BEFORE CLASS: lots of hands-on demos with currents

First hour exam: in class Wed February 26
Last year’s exam will be posted today
HW3 is being handed back today
HW4 is due today

class web site
http://www.physics.rutgers.edu/ugrad/272
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…
Start with current in a thin wire

moving charged particles (electrons, holes, ions)

Current =

Net charge that passes through a given point in the wire PER TIME

Pick one of two directions as positive

Straight wires and curved wires

Units of current: Coulombs/sec = Amperes

Assume one type of moving charged particle

Assume uniform linear density for the moving charge

relate linear density of moving charge, speed of moving charge, current
current in a thick wire

Current = net charge per time that passes through a cross-sectional surface of the wire

More than one type of moving charge
Positive, negative
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?
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?
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

For the wire, the surface we use is the cross section
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
The systems we consider have large numbers of charged particles moving together: analogy to fluids

Density \( n \) = number per volume

Velocity \( \vec{v} \)

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: analogy to fluids

Density $n = \text{number per volume}$
Velocity $\vec{v}$

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
Let’s compute the current for flat surface of area $A$ & normal vector $\hat{n}$

number density $n$
charge $q$
velocity $\vec{v}$

$$I = nq(\vec{v} \cdot \hat{n})A$$

Define current density $\vec{j} = qn\vec{v}$

Then $I = (\vec{j} \cdot \hat{n})A$

$n, \nu$ vary from point to point
Current density is a vector field $\vec{j}(\vec{r}) = qn(\vec{r})\vec{v}(\vec{r})$
$I$ is the flux of the current density through the surface $\int_S \vec{j} \cdot \hat{n} \, dA$
Equation of continuity

Closed surface

\[ I = -\frac{dq_{\text{enc}}}{dt} \quad \int_S \vec{j}(\vec{r}, t) \cdot d\vec{A} = -\frac{\partial}{\partial t} \int_V \rho(\vec{r}, t) \, dV \]

Divergence theorem

\[ \nabla \cdot \vec{j}(\vec{r}, t) = -\frac{\partial \rho(\vec{r}, t)}{\partial t} \]

Steady currents

\[ \frac{\partial \vec{j}(\vec{r}, t)}{\partial t} = 0 \quad \nabla \cdot \vec{j}(\vec{r}, t) = 0 \]
Drift speed, drift velocity and current density

Suppose all particles have mass $m$ moving at same speed $v$
For fluids, mass flow rate in pipe is $m \cdot n \cdot v \cdot A$

For electric current, if charge of moving particles is $q$
$I = q \cdot n \cdot v \cdot A$
$v$ is called the “drift speed”

Current density $\vec{j}(\vec{r}) = qn\vec{v}(\vec{r})$
$\vec{v}(\vec{r})$ is called the drift velocity

Current through a surface $S$ is $\int_{S} \vec{j} \cdot \hat{n} \, dA$
$S = \text{closed surface}$
Equation of continuity: $\vec{\nabla} \cdot \vec{j}(\vec{r}) = -\frac{d\rho(\vec{r})}{dt}$
Mostly we consider charges moving in metal wires. Number density \( n \) of free charges is a fixed property of the metal (Cu, Al, etc).

Free charges + fixed ions = conductor with moving charge is charge neutral.

Free charges behave like an incompressible fluid. A wire is like a pipe for charge:

\[
\vec{j} = nq\vec{v} \propto \vec{v}
\]
Q: When does current flow through a wire?
A: When there is a difference in potential between the ends of the wire.
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 -> light, heat

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

Current through a wire (here, inside a bulb)
Free charge = electrons
more voltage -> brighter glow (larger current)
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

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