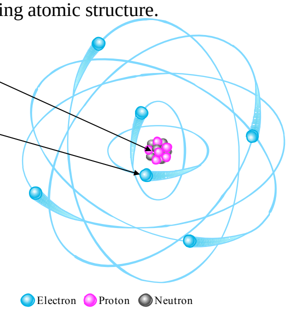
We will start with a little revision

The Bohr atom

The atom is the smallest particle of an element that retains the characteristics of that element

The Bohr atom is useful for visualizing atomic structure.

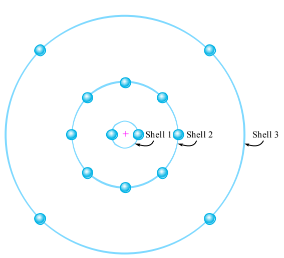
- The nucleus is positively charged and has the protons and neutrons.
- Electrons are negatively charged and in discrete shells.
- The atomic number is the number of protons and determines the particular element.
- In the neutral atom, the number of electrons is equal to the number of protons.



The valence shell

The outer shell is called the *valence shell*. Electrons in this shell are involved in chemical reactions and they account for electrical and thermal conductivity in metals.

A neutral Si atom is shown. There are 4 electrons in the valence shell.

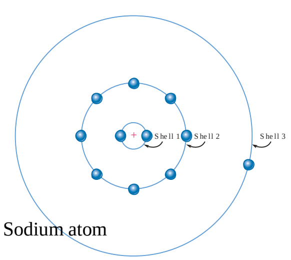


The valence shell

Metals have one, two or three electrons in the valence shell. The atom illustrated here is a sodium atom (Na), with only one electron in its outer shell.

Sodium is highly reactive, and easily gives up its single valence electron. For this reason, it is not used in electrical work.

Non-metals have either complete or nearly complete outer shells, so they make poor electrical conductors.



Sodium atom

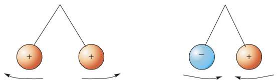
Categories of electronic materials

3 Categories of materials are used in electronics

1. Conductors
   - Large number of free electrons and easily conduct electricity. Most metals are conductors
2. Semiconductors
   - Fewer electrons than conductors , 4 valence electrons in their outer shell. Basis for a large number of devices since their conduction can be varied over a wide range by a variety of means
3. Insulators
   - Poor conductors, very few free electrons

Electrical charge

There is a force (*F*) between electrical charges. Like charges repel; unlike charges attract.
Positive charge is due to a deficit of electrons on an atom, negative charge is due to an excess of electrons on an atom
The force is directly proportional to charge.
The force is inversely proportional to square of distance…like gravity
Unit of charge is the Coulomb
One coulomb is the charge possessed by 6.25×10^{18} electrons
The electron has a charge of 1.6×10^{-19}C



Coulomb's Law

A force (F) exists between two point-source charges (Q_1, Q_2) that is directly proportional to the product of the two charges and inversely proportional to the square of the distance (d) between the charges.

Coulomb: the unit of electrical charge

One coulomb is the total charge possessed by
$6.25 \times 10^{18}\ electrons$

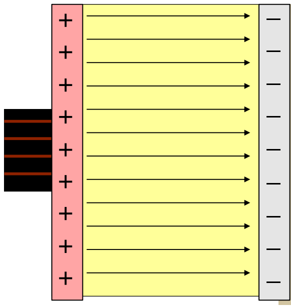
The total charge Q for a given number of electrons is

$$Q = \frac{\text{number of electrons}}{6.25 \times 10^{18}\ electrons/C}$$

Example
How many Coulombs do 93.8×10^{16} electrons represent?

$$Q = \frac{93.8 \times 10^{16}}{6.25 \times 10^{18}\ electrons/C} = 0.15 \text{ coulombs of } 0.15 \text{ C}$$

Voltage



Force is required to move a charge against the electric field.

When force is applied over a distance, work is done. Work done in moving a charge against the electric field leads to the definition of voltage:

Voltage is the work per charge done against the electric field.

Voltage

The defining equation for voltage is

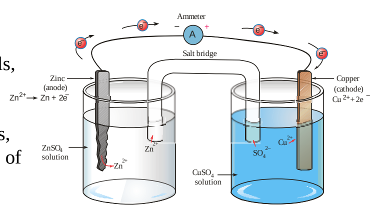
$$V = \frac{W}{Q}$$

One volt is the potential difference (voltage) between two points when one joule of energy is used to move one coulomb of charge from one point to the other. Analogy is in plumbing – voltage correspond to pressure difference which causes a current of water to flow

Voltage

Voltage is responsible for establishing current.

Sources of voltage include batteries, solar cells, fuel cells, and generators. A Cu-Zn battery, such as you might construct in a chemistry class, is shown. This is an example of a single cell battery.



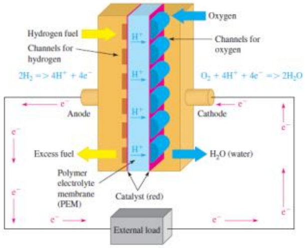
Batteries

An automobile battery is an example of a multiple cell battery. Like all batteries, the automotive battery does *not* store charge – it stores chemical energy that can be converted to current when an external path is provided to allow the chemical reaction to proceed.

Rather than saying “charging” a battery, it is more accurate to say “reversing the chemical reaction” in a battery.

Fuel cells

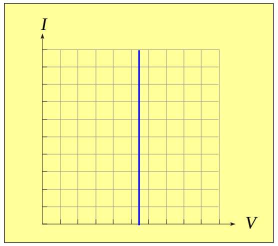
A fuel cell is a device that converts chemical energy into dc voltage directly by combining a fuel (usually hydrogen) with an oxidizing agent (usually oxygen). The hydrogen and oxygen react to form water. The process differs from batteries in that the reactants constantly flow into the cell where they combine and produce electricity.



Voltage

Ideally, a voltage source can provide a constant voltage for any current required by a circuit.

The *IV* curve for an ideal voltage source has a constant voltage for all current.



In practice, ideal sources do not exist, but they can be closely approximated by actual sources.

Current

Current (I) is the amount of charge (Q) that flows past a point in a unit of time (t). The defining equation is:

$$I = \frac{Q}{t}$$

One ampere is a number of electrons having a total charge of 1 C moving through a given cross section in 1 s.

Conventionally, current is assumed to flow from positive to negative terminals. This is the opposite direction to the flow of electrons

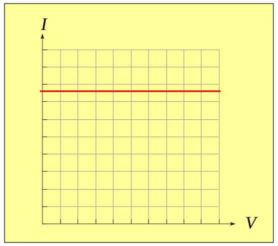
Question:

What is the current if 2 C passes a point in 5 s? 0.4 A

Current

Ideally, a current source can provide a constant current for any load.

The *IV* curve for an ideal current source has a constant current as indicated by the straight line.



Current

Current sources are not as common as voltage sources, but they are useful for production testing. The units shown here include current sources as well as measurement instruments and can operate using a built-in microprocessor to direct a test sequence.

Resistance

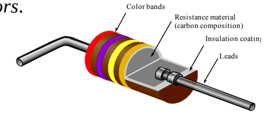
Resistance is the opposition to current.

One ohm (1 Ω) is the resistance if one ampere (1 A) is in a material when one volt (1 V) is applied.

Conductance is the reciprocal of resistance and its unit is the siemens.

$$G = \frac{1}{R}$$

Components designed to have a specific amount of resistance are called *resistors*.



Resistance color-code

Resistance value, first three bands:

First band – 1st digit

Second band – 2nd digit

*Third band – Multiplier (number of zeros following second digit)

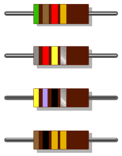
Fourth band - tolerance

Color	Digit	Multiplier	Tolerance
Black	0	10^0	
Brown	1	10^1	1% (five band)
Red	2	10^2	2% (five band)
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold	±5%	10^{-1}	5% (four band)
Silver	±10%	10^{-2}	10% (four band)
No band	±20%		

* For resistance values less than 10 Ω, the third band is either gold or silver. Gold is for a multiplier of 0.1 and silver is for a multiplier of 0.01.

Question

What is the resistance and tolerance of each of the four-band resistors?



5.1 kΩ ± 5%

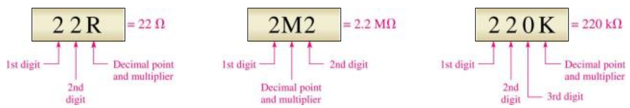
820 kΩ ± 5%

47 Ω ± 10%

1.0 Ω ± 5%

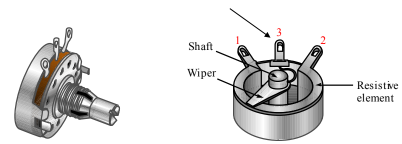
Alphanumeric Labeling

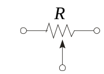
- Two or three digits, and one of the letters R, K, or M are used to identify a resistance value.
- The letter is used to indicate the multiplier, and its position is used to indicate decimal point position.



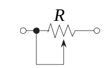
Variable resistors

Variable resistors include the potentiometer and rheostat. The center terminal of a variable resistor is connected to the wiper.





Variable resistor (potentiometer)



Variable resistor (rheostat)

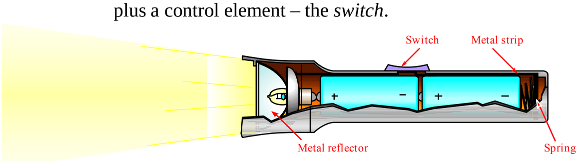
To connect a potentiometer as a rheostat, one of the outside terminals is connected to the wiper.

The electrical circuit

A basic electric circuit consists of

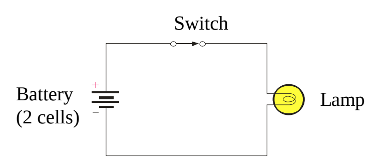
1) a voltage source
2) a path
3) a load.

An example of a basic circuit is a torch, which has each of these plus a control element – the *switch*.



The electric circuit

Circuits are described pictorially with schematics. For example, the torch can be represented by



Review of V, I, and R

Voltage is the amount of energy per charge available to move electrons from one point to another in a circuit and is measured in volts.

Current is the rate of charge flow and is measured in amperes.

Resistance is the opposition to current and is measured in ohms.

Ohm's law

The most important fundamental law in electronics is **Ohm's law**, which relates voltage, current, and resistance.

Georg Simon Ohm (1787-1854) formulated the equation that bears his name:

$$I = \frac{V}{R}$$

Question:

What is the current in a circuit with a 12 V source if the resistance is 10 Ω? 1.2 A

Ohm's law

If you need to solve for voltage, Ohm's law is:

$$V = IR$$

Question:

What is the voltage across a 680 Ω resistor if the current is 26.5 mA? 18 V

Ohm's law

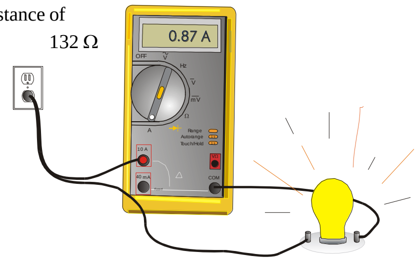
If you need to solve for resistance, Ohm's law is:

$$R = \frac{V}{I}$$

Question:

What is the (hot) resistance of the bulb? 132 Ω

115 V



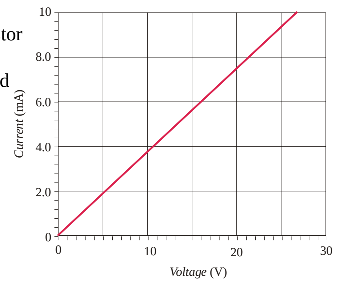
Graph of Current versus Voltage

Notice that the plot of current versus voltage for a fixed resistor is a line with a positive slope. What is the resistance indicated by the graph?

2.7 kΩ

What is its conductance?

0.37 mS



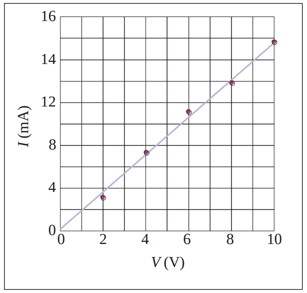
Example A student takes data for a resistor and fits the straight line shown to the data. What is the conductance and the resistance of the resistor?

The slope represents the conductance.

$$G = \frac{14.8\ \text{mA - 0 mA}}{10.0\ \text{V - 0 V}} = 1.48\ \text{mS}$$

The reciprocal of the conductance is the resistance:

$$R = \frac{1}{G} = \frac{1}{1.48\ \text{mS}} = 676\ \Omega$$

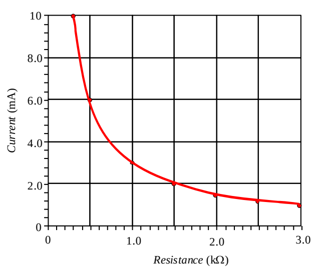


Graph of Current versus Resistance

If resistance is varied for a constant voltage, the current versus resistance curve plots a hyperbola.

Question:

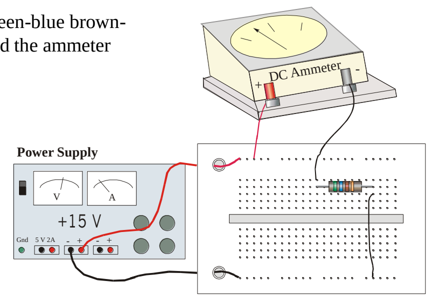
What is the curve for a 3 V source?



Application of Ohm's law

26.8 mA

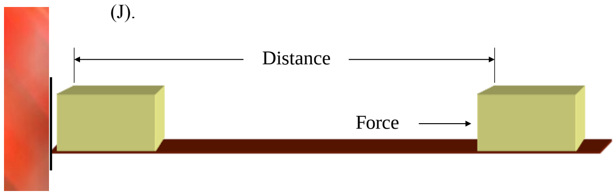
The resistor is green-blue brown-gold. What should the ammeter read?



Energy and Power

When a constant force is applied to move an object over a distance, the work is the force times the distance.

The force must be measured in the same direction as the distance. The unit for work is the newton-meter (N-m) or joule (J).



Energy and Power

Energy is closely related to work. Energy is the ability to do work. As such, it is measured in the same units as work, namely the newton-meter (N-m) or joule (J).

Example What amount of energy is converted to heat in sliding a box along a floor for 5 meters if the force to move it is 400 n?

$W = Fd$ = (400 N)(5 m) = 2000 N-m = 2000 J

Energy and Power

Power is the rate of doing work. Because it is a *rate*, a time unit is required. The unit is the joule per second (J/s), which defines a watt (W).

$$\boxed{P = \frac{W}{t}}$$

Example What power is developed if the box in the previous example is moved in 10 s?

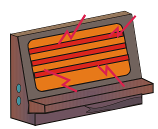
$$P = \frac{W}{t} = \frac{2000\text{ J}}{10\text{ s}} = 200\text{ W}$$

Energy and Power

The kilowatt-hour (kWh) is a much larger unit of energy than the joule. There are 3.6 x 10^6 J in a kWh. The kWh is convenient for electrical appliances.

Question:

What is the energy used in operating a 1200 W heater for 20 minutes?



1200 W = 1.2 kW

20 min = 1/3 h

1.2 kW X 1/3 h = 0.4 kWh

Energy and Power

In electrical work, the rate energy is dissipated can be determined from any of three forms of the power formula.

$P = I^2 R$ $P = VI$ $P = \frac{V^2}{R}$

Together, the three forms are called Watt's law.

Energy and Power

Example-1:
What power is dissipated in a 27 Ω resistor if the current is 0.135 A?

Solution:
Given that you know the resistance and current, substitute the values into $P = I^2R$.

$$\begin{aligned} P &= I^2 R \\ &= (0.135\ \text{A})^2 (27\ \Omega) \\ &= 0.49\ \text{W} \end{aligned}$$

Energy and Power

Example-2:
What power is dissipated by a heater that draws 12 A of current from a 120 V supply?

Solution:
The most direct solution is to substitute into $P = IV$.

$$\begin{aligned} P &= IV \\ &= (12\ \text{A})(120\ \text{V}) \\ &= 1440\ \text{W} \end{aligned}$$

Energy and Power

Example-3:
What power is dissipated in a 100 Ω resistor with 5 V across it?

Solution:
The most direct solution is to substitute into $P = \frac{V^2}{R}$.

$$\begin{aligned} P &= \frac{V^2}{R} \\ &= \frac{(5\ \text{V})^2}{100\ \Omega} = 0.25\ \text{W} \end{aligned}$$

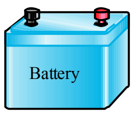
It is useful to keep in mind that small resistors operating in low voltage systems need to be sized for the anticipated power.

Ampere-hour Rating of Batteries

Expected battery life of batteries is given as the ampere-hours specification. Various factors affect this, so it is an approximation. (Factors include rate of current withdrawal, age of battery, temperature, etc.)

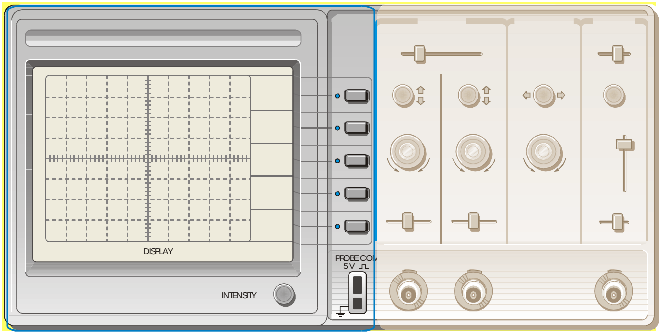
Question:

How many hours can you expect to have a battery deliver 0.5 A if it is rated at 10 Ah?



20 h

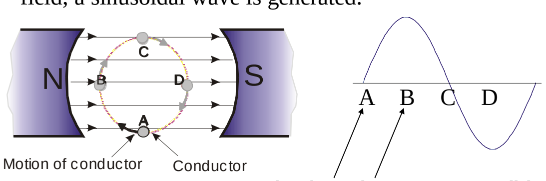
Oscilloscopes



Generation of a sine wave

Sinusoidal voltages are produced by ac generators and electronic oscillators.

When a conductor rotates in a constant magnetic field, a sinusoidal wave is generated.



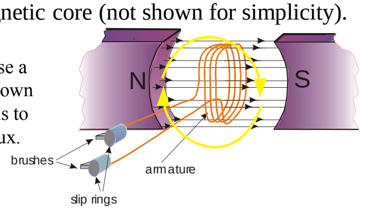
When the loop is moving perpendicular to the lines of flux, the maximum voltage is induced.

When the conductor is moving parallel with the lines of flux, no voltage is induced.

AC generator (alternator)

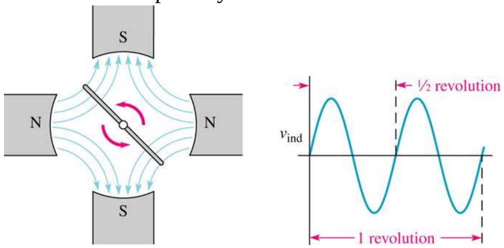
Generators convert rotational energy to electrical energy. A stationary field alternator with a rotating armature is shown. The armature has an induced voltage, which is connected through slip rings and brushes to a load. The armature loops are wound on a magnetic core (not shown for simplicity).

Small alternators may use a permanent magnet as shown here; other use field coils to produce the magnetic flux.



AC generator (alternator)

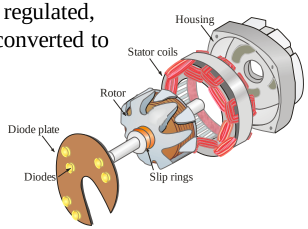
By increasing the number of poles, the number of cycles per revolution is increased. A four-pole generator will produce two complete cycles in each revolution.



Alternators

In vehicles, alternators generate ac, which is converted to dc for operating electrical devices and charging the battery. A basic vehicle alternator is illustrated. AC is more efficient to produce and can be easily regulated, hence it is generated and converted to dc by diodes.

The output is taken from the rotor through the slip rings.



AC Motors

There are two major classifications of ac motors. These are the **induction motor** and the **synchronous motor**. Both types use a rotating field in the stator windings.

Induction motors work because current is induced in the rotor by the changing current in the stator. This current creates a magnetic field that reacts with the moving field of the stator, which develops a torque and causes the rotor to turn.

Synchronous motors have a magnet for the rotor. In small motors, this can be a permanent magnet, which keeps up with the rotating field of the stator. Large motors use an electromagnet in the rotor, with external dc supplied to generate the magnetic field.