coffee cup brooch

# Electric Currents, Resistivity, Ohm's Law

An applied potential difference (voltage) in a conductor creates an electric field.

When current flows in conductor, electrons flow but the ions are "frozen" and don't move

Electrons feel electric field then electrons try to make E-field zero but don't succeed bc of potential diff applied across conductor

## Ohm's Law Example:

Consider conductor, say copper (Cu), at room temp (300 K), the free electrons in Cu move at $10^6$ m/sec. The time between collisions is about $\tau = 3\times10^{-19}$ sec. The number of free electrons per cubic meter is $n = 10^{29}/m^3$

If we apply a potential difference across conductor then electrons experience force:

$$F = qE$$

and they accelerate as

$$a = \frac{F}{m_e}$$

and they pick up speed on collisions called drift velocity

$$v_d = a\tau$$

So we can solve for drift velocity

$$V_d = \frac{qE}{m_e}\tau$$

Now consider 10m copper wire and we apply potential difference of 10V. The drift velocity of free electrons is.

We know $E = \frac{\Delta V}{d} = \frac{10V}{m} = 1\frac{V}{m}$

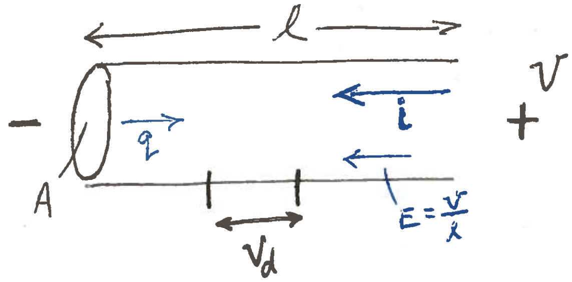
then $V_d = \frac{1.6\times10^{-9}c \times 1\frac{V}{m}}{10^{-30}kg} 3\times10^{-14}s$

$\approx 5\times10^{-3} m/s$

$= \frac{1}{2}$ centi-meter/sec

The free electrons move at a million m/s but due to electric field the electrons only travel at .5 cm/s along the wire. Takes 30 min to travel 10m!

## Ohm's Law (for conductors)




We want to measure the # electrons through cross-section per second:

$$I = V_d A \cdot n \cdot q$$

I: current; $V_d A$: volume; n: # electrons per $m^3$; q: charge

$$I = \frac{q^2 n \tau}{m_e} AE$$

$\frac{q^2 n \tau}{m_e}$: Conductivity (property of conductor) $[\sigma]$

If we continue to simplify our expression for current we see

$$I = \sigma A \frac{V}{l}$$

And we can solve for the potential difference

$$V = \underbrace{\frac{l}{\sigma A}}_{\text{Resistivity } [R]} I$$

$$R = \frac{l}{\sigma A} = \frac{l\rho}{A}$$

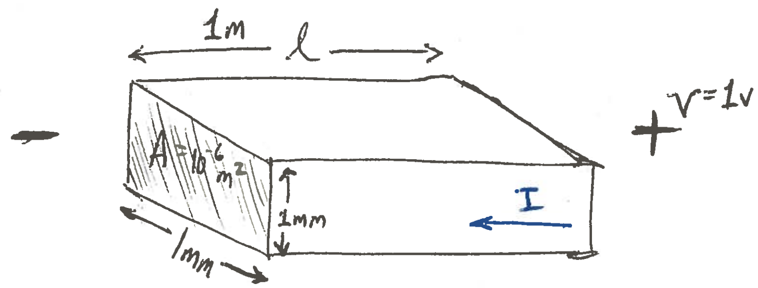
$$[R] = [\Omega]$$

And we get Ohm's Law: $V = IR$

Resistance $\left(R = \frac{l}{\sigma A}\right)$ is directly proportional to length and inversely proportional to area!

As temp increases, so does resistance!

# Conductors vs Insulators




Apply potential difference across chunk of material. A current flows.

1. Say good conductor... $\sigma \approx 10^8 \longrightarrow \rho = 10^{-8}$

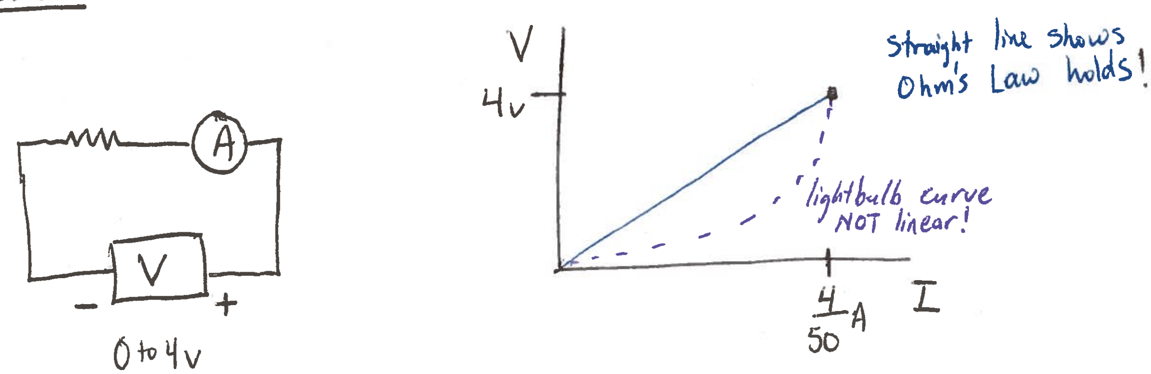
$$R = \frac{\ell}{\sigma A} = \frac{1\,m}{10^8 \cdot 10^{-6}} = \underline{10^{-2}\,\Omega} \qquad I = \frac{V}{R} = \underline{100\,A}$$

2. Say good insulator $\sigma \approx 10^{-12}$ to $10^{-16}$

$$R = \frac{\ell}{\sigma A} = \frac{1\,m}{10^{-14}\,10^{-6}} = \underline{10^{20}\,\Omega} \qquad I = \frac{V}{R} = \underline{10^{-20}\,A}$$

Huge difference between condutor and insulator!

## DEMO:




If we swap resistor w/ lightbulb where $R_{cold} = 7\Omega$, $R_{hot} = 50\Omega$ the resistance is not linear! It is a function of temperature.

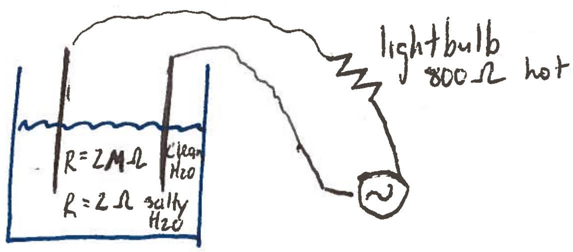
Conductivity increases w/ # of charge carriers (electrons)

**DEMO** Increase Ions by heat

Charge electroscope. Electrons cannot go out into air, they stay. When we heat the surrounding air (w/ candle) we ionize the air and the electrons / ions allow charge to dissipate.

**Demo** Increase ions by salt

Conductivity of water is low $\approx 2 \times 10^5 \, \Omega m$ but the conductivity of salt water is high!




- Cannot see light when water is clean, resistance is too high!
- but can see light when salt introduced bc resistance is low!