Physics 6C
Introduction to Physics III
Electricity and Magnetism

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I will return the exams following the lecture.

Be sure to double check that the points agree between the front page and the following pages and that they are added correctly on the front page.

Also, it is a good idea to check that the score was recorded correctly. The recorded scores are posted online.

See me, not the TAs, about all errors.

A: 82-100; B: 62-81; C: 45-62
Power: Circuit Element with 2 Leads

In a **steady state** situation:

- **The current coming out is the same as the current going in!**
- **Otherwise charge would pile up inside the circuit element!**

![Black Box Diagram]

Each charge experiences a change in potential: \( \Delta V = V_b - V_a \)
- \( \Delta Q \) charge flows through in time \( \Delta t \).
- Change of potential energy of the charges in this time is
  \[
  \Delta U = \Delta Q \cdot (V_b - V_a)
  \]

**Power**

\[
P = \frac{\Delta U}{\Delta t} = \frac{\Delta Q}{\Delta t} \cdot (V_b - V_a) = I \cdot \Delta V
\]
Battery or Other EMF Source

- $V_b > V_a$
- So, if the current is going from – to +, then the charges increase in potential energy.

- The battery delivers power $I\mathcal{E}$ to the circuit (chemical potential energy turns into electrical energy).
- If the current is in the opposite direction, then $I \cdot \Delta V < 0$ and the battery takes power from the circuit (this will charge the battery, turning electrical energy into chemical potential energy).
Single-Loop Example

\[ I = 0.25 \text{ A} \]
Jump Starting a Car

- Don’t do this if you do not understand 100% what you are doing! *It can be dangerous!*
- Batteries must be connected in parallel!
- The last connection will make a spark, which can cause an explosion (if hydrogen gas is present).

```
<table>
<thead>
<tr>
<th>Voltage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 V (Positive</td>
<td>Delivers Power</td>
</tr>
<tr>
<td>battery terminal)</td>
<td></td>
</tr>
<tr>
<td>0 V (chassis)</td>
<td>absorbs and stores power</td>
</tr>
<tr>
<td>Nearly dead</td>
<td></td>
</tr>
<tr>
<td>battery</td>
<td></td>
</tr>
<tr>
<td>0 V (Negative</td>
<td></td>
</tr>
<tr>
<td>battery terminal)</td>
<td></td>
</tr>
</tbody>
</table>
```

Diagram:
- 12 V (Positive battery terminal)
- Nearly dead battery
- 0 V (chassis)
- Last connection!
Car Batteries in Series

Very bad!

The current will be enormous (hundreds of amps).

The wires will get extremely hot and start to melt. The insulation will melt first and may catch on fire.

Batteries will get hot and produce hydrogen and may explode.
Resistors

- Charges *always* lose potential energy when passing through a resistor, *no matter which direction*.
- So, below, $V_b > V_a$.
  - But if we reverse the current, then $V_b < V_a$.

\[ \Delta V = V_b - V_a = IR \]

\[ P = I\Delta V = I^2R = \frac{\Delta V^2}{R} \text{ Heat!} \]
Which Lamps are Brighter?

Identical batteries

Identical bulbs

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What happens to the brightness of bulb A when the switch is closed?
With the switch closed, how does the brightness of B compare with that of C?
What happens to the brightness of B when the switch is closed?
Which Lamp is Brighter?

Assume that all batteries are identical and that all bulbs are identical.
Identical Ideal Batteries in Parallel

\[ I = \frac{1.5}{R} \quad \text{and} \quad P = \frac{(1.5)^2}{R} \]

Same as with 1 battery.

But each battery is supplying half the current (and half the power), so the batteries will last twice as long.
Which Lamp is Brighter?

Note, these batteries are identical, but are real (not ideal) batteries. They have an internal resistance of $r$.

If the lamp has a low resistance, so the current is high, then the difference could be large.

- a) $A$ is twice as bright.
- b) $A$ is somewhat brighter
- c) Brightness is the same.
Kirchhoff’s Junction Rule

The current flowing into a junction equals the current flowing out of the junction.

\[ I_3 = I_2 + I_1 \]
Parallel Resistors

\[ R_1 R_2 \]

\[ I_3 - I_2 - I_1 = 0 \]

\[ I_3 - \frac{V}{R_2} - \frac{V}{R_1} = 0 \]

\[ I_3 = \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \cdot V = \frac{1}{R_{eq}} \cdot V \]
Series vs Parallel

\[ R_{eq} = R_1 + R_2 \]

The equivalent resistance is higher than either of the two individual resistances.

\[ \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \]

The equivalent resistance is lower than either of the two individual resistances.
Series or Parallel?

Series

\[ R_1 \]

\[ R_2 \]
Series or Parallel?

Parallel
Series or Parallel?

Parallel
Series vs Parallel

• Are $R_1$ and $R_2$ in series?
• Are they in parallel?

Neither!

$R_2$ and $R_3$ are in parallel.
What is the difference between these schematics?

Nothing!
Equivalent Resistance?

This wire is ~zero resistance in parallel with the 10 Ω resistor!

These 3 resistors are in parallel

\[ R_{eq} = 7 \, \Omega \]
Example

What is the voltage across the battery and the current flowing through it?

\[ R_{eq} = \frac{199 \text{ V}}{16.95 \text{ A}} = 11.7 \Omega \]
Example: Rank the Light Bulb Brightness

Assume that all of the bulbs are identical.

a) C=D>B>A=E
b) A=E>B>C=D
c) A>B=C=D>E
d) A>B>C>D>E