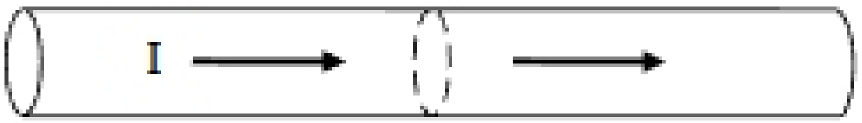
Electric Currents and Simple Circuits

Electrons can flow along inside a metal wire if there is an E-field present to push them along (recall $\vec{F} = q\vec{E}$). The flow of electrons in a wire is similar to the flow of water in a pipe.

Definition: electric current $I = \frac{\Delta Q}{\Delta t}$ = rate of flow of charge

units [I] = coulomb/second = 1 C / 1 s = 1 ampere (A) = "amp"

"It's not the voltage that kills you, it the *amps*." About 0.05 A is enough to kill you.
If current I = 1 A in a wire, then 1 coulomb of charge flows past any point every second.

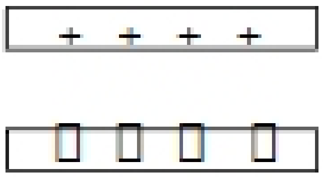


In *electrostatic* problems, $\vec{E} = 0$ inside a metal, but if I ≠ 0, then the situation is not static, the E-field is not zero.
Electrons flow in metals, not protons, so (–) charges are moving when there is a current. The

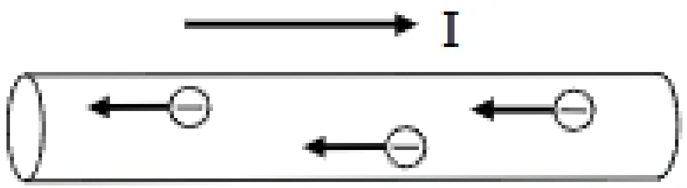
electron feel a force $\vec{F} = -e\vec{E}$ and goes "upstream" against the E-field.

The flow of (–) charge in one direction is electrically equivalent to the flow of (+) charge in the opposite direction:

<u>either</u> way, get:



By convention, we define current I as the flow of imaginary (+) charges, when it is really (–) charges flowing the other way:



(Some texts refer to I as the "conventional current" to distinguish it from the "electron current".)

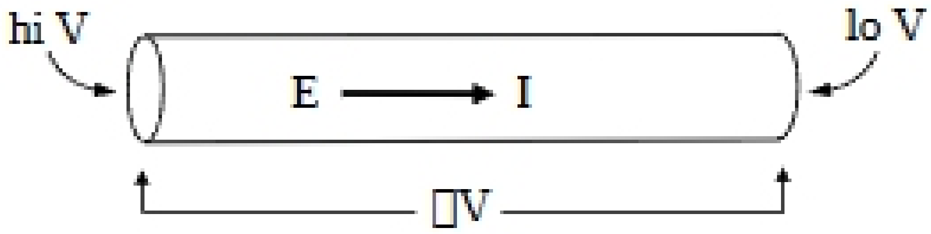
Example: How many electrons flow past per second when the current is 1 A?

$$I = \frac{DQ}{Dt} = \frac{DN\text{�}}{Dt} \;\text{�}\; \frac{DN}{Dt} = \frac{I}{e} = \frac{1\,A}{1.6\text{�}10^{-19}\,C} = \frac{1\,C/s}{1.6\text{�}10^{-19}\,C} = 5.6\text{�}10^{18}\,s^{-1}$$

About 0.01 A = 10 mA flowing though your heart is lethal, yet I could grab a wire carrying 1000A and be safe! Why? Because my body has a much higher *electrical resistance* than the metal. The electrons prefer to flow through the metal wire.

For most materials, the current I is proportional to the voltage difference between the ends.

$I \text{ � } E$ (since $\overset{|}{F} = q\overset{|}{E}$) and $DV \text{ � } E$, so $I \text{ � } DV$



From now on, we usually follow the (bad) convention and write "V" when we really mean "□V".

$$I \text{ � } V \;(\text{ really } I \text{ � } DV) \;\text{�}\; \frac{V}{I} = \text{constant}$$

Definition of resistance R (of a piece of wire or other material): $R \text{ � } \frac{V}{I}$

The experimental fact that (for most materials) the ratio R = V / I is a <u>constant</u>, independent of V or I, is called

Ohm's Law : $R = \frac{V}{I} = \text{constant}$, usually written $\boxed{V = I\,R}$ (R constant)

Units: [R] = volt / ampere = ohm (□) ["□" is Greek letter omega]

Ohm's Law should be written $\Delta V = I R$, but the (bad) convention is to write $V = I R$.
"Ohm's Law" is not really a law, because it is not always true. For many materials, Ohm's Law is approximately true, the resistance R is approximately constant, independent of V or I. Materials that obey Ohm's Law are called "ohmic materials". But some materials are "non-ohmic"; they do not obey Ohm's Law.

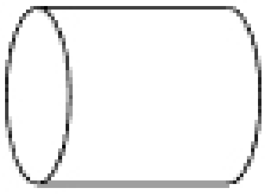
The average speed of electrons in a current-carrying wire results from a competition between two effects: (1) the E-field, which causes an acceleration according to $\vec{F} = q\vec{E} = m\vec{a}$, making the electrons go faster and faster, and (2) the scattering of electrons due to impurities and thermal vibrations, which act like friction, making the electrons slow down.

For typical currents in real wires, the average electron speed (often called the *drift velocity*) is actually quite slow, typically less than 0.1 mm/s. (Incidentally, the term *drift velocity* is incorrect, it should be called the *drift speed*.)

A material with lots of electron scattering has a high resistance:
$R_{\text{wire}} << 1\ \Omega$, $R_{\text{human}} \approx 10^5\ \Omega$

$$I = \frac{V}{R} = \frac{10\text{ V}}{10^5\ \Omega} = 10^{-4}\text{ A (harmless)}$$
$$I = \frac{V}{R} = \frac{100\text{ V}}{10^5\ \Omega} = 10^{-3}\text{ A (painful!)}$$
⇒ 10 V safe, 100 V dangerous !

The resistance R of a piece of material depends on its shape and composition.
Shape: long and skinny  ⇒ R big

short and fat  ⇒ R small

— just like the flow of water through a pipe. Long skinny water pipes resist flow of water.
Turns out that $R \propto \frac{L}{A}$,
so big L means big R, big A means small R