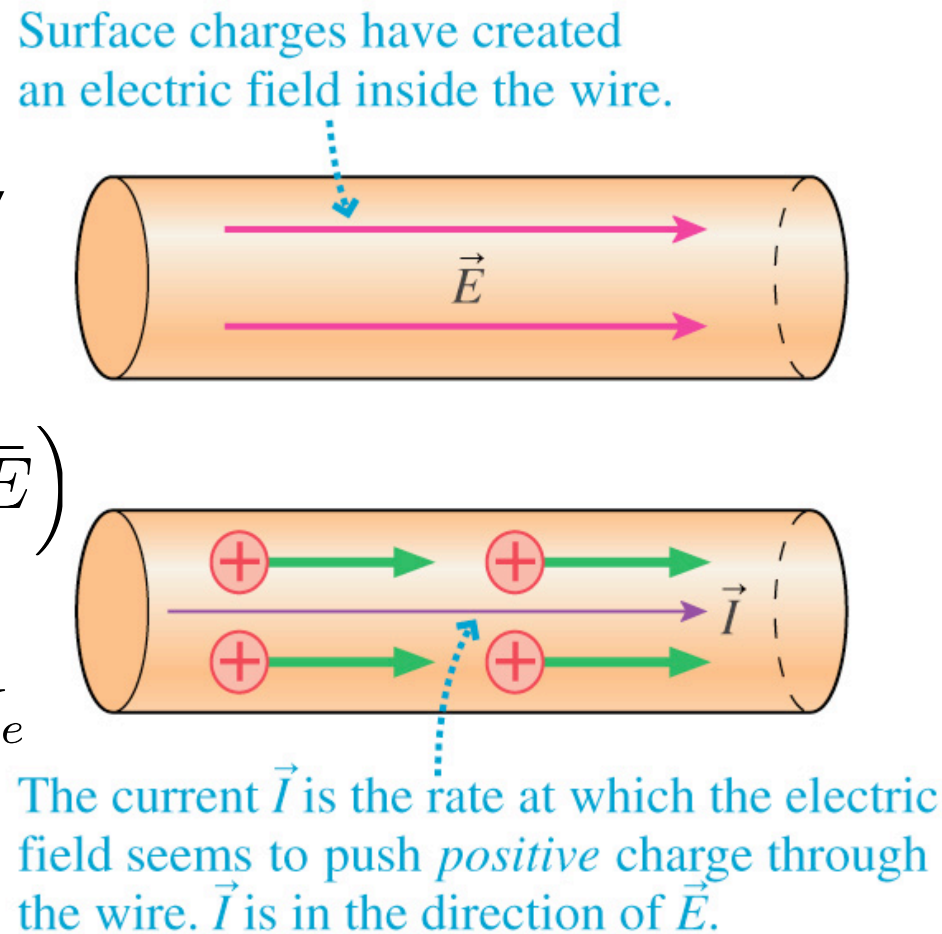
Lecture 32

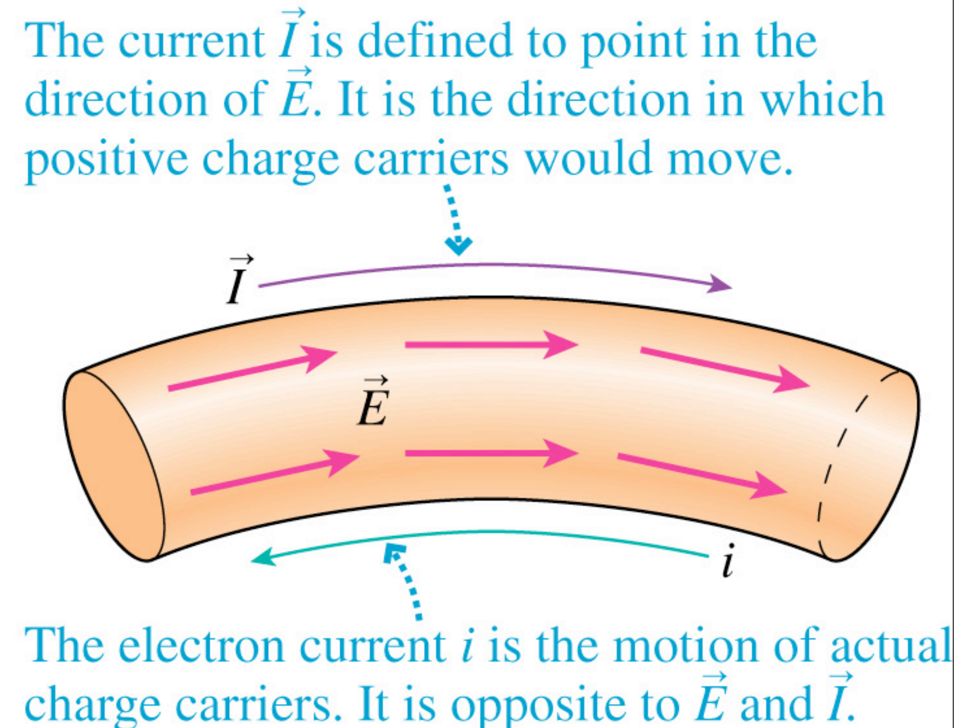
- current and current density
- conductivity and resistivity
- chapter 29 (Electric Potential)

Current and Current Density

$$\bar{I} \equiv \left(\frac{dQ}{dt},\ \text{in direction of } \bar{E}\right)$$

$$Q = I\Delta t;\ N_e = i\Delta t;\ Q = eN_e$$
$$\Rightarrow I = \frac{Q}{\Delta t} = \frac{eN_e}{\Delta t} = ei$$





- connect ideas of electron current to conventional definition (before atoms...) of current: rate of flow of charge in a wire (units 1 ampere, A = 1 C/s: 1 A in lightbulb; mA in computers)
- charge delivered in terms of electrons
- current direction defined to be in which positive charges seem to move (opposite to direction of electrons - charge carriers in metals, makes no difference at macroscopic level): current in a wire from positive to negative terminal of battery

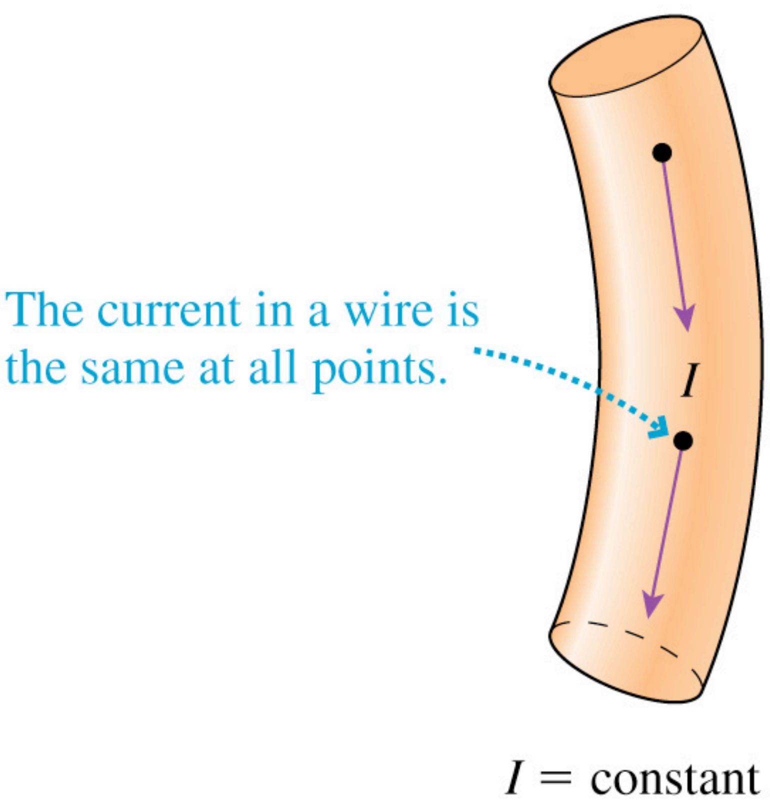
Current and Current Density

- current density (same for all wires for given E; units $\mathrm{A/m^2}$):

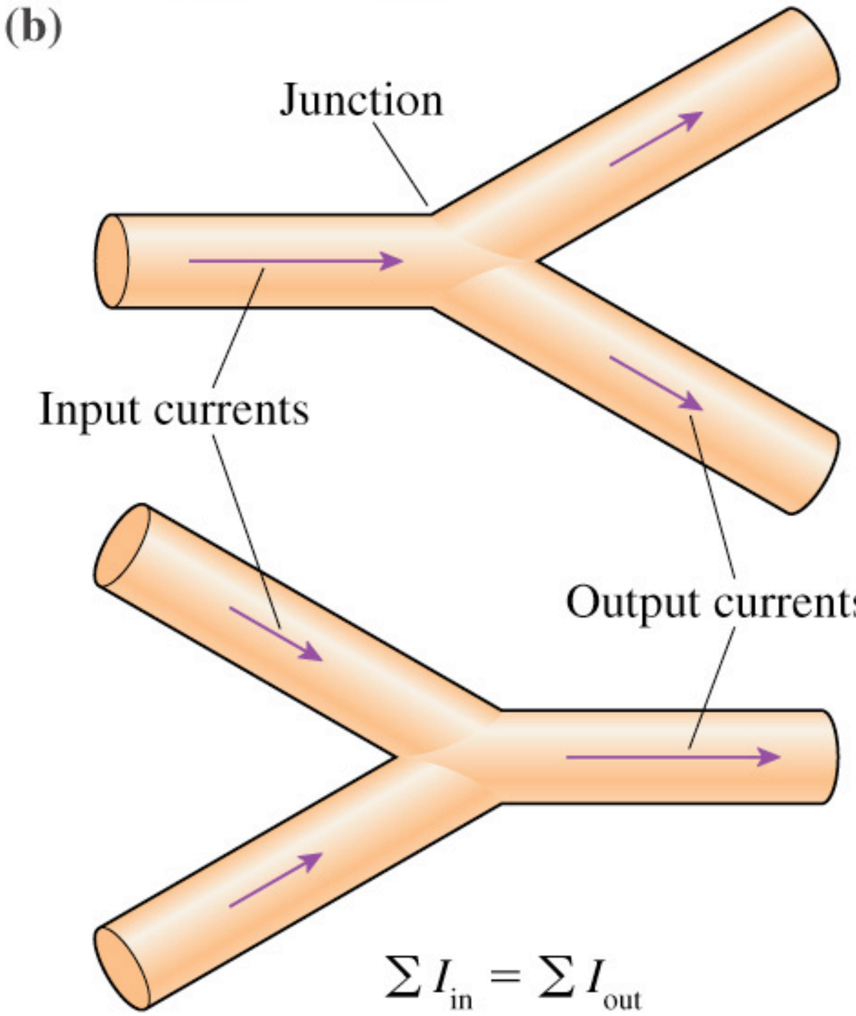
$$I = ei = nev_d A \longrightarrow J = \text{current density} = \frac{I}{A} = nev_\mathrm{d} \longrightarrow I = JA$$

- conservation of charge $\longrightarrow$ ...of electron current $\longrightarrow$ ....of conventional current, even at junctions: $\sum I_\mathrm{in} = \sum I_\mathrm{out}$

(a)



(b)



Conductivity and Resistivity

- characterize material: $J = nev_d = ne\left(\frac{e\tau E}{m}\right) = \frac{ne^2\tau}{m}E$

  conductivity, $\sigma = \frac{ne^2\tau}{m}$ $\longrightarrow$ $J = \sigma E$

- current caused by E exerting forces on charge carriers, $\propto E, n, \tau$

- conductivity decreases with temperature (more collisions...)

- more practical: resistivity, $\rho = \frac{1}{\sigma} = \frac{m}{ne^2\tau}$

- Units: $\mathrm{AC/N\ m^2} \equiv \Omega^{-1}\ \mathrm{m}^{-1}$ for σ; Ω m for ρ (Ω is ohm)

Example: A 2.0-mm-diameter aluminium wire carries a current of 800 mA. What is the electric field strength inside the wire?

$$E = \frac{J}{\sigma} = \frac{I}{\sigma A} = \frac{I}{\sigma \pi r^2} = \frac{0.80\ \mathrm{A}}{(3.5\times10^{-7}\Omega^{-1}\mathrm{m}^{-1})\pi(0.0010\ \mathrm{m})^2}$$

$= 0.00072\ \mathrm{N/C}$

- small E (very few surface charges) enough to carry considerable current due to huge n

- superconductivity: loss of resistance at low temperature (carry huge currents without heating, create huge magnetic fields)

Chapter 29 (Electric Potential)

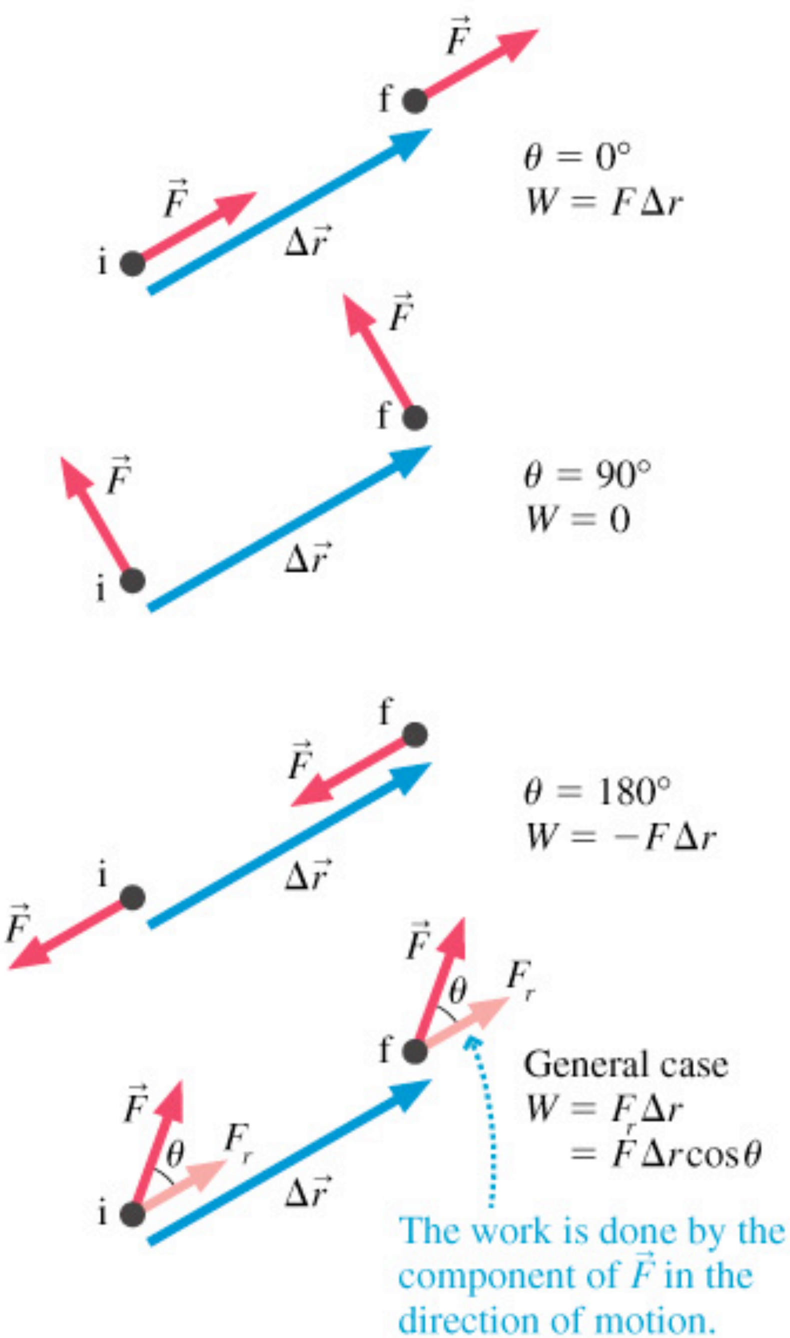
- apply concept of energy to electric phenomena
- use conservation of energy and electric potential energy to analyze motion of charged particles
- calculate potential of charge distributions

- chapter 30: relate electric field to electric potential

- chapter 31: circuits (practical applications of electric field and electric potential)

Mechanical Energy

- analogy between gravitational and electric forces: inverse square law; uniform field (near earth and in capacitor)
- For conservative forces (work done independent of path e.g. gravitational and electric):



$$\Delta E_{mech} = \Delta K + \Delta U = 0$$

$$K = \Sigma K_i, K_i = \frac{1}{2} m_i v_i^2$$

Potential energy U is interaction energy of system:

$$\Delta U = U_f - U_i = -W_{\text{interaction forces}}$$

Constant force,
linear displacement:

$$W = \bar{F}.\Delta\bar{r} = F\Delta r\cos\theta$$

In general:

$$W = \sum_j (F_s)_j \Delta s_j$$

$$\rightarrow \int_{s_i}^{s_f} F_s ds = \int_{s_i}^{s_f} \bar{F}.d\bar{s}$$