Chapter 25

- Current
- Resistivity as a property of materials
- Temperature dependence of resistivity
- Emf
- Power

Electrostatics versus Electric Current

- Notice that flow of positive charge in one direction,
  - Becomes more negative
  - Becomes more positive
- It’s completely equivalent to negative charge in the opposite direction.
  - Becomes more negative
  - Becomes more positive

Note: Current arrow is drawn in direction in which positive charge carriers would move, even if the actual charges are negative & move in the opposite direction.
Drift Velocity

Microscopic View of an Electron in Motion

Drift Speed, Total Charge & Current

Relationship between Current and Drift Speed

Find $v_d$ for 14-gauge copper wire carrying a current of 1 A. Assume there is 1 free electron/atom.

\[ n = n_{\text{atoms}} = \frac{\rho N}{M} \]

\[ v_d = \frac{I}{qnA} \]
Electric Current

one \( q \) in \( \rightarrow \) one \( q \) out

Resistance

Resistance is a property of the object, i.e., it depends on the shape and material.

Resistance & Ohm's Law

ohmic (a) \hspace{1cm} (b) Non-ohmic

Resistivity

Resistivity is a property of the material.
Resistivity & Temperature Coefficients

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity $\rho$ (Ωm)</th>
<th>Temp. coeff. $\alpha$ (K$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>$1.6 \times 10^{-8}$</td>
<td>$3.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>Cu</td>
<td>$1.7 \times 10^{-8}$</td>
<td>$3.9 \times 10^{-3}$</td>
</tr>
<tr>
<td>W</td>
<td>$5.5 \times 10^{-8}$</td>
<td>$4.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Si</td>
<td>640</td>
<td>$-7.5 \times 10^{-2}$</td>
</tr>
<tr>
<td>Si, n-type</td>
<td>$8.7 \times 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td>Si, p-type</td>
<td>$2.8 \times 10^{-3}$</td>
<td></td>
</tr>
<tr>
<td>glass</td>
<td>$10^{10}$ – $10^{14}$</td>
<td></td>
</tr>
</tbody>
</table>

See TM Table 25-1 for more.

Temperature Dependence of Resistances

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

\[
R = \rho \frac{L}{A} \quad \Rightarrow \quad R = R_o (1 + \alpha (T - T_o))
\]

Heated Tungsten Light Bulb filament at 3000 K: \(\alpha = 4.5 \times 10^{-3} / K\)

Temperature Dependence

\(\rho\) for copper (Cu) as a function of temperature

Notice: Resistivity increases as temperature increases.

This curve does not deviate greatly from a straight line.

DEMO: Temperature Dependence

Lower Cu initially at room temperature (~300ºK) into liquid N$_2$. 

liquid nitrogen \(~77ºK\)

vacuum bottle
DEMO: Temperature Dependence

Heat the Ge with a candle.

Temperature Stable Resistor

A temperature-stable resistor is to be made by connecting a resistor made of silicon in series with one made of nichrome. If the required total resistance is 1300 \( \Omega \) in a wide temperature range around 20ºC, what should be the resistances of the two resistors?

\[
R_{\text{total}} = R_N + R_{\text{Si}} = 1300 \Omega
\]

In general:

\[
R = R_N (1 + \alpha_N (T - T_o)) + R_{\text{Si}} (1 + \alpha_{\text{Si}} (T - T_o)) = 1300 \Omega
\]

\[
(R_{\text{Si}} R_N + R_{\text{Si}} \alpha_N (T - T_o)) + (R_{\text{Si}} \alpha_{\text{Si}} R_N) (T - T_o) = 0
\]

\[
(R_{\text{Si}} \alpha_N + R_{\text{Si}} \alpha_{\text{Si}}) (T - T_o) = 0
\]

\[
(1300 \Omega - R_{\text{Si}}) \alpha_N + R_{\text{Si}} \alpha_{\text{Si}} = 0
\]

Power in Electric Circuits

- Power associated with transfer: \( P=IV \)
- Power associated with dissipation of \( U \) into thermal energy in the resistor: \( P=I^2R = \frac{V^2}{R} \)

Units of Power:
- Volts Ampere=Joule/second=Watt

Take a 100 W light bulb powered by 110 Volts (RMS AC). What is the resistance of the (hot) filament? We know \( P \) and \( V \), don’t know \( I \) or \( R \), are asked for \( R \). So we choose the last form below, and solve for \( R \):

\[
R = \frac{V^2}{P} = \frac{110 \times 110}{100} = 121 \Omega
\]

Note that the cold filament will have ~13 times less resistance, and therefore there will be a big surge in current as the bulb is turned on. Often, used lightbulbs burn out at this instant.
Real Battery

In an ideal battery:
\[ r = 0 \]
\[ V_a - V_b = \varepsilon \]
\[ I = \frac{\varepsilon}{R + r} \]

Over the battery:
\[ V_a - V_b = \varepsilon - Ir \]

Note: \( \varepsilon \) arrows always points from negative to positive.

Examine potential as we start from point b and end at a:
\[ \varepsilon - Ir - IR = 0 \]
\[ I = \frac{\varepsilon}{R + r} \]

Effect of Internal Resistance

In an ideal battery:
\[ r = 0 \]
\[ V_a - V_b = \varepsilon \]
\[ I = \frac{\varepsilon}{R} \]

In a real battery:

Impedance Matching

\[ P \]

\[ 1 \ 2 \ 3 \ \frac{R}{r} \]