Physics 122: Electricity & Magnetism – Lecture 12 Current & Resistance

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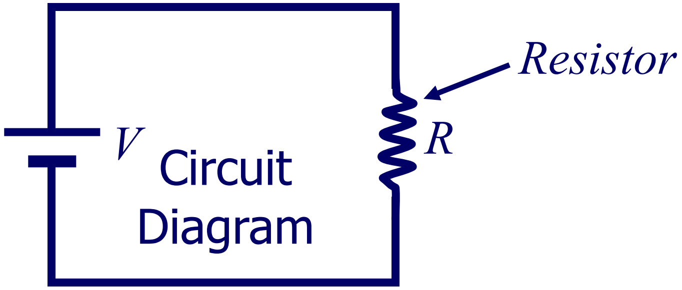
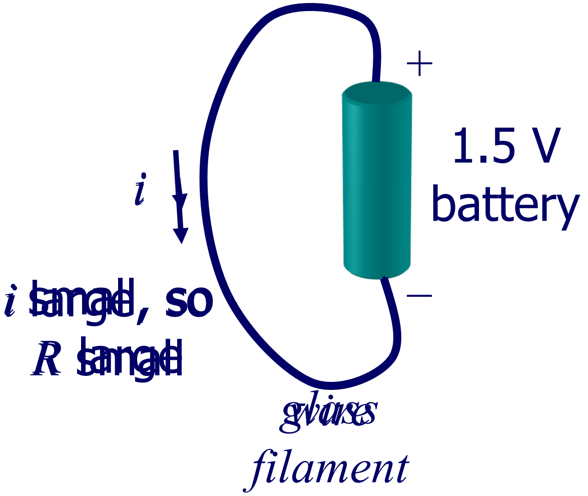
Resistance

- Resistance is defined to be $R = \dfrac{V}{i}$. That is, we apply a voltage V, and ask how much current i results. This is called Ohm's Law.
- If we apply the voltage to a conducting wire, the current will be very large so R is small.
- If we apply the voltage to a less conducting material, such as glass, the current will be tiny so R is very large.
- The unit of resistance is the ohm, Ω. (Greek letter omega.)

1 ohm = 1 Ω = 1 volt per ampere = 1 V/A





Resistivity and Conductivity

- Rather than consider the overall resistance of an object, we can discuss the property of a material to resist the flow of electric current.
- This is called the *resistivity*. The text uses (re-uses) the symbol ρ for resistivity. Note that this IS NOT related to the charge density, which we discussed earlier.
- The resistivity is related not to potential difference V and current i, but to electric field E and current density J.

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

Definition of resistivity

Units V/m over A/m^2 = Vm/A = ohm-meter = Ωm

(a)

(b)

- Note that the ability for current to flow in a material depends not only on the material, but on the electrical connection to it.

Note use (re-use) of σ for conductivity. NOT surface charge density.

$$\sigma = \frac{1}{\rho}$$

Definition of conductivity

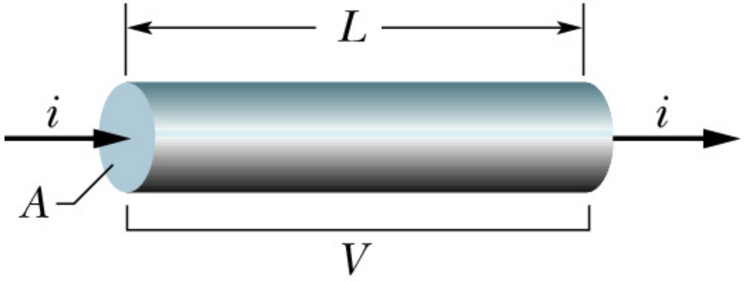
More on Resistivity

- Since resistivity has units of ohm-meter, you might think that you can just divide by the length of a material to find its resistance in ohms.

$$\xcancel{R = \rho / L ?}$$

since $E = V / L$ and $J = i / A$

resistivity is $\rho = \dfrac{E}{J} = \dfrac{V / L}{i / A} = RA / L$



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

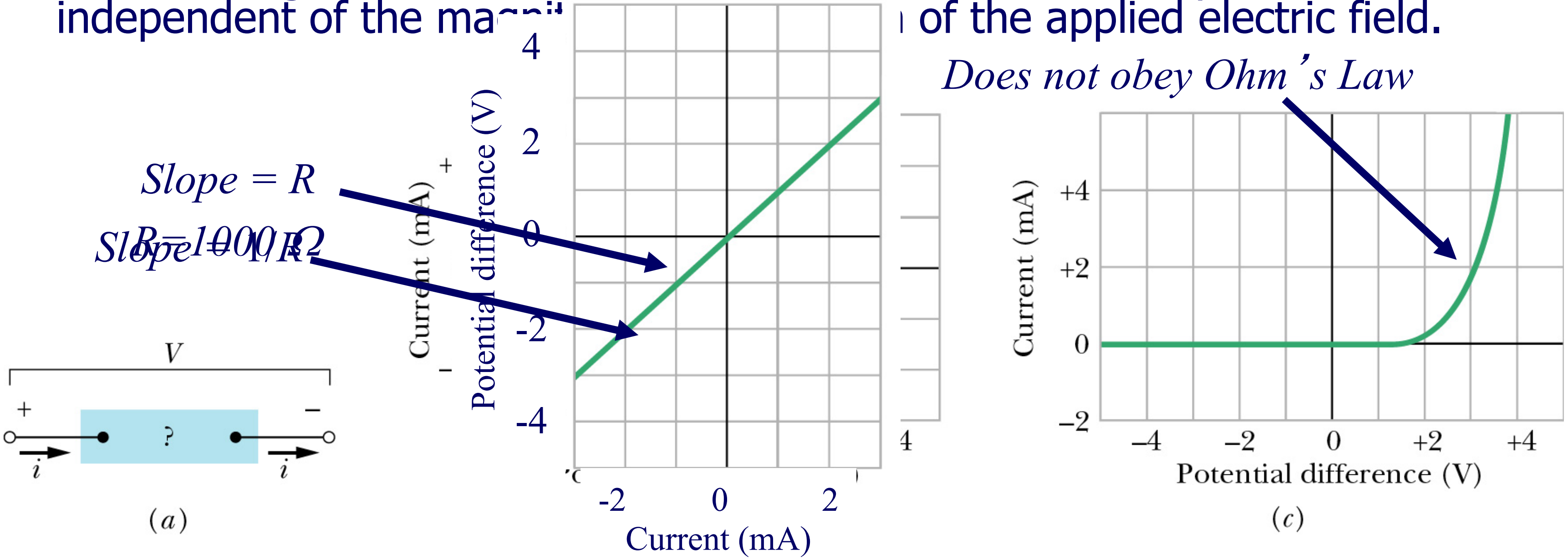
Resistance from resistivity

- Dependence on temperature: you can imagine that a higher temperature of a material causes greater thermal agitation, and impedes the orderly flow of electricity. We consider a temperature coefficient α: $\rho - \rho_0 = \rho_0 \alpha (T - T_0)$

Ohm's Law

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

- Ohm's law is an assertion that the current through a device is always directly proportional to the potential difference applied to the device.
- A conducting device obeys Ohm's law when the resistance of the device is independent of the magnitude and polarity of the applied potential difference.
- A conducting material obeys Ohm's law when the resistivity of the material is independent of the ma of the applied electric field.



Slope = R

Slope = 1/R

R=1000 Ω

Does not obey Ohm's Law

Electric Power

- Recall that power is energy per unit time, $P = \frac{dU}{dt}$ (watts). Recall also that for an arrangement of charge, dq, there is an associated potential energy $dU = dqV$.
- Thus, $P = \frac{dq}{dt}V = iV$

Rate of electrical energy transfer

Units: $1\ \mathrm{VA} = (1\ \mathrm{J/C})(1\ \mathrm{C/s}) = 1\ \mathrm{J/s} = 1\ \mathrm{W}$

- In a resistor that obeys Ohm's Law, we can use the relation between R and i, or R and V, to obtain two equivalent expressions:

$$P = i^2R$$

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

Resistive dissipation

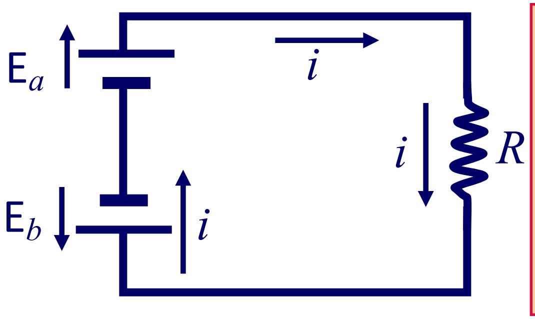
- In this case, the power is dissipated as heat in the resistor.

Superconductivity

- In normal materials, there is always some resistance, even if low, to current flow. This seems to make sense—start current flowing in a loop (using a battery, say), and if you remove the battery the current will eventually slow and stop.
- Remarkably, at very low temperatures (~4 K) some conductors lose all resistance. Such materials are said to be *superconductors*. In such a material, once you start current flowing, it will continue to flow "forever," like some sort of perpetual motion machine.
- Nowadays, "high-temperature" superconductors have been discovered that work at up to 150 K, which is high enough to be interesting for technological applications such as giant magnets that take no power, perhaps for levitating trains and so on.

How Do Batteries Work?

- A battery is a source of charge, but also a source of voltage (potential difference).
- We earlier saw that there is a relationship between energy, charge, and voltage $U = qV$.
- Thus, a battery is a source of energy. We describe a battery's ability to create a charge flow (a current) as an *electromotive force*, or emf.
- We need a symbol for emf, and we will use an E, but it needs to be distinguishable from electric field, so we will use a script $\mathcal{E}$.
- The unit of emf is just the volt (V).
- Other sources of emf are, for example, an electric generator, solar cells, fuel cells, etc.



Here is a case where two emf sources are connected in opposing directions. The direction of i indicates that $\mathcal{E}_a > \mathcal{E}_b$. In fact, emf a charges emf b.

Summary

- Current, i, is flow of charge (charge per unit time), units, amperes (A).
- Net current into or out of a junction is zero.
- Current density, J, (current per unit area) is a vector. $\boxed{i = \int \vec{J} \cdot d\vec{A}}$
- J is proportional to the density of charge carriers, ne, and the drift speed of the carriers through the material. $\boxed{\vec{J} = ne\vec{v}_d}$
- Resistance, R, (units, ohms, Ω) is the proportionality between voltage V applied, and current, i. $\boxed{R = \frac{V}{i}}$
- Ohm’s Law states that R is a constant. It is not always a constant, but if not, the device does not obey Ohm’s Law.
- Resistivity (ρ) and conductivity (σ) are properties of materials. Resistivity units, ohm-meter. $\boxed{\rho = \frac{E}{J}}$ $\boxed{\sigma = \frac{1}{\rho}}$
- Resistance is related to resistivity by $\boxed{R = \rho \frac{L}{A}}$
- Electric power P (units watts, W) is $\boxed{P = iV}$. For resistors: $\boxed{P = i^2 R}$ $\boxed{P = \frac{V^2}{R}}$