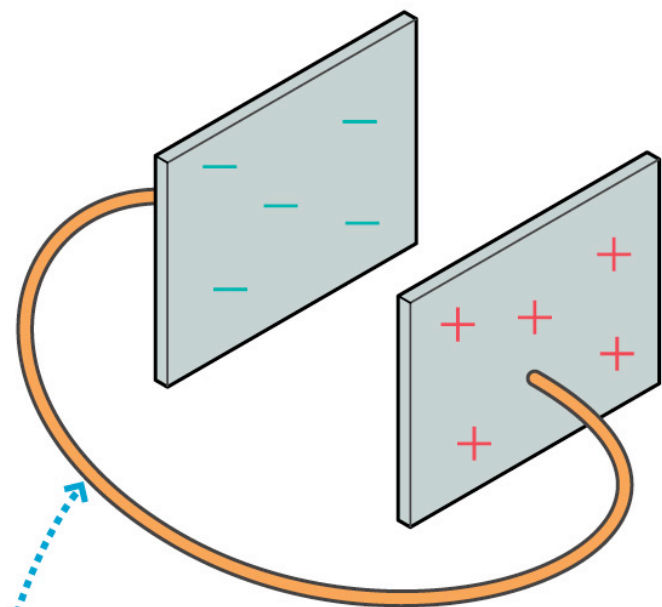


# Lecture 24

- start chapter 31 (Current and Resistance)
- creating current: model of conduction

# Outline of Chapter 31 (Current and Resistance)

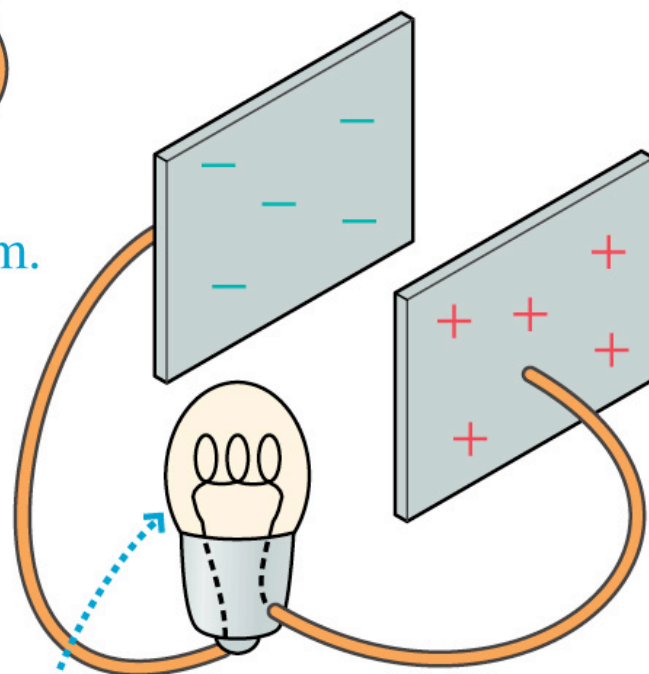
- motion of charges thru' wire (current): due to electric field inside wire (relation to charging/electrostatics)
- law of conservation of current
- relate current to conductivity



The connecting wire gets warm.

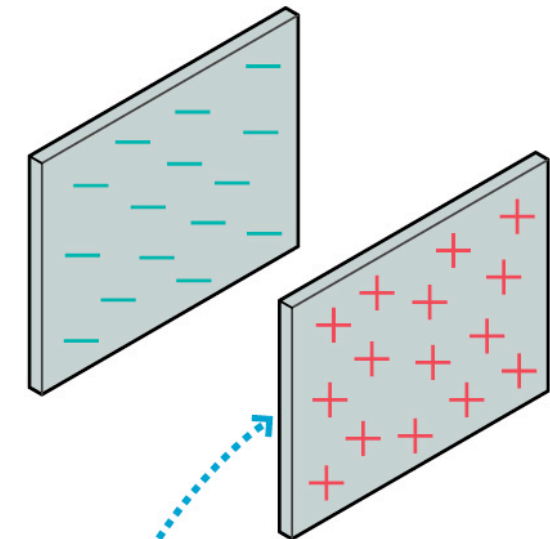
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indicators of  
current



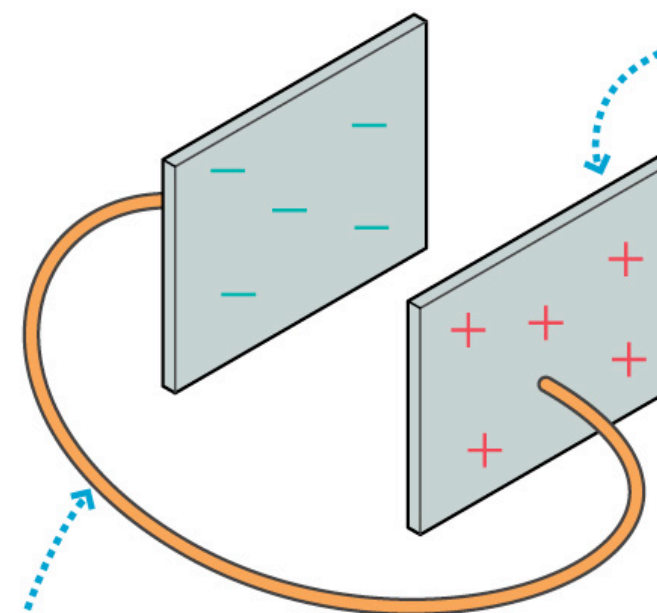
A light bulb glows. The light bulb filament is part of the connecting wire.

(a)



A charged parallel-plate capacitor  
excess charge moves (current)

(b)



The net charge  
of each plate is  
decreasing.

A connecting wire discharges the capacitor.

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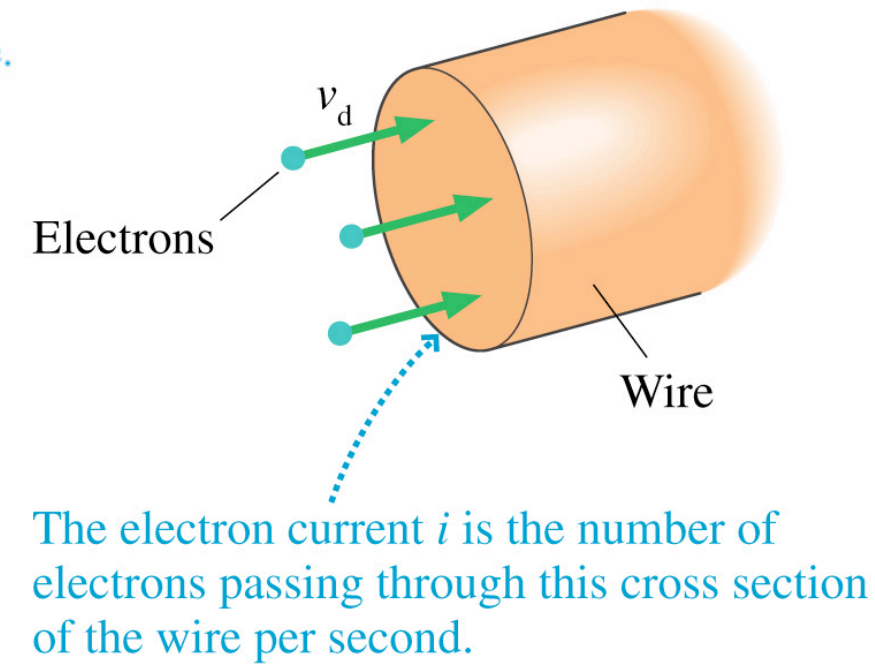
# Electron Current

- charge carriers (that move): electrons in metals
- no current : electrons moving rapidly, no net motion
- push on sea of electrons using  $\vec{E}$ : drift speed  $v_d$  superposed on random thermal

Ions (the metal atoms minus one valence electron) occupy fixed positions in the lattice.

The metal as a whole is electrically neutral.

The conduction electrons (one per atom) are free to move around. They are bound to the solid as a whole, not to any particular atom.



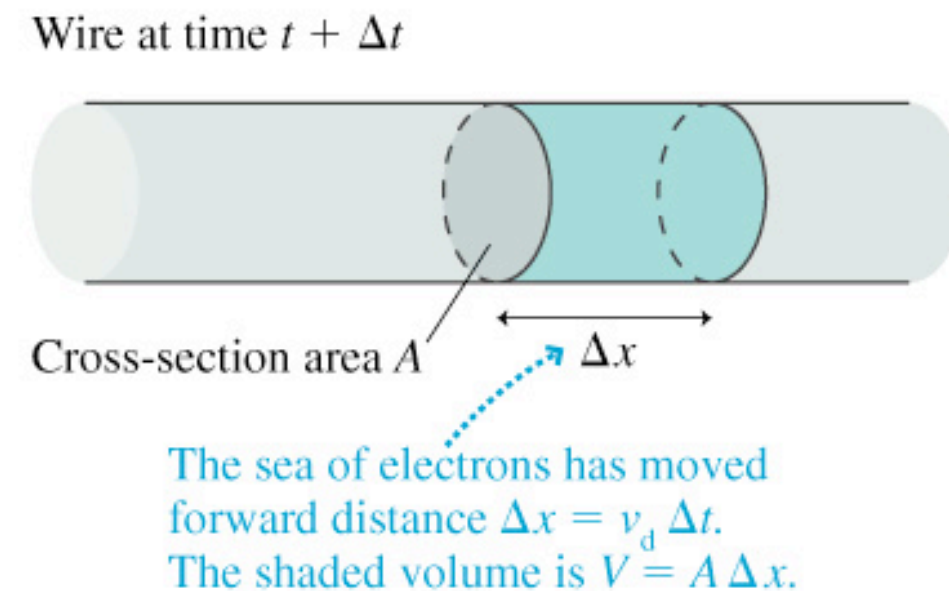
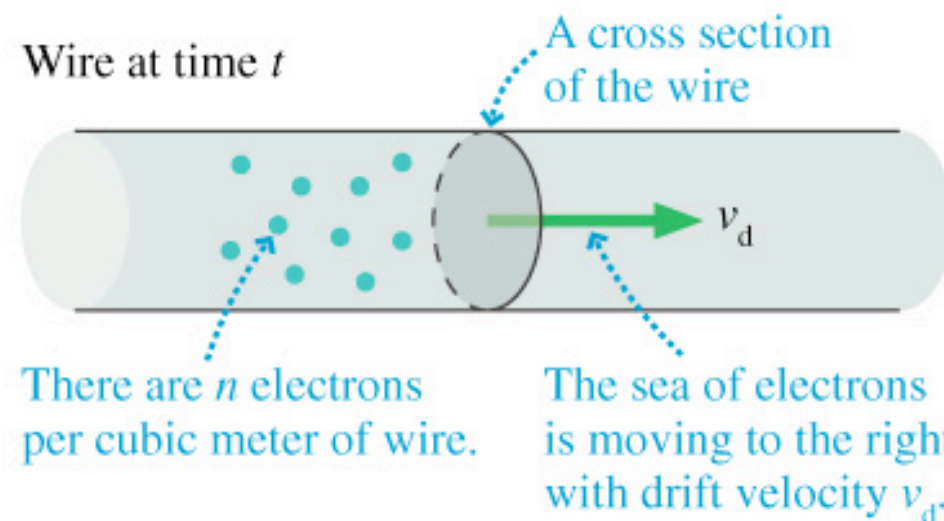
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$$N_e = i\Delta t$$

$$N_e = nV = nA\Delta x = nAv_d\Delta t$$

$$i = nAv_d$$

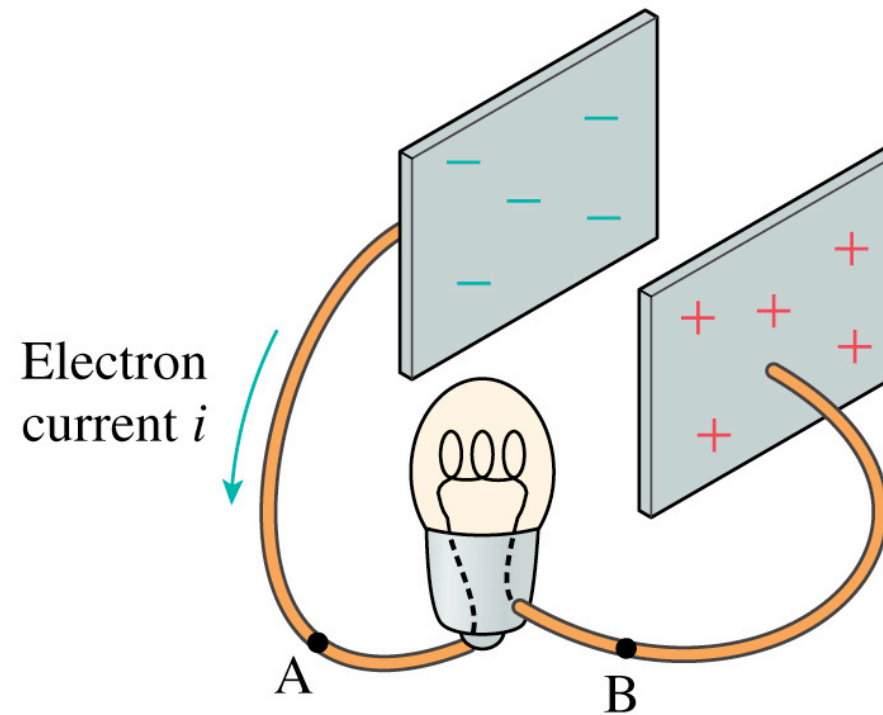
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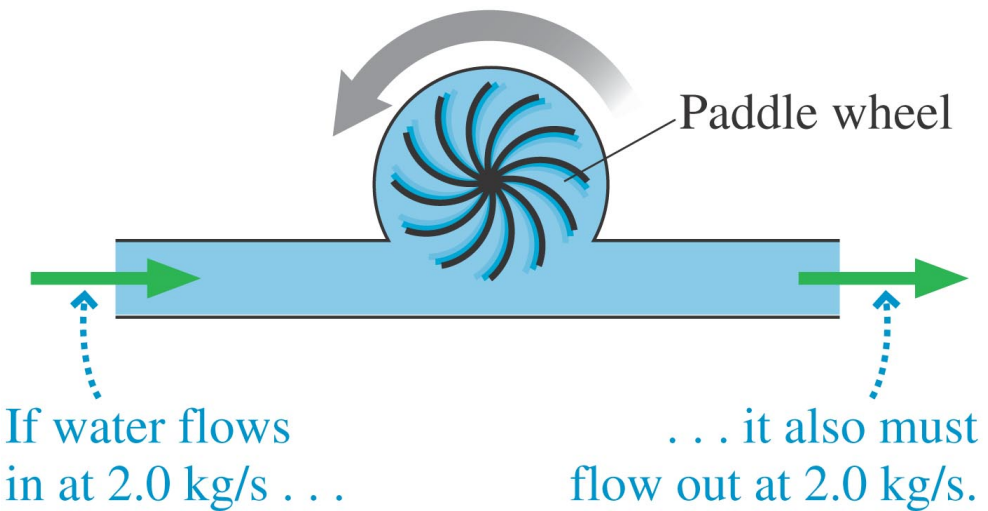


- electron current same at A and B: can't be created/destroyed/stored: lightbulb uses energy (work done to push electrons)

# Conservation of current

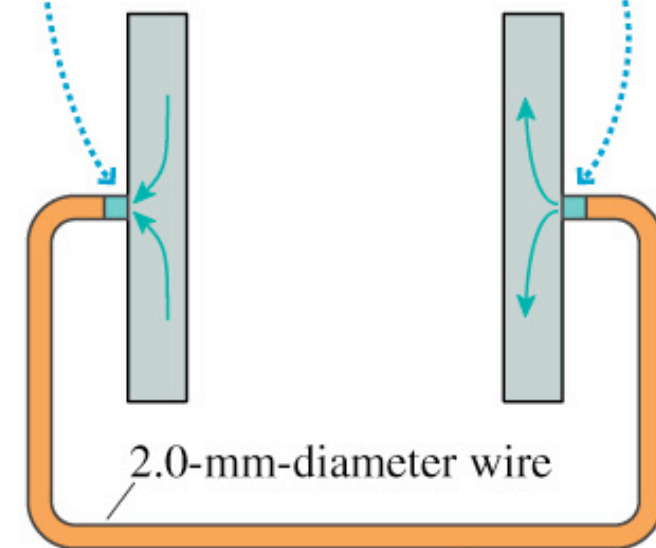
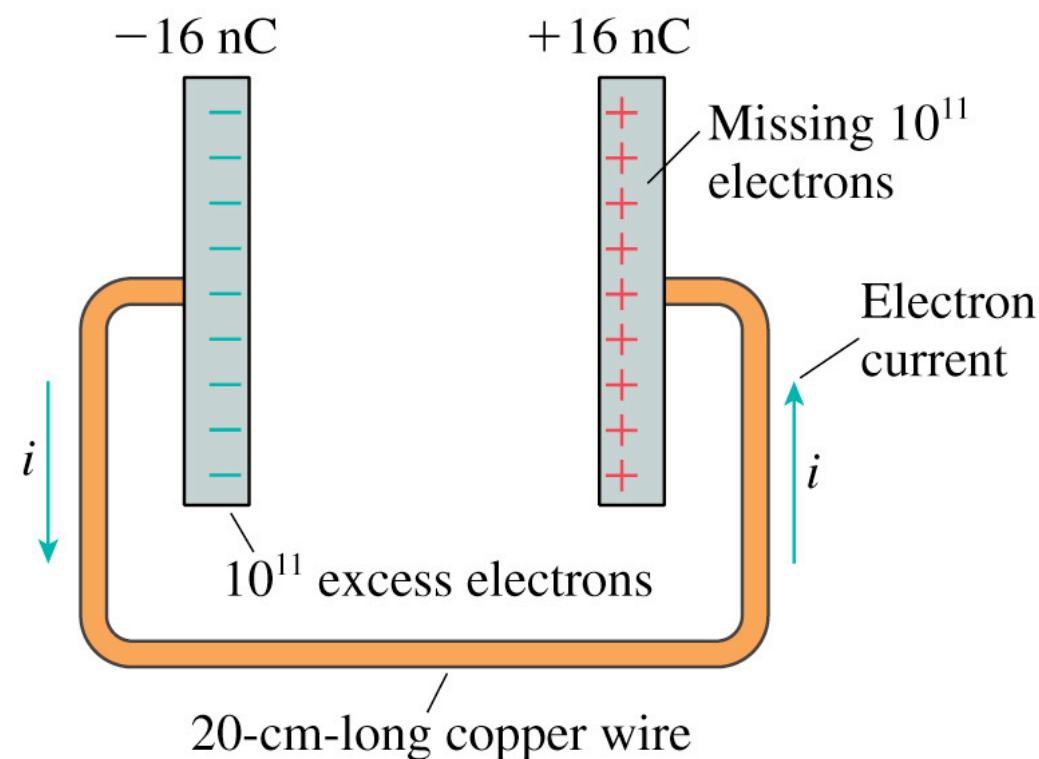


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1. The  $10^{11}$  excess electrons on the negative plate move into the wire. The length of wire needed to accommodate these electrons is only  $4 \times 10^{-13}$  m.

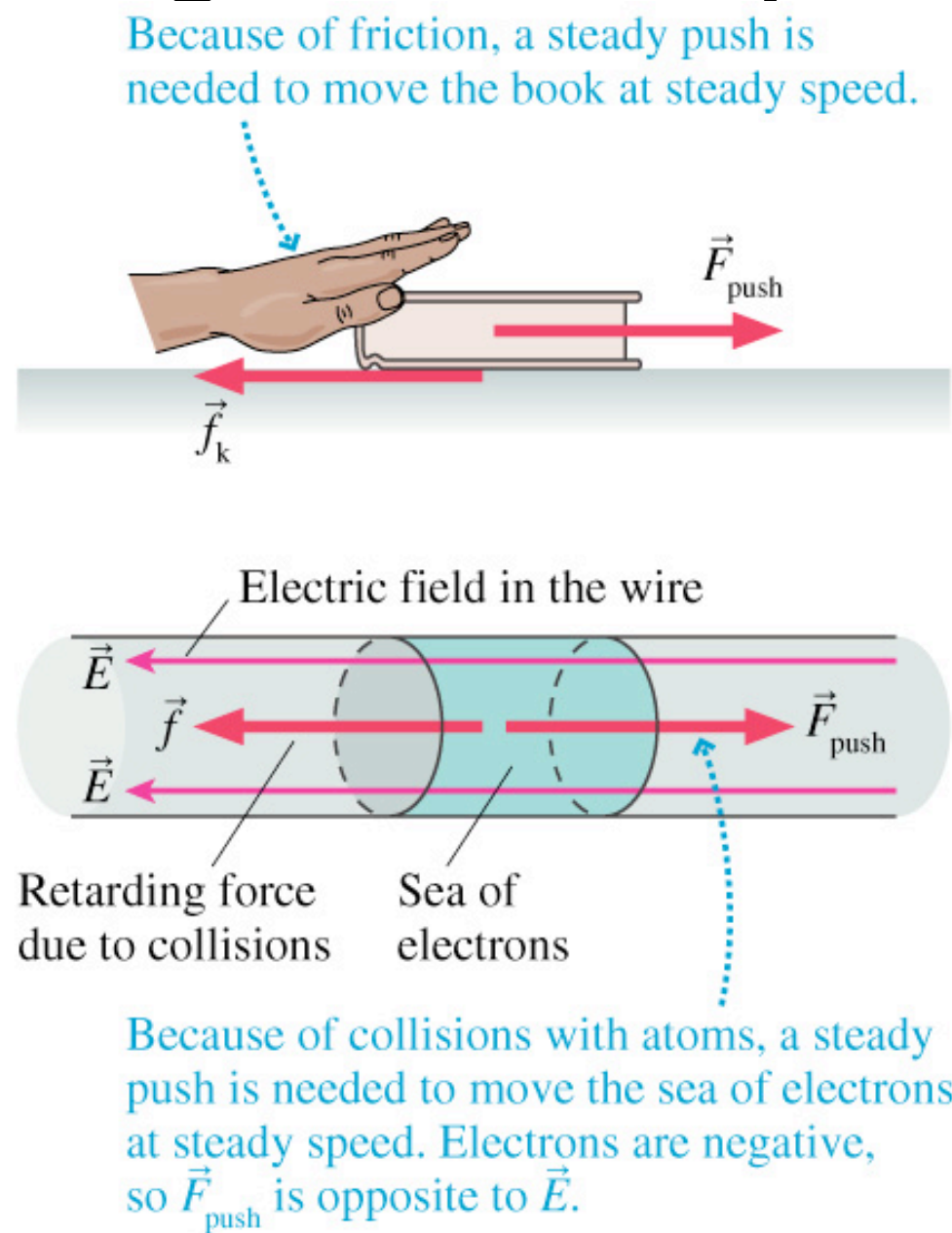
3.  $10^{11}$  electrons are pushed out of the wire and onto the positive plate. This plate is now neutral.



2. The sea of  $5 \times 10^{22}$  electrons in the wire is pushed to the side. It moves only  $4 \times 10^{-13}$  m, taking almost no time.

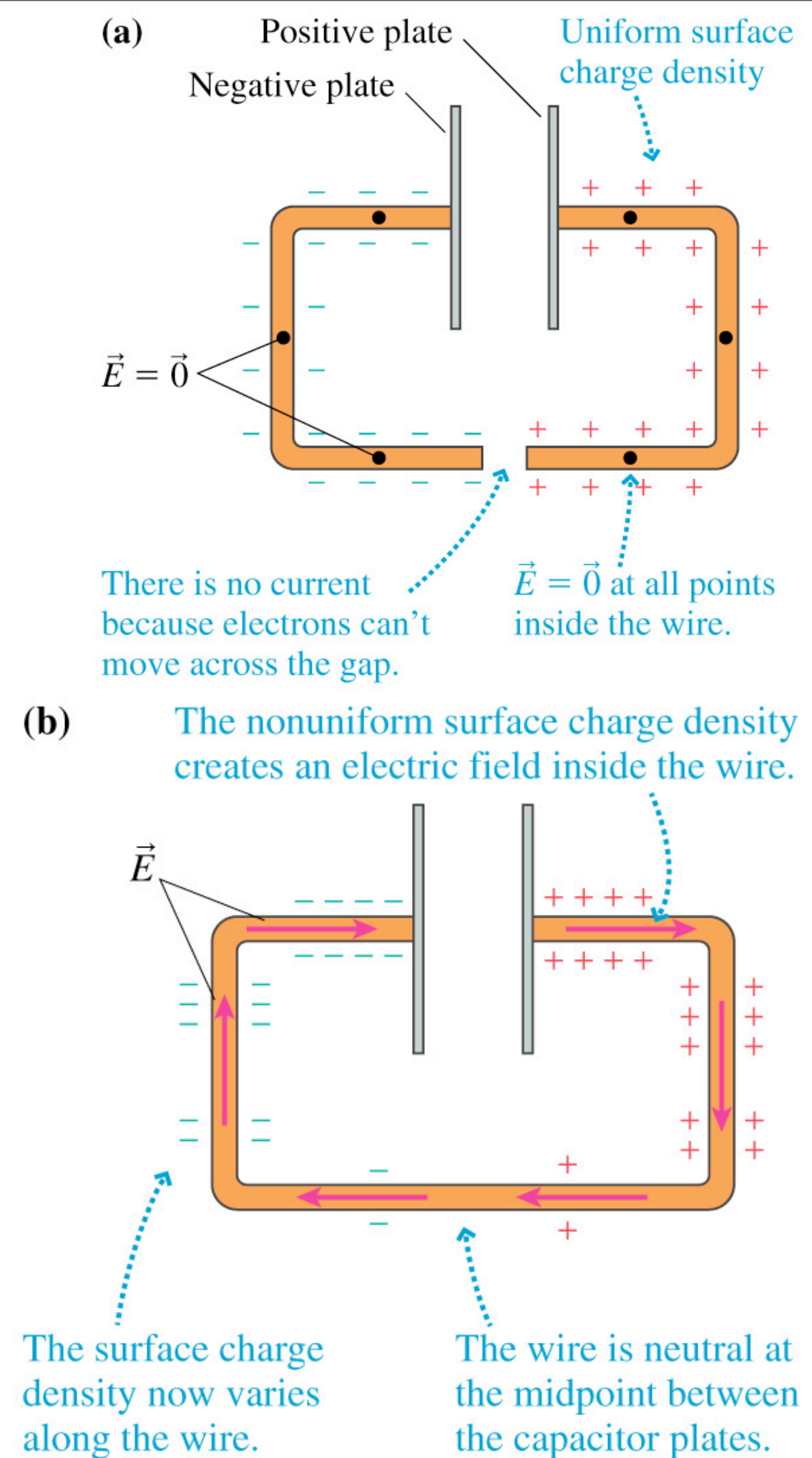
- wire full of electrons, don't have to move from plate to plate (just shift/rearrange)

# Creating Current by $\vec{E}$



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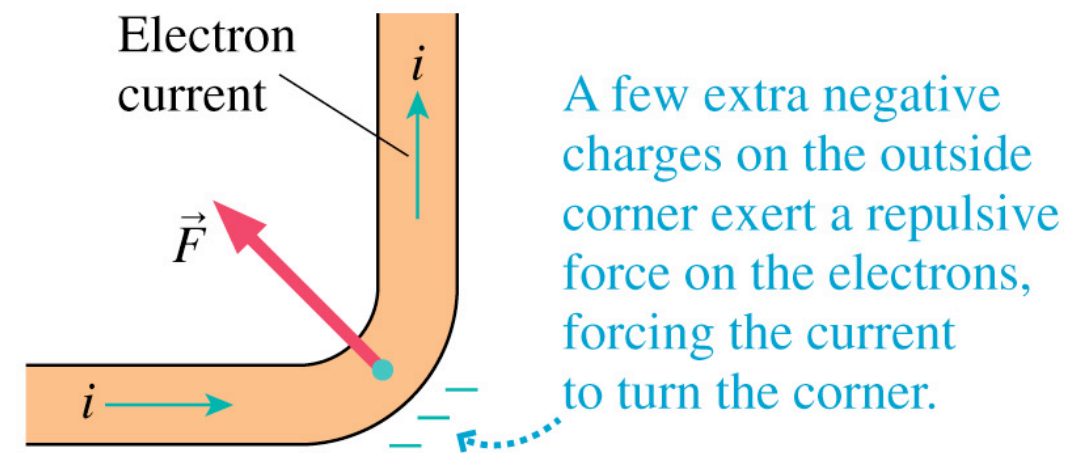
- electron current is non-equilibrium motion of charges sustained by internal  $\vec{E}$
- establishing  $\vec{E}$  in wire



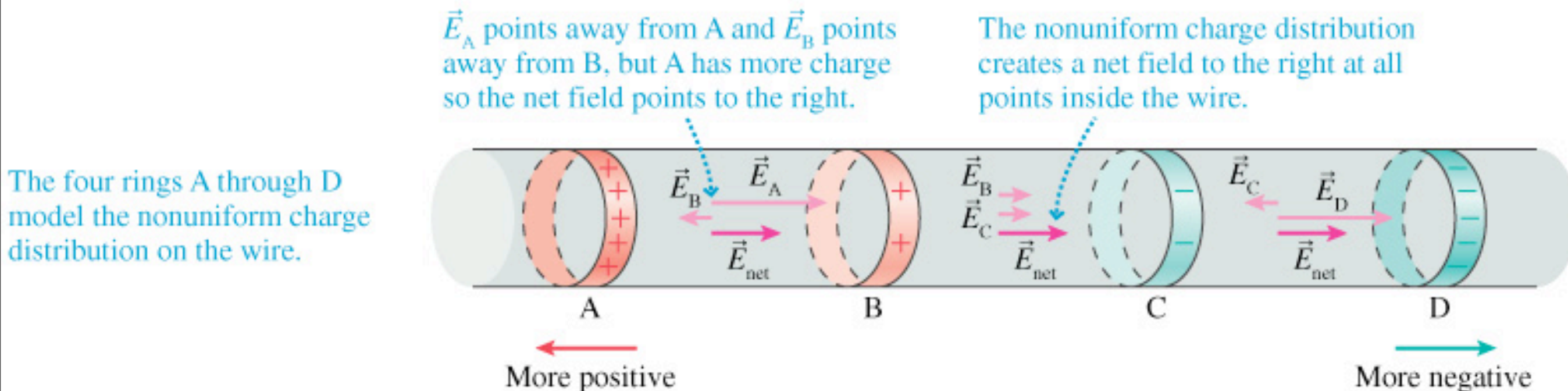


# Creating Current by $\vec{E}$

- model wire with rings of varying charge: use  $\vec{E}$  (i) points away from positive ring; (ii)  $\propto$  charge and (iii) decrease with distance
- net  $\vec{E}$  inside wire (from non-uniform charge distribution) pushes electron current
- how electron current turns a corner

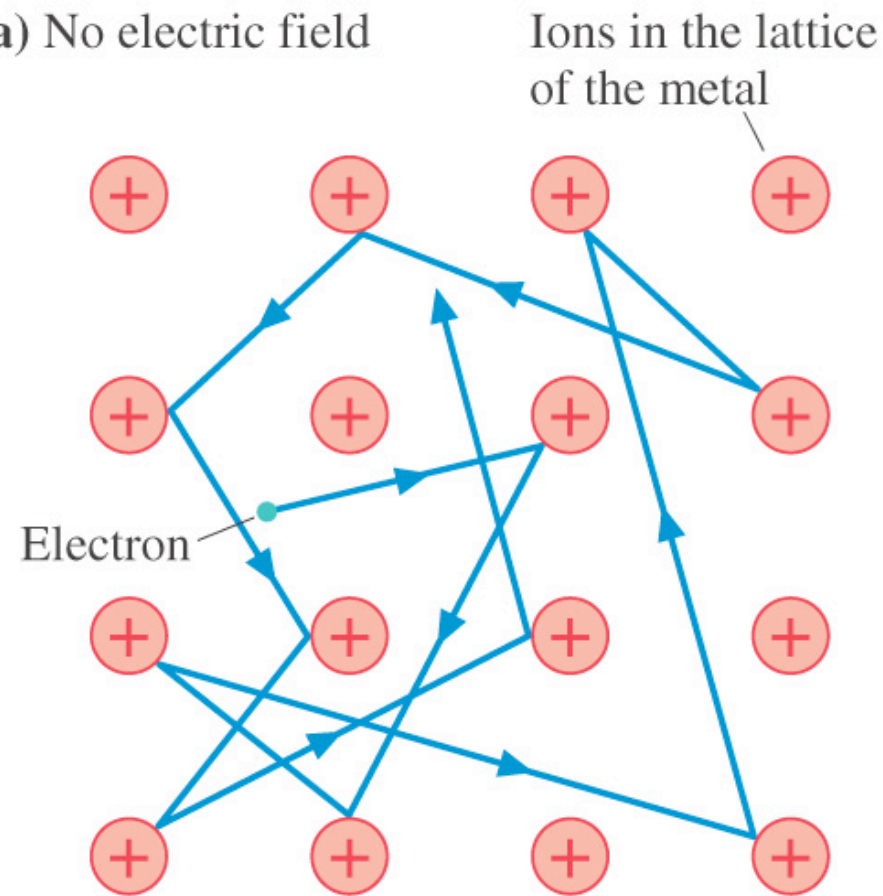


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# Model of conduction

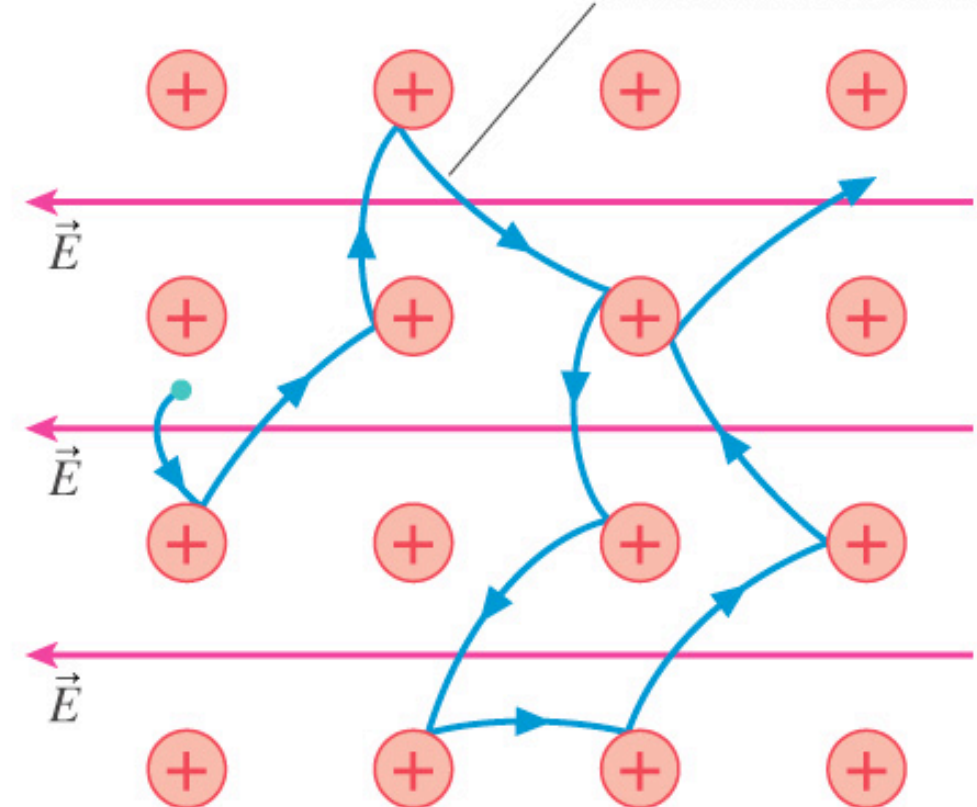
(a) No electric field



The electron has frequent collisions with ions, but it undergoes no net displacement.

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(b) With an electric field



A net displacement in the direction opposite to  $\vec{E}$  is superimposed on the random thermal motion.

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- micro/macro link (like relating  $T$ ,  $p$  f gas to energy of molecules): conduction electrons are “free” (average kinetic energy  $\frac{3}{2}kT$  )
- $\bar{E} = 0$ : zero average velocity; straight lines between collisions
- $\bar{E} \neq 0$ : drift in direction opposite to  $\vec{E}$  ; net (small) motion (between collisions) superimposed on (larger) thermal motion

# Model of conduction (current $\propto \bar{E}$ )

- After collision:  $a_x = \frac{F}{m} = \frac{eE}{m}$ ;  $v_x = v_{ix} + a_x \Delta t = v_{ix} + \frac{eE}{m} \Delta t$
- till next collision (transfers energy to ion; raises temperature of wire); rebounds with new velocity (“reset”)
- repeated speeding up (between collisions) non-zero average velocity for single electron (drift speed,  $v_d$ )
- average over all electrons:  $v_d = \bar{v}_x = \bar{v}_{ix} + \frac{eE}{m} \bar{\Delta t}$   
 $\tau \equiv \bar{\Delta t}$  (some shorter, other larger):  $v_d = \frac{e\tau}{m} E \Rightarrow$  Using  $i = nAv_d \rightarrow i = \frac{ne\tau A}{m} E$

(b)

(a) The acceleration between collisions (the slope of the line) is  $a = eE/m$ .

