No quiz in Fri/Mon recitations.

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

We are getting the exams graded and I will email you when you can look up the results in the gradebook.

Make sure your clickers are out and ready before class starts
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

Split wire: net flow at junction is zero
\( i_{\text{in}} = i_{\text{out}}; \quad i_0 = i_1 + i_2 \)

Current is NOT a vector
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

If $I$ is proportional to $V$, then the object obeys “Ohm’s law”
Ratio $V/I$ is called the 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 = $\text{(V/m)} \times \text{(A/m}^2\text{)}^{-1} = \text{(V/A)} \text{ m}$

Resistance of object is proportional to resistivity

Resistivity increases with temperature

$$\rho(T) = \rho\,(T=300\text{K}) + \alpha(T-300\text{K})$$
Resistance of a wire
Length L, cross section A, resistivity $\rho$

$E = \frac{V}{L}$

$J = \frac{E}{\rho} = \frac{V}{(\rho L)}$

$I = jA = \frac{VA}{(\rho L)}$

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

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

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: $i\mathcal{E} = \mathcal{E}^2 / R = i^2 R$
Resistors that obey Ohm’s law $V=iR$

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

$I \rightarrow V = iR$, 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
Only difference between bulbs A & B is that B’s filament is thicker. Each is in a simple circuit with a 120 V battery.

A) B will be brighter because it has higher resistance.
B) B will be dimmer because it has higher resistance.
C) B will be brighter because it has lower resistance
D) B will be dimmer because it has lower resistance
E) Equal brightness.
Only difference between bulbs A & B is that B’s filament is thicker. Each is in a simple circuit with a 120 V battery.

A) B will be brighter because it has higher resistance.
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C) B will be brighter because it has lower resistance.
D) B will be dimmer because it has lower resistance.
E) Equal brightness.
Clicker

What happens to the brightness of a bulb in a simple circuit with an ideal battery if a second identical bulb is added in parallel?

(A) Gets brighter
(B) Stays the same
(C) Gets dimmer
(D) Goes out
Clicker

What happens to the brightness of a bulb in a simple circuit with an ideal battery if a second identical bulb is added in parallel?

(A) Gets brighter  
(B) **Stays the same**  
(C) Gets dimmer  
(D) Goes out

![Circuit Diagram]

Potential difference is the same; current through battery doubles
What happens if the two bulbs have different resistance?

Bulbs are resistors, obey Ohm’s law
brightness = power = IV = \( V^2/R \)
Bulbs usually labeled by power (100W) at standard voltage

Let’s check!
Resistors in series

CURRENT IS THE SAME IN THE TWO RESISTORS

\[ V = V_1 + V_2 = i R_1 + i R_2 = i (R_1 + R_2) \]
\[ V/i = R_1 + R_2 \]

Combination behaves like a resistor of resistance \( R_1 + R_2 \)
What happens to the brightness of a bulb in a simple circuit with an ideal battery if a second identical bulb is added in series?

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Clicker

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\[ P = \varepsilon^2 R \]

\[ R_{\text{eff}} = R_1 + R_2 = 2R \]
\[ I = \frac{\varepsilon}{R_{\text{eff}}} = \frac{\varepsilon}{2R} \]
\[ P_1 = I^2 R = \varepsilon^2 R/4 \]

total current goes down
What happens if the two bulbs have different resistance?

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

Let’s check!
Analyzing circuits, part 1

Voltage change across each circuit element:
Battery: $+\mathcal{E}$ from small plate (-) to large plate (+)
Resistor: decreases by $iR$ in direction of current arrow

LOOP RULE: total voltage change around loop is ZERO
If the potential at point P is 100 V, what is the potential at point Q?
Energy delivered / lost by each circuit element

50 V battery is charging
A real battery

The voltage difference between the terminals decreases as the current through the battery increases.

Behaves like an ideal battery $\mathcal{E}$ in series with internal resistor $r$. 
Analyze a circuit with a real battery
Analyze a circuit with a real battery