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,…

Motion Of Charged Particle In The Electric Field

- Fundamental Formulas:
  - $F = qE$
  - $a = \frac{F}{m} = \frac{qE}{m}$
  - $v = v_i + at$ if $v_i > 0$, then $v = at$
- A Picture to remember

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): $|v_{av}| = v_{av} > 0$, $|v_{av}| > 0$
  - 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)”
  - $I = constant$

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

\[ I_{in} \rightarrow I_{out} \]

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

- Current \( \leftrightarrow \) motion of charged particles

- Average drift velocity: \( \nu_d \frac{\Delta t}{\Delta x} \)

- \( n \): number density

- Show that:
  \[ I_{\text{average}} = \frac{\Delta Q}{\Delta t} = nq\nu_d \]

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

- Note: \( \nu_d \propto E \) (why?)

Ohm’s Law: Resistance

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

\[ I \propto \frac{\Delta V}{R} \]

- 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): \( \mathbf{J} = \sigma \mathbf{E} \)
  - \( \sigma \): called conductivity
  - Also: \( \rho = \frac{1}{\sigma} \) is called resistivity

- Ohm’s Law (macroscopic): \( \Delta V = RI \)

- \( R \): Resistance (unit: Ohm \( \Omega = \text{Volt/Amp} \))

- Exercise: relate \( R \) to \( \rho \)

Resistivity For Various Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity (intrinsic)</th>
<th>Temperature Coefficient of Resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>1.6 x 10^-8 ( \Omega \cdot \text{m} )</td>
<td>5 x 10^-3 ( %/^\circ \text{C} )</td>
</tr>
<tr>
<td>Lead</td>
<td>9.6 x 10^-8 ( \Omega \cdot \text{m} )</td>
<td>3 x 10^-3 ( %/^\circ \text{C} )</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2 x 10^-7 ( \Omega \cdot \text{m} )</td>
<td>4 x 10^-3 ( %/^\circ \text{C} )</td>
</tr>
<tr>
<td>Tin</td>
<td>5.3 x 10^-6 ( \Omega \cdot \text{m} )</td>
<td>3 x 10^-3 ( %/^\circ \text{C} )</td>
</tr>
<tr>
<td>Iron</td>
<td>1.9 x 10^-5 ( \Omega \cdot \text{m} )</td>
<td>4 x 10^-3 ( %/^\circ \text{C} )</td>
</tr>
<tr>
<td>Platinum</td>
<td>1.1 x 10^-4 ( \Omega \cdot \text{m} )</td>
<td>3 x 10^-3 ( %/^\circ \text{C} )</td>
</tr>
<tr>
<td>Silver</td>
<td>1.5 x 10^-7 ( \Omega \cdot \text{m} )</td>
<td>5 x 10^-3 ( %/^\circ \text{C} )</td>
</tr>
<tr>
<td>Carbon</td>
<td>6 x 10^-9 ( \Omega \cdot \text{m} )</td>
<td>5 x 10^2 ( %/^\circ \text{C} )</td>
</tr>
<tr>
<td>Glass</td>
<td>10^10 ( \Omega \cdot \text{m} )</td>
<td>1 x 10^10 ( %/^\circ \text{C} )</td>
</tr>
<tr>
<td>Ceramic</td>
<td>10^13 ( \Omega \cdot \text{m} )</td>
<td>1 x 10^13 ( %/^\circ \text{C} )</td>
</tr>
</tbody>
</table>

Resistors

\[ R = \rho \frac{l}{A} \]
Resistance And Temperature

- Resistivity is usually temperature dependent.

![Graphs showing the relationship between resistivity and temperature for Normal Metal, Semiconductor, and Superconductor.]

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.

Superconductivity

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

![Graph showing the critical temperature for various superconductors with a table below listing the materials and their critical temperatures.]

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: \( \Delta V = 1.5V \)
  - \( \Delta V \) on Resistor → 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:

\[ U = Q \Delta V = \frac{\Delta V}{R} \Delta V = \frac{(\Delta V)^2}{R} \Delta t \]

Power:

\[ P = \frac{U}{\Delta t} = \frac{(\Delta V)^2}{R} \]

Energy Flow: Chemical → Electrical U → KE → 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?

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

1. Copper
2. Nichrome
3. Same