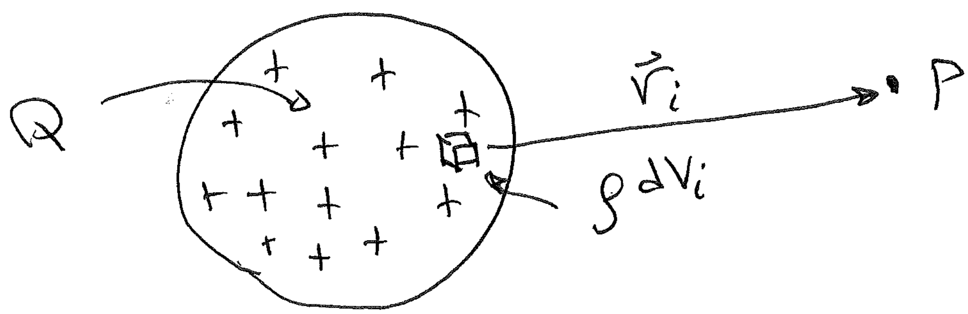
Setlist L7 (90 minutes)

Current and resistance
Prep: Current worksheet, nail burner.

1. Last Class: Gauss's Law
2. Gauss's Law, Maxwell's equations, and Maxwell.
3. The microscopic definition of current. The video and relation to biology.
4. Worksheet Q1
5. Show Python random walk. Explain random walk. Do one ion. Show that as we get more and more, the average gets closer to zero.
6. Show the Plinko!™ video.
7. Worksheet Q2
8. Talk about plink current. Show python drift. Note that for many ions we expect the average drift to me xDrift*numSteps.
9. Worksheet Q3
10. Clicker questions to debrief Q3 - do all three in a row. All of them increase the current.
11. Worksheet Q4
12. Debrief Q4
13. In a metal, how do we know that it's electrons that are moving?
14. Electric field and V. Wasn't the electric field supposed to be zero in a conductor?
15. Clicker Question - Current conservation - D
16. Current Density
17. Clicker Question - Greatest current density - B
18. Clicker Question - conductivity is a material constant - D
19. Demo - Nail burner, welding and current density
20. Superconductivity video. Conductors with infinite conductivity.

Gauss's Law: $\Phi = \dfrac{q_{inside}}{\epsilon_0} = EA$

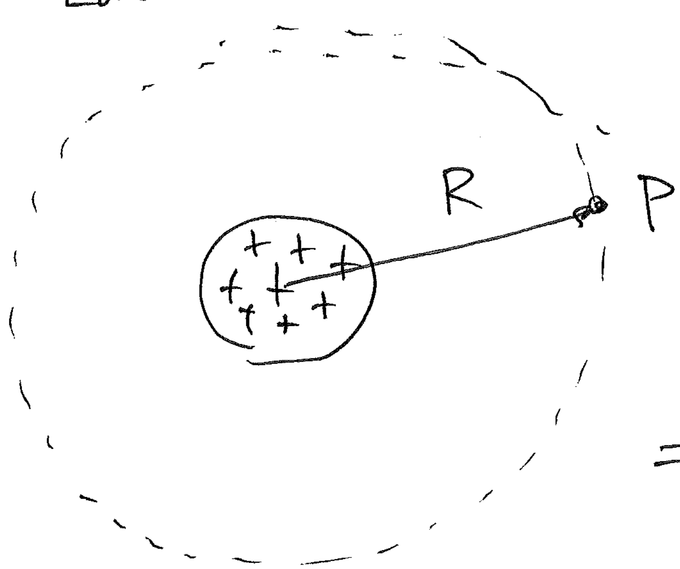
Consider the charge configuration below. How do we find the electric field?



We sum up all the electric fields from the tiny pieces.

$$\vec{E} = \sum_i \frac{\rho\, dV_i}{r_i^2}\,\hat{r}_i$$

Very complicated. With Gauss's Law

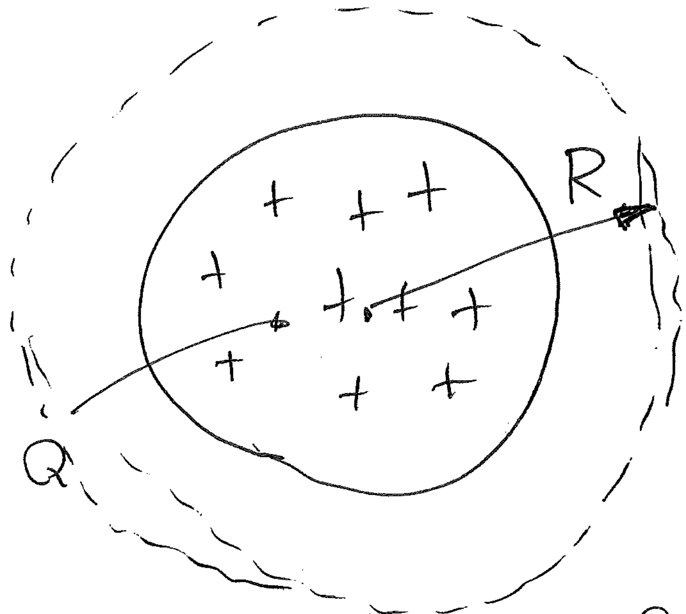


$$\Phi = EA = \frac{Q_{inside}}{\epsilon_0}$$

$$\Rightarrow E\,4\pi R^2 = \frac{Q}{\epsilon_0}$$

$$\Rightarrow E = \frac{Q}{4\pi\epsilon_0 R^2}$$

We can easily find the electric field. Another thing we notices is that if the charge changes size

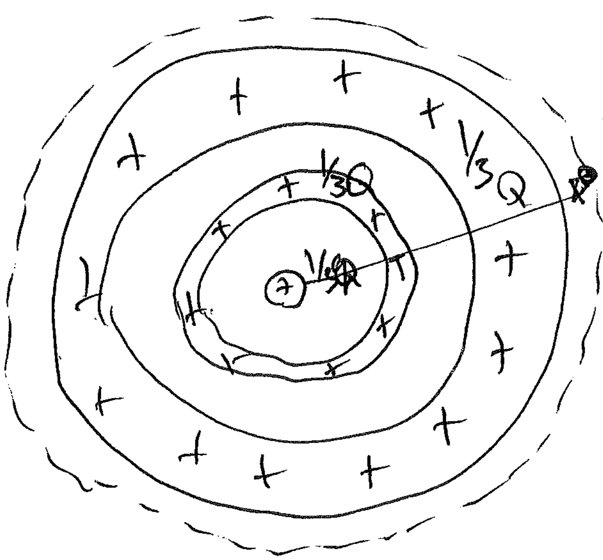


$$A_1 E = \frac{Q_{inside}}{\epsilon_0}$$

$$\Rightarrow E = \frac{Q}{4\pi\epsilon_0 R^2}$$

the electric field stays the same!

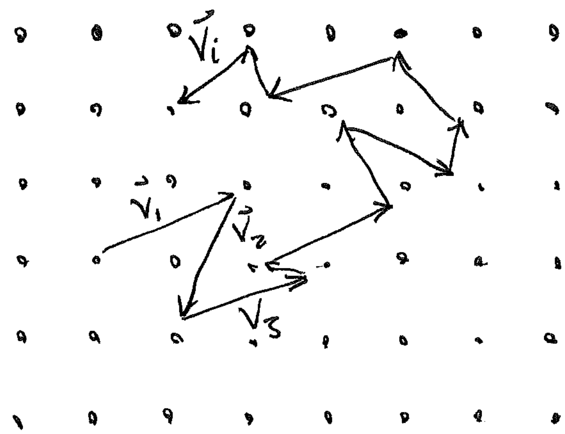
In fact, any charge distribution inside with a spherical symmetry has the same electric field!



$$E = \frac{Q}{4\pi\epsilon_0 R^2}$$

Drift speed (the average motion of electrons)

Consider an electron bouncing around in a grid of atoms.



After a single bounce, and before the next bounce, its velocity is

$$\vec{v}(t) = \vec{v}_0 \qquad \text{constant.}$$

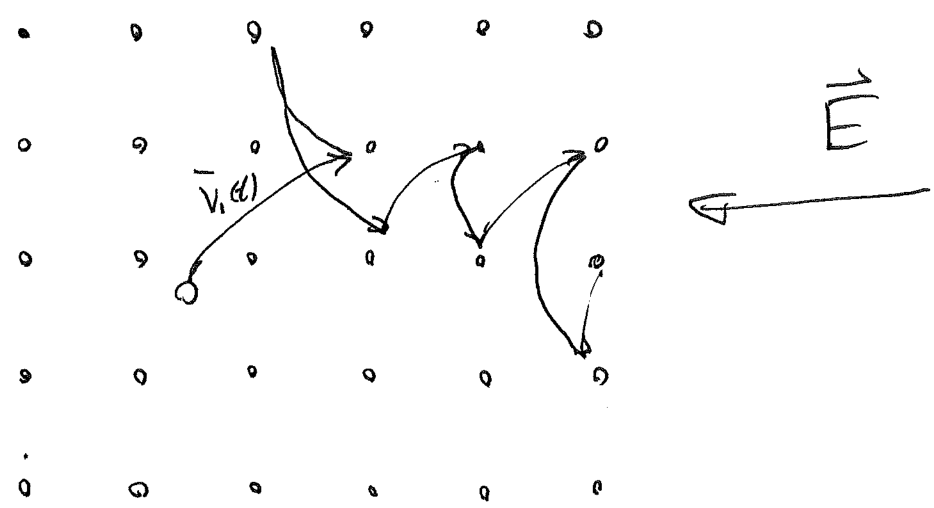
After many bounces it ends up in some spot. Now imagine another ion. It acts the same but ends up in a different spot.

On average, the velocity of a bunch of ions is

$$\langle \vec{v}(t) \rangle = 0.$$

they all cancel each other out.

Now let's think of an election in an electric field.



After a single bounce

$$\vec{v}(t) = \vec{v}_0 + \frac{qE}{m}t$$

this is the time betwee bounces.

For many elections, the avesge velocity between bounces is

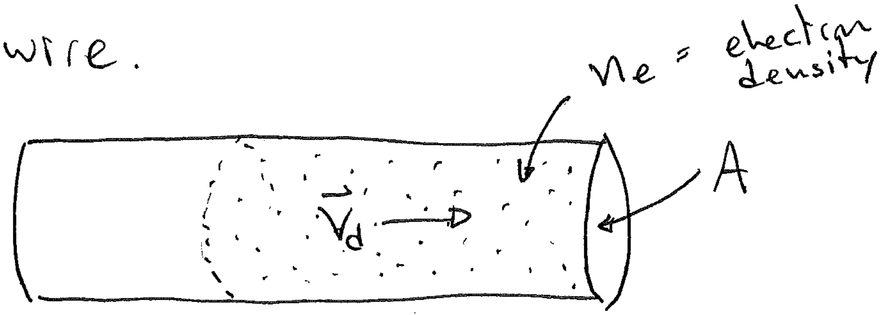
$$\langle \vec{v}(t) \rangle = \cancel{\langle \vec{v}_0 \rangle}^{0} + \langle \frac{qE}{m} t \rangle$$

$$\boxed{\vec{v}_{drift} = \frac{q\vec{E}}{m} \langle t \rangle}$$

average time between bounces.

this is called the drift current.

Now that we have the drift velocity, let's think of what this looks like in a wire.



The number of electrons that pass through A after time Δt is

$$N = v_d \Delta t \, A \, n_e$$

The amount of charge is

$$N = q \, v_d \, A \, n_e \, \Delta t$$

The charge per unit time is

$$\boxed{I = \frac{N}{\Delta t} = q \, n_e \, v_d \, A}.$$

This is the current related to the drift velocity.

Substituting in the drift velocity we find

$$\vec{I} = \frac{n_e q^2 \langle t \rangle}{m} A \vec{E}$$

call this mess the conductivity denoted. σ

So

$$\vec{I} = \sigma A \vec{E}$$

proportional to $\vec{E}$!

The conductivity σ is an indicator of how good a conductor a material is.

Even more fundamental is the current density

$$\vec{J} = \frac{\vec{I}}{\vec{E}} = \sigma A .$$