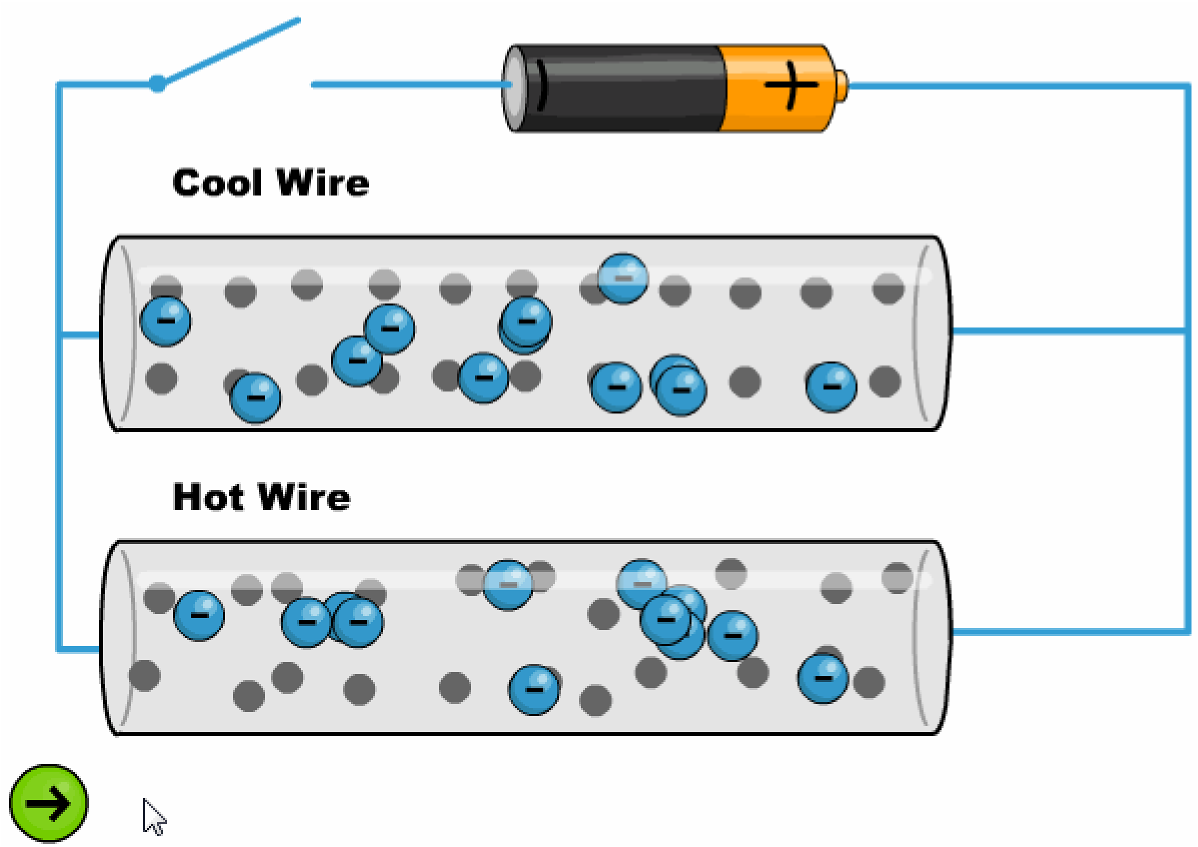
# Electric Current and Resistance



# Electric Current

The electric current through a cross sectional area A is defined as the total charge that flows through that area per unit of time :

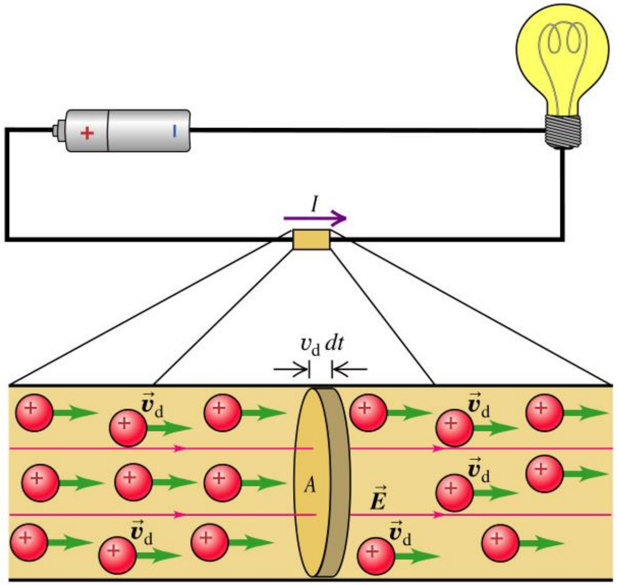
$$I = \frac{dq}{dt}$$

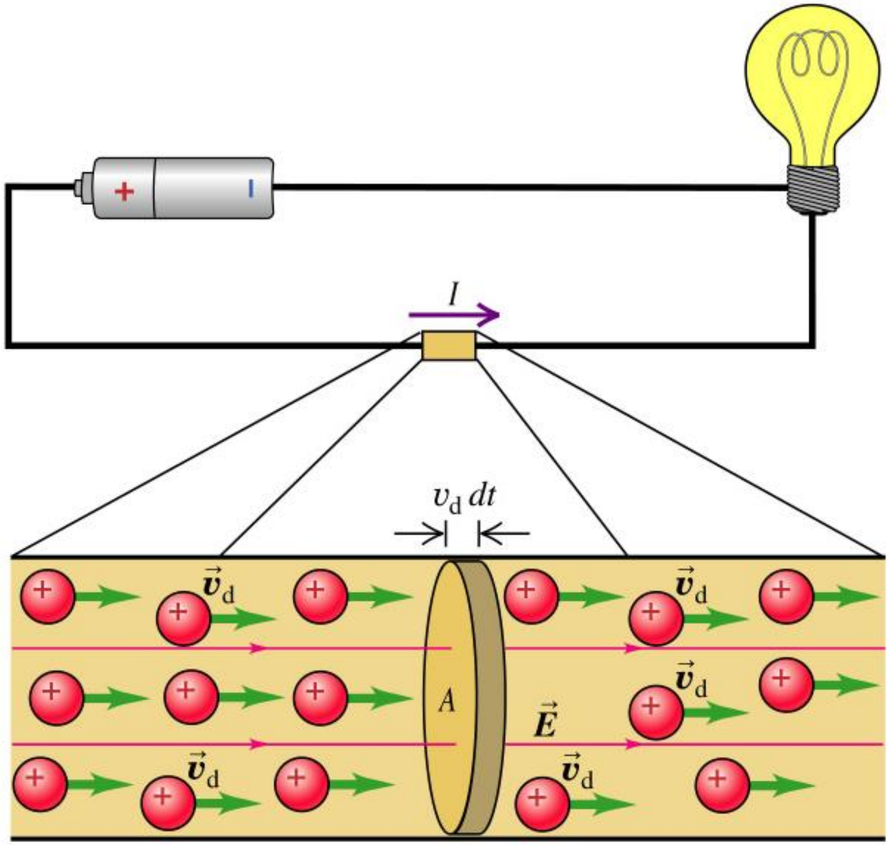
1 coulomb per second is defined as an ampere

The electric charge change can be due to the movement of positive or negative charges, however, the direction of the current is the direction of the movement of the positive charges

# Electric Current and drift velocity

As it is known, the electric current in a conductor is given due to the movement of negative electric charges So what is the relationship between the electric current and the mean speed of the moving electric charges in the conductor (drift velocity)?






$$I = \frac{dq}{dt} = \frac{nqv_dA\,dt}{dt} = nqv_dA$$

# Electric Current and Drift Velocity

Starting from the definition of electric current:

$$I = \frac{dq}{dt} = \frac{nqv_d A\,dt}{dt} = nqv_d A$$

where $n$ is the number of electrically charged particles per unit of volume, and $v_d$ is the drift velocity of these particles

# Electric current and drift velocity

The product: $J = nqv_d$ is called electric charge current densitiy , and is defined as:

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

# Example 1

A copper wire has a perimeter of 1.02 mm. The wire conducts a constant current of 1.67 A to a lamp of 200 watts. The density of the free electrons is $8.5 \times 10^{28}$ electrons per cubic meter. Find the magnitude of

(a) The current density

(b) The drift velocity.

# Electric Conductivity and Resistivity

- The conductivity $\sigma$ (units $\frac{1}{\Omega \cdot m}$), is the capacity of a material to let electric charges flow .

- The resistivity is the inverse of the conductivity $\rho = \frac{1}{\sigma}$, (units $\Omega \cdot \mathrm{m}$) . Therefore, we can think of it as the measure of the material opposing to the flow of the electric charge

# Table of resistivities

**Table 25.1 Resistivities at Room Temperature (20°C)**

| | Substance | $\rho\,(\Omega \cdot m)$ | Substance | $\rho\,(\Omega \cdot m)$ |
|---|---|---|---|---|
| *Conductors* | | | *Semiconductors* | |
| Metals: | Silver | $1.47 \times 10^{-8}$ | Pure carbon (graphite) | $3.5 \times 10^{-5}$ |
| | Copper | $1.72 \times 10^{-8}$ | Pure germanium | 0.60 |
| | Gold | $2.44 \times 10^{-8}$ | Pure silicon | 2300 |
| | Aluminum | $2.75 \times 10^{-8}$ | *Insulators* | |
| | Tungsten | $5.25 \times 10^{-8}$ | Amber | $5 \times 10^{14}$ |
| | Steel | $20 \times 10^{-8}$ | Glass | $10^{10}$–$10^{14}$ |
| | Lead | $22 \times 10^{-8}$ | Lucite | $>10^{13}$ |
| | Mercury | $95 \times 10^{-8}$ | Mica | $10^{11}$–$10^{15}$ |
| Alloys: | Manganin (Cu 84%, Mn 12%, Ni 4%) | $44 \times 10^{-8}$ | Quartz (fused) | $75 \times 10^{16}$ |
| | Constantan (Cu 60%, Ni 40%) | $49 \times 10^{-8}$ | Sulfur | $10^{15}$ |
| | Nichrome | $100 \times 10^{-8}$ | Teflon | $>10^{13}$ |
| | | | Wood | $10^{8}$–$10^{11}$ |

**Table 25.2 Temperature Coefficients of Resistivity (Approximate Values Near Room Temperature)**

| Material | $\alpha\,[(°C)^{-1}]$ | Material | $\alpha\,[(°C)^{-1}]$ |
|---|---|---|---|
| Aluminum | 0.0039 | Lead | 0.0043 |
| Brass | 0.0020 | Manganin | 0.00000 |
| Carbon (graphite) | −0.0005 | Mercury | 0.00088 |
| Constantan | 0.00001 | Nichrome | 0.0004 |
| Copper | 0.00393 | Silver | 0.0038 |
| Iron | 0.0050 | Tungsten | 0.0045 |

# Ohm's Law

For many materials, specially metals, to certain temperature , J is proportional to the electric field in certain point :

$$E \propto J \longrightarrow E = \rho J$$

where ρ is called the resistivity of the material

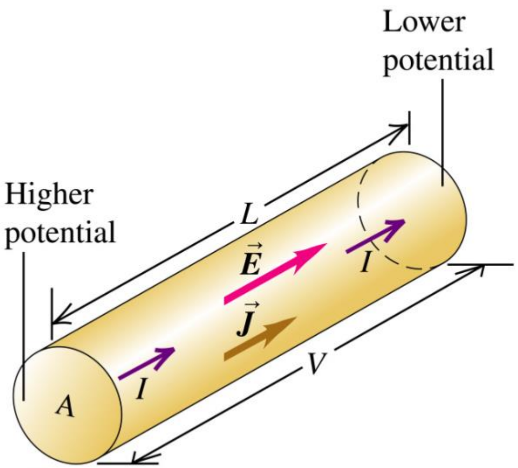
If a material follows this equation, it is said to be an ohmic material to certain temperature

**Ohm's Law is not a fundamental law of nature!**

# Resistence of a wire

Consider a cilindrical conductor. Then :

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




However, $E = \dfrac{V}{L}$

Therefore, $\dfrac{V}{L} = \rho \dfrac{I}{A} \Rightarrow V = \left(\rho \dfrac{L}{A}\right) I$

# Resistence of a wire

The relationship :

$$R = \left(\rho \frac{L}{A}\right)$$

is called resistence , therefore:

$$V = RI$$

This is usually used as the Ohm's Law

The units of the resistence are volt/ampere which are defined as ohm ($\Omega$).

# Difference between Resistence and Resistivity

- Both gives magnitude of opposition of the material for flowing charges;  considering the following differences

- Resistivity is an intrinsic property of the material.
- Resistance depends of the dimensions of the material

# Example 2

A copper wire has a radius of 0.5cm. The wire length is 4 m and a current of 3.6 A is travelling through it . Find the magnitude of

(a) Current density of the wire

(b) The electric field in the wire

(c) The resistence of the wire

# Change of resistivity with temperature

The resistivity of the materials change with the temperature. For many ohmic materials it holds the following relationship between a range temperature:

$$\rho = \rho_o[1 + \alpha(T - T_o)]$$

The same equation is valid for the resistence :

$$R = R_o[1 + \alpha(T - T_o)]$$

# Example 3

Suppose that at $20^0C$ the resistence of a thermometer of platinum is $164.2\Omega$ , $\alpha = 3.92x10^{-3}(C^0)^{-1}$. When it placed in a particular solution, the resistence is $187.4\Omega$

What is the temperature of the solution?

# Electrical Power

# General Relation of Power

- The power transformed by an electrical device is given by

$$P = \frac{dW}{dt} = \frac{V\,dq}{dt} = VI$$

# Power dissipated in resistance

The resistances adquire energy, the power given by a resistance connnected to a potential difference is given by : $P = VI$

Which can be rewritten as

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

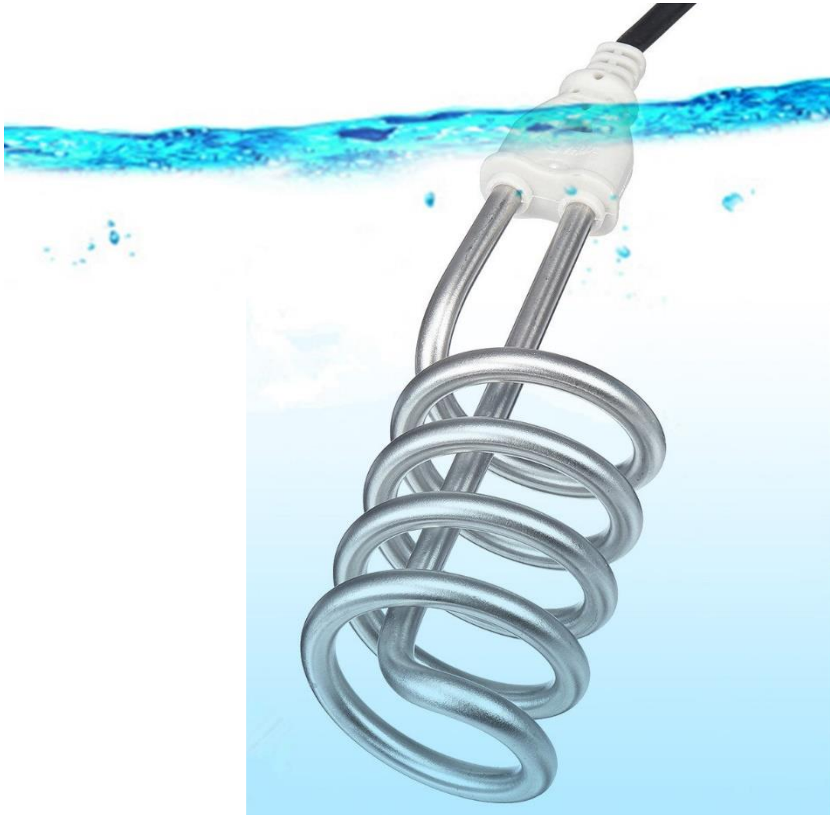
The process where a material with resistance R losses energy is called joule heat.

# Example 4

- An electrical heater uses 15.0 A when is connected to a line of 120V. What is the required power and how much does it cost a month (30 days) if the heater works during 3.0 h per day and the company charges $0.092 cents per kWh?

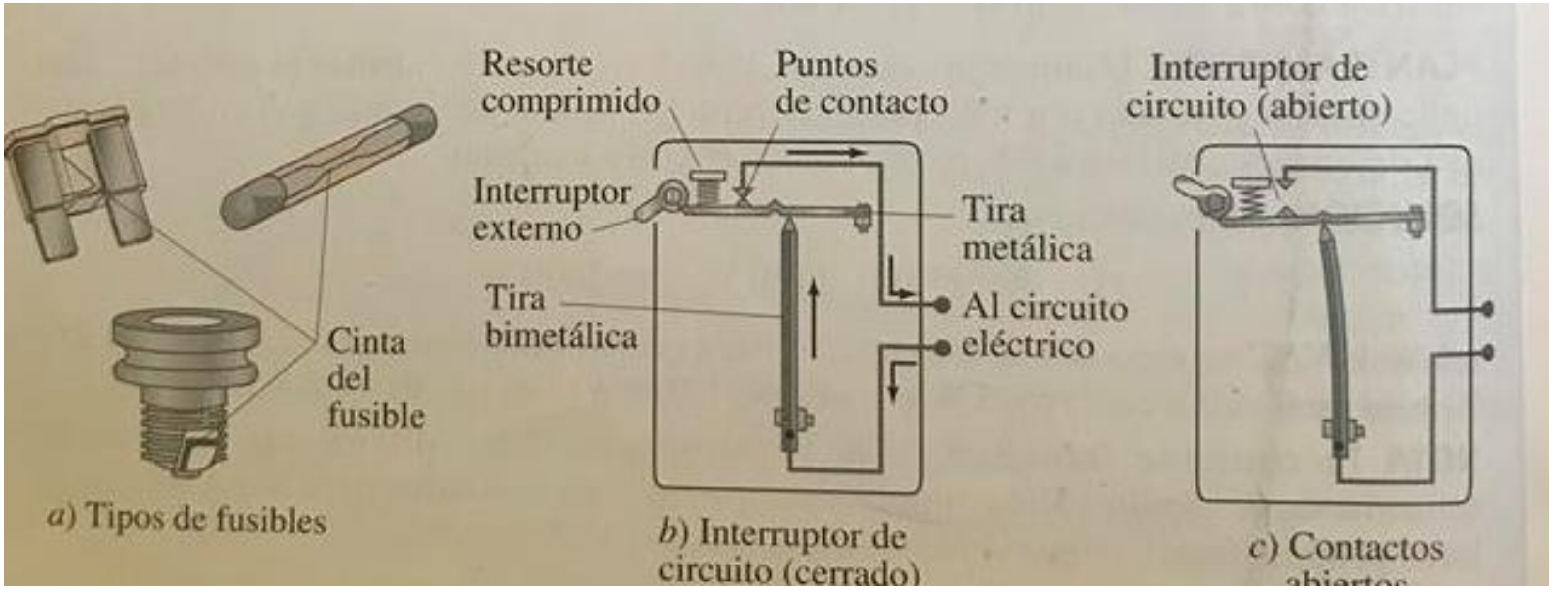
# Example 5

- A heater has to increase the temperature of 1.5 kg of water from $10°C$ to $50°C$ in 10.0 min, while it works at 110V. What is the required resistance of the heater?



- Specific
- Heat of
- Water $4186\frac{J}{kg°C}$

# Fuses and electrical switches




# Example 6

Each device connected to the same voltage 120$V$.

Calculate the electrical current taken from all the devices . If a fuse is designed for maximum 20 A , Should the fuse burn and would there be current interruption ?

Light bulb 100W

Heater 1800W

Stereo 350W

Hair dryer1200W

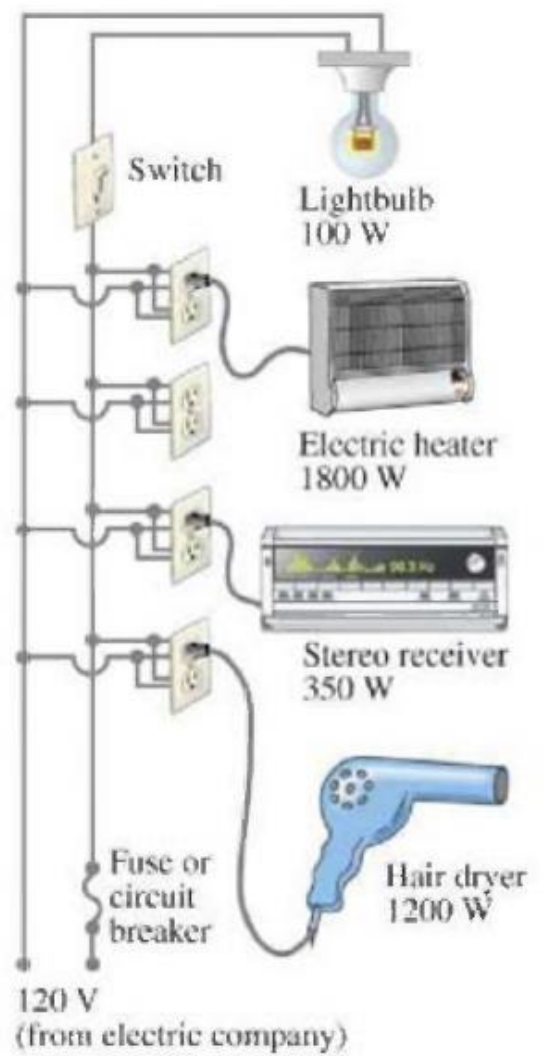
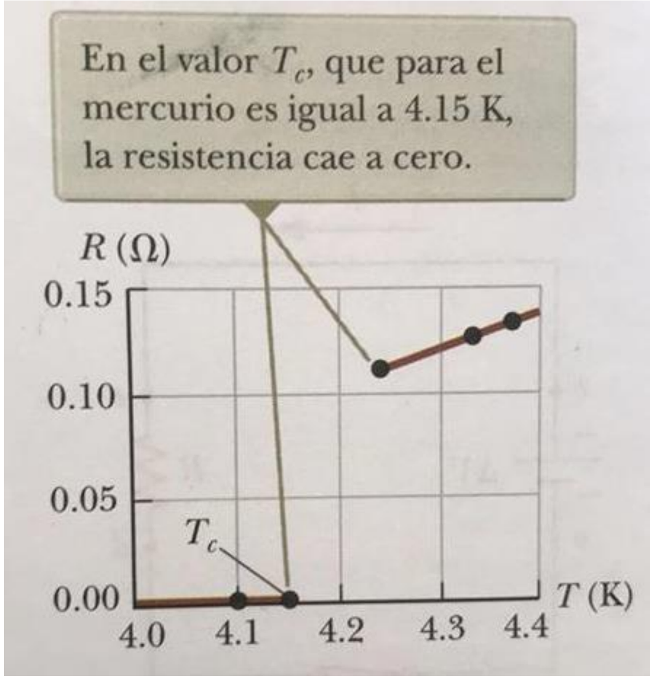
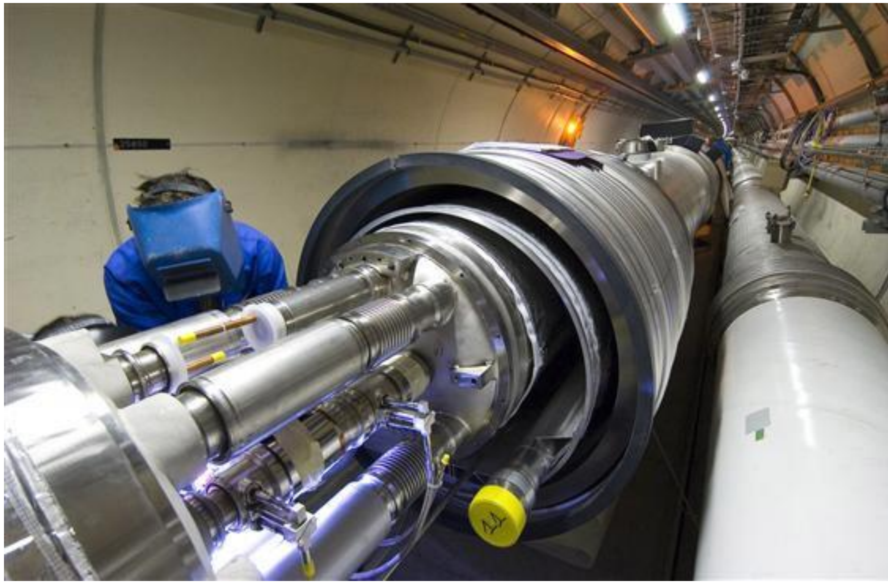



**FIGURE 25–20** Connection of household appliances.

# Superconductors

- Certain materials reduce their resistance when they drastically reduce their temperature
- ¡Mercury at $\approx 4°K \approx -269.15°C$, reduces its electrical resistance to zero.



- Actual research consists in trying to find/ design materials such thay they can become superconductors without the necessity of reducing so drastically the temperatura.

# Homework

- 1,3,5,9,11,15,17,19,21,27,29,31,37,39,43,47
- Chapter 27 Physics for Sciences and Engineering Serway