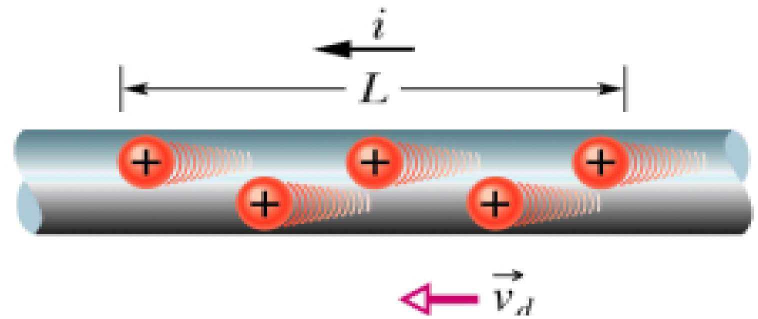
Lecture 13

Chapter 27

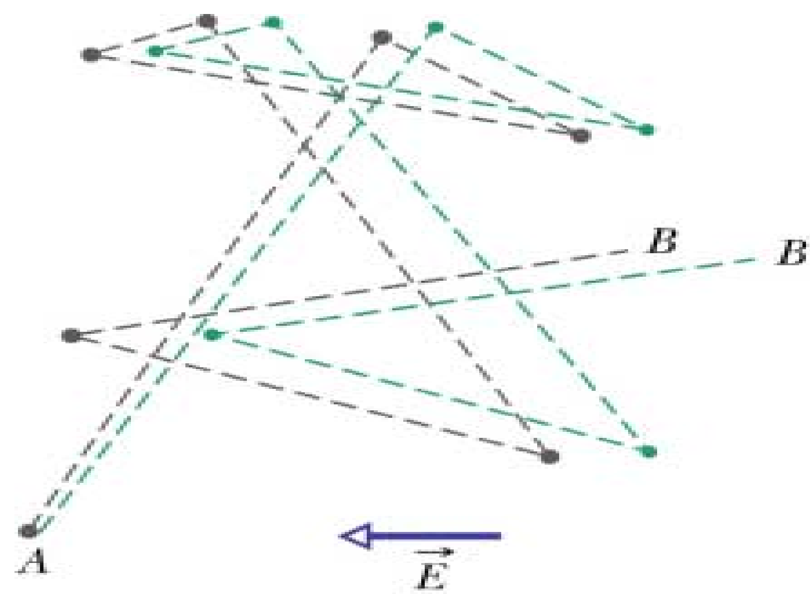
Current and Resistance

Current (10)

- Electrons have random motion with speeds ≈ 10^6 m/s – gray line



- Drift speeds are tiny $v_d \approx 10^{-5}$ or 10^{-4} m/s

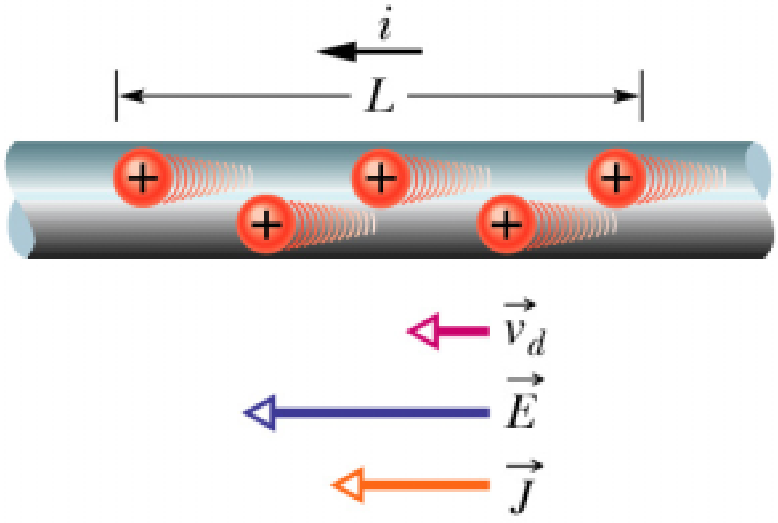


- Motion of electrons in *E* is due to both random motion and drift speed

Current (11)

- Relate the drift speed, v_d , to the charge density
- Assume J uniform across cross-sectional area A
- Total charge in length L is

$$q = ne(AL)$$



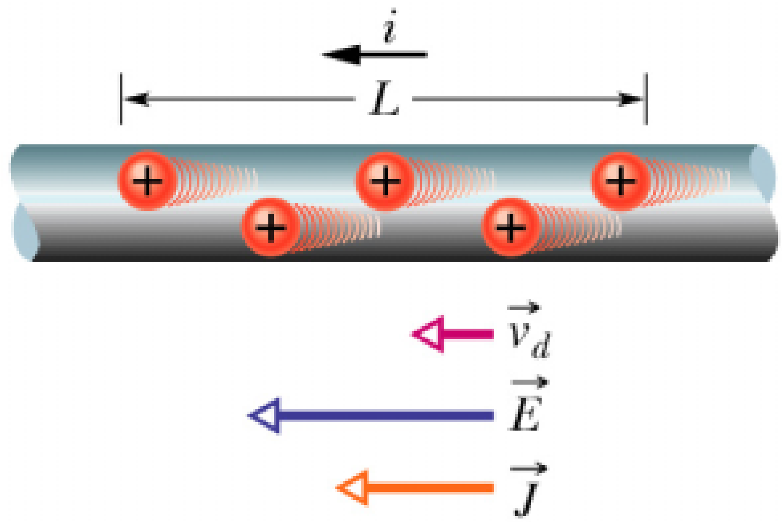
- All charges move with same drift speed so charge moves through any cross section in time

$$t = \frac{L}{v_d}$$

Current (12)

- Current is given by

$$i = \frac{q}{t} = \frac{neAL}{L/v_d} = neAv_d$$



- Solving for drift speed

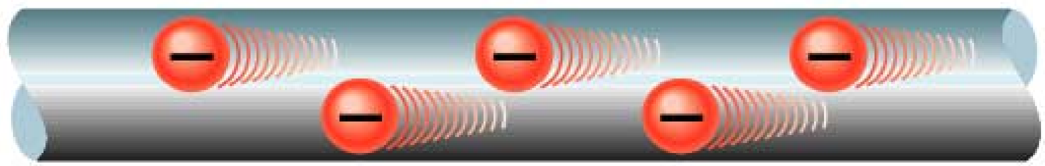
$$v_d = \frac{i}{neA}$$ BUT $$J = \frac{i}{A}$$

$$\vec{v}_d = \frac{\vec{J}}{ne}$$

- J, v_d same dir. for + charge
- J, v_d opposite dir. for - charge

Current (13)

- Checkpoint #2 – Conduction electrons move leftward in wire. The following are leftward or rightward?



- A) Current, *i* , is

  rightward

- B) Current density, *J* , is

  rightward

- C) *E* field in wire is

  rightward

Current (14)

- Different types of conductors, i.e. glass and copper, give very different *i* for the same *V*
- Define this characteristic as resistance

$$R = \frac{V}{i}$$

- SI unit is ohm, Ω

$$1\Omega = 1V/A$$

- A resistor is a device used to provide a specified resistance in a circuit

Current (15)

- Rearrange resistance relation
- For given V greater R, smaller i

$$i = \frac{V}{R}$$

- Macroscopic quantities V, i and R work well for electrical measurements
- Use microscopic quantities E, J, and ρ when talk about electrical properties of materials

Current (16)

- Resistivity, ρ, of a material is defined as
- SI unit is Ω·m

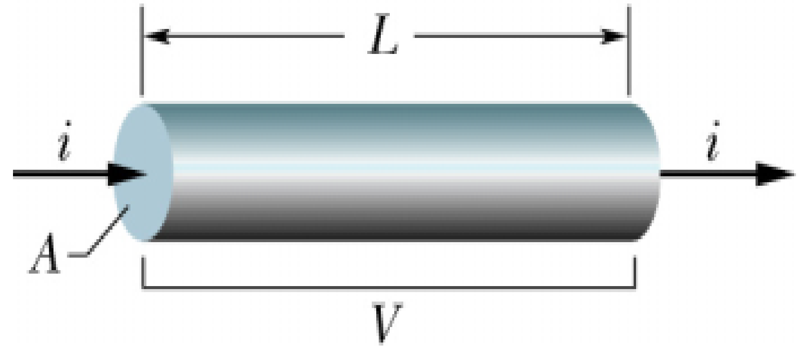
$$\rho = \frac{E}{J}$$

- Conversely speak of a material's conductivity, σ
- SI unit is $(\Omega \cdot m)^{-1}$

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

Current (17)

- Know ρ of material can calculate R for a length of wire of that material

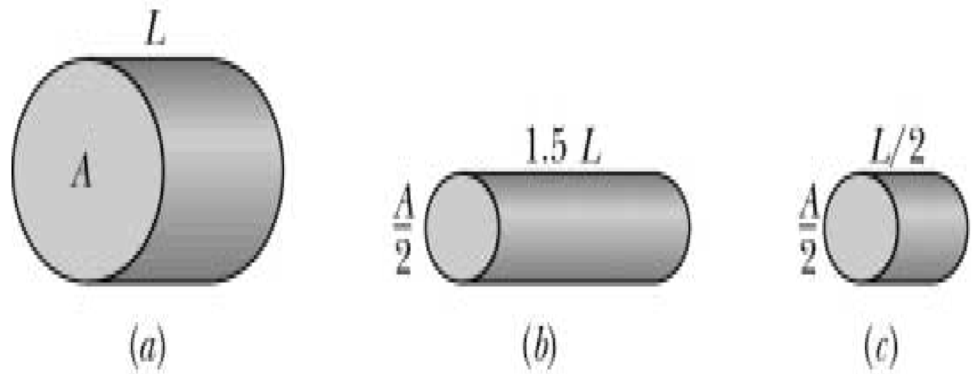


$$\rho = \frac{E}{J}$$ BUT $$E = \frac{\Delta V}{\Delta s} = \frac{V}{L}$$ $$J = \frac{i}{A}$$

$$\rho = \frac{V/L}{i/A} = \frac{V}{i}\frac{A}{L}$$ BUT $$R = \frac{V}{i}$$ SO $$R = \rho\frac{L}{A}$$

Current (18)

- Checkpoint #3 – 3 copper conductors with same applied *V*. Rank *i* through them, greatest first.



$$R = \rho \frac{L}{A}$$

$$R_a = \rho \frac{L}{A}$$

$$R_b = \rho \frac{1.5L}{A/2} = \rho \frac{3L}{A}$$

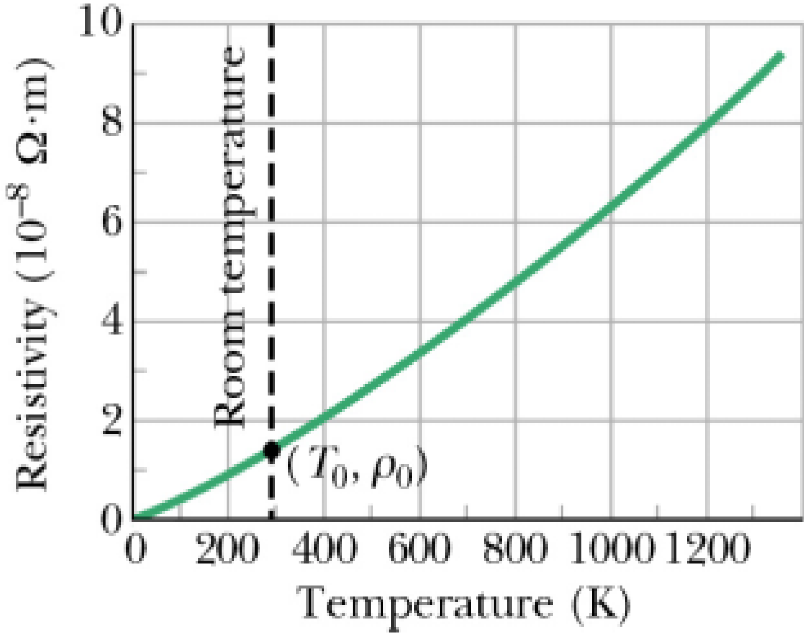
$$R_c = \rho \frac{L/2}{A/2} = \rho \frac{L}{A}$$

$$i = \frac{V}{R}$$

a and c tie, then b

Current (19)

- Resistivity, *ρ,* varies with temperature due to thermal vibrations
- For metals, relation is fairly linear – e.g. copper →
- T_0 and ρ_0 are reference points measured at room temperature
- α is temperature coefficient of resistivity



$$\rho - \rho_0 = \rho_0 \alpha (T - T_0)$$

Current (20)

- Resistivities for some common materials
- Typically for metals – if temperature increases, ρ increases
- Glass will conductor at high temperatures

Material	Resistivity, ρ
Copper	1.69×10^{-8}
Silicon	2.5×10^{3}
Silicon, n-type	8.7×10^{-4}
Glass	10^{10} - 10^{14}

Current (21)

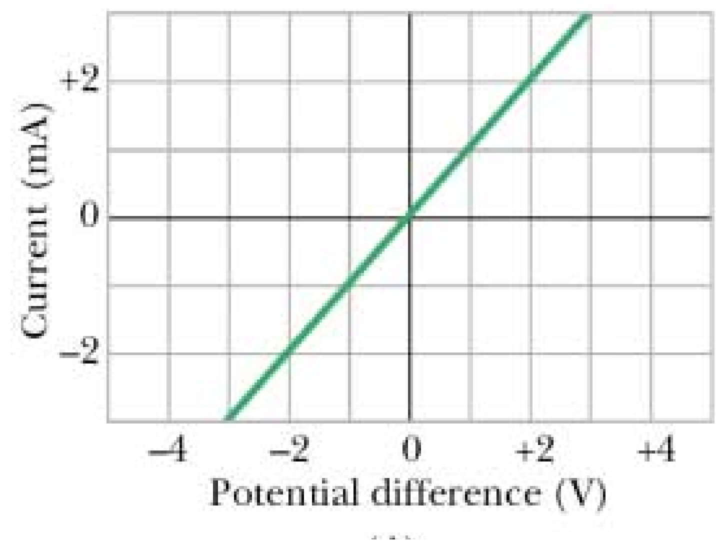
- So far have assumed that *R* is independent of the magnitude and polarity of the applied *V*
- This is known as Ohm's law
- Ohm's law is not generally valid, but it is a good empirical rule for most systems

$$R = \frac{V}{i}$$

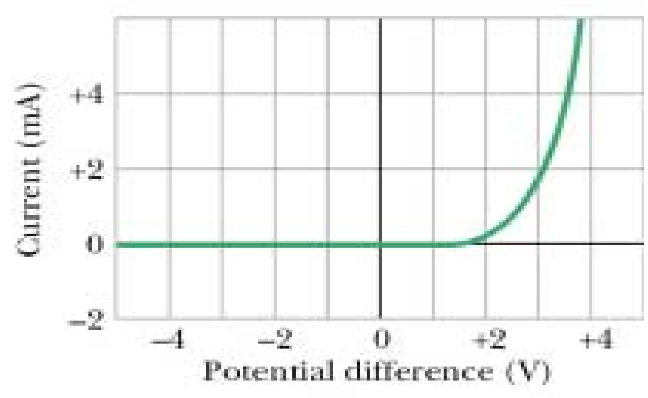
$$V = iR$$

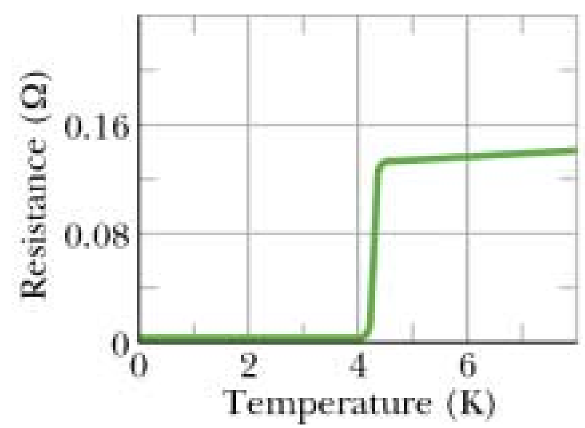
Current (22)

- Ohm's law says: *R* is independent of size and direction of *V*
- Slope of *i* vs. *V* is a straight line



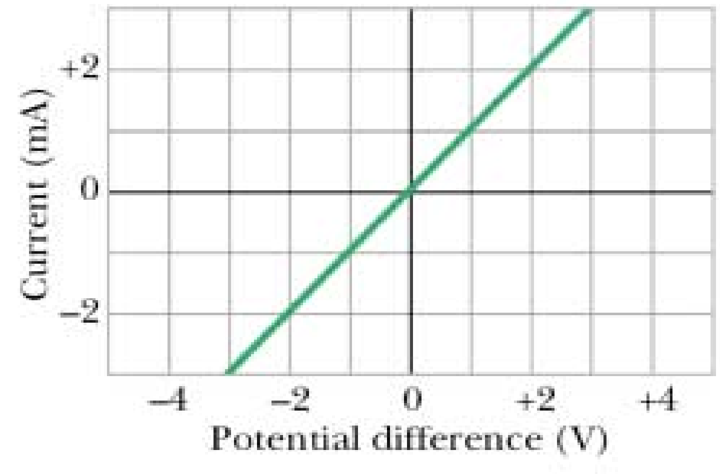
- What about these other graphs?

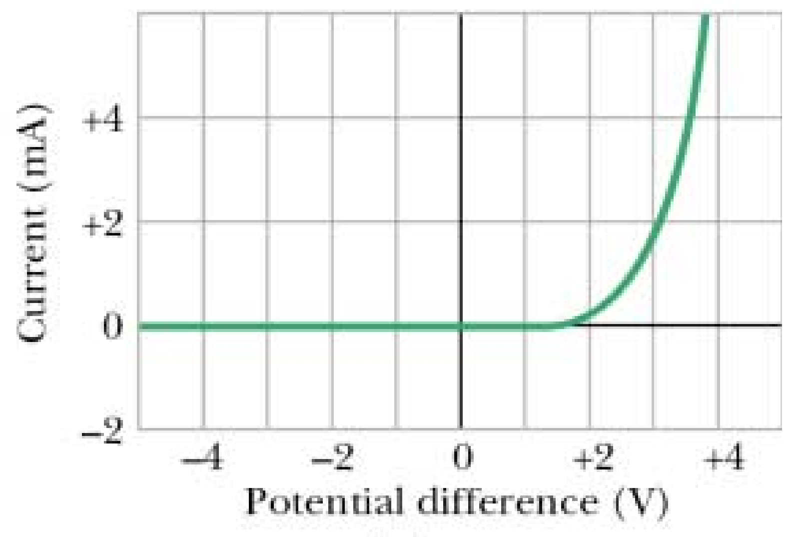




Current (23)

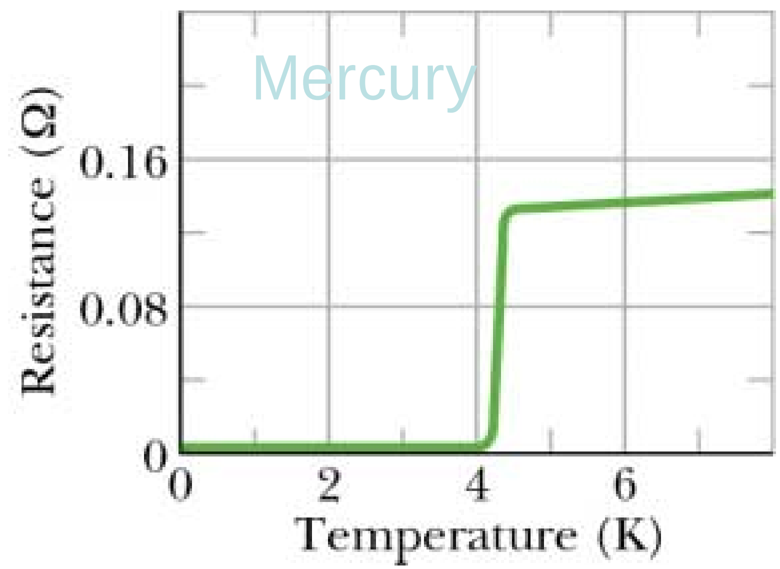
- Metal: *n* is large but constant with *T*, *R*↑ when *T*↑ due to increase in collision rate of charge carriers
- Semiconductor: Like insulator but takes less energy to free electrons
- Add charge carriers by process called doping
- Semiconductor: n is small but increases with T, R↓ with T↑, increase in *n* is greater than increase in collision rate





Current (24)

- Superconductors: *R* goes to zero at some *T*
- Once start charges moving no thermal losses so current forever
- Temperatures are usually very low (4-20K)

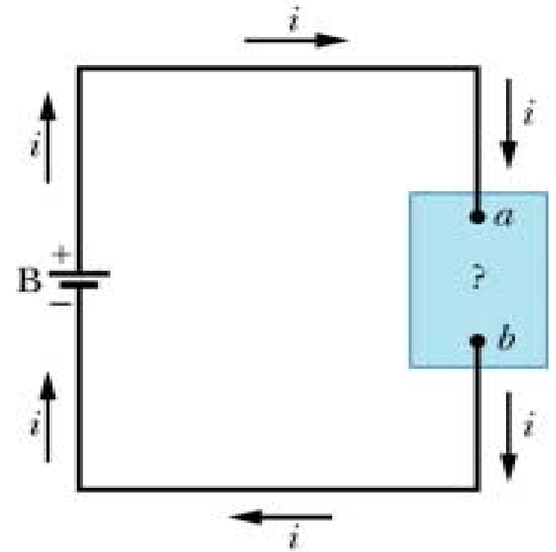


Current (25)

- Calculate the amount of power, *P*, in a circuit

$$P = \frac{dU}{dt}$$

$$dU = dqV = idtV$$



$$P = iV$$

- SI unit is watt, W

$$1W = 1V \cdot A$$

Current (26)

- Transfer potential energy, *U*, to some other form

$$P = iV$$

$$R = \frac{V}{i}$$

- For resistors energy is transferred to thermal energy – heat
- Use resistance definition to find

$$P = i^2 R$$

$$P = \frac{V^2}{R}$$