch because it can complete a circuit in either direction, or it is "common" to both sides.
- **Normally Closed (N.C.):** Normally Closed is referred to as the point that has a path for current to flow with the switch in its normal or de-activated position.
- **Normally Open (N.O.):** Normally Open is referred to as the point that has a path for current to flow when the switch is flipped or activated.



S.P.D.T. Switch

3.4. Double Pole, Double Throw (D.P.D.T.) Switch

This switch is a combination of two S.P.D.T. switches built together with one action.



D.P.D.T. Switch

As mentioned before, the possibilities of different types and styles of switches are practically endless. The types of switches we just went through are the most popular and were used to illustrate basic switch configurations.

3.5. "Need to Know Information" Concerning Switches

Technicians often confuse the action of a switch or the terms we use to describe its position. You must know this!

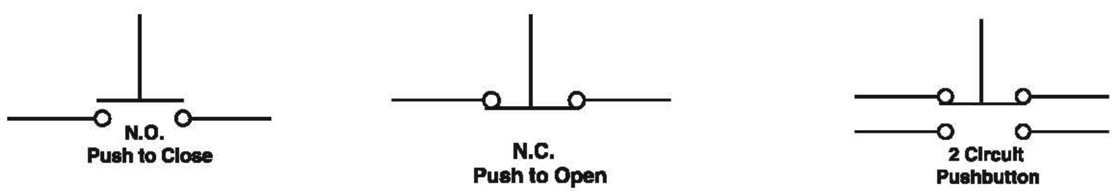
- When a switch is **Closed**, it is "**ON**." It completes the circuit path to the load, allowing the load to be energized and to do the work it was designed to do.

- When a switch is **Open**, it is "**OFF**." It opens the current path and turns the load OFF.

- Normally Open (N.O.) and Normally Closed (N.C.) refer to the position of the switch or contact in its non-activated position. These switches and contacts can be either open or closed, depending on the switch's position.

3.6. Other Types of Switches

3.6.1. Push Button



3.6.2. Automatic Switches and Controls

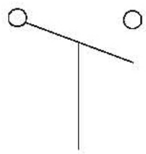
Automatic switches are used when input is needed from another medium to control or help control a circuit. As previously mentioned, HVAC systems rely mostly on temperature, pressure, and flow to control the equipment.

- **Operating Controls** are used to activate a circuit. These controls are usually "normally open" and are the primary means of cycling on and off the system.

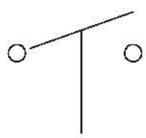
- **Safety Controls** are used to de-activate a circuit when something goes wrong. These controls are usually "normally closed" and are the primary means of protecting the equipment, structure, and people. Some of these switches have to be manually reset if they trip.

While there are endless types of switches and applications, there are only four possible actions of a switch operator, regardless of what medium is being measured. These are:

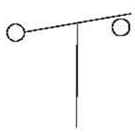
1) Normally Open, Close on a Rise



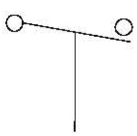
2) Normally Open, Close on a Fall



3) Normally Closed, Open on a Rise



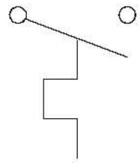
4) Normally Closed, Open on a Fall



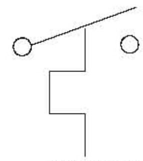
3.7. Thermostats

Thermostats are temperature-controlled switches that usually have a bi-metal disk inside the body of the thermostat. Heat causes the bi-metal to warp and through a mechanical linkage, the switch contacts will open or close, depending upon the design of the thermostat.

Cooling thermostats usually close on a temperature rise and open on a temperature fall. Heating thermostats are the opposite. They close on a temperature fall and open on a temperature rise. Examples of both are below.



Closes on a Temperature Rise

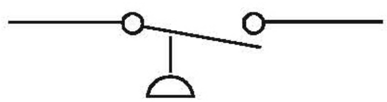


Closes on a Temperature Fall

3.8. Pressure Switches

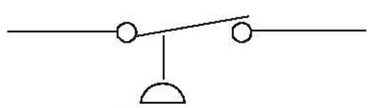
Pressure switches are used to monitor the pressures within heating and air conditioning systems. They can be used as operating controls or as safety controls.

- **Air Pressure Switches:** Air pressure switches usually have a hose attached from a pressure source connected to the switch. These switches are normally open and measure the air pressure within a heat exchanger or duct system.

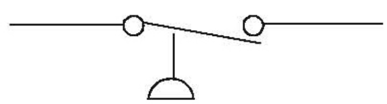


Pressure Activated Switch

- **Refrigerant Pressure Switches:** Refrigerant pressure switches are either mounted directly on a refrigerant line in the system or mounted in the control panel with a copper tube connected from the line to the switch. These are usually closed safety switches that open to shut the system down if abnormal pressures are reached.



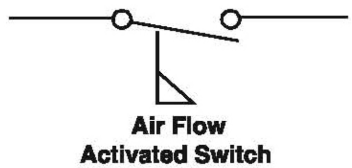
High Pressure Switch



Low Pressure Switch

3.9. Flow Switches

Flow switches are used to detect the flow of air and water. The most common flow switch we use has a "sail" attached to sense the movement of air in a duct, which activates the switch. These are most often open switches used to energize air cleaners and other air purifiers when airflow is detected.



3.10. Fuses and Overloads

Two of the most common safety devices used in HVAC products are fuses and overloads.

- **Fuses:** Fuses are current-sensitive devices wired in series with the load that they are designed to protect. When current flow through a fuse exceeds its ampere rating, the fuse is designed to open, stopping the current flow. Most fuses are "one shot" devices. If they open, they must be replaced and the cause of the high current should be found and repaired.

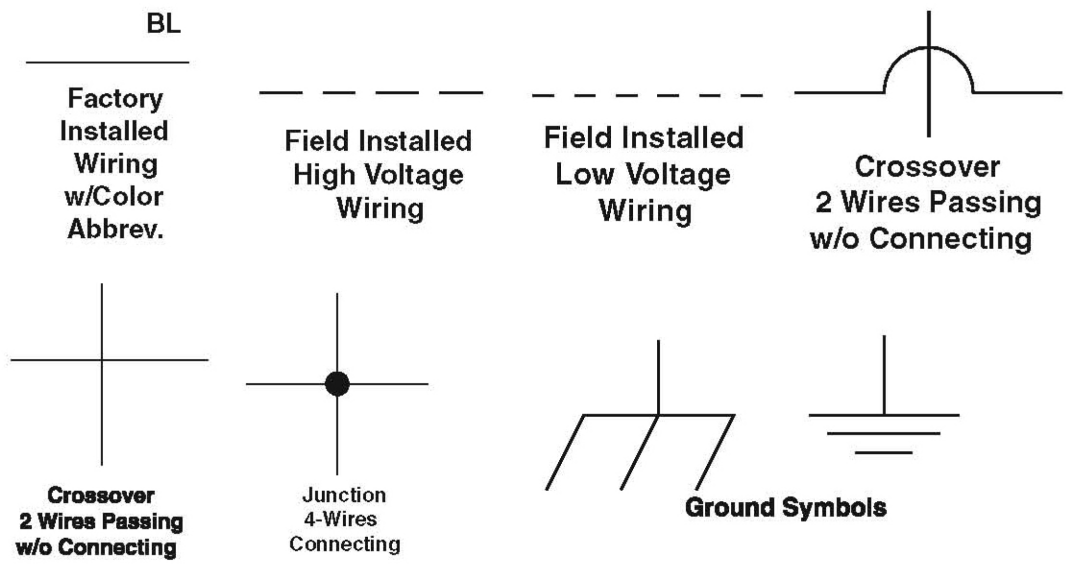
- **Overloads:** Overloads are often wired in series with motors. They are designed to sense high temperatures. If the load on a motor increases to an unsatisfactory level, the motor will run hotter than normal, and the overload will open the circuit to the motor. This will prevent the motor from burning. Most overloads automatically reset after the surface they are mounted on cools to a safe level.

The symbols below are typical of fuses and overloads.

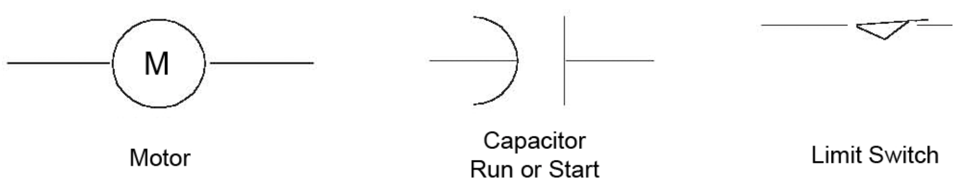
3.11. Other Symbols

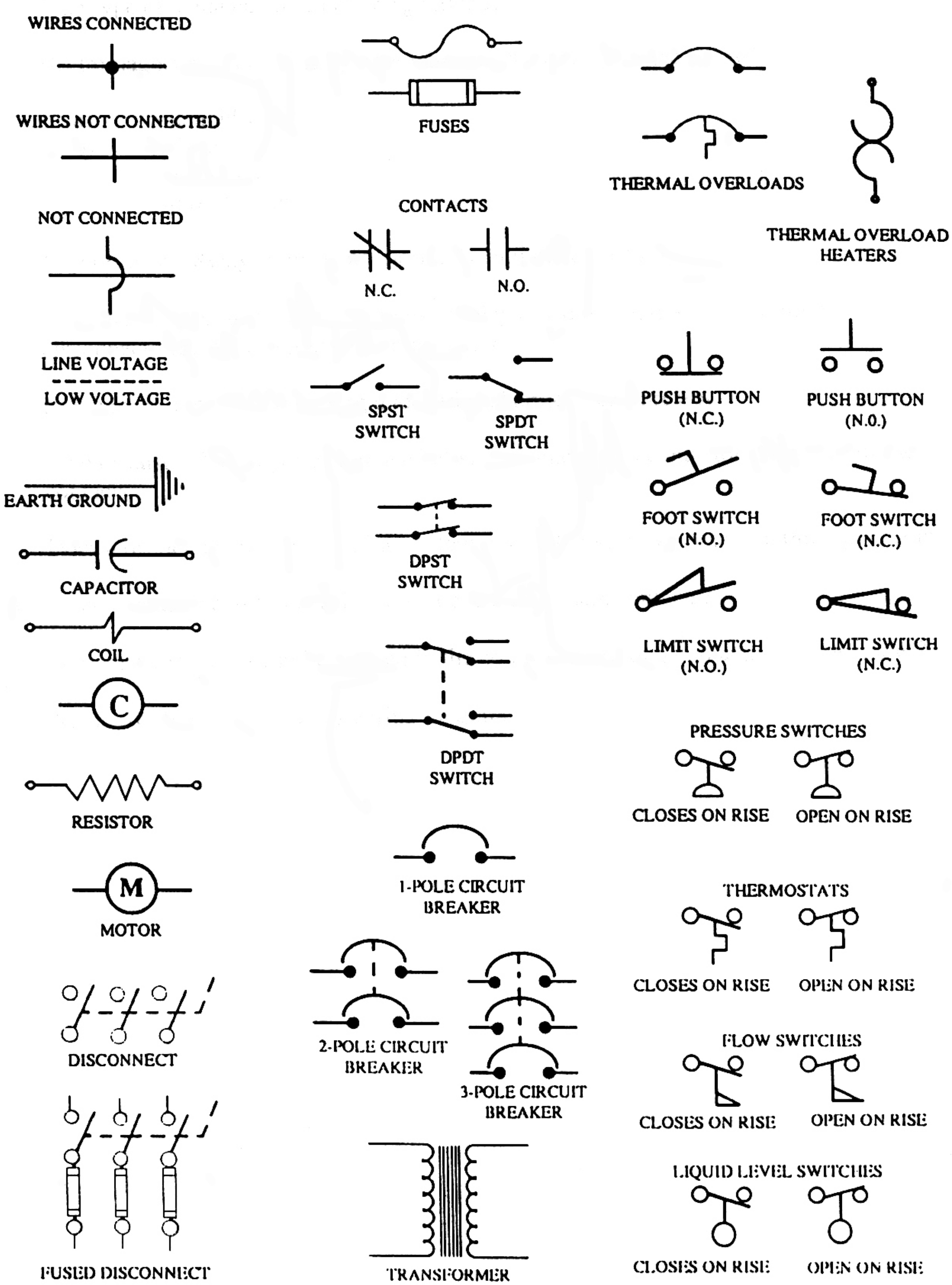
We have attempted to show a few of the most common component symbols and switches found on a wiring diagram. There are a few other very important symbols you should be familiar with.

Wiring is the conductor of electrical current that connects the components to switches and source voltage. The following are several depictions you may see on wiring diagrams.



Some other component symbols you will likely see are:




WIRES CONNECTED
WIRES NOT CONNECTED
NOT CONNECTED
LINE VOLTAGE
LOW VOLTAGE
EARTH GROUND
CAPACITOR
COIL
C
RESISTOR
M
MOTOR
DISCONNECT
FUSED DISCONNECT
FUSES
CONTACTS
N.C.
N.O.
SPST SWITCH
SPDT SWITCH
DPST SWITCH
DPDT SWITCH
1-POLE CIRCUIT BREAKER
2-POLE CIRCUIT BREAKER
3-POLE CIRCUIT BREAKER
TRANSFORMER
THERMAL OVERLOADS
THERMAL OVERLOAD HEATERS
PUSH BUTTON (N.C.)
PUSH BUTTON (N.O.)
FOOT SWITCH (N.O.)
FOOT SWITCH (N.C.)
LIMIT SWITCH (N.O.)
LIMIT SWITCH (N.C.)
PRESSURE SWITCHES
CLOSES ON RISE
OPEN ON RISE
THERMOSTATS
CLOSES ON RISE
OPEN ON RISE
FLOW SWITCHES
CLOSES ON RISE
OPEN ON RISE
LIQUID LEVEL SWITCHES
CLOSES ON RISE
OPEN ON RISE

4. Loads and Controls

4.1. Solenoids

A solenoid is a coil of wire that creates strong magnetic fields when voltage is applied. When a plunger is inserted into the center of the coil, the plunger will be pulled up or pushed down to do work. The work that it does is usually opening a valve that allows refrigerant or a liquid to flow. Other solenoids work to actuate relays.

Solenoids can be designed to operate on low 24 VAC or high voltage of 120 and 240 VAC when the job requires.

4.2. Heaters

Heaters in heating and cooling products have many applications. They can range from resistive strip heaters installed in an air handler to supply total heat or supplemental heat for heat pumps. Other examples are crankcase heaters for air conditioner compressors. Whatever their application, a heater is a resistive load that does work when voltage is applied.

The symbol for the heater is that of a resistor. The description or abbreviation that usually accompanies the symbol will give the technician an indication of its use.

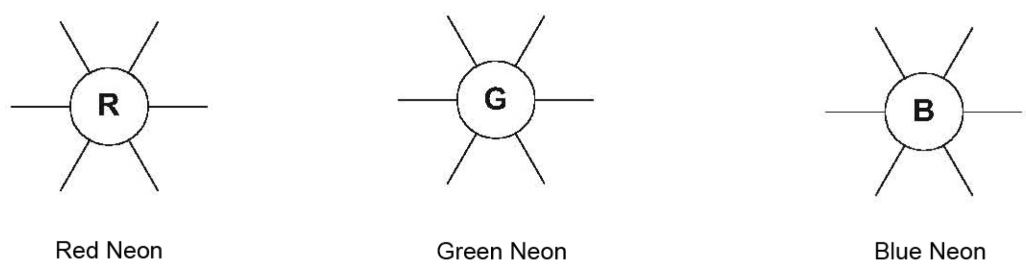
The symbols above are representations of the symbols you will find on a schematic or wiring diagram.

4.3. Low Voltage Signal Lights

Low voltage lights are often found in the heat pump wall thermostat. They signal the homeowner or technician that the "AUX HEAT" (Auxiliary Heat Strips) is energized. Emergency Heat also has an indicator that shows the user that the heating element(s) are energized when the "EMERG. HEAT" switch on the wall thermostat is closed. Other heat pump wall thermostats have a "System" light to show the user that the system unit is either heating or cooling.

On most modern heating and cooling products, the system control boards (the electronic brains) have signal lights installed to indicate their service status or troubleshooting codes. By establishing a series of blinks, the signal lights can display a failure code to aid the service technician in troubleshooting the product.

All of these signal lights are neon bulbs that are powered by 24 VAC from the heating or cooling appliance's transformer. The symbols for the signal lights are:



Different colors of signal lights often represent various functions occurring at the time the light is illuminated. Green often represents a diagnostic signal light. Blue or amber usually indicates that the auxiliary heat is energized, and red is often used to indicate the emergency heat is activated. Both red and blue/amber lights are found on heat pump wall thermostats.

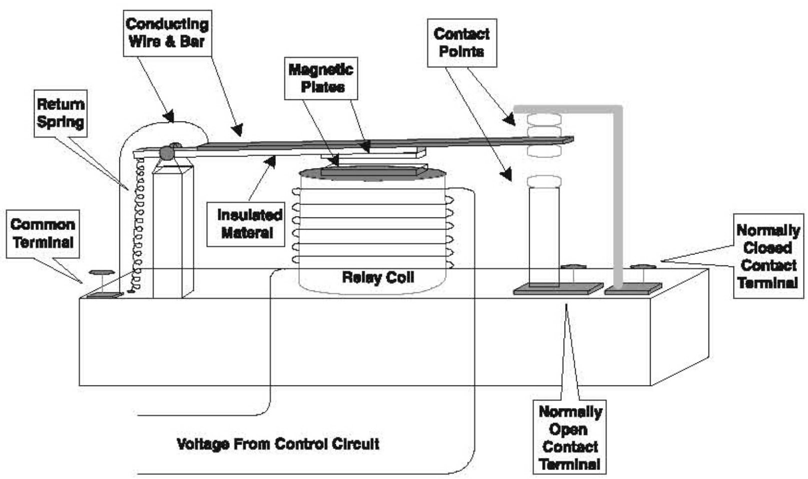
4.4. Magnetic Controllers

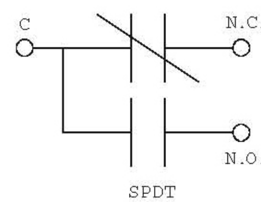
Magnetic controllers, such as relays and contactors, are primarily used when the device used to control a load can't handle the amps of the load or is rated at a different voltage than the device used to control the load. Although the sky is the limit when it comes to the sizes, shapes, and applications of these controllers, they all have the same basic wiring circuits and components.

- **The Control Circuit:** This circuit is used to operate the relay or contactor by creating a magnetic field to change the position of the contacts. The magnetic coil in the controller is the load for the control circuit.

- **The Load Circuit:** This circuit uses the contacts from the controller to make or break the path to the main load being controlled. Although this circuit is influenced by the magnetism in the control circuit, it should be noted that the control circuit and the load circuit are electrically independent of each other, and in no way transfer voltage from one to the other. When it comes to the contacts and the load circuit, the easy way to look at it is, "you can only get out what you put in."

The following illustration shows the basic components of these magnetic controllers. In this illustration, an S.P.D.T. (single pole, double throw) contact is shown.





4.4.1. Types of Magnetic Controllers

There are three types of magnetic controllers that are most popular in our industry. Although they all work on the same principal, they have different names because they are used for different purposes.

- **Control Relays**
  Control relays are used to operate control circuits and light duty loads. These relays are available in many different designs and contact arrangements, with a choice of 24, 120, and 240 volts for the coil. The key point that separates these relays apart from the others is that the contacts are limited to about three amps.

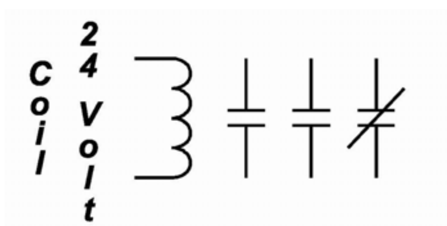
- **Pilot Duty Control Relays**

  These relays may look the same as the control relay, but they are specifically designed for use with controls only. They are not rated to start and stop small motors, even if the amperage is within the rating of the contacts.

- **Fan Duty Relays**

  Fan duty relays are often referred to as "service duty" relays. They have a wide range of applications, but are primarily used to control fan motors. The key point that separates these relays from the others is that the contacts are rated for around 15 amps.

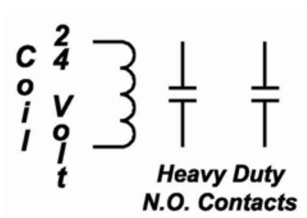
  A typical symbol for a relay is:

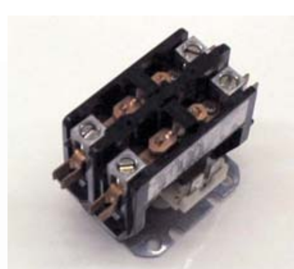


The relay coil  is the load in the control circuit. When the coil is supplied with its rated voltage (usually 24 VAC), the Normally Open (N.O.) contacts close and the Normally Closed (N.C.) contacts open.

- **Contactors**

  Contactors are the workhorses that close heavy contacts to control high current in a compressor and condenser fan circuit. Contactors begin at around 20-amp rating on their contacts and go up to 30 and 40 amps for most residential systems. The magnetic coil is a load in the control circuit that is typically supplied with 24 VAC from the wall thermostat. The typical symbol for a contactor is:



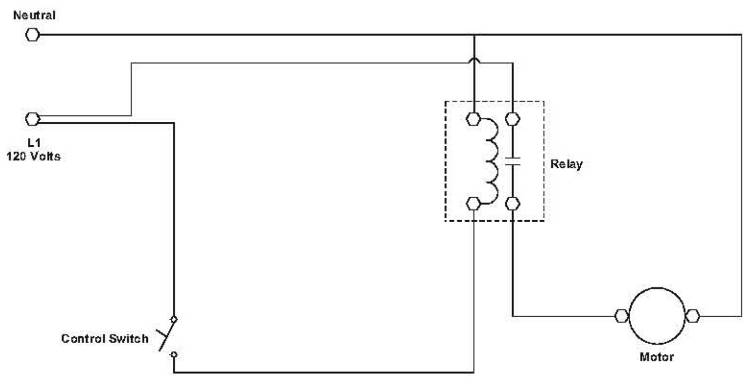


The heavy-duty contacts shown are wired in the high voltage section, usually 240 VAC, going to the compressor and fan motor. The coil  is the 24 VAC load.

4.4.2. Wiring Diagrams Using a Relay

4.4.2.1. The Pictorial Diagram

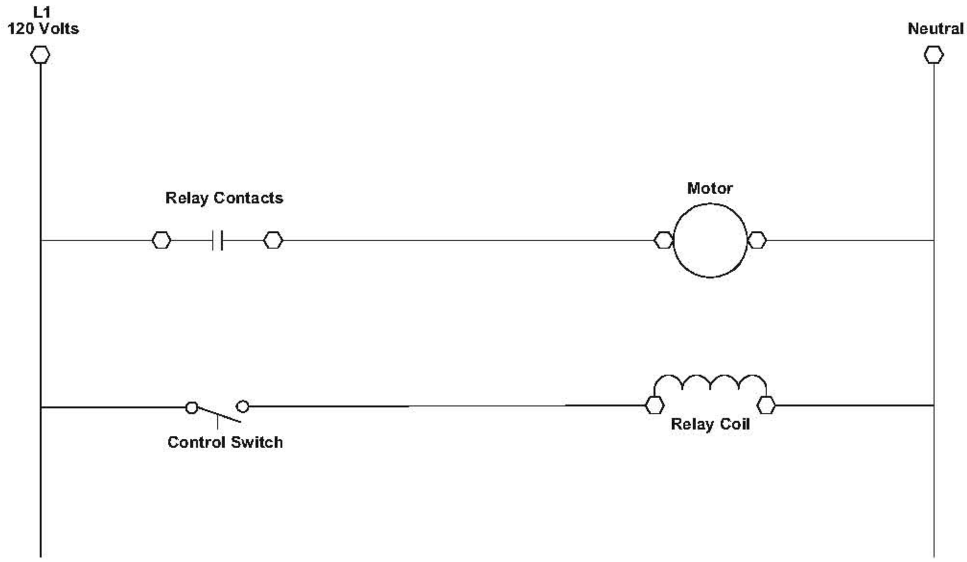
This diagram illustrates how a relay is used to control the main load. In the following example, both the control circuit and the load circuit are 120 volts. Circuits like this one are typically used when the main load draws more amperage than the control switch is rated for. In the pictorial diagram, the entire relay is shown in one piece with the control and load circuits wired to it.



4.4.2.2. The Ladder Diagram

The ladder diagram for the same circuit shows the logic behind the control circuit and the load circuit. This diagram shows the technician that there are two basic circuits in this project.

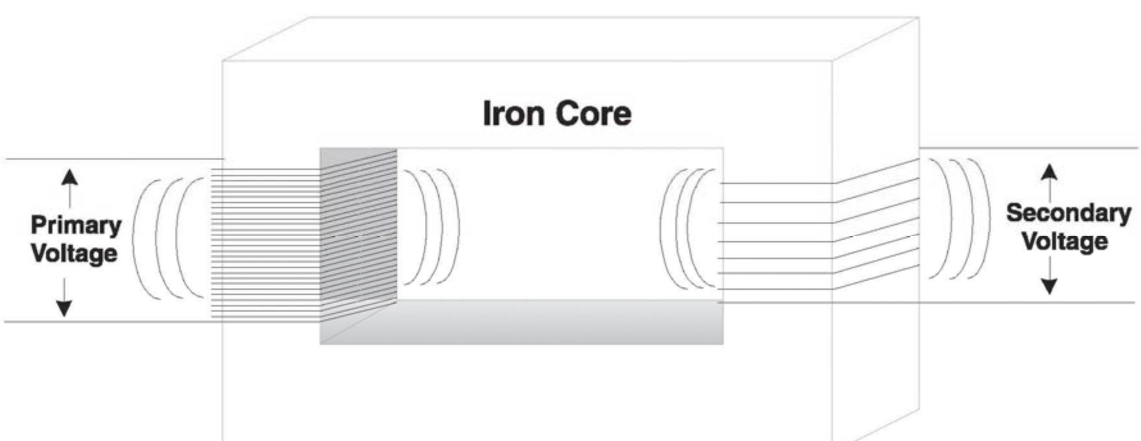
- When the control switch closes, the relay coil is energized.
- When the relay contacts close (from magnetism), the motor is energized.



The difficult part of reading a ladder diagram is realizing that even though the relay coil and relay contact are both part of the same component, they are separated into their respective circuits in the ladder diagram. The only thing that lets you know they belong to the same component is they both carry the name "relay."

4.5. Transformers

The source of our control circuit voltage comes from the step-down transformer. Transformers used in HVAC utilize line voltage of 120, 208, or 240 VAC to supply the primary winding of a transformer. The secondary side of a transformer is the control voltage side. Almost all transformers used in HVAC produce 24 VAC on the secondary side of the transformer.



- **Primary Windings:** Primary windings are used to induce magnetism into a metal core through a coil of insulated wire wrapped around the core. Like any other magnetic device, the primary winding is a load; therefore, it should match the voltage being applied.

- **Secondary Windings:** Secondary windings are used to produce or generate a voltage from the magnetism in the metal core. The secondary winding works much like generator; therefore, it is classified as a power source for the secondary circuit.

4.5.1. The Winding Ratio

The winding ratio, or the “turns of wire” in the primary compared to the secondary, determines the level of voltage that will be produced from the secondary winding. A typical 120 / 24 volt transformer has 5 windings on the primary for every 1 winding on the secondary.

4.5.2. The Wattage or (VA)

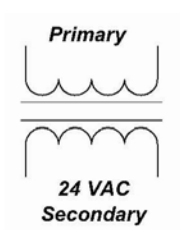
The wattage of a transformer is the same on the primary as it is on the secondary. Therefore, on a step-down, as the voltage goes down, the amperage goes up. Transformers have the following three key electrical ratings:

- Primary Voltage Rating

- Secondary Voltage Rating

- VA Rating (Volt-Amps) — The VA rating is the wattage rating for the transformer.

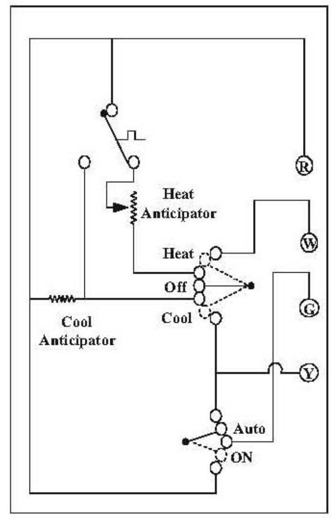
The typical symbol for a transformer is:



4.6. 24-Volt Wall Thermostats for Heating and Cooling Systems

Wall thermostats are used to automatically control heating and air conditioning systems for uninterrupted comfort in the home or business. They have a combination of circuits that work together to control the system. For the purpose of this Self Study, the terminals and functions of a standard Gas Heat / AC thermostat will be discussed. The following is an example of this type of thermostat.

24-Volt / Thermostat Terminal Designations



- **R** = 24v power to thermostat
- **G** = indoor blower control circuit
- **W** = heating control circuit
- **Y** = cooling control circuit
- **C** = 24v common to transformer

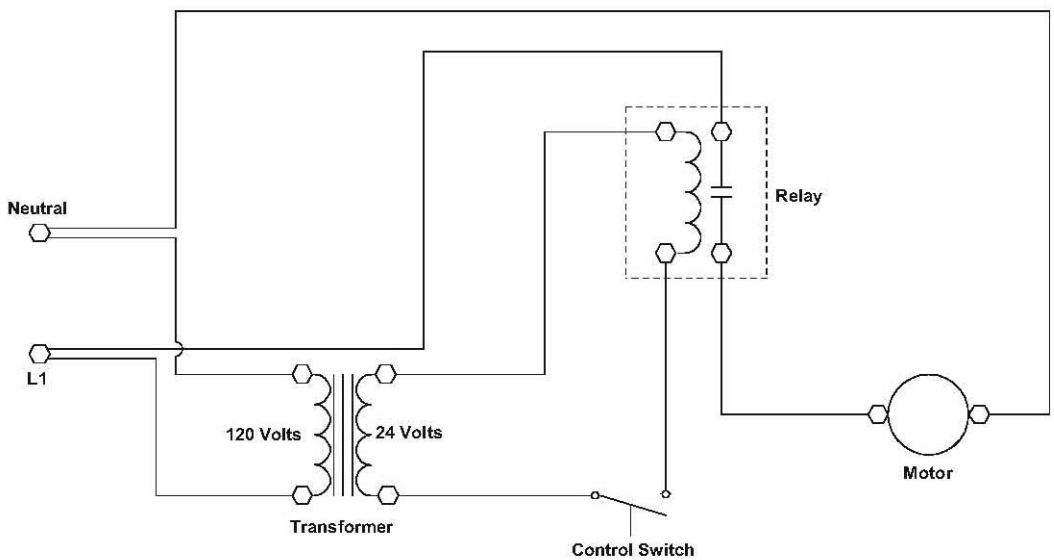
Thermostat Functions

- Call for Fan On = "R" supplies 24V power to "G"
- Call for Heat (auto) = "R" supplies 24V power to "W"
- Call for Cool (auto) = "R" supplies 24V power to "Y" and "G"

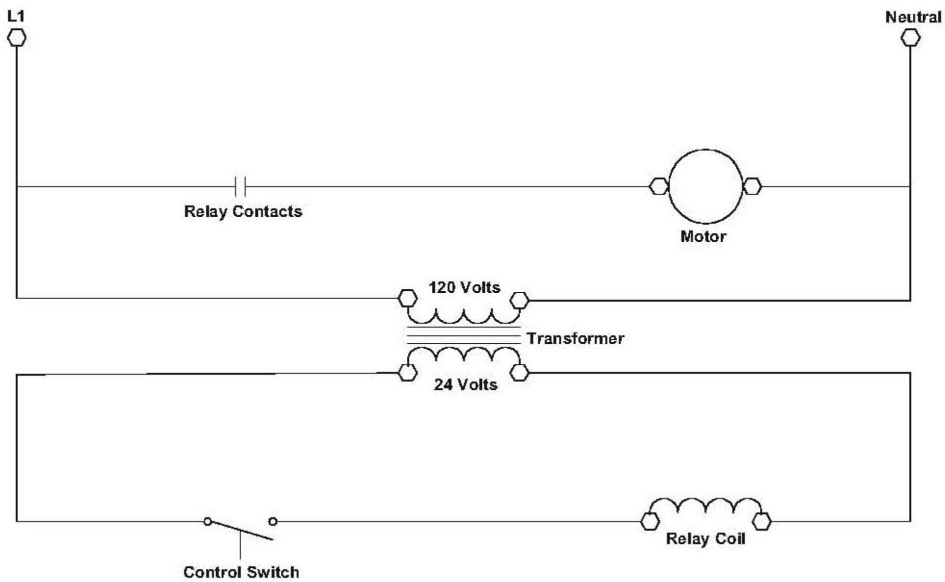
4.7. 24-Volt Circuits and Wiring Diagrams

This diagram is very similar to the previous one, except a 24-volt control system is used. Keep in mind that the secondary of the transformer is a voltage source for the control circuit. For the 24-volt circuit to be complete, current must leave one side of the secondary (called "R") and flow through the control switch to the coil. Current must then return back to the opposite side of the secondary (called "C"). The relay then energizes the motor through its contacts, using the main 120-volt power source.

4.7.1. Pictorial Diagram



4.7.2. Ladder Diagram



4.8. Motors

Motors are one of the most popular electrical loads used in our industry. Like any other load, they receive voltage, consume electrical energy (measured in watts), and create a rotational force that drives the devices that do work. There are several types of motors that technicians will see used in compressors, fan motors, draft inducer motors, and pump motors, just to name a few.

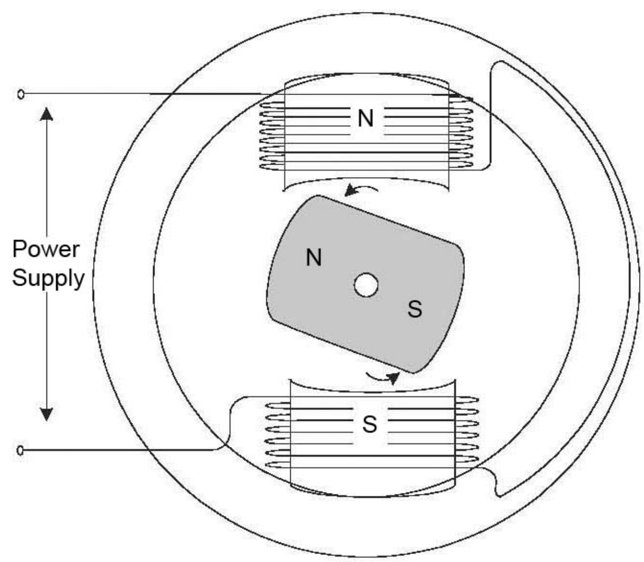
This Self Study will go through the principals of how a motor works and some of its characteristics. (Other courses provide more details about motors, applications, and how to troubleshoot them.)

4.8.1. How a Basic Motor Works

As you know, opposite magnets attract and like magnets repel. It is this theory that causes the motor to work. In the following illustration the motor has two stationary field windings, called "Run" windings, located on each side of the motor. These windings are wound in opposite directions from each other, causing the magnetic poles to be opposite. When the alternating current (AC) polarity reverses from the power source at 60 times per second, the magnetic poles also reverse. It is this constantly reversing polarity that keeps this motor running.

The rotor is in the center of the motor, mounted on bearings and constantly changing its magnetic pole as well. The rotor is magnetized from the stationary "Run" windings, so it, too, is reversing its polarity at 60 times per second.

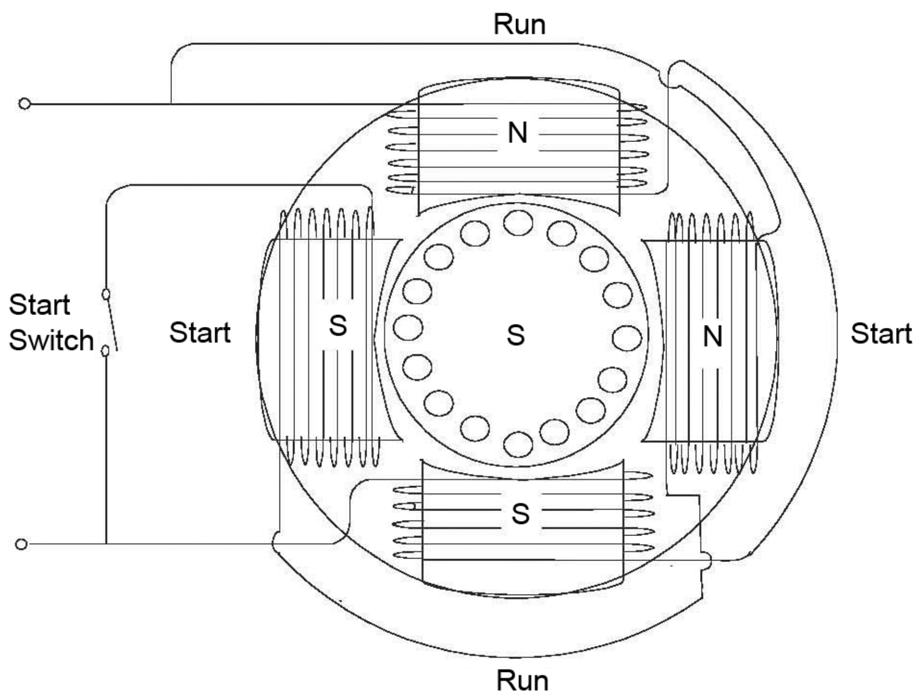
It is the constant attraction to the next pole and the push away from the last pole that keeps this motor running. As soon as the magnets get to where they want to be, the current changes and the rotor is then attracted to the next pole around the motor.



The only problem with the motor used in this illustration is there is no way for it to start except for "giving it a spin" by hand. A motor that only has a run winding will run in either direction depending on which way it is spun during start up. Without any help on start up, the motor will be "stuck" if the rotor is pointing towards the run windings because of the magnetic attraction. When the polarity reverses, the rotor will be pushed away in both directions and doesn't know which way to go, so it just sits there. It is, however, remotely possible for this motor to start by itself if the rotor is pointing at the exact right spot, but it is not likely.

4.8.2. The Split Phase Motor

The type of motor illustrated below is referred to as a "split phase" motor and is typically used in belt drive blowers, stationary power equipment, and direct drive pumps. In this motor, a switch is needed to de-energize the start winding after the motor gets to around 70% of its full speed. This is typically accomplished using a centrifugal speed switch inside the motor.

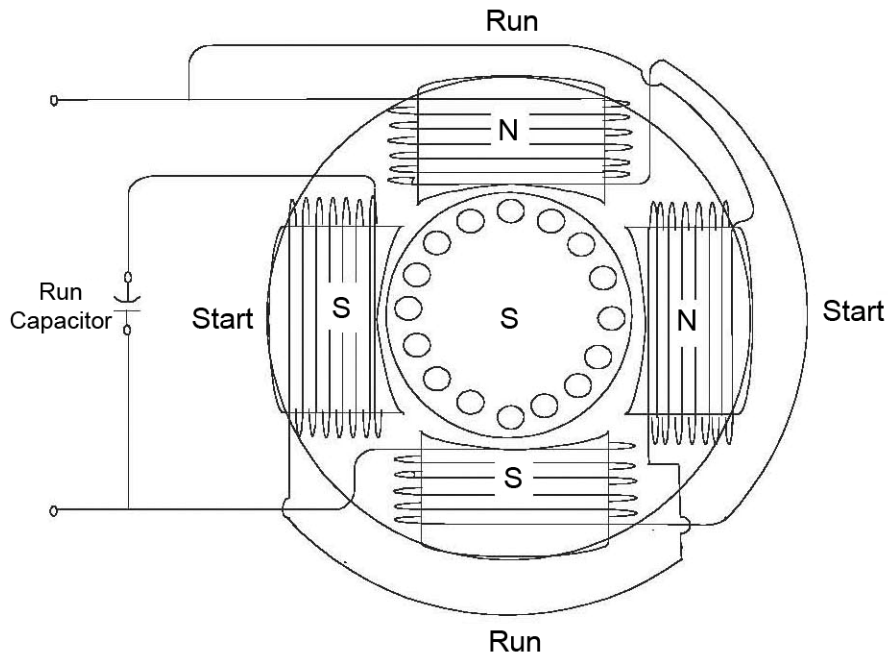


The split phase motor incorporates the use of a start winding that is constructed using a smaller wire but has more wraps. This winding gives the motor the sense of direction and additional torque, no matter which way the rotor is pointing when power is applied.

The rotor shown is constructed with copper bars running along the length of the rotor. These bars, in conjunction with the laminated steel in the rotor, provide a means for the magnetism to be induced into the rotor.

4.8.3. The PSC (Permanent Split Capacitor) Motor

The PSC motor is a common motor used in our industry in residential equipment. It is most commonly used in compressors, blower motors, and condenser fan motors. It also uses a start winding to help get the motor going; however, in this motor the start winding remains energized after the motor is running. The purpose of the "run capacitor" in simple terms is to keep the start winding energized by allowing a small amount of current to continually flow into the winding. This current through the capacitor and start winding helps get the motor started and also helps it to "run" – hence the name "run capacitor." The run capacitor also changes the phase of the current going into the start winding to improve the overall performance and efficiency of the motor.



A full list of motors and their use is provided in various HVACLS courses. This section is designed for technicians to understand the concept of AC electric motors.

5. Meters, Diagrams, and Troubleshooting

“Which meter to choose?" has likely crossed your mind when first entering the HVAC Repair and Installation Industry. The choices are broad, but with a little information you can make the "right choice."

Meters come in two basic types. One is a VOM (Volt Ohm Meter), which is a multi-function meter for reading volts, ohms, and amps, using two meter leads. The other type of meter is amp meter. The clamp amp meter can also be a multi-function meter.

5.1. Volt Ohm Meters

Volt Ohm meters are available today in either analog or digital. Analog meters use a d'arsonal needle movement to display ohms, volts, and amperes.

Looking closely at the scale, you will see the top scale is the "ohms scale." From left to right we read "infinity"[1] to "zero"[2] ohms. When using an analog meter for measuring resistance, it is best to set a range on the meter that will allow the meter to display resistance in the center of the ohm scale.

The scales below the ohms scale are the "AC" and "DC" Volts scales. These scales are usually color distinctive. They correspond to the AC and DC Volt Ranges set in the center of the meter with the rotating dial. (For more information on your specific brand of analog meter, refer to the owner's manual.)

Digital meters are becoming increasingly popular today. They are easier to use and easier to read. Their capabilities have been greatly expanded. In addition to volts and ohms, many Digital VOMs today display amperes, continuity, frequency in hertz, temperature, and capacitance in micro-farads. The ranges for these additional features vary between model, manufacturer, and price.

[1]*Infinity refers to an immeasurable quantity. Infinity can also refer to an open. In electrical circuitry, this means that current cannot flow because of a break in a wire, switch, or motor winding.*

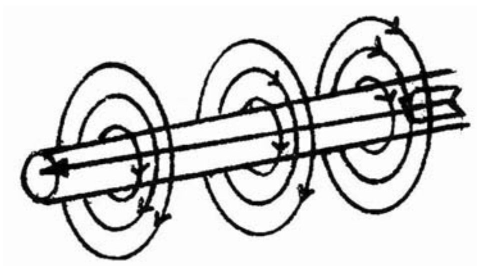
[2]*Zero ohms on an analog meter refer to continuity. Continuity shows a completed path or closed path for current to flow if electricity were applied.*

5.2. Amp Meters

5.2.1. Clamp Amp Meter

Like the volt ohmmeter, the clamp amp meter is available in both analog and digital. Whether you choose one or other, the clamp amp meter measures Alternating Current around a wire by the magnetic field generated as current flows along the wire. It then displays the amount of current, either by a needle on a scale or by a digital, direct read-out display.

Remember: *The strength of the magnetic field around the wire is directly proportional to the amount of current flowing through the wire.*



Magnetic Field around a Conductor

The ability to measure current is a quick and effective way to determine the operational characteristics of a motor, an element, a heat anticipator, or any electrical component where voltage is applied and electrical current is flowing. To use the meter, you need only to clamp it around one (and only one) lead or wire going to the load being tested.

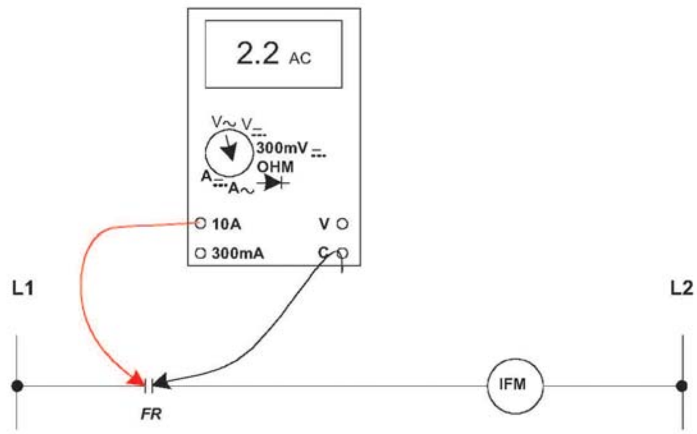
Many say today that the clamp amp meter is the most valuable tool that an HVAC technician can carry. It can also be the most functional because of added features in many modern digital amp meters. Like the VOM, the modern digital clamp amp meter offers similar functions, such as voltage reading, ohms, continuity, capacitance, frequency, and temperature.

One last note: *Most clamp amp meters measure only AC current and not DC current. Choose wisely!*

5.2.2. In-Line Amp Meters

Many VOMs have an added feature of measuring current in both DC amperes and AC amperes. Since these multi-function meters do not usually have a clamp as an optional feature, you must place the meter leads in series with one of the wires going to the load being tested. Additionally, the meter must be set to the AC amps or DC amps scale, and the red meter lead moved to a milliamp (mA) or 10A or 20A jack. (Again, refer to your meter's operating instructions in the owner's manual.)

To use, safely disconnect a wire from a terminal going to the load being tested and "fill the hole" with the two meter leads. The meter will then display the current flowing through the wire, the load, and the meter when voltage is applied.

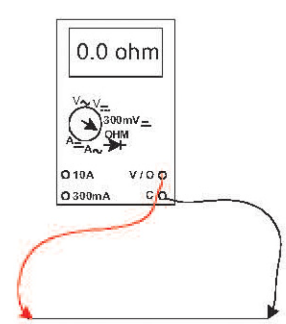


5.3. Ohm Meters: "A Closer Look!"

Ohmmeters are used to measure the amount of resistance in a circuit. As service technicians, you often use them to try and determine the operating conditions of a component or a circuit by seeing if the meter shows ***continuity***, ***resistance of the load***, an ***open***, or a ***short***.

5.3.1. Continuity

Continuity is a term that means a continuous or complete path. When you use your ohmmeter to test for continuity of a wire, switch, or a load, you should be trying to determine if a continuous or complete path for current to flow is available.



When testing for continuity, the meter should be set to the lowest ohms scale on an analog meter and the continuity setting on a digital meter. If testing a wire, place one meter lead on one end of the wire and the other meter lead on the other end of the wire. If you have continuity—a continuous path—the analog meter should read "0" ohms. Likewise, the digital meter should display "0.00" ohms.

5.3.2. The Resistance of a Load

The resistance of a load is the designed resistance that a motor, heater, or transformer normally has. When you use your ohmmeter to measure the resistance by placing the meter leads across the terminals of the motor, heater, or transformer, you are comparing the designed resistance to the measured resistance. A positive indication that a motor, heater, or transformer is operationally OK is that the designed resistance is very close to or equal to the measured resistance.

5.3.3. An Open

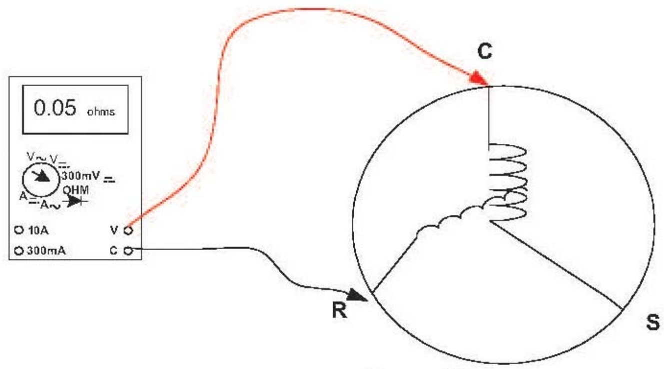
An “**open**” is a term we use to state that a wire, switch, or load—such as a motor, heater, or transformer—**does not have** a continuous or compete path for current to flow. The open could be a broken wire. An open could be a switch that did not close. An open could be a motor winding that has burned open or broken due to high current flow.

A continuity tester or an ohmmeter, when placed across an open wire, switch, or load, would display “infinity.” On an analog meter, the needle would not move. It would be seen resting next to the symbol ∞, which represents infinity. Again, infinity is immeasurable, goes on forever, or open.

On a digital meter, infinity could be the flashing of the display or a “flashing number” that represents infinity or an open. (Refer to your owner's manual!)

5.3.4. A Short

A **short**, in electrical terms, means "the lack of resistance or no measurable resistance found, but the meter displays continuity." This condition, when found on a motor or a heater, would prevent the component from functioning. The other problem that exists when a load loses its resistance or is “shorted” is that excessive current will flow when voltage is applied. If a circuit breaker or fuse is in series with this shorted load, the excessive current will cause the circuit breaker to “trip” or the fuse to “open,” stopping the flow of current.



5.3.5. Rules to Remember for Using an Ohmmeter

There are some "Rules to Remember" for using an ohmmeter. They are:

1) An ohmmeter can measure continuity, but it cannot definitively show that a switch or wire will carry current when voltage is applied. Most ohmmeters apply only 9VDC to a wire or switch. This is not enough electrical pressure to test the current carrying capabilities of a switch or wire.

2) An ohmmeter can accurately measure resistance, but it cannot definitively show that a motor or heater will carry the current or operate correctly when voltage is applied. Most ohmmeters apply only 9VDC to a motor or heater. This is not enough electrical pressure to test the current carrying capabilities of a motor or heater.

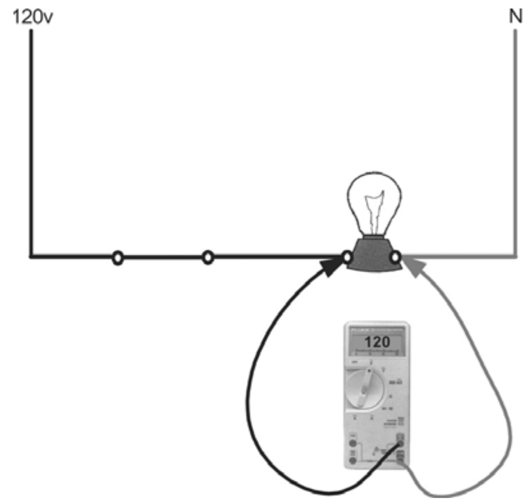
3) "An ohmmeter will tell you if something is bad, but it won't tell you if something is good!!"

No. 3 is the most important rule to remember!!

Remember, an ohmmeter is an indicator that a circuit or its component will work. Only when line voltage is applied and current is measured will you definitively know the circuit and its components are performing correctly!

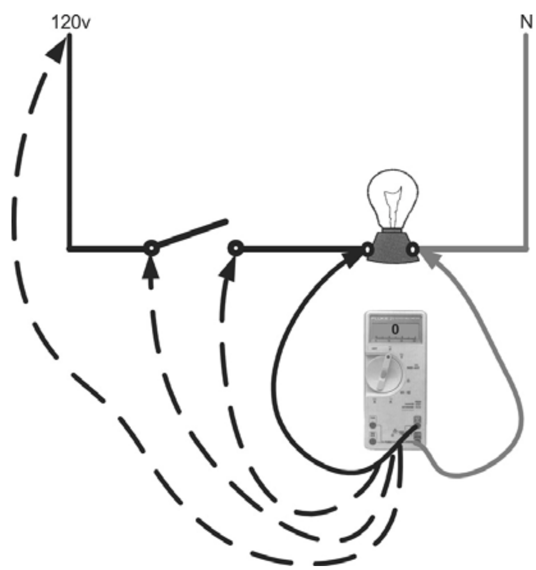
5.4. Basic Troubleshooting Using a Volt Meter

5.4.1. The Hop-Scotch Method



A voltmeter only displays a value when there is a difference in pressure between one lead and another. As previously stated, the final destination of each side of line voltage is the load. The hop-scotch method steps through each circuit until you get to THE LOAD, which is the "the End of the Line."

When testing a circuit, it is important to double-check the meter settings. Make sure the meter is set on voltage, then put one lead across each side of the load as shown.



The hop-scotch method always compares one line against the other. If you place both meter leads on the same line, you are not using the hop-scotch method.

If the load is not working and the voltage is correct, then you must assume the load is at fault. If the voltage is not there, keep one lead of the meter on the neutral side and work back towards the supply. At the point you see the voltage, stop. This is where something has made the circuit stop operating. Remember, current must have a complete path in order to flow.

The key to electrical troubleshooting is being able to accurately interpret the readings you measure with your volt meter and amp meter.

Interpreting Volt Meter Readings

- No voltage at the load = the circuit feeding the load is incomplete. (The load cannot be blamed for this problem.)
- Full voltage at the load = the circuit feeding the load is complete. (The load should be working.)

Diagnosing Loads

- If full voltage is applied to a load, it should be working. If it's not working, the load is OPEN.

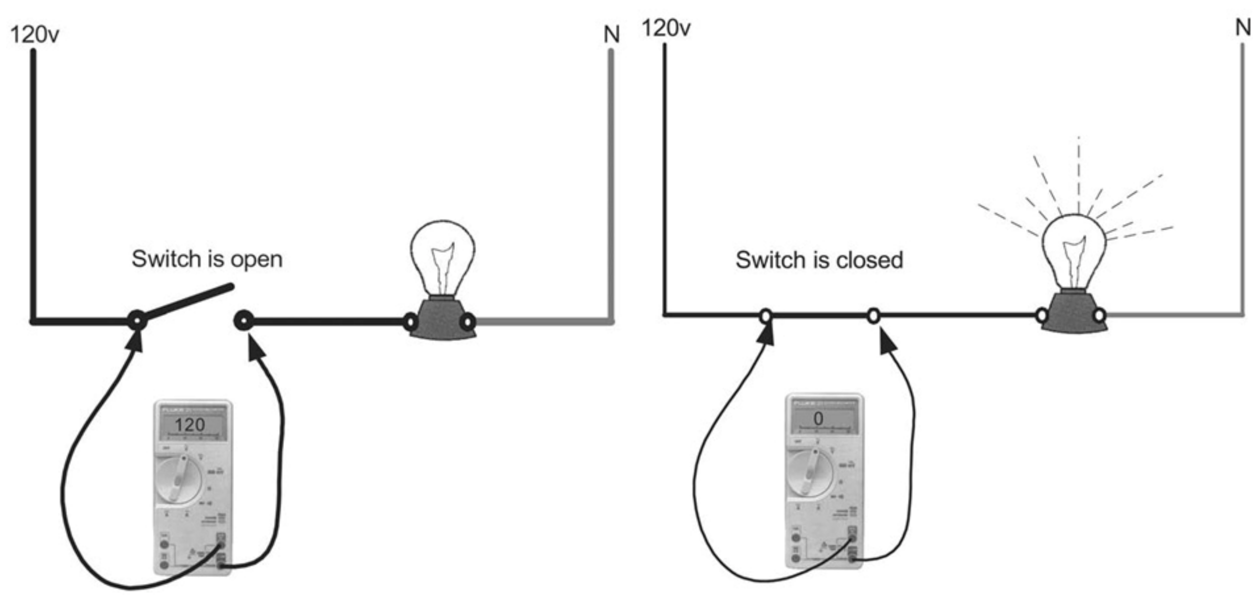
Verify the Operation of a Load by

- Visual observation
- Proper amp draw
- An amp meter displays the value of current flowing through a circuit. Measuring the proper amps in a circuit confirms that it is working.

5.4.2. Other Methods of Troubleshooting

Measuring voltage on the same side of a line can be useful; however, the rules change from the hop-scotch method.

- Voltage across a switch = the switch is open!
- No voltage across a switch = a strong possibility the switch is closed!



5.5. Review

Two types of test meters are available for HVAC technicians.

The **volt ohm meter** is a multi-test meter that reads and displays Volts, Ohms, and Amperes. The digital versions offer a wide variety of additional functions. Audible continuity tests, frequency in hertz, temperature, capacitance in micro-farads, and expanded ampere ranges from microamps to amperes in both AC and DC measures are common.

The **clamp amp meter** is the second type of meter. Available in both analog and digital, this meter measures AC current when clamped around one, and only one, of the two wires going to a resistive or inductive load. With additional features available in a growing number of amp clamps, you can read resistance, voltage, capacitance, and temperature. The amp clamp is proving to be the most valuable tool that an HVAC technician can carry.

Ohm meters that are an included feature in most VOMs and amp clamps can allow the technician to test for continuity, designed resistance of a load, an open in a circuit, and a short in a circuit or a component. When testing a component or wire with an ohmmeter, it must be remembered that when continuity is found in a wire or a switch, as well as a motor or heating element, this is ONLY an indication that the component can carry current. Only when voltage is applied and current is measured can you be assured that the circuit and components are working properly.

The volt meter is the most useful meter for troubleshooting. It is designed to read the difference in electrical pressure (volts) from one point to another. The key to troubleshooting is being able to interpret the readings.

5.6. Review Questions

1) Switches are control devices that are wired in _______ with the load.

   a) Series

   b) Parallel

   c) Front

   d) Both b and c

2) Which term describes the number of contacts that a switch has?

   a) Poles

   b) Throw

   c) Open

   d) Closed

3) Which term describes the number of operating positions a switch has?

   a) Poles

   b) Throw

   c) Open

   d) Closed

4) A switch described as a S.P.S.T. switch has ______ pole(s) and ________ throw(s).

   a) 1, 2

   b) 1, 1

   c) 2, 1

   d) 2, 2

5) How many terminals (connecting points) would the S.P.S.T. switch have?

a) 1

b) 2

c) 3

d) 4

6) Switches that are described as N.C. will allow current to flow:

a) When activated

b) When de-activated

c) Never

d) None of the above

7) When a switch is Closed, it is said to be "ON."

a) True

b) False

8) When a switch is Open, it is said to be "OFF."

a) True

b) False

9) Thermostats are temperature-controlled switches that usually have a bi-metal disk, which warps with a change in temperature, thus opening or closing the switch. Thermostat switches can:

a) Close on a temperature rise

b) Close on a temperature fall

c) Open on a temperature rise

d) Open on a temperature fall

e) All of the above

10) Two of the most common safety devices used in the HVAC industry are the fuse and the overload. These safety devices are usually wired in __________ with the load.

a) Series

b) Parallel

c) Series Parallel

d) All of the above

11) Which safety device is temperature sensitive?

a) Fuse

b) Overload

12) A solenoid is a coil of wire that creates a strong _________ field when voltage is applied to the two terminals of the coil and pulls or pushes a plunger to do work.

a) Circular

b) Inductive

c) Magnetic

d) Resistive

13) Relays and contactors are examples of magnetic controllers. Each device is made up of two circuits. They are:

a) Control & Resistive

b) Control & Load

c) Inductive & Load

d) Inductive & Resistive

14) A Pilot duty relay is a control relay whose switch contacts are usually limited to ______ amps of current.

a) 3

b) 5

c) 15

d) 20

15) The Fan Duty Relay is often referred to as a “Service Duty” relay whose switch contacts are usually limited to _______ amps of current.

a) 3

b) 5

c) 15

d) 20

16) The workhorse of the HVAC industry is the contactor. The contactor’s switch current ratings usually begin at _____ amps of current.

a) 10

b) 20

c) 30

d) 40

17) Wiring diagrams are depictions (road maps) of the electrical circuits and components of an HVAC system. Which type of diagram better shows the control and load circuits?

a) Pictorial

b) Ladder

18) Step-down transformers are used as the source of voltage for control circuitry in HVAC products. When replacing a transformer, the technician must know three key electrical ratings to assure correct placement. They are Primary Voltage, Secondary Voltage, and

a) Amp Rating

b) VA Rating

c) Resistance Rating

d) Both b & c

19) The 24-volt Wall Thermostat is a distributor of the 24VAC found on the "R" terminal of the thermostat. During a call for cool (auto), the thermostat will supply the "R," 24VAC to which circuits?

a) G

b) W & G

c) Y & G

d) Y & W

20) Motors operate by the attraction and repulsion of magnets found in the rotor and the motor windings. In the HVAC industry, the most popular type of motor used is the

a) Shaded Pole

b) PSC

c) Split Phase

d) Both a & b

21) Multi-test meters like the volt ohm meter and amp meter allow the technician to test the electrical health of a circuit. Which meter allows the technician to quickly and effectively test a motor, an element, or heat anticipator when voltage is applied and current is flowing?

a) VOM

b) Amp Meter

22) Which term defines a continuous ore complete path?

a) Continuity

b) Open

c) Short

d) Both b & c

23) An electrical term that means “the lack of resistance or no measurable resistance found, but continuity exists” is:

a) Continuity

b) Open

c) Short

d) Both b & c

24) A voltage value on the “same side of the line” with both VOM meter leads across a switch tells the technician that the switch is

a) Closed

b) Shorted

c) Open

d) Both a & b

Appendix: Answers to Review Questions

Section 1

1) (a) Atom
2) (b) Electrons
3) (d) All of the above
4) (d) Both b & c
5) (d) All of the above
6) (c) Direct, Negative, Positive
7) (c) Volts
8) (a) Current
9) (b) Resistance
10) (d) Watts
11) (d) All of the above
12) (a) P = I x E
13) (b) 21
14) (b) 240 volts
15) (d) 7432
16) (c) 34,130

Section 2

1) (a) Series Circuit
2) (b) Parallel
3) (a) True
4) (a) True
5) (a) Divided Proportionally (Unequally)
6) (c) E = I x R
7) (d) 120
8) (d) 1
9) (a) 30, 40, 50
10) (b) 240
11) (c) Less than the smallest
12) (d) 18.75 ohms
13) (c) 12.76 ohms
14) (d) Ladder

Section 5

1) (a) Series
2) (a) Poles
3) (b) Throw
4) (b) 1, 1
5) (b) 2
6) (b) When de-activated
7) (a) True

8) (a) True
9) (e) All of the above
10) (a) Series
11) (b) Overload
12) (c) Magnetic
13) (b) Control & Load
14) (a) 3
15) (c) 15
16) (c) 30
17) (b) Ladder
18) (b) VA Rating
19) (c) Y & G
20) (b) PSC
21) (b) Amp Meter
22) (a) Continuity
23) (c) Short
24) (c) Open