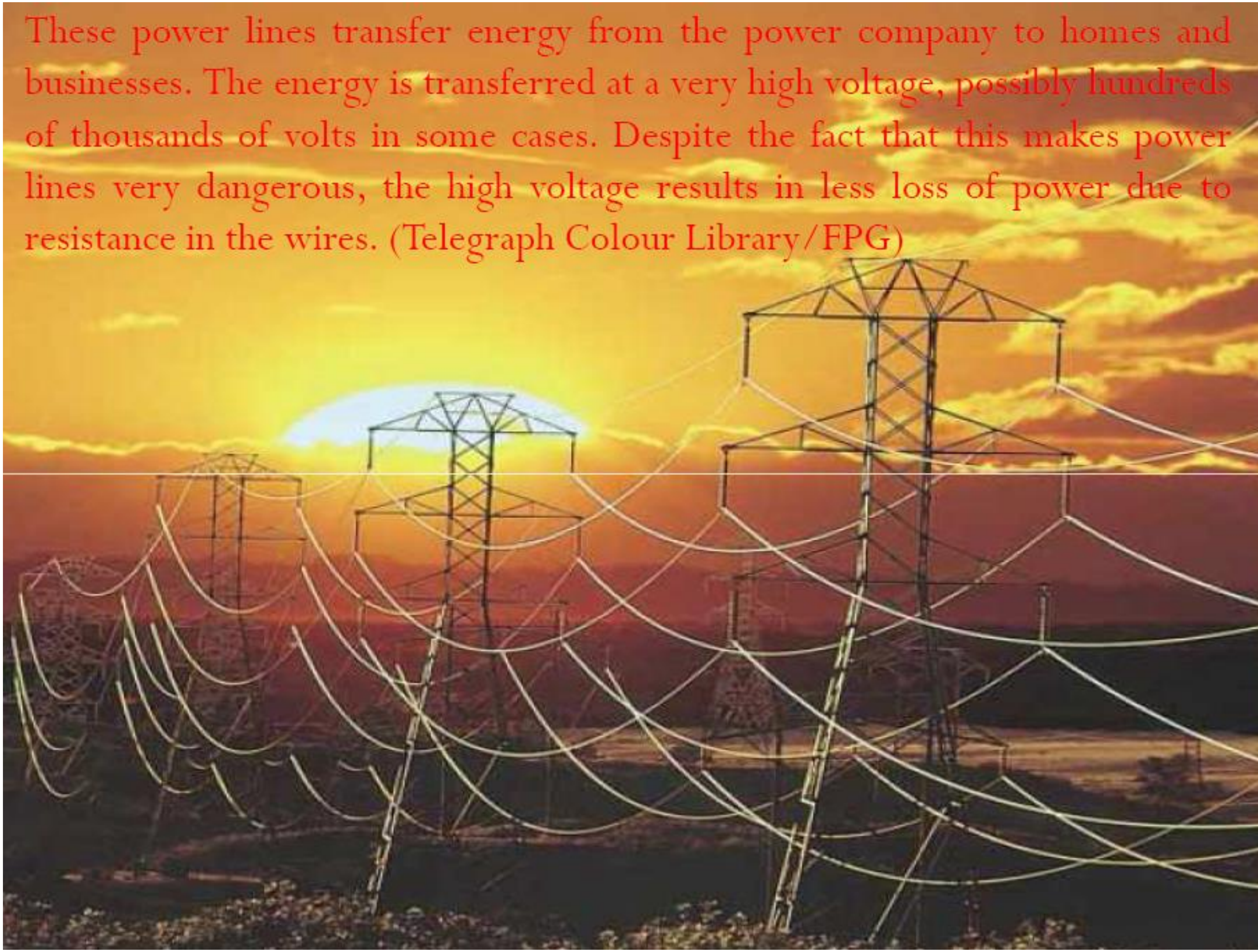
Electric Current-II

Dr. M. Imran Malik

School of Electrical Engineering & Computer Science
National University of Sciences & Technology (NUST), Pakistan

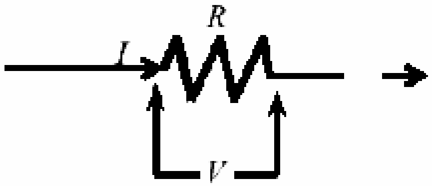


These power lines transfer energy from the power company to homes and businesses. The energy is transferred at a very high voltage, possibly hundreds of thousands of volts in some cases. Despite the fact that this makes power lines very dangerous, the high voltage results in less loss of power due to resistance in the wires. (Telegraph Colour Library/FPG)

Resistance and Resistivity

- As electrons move under the effect of applies electric field in the conductor, they collide with each other, with ions and with the walls of conductor. These collisions opposes the electric current.
- Measurement in the opposition of current is called resistance.
- Resistance depends on geometry of the conductor.
- Resistance is directly proportional to the length of conductor.
- Resistance is inversely proportional to the cross sectional area of conductor.

$$R \propto L \qquad R \propto 1/A$$



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

SI unit of resistance is *ohm* (Ω)

ρ is constant of proportionality and is called resistivity of material. It depends on material but does not on the geometry of material

Two conductors are made of the same material and have the same length. Conductor A is the solid wire of diameter D. Conductor B is the hollow tube of outside diameter 2D and inside diameter D. Find the resistance ratio, RA/RB, measured between their ends.

If the length of each conductor is L and has resistivity ρ, then

$$R_A = \rho\frac{L}{A} = \rho\frac{L}{\pi D^2/4} = \rho\frac{4L}{\pi D^2}$$

$$R_B = \rho\frac{L}{A} = \rho\frac{L}{(\pi 4D^2/4 - \pi D^2/4)} = \rho\frac{4L}{\pi 3D^2}$$

$$R_A / R_B = 3$$

A wire with a resistance of 6Ω is drawn out through a die so that its new length is three times its original length. Find the resistance of the longer wire, assuming that the resistivity and density of the material are not changed during the drawing process.

Originally we have a resistance R1 made out of a wire of length $l1$ and cross sectional area A1. The volume of this wire is $V1 = A1l1$. When the wire is drawn out to the new length we have $l2 = 3l1$ and area A2, but the volume of the wire should be constant so

$$A_2 l_2 = A_1 l_1$$

$$A_2 3 l_1 = A_1 l_1$$

$$A_2 = A_1 / 3$$

The original resistance is

$$R_1 = \rho \frac{l_1}{A_1}$$

The new resistance will be

$$R_2 = \rho \frac{l_2}{A_2} = \rho \frac{3l_1}{A_1/3} = 9\rho \frac{l_1}{A_1} = 9R_1$$

$$R_1 = 6\Omega \qquad \Rightarrow \qquad R_2 = 9R_1 = 54\Omega$$

Ohm' Law: Microscopic

Between collision with the lattice ions, the electrons in the conductor are accelerated by the electric field, and so their drift velocity is proportional to the applies electric field;

$$\vec{v}_d \propto \vec{E} \qquad (1)$$

Moreover, we have seen that the current density J is proportional to the drift velocity of electrons;

$$\vec{J} \propto \vec{v}_d \qquad (2)$$

From (1) and (2) $\vec{J} \propto \vec{E}$

$$\boxed{\vec{J} = \sigma\vec{E}} \qquad \boxed{\vec{J} = \frac{1}{\rho}\vec{E}}$$

Here, proportionality constants are;

$$\sigma = Conductivity \qquad \rho = \text{Re}\,sistivity$$

$$\sigma = 1/\rho$$

$$\rho = \frac{E}{J} \quad \Rightarrow \quad \frac{V/m}{A/m^2} = \frac{V}{A} m = \Omega\ m \quad \text{(ohm-meter)}$$

Note: You should not be confused with *ohmmeter*, which is an instrument that measures resistance

$$\sigma = \frac{J}{E} \quad \Rightarrow \quad \frac{A/m^2}{V/m} = \frac{A}{V}\frac{1}{m} = \Omega^{-1} m^{-1} \quad \text{(siemens/meter)}$$

Resistivity (conductivity) of any material can be determined by applying electric field E and measuring the resultant current density J i.e.,

$$\boxed{\vec{E} = \frac{1}{\sigma}\vec{J}} \qquad \boxed{\vec{E} = \rho\vec{J}}$$

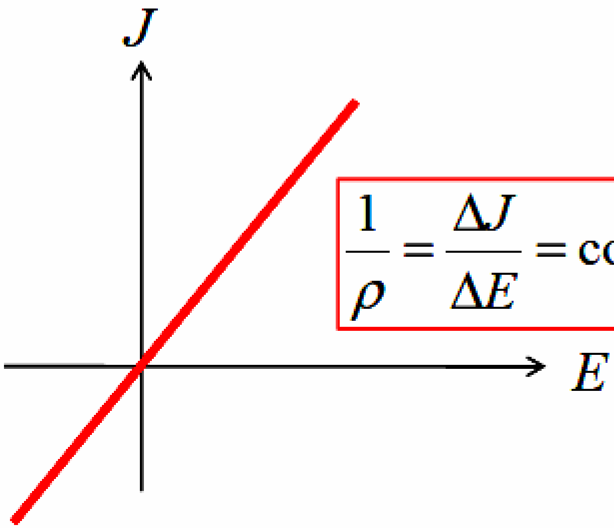
- For some materials, resistivity (or conductivity) is not a constant but depends on the strength of the electric field. (Non Ohmic)
- For the other materials, resistivity (or conductivity) is constant and does not depend on the strength of the electric field for a wide range of electric field. For such materials, a plot of E against J gives a straight line, whose slop is reciprocal of resistivity ρ. (Ohmic)

Ohm's Law: The resistivity (or conductivity) of a material is independent of the magnitude and direction of the applied electric field. A plot of E against J gives a straight line, whose slope is reciprocal of resistivity ρ.

Ohm’ Law: Microscopic

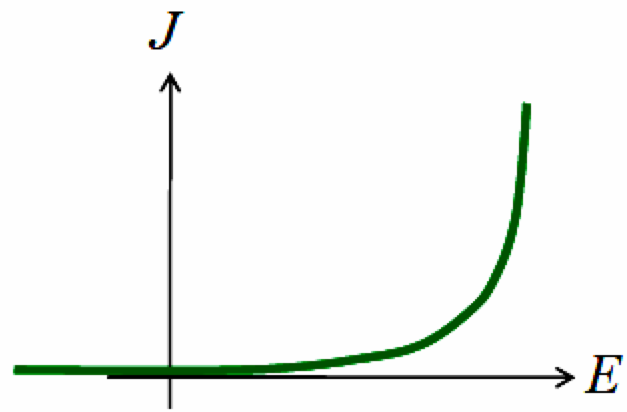
$$\boxed{E = \rho J; \quad \rho \text{ is constant}}$$

Ohmic



$$\boxed{\frac{1}{\rho} = \frac{\Delta J}{\Delta E} = \text{constant}}$$

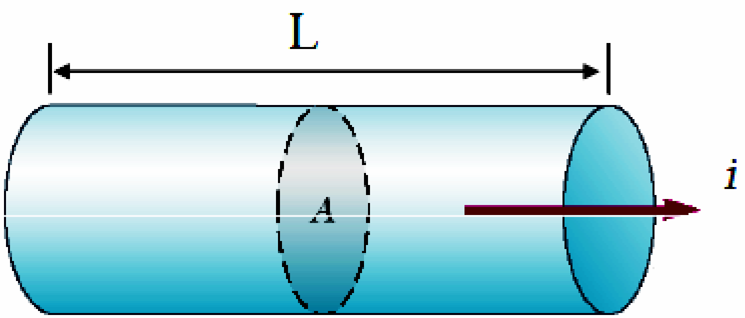
Non Ohmic



Note: $E=\rho J$ is not the statement of Ohm’s law. Its just a mathematical expression relating field, current density and resistivity and is valid for both ohmic and non-ohmic materials.

Ohm' Law: Macroscopic

As we have discuss before, resistance is the property of an object while resistivity is a property of a materials.



Let's apply potential difference ΔV across the ends a conductor having cross-sectional area A and length L. If current density is J then

$$\rho = \frac{E}{J} = \frac{\Delta V / L}{i / A} \qquad \therefore \Delta V = EL \;\&\; J = i/A$$

$$\rho = \frac{\Delta V}{i}\frac{A}{L}$$

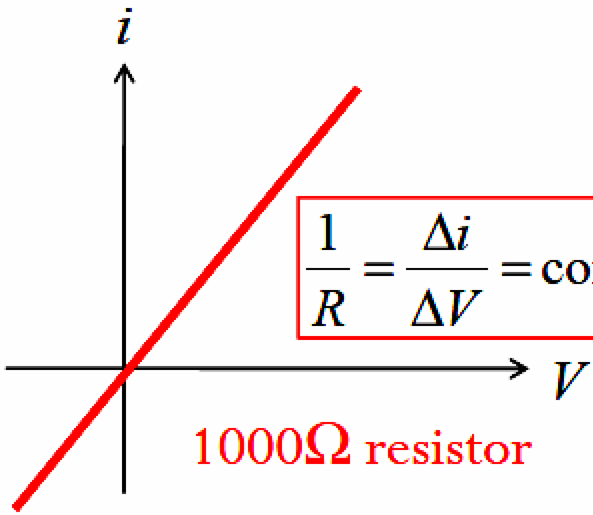
$$\frac{\Delta V}{i} = \rho\frac{L}{A}$$

$$\Delta V = Ri \qquad \therefore R = \rho\frac{L}{A}$$

Ohm's Law: The resistance of an object is independent of the magnitude or polarity of the applied potential difference. A plot of V against i gives a straight line, whose slope is reciprocal of resistance R.

$$\boxed{\Delta V = Ri; \quad \text{R is constant}}$$

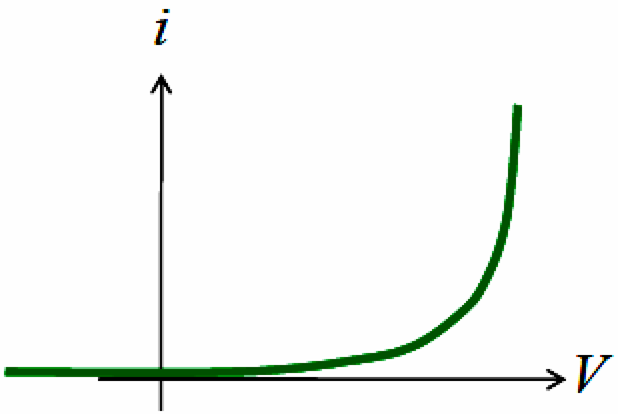
Ohmic



$$\boxed{\frac{1}{R} = \frac{\Delta i}{\Delta V} = \text{constant}}$$

1000Ω resistor

Non Ohmic



pn junction diode

Note: ΔV=iR is not the statement of Ohm’s law. Its just a mathematical expression relating potential, current and resistance and is valid for both ohmic and non-ohmic materials.

Power Dissipation

When a resistance R is connected across a DC/AC source of potential V and as a result current I passes through it, then power dissipated can be expressed in different ways as

$$\boxed{P = VI}$$

$$\boxed{P = V^2 / R}$$

$$\boxed{P = I^2 R}$$

Combinations of Resistors

When resistors R1, R2, R3,…. are connected across a DC source of potential V in series (same current through each) then net resistance will be

$$\boxed{R = R_1 + R_2 + R_3 + \ldots\ldots.}$$

When resistors R1, R2, R3,…. are connected across a DC source of potential V in parallel (same potential across each) then net resistance will be

$$\boxed{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots.}$$

Electric Shock

The damaging effects of shock are the result of current passing through the body.

From Ohm's law, current depends on the voltage *and* on electrical resistance.

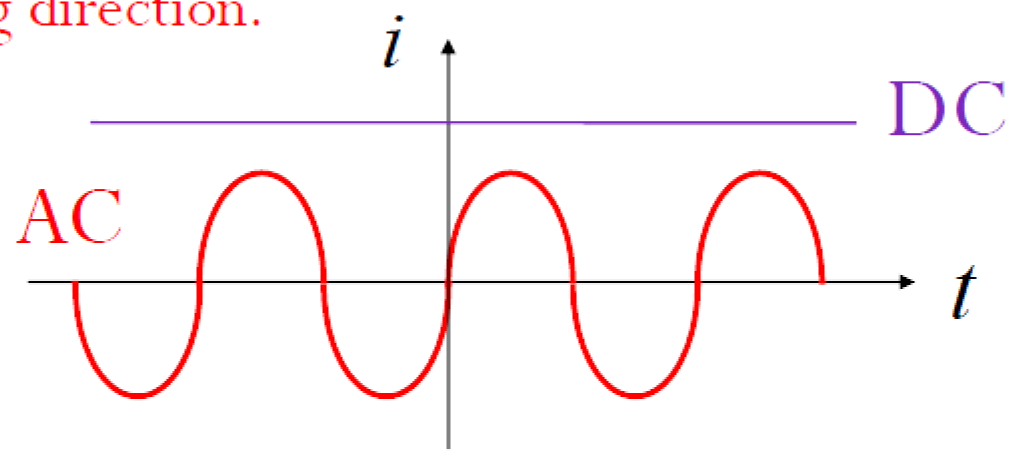
When dry, skin's resistance around 100,000 Ω. Resistance drops as low as 100 Ω when wet and salty.

Effects of Electric Shock on Human Body	
Current (A)	Effect
0.001	Can be felt
0.005	Is painful
0.010	Causes involuntary muscle contractions (spasms)
0.015	Causes loss of muscle control
0.070	If through the heart, serious disruption; probably fatal if current lasts for more than 1 s

Direct & Alternating Current

Direct current (DC) is current that flows in only one direction.

Alternating current (AC) is current that flows back and forth with alternating direction.

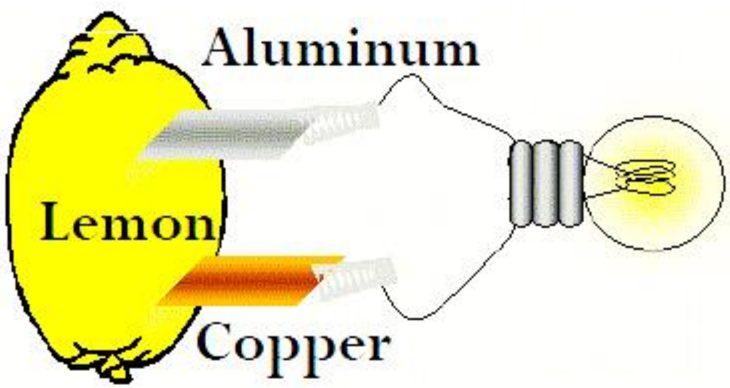


Easy to produce small DC currents using batteries, which also have low voltages.

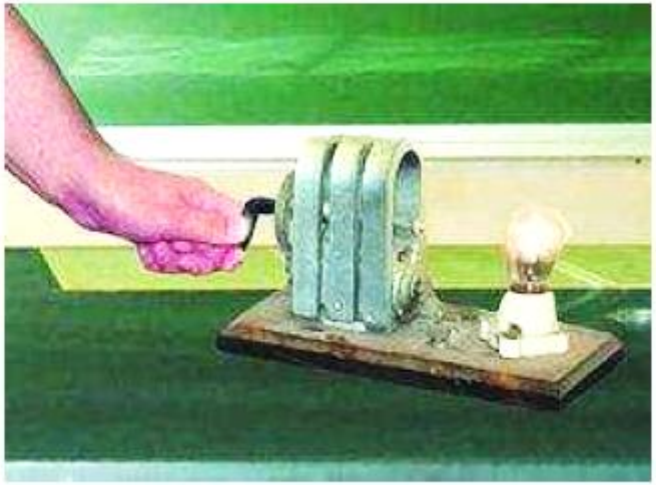
For major power lines, less ohmic heating if high voltage AC current is used instead of DC.

Voltage Source

Charges flow only when they are "pushed" or "driven." A sustained current requires a suitable pumping device to provide a difference in electric potential—a voltage.



Simple Chemical Battery



Simple Mechanical Generator