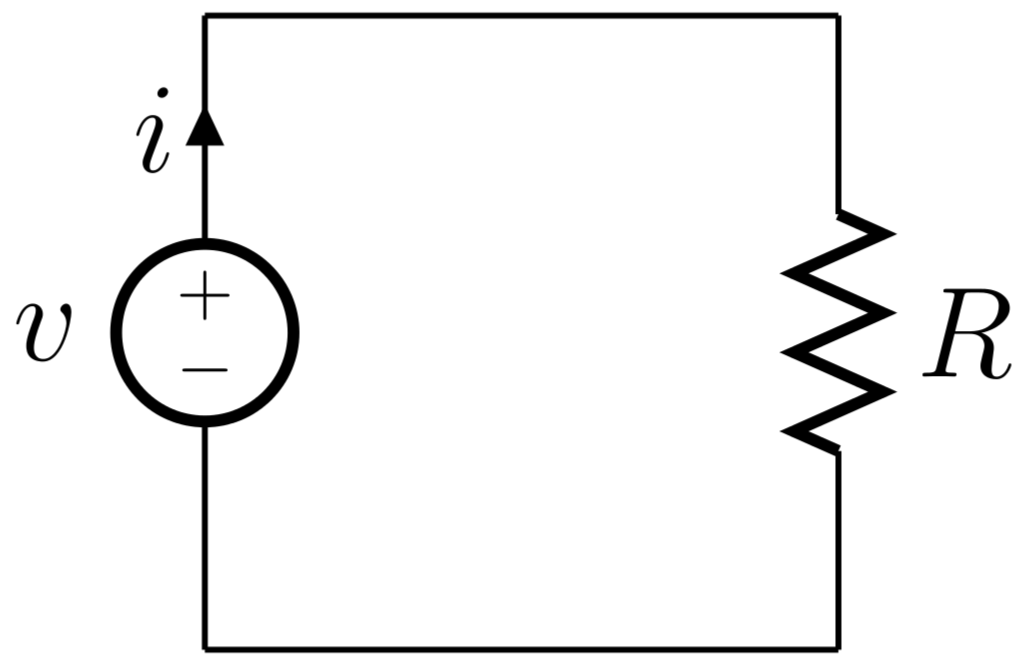
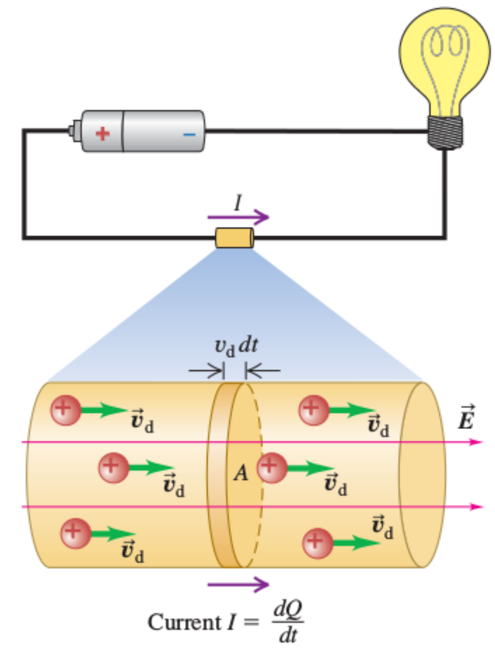
Electric current and circuits



Electric current

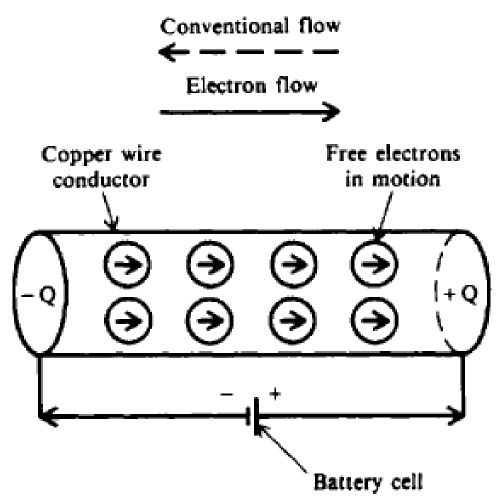
ELECTRIC CURRENT: Flow of electric charges through a medium



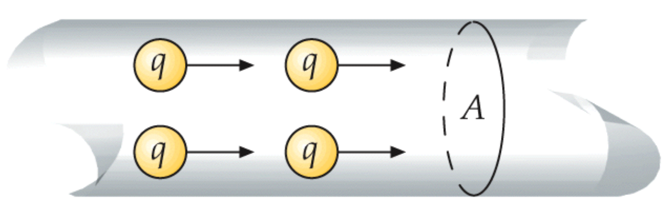
When two conductors having different potentials are connected, there is a transference of charge due to their potential difference. As long as this current flows, the system is not in electrostatic equilibrium.

Direction of the current: conventionally considered to be that in which a positive charge would have to move to produce the same effects as the actual current → opposite to the direction of motion of the electrons.

Current flows on the same direction as **E**.



CURRENT INTENSITY: Rate of flow of charge through surface A



$$I = \frac{charge}{time\,interval} = \frac{\Delta Q}{\Delta t}$$

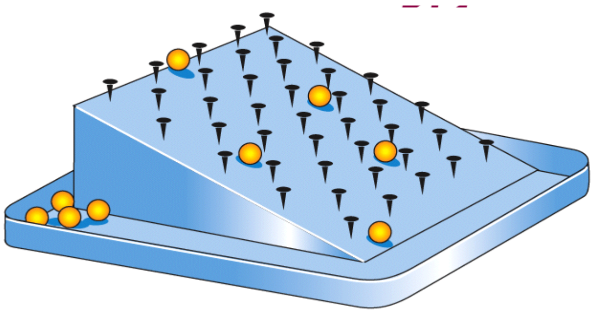
I is a scalar

SI UNIT: Ampere A = C/s

Electric current

Drift speed: Speed of the flowing charges

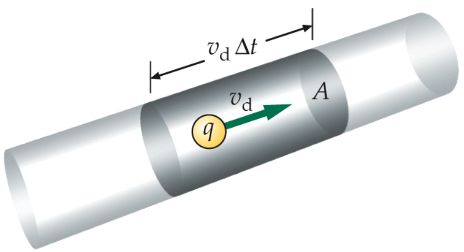
The motion of free electrons in a metal wire is complex:



When an **E** is applied, the kinetic energy gained by the free charges due to acceleration is continuously dissipated due to their collisions with the lattice ions.

As a consequence, the electrons in a current acquire a constant speed on average, called drift speed υ_d.

The drift speed can be related to I: $I=\frac{\Delta Q}{\Delta t}=qnA\upsilon_d$



n=density of charge carriers

Drift velocity: Average velocity of the mobile charges $\vec{\upsilon}_d$ (*motion of positive charges*!)

CURRENT DENSITY (VECTOR!): Current intensity per unit area $j=\frac{I}{A}$

$$\vec{j}=nq\vec{\upsilon}_d$$

UNITS: A /m²

Electric current

OHM´S LAW:

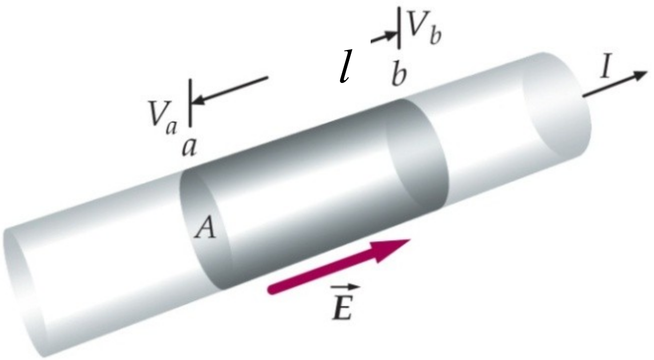
For ideal conductors, the current density **j** at a point of the wire is linearly proportional to the electric field at that point:

$$\vec{j} = \sigma \vec{E}$$

σ= electrical conductivity
σ is constant for a given conductor at a given temperatue

It is an empirical law

There is another way of expressing Ohm's law, for a homogeneous conductor with constant cross-section:



V=IR

Potential drop ($V_a - V_b$)

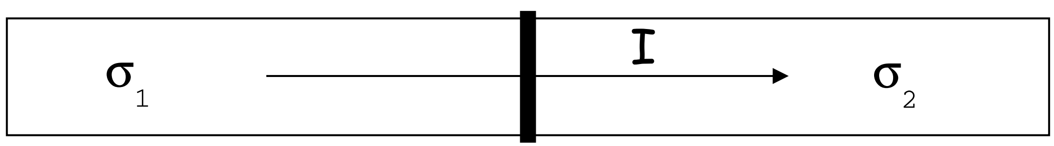
R = resistance
Unit: Ohm Ω = V/A

$$V_b - V_a = -\int_a^b \vec{E}\cdot d\vec{l} = -El = -\frac{Il}{\sigma A} \rightarrow V_a - V_b = El = I\frac{l}{\sigma A} = IR$$

Electric current

Example:

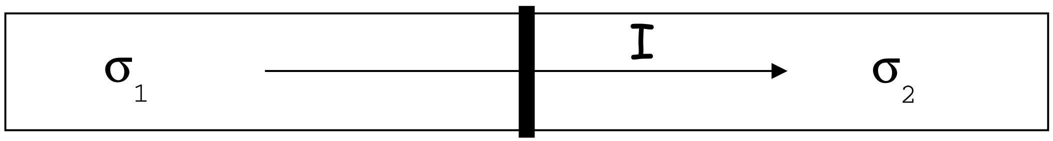
A wire with a homogeneous cross-sectional area $S = 3\ mm^2$ carries a stationary current $I = 2$ A. The wire consists on two parts made of different conductors as show in the figure. The electric conductivities of these conductors are $\sigma_1 = 9\times10^7$ S/m and $\sigma_2 = 5\times10^6$ S/m. Find the magnitude of the electric field on each conductor.



Electric current

Example: Exercise 6

A wire with a homogeneous cross-sectional area $S = 3\ mm^2$ carries a stationary current $I = 2$ A. The wire consists on two parts made of different conductors as show in the figure. The electric conductivities of these conductors are $\sigma_1 = 9\times10^7$ S/m and $\sigma_2 = 5\times10^6$ S/m. Find the magnitude of the electric field on each conductor.



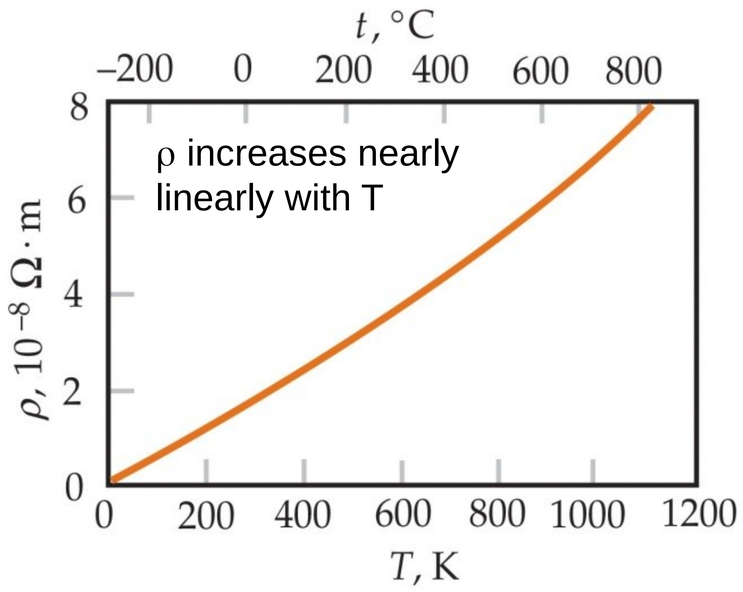
Answer: $E_1 = 7.4\times10^{-3}$ V/m $\qquad$ $E_2 = 0.133$ V/m

Ohm’s law: Resistance

$$R = \frac{l}{\sigma A} = \rho \frac{l}{A}$$

Length of the wire

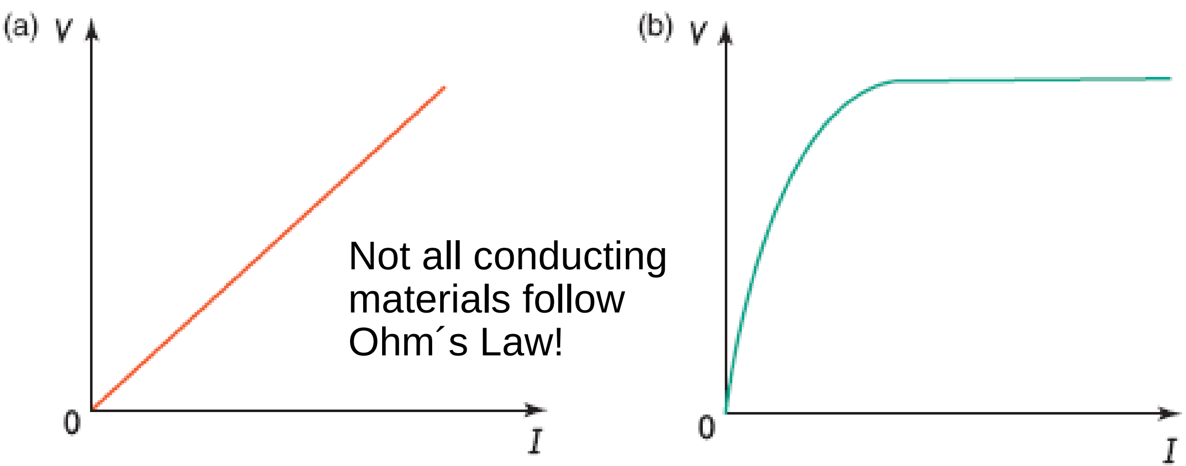
Cross-sectional area



ρ= electrical resistivity (Units: Ω.m)
σ= 1/ ρ electrical conductivity
(Units: 1/Ω.m=S/m, S=Siemens)

ρ depends on T, so R also does.

Conductors that satisfy Ohm’s law are called linear or ohmic conductors.



Not all conducting materials follow Ohm´s Law!

The V versus I graphs for (a) an ohmic device and (b) a diode, which is a non-ohmic device

Ohm's law: Resistance

Example:

A Cu wire of diameter 1 mm and length 80 m is welded to a Fe wire of the same diameter and length 70 m. The current intensity along them is 2 A.

a) Find the electric field in each conductor.

b) What is the potential difference between the ends of each wire?

Data: ρ_{Cu} =1,7 x 10^{-6} Ωcm, ρ_{Fe} =1,0 x 10^{-5} Ωcm.

Ohm's law: Resistance

Example: Exercise 1

A Cu wire of diameter 1 mm and length 80 m is welded to a Fe wire of the same diameter and length 70 m. The current intensity along them is 2 A.

a) Find the electric field in each conductor.

b) What is the potential difference between the ends of each wire?

Data: ρ_{Cu} =1,7 x 10^{-6} Ωcm, ρ_{Fe} =1,0 x 10^{-5} Ωcm.

Answer:

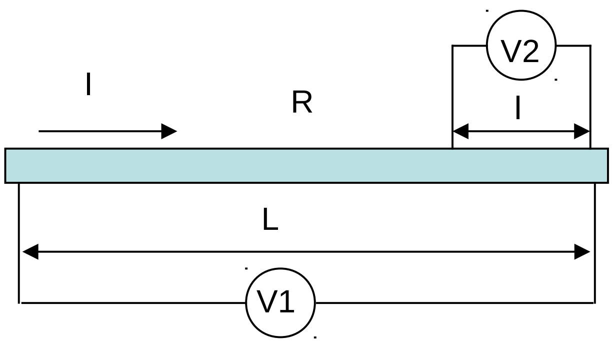
a) $E_{Cu}=4.3\times10^{-2}\ V/m \quad E_{Fe}=0.25\ V/m$

b) $\Delta V_{Cu}=3.4\ V \quad \Delta V_{Fe}=17.5\ V$

Ohm’s law: Resistance

Example:

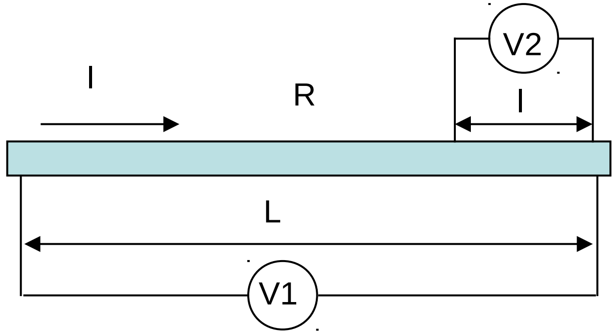
In the figure attached, the voltmeter V_1 measures a voltage drop of 240 V when a Cu wire of length L, constant cross-section and resistance R carries a current of intensity I. At what distance from the end of the wire would we have to connect the voltmeter V_2 so that it measures a voltage drop of 40 V? (Tip: find the distance l as a function of L).



Ohm’s law: Resistance

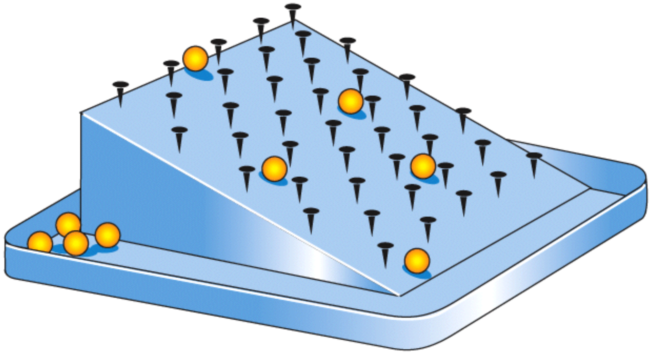
Example: Exercise 3

In the figure attached, the voltmeter V_1 measures a voltage drop of 240 V when a Cu wire of length L, constant cross-section and resistance R carries a current of intensity I. At what distance from the end of the wire would we have to connect the voltmeter V_2 so that it measures a voltage drop of 40 V? (Tip: find the distance l as a function of L).



Answer: I=L/6

Heat generated by a current: Joule's law



The kinetic energy gained by the free charges due to acceleration is continuously dissipated in the form of heat due to their collisions with the lattice ions.

As a consequence, the conductor heats up.

This phenomenon is called “Joule heating”.

Electric power is the time rate of doing work. The power delivered to the conductor is given by Joule's law:

$$P = \frac{dW}{dt} = V\frac{dq}{dt} = VI$$

For materials that follow Ohm´s Law: $$P = VI = I^2 R$$