Chapter 25

• Current
• Resistivity as a property of materials
• Temperature dependence of resistivity
• Emf
• Power
Electrostatics versus Electric Current

No current

Diagram showing electrostatics versus electric current with negative charges moving in a conductor.
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.
Electric Current

- Notice that flow of positive charge in one direction,

- It’s completely equivalent to negative charge in the opposite direction.
Drift Velocity
Drift Speed, Total Charge & Current

\[ I = enAv_d \]

- \( n \) = number of charge carriers per unit volume
- \( q \) = charge of each particle
- \( v_d \) = drift velocity

2/12/2020
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.

$$n = n_{atoms} = \frac{\rho N}{M} \sim 10^{23} \text{ cm}^{-3}$$

$$v_d = \frac{I}{qnA} \sim 3 \times 10^{-5} \text{ m/s}$$
Microscopic View of an Electron in Motion

with $\vec{E}$
without $\vec{E}$
Electric Current

One $q$ in

One $q$ out
Resistance

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

\[ I = enAv_d = enAuE = \frac{enAu}{d}V \]
Resistance & Ohm’s Law

(a) ohmic

(b) Non-ohmic
Resistivity

Resistivity is a property of the material.
QUIZ lecture 10

Two cylindrical resistors are made from the same material and are equal in diameter. The first resistor has a length $L$, and the second resistor has a length $2L$. If the same current flows through both, compare the voltage across the two resistors.

(A) $V_1 < V_2$
(B) $V_1 = V_2$
(C) $V_1 > V_2$
Two cylindrical resistors are made from the same material and are equal in length. The first resistor has a diameter $d$, and the second resistor has a diameter $2d$. If the same current flows through both, compare the voltage across the two resistors.

(A) $V_1 < V_2$

(B) $V_1 = V_2$

(C) $V_1 > V_2$
QUIZ lecture 10

The figure shows three cylindrical copper conductors along with their face areas and lengths. Rank then according to the current through them, greatest first, when the same potential difference V is placed across their lengths.

(A) $1 < 2 < 3$
(B) $2 < 3 < 1$
(C) $2 < 3 = 1$
(D) $1 = 3 < 2$
(E) $2 = 3 < 3$
A human being can be electrocuted if a current as small as 50 mA passes near the heart. An electrician working with sweaty hands makes good contact with the two conductors that he is holding. If his resistance is 2000 $\Omega$, which of the following might be the fatal voltage?

(A) 0.01 V
(B) 0.1 V
(C) 1.0 V
(D) 10 V
(E) 100 V
Temperature Dependence of Resistances

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

\[ R = \rho \frac{L}{A} \]

\[ R = R_o (1 + \alpha (T - T_o)) \]

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 increases. Notice: Resistivity increases as temperature increases. This curve does not deviate greatly from a straight line.
<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity $\rho$ ($\Omega \text{m}$)</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>
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<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.
Lower Cu initially at room temperature (~ 300°K) into liquid N$_2$. 

liquid nitrogen ~ 77°K 
vacuum bottle
DEMO: Temperature Dependence

Heat the Ge with a candle.
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 Ω in a wide temperature range around 20ºC, what should be the resistances of the two resistors?

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

In general:  \[ R = R_o (1 + \alpha (T - T_o)) \]

\[ R_{oN}(1 + \alpha_N (T - T_o)) + R_{oSi}(1 + \alpha_Si (T - T_o)) = 1300\Omega \]

\[ (R_{oN} + R_{oSi}) + R_{oN} \alpha_N (T - T_o) + R_{oSi} \alpha_Si (T - T_o)) = 1300\Omega \]

\[ (R_{oN} \alpha_N + R_{oSi} \alpha_Si)(T - T_o) = 0 \]

\[ (1300\Omega - R_{oSi}) \alpha_N + R_{oSi} \alpha_Si = 0 \]
Power in Electric Circuits

Power associated with transfer: \( P = IV \)

For a Resistor: \( P = I^2R = V^2/R \)

\[ dU = dqV = idtV \]

\[ P = \frac{dU}{dt} = iV \]

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

Power associated with dissipation of U into thermal energy in the resistor.
Power in Electric Circuits

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 $R$:

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

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

internal resistance
emf

Examine potential as we start from point b and end at a:

\[ \varepsilon - Ir - IR = 0 \]

\[ I = \frac{\varepsilon}{R + r} \]

Over the battery:

\[ V_a - V_b = \varepsilon - Ir \]

In an ideal battery:

\[ r = 0 \]

\[ V_a - V_b = \varepsilon \]

\[ I = \frac{V}{R} \]

Note: \( \varepsilon \) arrows always points from negative to positive.
Effect of Internal Resistance

$r = 0$

(real battery)

(ideal battery)