Homework #5 is due next Tuesday 16 Oct at 11:59PM

Hour exam 1 is graded. Class average is 148/200 (74%)

Make sure your clickers are out and ready

Today ask me questions BEFORE class
– I have to leave right after

COME DOWN AND PLAY WITH BURNING RESISTOR AND BULB CIRCUITS THEY ARE REALLY FUN!

Question for burning resistor – what is the V that makes it smoke? What V is “safe”?
Energy and power

Charges move downhill in potential: potential energy decreases

\[ + \quad \rightarrow \quad - \]

Current at the two ends is equal
velocity of moving charges is the same at two ends
kinetic energy doesn’t charge
Therefore, the total energy of the moving charges decreases

energy is lost to heat and light
Energy and power

Charges move downhill in potential: potential energy decreases

\[ dU = dq \ V = I \ V \ dt \] (dU is the magnitude of the decrease)

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

If system obeys Ohm’s law, can also write \( P = i^2R = V^2/R \)
Energy and power

Charges move downhill in potential: potential energy decreases

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

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DEMO: burning resistor

What’s the \( V \) needed? What is the corresponding \( P \)?
“power rating”—how much power is “safe”?
Consider systems with “steady current”
Current through any surface doesn’t change with time.
no buildup or depletion of charge at any point

Analogy with fluids:
equation of continuity
i is the same for all
cross sections of the wire
Drift speed, drift velocity and current density

Current density $\vec{j}(\vec{r})$ is a vector field that describes the flow of a fluid.

Current through a surface $S = \int_S \vec{j} \cdot \hat{n} dA$

$\vec{j}(\vec{r}) = qn\vec{v}(\vec{r})$

drift velocity and drift speed
current flows through a wire when there is a voltage difference \( V \) between the ends

\[ + \quad \begin{array}{c}
\text{wire}
\end{array} \quad - \]

If \( I \) is proportional to \( V \), then the object obeys “Ohm’s law”

Ratio \( V/I \) is called the \textit{resistance} \( R \) of the object

Resistance – characteristic of the object

• length of wire
• cross sectional area
• material it’s made out of
• temperature
Materials that obey Ohm’s law have a property called **resistivity** $\rho$

$$\vec{j}(\vec{r}) = \frac{\vec{E}(\vec{r})}{\rho}$$

Measure, store in a table

Units = $(V/m) \times (A/m^2)^{-1} = (V/A) \text{ m}$

Resistance of object is proportional to resistivity

Resistivity increases with temperature $\rho(T) = \rho \ (T=300K) + \alpha(T-300K)$

### Resistivities of Some Materials at Room Temperature (20°C)

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity, $\rho$ (Ω ⋅ m)</th>
<th>Temperature Coefficient of Resistivity, $\alpha$ (K⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical Metals</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td>$1.62 \times 10^{-8}$</td>
<td>$4.1 \times 10^{-3}$</td>
</tr>
<tr>
<td>Copper</td>
<td>$1.69 \times 10^{-8}$</td>
<td>$4.3 \times 10^{-3}$</td>
</tr>
<tr>
<td>Gold</td>
<td>$2.35 \times 10^{-8}$</td>
<td>$4.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>Aluminum</td>
<td>$2.75 \times 10^{-8}$</td>
<td>$4.4 \times 10^{-3}$</td>
</tr>
<tr>
<td>Manganin</td>
<td>$4.82 \times 10^{-8}$</td>
<td>$0.002 \times 10^{-3}$</td>
</tr>
<tr>
<td>Tungsten</td>
<td>$5.25 \times 10^{-8}$</td>
<td>$4.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Iron</td>
<td>$9.68 \times 10^{-8}$</td>
<td>$6.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Platinum</td>
<td>$10.6 \times 10^{-8}$</td>
<td>$3.9 \times 10^{-3}$</td>
</tr>
<tr>
<td><strong>Typical Semiconductors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silicon, pure</td>
<td>$2.5 \times 10^3$</td>
<td>$-70 \times 10^{-3}$</td>
</tr>
<tr>
<td>Silicon, n-type</td>
<td>$8.7 \times 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td>Silicon, p-type</td>
<td>$2.8 \times 10^{-3}$</td>
<td></td>
</tr>
<tr>
<td><strong>Typical Insulators</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>$10^{10}$ − $10^{14}$</td>
<td></td>
</tr>
<tr>
<td>Fused quartz</td>
<td>$\sim 10^{16}$</td>
<td></td>
</tr>
</tbody>
</table>
Resistance of a wire
Length L, cross section A, resistivity $\rho$

Voltage difference $V$

$E = \frac{V}{L}$
$J = \frac{E}{\rho} = \frac{V}{(\rho L)}$
$I = jA = \frac{VA}{(\rho L)}$
Resistance $= \frac{V}{I} = \frac{\rho L}{A}$
Chapter 27

Introduction to circuits
Q: When does current flow through a wire?
A: When there is a potential difference between the ends

Electric field inside the wire -> force that drives the motion of charges

To maintain a steady current, need (1) at least one closed loop path for moving charges: a CIRCUIT
Circuit diagram: devices + connecting lines ("wires")
potential on "wire" between devices is CONSTANT
Q: When does current flow through an object?
A: When there is a potential difference across it

Electric field inside the object -> force that drives the motion of charges

Need (2) a device that can have current flow in the direction of potential increase = BATTERY
Mechanical analogy: Playground

Parent lifts toddlers from ground to top of slide
Toddlers slide down slide (with friction) & stop at bottom

Toddler = charge
Parent = battery
Slide = resistor
Energy and power

Charges move downhill in potential: potential energy decreases

\[ dU = dq \ V = I \ V \ dt \] (dU is the magnitude of the decrease)
\[ \frac{dU}{dt} = P = iV \]
If system obeys Ohm’s law, can also write \[ P = i^2R = \frac{V^2}{R} \]
Ideal battery maintains specified voltage $\mathcal{E}$ between + and – terminal. The same no matter how much current flows through the battery. Here, the current is zero.
Ideal battery maintains specified voltage $\mathcal{E}$ btwn + and – terminal

charges arrive at small terminal at rate given by current $i$

battery does work $q \mathcal{E}$ on charges to place them at + terminal

Rate of energy delivery by battery = $i \mathcal{E}$

charges flow through the resistor and lose energy $q \mathcal{E}$

Rate of energy loss = $i \mathcal{E}$
Ideal battery maintains specified voltage $\mathcal{E}$ btwn + and – terminal. Potential difference between the ends of the resistor is also $\mathcal{E}$.

Current $i$ flows from + to – potential.

Assume Ohm’s law: resistor has resistance $R$: $i = \mathcal{E} / R$

- $i$ doubles if $\mathcal{E}$ doubles
- Rate of energy loss: $i\mathcal{E} = \mathcal{E}^2 / R = i^2R$
Resistors that obey Ohm’s law $V=IR$

$V \to I = \frac{V}{R}$ from higher to lower pot

$I \to V = iR$, decreasing in direction of current

Bulbs are resistors, obey Ohm’s law

brightness = power = $IV = \frac{V^2}{R}$

Bulbs usually labeled by power (100W) at standard voltage

higher power rating = lower resistance

Any conducting object in a circuit will be a resistor

e.g. human body