Chapter 23

Electric Circuits

Flow of Charge

Just as water can be made to flow through a pipe by maintaining a pressure difference across the two ends of the pipe, electric charge can be made to flow through a conductor by maintaining an *electric potential difference* or *voltage* across the two ends of the conductor. That is...

Electric charge flows through a conductor because of a difference in electric potential (a.k.a. voltage) across the conductor.

Electric Current

Just as the fluid current in a river or pipe is the flow of H_2O molecules, an electric current is the flow of electric charge.

In metal wires, loosely bound outer electrons in the metal atoms are able to move freely throughout the atomic lattice. It is the (negatively charged) electrons that constitute the flow.

The (positively charged) protons are bound in the atomic nuclei and do not participate in the flow.

Electric Current…

...is measured in units called "Amperes" (abbr. "A") and is designated by the symbol I.

...is defined as the flow of (+) charge. Since electrons are negatively charged, the flow of the electrons in a metal wire is actually opposite that of the electric current.

Mathematically, (electric) current is rate at which charge flows. That is, $I \equiv \frac{\Delta q}{\Delta t}$. Thus, $1\ \text{Ampere} = 1\ \frac{\text{Coulomb}}{\text{second}}$.

As an example, a current 10 A means that 10 C of charge flow past a point every second.

Electrical Resistance

The greater the voltage that pumps the charges, the greater the current. However, the amount of current also depends on how difficult it is for the charge to flow through the conductor. This difficulty can be described conceptually as “electrical friction” and is called the *electrical resistance*. The greater the resistance, the less the current.

Different materials of the same size and shape have different amounts of resistance. Good conductors (like, copper and aluminum) have very low resistance while good insulators have very high resistance.

Ohm's Law

The mathematical relationship between current, voltage and resistance is given by Ohm's law:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \quad \text{or} \quad I = \frac{V}{R}.$$

For current in Ampere and voltage in Volts, the resistance is measured in units called "Ohms" (abbr. Ω).

That is, $1\ \Omega \equiv 1\ \text{V/A}$.

For example, if a potential difference is 10 V is maintained across a material having a resistance of 5 Ω, then the current through that material will be $I = (10\ \text{V}) / (5\ \Omega) = 2\ \text{A}$.

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Electric Power

When charge moves through a conductor with that has nonzero resistance, energy is expended.

As examples, this expenditure may be...

the lighting of a lamp (radiant energy),

the turning of a motor (mechanical energy), or

the heating of a wire (thermal energy).

Recall that the rate at which energy is expended or transferred into another form is the power.

Electric Power (cont'd)

Electric Power = Voltage x Current ($P = VI$).

Note the units: 1 Watt = (1 V)(1 A)

Recall that 1 Volt = $1\ \frac{\text{J}}{\text{C}}$ and 1 Ampere = $1\ \frac{\text{C}}{\text{s}}$.

$$\text{So, } (1\text{ V})(1\text{ A}) = (1\ \tfrac{\text{J}}{\text{C}})(1\ \tfrac{\text{C}}{\text{s}}) = 1\ \tfrac{\text{J}}{\text{s}} = 1 \text{ Watt.}$$

Combining with Ohm's law: ($V = IR$) gives:

$$P = VI = (IR)(I) = I^2R.$$

$$\text{Alternatively, } P = VI = (V)\left(\frac{V}{R}\right) = \frac{V^2}{R}.$$

Examples...

Question: How much current flows through an incandescent light bulb rated as “60 W” at home?

(Household voltage in the United States is 120 V.)

Answer: $I = \frac{P}{V} = \frac{60\ \text{W}}{120\ \text{V}} = 0.5\ \text{A}$.

Question: What is the filament resistance of this same light bulb?

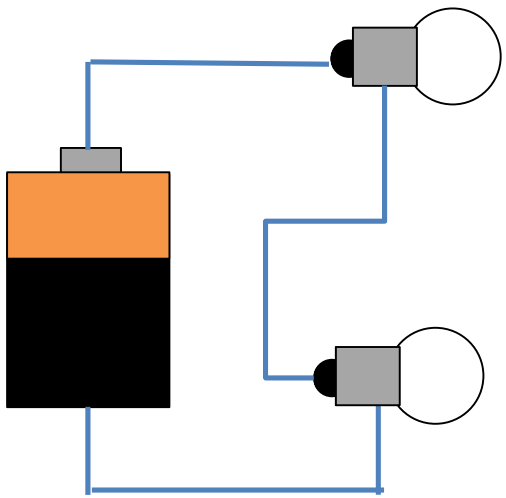
Answer: $R = \frac{V}{I} = \frac{120\ \text{V}}{0.5\ \text{A}} = 240\ \Omega$.

Electric Circuits

Electrons flow through a circuit (a complete loop that has no gaps). A typical circuit ideally consists of a voltage source (to push the charges), a conductor (to carry flow of charge), and a device (which has resistance).

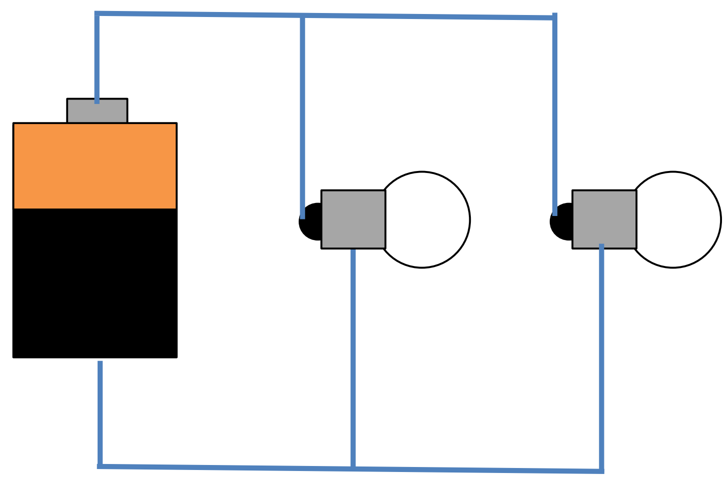
Usually, there are more than one device in the circuit. Depending on how the voltage source(s) and device(s) are arranged, a simple circuit will generally be one of two types: a series circuit or a parallel circuit.

Series vs. Parallel Circuits



Series Circuit

(single pathway)



Parallel Circuit

(multiple pathways)

Characteristics of Series Circuits

- Current is the same in each device since there is only a single pathway for the charge to flow.
- Resistance in the circuit is the sum of all the individual resistances of each device.
- As the number of resistors increases, the total current decreases.
- Voltage supplied by power source equals the sum of all the individual voltages across each individual device.
- The voltage across each device is the current times the resistance of that device.

Characteristics of Parallel Circuits

- Each branch has the same voltage across it since each branch has its own connection to the power source.
- The sum of the individual currents in each branch equals the total current supplied by the power source since the current from the source divides among the individual branches in the multiple pathway circuit.
- As the number of branches increases, the total resistance of the circuit decreases
- As the number of branches increases, the total current supplied by the source increases.