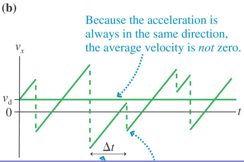
A Model of Conduction

- Suppose an electron just had a collision with an ion and has rebounded with velocity $\vec{v}_0$. The acceleration of the electron between collisions is

$$a_x = \frac{F}{m} = \frac{eE}{m}$$



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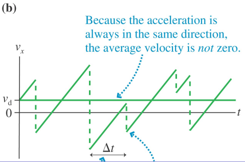

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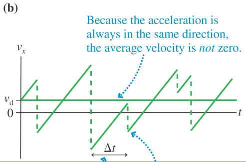

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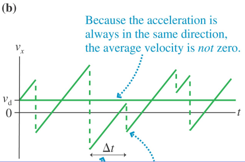
- This accelerating and colliding leads to the non-zero average velocity v_d



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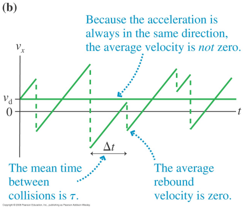

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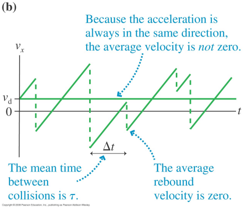

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- Substituting into our expression for electron current gives

$$i_e = n_e A v_d = \frac{n_e e \tau A}{m}E$$

Current and Current Density (31.3)

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- In other words, we now know that electrons are carrying the charges and are negative, but all practical circuits are discussed in terms of the flow of positive charge!
- The microscopic understanding does not mesh well with the traditional convention. Nonetheless, we still use it. It makes no difference to practical calculations.

The Current Density in a Wire

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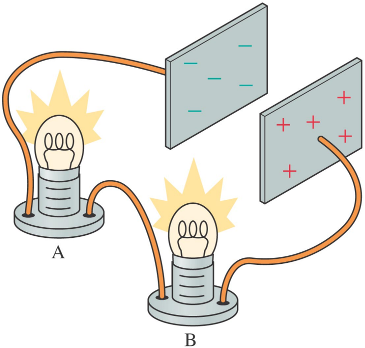
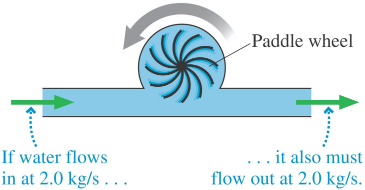
- It can be useful to rearrange this and say that a specific piece of metal shaped into a wire with cross-sectional area A has current

$$I = JA$$

Conservation of Current





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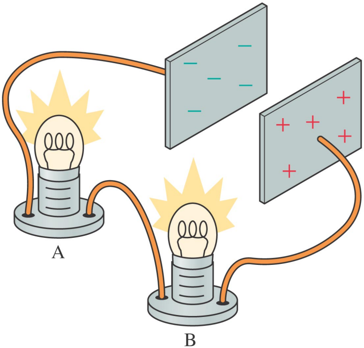

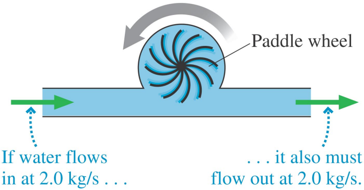

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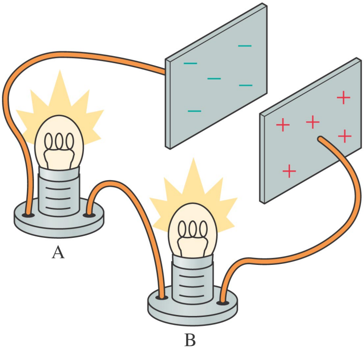

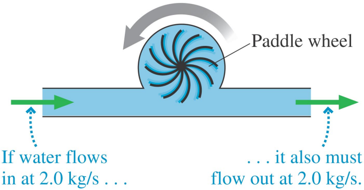

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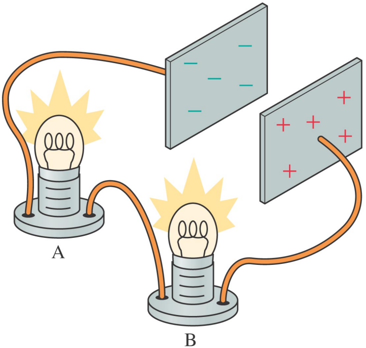

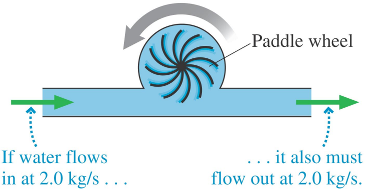

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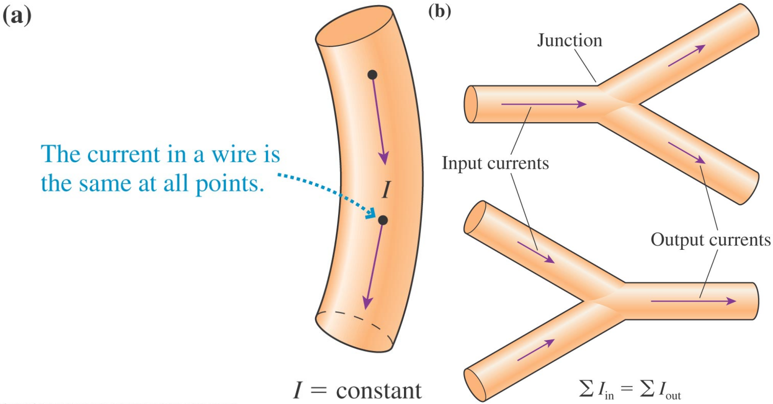
- Neither, they are equally bright! The first lightbulb does not destory or “use-up” any of the electrons passing through it.
- Further, the electrons do not slow down (see water example).
- The law of current reads: The current is the same at all points on a current-carrying wire.

Conservation of Current



The sum of the currents entering a junction must equal the sum of those leaving is Kirchoff's junction law.

Conductivity and Resistivity (31.4)

- The current density can be expressed as

$$J = n_e e v_d = n_e e \left(\frac{e \tau E}{m} \right) = \frac{n_e e^2 \tau}{m} E$$

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- The coefficent in front of the electric field depends only on the conducting material and is referred to as the conductivity

$$\sigma = \frac{n_e e^2 \tau}{m}$$

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  Current density depends only on the material and the electric field.
- It is also useful to define resistivity

$$\rho = \frac{1}{\sigma} = \frac{m}{n_e e^2 \tau}$$

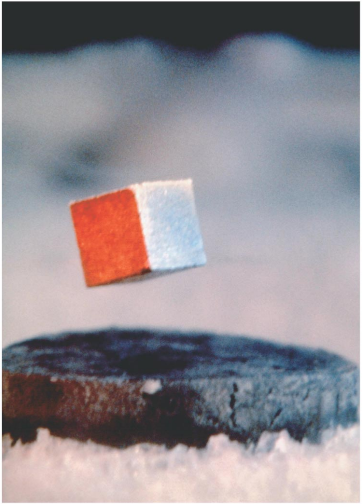
Conductivity and Resistivity

TABLE 31.2 Resistivity and conductivity of conducting materials

Material	Resistivity (Ω m)	Conductivity (Ω^{-1} m^{-1})
Aluminum	2.8×10^{-8}	3.5×10^{7}
Copper	1.7×10^{-8}	6.0×10^{7}
Gold	2.4×10^{-8}	4.1×10^{7}
Iron	9.7×10^{-8}	1.0×10^{7}
Silver	1.6×10^{-8}	6.2×10^{7}
Tungsten	5.6×10^{-8}	1.8×10^{7}
Nichrome*	1.5×10^{-6}	6.7×10^{5}
Carbon	3.5×10^{-5}	2.9×10^{4}

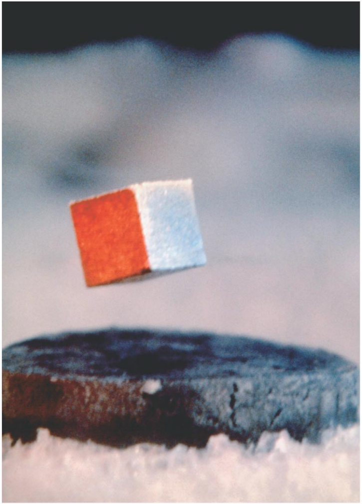
*Nickel-chromium alloy used for heating wires.

Superconductivity



- A very interesting feature of metals is that their resistivity gradually drops with temperature.

Superconductivity



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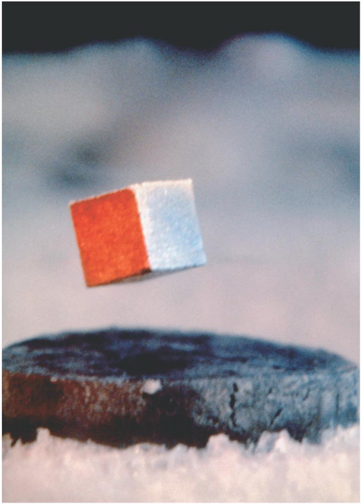

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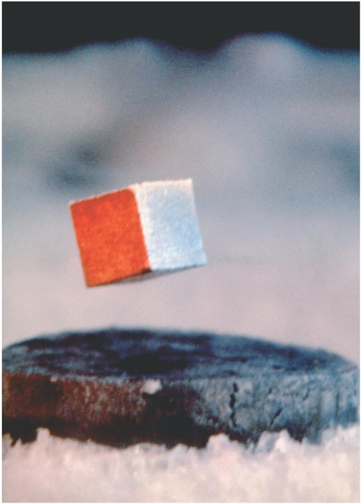

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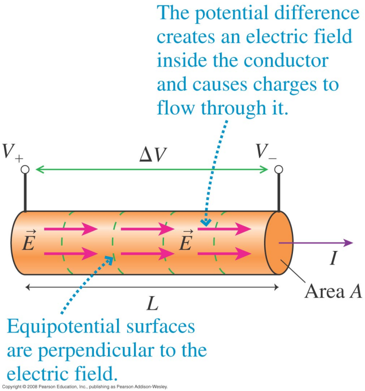
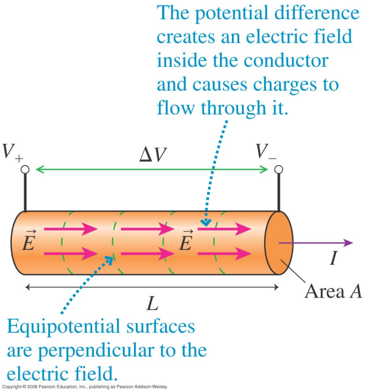
- However, at very low temperatures there is a sudden transition to **zero** resistivity! This is known as superconductivity.
- Electrons in a superconductor move with friction. Superconducting wires can sustain enormous currents.
- The discovery of “high temperature” superconductors has had a big impact on their usefulness.



- We know that current is related to electric field and that electric field is related to potential.

Resistance and Ohm's Law (31.5)



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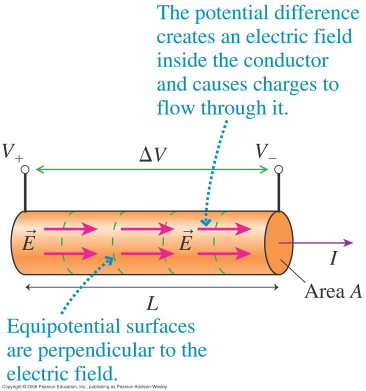

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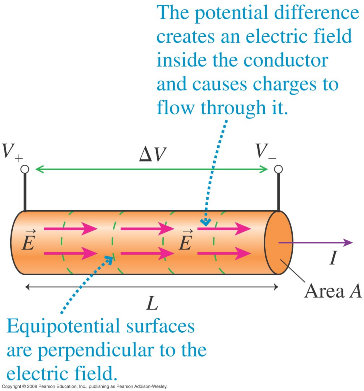

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- The current in terms of field is

$$I = JA = A\sigma E = \frac{A}{\rho}E$$

Resistance and Ohm's Law

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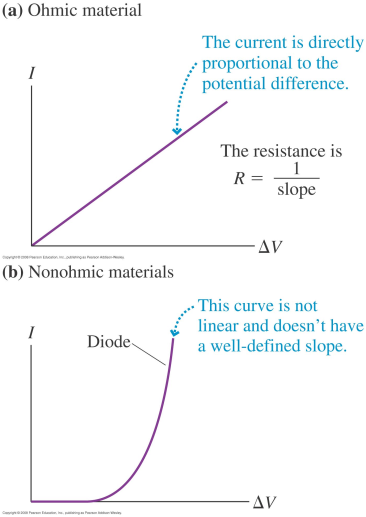
- We can now write Ohm's Law as

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

More on Ohm's Law



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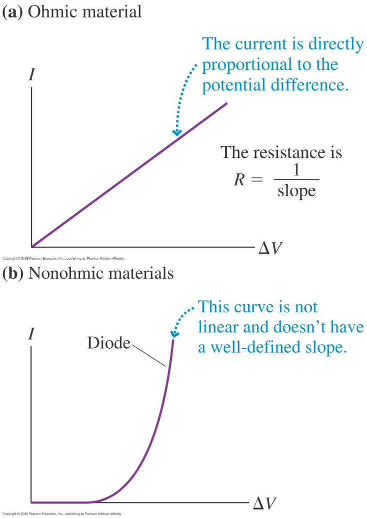
More on Ohm's Law



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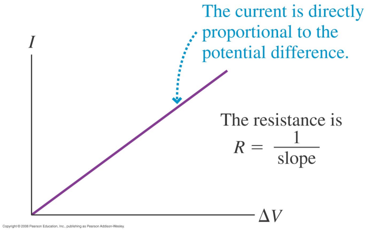
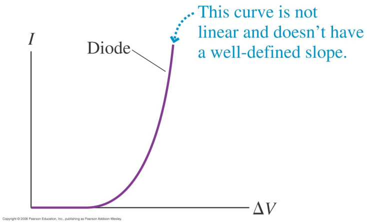
More on Ohm's Law

(a) Ohmic material



(b) Nonohmic materials



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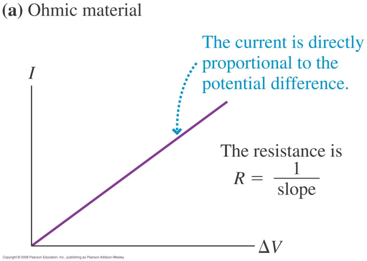
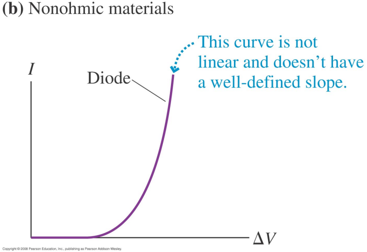
- Resistors are poor conductors with R ranging from 10 to 1M Ω. They are used to control the current in a circuit.

More on Ohm's Law





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- Resistors are poor conductors with R ranging from 10 to 1M Ω. They are used to control the current in a circuit.
- Insulators have very high resistance $R = \infty$. There is no current, even if there is a potential difference across it (eg. glass, plastic, air).