Physics 202, Lecture 9

Today’s Topics

- Current And Resistance (Ch. 27)
- Motion of Charged Particle In Electric Field (review)
- Current: Macroscopic and Microscopic Views
- Resistance: Macroscopic and Microscopic Views
- Electrical Power

Expected from Preview:
Current, current density, drift velocity, Ohm, Ampere, power, ...
Review: Motion Of Charged Particle In The Electric Field

- **Fundamental Formulas:**
  - \( F = qE \)
  - \( a = \frac{F}{m} = \frac{qE}{m} \)
  - \( v = v_i + at \rightarrow \) if \( v_i = 0 \), then \( v = at \)

- **A Picture to remember**

  If initially at rest
  
  **Motion of +q:**
  Same dir. as \( E \)
  From high \( V \) to low \( V \)

  **Motion of -q:**
  Opposite dir. as \( E \)
  From low \( V \) to high \( V \)

\[ E \]

higher potential \( V \)

\[ +q \rightarrow \]

\[ \leftarrow -q \]

lower potential \( V \)
Charge Motion in a Conductor

- Without electric field:
  - electrons move randomly (thermal motion) \(|v_{av}|=0, |v|_{av} > 0\)

- With electric field applied:
  - electron motion = thermal + drift (directional): \(|v_{av}|= v_{drift}>0, |v|_{av} > 0\)
  - i.e. a net charge \(\Delta Q\) is moving directionally

- Average current: \(I = \frac{\Delta Q}{\Delta t}\)
- Instantaneous current: \(i = \frac{dQ}{dt}\)

"direct current (DC)"
\(I = \text{constant}\)
**Current: Macroscopic View**

- **Definition:** \( I = \frac{dQ}{dt} \)
- **Unit:** 1 Ampere = 1 Coulomb/1 sec
- **Current is directional:** Follows positive charge
  - **Equivalence Principle:**
    - +q moving in +x direction \( \leftrightarrow \) –q in moving –x direction
  - The following pictures represent the same current
- **Charge conservation \( \rightarrow \) Current conservation**

\[ I_{in} = I_{out} \]
Current: Microscopic View

- Current ↔ motion of charged particles

Show that:

\[ I_{\text{average}} = \frac{\Delta Q}{\Delta t} = nqv_d A = I \]

- Current density \( J = \frac{I}{A} = nqv_d \) (vector)

Note: \( v_d \propto E \) (why?)
Ohm’s Law: Resistance

- It can be shown experimentally and theoretically that for many material, the electric current is proportional to $\Delta V$ (shorts for $V$)

$$I \propto V$$

- For a fixed material and geometry

$$I = \frac{V}{R} \quad \text{or} \quad V = RI$$

- $R$: resistance
Conductivity And Resistance

- Ohm’s Law (microscopic): \( J = \sigma E \)
  - \( \sigma \) is called conductivity
  - also: \( \rho = 1/\sigma \) is called resistivity
- Ohm’s Law (macroscopic): \( \Delta V = RI \)
- \( R \): Resistance. (unit: Ohm \( \Omega = \text{Volt/Amper} \))
- Exercise: relate \( R \) to \( \rho \)

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

Length & Cross-section (shape)

Resistivity (intrinsic)
# Resistors

## Resistivity For Various Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity(\text{a}(\Omega \cdot \text{m}))</th>
<th>Temperature Coefficient(b[\text{°C}^{-1}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>(1.59 \times 10^{-8})</td>
<td>(3.8 \times 10^{-3})</td>
</tr>
<tr>
<td>Copper</td>
<td>(1.7 \times 10^{-8})</td>
<td>(3.9 \times 10^{-3})</td>
</tr>
<tr>
<td>Gold</td>
<td>(2.44 \times 10^{-8})</td>
<td>(3.4 \times 10^{-3})</td>
</tr>
<tr>
<td>Aluminum</td>
<td>(2.82 \times 10^{-8})</td>
<td>(3.9 \times 10^{-3})</td>
</tr>
<tr>
<td>Tungsten</td>
<td>(5.6 \times 10^{-8})</td>
<td>(4.5 \times 10^{-3})</td>
</tr>
<tr>
<td>Iron</td>
<td>(10 \times 10^{-8})</td>
<td>(5.0 \times 10^{-3})</td>
</tr>
<tr>
<td>Platinum</td>
<td>(11 \times 10^{-8})</td>
<td>(3.92 \times 10^{-3})</td>
</tr>
<tr>
<td>Lead</td>
<td>(22 \times 10^{-8})</td>
<td>(3.9 \times 10^{-3})</td>
</tr>
<tr>
<td>Nichrome(c)</td>
<td>(1.50 \times 10^{-6})</td>
<td>(0.4 \times 10^{-3})</td>
</tr>
<tr>
<td>Carbon</td>
<td>(3.5 \times 10^{-5})</td>
<td>(-0.5 \times 10^{-3})</td>
</tr>
<tr>
<td>Germanium</td>
<td>(0.46)</td>
<td>(-48 \times 10^{-3})</td>
</tr>
<tr>
<td>Silicon</td>
<td>(640)</td>
<td>(-75 \times 10^{-3})</td>
</tr>
<tr>
<td>Glass</td>
<td>(10^{10}) to (10^{14})</td>
<td></td>
</tr>
<tr>
<td>Hard rubber</td>
<td>(\sim 10^{13})</td>
<td></td>
</tr>
<tr>
<td>Sulfur</td>
<td>(10^{15})</td>
<td></td>
</tr>
<tr>
<td>Quartz (fused)</td>
<td>(75 \times 10^{16})</td>
<td></td>
</tr>
</tbody>
</table>

\(a\) All values at 20°C.
\(b\) See Section 27.4.
\(c\) A nickel–chromium alloy commonly used in heating elements.
Ohmic and non-Ohmic Materials

- **Ohmic:**
  
  Linear I-V relationship

- **non-Ohmic:**

  Non-linear I-V

For the rest of the course, we assume ohmic for all materials
Resistance And Temperature

- Resistivity is usually temperature dependent.

Normal Metal
(See demo)

Semiconductor

Superconductor
Superconductivity

- Superconductors: temperature $T < T_c$, resistivity $\rho = 0$
  - Super conductivity is a quantum phenomenon.
  - Super conductors have special electric and magnetic features

![Graph showing $R(\Omega)$ vs $T(K)$ with $T_c$ marked]

<table>
<thead>
<tr>
<th>Material</th>
<th>$T_c$(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HgBa$_2$Ca$_2$Cu$_3$O$_8$</td>
<td>134</td>
</tr>
<tr>
<td>Tl–Ba–Ca–Cu–O</td>
<td>125</td>
</tr>
<tr>
<td>Bi–Sr–Ca–Cu–O</td>
<td>105</td>
</tr>
<tr>
<td>YBa$_2$Cu$_3$O$_7$</td>
<td>92</td>
</tr>
<tr>
<td>Nb$_3$Ge</td>
<td>23.2</td>
</tr>
<tr>
<td>Nb$_3$Sn</td>
<td>18.05</td>
</tr>
<tr>
<td>Nb</td>
<td>9.46</td>
</tr>
<tr>
<td>Pb</td>
<td>7.18</td>
</tr>
<tr>
<td>Hg</td>
<td>4.15</td>
</tr>
<tr>
<td>Sn</td>
<td>3.72</td>
</tr>
<tr>
<td>Al</td>
<td>1.19</td>
</tr>
</tbody>
</table>
Electrical Power

- Electric Power:
  \[ P = \frac{dU}{dt} = \frac{d(Q\Delta V)}{dt} = I\Delta V \]

- For resistors (ohmic):
  \[ P = I\Delta V = I^2R = \frac{(\Delta V)^2}{R} \]

Power unit: watts (W=J/s)
Energy unit: kWH

1 kWH = 3.6 MJ
Example: Battery Connected To A Resistor

- Show the energy flow of this battery-resistor set-up

  ➢ Chemical Process $\rightarrow \Delta V = 1.5V$
  ➢ $\Delta V$ on Resistor $\rightarrow$ Current $I = \frac{\Delta V}{R}$

Charge flow through the resistor in $\Delta t$:

$Q = I\Delta t = \frac{\Delta V}{R}\Delta t$

Electrical potential energy released:

$U = Q\Delta V = \frac{\Delta V}{R}\Delta t \Delta V = (\Delta V)^2/R\Delta t$

Power: $P = \frac{U}{\Delta t} = \frac{(\Delta V)^2}{R}$

Energy Flow: Chemical $\rightarrow$ Electrical $U \rightarrow K_E \rightarrow$ thermal/light

Chemical Process $\rightarrow$ Electrical $U$ $\rightarrow$ $K_E$ $\rightarrow$ thermal/light
Demo/ Quiz 1:
Consumption of Electric Power On Resistors

- A voltage is applied to a wire of length L. When L increases, Does power consumed increase or decrease?

1. Increases
2. Decreases
3. Same
Demo/ Quiz 2:
Consumption of Electric Power On Resistors

When a current passes through serially connected wire segments made of copper and nichrome, which metal: copper or nichrome, consume more energy?

(\(\rho_{Cu} \sim 10^{-8} \ \Omega m\), \(\rho_{Ni} \sim 10^{-6} \ \Omega m\), All segments have about the same length and diameter.)

1. Copper
2. Nichrome
3. Same
Quiz 3: 30W and 60W Light Bulbs

Which has larger resistance?

30 W, 60 W, same, can’t determine

\[ P = \frac{\Delta V^2}{R} \]