Alternating Current

Current from a battery flows steadily in one direction. This is called

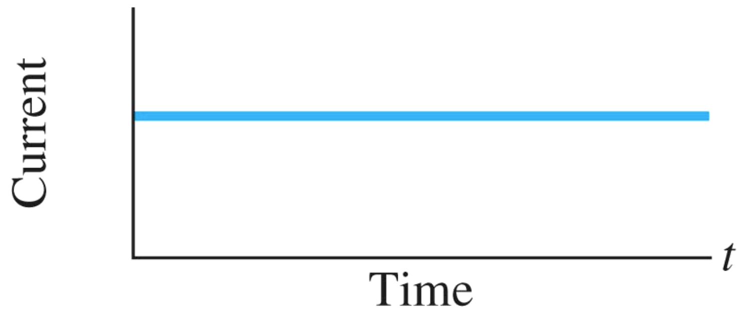
Direct Current,

or **DC**.

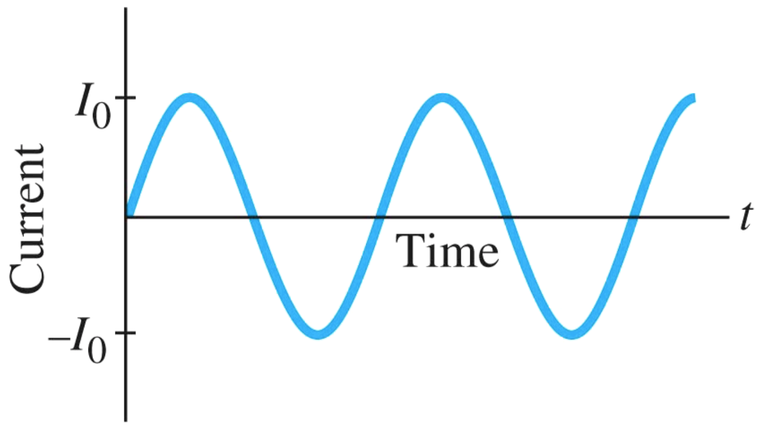
By contrast, current from a power plant varies sinusoidally with time. This is called

Alternating Current,

or **AC**.



(a) DC



(b) AC

If the **current is AC**, both the current and the voltage vary sinusoidally with time:

,

$$V = V_0 \sin 2\pi f t = V_0 \sin \omega t,$$

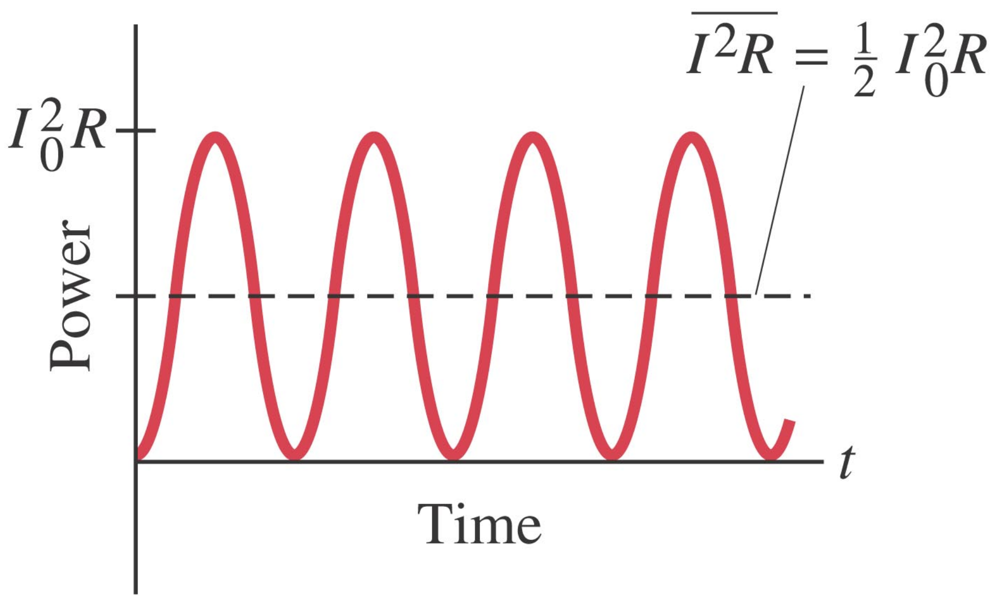
$$I = \frac{V}{R} = \frac{V_0}{R} \sin \omega t = I_0 \sin \omega t.$$

Just as for DC circuits, in **AC circuits**, the **Power P** in the circuit is obtained by multiplying the current & the voltage:

$$\mathbf{P = I(t)V(t) = [I_0 \sin(\omega t)][V_0 \sin(\omega t)] = I_0 V_0 \sin^2(\omega t)}$$

If the total resistance in the circuit is **R**:

$$P = I^2R = I_0^2 R \sin^2 \omega t.$$



Since the power is a function of time, we often are interested in the Average Power [averaged over one period **T = (2π/ω)**]. This is calculated by integrating **P(t)** over one period:

$$\overline{P} = T^{-1}\int I_0 V_0 \sin^2(\omega t)\,dt$$

(0 < t < T)

After using **V = IR**, this gives: $\overline{P} = \frac{1}{2} I_0^2 R$

or $$\overline{P} = \frac{1}{2}\frac{V_0^2}{R}.$$

Because they are sine functions, the current & the voltage both average to zero over one period. So, it is common to square them, take the average, then take the square root.

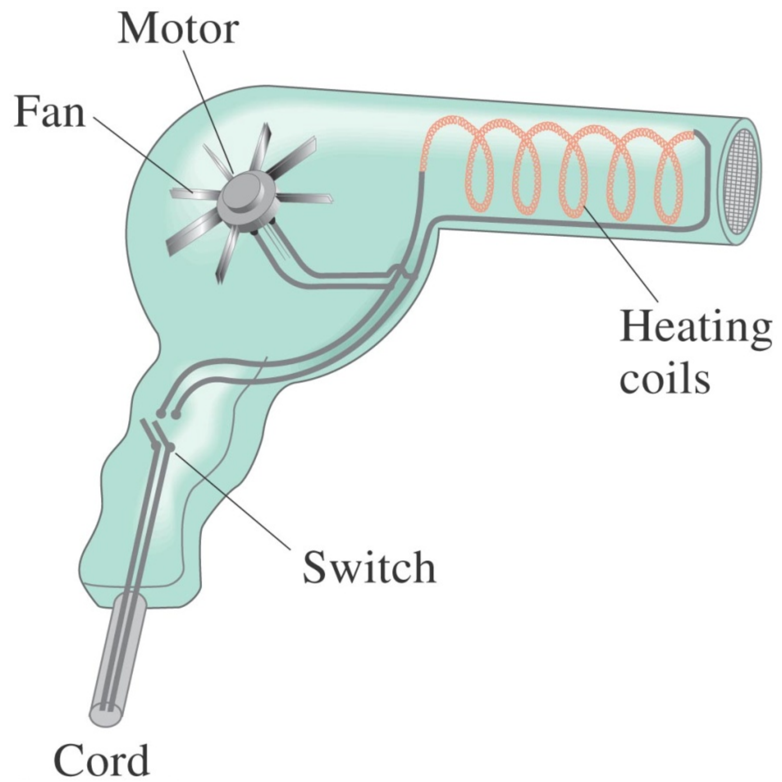
This gives their ***root-mean-square*** **(rms)** values:

$$I_{\mathrm{rms}} = \sqrt{\overline{I^2}} = \frac{I_0}{\sqrt{2}} = 0.707\, I_0,$$

$$V_{\mathrm{rms}} = \sqrt{\overline{V^2}} = \frac{V_0}{\sqrt{2}} = 0.707\, V_0.$$

Example: Hair dryer.

(a) Calculate the resistance and the peak current in a **1000-W** hair dryer connected to a **120-V** line.
(b) What would happen if it is connected to a **240-V** line in Britain?



Electrons in a conductor have large, random (thermal) speeds just due to their temperature: $v_{themal} = (3k_BT/m)^{1/2}$. When a potential difference **V** is applied, the electrons also acquire an average drift velocity $\mathbf{v_d}$, anti-parallel to the electric field **E**. In general

$$v_d, << v_{themal}$$

Microscopic View of Electric Current:
Current Density & Drift Velocity

It is convenient to define **the current density j** (current per unit area). **j** is a convenient concept for relating the microscopic motions of electrons to the macroscopic current:

$$j = \frac{I}{A} \qquad \text{or} \qquad I = jA.$$

If the current is not uniform:

$$I = \int \vec{\mathbf{j}} \cdot d\vec{\mathbf{A}}$$

The drift velocity $\mathbf{v_d}$ is related to the current in the wire, and also to the number of electrons per unit volume:

$$\begin{aligned} \Delta Q &= (\text{no. of charges}, N) \times (\text{charge per particle}) \\ &= (nV)(-e) = -(nAv_\mathrm{d}\Delta t)(e) \end{aligned}$$

and

$$I = \frac{\Delta Q}{\Delta t} = -neAv_\mathrm{d}.$$

Example

Electron speeds in a wire.

A copper wire **3.2 mm** in diameter carries a **5.0-A** current.

Calculate:

(a) The current density **j** in the wire.

(b) The drift velocity $\mathbf{v_d}$ of the free electrons.

(c) Estimate the rms thermal speed $\mathbf{v_{themal}}$ of electrons assuming they behave like an ideal gas at **T = 20°C**.

Assume that one electron per Cu atom is free to move (the others remain bound to the atom).

The electric field inside a current-carrying wire can be found from the relationship between the current, voltage, and resistance. Assume a length **ℓ** of wire & using:

R = (ρℓ)/A, I = jA, & **V = Eℓ**.

Substituting in Ohm's law **V = IR** gives:

$$j = \frac{1}{\rho} E = \sigma E.$$

ρ ➔ ***the resistivity*** of the material in the wire

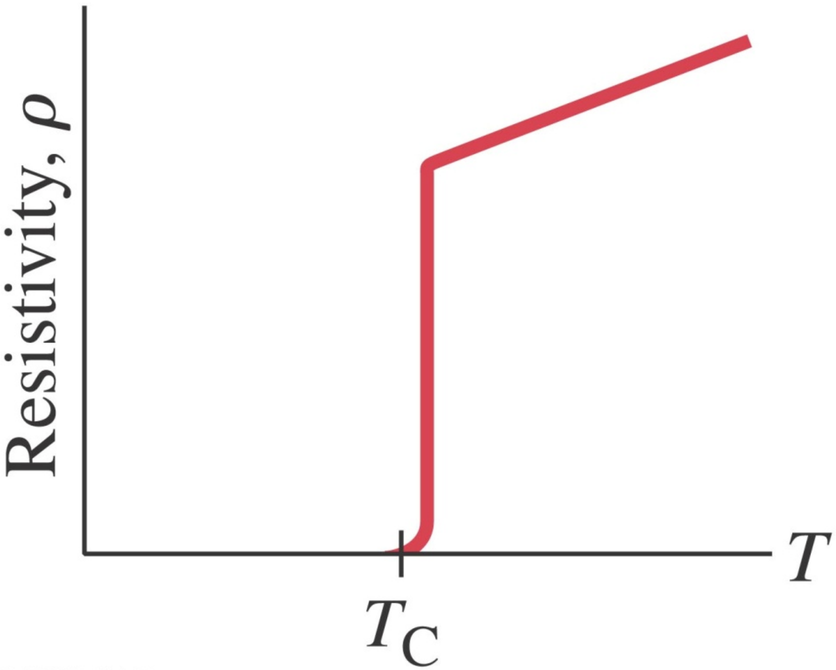
σ = (1/ρ) ➔ ***the conductivity***

Electric field inside a wire.

Calculate the electric field **E** inside the wire in the previous example. (The current density was found to be $\mathbf{j = 6.2 \times 10^5\ A/m^2}$.)

Superconductivity*

In general, resistivity decreases as temperature decreases. Some materials, however, have resistivity that falls abruptly to zero at a very low temperature, called the critical temperature, T_C.



Electrical Conduction in the Nervous System*

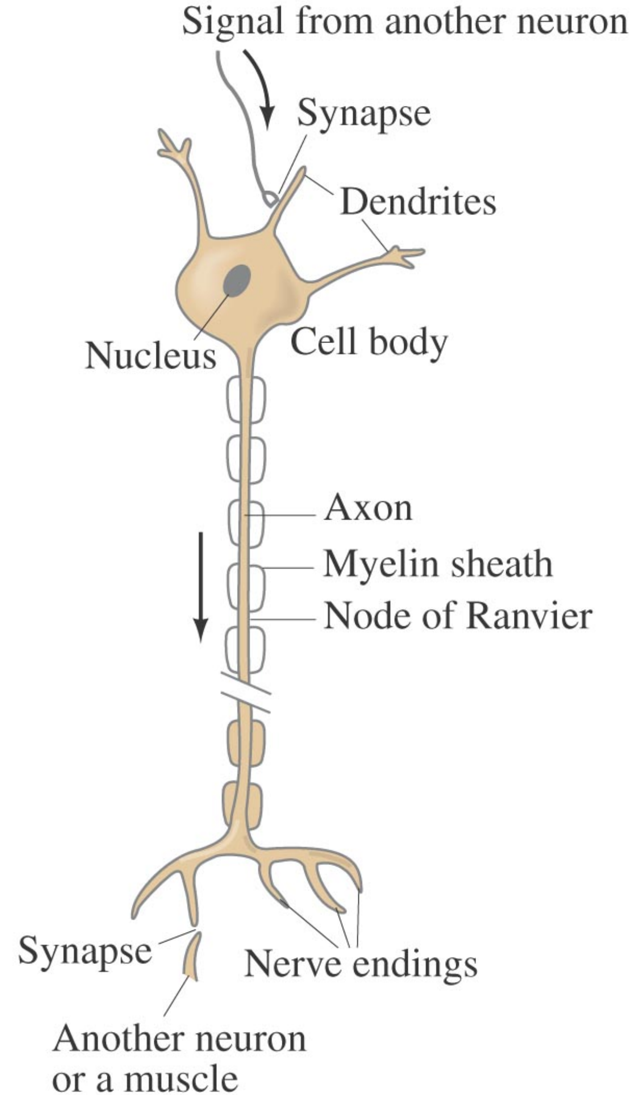
The human nervous system depends on the flow of electric charge.

The basic elements of the nervous system are cells called neurons.

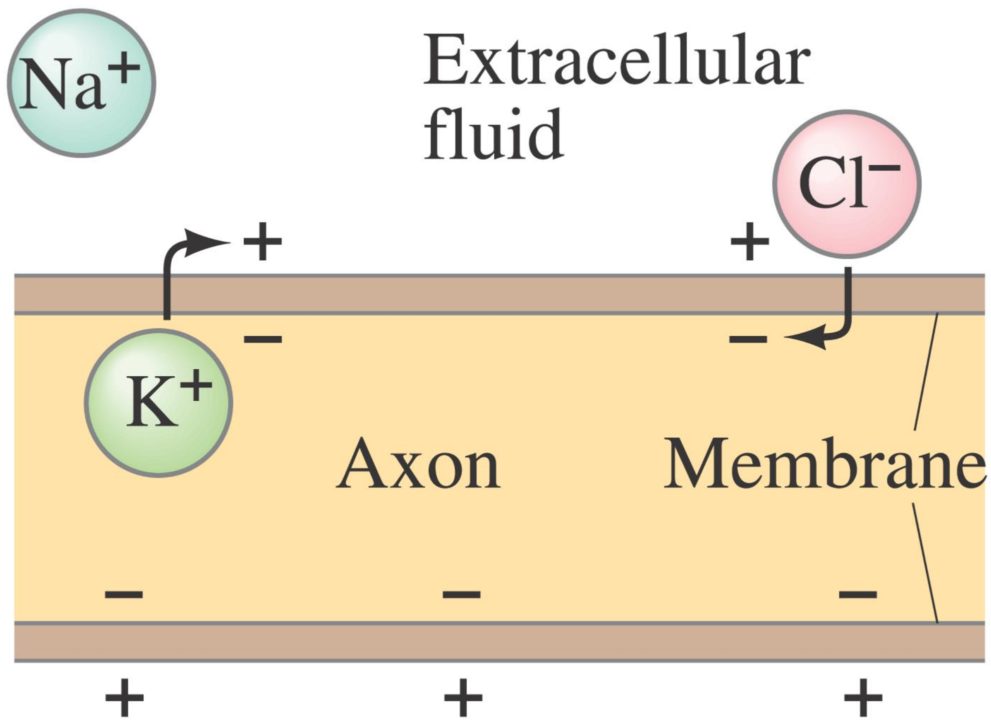
Neurons have a main cell body, small attachments called dendrites, and a long tail called the axon.

Signals are received by the dendrites, propagated along the axon, and transmitted through a connection called a synapse.

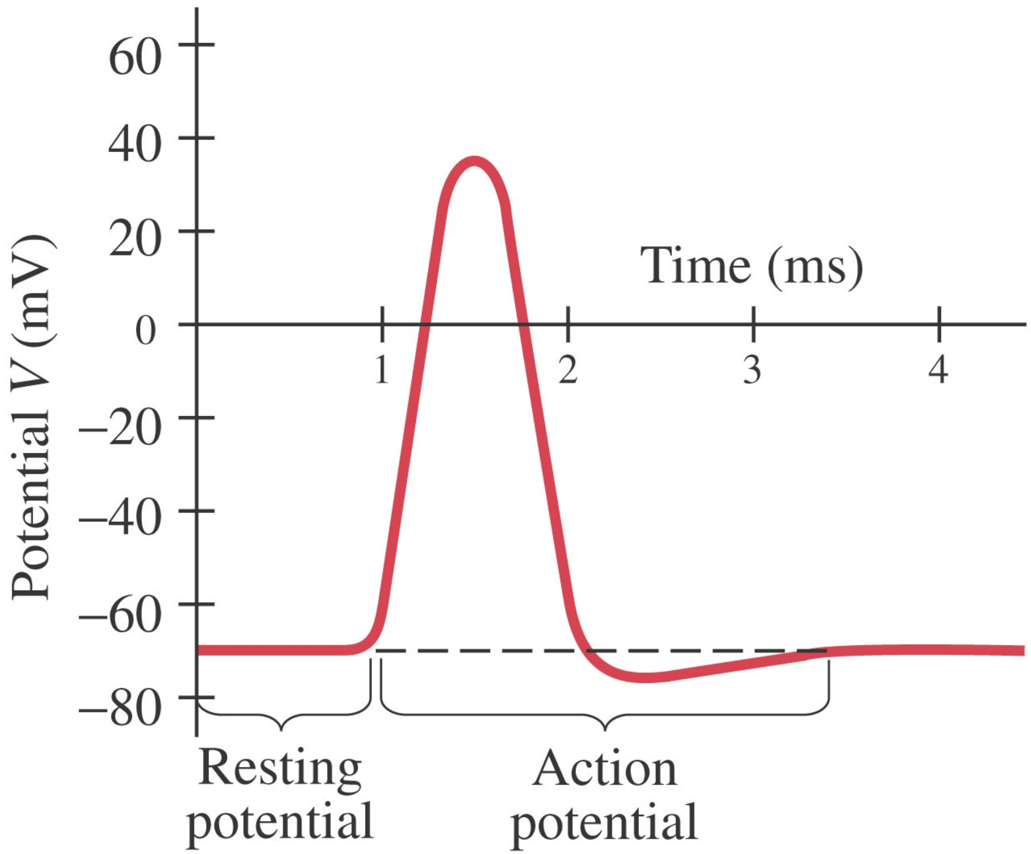
Those facts investigating in a new era of science called “Medical Physics”



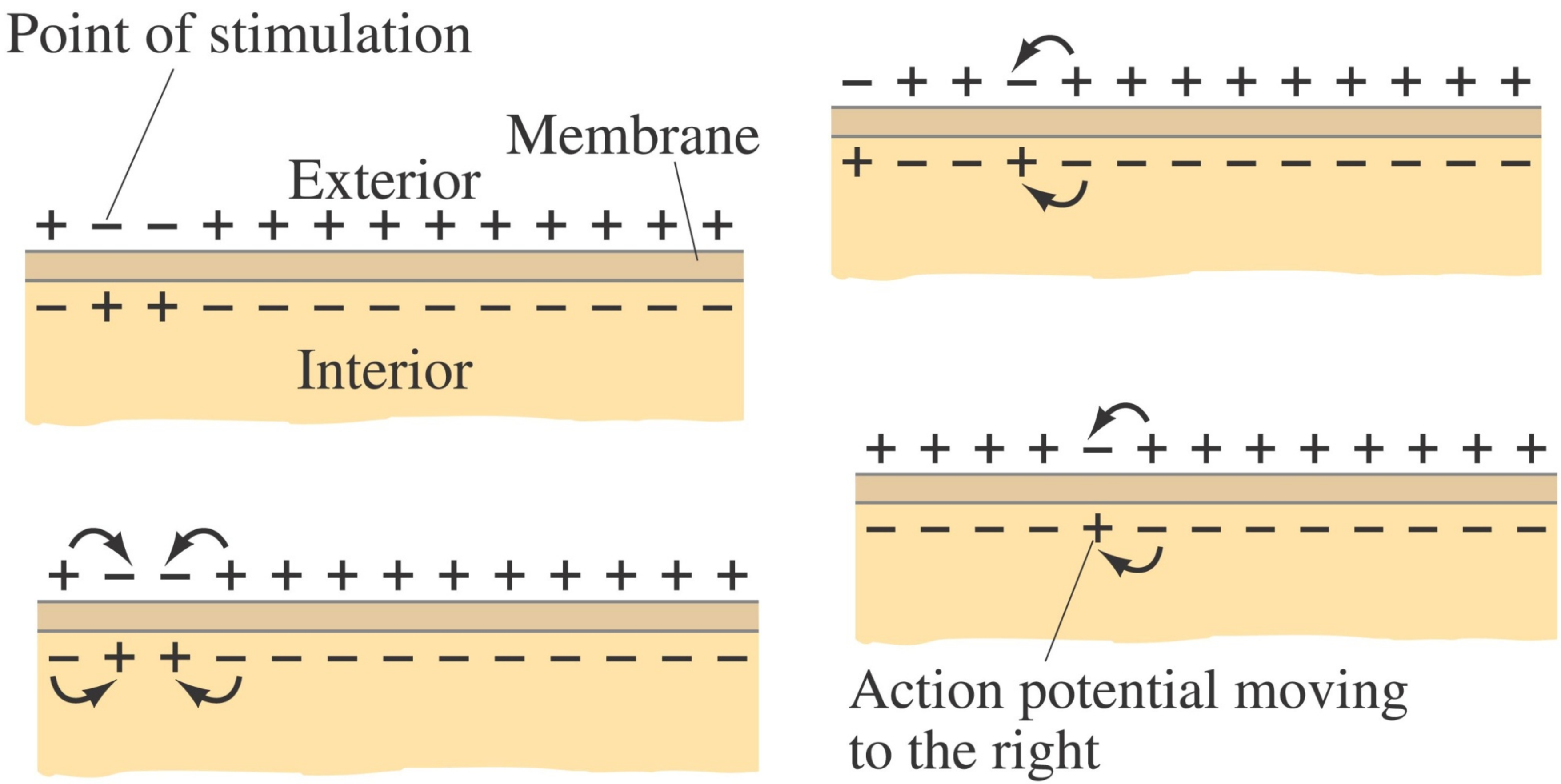
This process depends on there being a dipole layer of charge on the cell membrane, and different concentrations of ions inside and outside the cell.



This applies to most cells in the body. Neurons can respond to a stimulus and conduct an electrical signal. This signal is in the form of an action potential.



The action potential propagates along the axon membrane.



Summary of Chapter

- A battery is a source of constant potential difference.
- Electric current is the rate of flow of electric charge.
- Conventional current is in the direction that positive charge would flow.
- Resistance is the ratio of voltage to current:

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

$$V = IR.$$

- Ohmic materials have constant resistance, independent of voltage.
- Resistance is determined by shape and material:

$$R = \rho \frac{\ell}{A}.$$

- ρ is the resistivity.

- Power in an electric circuit:

$$P = IV.$$

- Direct current is constant.
- Alternating current varies sinusoidally:

$$I = \frac{V}{R} = \frac{V_0}{R}\sin\omega t = I_0 \sin\omega t.$$

- The average (rms) current and voltage:

$$I_{\text{rms}} = \sqrt{\overline{I^2}} = \frac{I_0}{\sqrt{2}} = 0.707\, I_0 ,$$

$$V_{\text{rms}} = \sqrt{\overline{V^2}} = \frac{V_0}{\sqrt{2}} = 0.707\, V_0 .$$

- Relation between drift speed and current:

$$I = \frac{\Delta Q}{\Delta t} = -neAv_{\text{d}} .$$