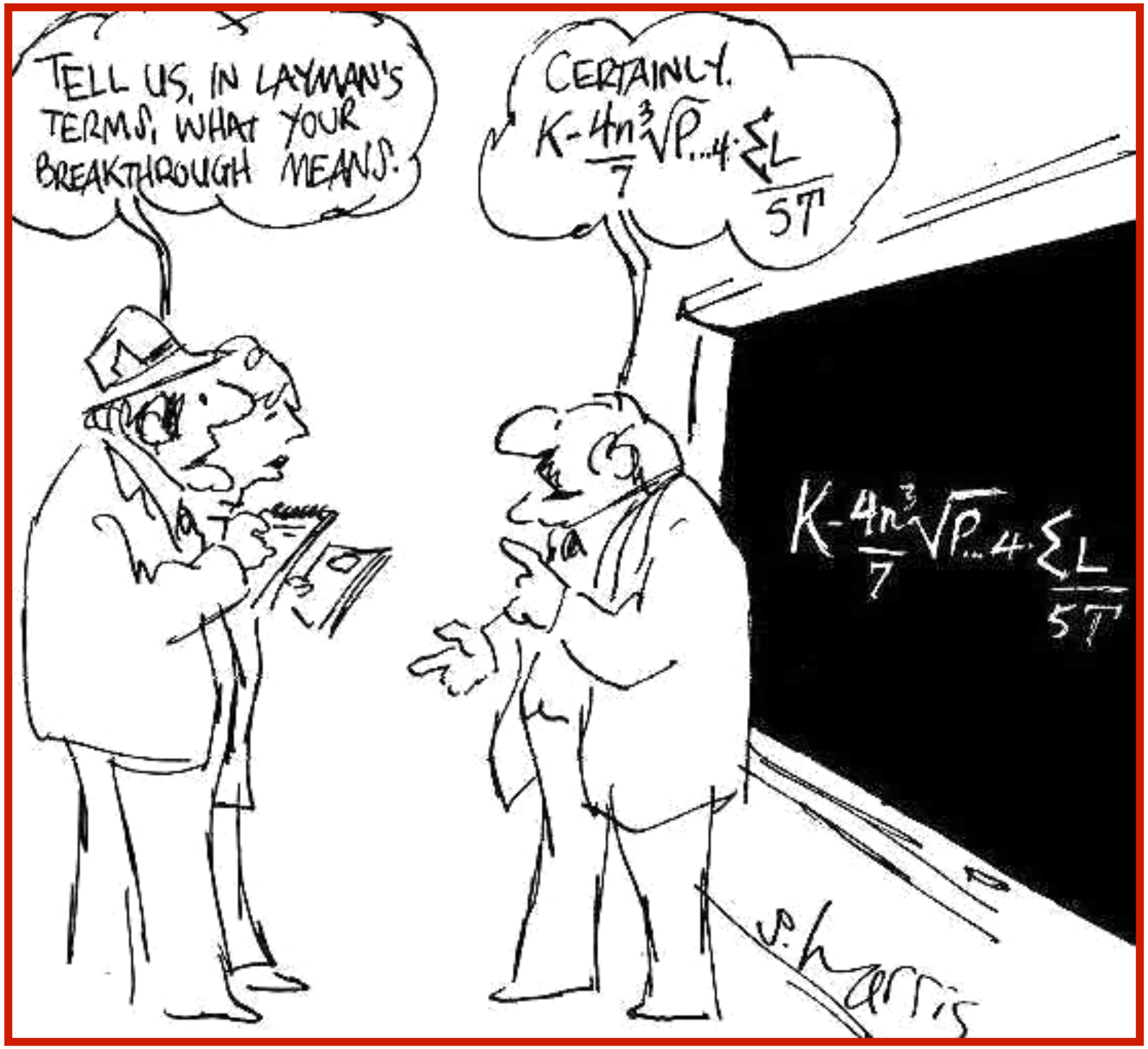
Ohm’s *“Law”*: Resistance & Resistors



- ***Experimentally,*** it is ***often*** (***but not always!***) found that **the current I** in a wire is proportional to the **potential difference V** between its ends:

$$I \propto V.$$

The ratio of voltage to current is called the

***Resistance* R**

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

$$V = IR.$$

- In many conductors, the resistance is independent of the voltage; this relationship is called

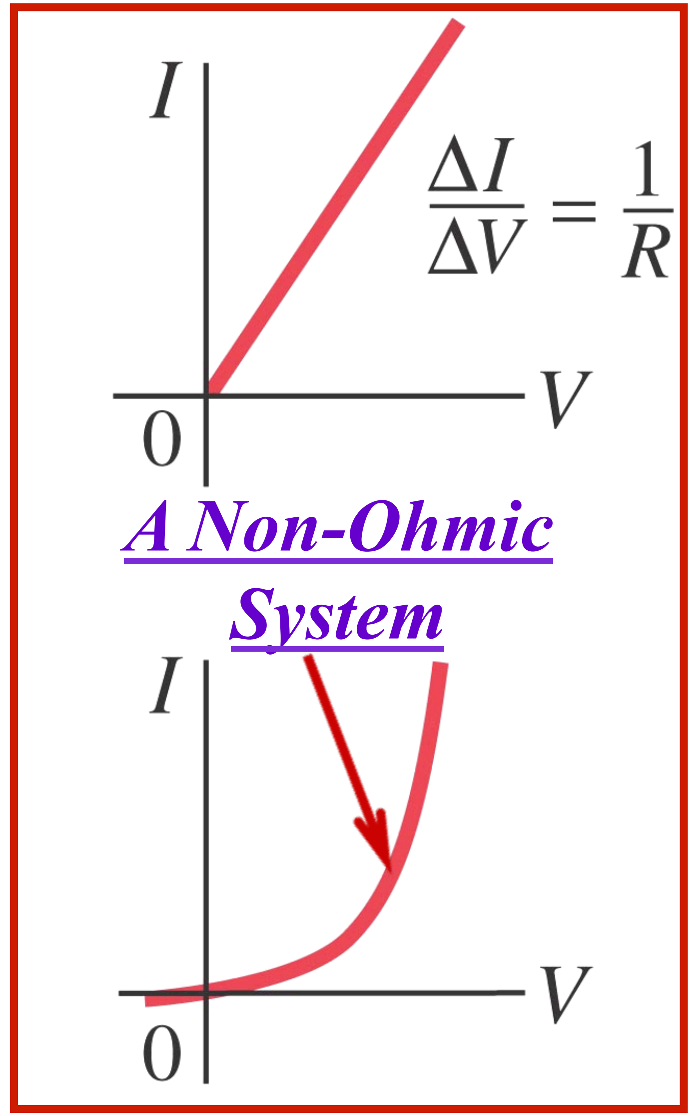
Ohm's "Law".

- **Note:** This ***isn't really a "Law"***, but a relationship that only holds sometimes! Materials that do not follow Ohm's Law are called

Non-Ohmic Materials

SI Unit of Resistance:

The Ohm, Ω: 1 Ω ≡ 1 V/A.



Georg Simon Ohm

Georg Simon Ohm: March 16, 1787 - July 7,1854

•German physicist, high school teacher. Research on Volta’s electrochemical cell. Found current flowing through a wire is proportional to cross sectional area & inversely proportional to its length. Using this, he was able to define the relation between voltage, current, & resistance. These relationships are of such importance, that ***they represent the beginning of electrical circuit analysis***. When he published his finding in 1827, his ideas were dismissed by his colleagues. He was forced to resign from his high school teaching position & he lived in poverty & shame until he accepted a position at Nüremberg in 1833.

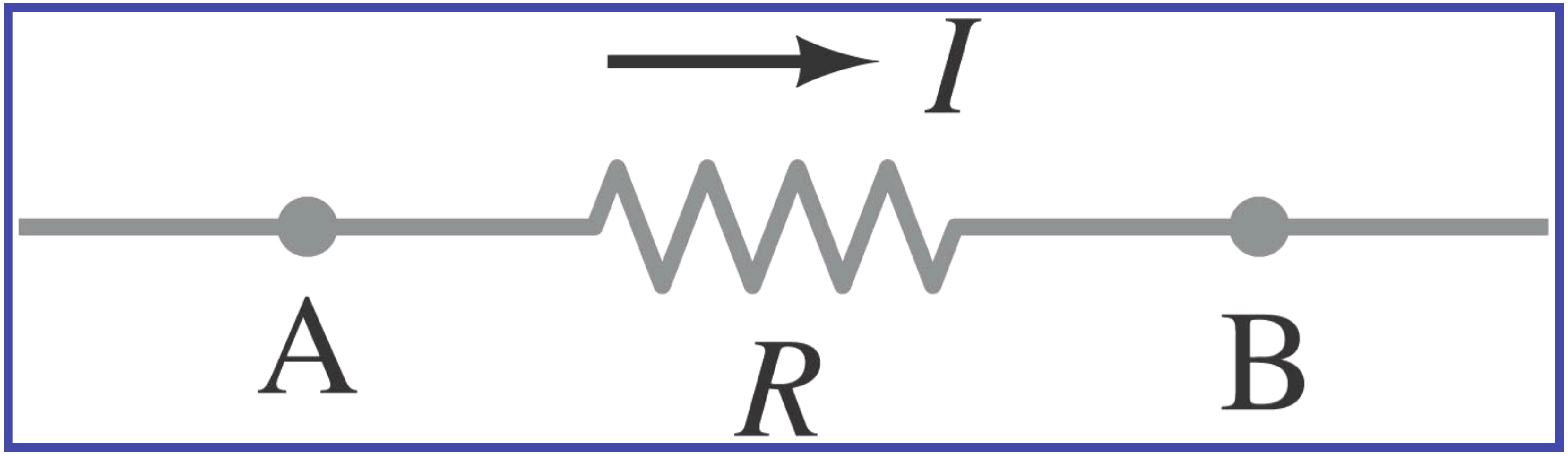
Conceptual Example

Current and Potential.

A current **I** enters a resistor **R** as shown.

(a) Is the potential higher at point **A** or at point **B**?

(b) Is the current greater at point **A** or at point **B**?



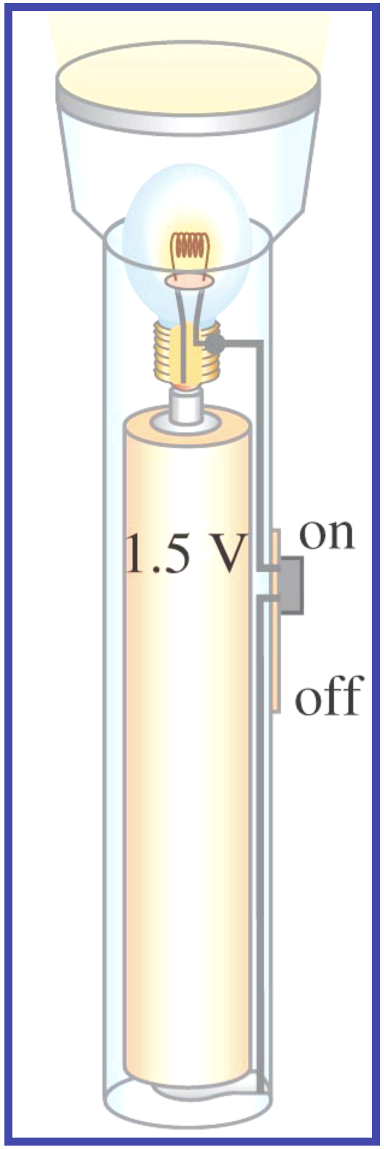
Example

Flashlight Bulb Resistance.

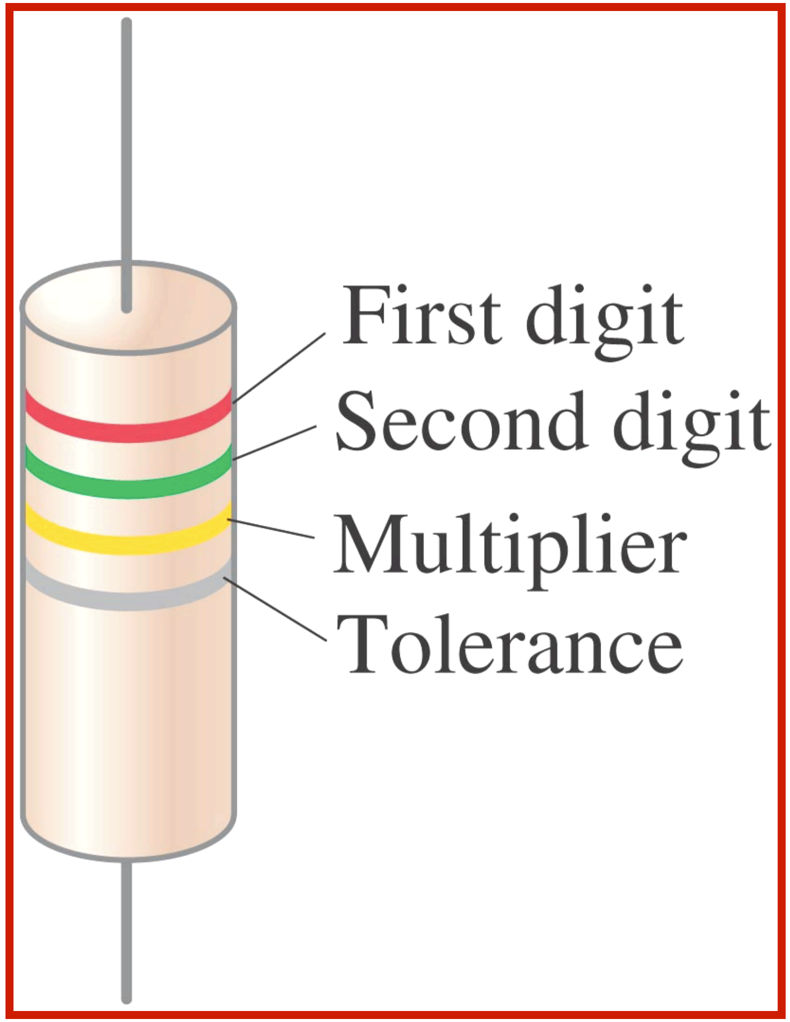
A small flashlight bulb draws a current of **I = 300 mA** from its battery, which supplies **V = 1.5 V**.

(a) Calculate the resistance **R** of the bulb.

(b) Suppose that the battery becomes weak so the voltage drops to **1.2 V**, Calculate the current now.



Standard resistors are manufactured for use in electric circuits; they are color-coded to indicate their value and precision.



This is the ***standard resistor color code***. Note that the colors from red to violet are in the order they appear in a rainbow.

Resistor Color Code

Color	Number	Multiplier	Tolerance
Black	0	1	
Brown	1	10^1	1%
Red	2	10^2	2%
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5%
Silver		10^{-2}	10%
No color			20%

Some Clarifications

- Batteries maintain a (nearly) constant potential difference; the current varies.
- Resistance is a property of a material or device.
- Current is ***not a vector*** but it does have a direction.
- Current and charge do not get used up.
- Whatever charge goes in one end of a circuit comes out the other end.

Resistivity

- The **resistance** of a wire is proportional to its length and inversely proportional to its cross-sectional area:

$$R = \rho \frac{\ell}{A}.$$

- **ρ** is called ***The Resistivity***, & is characteristic of the material.

This table gives the **resistivity** and **temperature coefficients** of typical conductors, semiconductors, and insulators.

TABLE 25–1 Resistivity and Temperature Coefficients (at 20°C)

Material	Resistivity, ρ ($\Omega \cdot m$)	Temperature Coefficient, α $(C°)^{-1}$
Conductors		
Silver	1.59×10^{-8}	0.0061
Copper	1.68×10^{-8}	0.0068
Gold	2.44×10^{-8}	0.0034
Aluminum	2.65×10^{-8}	0.00429
Tungsten	5.60×10^{-8}	0.0045
Iron	9.71×10^{-8}	0.00651
Platinum	10.60×10^{-8}	0.003927
Mercury	98.00×10^{-8}	0.0009
Nichrome (Ni, Fe, Cr alloy)	100.00×10^{-8}	0.0004
Semiconductors†		
Carbon (graphite)	$(3-60) \times 10^{-5}$	-0.0005
Germanium	$(1-500) \times 10^{-3}$	-0.05
Silicon	$0.1-60$	-0.07
Insulators		
Glass	$10^{9}-10^{12}$	
Hard rubber	$10^{13}-10^{15}$	

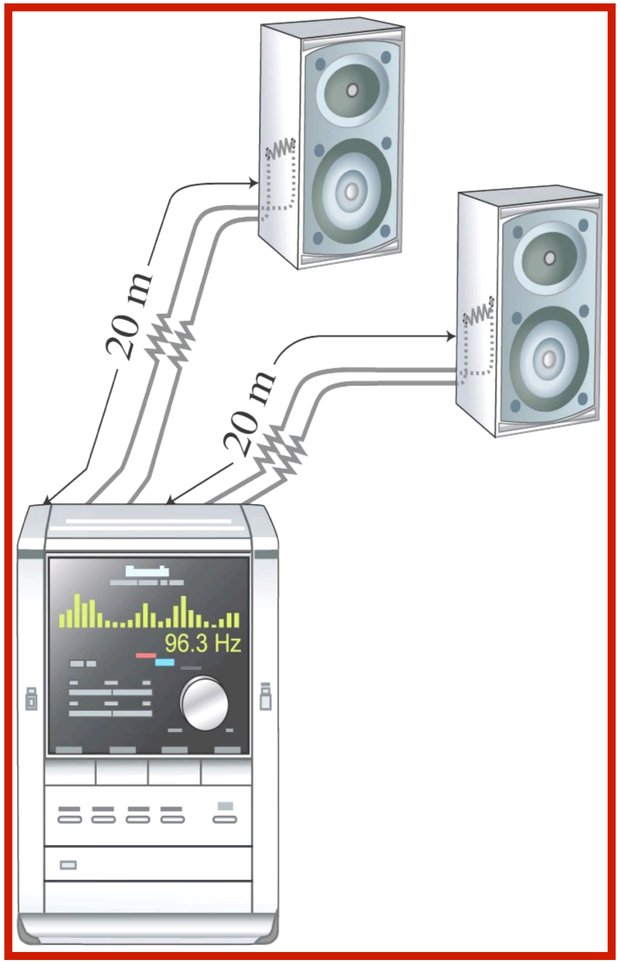
† Values depend strongly on the presence of even slight amounts of impurities.

Example: Speaker Wires

Suppose that you want to connect your stereo to remote speakers.

(a) If each wire must be **ℓ = 20 m** long, calculate the diameter of copper wire should you use to keep the resistance **R** less than **$R = 0.10\ \Omega$** per wire.

(b) If the current to each speaker is **$I = 4.0$ A**, calculate the potential difference, or voltage drop **V** across each wire.

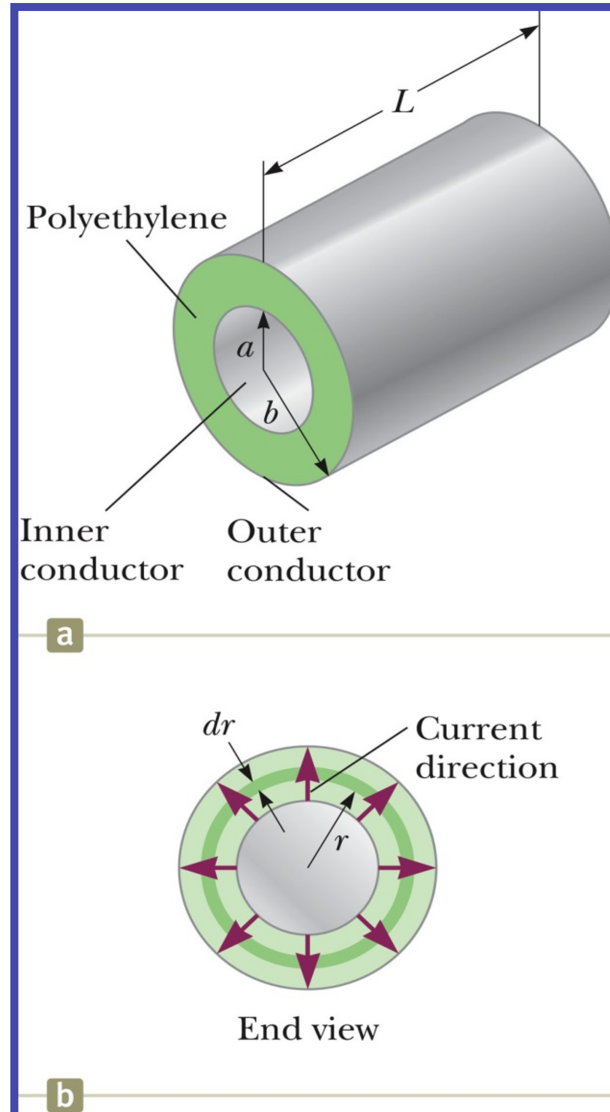


Resistance of a Cable, Example

Coaxial Cable

Assume the plastic between the conductors to be concentric elements of thickness **dr.** The resistance of the hollow cylinder of plastic is obtained by starting with:

$$dR = \frac{\tilde{n}}{2\partial rL} dr$$



- Total resistance across the entire thickness is:

$$R = \int_a^b dR = \frac{\tilde{n}}{2\partial L}\, ln\left(\frac{b}{a}\right)$$

- This is the radial resistance of the cable. The calculated value is fairly high, which is desirable since you want the current to flow along the cable and not radially out of it!!

Conceptual Example

Stretching changes resistance.

Suppose a wire of resistance **R** could be stretched uniformly until it was twice its original length. What would happen to its resistance?

For a given material, the resistivity **ρ** ***increases with temperature:***

$$\rho_T = \rho_0[1 + \alpha(T - T_0)]$$

Using the relationship between resistance **R** & resistivity **ρ:**

$$R = \rho \frac{\ell}{A}.$$

The temperature dependence of **R** becomes:

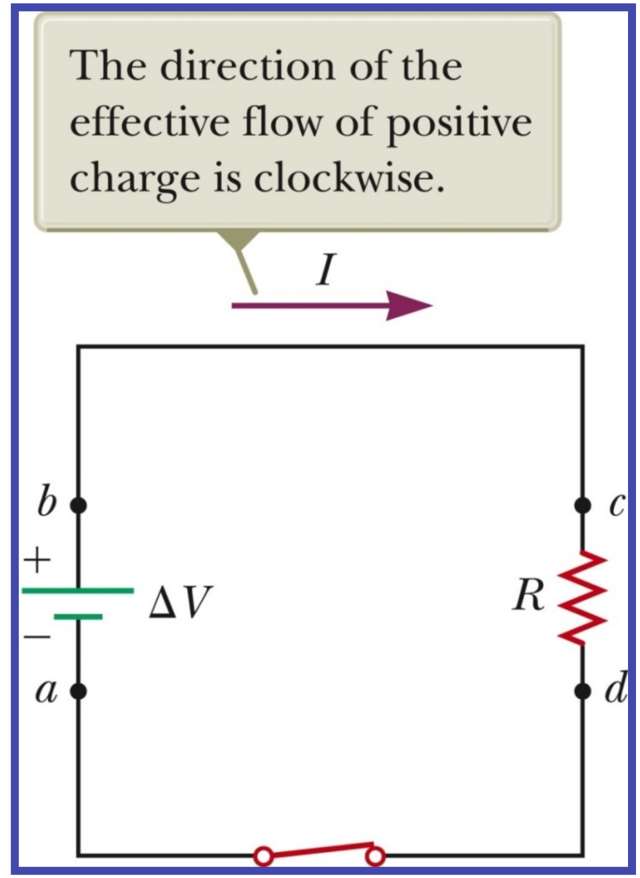
$$\mathbf{R_T = R_0[1 + \alpha(T - T_0)]}$$

Example: Resistance Thermometer.

- The variation in electrical resistance with temperature can be used to make precise temperature measurements.
- **Platinum** is commonly used, since it is relatively free from corrosive effects & has a high melting point.
- At $\mathbf{T_0 = 20.0°C}$, the resistance of a platinum resistance thermometer is $\mathbf{R_0 = 164.2\ \Omega}$.
- When placed in a particular solution, the resistance is $\mathbf{R = 187.4\ \Omega}$. Calculate the temperature of this solution.

Electrical Power

- Assume a circuit as shown. As a charge moves from **a** to **b**, the electric potential energy of the system increases by **QdV.**
  - The chemical energy in the battery must decrease by this same amount.
- This electric potential energy is transformed into internal energy in the resistor.
  - This corresponds to increased vibrational motion of the atoms in the resistor



- The resistor is normally in contact with the air, so its increased temperature will result in a transfer of energy by heat into the air.
- The resistor also emits thermal radiation. After some time interval, the resistor reaches a constant temperature.
  - The input of energy from the battery is balanced by the output of energy by heat and radiation.
- The rate at which the system's potential energy decreases as the charge passes through the resistor is equal to the rate at which the system gains internal\ energy in the resistor. The **power** is the rate at which the energy is delivered to the resistor.

- **Power**, as in kinematics, is the ***energy transformed by a device per unit time***:
- For a current carrying circuit, **potential energy is:**

$$\mathbf{U = qV}$$

So the power it transforms is

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

$$P = IV.$$

- So, the power is given by **P = IV.** Applying **Ohm's "Law",** alternative expressions can be found:

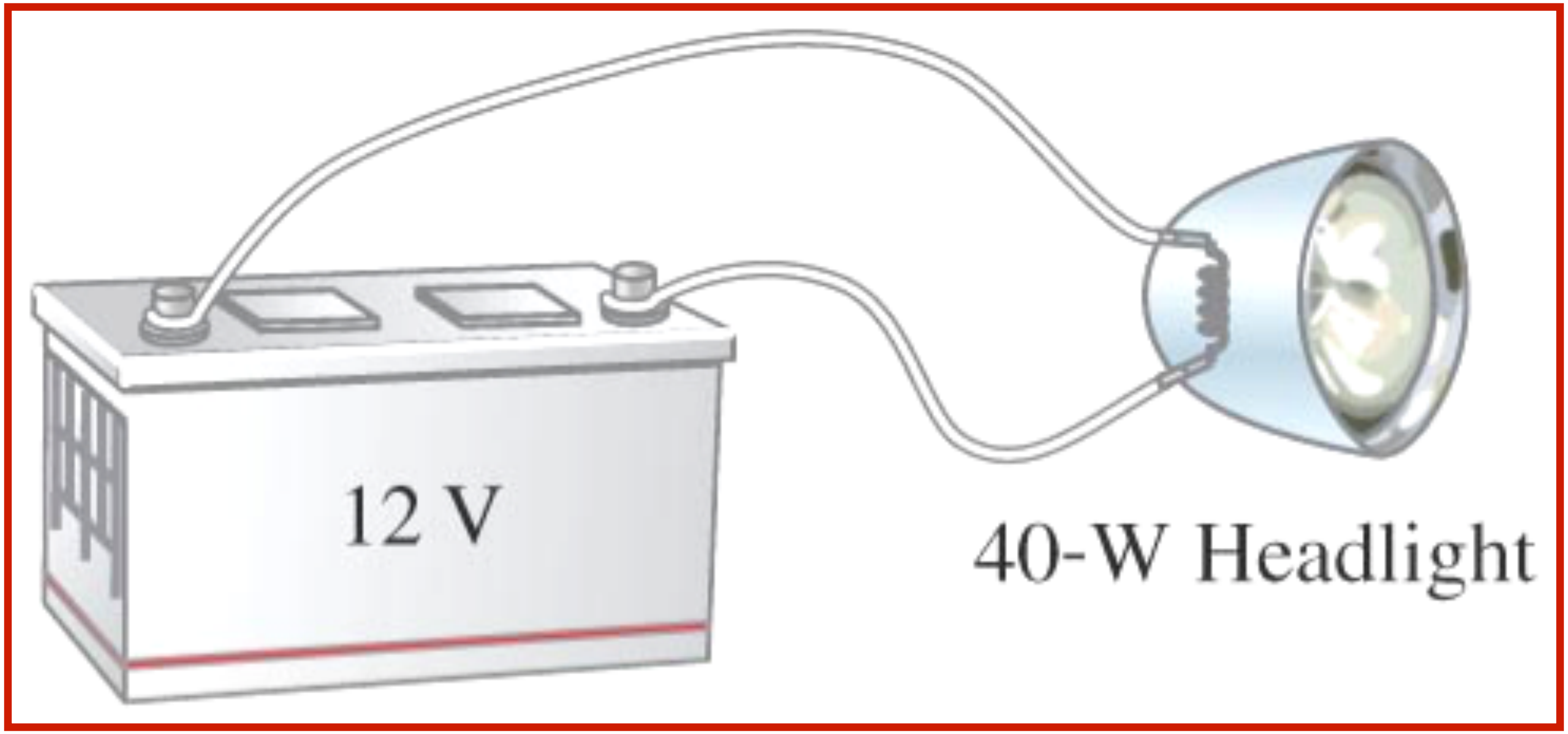
$$P = IV = I(IR) = I^2 R$$

$$P = IV = \left(\frac{V}{R}\right)V = \frac{V^2}{R}.$$

The ***SI unit of power*** is **the watt, W**.

Example: Headlights.

Calculate the resistance **R** of a **P = 40 W** automobile headlight designed for **V = 12 V**.



A side note!

What you pay for on your electric bill is ***not power***, but ***energy*** – the power consumption multiplied by the time. We have been measuring energy in **Joules**, but the electric company measures it in kilowatt-hours, **kWh**:

$$\mathbf{1\ kWh = (1000\ W)(3600\ s)}$$

$$\mathbf{= 3.60 \times 10^{6}\ J.}$$

Example:

Electric heater.

An electric heater draws a steady current **I = 15.0 A** on a **V = 120-V** line. How much power does it require and how much does it cost per month (30 days) if it operates **3.0 h** per day and the electric company charges **9.2 cents per kWh?**

Example: Lightning Bolt

- Lightning is a spectacular example of electric current in a natural phenomenon. There is much variability to lightning bolts, but a typical event can transfer

10^9 J of energy across a potential difference of perhaps

$V = 5 \times 10^7$ V during a time interval of about **0.2 s**.

Use this information to estimate

(a) the total amount of charge transferred between cloud and ground,

(b) the current in the lightning bolt,

(c) the average power delivered over the **0.2 s.**

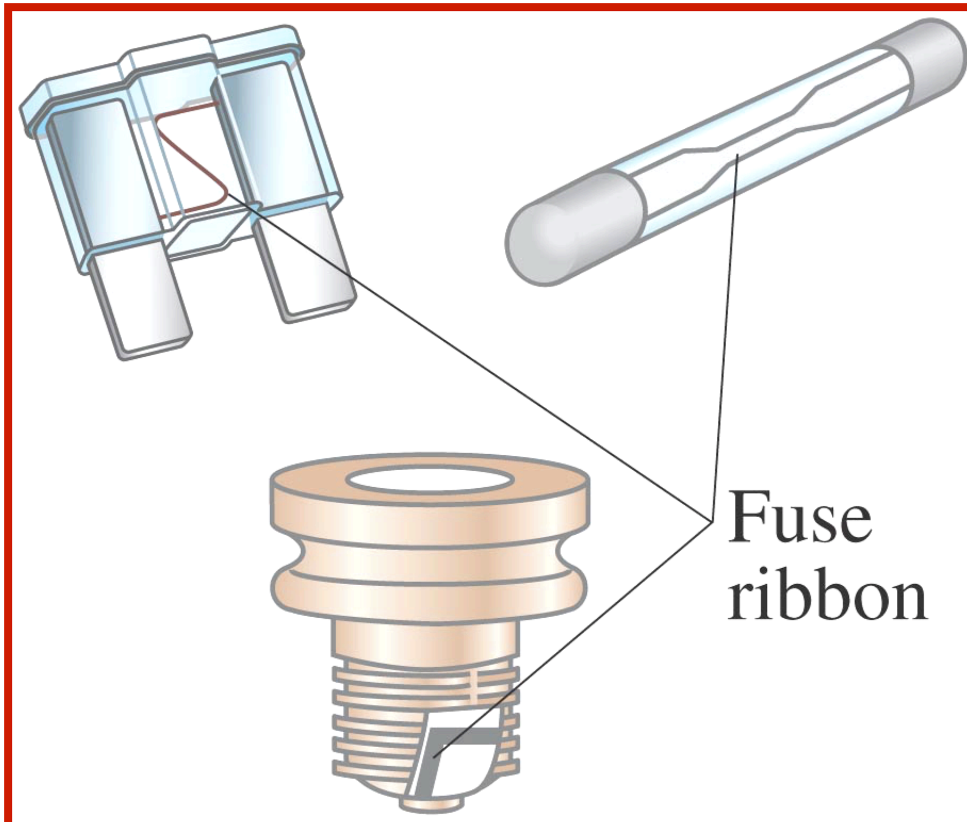
Power in Household Circuits

The wires used in homes to carry electricity have very low resistance.

However, if the current is high enough, the power will increase and the wires can become hot enough to start a fire.

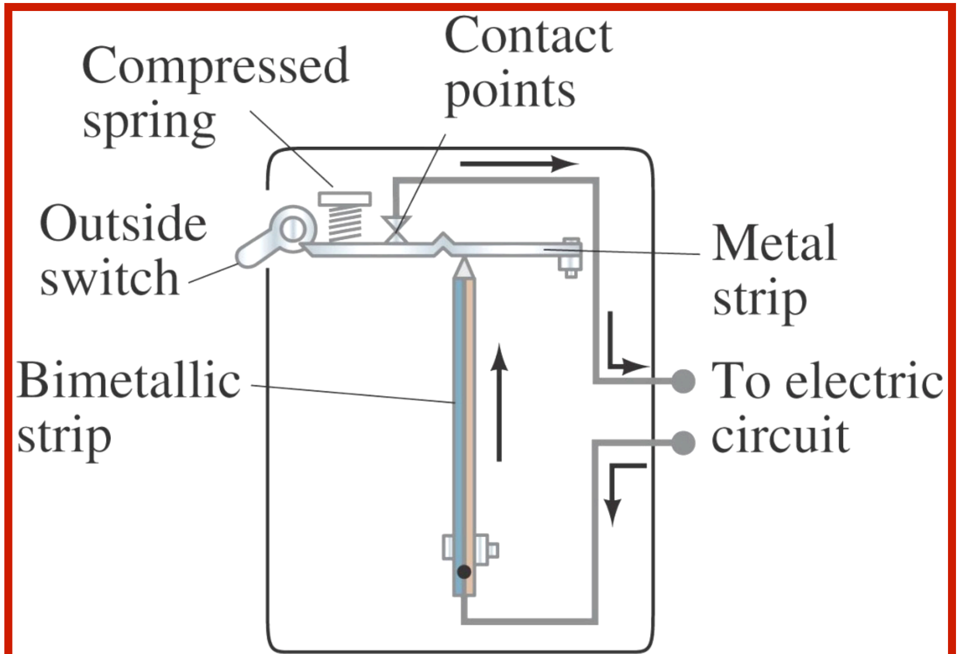
To avoid this, we use fuses or circuit breakers, which disconnect when the current goes above a predetermined value.

Fuses are one-use items – if they blow, the fuse is destroyed and must be replaced.

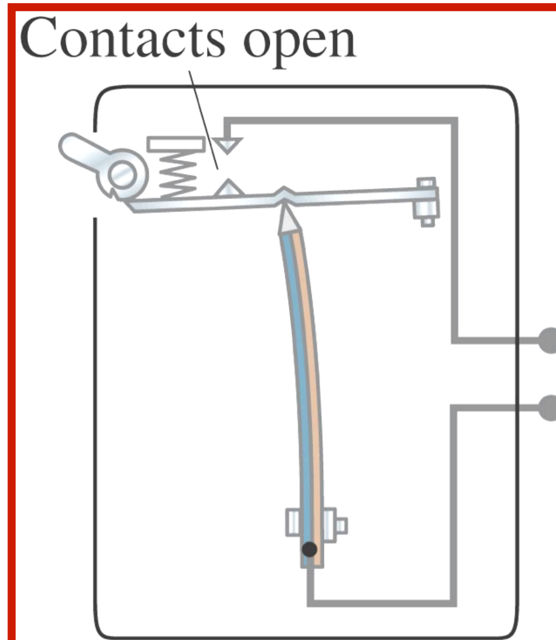


(a) Types of fuses

Circuit breakers, which are now much more common in homes than they once were, are switches that will open if the current is too high; they can then be reset.



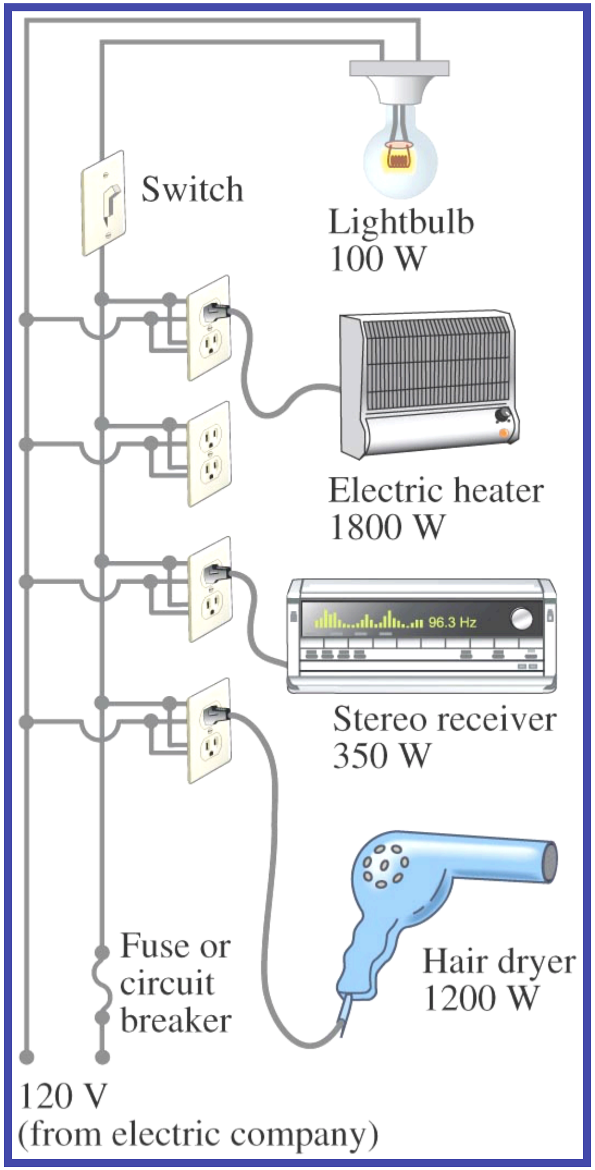
(b) Circuit breaker (closed)



(c) Circuit breaker (open)

Example:
Will a fuse blow?

Calculate the total current drawn by all the devices in the circuit shown.



Conceptual Example:

A dangerous extension cord.

Your **1800-W** portable electric heater is too far from your desk to warm your feet. Its cord is too short, so you plug it into an extension cord rated at **11 A**. Why is this dangerous?