Next homework is due **WEDNESDAY** AFTER SPRING BREAK at 11:59 PM
BEFORE CLASS demos / ask me about prelecture material

Chapter 26

Current and Resistance
Up to now we have been considering systems where the arrangement of charges is fixed, studying the electric field produced and its description by a potential function.

“electrostatics”

Rules include

“Electric field inside a conductor is zero”

Now we allow charges to move:
New quantities: current, resistance…
New rules: Ohm’s law…
The systems we consider have large numbers of charged particles moving together
Density $n = \text{number per volume}$
Velocity $v$

Analogy to fluid flow

mass flow rate = mass that passes through surface per time
= increase in mass on the far side of the surface per time

Mass flow rate can be positive or negative
negative if mass is moving FROM far side TO near side
The systems we consider have large numbers of charged particles moving together.

Density $n = \text{number per volume}$

Analogy to fluid flow

Mass flow rate = mass that passes through surface per time = increase in mass on the far side of the surface per time

**Electric current** = NET charge that passes through surface in a given time = increase in charge on the far side of the surface per time
Electric current =
NET charge that passes through surface per time unit
1 C/s = 1 A (Ampere)

A number (not a vector)
Can be positive or negative

Positive if net charge on the far side is increasing

Negative if net charge on the far side is decreasing
**Current** = NET charge that passes through surface per time
= change in net charge on “far” side of the surface per time

Scalar: **positive** or **negative**

**Positive** charges move **to** far side: current is **positive**

**Positive** charges move **from** far side: current **negative**

**Negative** charges move **to** far side: current **negative**

**Negative** charges move **from** far side: current **positive**
Of the following four situations in which positive and negative charges move horizontally through a surface at rates shown in the figure, in which situation does the current have the smallest magnitude?
Clicker

Of the following four situations in which positive and negative charges move horizontally through a surface at rates shown in the figure, in which situation does the current have the smallest magnitude?
Mostly we consider charges moving in metal wires. The number density $n$ of free charges is a property of the metal (Cu, Al, etc) – behaves like incompressible fluid.

A wire is like a pipe for charge.
Consider systems with “steady current”
Current 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
\[ i_{in} = i_{out}; \quad i_0 = i_1 + i_2 \]

Current is NOT a vector
Steady currents flow in the wires shown. What is the magnitude and direction of the current $i$?

(a) Zero
(b) 2 A, into the junction
(c) 2 A, out of the junction
(d) 8 A, into the junction
(e) 8 A, out of the junction
Steady currents flow in the wires shown. What is the magnitude and direction of the current $i$?

(a) Zero  
(b) 2 A, into the junction  
(c) 2 A, out of the junction  
(d) 8 A, into the junction  
(e) 8 A, out of the junction
Q: When does current flow through a wire?
A: When there is a difference in potential between the ends

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

For + charges, force points from higher electric potential to lower
Current flows same direction as electric field
Q: When does current flow through a wire?
A: When there is a voltage difference between the ends

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

But wait: the wire is a conductor
Isn’t the electric field zero inside a conductor?
Q: When does current flow through a wire?
A: When there is a voltage difference between the ends

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

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

But wait: the wire is a conductor
Isn’t the electric field zero inside a conductor?
THAT RULE APPLIES ONLY IN ELECTROSTATICS
Q: When does current flow through a wire?
A: When there is a voltage difference between the ends

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

The usual way to create a voltage difference between the ends:
Make a circuit with a charged capacitor, a battery or a power supply
DEMOS

Apply a voltage across an object with free charge
How do we know a current is flowing?
Moving charges collide with atoms in object $\rightarrow$ light, heat

Current through a pickle (cucumber in salt water)
Free charge = salt ions Na+, Cl-

Current through a wire
Free charge = electrons
more voltage $\rightarrow$ brighter glow (larger current)
Q: When does current flow through a wire?
A: When there is a voltage difference \( V \) between the ends

If \( V \) increases, expect \( I \) to increase.

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)

Unit 1 V/A = 1 Ohm
DEMOS

Apply a voltage across an object with free charge
Measure current with an ammeter

Find resistance of object
$V = I R$ so $R =$ slope of the plot of $V$ vs $I$. 
The resistance of an object depends on the material.

Materials that obey Ohm’s law have a property called **resistivity** $\rho$.

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 $\rho(T) = \rho(T=300\text{K}) + \alpha(T-300\text{K})$
DEMOS

Object = coil of copper wire
Apply a voltage across the coil
Measure current by brightness of the light bulb

Cool down the copper wire with liquid nitrogen
What happens to the resistivity of the copper?
What happens to the resistance of the coil?
What happens to the current through the coil?
Drift speed, drift velocity and current density

For fluids, mass flow rate in pipe is \( \rho \nu A \) (\( \rho = \text{mass/volume} \))

For electric current, if charge of moving particles is \( q \)

\[ I = q n \nu A \]

\( \nu \) is called the “drift speed”

Current density

\[ \vec{j}(\vec{r}) = qn\vec{\nu}(\vec{r}) \]

\( \nu \) is called the drift velocity

Current through a surface \( S = \int_S \vec{j} \cdot \hat{n} \, dA \)
The resistance of an object depends on the material.

Materials that obey Ohm’s law have a property called **resistivity** \( \rho \) 

\[ j = \frac{E}{\rho} \]

Measure, store in a table

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

Resistance of object is proportional to resistivity.

Resistivity increases with temperature

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

\[
\begin{align*}
E &= V/L \\
J &= E/\rho = V/(\rho L) \\
I &= jA = VA/(\rho L) \\
\text{Resistance} &= \frac{V}{I} = \frac{\rho L}{A}
\end{align*}
\]
Energy and power

Charges move downhill in potential: potential energy decreases

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
(like the box moving with kinetic friction in prelecture)

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 \( P = i^2R = V^2/R \)

DEMO: burning resistor