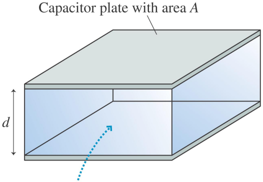
The Energy in the Electric Field



The capacitor's energy is stored in the electric field in volume *Ad* between the plates.

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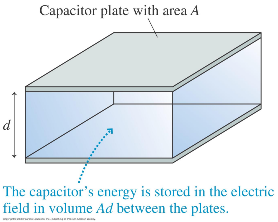
- Where is the energy in a capacitor actually stored? Where is the "spring" we are stretching?

The Energy in the Electric Field



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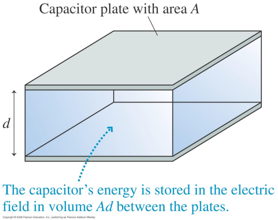

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$$U_C = \frac{C(\Delta V)^2}{2} = \frac{1}{2}\frac{\epsilon_0 A}{d}(Ed)^2 = \frac{\epsilon_0}{2}(Ad)E^2$$

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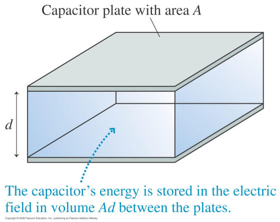

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- In fact, let's define the energy density in the capacitor

$$u_E = \frac{\text{energy stored}}{\textit{Volume}} = \frac{U_C}{Ad} = \frac{\epsilon_0}{2}E^2$$

The Energy in the Electric Field

Example 30.10

The plates of a parallel-plate capacitor are separated by 1.0mm. What is the energy density in the capacitor's electric field if the capacitor is charged to 500V?

- The electric field is

$$E = \frac{\Delta V_C}{d} = \frac{500V}{0.0010m} = 5.0 \times 10^5 V/m$$

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$$E = \frac{\Delta V_C}{d} = \frac{500V}{0.0010m} = 5.0 \times 10^5 V/m$$

- The energy density is then

$$u_E = \frac{\epsilon_0}{2}E^2 = \frac{(8.85 \times 10^{-12} C^2/Nm^2)(5.0 \times 10^5 V/m)^2}{2} = 1.1 J/m^3$$

Current and Resistance (Chapter 31)

- Until now we have been talking about electrostatics. Now we turn to moving charges - current and resistance.

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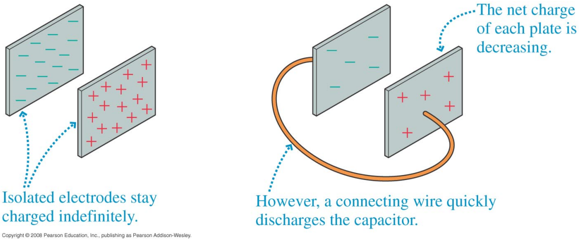
- What causes charges to flow through a wire? What determines the properties of the flow?
- We will need to understand this at both the macroscopic and microscopic levels.
- All that stuff we have been learning about electric field was not just a waste of time...

The Electron Current (31.1)



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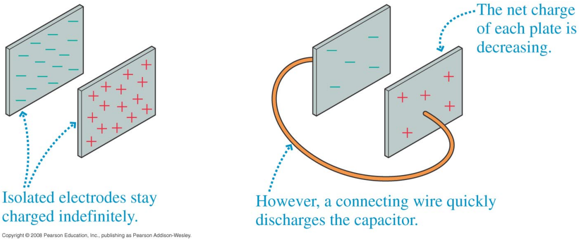

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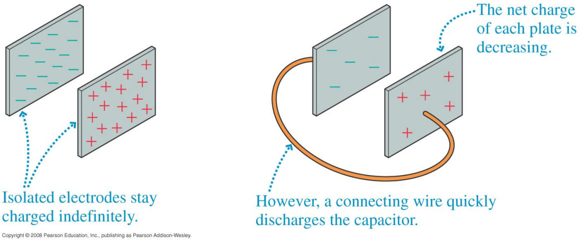

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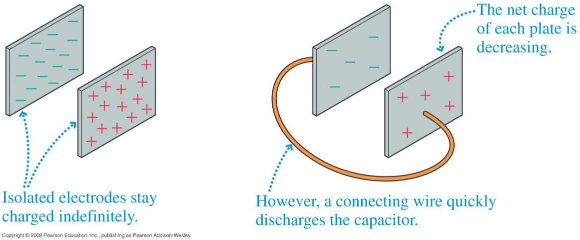

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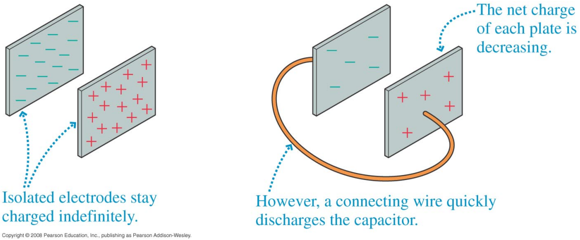

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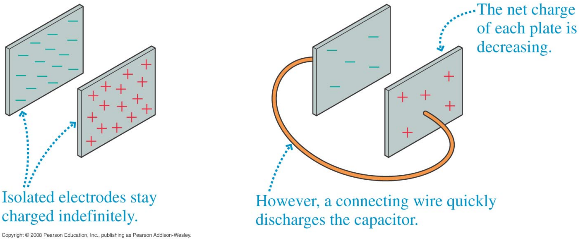

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  - What makes it move?
  - How fast does it move?
  - What controls its motion?

Charge Carriers

- So, what happens when a capacitor discharges? What is moving? Are positive charges moving or negative?

When a metal bar accelerates to the right, inertia causes the charge carriers to be displaced to the rear surface. The front surface becomes oppositely charged.

Sea of positive charge carriers

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Sea of negative charge carriers

Charge Carriers

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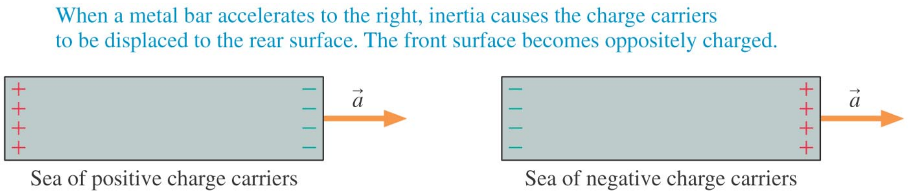
- Of course, it is the electrons that are moving. But how do we know?



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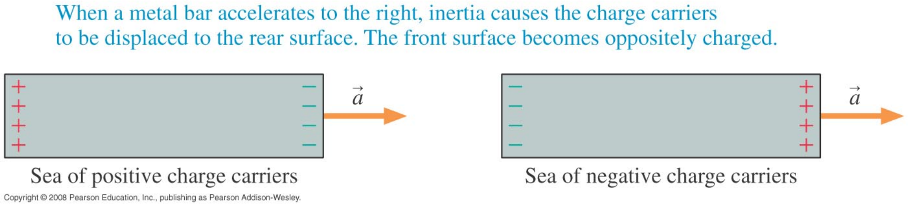
Charge Carriers

- So, what happens when a capacitor discharges? What is moving? Are positive charges moving or negative?
- Of course, it is the electrons that are moving. But how do we know?
- A very neat experiment was performed by Tolman and Stewart in 1916. Imagine the electrons are “fluid” and throw a metal rod. See what charge the “back-end” picks up....it is negative!



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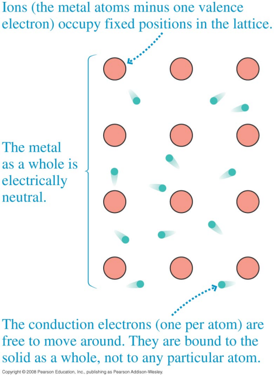

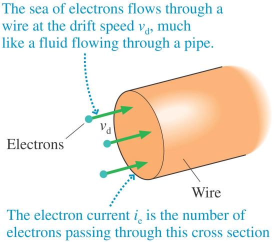

- In a metal each atom has a conduction electron which is free to move around, generally at random.

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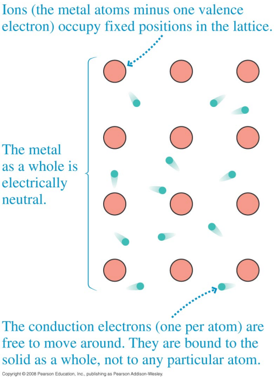

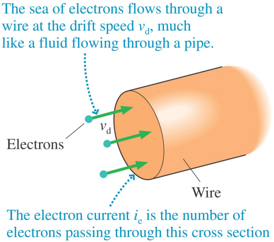

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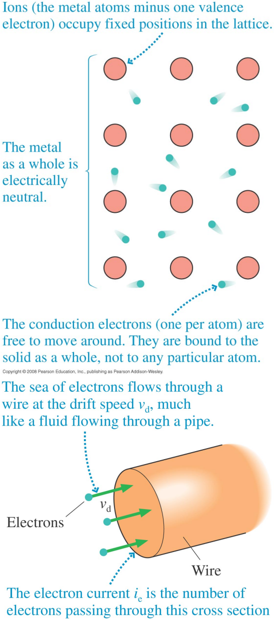

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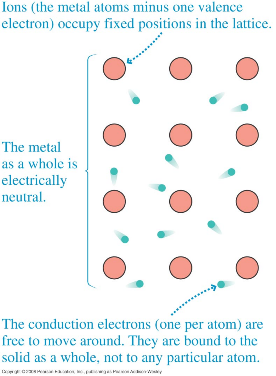

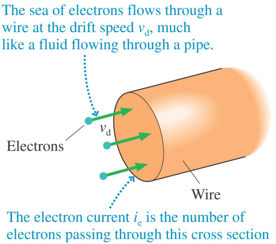

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- However, we can push the entire sea of electrons in one direction using an electric field (liquid through a pipe).
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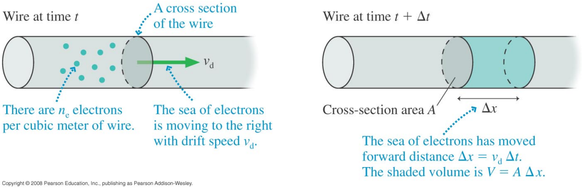
- If you push the electrons and count the number that pass per second you can define the electron current as

$$i_e = \frac{N_e}{\Delta t}$$

Charge Carriers



- The figure above shows the sea of electrons moving to the right a distance Δx in time Δt.

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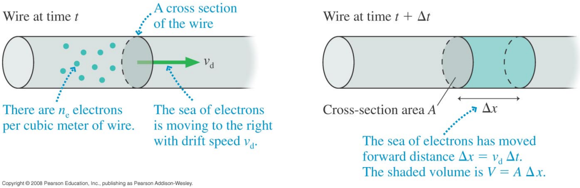

- The figure above shows the sea of electrons moving to the right a distance Δx in time Δt.
- The electrons travel $\Delta x = v_d \Delta t$ to the right, forming a cylinder of volume $V = A\Delta x$. The number of electrons in the cylinder is

$$N_e = n_e V = n_e A \Delta x = n_e A v_d \Delta t$$

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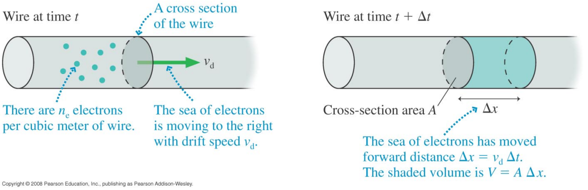

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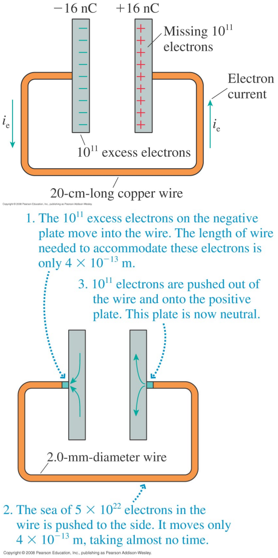
- The electron current in the wire is then

$$i_e = n_e A v_d$$

increase the current by increasing the electron density, the area of the "pipe" or the drift velocity.

Discharging a Capacitor



- That drift velocity is pretty slow. It would take a long time to turn on a light if electricity flowed from the switch to the bulb at 10^{-4}m/s!

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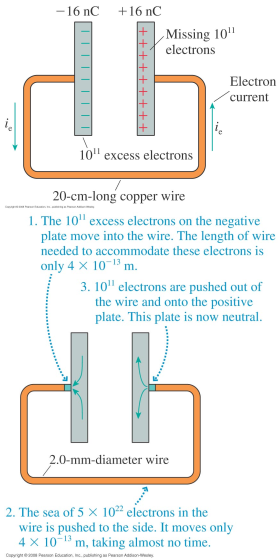

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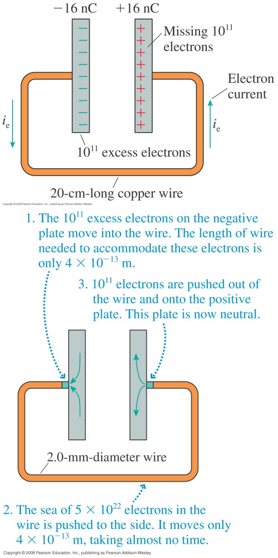

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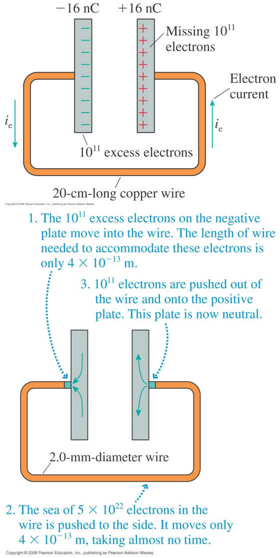

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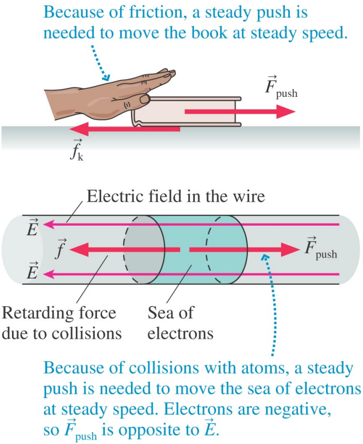
- The length of copper wire which holds 10^{11} electrons is only 4×10^{-13}m...which only takes 4ns to cross at v_d.



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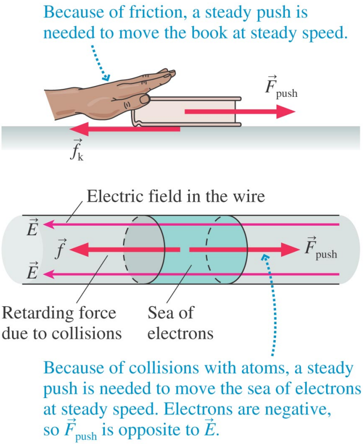
- If you push a book across a table you need to keep pushing or it will stop (and heat up) due to friction.

Creating a Current (31.2)



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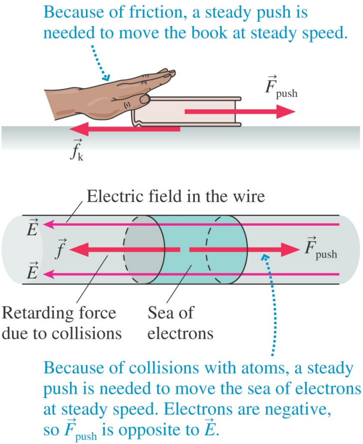

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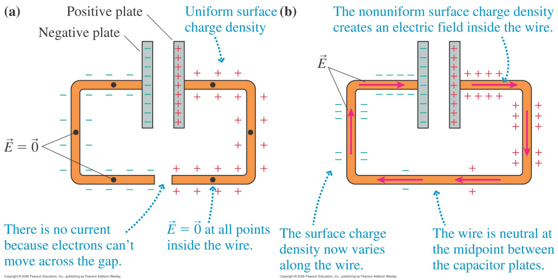
- To push the electrons you need to set up an electric field in the conductor. An electron current is a non-equilibrium motion of charges sustained by an internal electric field.

Establishing the Electric Field in a Wire



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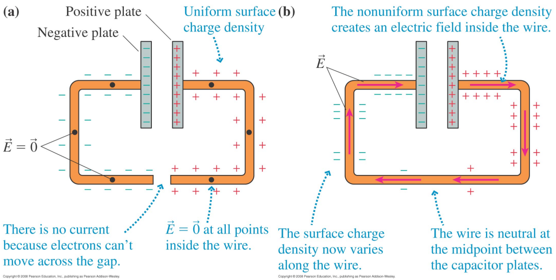

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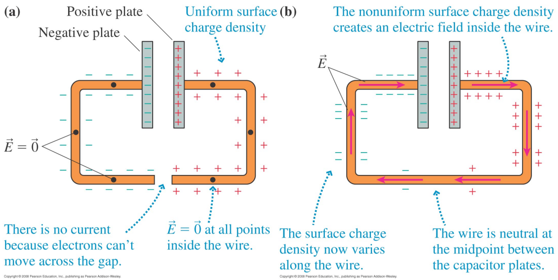

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- On the right is a picture just after connection. Positive flow into the negative side has begun but there is still a non-uniform distribution.
- The non-uniform distribution creates an internal electric field...which sustains a current.

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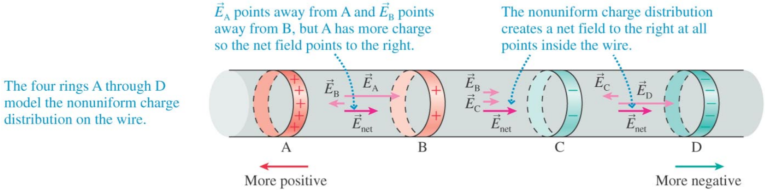

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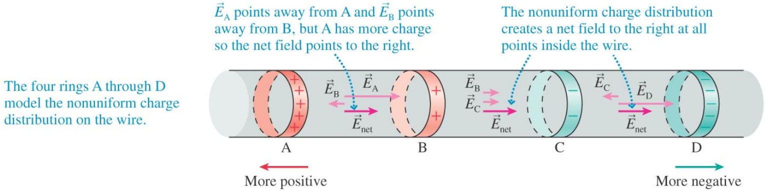

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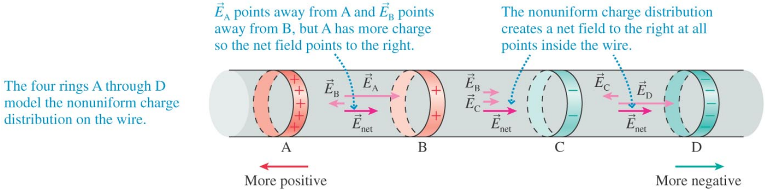

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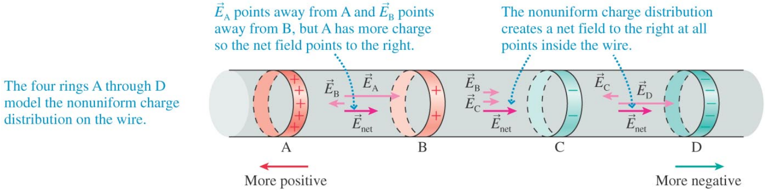

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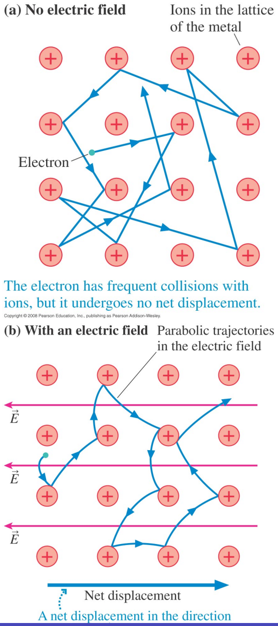
- The electric field drives charges inside the wire.

A Model of Conduction



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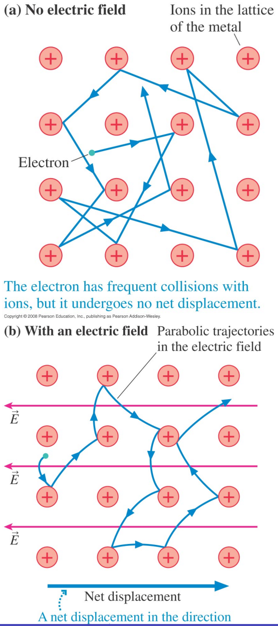

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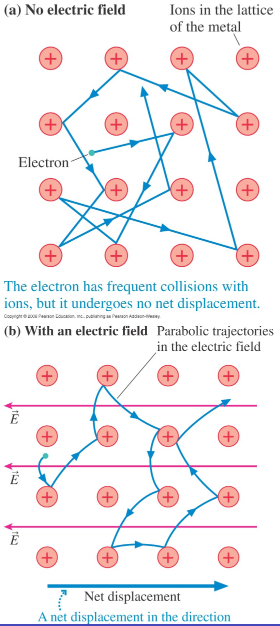

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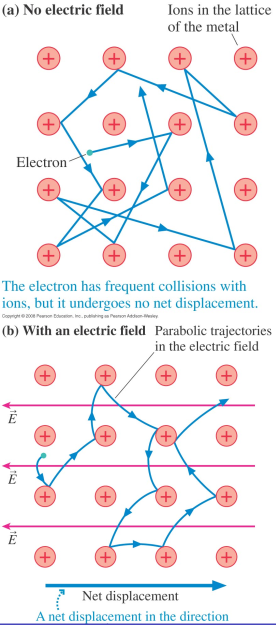

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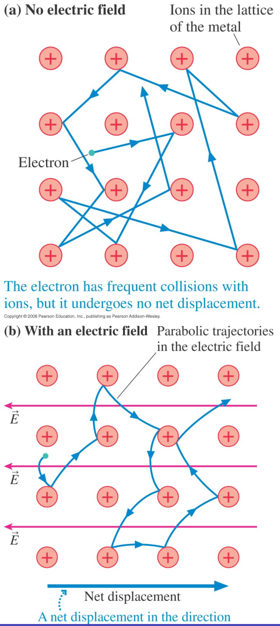

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- There is a net movement to the right, but it is small compared to the random motion.