Current and Resistance

- When there is a net flow of charge in a region an electric **current** is said to exist.

- A current through a surface is defined as the **rate at which charge flows through this surface**

- If ΔQ amount of charge passes through a surface in a time interval Δt, the average current I_{av} is the charge that passes through that surface per unit time:

$$I_{av} = \frac{\Delta Q}{\Delta t} \qquad (1)$$

- The instantaneous current I through a surface:

$$I = \frac{dQ}{dt} \qquad (2)$$

-

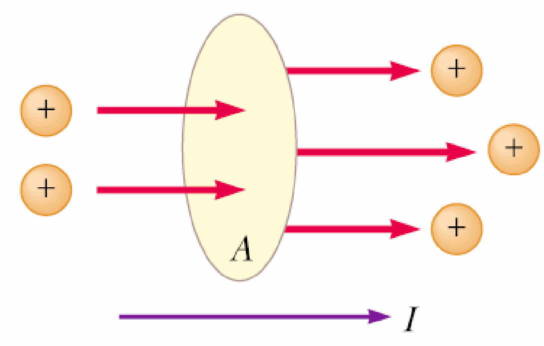
- The unit of current is the **ampere**

$$1\ A = \frac{1\ C}{1\ S} \qquad (3)$$

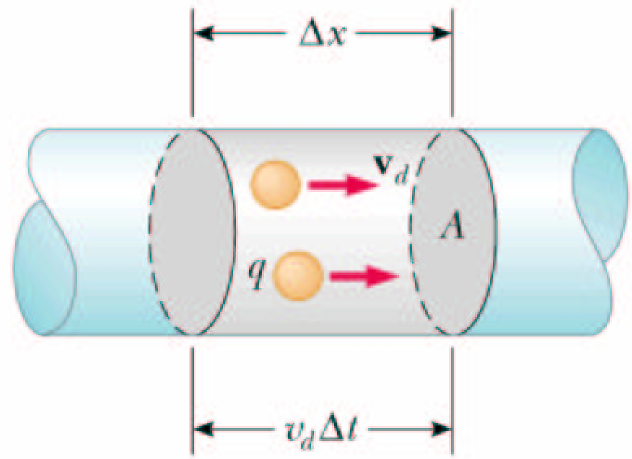
- The direction of the current is defined to be along the flow of **positive charges**

- It is the negatively charged electrons that really flow to generate the current. The direction of the current is opposite to the direction of the electron flow.

Serway, Physics for Scientists and Engineers, 5/e
Figure 27.1



Serway, Physics for Scientists and Engineers, 5/e
Figure 27.2



Microscopic model of Current

- ΔQ = number of charge carriers (electrons) in the section of the wire × charge per carrier = $(nA\Delta x)q$
- But if the drift velocity of the charge carriers is v_d: $\Delta x = v_d \Delta t$

$$\Delta Q = (nAv_d\Delta t)q \quad (4)$$

$$I_{av} = \frac{\Delta Q}{\Delta t} \quad (5)$$

$$= nv_d qA \quad (6)$$

Resistance and Ohm's Law

- The current going through a conductor will increase with the potential difference across the conductor.
- The current will will decrease if there is more resistance to the flow of current in the conductor **Of course!**

$$I \propto \Delta V \tag{7}$$

$$I \propto \frac{1}{R} \tag{8}$$

$$I \propto \frac{\Delta V}{R} \tag{9}$$

$$I = \frac{\Delta V}{R} \tag{10}$$

- For most material resistance follows **Ohm's Law**:

$$R = \frac{\Delta V}{I} \tag{11}$$

- Unit of resistance is Ω

$$1\Omega = \frac{1\,V}{1\,A} \tag{12}$$

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Figure 27.7

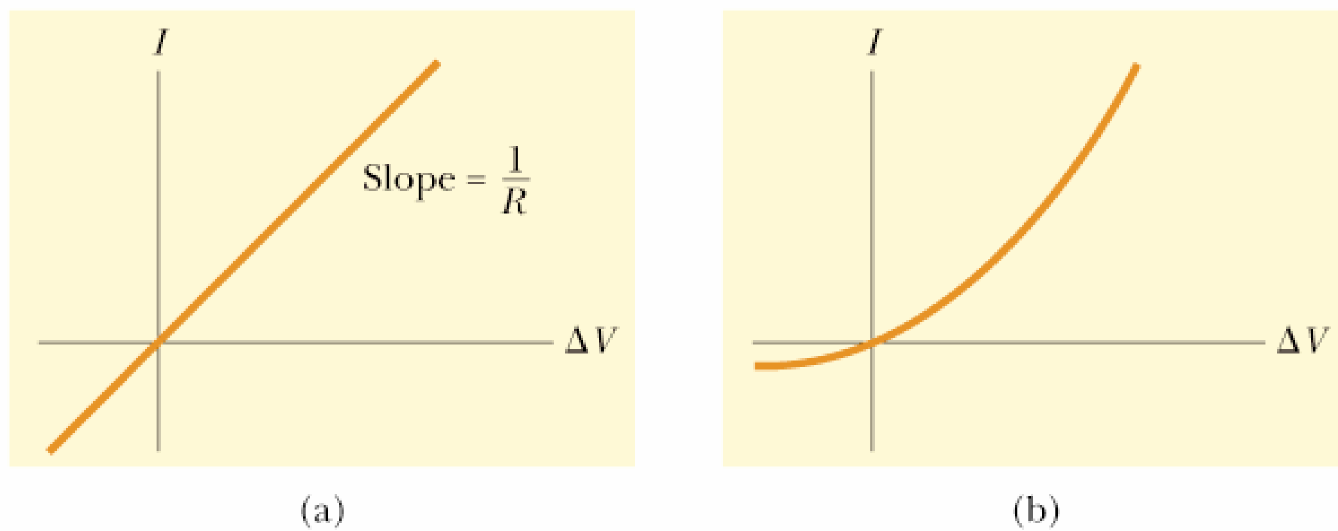

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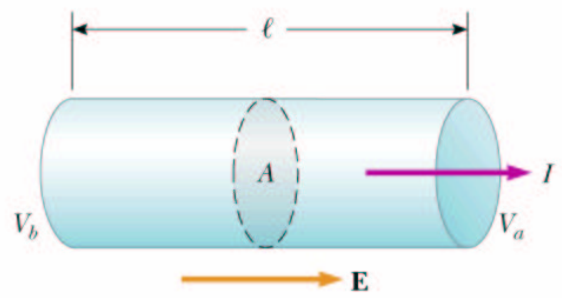
Figure 27.5



Ohm's Law, another way

- Current density J; current through a unit area:

$$J = \frac{I}{A} \tag{13}$$
$$= \frac{nqv_d A}{A} \tag{14}$$
$$J = nqv_d \tag{15}$$
$$\mathbf{J} = nq\mathbf{v}_d \tag{16}$$

- A potential difference applied across a conductor results in an electric field inside the conductor **Here the conductor is not in electrostatic equilibrium**

$$V_{AB} = -\int_A^B \mathbf{E} \cdot \mathbf{d}s \tag{17}$$
$$= -El \tag{18}$$

- The current density in the conductor increases with the applied electric field:

$$\mathbf{J} \propto \mathbf{E} \tag{19}$$
$$\mathbf{J} = \sigma \mathbf{E} \tag{20}$$

- σ: **conductivity** of the material.

Problem 27.11

The electron beam from a particle accelerator has a circular cross section of radius 1.00 mm.

- If the current is 8 μA, what is the current density in the beam assuming that it is uniform throughout?
- Find the electron density of the beam.

27.11 (a) $J = \frac{I}{A} = \frac{8.00 \times 10^{-6}\ \text{A}}{\pi\left(1.00 \times 10^{-3}\ \text{m}\right)^2} = \boxed{2.55\ \text{A}/\text{m}^2}$

(b) From $J = nev_d$, we have $n = \frac{J}{ev_d} = \frac{2.55\ \text{A}/\text{m}^2}{\left(1.60 \times 10^{-19}\ \text{C}\right)\left(3.00 \times 10^8\ \text{m}/\text{s}\right)} = \boxed{5.31 \times 10^{10}\ \text{m}^{-3}}$

(c) From $I = \Delta Q / \Delta t$, we have $\Delta t = \frac{\Delta Q}{I} = \frac{N_A e}{I} = \frac{\left(6.02 \times 10^{23}\right)\left(1.60 \times 10^{-19}\ \text{C}\right)}{8.00 \times 10^{-6}\ \text{A}} = \boxed{1.20 \times 10^{10}\ \text{s}}$

(This is about 381 years!)

Resistance, Resistivity and Conductivity

- Resistance of a conductor increases when the length of the conductor increases.
- Resistance of a conductor decreases when the cross sectional area of the conductor increases.

$$R \propto l \tag{21}$$

$$R \propto \frac{1}{A} \tag{22}$$

$$R \propto \frac{l}{A} \tag{23}$$

$$R = \rho \frac{l}{A} \tag{24}$$

- σ: **Resistivity** of the material.
- Unit is resistivity is Ωm.

$$\rho = \frac{1}{\sigma} \tag{25}$$

	Material	Resistivity Ωm
good conductor	Copper	1.7×10^{-8}
semi conductor	Silicon	640
good insulator	Rubber	1×10^{15}

ohm's Law

- We know that:

$$J = \frac{I}{A}$$

and;

$$El = \Delta V$$

-

$$\begin{aligned} \mathbf{J} &= \sigma \mathbf{E} \\ \frac{I}{A} &= \sigma \frac{\Delta V}{l} \\ I &= \sigma \frac{A}{l} \Delta V \\ I &= \frac{A}{l\rho} \Delta V \\ I &= \frac{\Delta V}{R} \end{aligned}$$

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Figure 27.8