Electricity Starts with Electrons

- An electron is one of the tiny particles that are the component parts of atoms. The other major parts of an atom are protons an neutrons.
  - Inside the atom, there are forces that pull electrons toward protons, push electrons away from each other and push protons away from each other.
  - The property of electrons and protons that causes these forces is called an electrical charge.
  - The charge of an electron has a negative polarity and the charge of a proton has a positive polarity.
  - There is an attracting force between negative and positive charges and a repelling force between charges that have the same polarity.

Electrical Charges

- Electrical charges are a properties of electrons and protons.
  - Electrical charges do not exist separately from protons and electrons.
  - Protons and electrons do not exist without electrical charges.
- In their normal state, atoms have the same number of protons as electrons so that the positive and negative charges are balanced and the electricity is hidden away inside the atom.

Static Electricity

- If some materials, such as shoes and carpeting, are rubbed together, electrons become dislodged from one material and take up residence on the other.
  - The atoms that are missing electrons become positively charged particles because they don't have enough negative charge to balance the positive charge of their protons.
  - The atoms that have extra electrons become negatively charged particles because they don't have enough protons to balance the negative charge of the extra electrons.
  - The charged particles are called positive or negative ions.
  - The electrical charge that is built up on objects is called static electricity.

Basic Electricity

Static Electricity

- The word “static” means “having no motion.”
  - Static electricity is an accumulation of charged particles that is just sitting around waiting for something to happen.
  - The repulsive forces spread the charge out over the surface of the charged object.
  - The charge remains on the object because electrons do not easily move through the air.
  - If a charged object touches an object that has a charge of the opposite polarity or even an object with no charge, the charge is further spread out.
  - If there is a lot of charge, the electrical force will be high enough to make electrons move through the air in a spark.

Basic Electricity

Electric Current

- When electrons move, that movement is called an electric current.
- When the electric charges of static electricity move to become spread out or neutralized, electric currents flow, but they stop as soon as the charge is dissipated or neutralized.
- Electric batteries and the electric company can cause electric current to flow continuously.

Conductors and Insulators

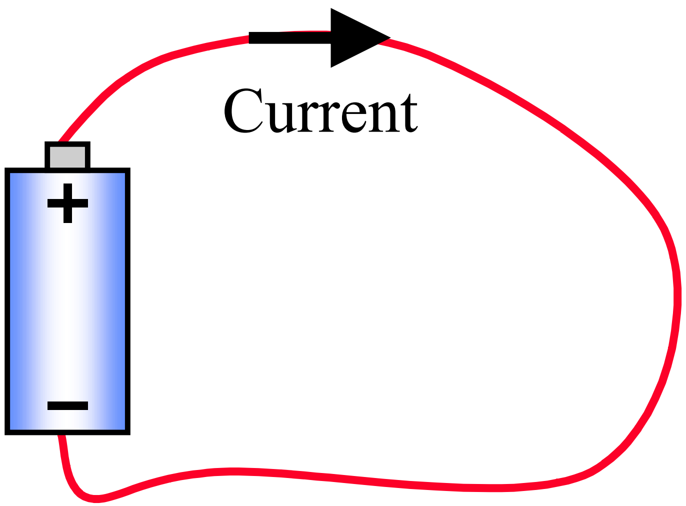
- Electrons move easily through materials like metal. Those materials are called electrical ***conductors***.
  - Some conductive materials let electrons flow more easily than others, those materials are called good conductors.
  - Copper and aluminum are good conductors.
  - Iron is only about 1/6 as good a conductor as copper.
- Electrons can not ordinarily move through materials like air, glass and plastic. Those materials are called electrical ***insulators***.

Electric Wires

- An electric wire is a wire made from copper or aluminum coated with some type of insulating material.
  - An electric current can flow in the wire.
  - The insulating material prevents the current from flowing out of the wire except where it is intended to flow.

Electric Circuit

- An electric circuit consists of a source of electricity and a path for current to flow away from the source and back again.
  - The path is usually an electric wire.
  - The current must flow back to the source because electrons taken away from a source must be replaced.
  - In electric circuits, the direction of current flow is arbitrarily defined as the direction opposite to the direction of the flow of electrons. The mathematical calculations of circuit analysis are easier when the current direction is defined this way.



Voltage and Current and Resistance

- Even when an electric current flows through a good conductor like copper, there is some resistance to the flow of current and some force is required to make the current flow.
  - The electrical force that makes current flow is measured in ***volts*** and called ***voltage***.
  - The current is measured in ***amperes*** or ***amps***.
  - The ***resistance*** is measured in ***ohms***.
  - The relationship among these three quantities is expressed by ***ohm's law***:

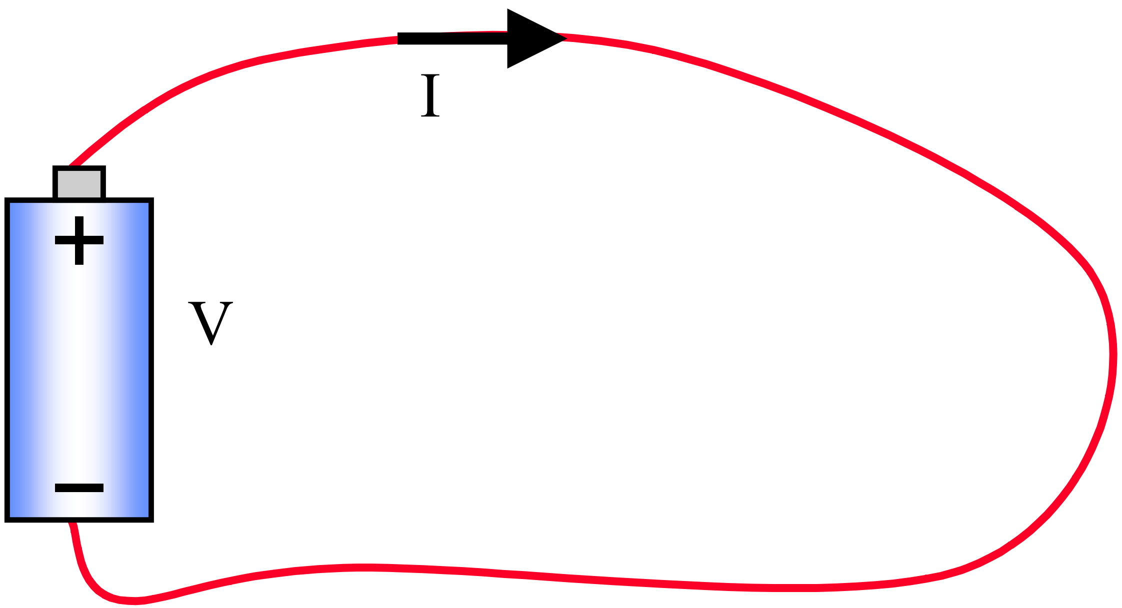
Ohm's Law

Voltage = Current × Resistance

$$V = I \times R$$

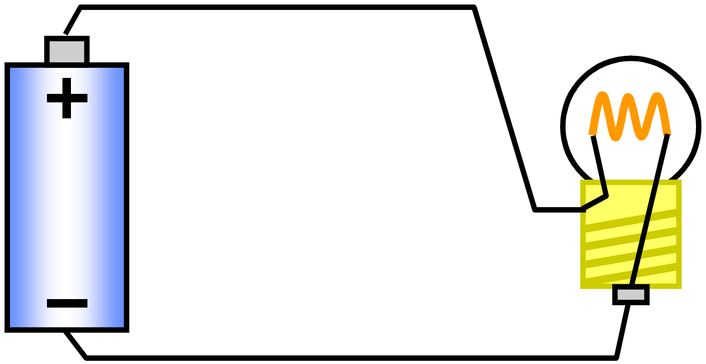
Ohm's Law Applied

- If $V = I \times R$ then $I = V/R$ and $R = V/I$
- If the battery voltage is 1.5 volts and the resistance of the wire is 2 ohms then $I = 1.5V/2\Omega$ or $I = 0.75A$.
  - Note that the ohm unit of resistance measurement is symbolized by the upper case Greek letter Omega: Ω.



Useful Circuits

- In the previous example, the only resistance in the circuit was the resistance of the loop of wire connecting the positive and negative terminals of the battery.
- Normally, the resistance of wire is considered to be practically zero and a wire directly connecting the positive and negative terminals of the source would be called a ***short circuit*** or a ***short***.
  - A short circuit allows a dangerously high current to flow.
- In a useful circuit, wire connects something like a light bulb to the source.



Resistance and Heat

- When current flows through a resistance, heat is produced.
  - In the case of a light bulb, a lot of heat concentrated in a small piece of resistive wire makes the wire hot enough to glow brightly.
- Heat produced by an electric current flowing through a resistance is energy that has been converted from electrical energy to heat energy.
- Mechanical energy is usually measured in foot-pounds, but electrical energy is measured in ***joules***. A foot-pound is equal to about 1.36 joules.
- One amp of current flowing through a one ohm resistor for one second converts one joule of electrical energy to heat.
- Power is the rate of energy usage. If one joule of energy is used in one second, the power is 1 ***watt***.

Power

- Power in an electric circuit is calculated by:

Power = Current × Voltage	$P = I \times V$
or	
Power = Current Squared × Resistance	$P = I^2 \times R$

- If 1/4 amp of current flows from a 1.5 volt battery through a light bulb, the power used by the bulb is 1/4 × 1.5 or 3/8 watt.
- A light bulb that uses 100 watts when connected to a 120 volt source has a current flowing through it that is 100/120 or 0.8 amps.
- The resistance of the 100 watt bulb is $100/0.8^2$ or 156 ohms.

Resistors

- Although there is resistance in everything that carries an electrical current, there are electrical components called ***resistors***.
  - The purpose of an electrical component resistor is to add a known value of resistance to an electrical circuit.
  - Resistors are manufactured in many different ratings and styles.
  - The basic specifications of resistors are:
    - Resistance value (ohms)

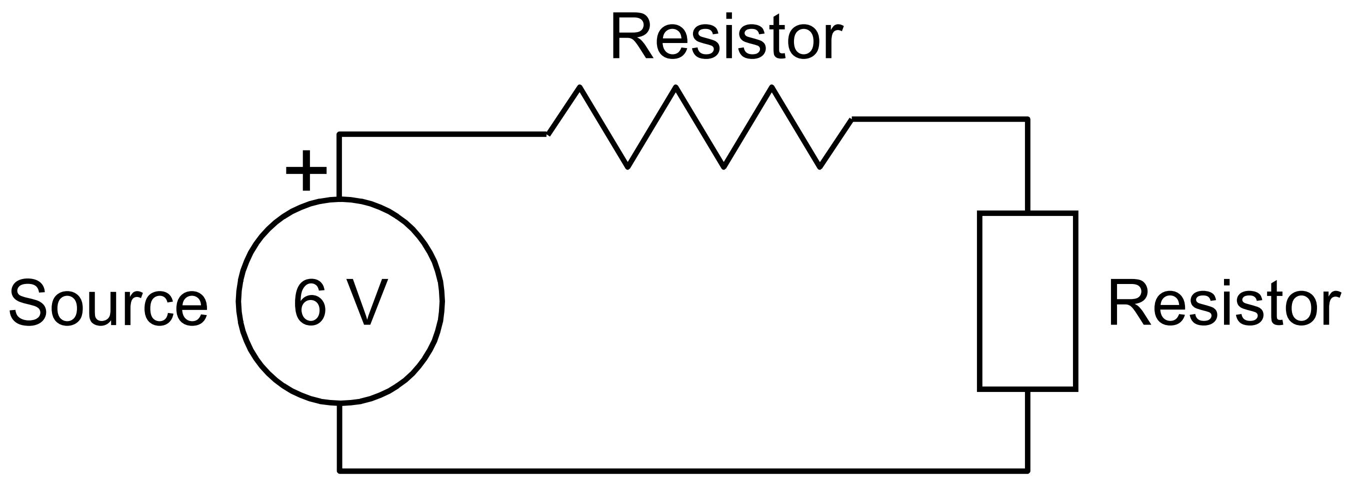
      Value often stated in K ohms (kilo ohms). A 1 K resistor is 1000 ohms.

      Typical range of catalog values: 1/10 ohm to 1 million ohms
    - Maximum power rating (watts)

      Typical range of catalog values: 1/8 watt to 1000 watts)
    - Resistance value tolerance (typically ±5% or ±1%)

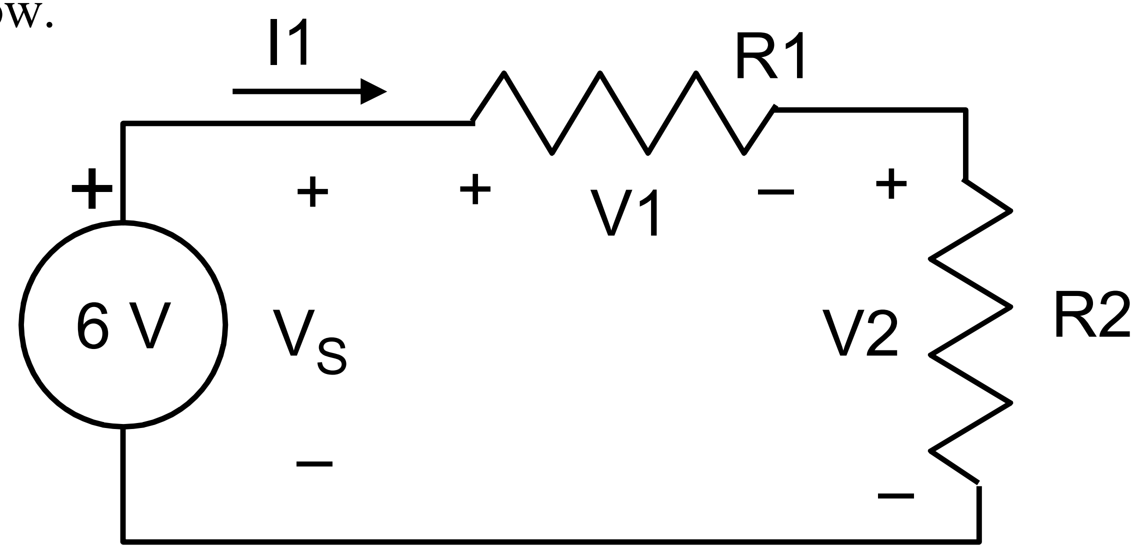
Circuit Diagrams

- Electrical circuit diagrams or ***schematic diagrams*** show electrical components as symbols and wires as lines connecting the symbols.
  - A battery or other voltage source is usually shown as a circle with the letter V and perhaps the voltage value inside the circle.
  - A resistor is shown in a schematic diagram as a zig-zag line or as a small rectangle.



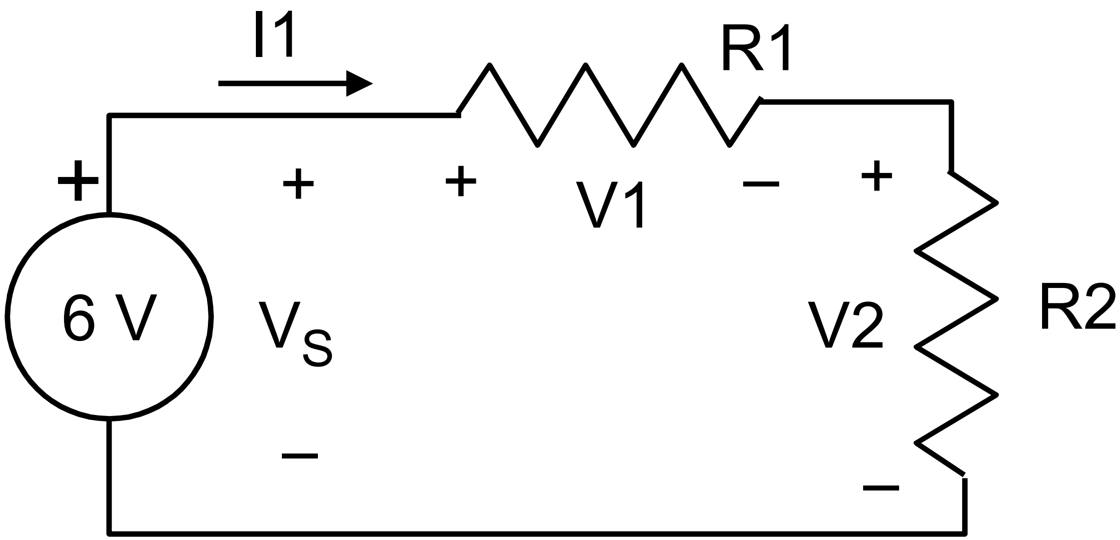
Circuit Diagrams

- In a schematic diagram, an arrow is often used to show current flow.
  - Various resistors in the circuit are shown as R1, R2 or something similar.
  - Various voltages are shown as V1, V2 or something similar.
  - Various currents are shown as I1, I2 or something similar.
  - Current flows out of the positive terminal of the source.
  - The voltage across a resistor is a voltage drop + to – in the direction of current flow.



Series Circuits

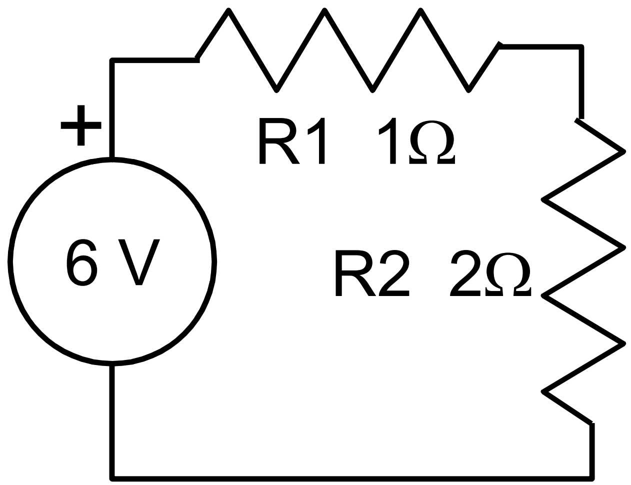
- This circuit is called a ***series circuit*** because one current flows from one component to the next of a series of components.
  - There is only one path available for current to flow.
  - If any component is disconnected or removed, no current will flow.



Basic Electricity

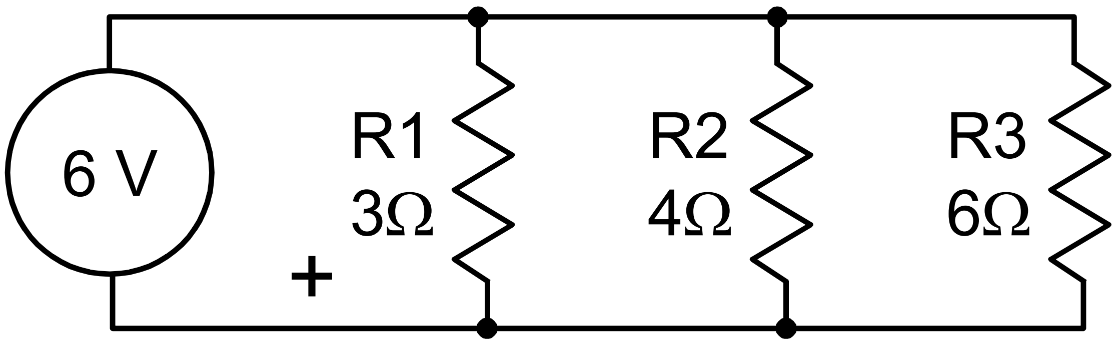
Series Circuits

- The total resistance of resistors connected in series is the sum of the resistances.
  - Total Resistance = R1 + R2 = 3Ω
- The current is the voltage divided by the total resistance.
  - I = 6V/ 3Ω = 2A
- The sum of the voltage drops across the resistors is equal to the source voltage.
  - R1 × I = 2A × 1Ω = 2V
  - R2 × I = 2A × 2Ω = 4V
  - V1 + V2 = 6V
- The source voltage is divided among the resistors according to the ratio of each resistor to the total. V1 = 6 × 1/3



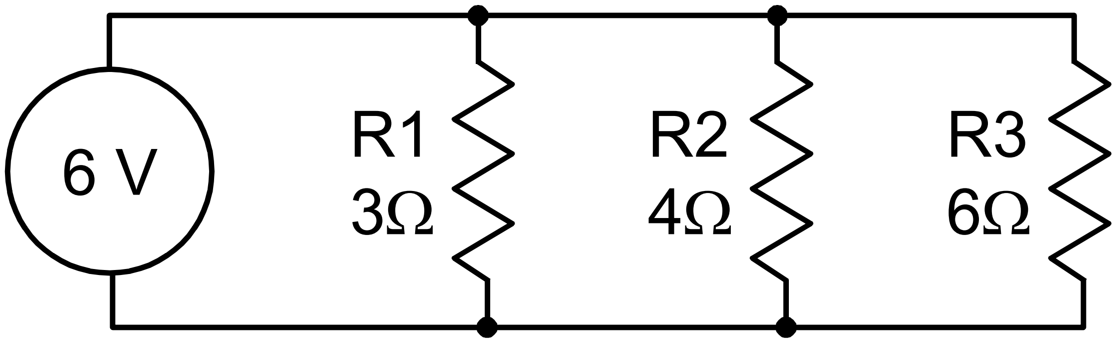
Parallel Circuits

- In a ***parallel circuit***, resistors are connected so that each end of each resistor is connected to the source.
- The voltage across each resistor is the full source voltage.
- There are two or more paths for current to flow.



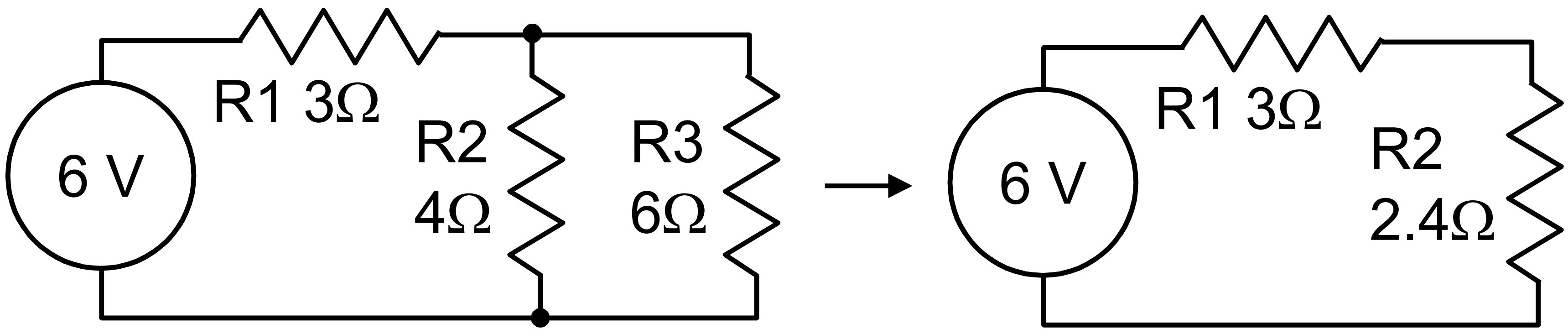
Parallel Circuits

- The total resistance can be calculated from:
  $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 \ldots + 1/R_N$
  - $1/R_T = 1/3 = 1/4 + 1/8 = .333 + .25 + .167 = .75$ $R_T = 1/.75 = 1.33\Omega$
- The total current flowing from the source is the sum of the currents in the individual resistors.
  - $I_T = 6V/1.33\Omega = 4.5A$
  - $I_1 = 6V/3\Omega = 2A$; $I_2 = 6V/4\Omega = 1.5A$; $I_3 = 6V/6\Omega = 1A$
  - $I_T = 2A + 1.5A + 1A = 4.5A$



Circuits with Both Series and Parallel Sections

- Circuits with both series and parallel sections can often be analyzed one section at a time or simplified.
  - The series/parallel circuit below has been simplified by calculating the total of R2 and R3 and showing the total as a new value of R2 connected is series with R1.



  - There are also more advanced mathematical analysis techniques.

Electrical Component Specifications

- All electrical components have specifications.
  - Specifications define how a component functions and provide the mathematical quantities that are needed to calculate the effect of the component in a circuit.
  - Specifications also define the limits of safe operation of the component.
  - Understanding specifications is an important part of buying, selling and using electrical components and equipment.
  - The simple circuits used to illustrate the preceding part of this presentation used three types of components, voltage sources, resistors and wire.
  - The principal specifications of resistors were explained when resistors were introduced.
  - The basic specifications of voltage sources are:
    - ≡ The output voltage
    - ≡ The maximum output current

Electrical Component Specifications

- Wire
  - Wire is often considered to have zero resistance, but the resistance of wire is actually quite important.
  - Current flowing through the resistance in a wire causes heat to be produced. If the wire gets too hot, the insulation will be damaged.
  - There is also a voltage drop across the resistance in a wire. If the voltage drop is too high, there may not be enough voltage delivered to the other components.
  - The resistance of a wire is determined by its diameter and length.
  - Since the diameter or size of a wire determines the resistance per foot and the amount of current that it can safely carry, wire size is an important specification.
  - The other basic wire specifications are the voltage and temperature ratings of the insulation.

Electrical Component Specifications

- Wire Sizes
  - In the USA, wire size is specified by American Wire Gauge (***AWG***) numbers.
  - In addition to AWG, wire size is specified by a measurement called thousands of circular mils (***MCM***).

Basic Electricity

Wire Data Table

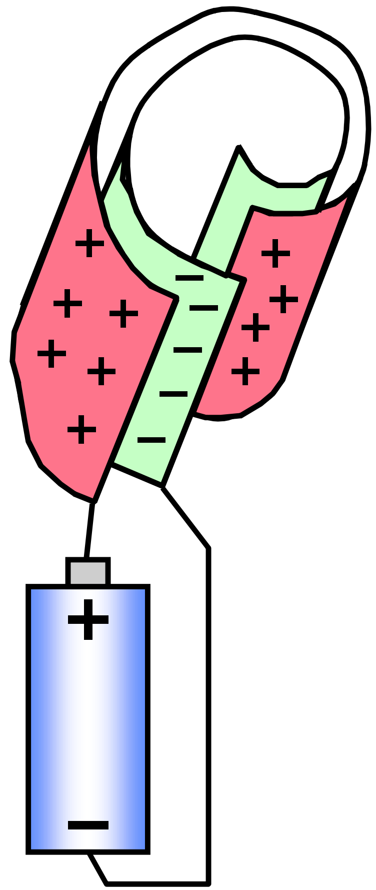
Wire Size	Cross Sectional Area		Current Capacity (Amps)	Resistance Ohms per 1000 ft.	Typical Application
	Circular Mils	Square mm			
AWG 40	9.9	0.00502		1000	
AWG 30	101	0.0512		100	
AWG 20	1020	0.517		10	
AWG 26	254	0.129		41	Telephone cord
AWG 16	2,580	1.31	10 - 15	4.1	Small appliance cord
AWG 14	4,110	2.08	15	2.6	Wall outlet wiring
AWG 10	10,400	5.27	30	1.0	
AWG 6	26,300	13.3	55	0.41	Stove cord
AWG 1	83,700	42.4	110	0.13	
AWG 0	106,000	53.7	125	0.10	
AWG 0000	212,000	107	195	0.05	150 Hp motor
500 MCM	500,000	253	320	0.02	
2000 MCM	2,000,000	1014	560	0.005	

Other Electrical Components

- In addition to resistors, there are two other other basic electrical components called ***capacitors*** and ***inductors***.
- While resistors use energy by converting it to heat, inductors and capacitors store energy.

Capacitors

- Capacitors store energy by allowing an electrical charge to build up inside them.
  - Capacitors typically contain strips of aluminum or aluminum foil separated by a thin insulating material.
  - The foil provides a large surface to allow an electrical charge to spread out.
  - The thin insulating material allows positively and negatively charged foil to be close together so that applying a relatively small voltage between the foils will transfer a relatively large amount of charge from one foil to the other.
  - Capacitors are sometimes called ***condensers***.



Capacitors

- The capacitance of a capacitor, stated in ***farads***, is the amount of charge that is transferred between the foils of a capacitor per volt of applied voltage.
  - Since 1 farad is a very large amount of capacitance, capacitance is usually stated in millionths of a farad or ***microfarads***.

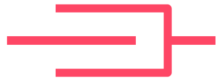
- The energy stored in a capacitor is given by:

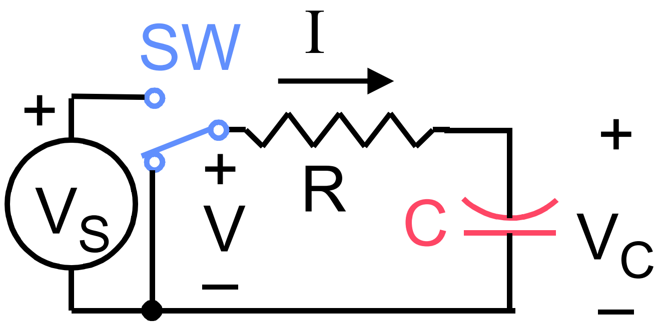
$$E(\text{joules}) = 1/2 \times C(\text{farads}) \times V^2(\text{volts})$$

Capacitors

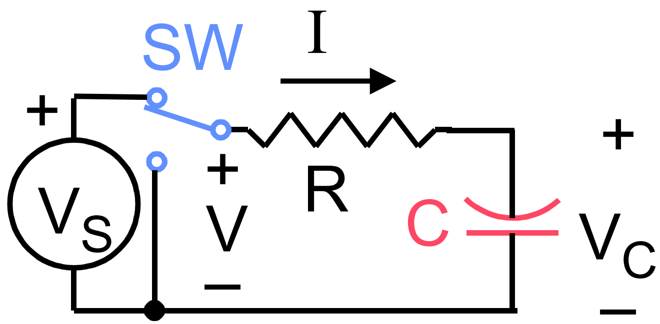
- Some capacitors have a chemical electrolyte in them that enables a capacitor of a given physical size to have a higher capacitance.
  - Capacitors of this type are called ***electrolytic*** capacitors.
  - A disadvantage of electrolytic capacitors is that they are polarized. They have one specific terminal that must be the positive terminal. Non-polarized capacitors can be charged in either direction.
- There are many different types of capacitors. Some of them are specially designed for very specific applications.
- The basic specifications of a capacitor are:
  - Capacitance value (microfarads) and tolerance (±%)
  - Rated voltage or working voltage (volts)
  - Type (electrolytic or other)
  - Temperature range

Capacitors

- This circuit introduces two additional schematic diagram symbols.
  - The capacitors in a schematic diagram are designated C1, C2 etc. and symbolized by two parallel lines one of which is slightly curved.
  - An alternate symbol for a capacitor is: 
  - Switches are usually designated S1, SW1 etc, and symbolized by two or more circles with a straight line showing the initial switch open/closed position.



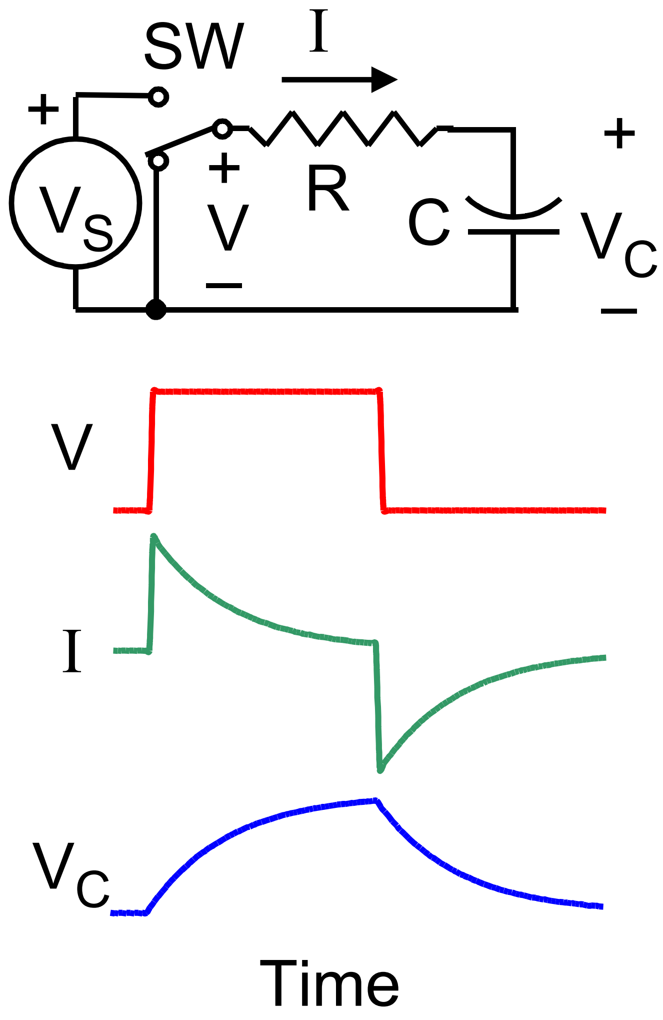
Switch set to disconnect resistor from voltage source and connect it across the capacitor.



Switch set to connect resistor to voltage source.

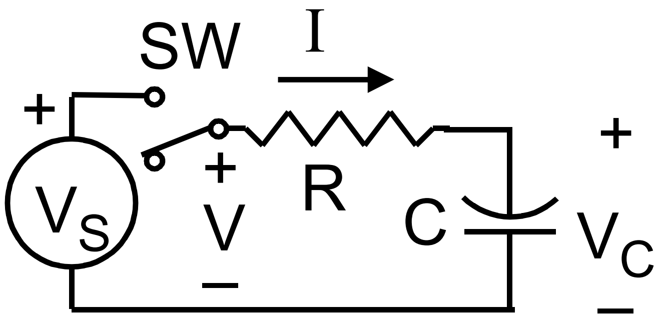
Capacitors

- Since capacitors have very little resistance, they depend on resistance elsewhere in the circuit to limit their charging and discharging current to a safe level.
  - When voltage is applied by switching the resistor to the voltage source, the voltage across the capacitor is zero and the current immediately rises to I = V/R.
  - As the capacitor charges, V_C slowly rises and the current falls as determined by $I = (V–V_C)/R$. When $V_C = V$, I = 0.
  - When the switch position is reversed, the capacitor discharges through the resistor.
  - A capacitor smoothes rapid voltage changes but can cause rapid current changes.



Capacitors

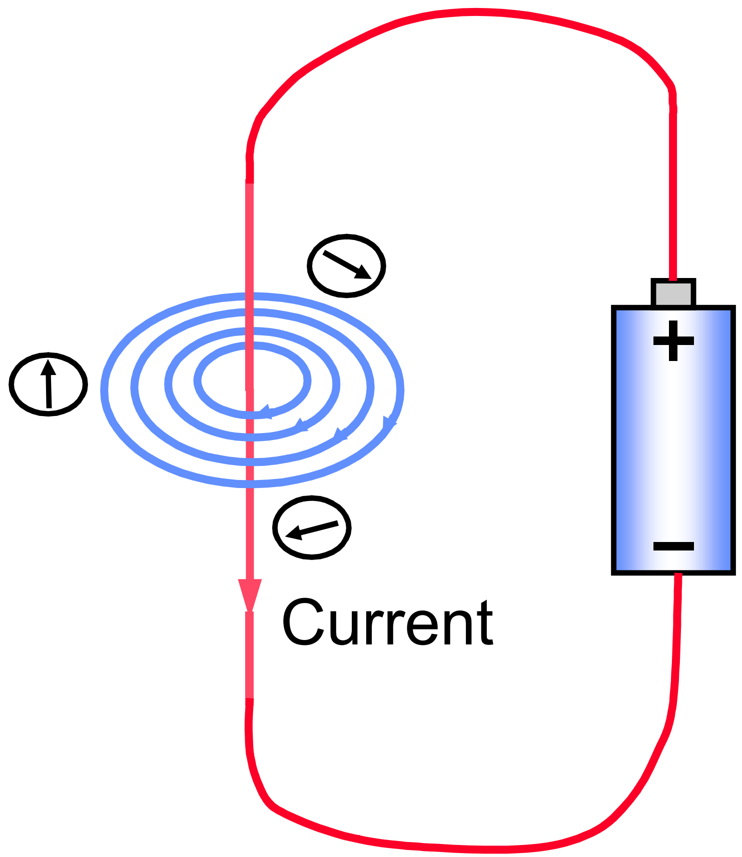
- Capacitors store energy quite effectively.
  - If the resistor is simply disconnected from the power supply after the capacitor is charged rather than connecting to a path to discharge the capacitor, the capacitor voltage V_C will be retained for a long time.
  - Capacitors can not store energy for months or years like batteries, but they can store energy for hours or days.



Basic Electricity

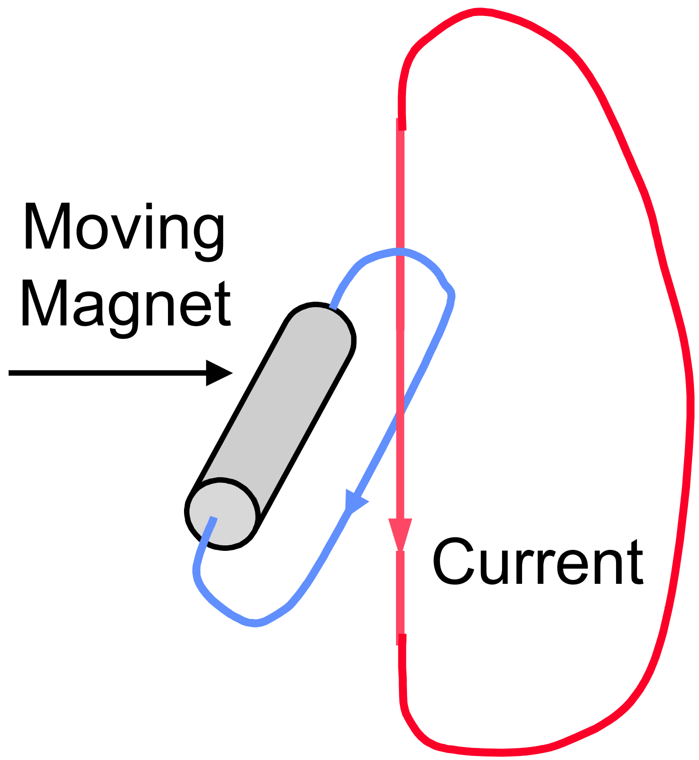
Electricity and Magnetism

- A current flowing through a wire, causes a magnetic field that surrounds the wire.
  - The magnetic field is indicated by circular lines.
  - Compasses point in the direction of the magnetic field.
  - The strength of the magnetic field is proportional to the magnitude of the current.



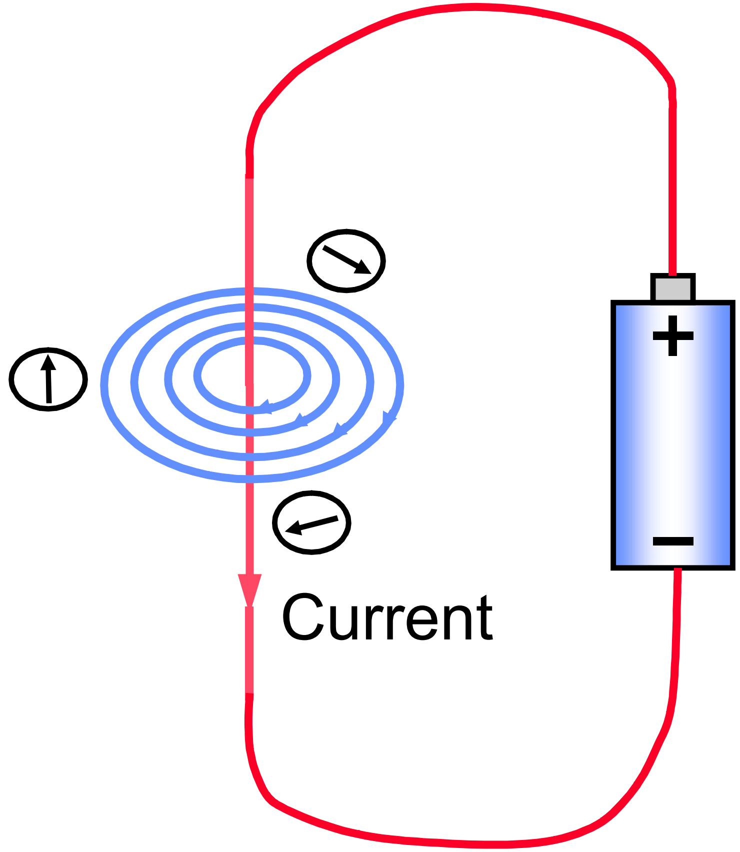
Electricity and Magnetism

- A magnetic field moving across a wire, causes a current to flow in the wire.
  - If a magnetic field around a wire increases or decreases, that also causes current to flow.
  - A current caused by a moving or changing magnetic field is said to be ***induced***.



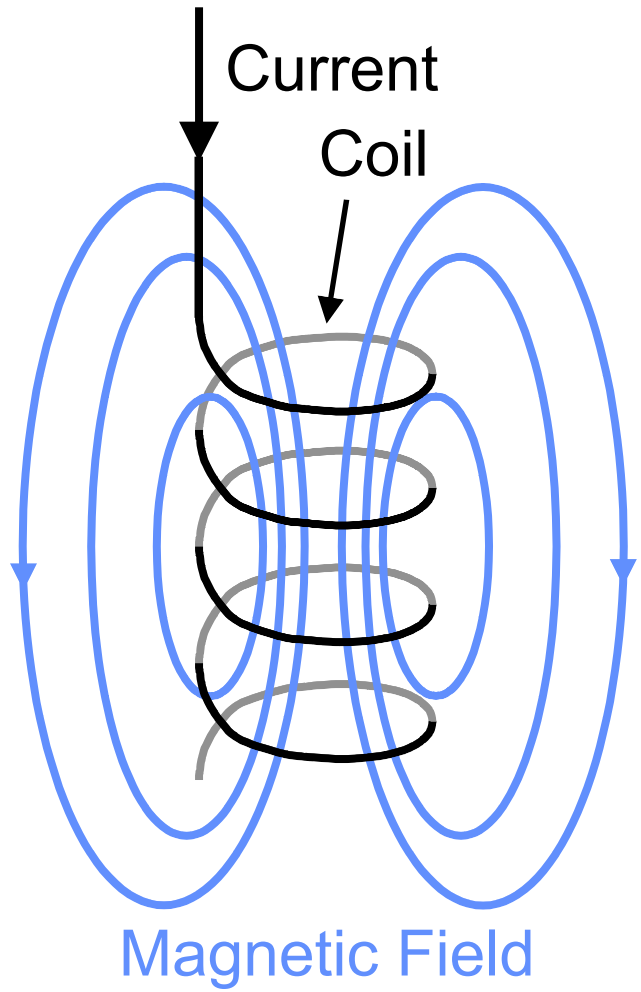
Inductance

- If the current in a wire changes, the magnetic field around the wire also changes.
  - The changing magnetic field induces a current that opposes the change in the current.
  - Self inductance is the phenomenon by which a magnetic field opposes any change in a current that is producing it.
  - Self inductance is usually simply called ***inductance***.



Inductors

- If a wire is wound into a coil, the magnetic field is concentrated around the coil and the inductance is increased.
  - If the coil is wound around an iron core, the magnetic field is further strengthened and mostly contained in the iron.
  - A coil of wire is an electrical component called an ***inductor***.
  - If a coil of wire is wound around a hollow space, it is an ***air core inductor***.
  - If a coil of wire is wound around an iron core, it is an ***iron core inductor***.
  - Inductors are also called ***reactors*** or ***chokes***.



Inductors

- The inductance of an inductor, stated in ***henrys*** is the strength of magnetic field per ampere of current flowing through the inductor.
  - Since 1 henry is a large amount of inductance, the inductance is usually stated in thousandths of a henry, ***millihenrys*** or millionths of a henry, ***microhenrys***.

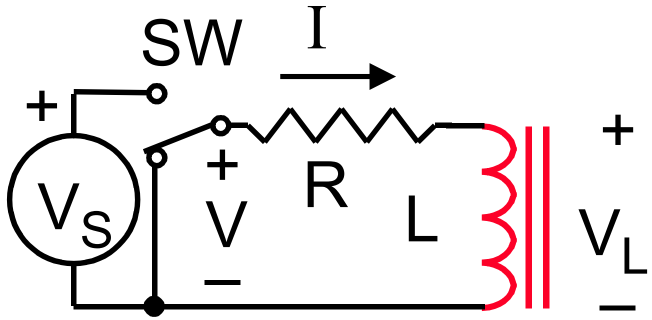
- The energy stored in a capacitor is given by:

$$E(\text{joules}) = 1/2 \times L(\text{henrys}) \times I^2(\text{amps})$$

Inductors

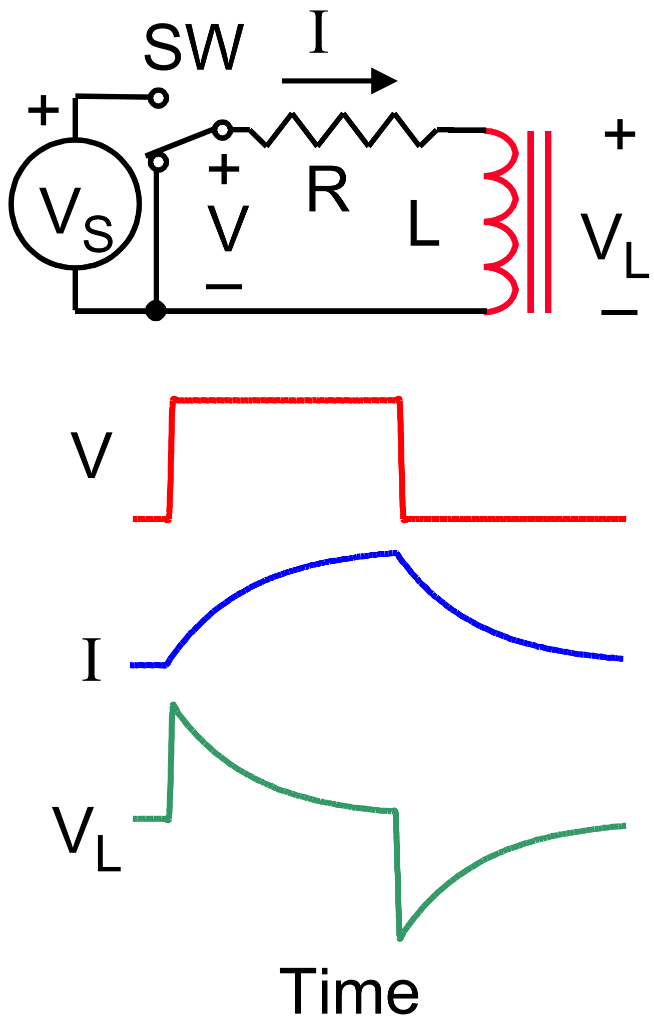
- There are many different types of inductors. Many of them are designed for specific applications.
- The inductors in a schematic diagram are designated L1, L2 etc. and symbolized by a series of loops or semicircles. Iron core inductors are symbolized by parallel lines adjacent to the series of loops.
- The basic specifications of an inductor are:
  - Inductance value (millihenrys or microhenrys)
  - Rated current
  - Rated voltage

Air Core Inductor Symbols



Inductors

- Inductors have relatively little resistance. Current is determined by resistance elsewhere in the circuit.
  - When voltage is applied by switching the resistor to the source, the voltage across the inductor immediately rises to $V_L = V_S$.
  - The current slowly rises and V_L falls as determined by $V_L = V - I \times R$.
  - When the current rises to $I = V/R$, $V_L = 0$.
  - When the switch position is reversed, the voltage across the inductor immediately rises to $V_L = -V$ and maintains the flow of current until the stored energy is dissipated..
  - An inductor prevents rapid current changes but can cause rapid voltage changes.



Alternating Current

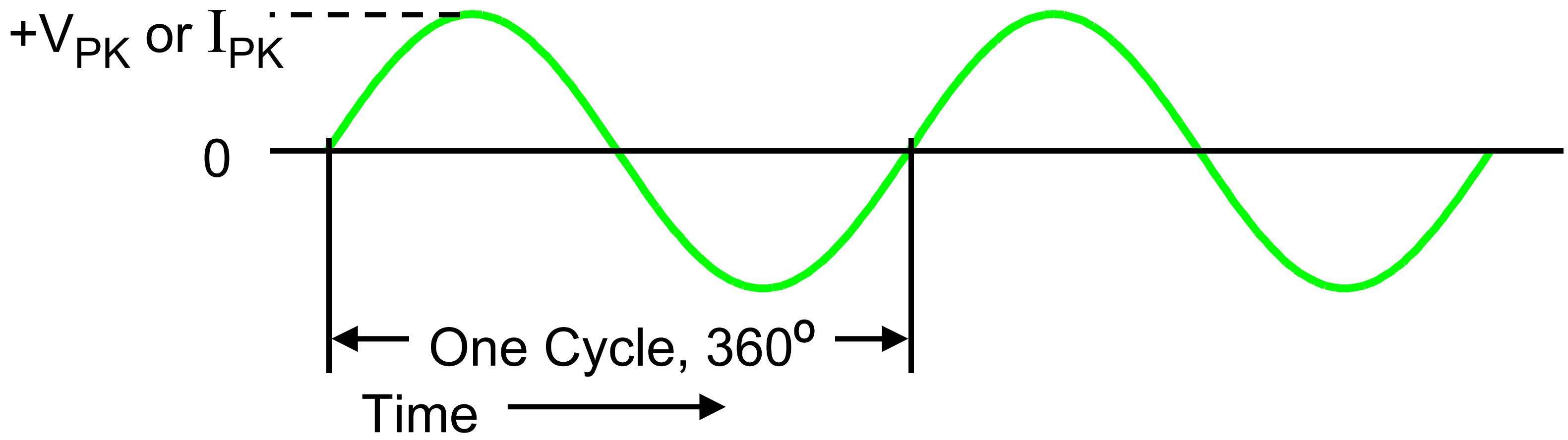
- The voltage supplied by a battery remains relatively constant over time until the battery becomes discharged.
  - The current supplied by a battery remains constant over time except for a delay in reaching a steady value after switching on a circuit that contains inductance and/or capacitance.
  - A power supply that produces a constant level of voltage and current is called a ***direct current*** or ***DC*** power supply.
- The voltage supplied by the electric company constantly varies in magnitude and the +/– polarity of the supply terminals constantly alternates direction.
  - The current supplied varies in magnitude and alternates polarity in the same way.
  - A power supply of this type is called an ***alternating current*** or ***AC*** power supply.

Alternating Current

- Alternating current power supplies have a specific characteristic of voltage and current vs. time called a ***sinusoidal waveform*** or ***sine wave***.
  - The instantaneous value of an AC voltage or current is given by: (V_{PK} & I_{PK} are peak values of voltage and current)

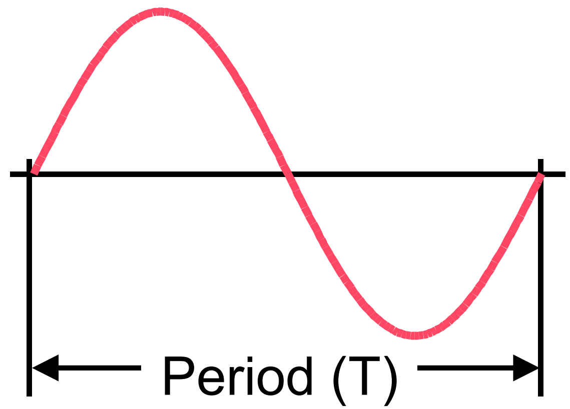
$$V = V_{PK} \times \sin(2 \pi f t) \ \& \ I = I_{PK} \times \sin(2 \pi f t)$$

  - The expression ($2 \pi f t$) is an angle that progresses from 0 to 360 degrees during one ***cycle*** of the waveform (f = frequency in cycles per second or hertz; t = time in seconds).



Alternating Current

- Frequency
  - The ***frequency*** (f)of an AC waveform is the number of ***cycles*** or polarity reversals that take place in one second. Frequency is stated in ***Hertz*** (***Hz***) or cycles per second.
  - In the USA, the frequency of AC power is 60 Hz.
  - The ***period*** (T) of an AC waveform is the time required for one cycle.
  - T = 1/f The period of a 60 Hz waveform is 1/60 of a second, .0166 sec. Or 16.67 milliseconds.

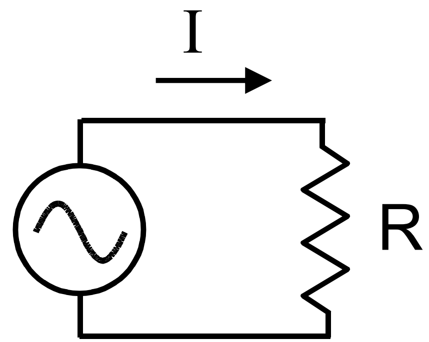


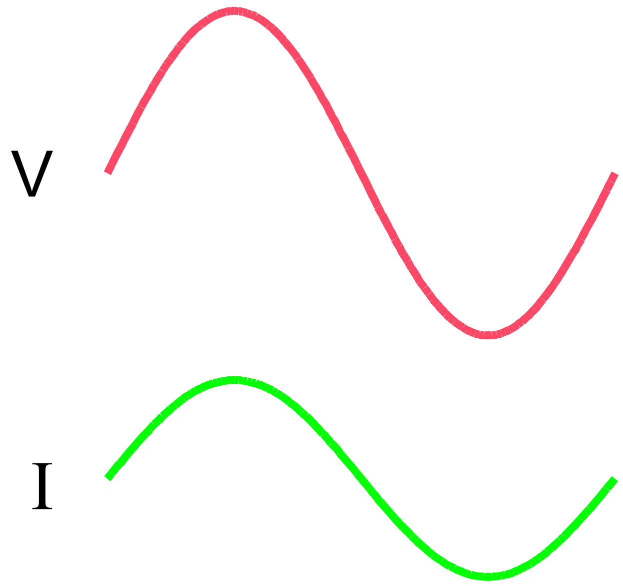
AC Voltage and Current Values

- Sinusoidal voltages and currents can be quantified in terms of instantaneous and peak values, but the ***Root Mean Square*** or ***RMS*** value is more useful.
  - The RMS value of an AC voltage or current is a value that can be used to calculate power using the same formula, P = I × V, that is used with DC voltages and currents.
  - The RMS value of a waveform is calculated by calculating the squares of the instantaneous values over one cycle and then calculating the average of the squared values.
  - For a sine wave, $$V_{RMS} = \frac{V_{PK}}{\sqrt{2}}$$
  - In AC circuits, voltage and current values are generally assumed to be RMS values unless otherwise stated.

AC Circuits with Resistors

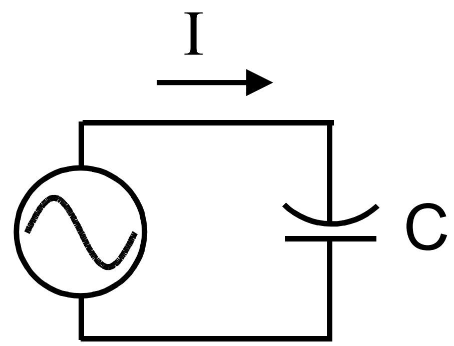
- AC circuits with resistors are similar to DC circuits.
  - The relationship between voltage, current and resistance is $V = I \times R$.
  - If voltage and current are stated as RMS values, Power = $I \times V$.
  - The current waveform is similar to the voltage waveform, but the peak and RMS values are determined by $I = V/R$.
  - In a schematic diagram, an AC voltage source is often shown as a circle with a sine wave in the center.

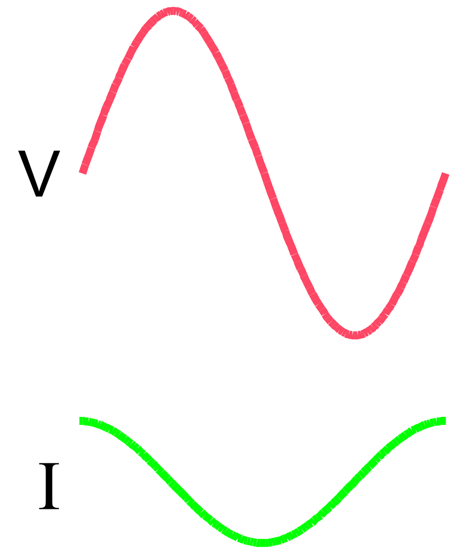




AC Circuits with Capacitors and Inductors

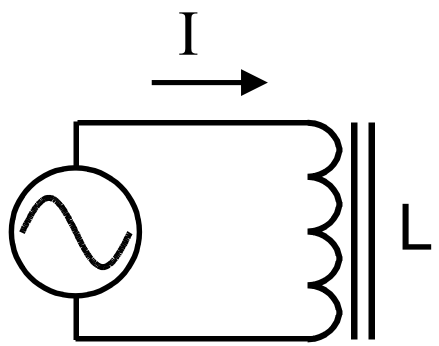
- When an AC voltage is applied to a capacitor, current flows in and out, continuously charging and discharging the capacitor.
  - The current waveform is sinusoidal, but the peak positive values occur when the voltage is increasing at its steepest rate (passing through 0).
  - The peak negative current occurs when the voltage is decreasing at its steepest rate.
  - The value of the current is given by: $I = V/X_C$
  - X_C is the ***reactance*** of the capacitor. Reactance is similar to resistance in that the relationship among V, I and X is $V = I \times X$, but no power is used by current flowing through a reactance. Power continuously transfers back and forth between the capacitor and the power source. $X = 1/(2 \pi f C)$

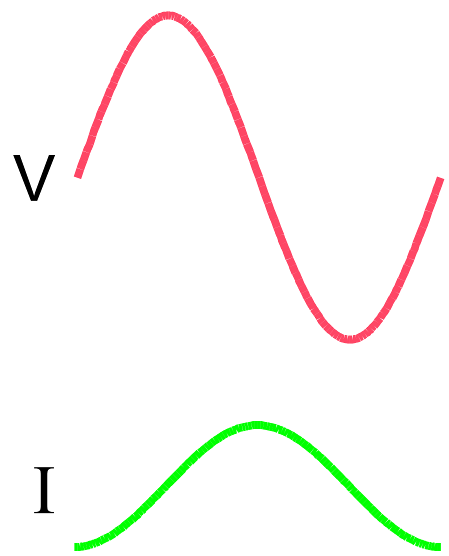




AC Circuits with Capacitors and Inductors

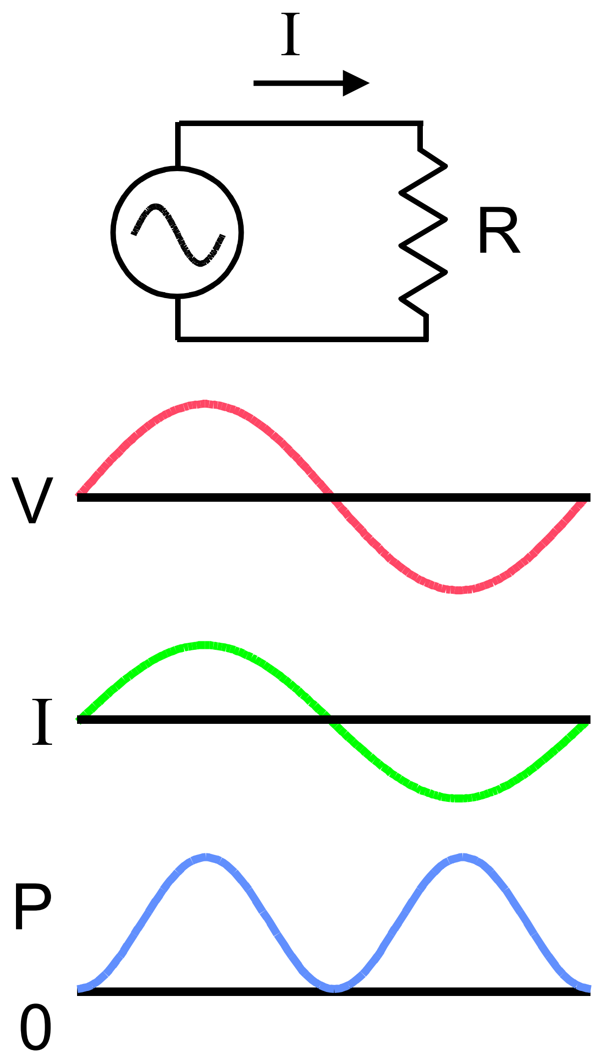
- When an AC voltage is applied to an inductor, the resulting current is sinusoidal as shown.
  - The current reaches its maximum rate of increase at the point of peak positive voltage.
  - The maximum rate of current decrease occurs at the point of peak negative voltage.
  - The value of the current is given by $I = V/X_L$.
  - X_L is the reactance of the inductor. $X_L = 2 \pi f L$





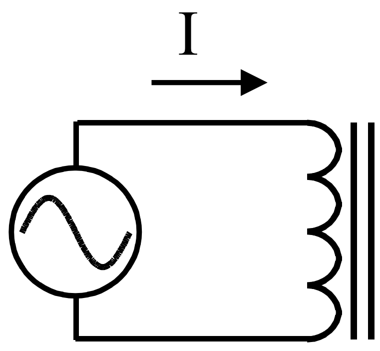
Power in AC Circuits

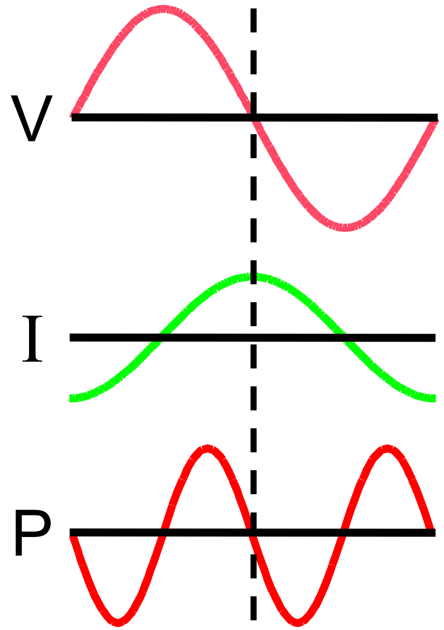
- The Power Waveform
  - When the load in an AC circuit is a resistor, the positive and negative peaks of the current waveform occur at the same times as the positive and negative peaks of the voltage waveform.
  - A power waveform can be calculated by multiplying the voltage by the current at each instant in time.
  - Note that the power waveform lies entirely above the zero line because +V × +I = +P and –V × – I = +P.
  - $P_{Average} = V_{RMS} \times I_{RMS}$



Power in AC Circuits

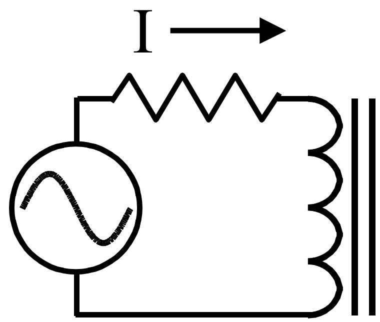
- Power in a Circuit with an Inductor or Capacitor
  - When the load in an AC circuit is an inductor or capacitor, the positive and negative peaks of the current waveform occur when the voltage waveform crosses through zero.
  - When the power waveform is calculated, it can be seen that the power waveform is centered on the zero line.
  - This shows that the average power delivered by the source is zero.
  - The positive power delivered by the source to the load is balanced by the negative power received by the source from the load.

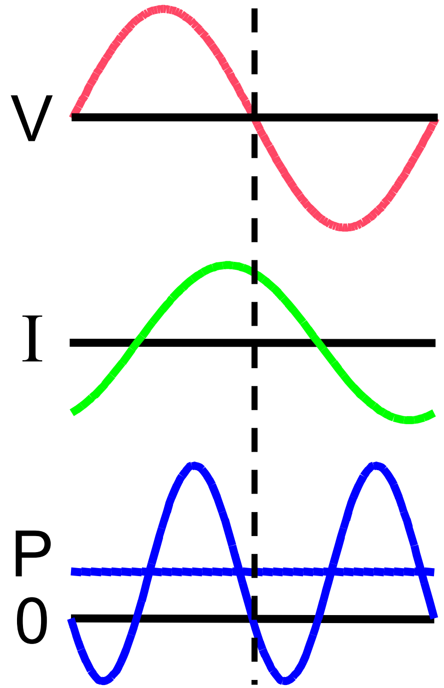




Power in AC Circuits

- Power in a Circuit with a Resistor and an Inductor or Capacitor
  - When the load in an AC circuit is resistor in series with an inductor or capacitor, the positive and negative peaks of the current waveform occur at an intermediate point between the peaks and zero points of the voltage waveform.
  - The power waveform shows both positive and negative values, but the average power is positive.
  - This shows that some power passes back and forth between the source and inductive or capacitive part of the load and some power is delivered by the source to the resistive part of the load.





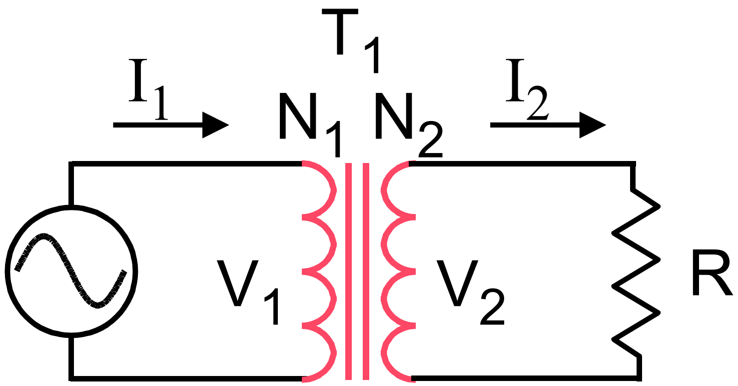
Power in AC Circuits

- Calculating Power in a Circuit with a Resistor and an Inductor or Capacitor
  - In a circuit with only resistance in the load, the power is $P = V \times I$ where V and I are the RMS values of voltage and current.
  - In a circuit with an inductive or capacitive load, multiplying $V \times I$ gives the ***apparent power***, but the ***real power*** delivered to the load is zero because the average of the power delivered to the load and returned to the source is zero.
  - In a circuit with both resistance and inductance or capacitance, the real power delivered to the load is some percentage of the apparent power depending on what percentage of the total load is resistance.
  - The ratio of the real power divided by the apparent power is called the ***power factor*** (***pf***). If the load is 100% resistive, pf = 1. If the load is 100% capacitive or inductive, pf = 0.
  - Real power is calculated:

$$P = V \times I \times pf$$

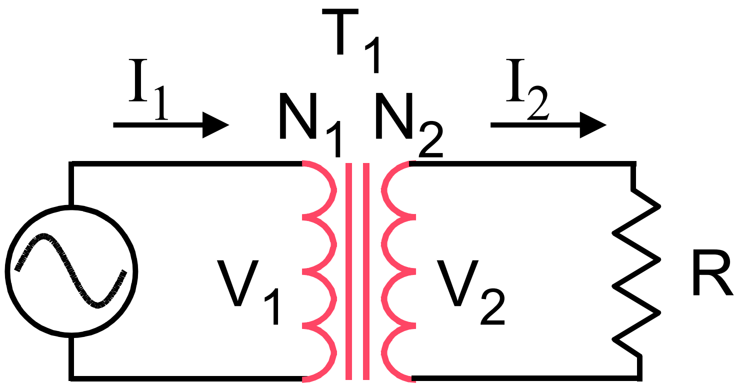
Transformers

- A ***transformer*** is a device that can change the voltage in an AC circuit.
  - A transformer consists of two coils of wire wound on the same iron core.
  - If one coil is connected to an AC power source, the resulting magnetic field induces a voltage in the other coil.
  - The coil that is connected to the power source is called the ***primary*** winding.
  - The coil that is connected to the load is called the ***secondary*** winding.
  - The transformers in a schematic diagram are designated T1 or TR1 etc. The symbol is similar to the symbol for an inductor.



Transformers

- The ratio of the number of turns in the primary and secondary coils determines the relationship between the primary and secondary voltages and currents.
  - The voltage ratio is directly proportional to the turns ratio and the current is inversely proportional to the turns ratio.
  - $V_2 / V_1 = N_2 / N_1$ or $V_2 = V_1 \times N_2/N_1$
  - $I_1 / I_2 = N_2 / N_1$ or $I_1 = I_2 \times N_2/N_1$
  - In this example, V_1 is the same as the supply voltage and $I_2 = V_2/R$.

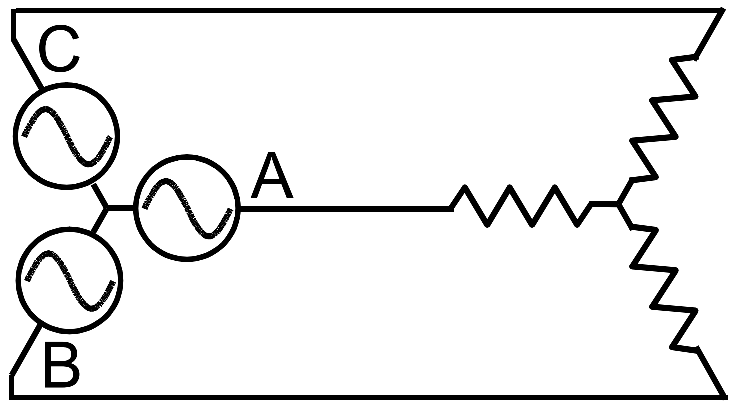


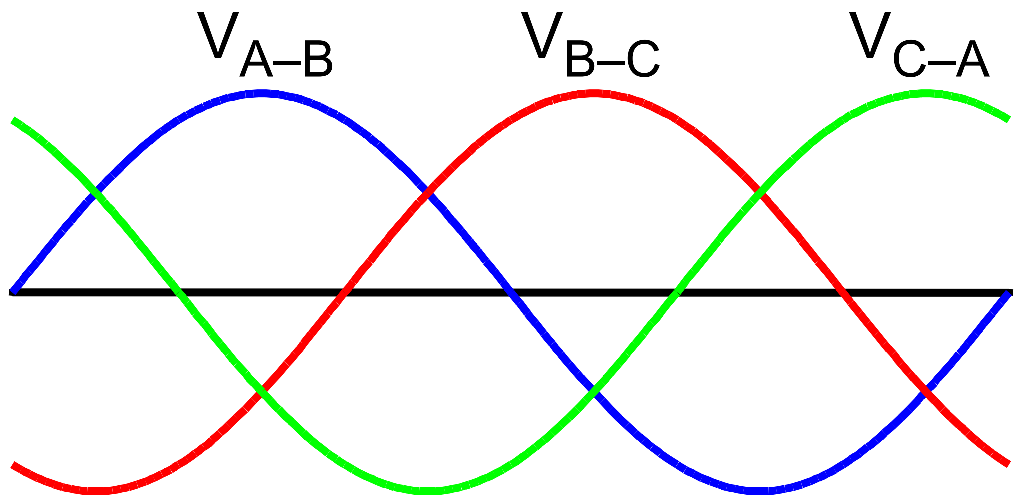
Transformers

- Specifications
  - Rather than the turns ratio, the rated primary and secondary voltages are usually specified for a transformer.
  - Rather than the rated primary or secondary current, the product of the rated current and voltage is often specified. This is called the ***VA*** (volt-amperes) of the transformer or the ***KVA*** (VA/1000).

Three Phase AC Power

- Three phase power is supplied wherever a large amount of power is required such as in industrial plants.
  - A three phase voltage source is a three-terminal source with peak voltages occurring at different times as shown here.





Advantages of Three Phase AC Power

- Motors that are designed to use three phase power have better operating characteristics than motors that use single phase power.
  - Some other types of equipment also have operating advantages over the equivalent single phase equipment.
- Three phase power is more economical to transmit and distribute.
  - The power delivered by a 3-phase source is given by:

$$P = V \times I \times 1.73 \times pf$$

  - With 3-phase power using 3 wires instead of 2, 73% more power is carried by 50% more wire.
  - Similar savings are realized in other power transmission and distribution components.

Electronics

- The field of electronics was originally concerned with the control of electrons moving through a vacuum in vacuum tubes.
- Today electronics is primarily concerned with controlling electric currents with semiconductor components such as transistors.
- A ***semiconductor*** is a material that is a conductor only under certain conditions.

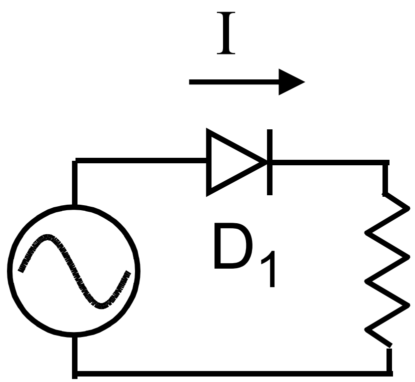
Semiconductors

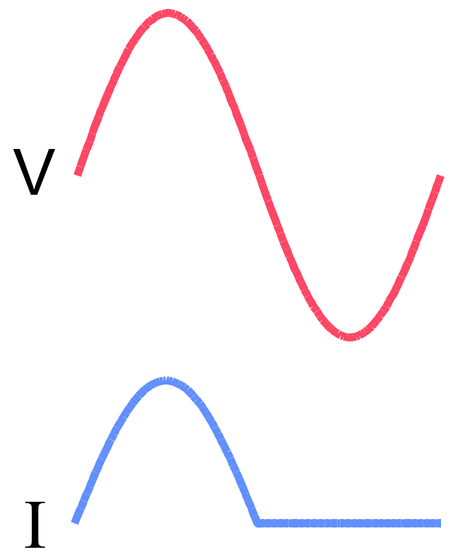
- Most semiconductors are made of silicon, a very abundant element that is found in various types of sand and rock.
  - To make semiconductor materials, purified silicon is “doped” by adding small amounts of various types of impurities.
  - Semiconductor devices are made from thin layers of various types of semiconductor materials.

Basic Electricity

Semiconductor Diodes

- A semiconductor ***diode*** is a two terminal component that conducts current in one direction but not the other.
  - The diodes in a schematic diagram are usually designated D1, D2 etc and symbolized by an arrow with a line across the tip.
  - If an AC voltage is applied to a diode, current is conducted only during the part of the cycle that produces current in the conducting direction of the diode.
  - Since the diode has only a small resistance in the forward direction, the resistance in the circuit determines the forward current.
  - This circuit uses a diode as a ***rectifier*** to convert AC power to DC power.





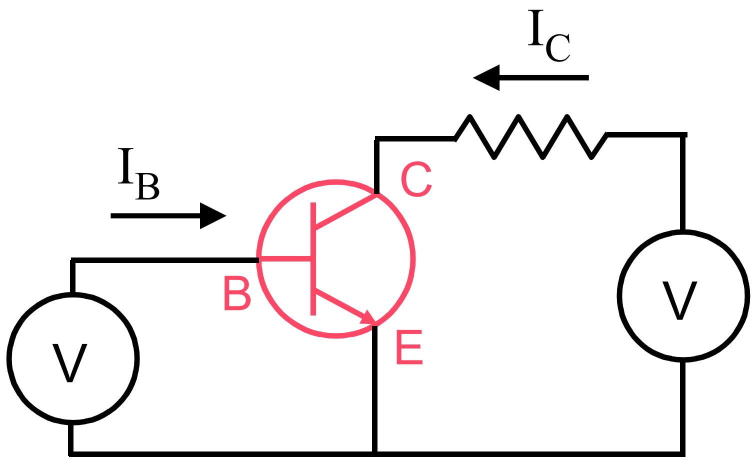
Semiconductor Diodes

- The basic specifications for a diode are:
  - Rated forward current (amps)
  - Maximum blocking voltage (volts)
    - ≡ Often called the peak inverse voltage (PIV)
  - A variety of different types of diodes are available with characteristics that make them suitable for various applications.

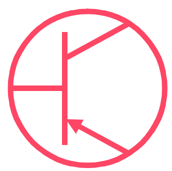
Transistors

- A ***transistor*** is a three terminal component that can be used as an amplifier or a switch.
  - The transistor terminals are called the emitter, base and collector and are marked E, B and C in the schematic diagram.
  - The base - emitter current is the control current and the collector - emitter current is the load current.
  - In NPN transistors current flows from the base and collector to the emitter.
  - In PNP transistors, the current flows in the opposite direction.
  - The arrow head on the emitter indicates the direction of current flow.

NPN Transistor Circuit

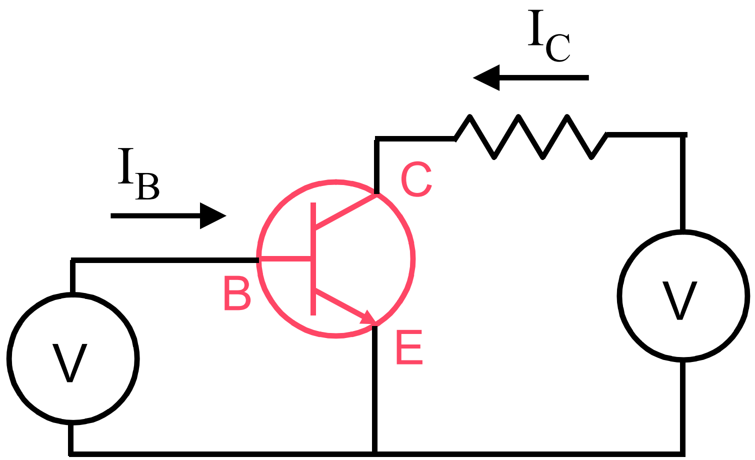


PNP Transistor Symbol



Transistors

- The principal characteristic of a transistor is that a small base current, driven by a low voltage controls a larger collector current driven by a larger voltage.
- Transistors can be used as amplifiers or switches
  - When the transistor is used as an amplifier, the base current can be varied to cause a corresponding variation in the collector current.
  - When the transistor is used as a switch, the base current is set to zero to turn off the collector current and set to its maximum value to turn on the collector current.



Transistors

- The basic specifications for a transistor are:
  - Rated collector current, I_C (amps)
  - Rated collector - emitter voltage with no base current, V_{CEO} (volts)
    This is the voltage that the transistor can withstand when it is turned off.
  - Current gain, h_{fe}
  - Power dissipation rating (watts)
    This is the safe level of power loss inside the transistor.
  - Characteristic curves and many more parameters are needed to completely define the characteristics of a transistor.
  - A variety of different types of transistors are available with characteristics that make them suitable for various applications.