ELECTRIC CURRENT & RESISTANCE

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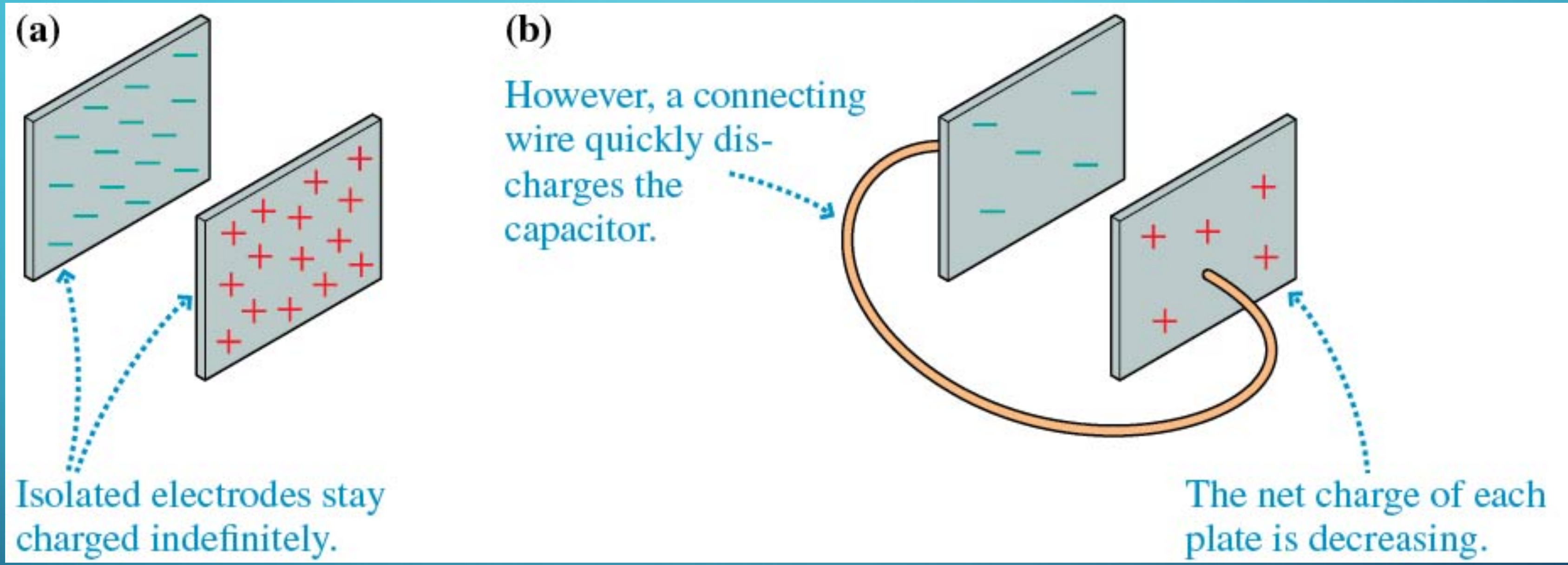
ESSENTIAL QUESTIONS

- What causes electric current?
- What's moving in electric current?
- How fast do the charges move in a wire?
- What impedes electric current?
- What laws and relationships govern electric current?

HOW CAN WE DETECT THE FLOW OF CHARGE?



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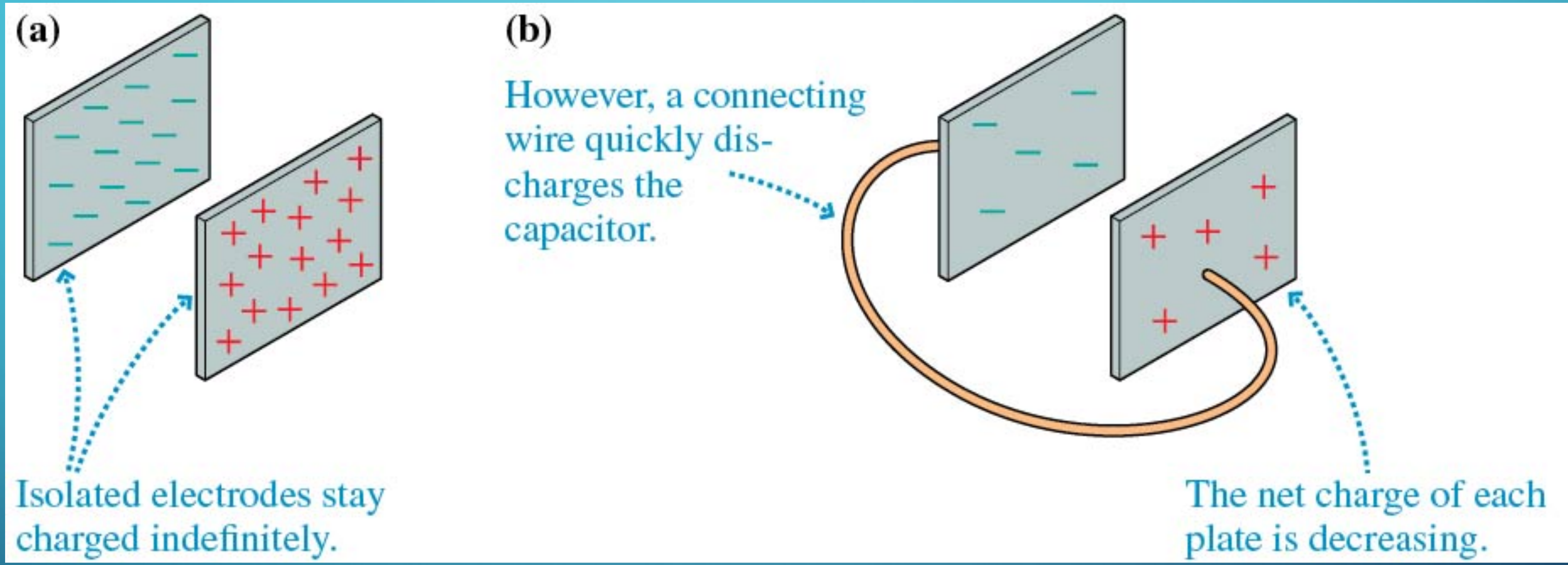

Two ways mentioned in your reading were heat and magnetic effects (as detected by a compass needle).

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- It depends on the materials…
  - In a liquid solution positive and negative ions can both move, but in a solid metal wire, it's the electrons that move.

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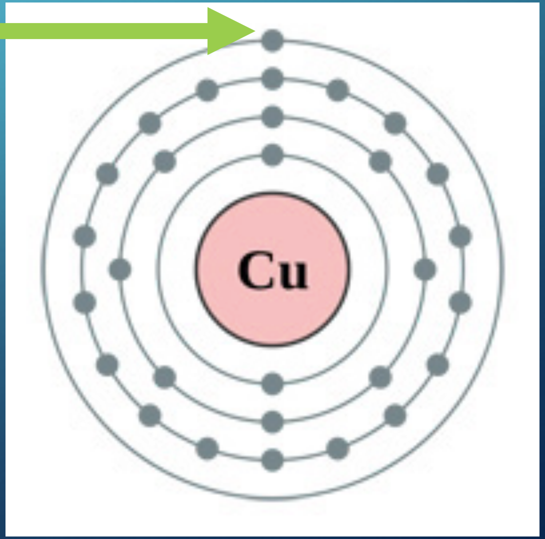

http://www.edinformatics.com/math_science/why_metals_conduct.htm

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- It depends on the materials…
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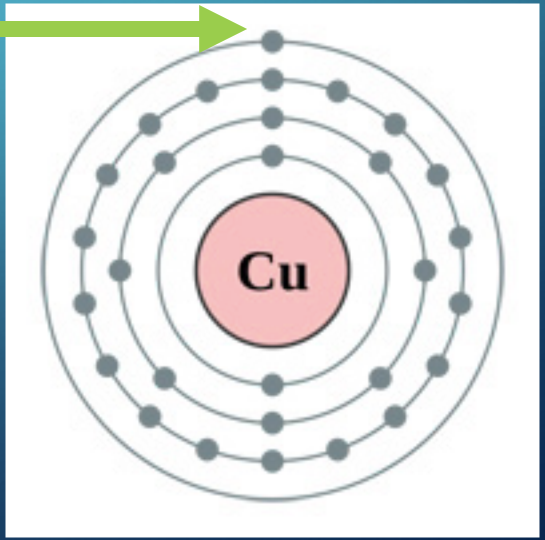
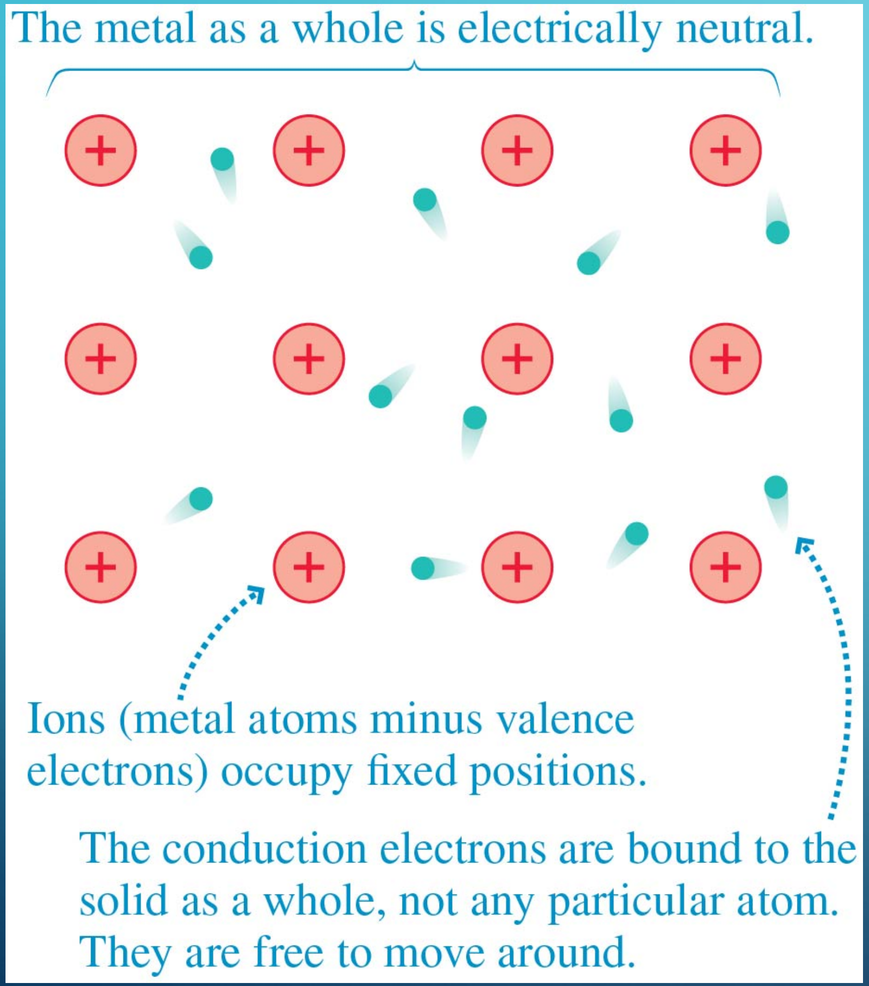
  - Which electrons?
  - Why can't the positive protons move?
    - They're tightly bound in the nucleus



SO…



…if electrons are the charge carriers in metal wires, how do we get them to move in a certain direction?

THE ANSWER OF COURSE IS…

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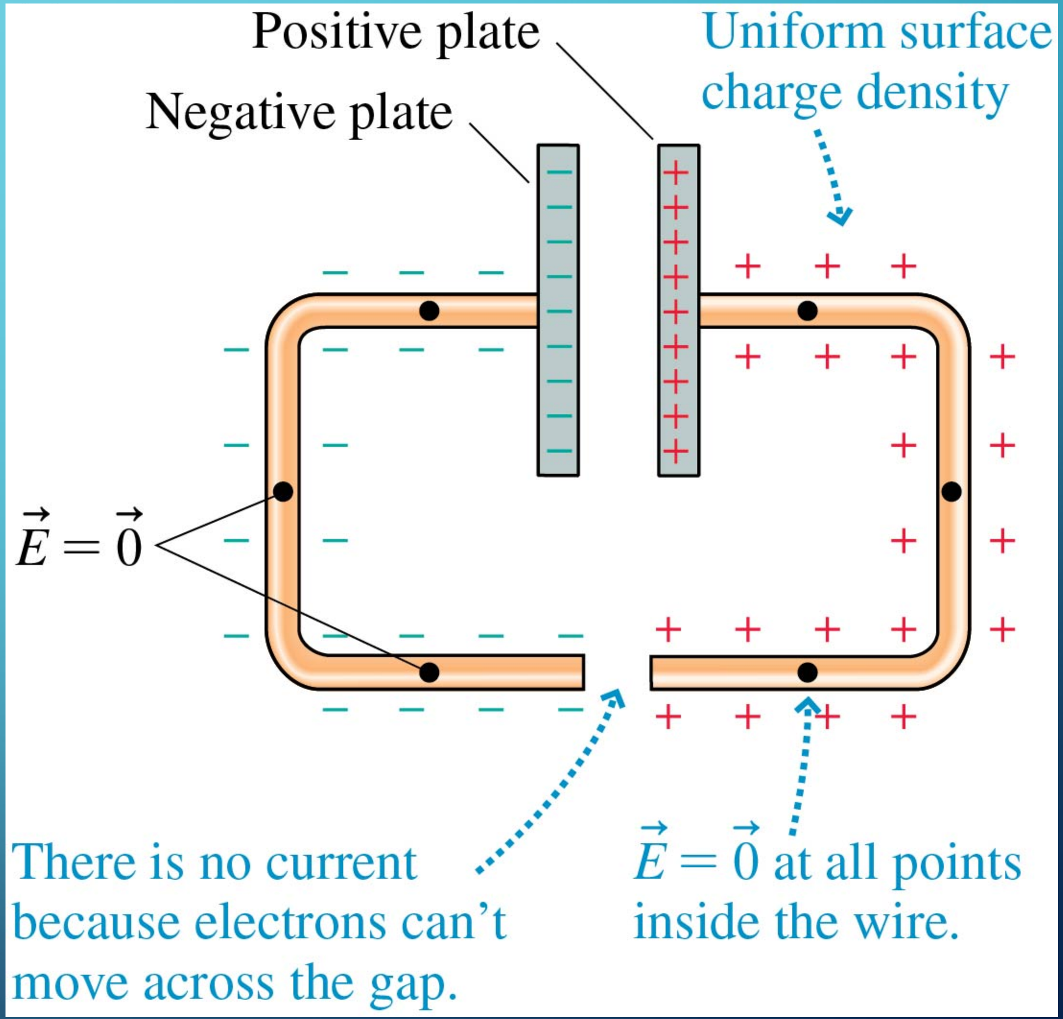
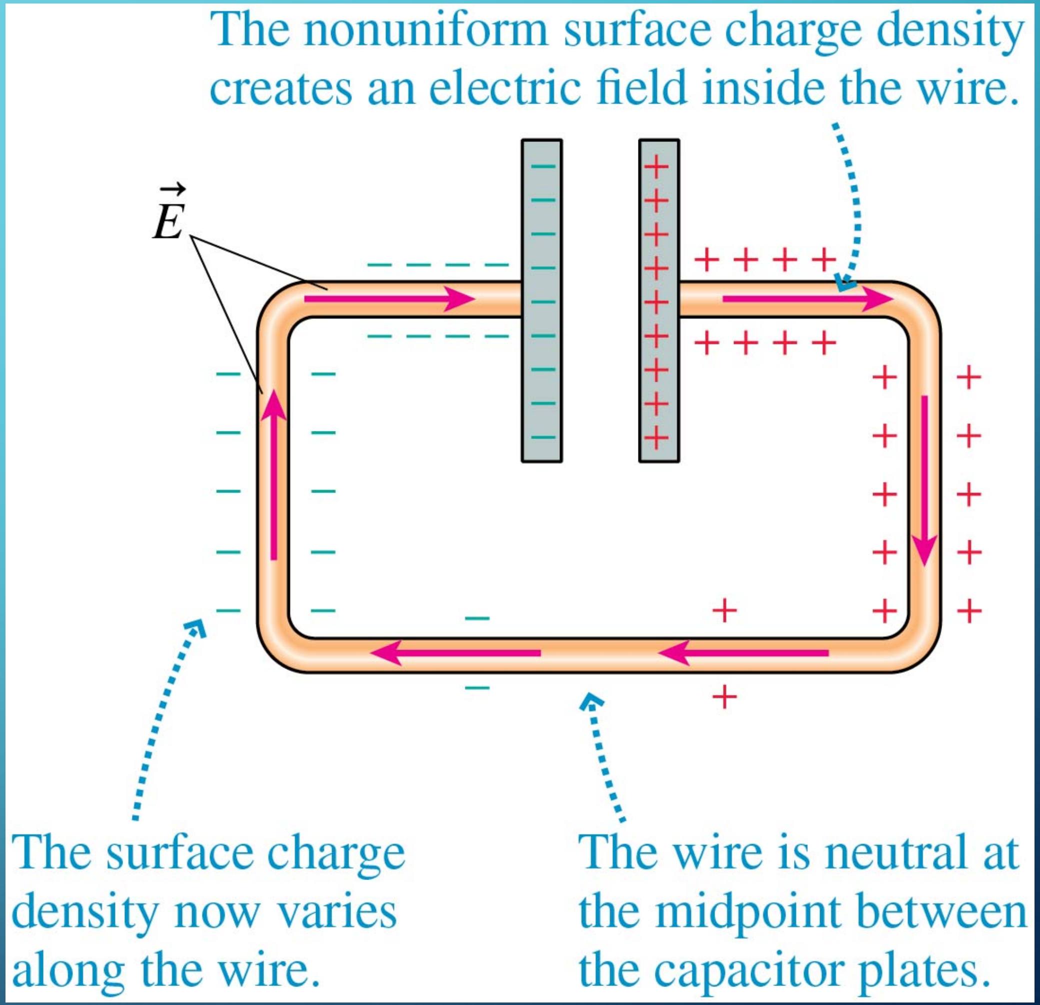
- …we have to push them!
- You remember the relationship between force, charge, and field?
  - $\vec{F} = q\vec{E}$
  - And of course if the charge q is the charge of an electron e…
  - $F = eE$
- So, we need to establish an electric field in the wire…

- The figure shows two metal wires attached to the plates of a charged capacitor.
- This is an electrostatic situation.
- What will happen if we connect the bottom ends of the wires together?

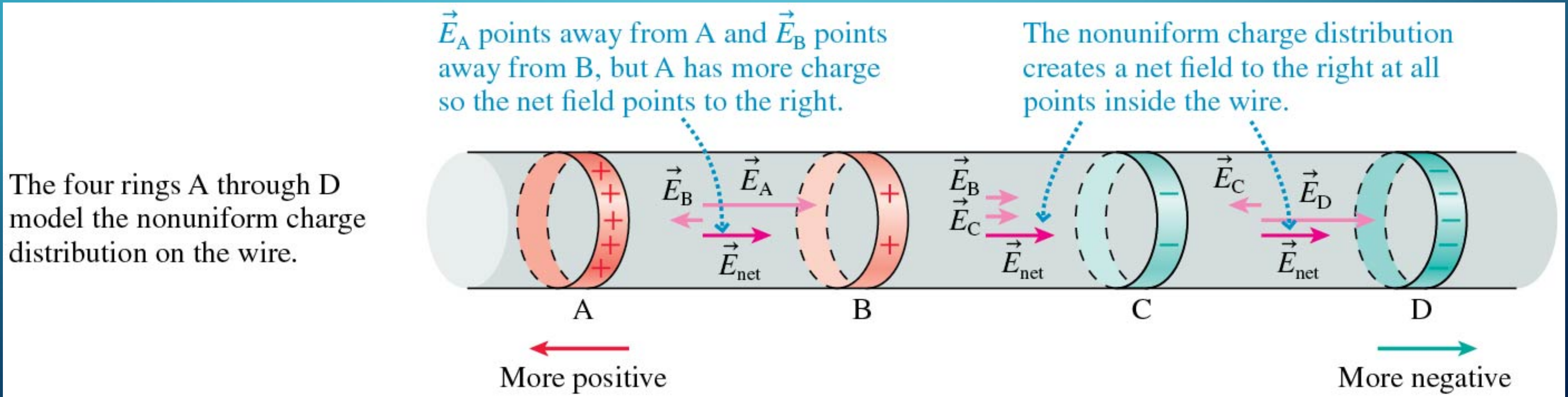


- Within a *very* brief interval of time ($\approx 10^{-9}$ s) of connecting the wires, the sea of electrons shifts slightly.
- The surface charge is rearranged into a *nonuniform* distribution, as shown in the figure.



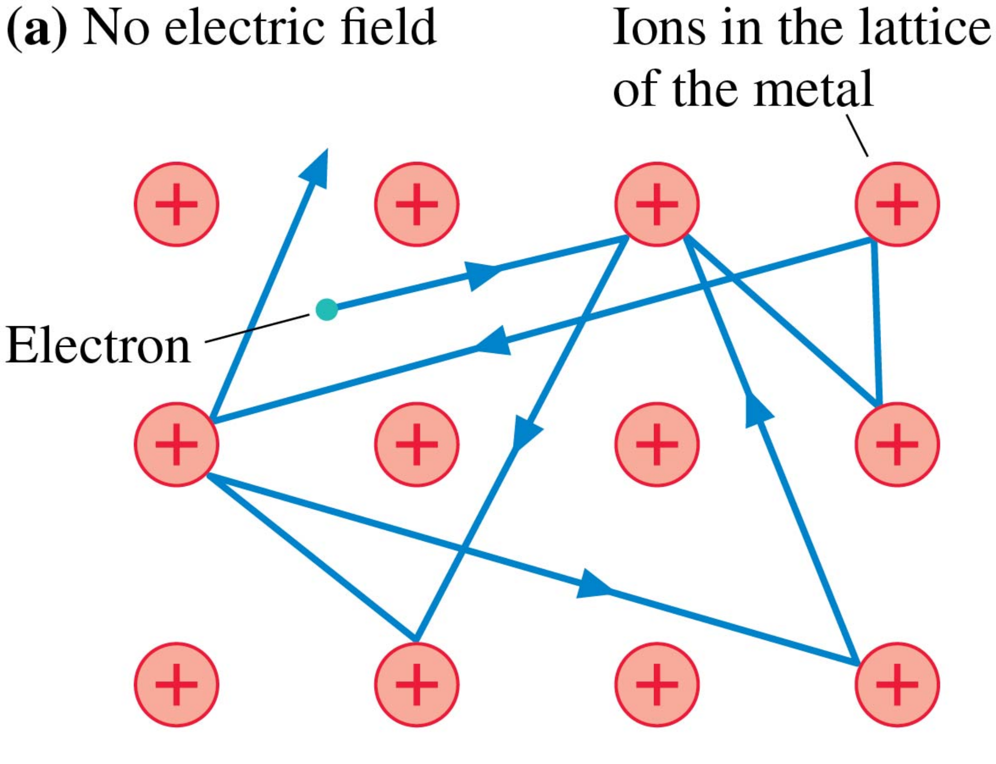
ESTABLISHING AN ELECTRIC FIELD IN A WIRE

The *nonuniform* distribution of surface charges along a wire creates a net electric field *inside* the wire that points from the more positive end toward the more negative end of the wire. This is the internal electric field that pushes the electron current through the wire.



SO…

- …electrons are the charge carriers and they get pushed by an electric field.
- How fast do those little guys move?
- Well, even without an external electric field the electrons are constantly colliding with charges in the metal.

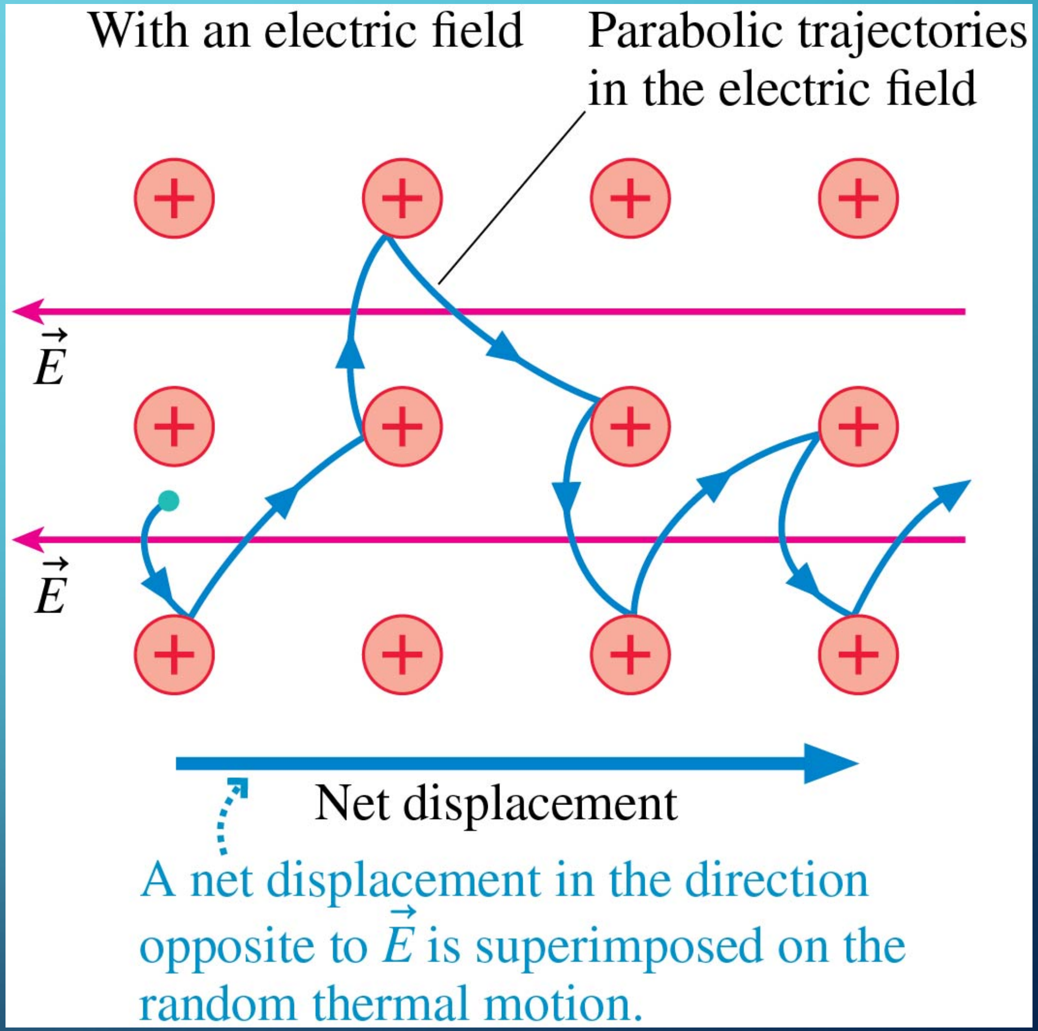


The electron has frequent collisions with ions, but it undergoes no net displacement.

DRIFT SPEED

Notice the field E pointing left and the electrons net displacement is right.

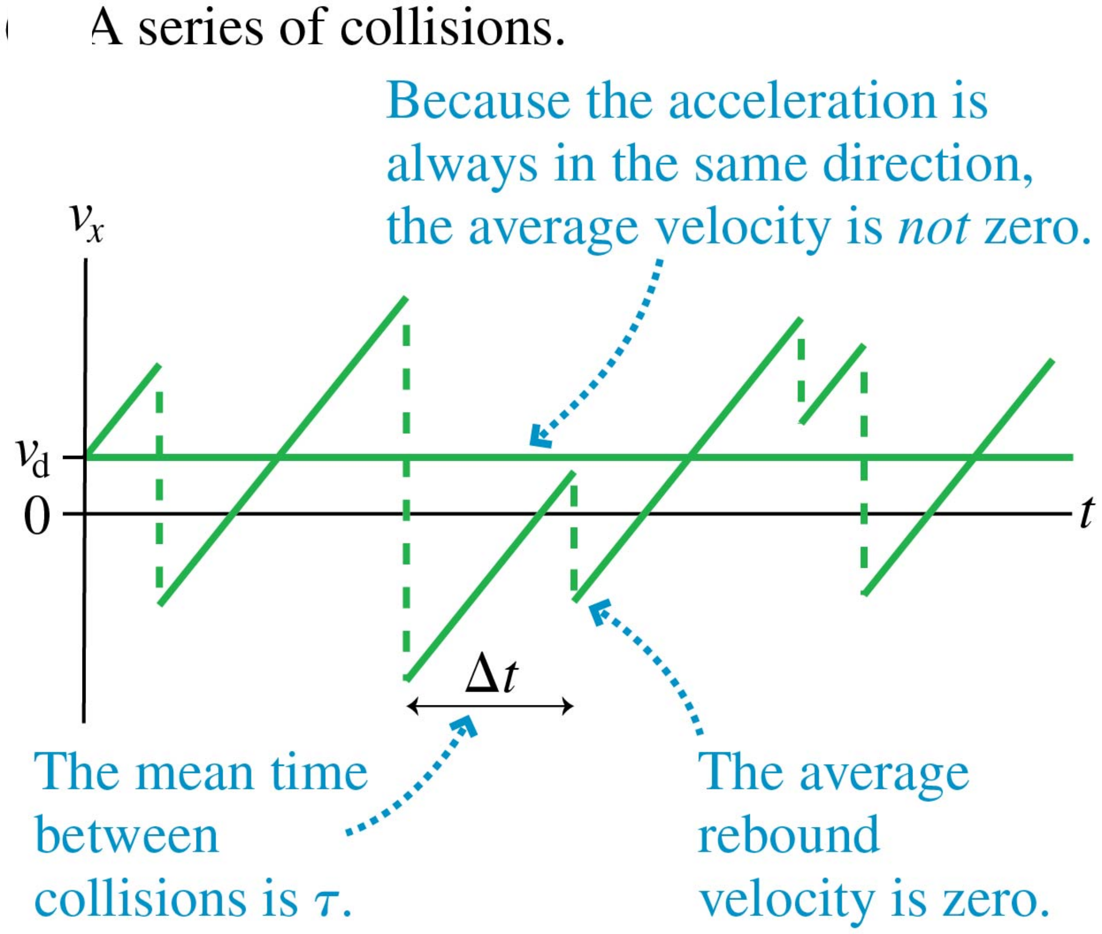
Because of collisions, the net drift speed of electrons to the right is limited.



DRIFT SPEED

Drift speed depends on a number of things including the electric field strength and properties of the particular metal…you read about those in your text.

PhET Simulation of Current in a Wire…



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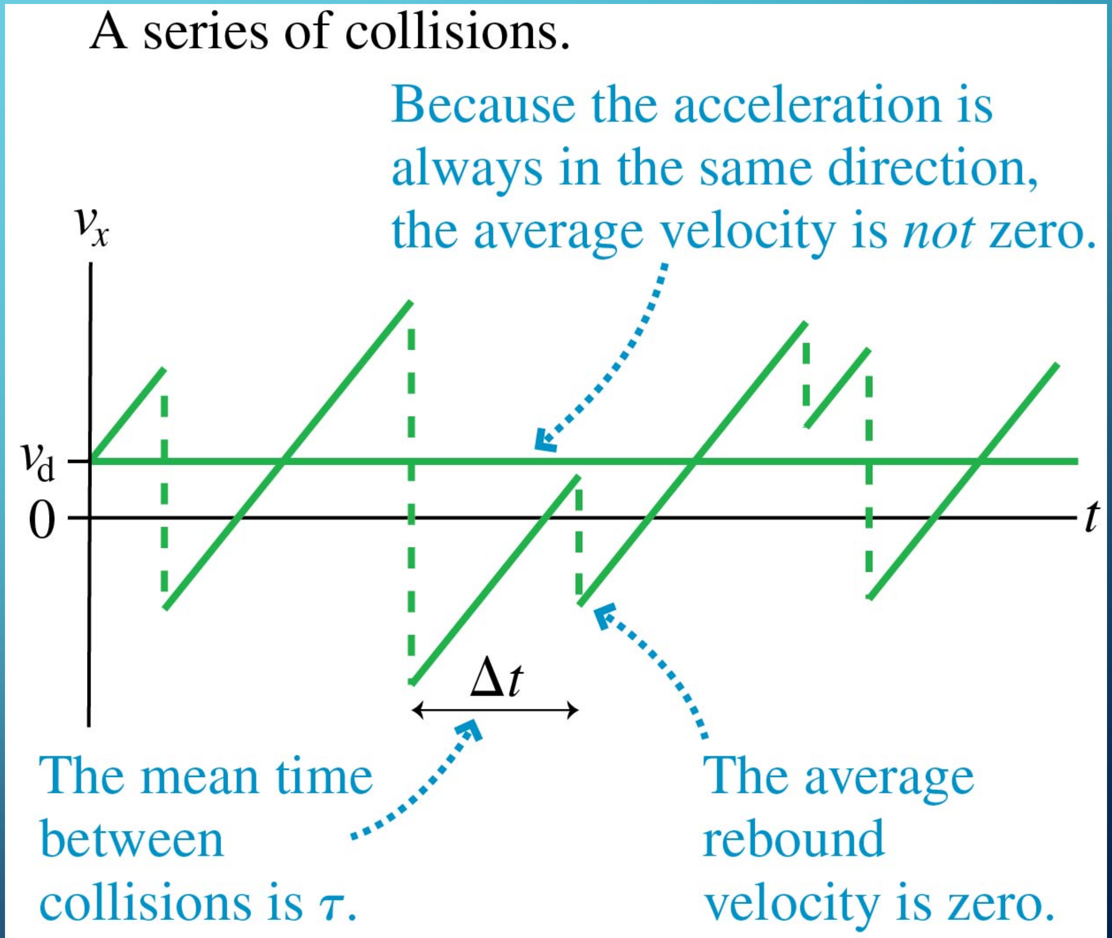
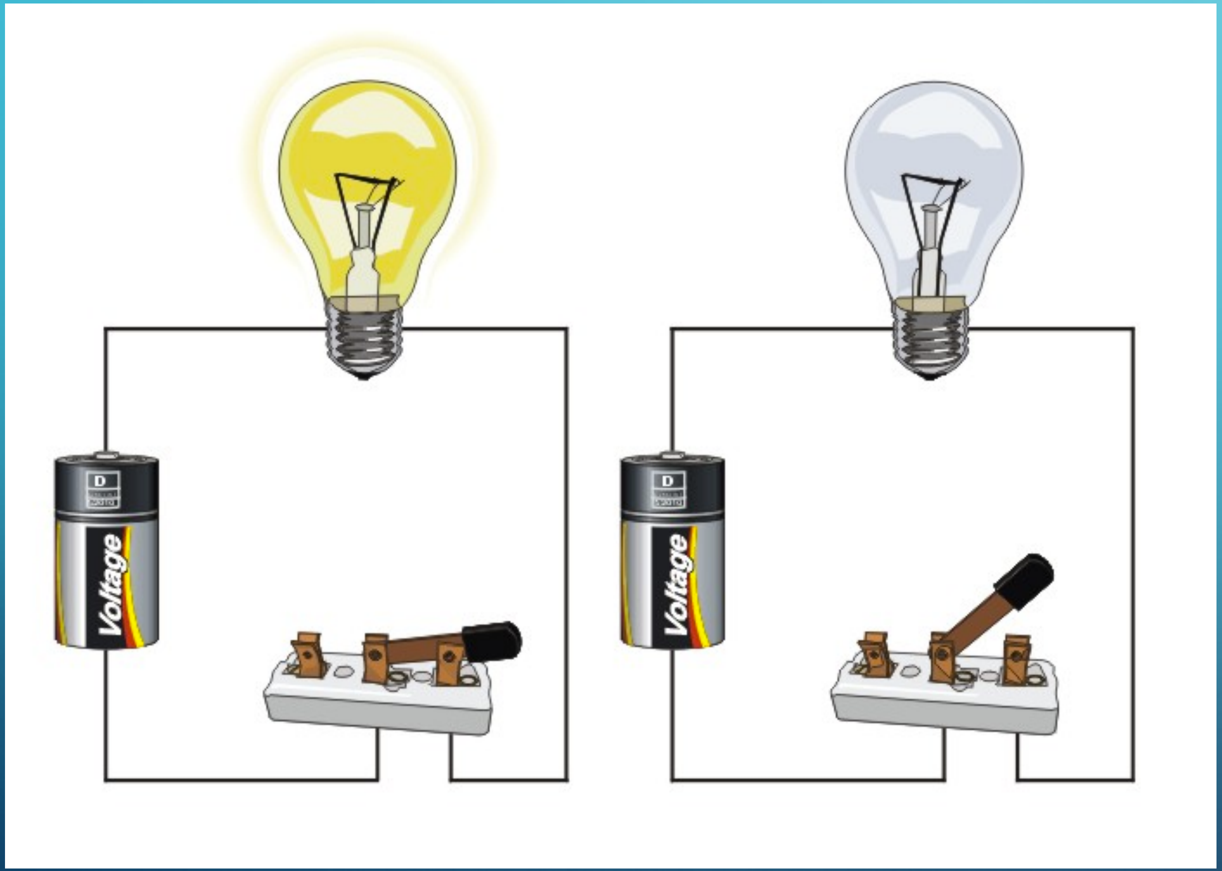
Perhaps surprisingly, A typical drift speed of electron current through a wire is $v_d \approx 10^{-4}$ m/s!



WAIT A MINUTE….



http://capeing.com/lighting/how-to-make-a-circuit-with-a-light-bulb-and-battery-and-switch.php

- With drift speeds that slow, it would take minutes for an electron to get from a battery to a lightbulb, but when we close the switch the bulb lights with almost no delay! Why?!

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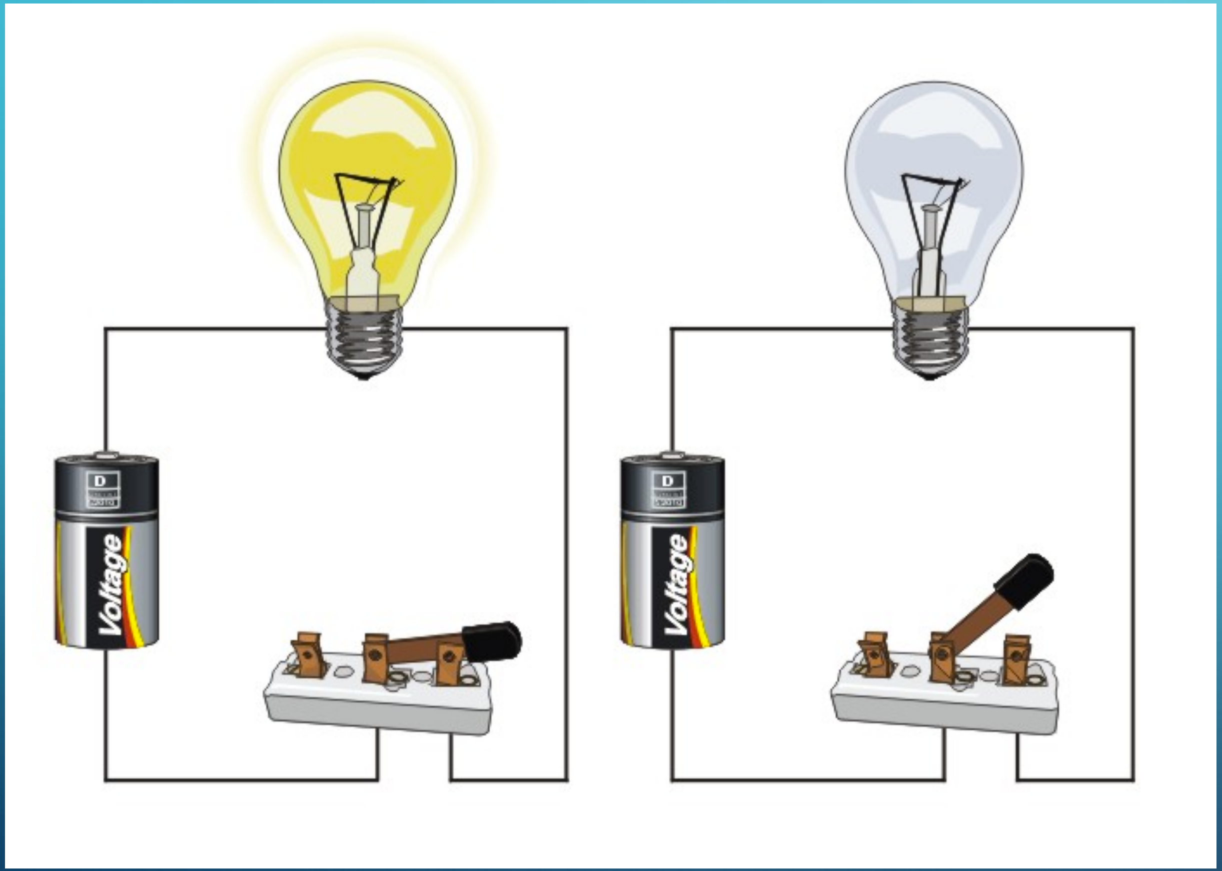

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- The entire "sea" of electrons in the wire and bulb filament start moving at basically the same time.
- It's as if the electrons are a long line of cars at a stoplight. When it turns green, they all start moving forward nearly at once! (including those in the lightbulb)

CURRENTS

ELECTRON CURRENT

- $i_e = \frac{N_e}{\Delta t}$ (that is: $\frac{\text{\# electrons}}{\text{time}}$)
- $i_e = n_e A v_d$
  - (that is: electron density $*$ Area $*$ drift speed)

CHARGE CURRENT

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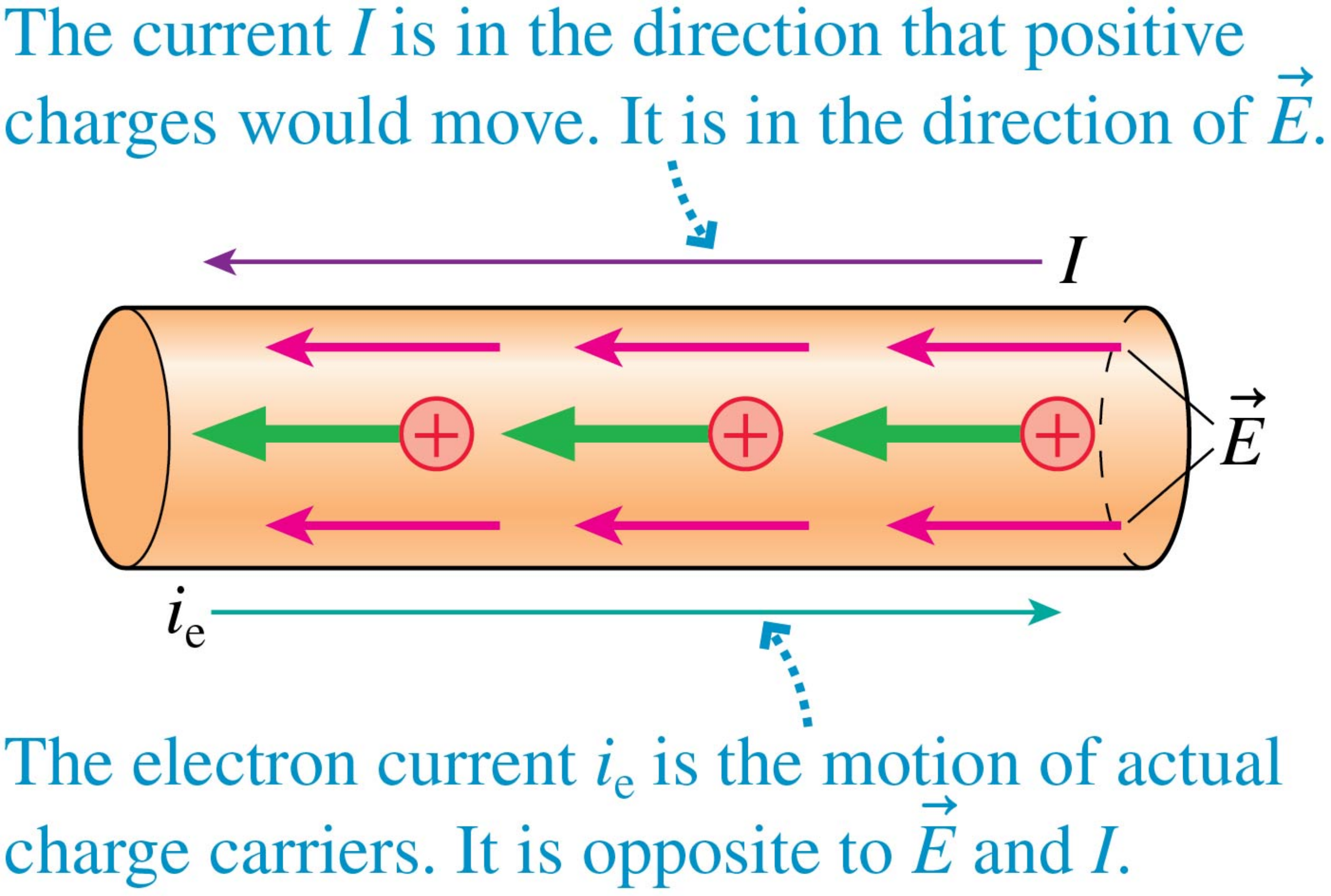
CHARGE CURRENT

- $I = e i_e$
  - (that is: elementary charge $*$ electron current)
- $I = \frac{Q}{\Delta t}$
  - Coulombs/second = Amperes (A)

CURRENT DENSITY

- Current density, J, is defined as the current per square meter of cross section:
- $J = \frac{I}{A}$
- In Amperes per square meter (A/m^2)
- More on this later…

DIRECTION OF CONVENTIONAL CURRENT



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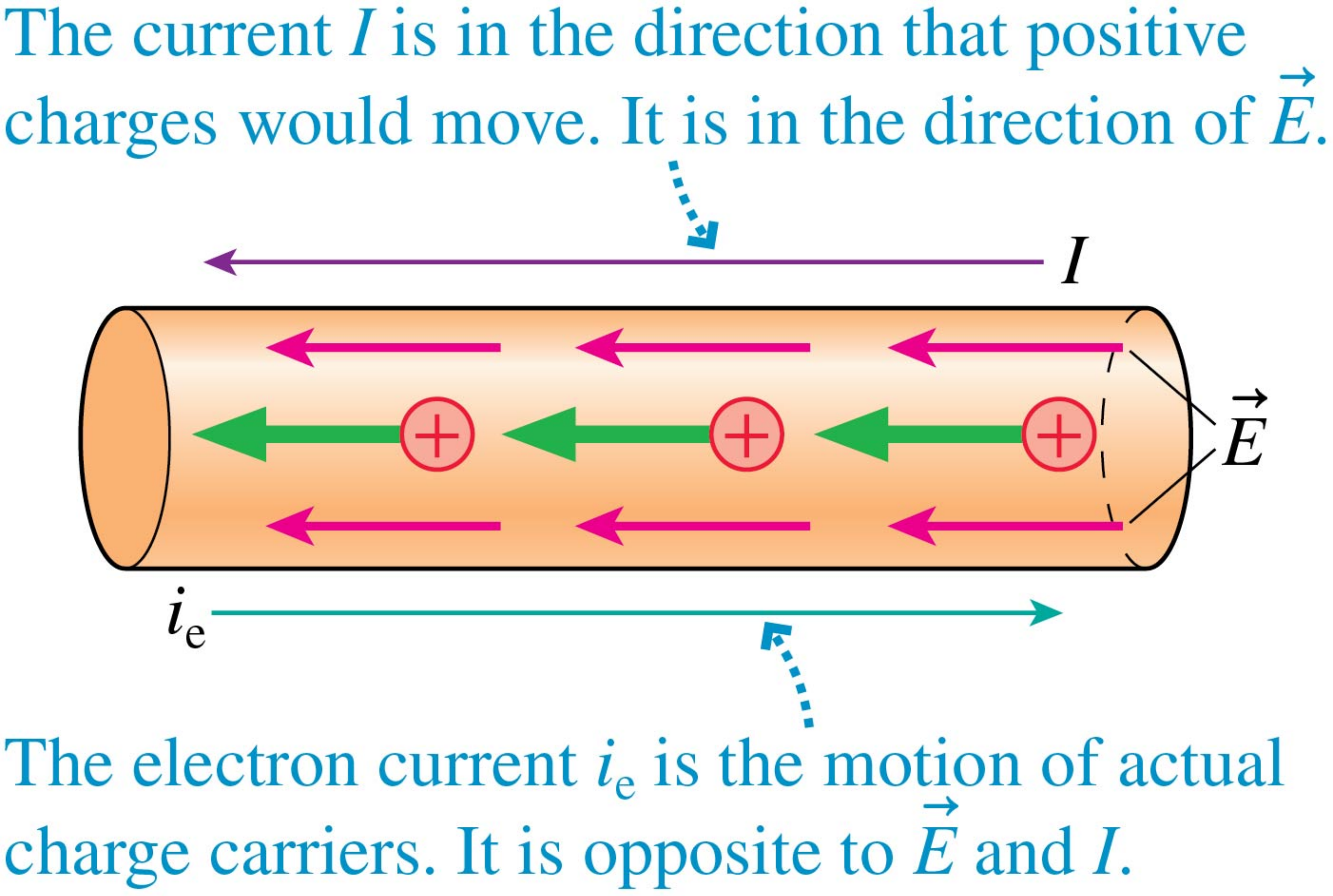
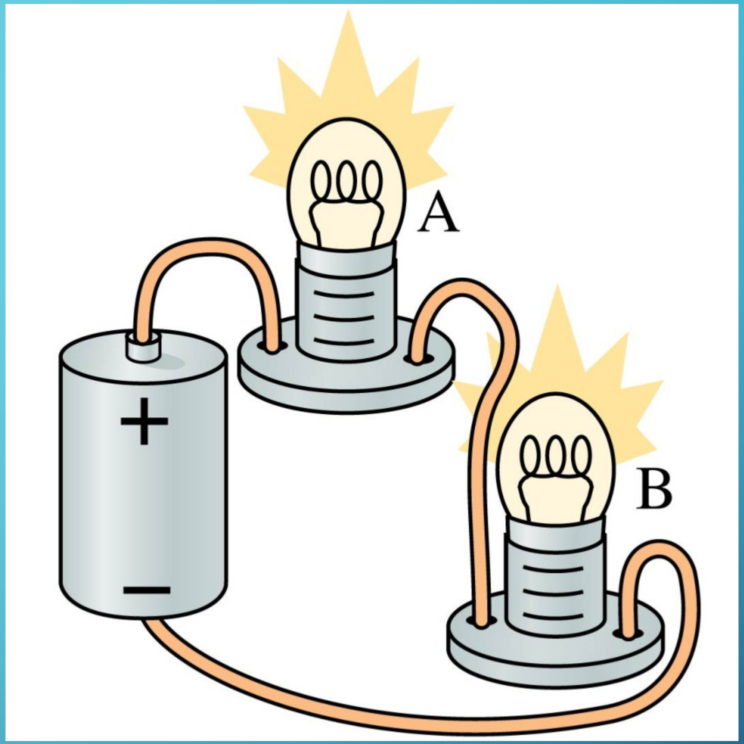


- Because of historical reasons, conventional (charge) current, I, is defined to be the direction of the movement of positive charges.
- It is, of course, the opposite of the direction of the electrons in a wire.
- Umm…Sorry?

- A and B are identical lightbulbs connected to a battery as shown. Which is brighter?

1. Bulb A
2. Bulb B
3. Both Equally Bright



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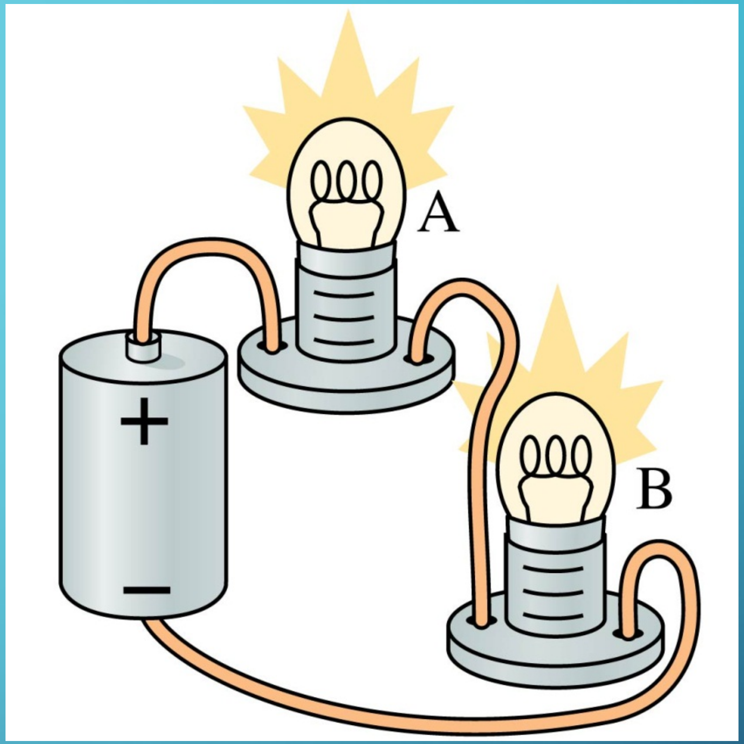
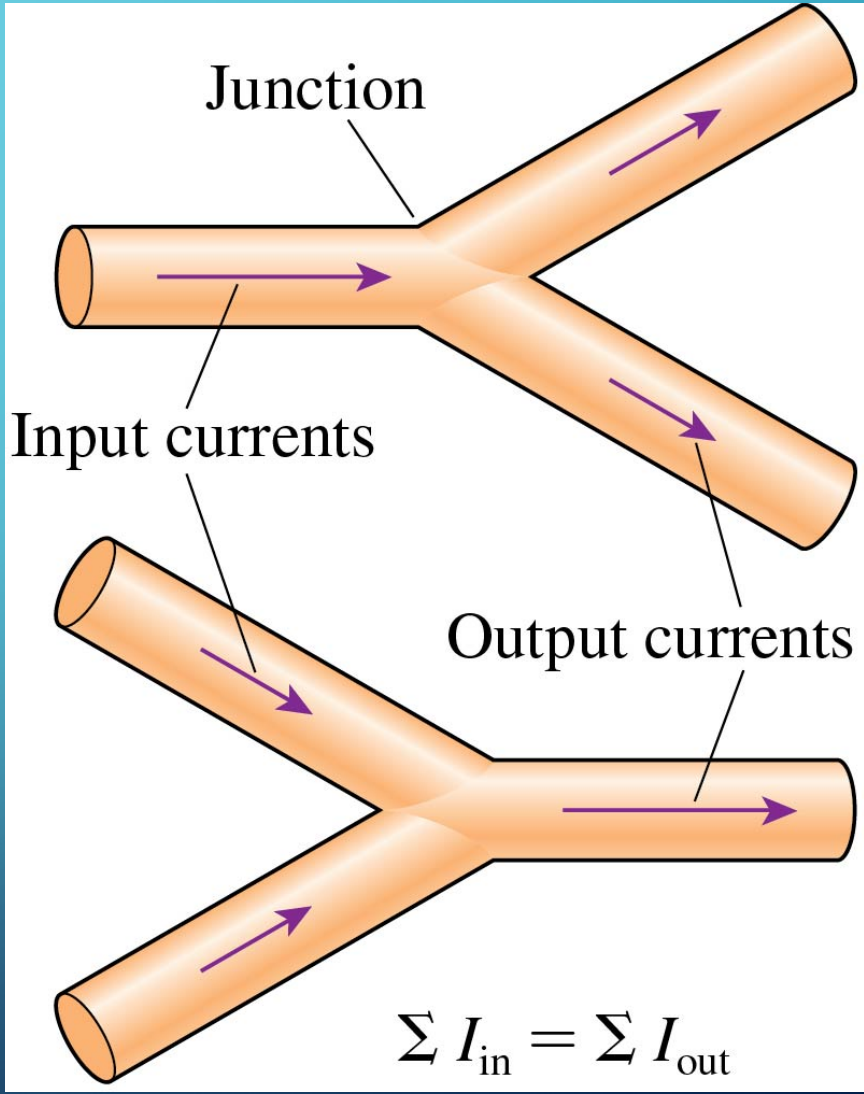


If Current is the same (doesn't get "used up"), what *does* change about the current?

CONSERVATION OF CURRENT

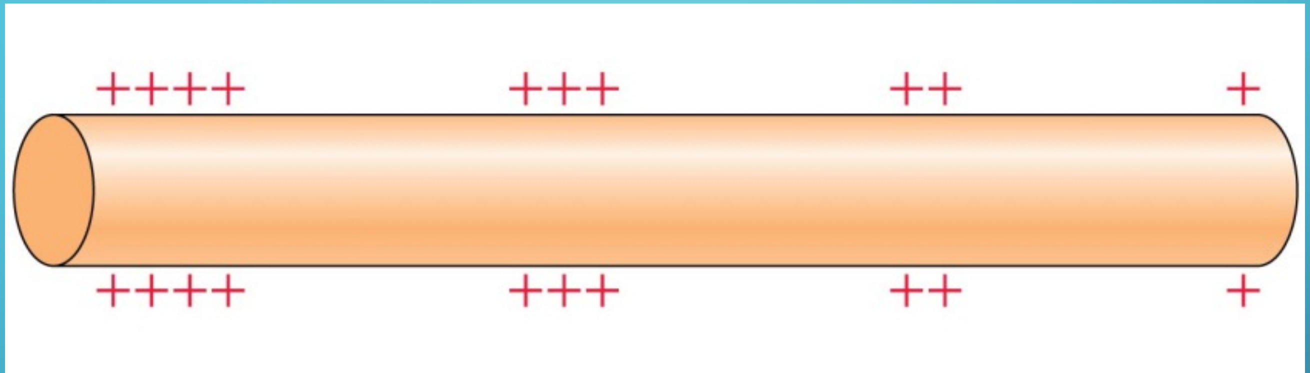
- The current is the same at all points in a current carrying wire.
- Also known as the Junction Rule or Kirchhoff's Junction Rule:
- $\sum I_{in} = \sum I_{out}$



A wire carries a current. If both the wire diameter and the electron drift speed are doubled, the electron current increases by a factor of

A 2	B 4
C 6	D 8

Surface charge is distributed on a wire as shown. Electrons in the wire



A Drift to the right

B Drift to the left

C On average stay at rest

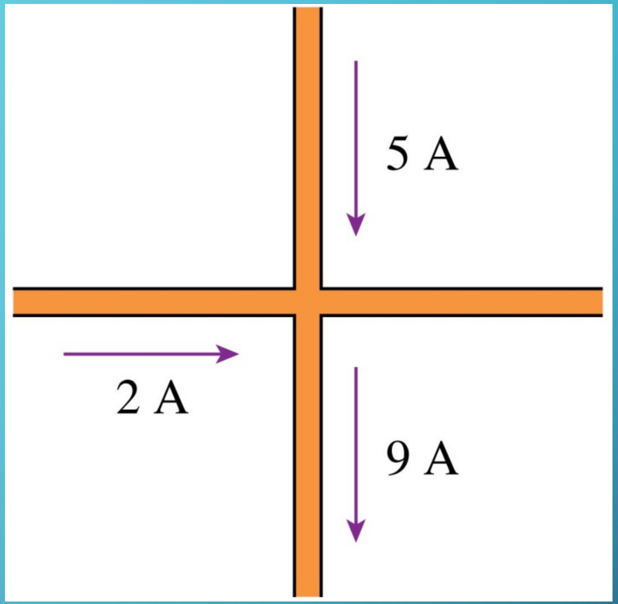
D Pick a different one!

Every minute, $120\ \mathrm{C}$ of charge flow through this cross section of the wire.

The wire's current is

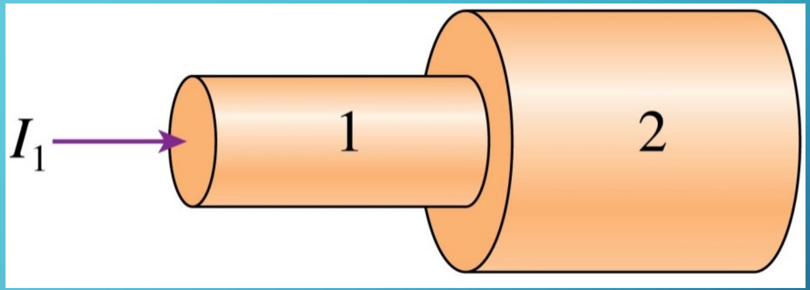
A 240 A	B 120 A
C 60 A	D 2 A

The current in the fourth wire is



A 16 A to the right	B 4 A to the left
C 2 A to the right	D 2 A to the left

Both segments of the wire are made of the same metal. Current I_1 flows into segment 1 from the left. How does current I_1 in segment 1 compare to current I_2 in segment 2?



- A $I_1 > I_2$
- B $I_1 = I_2$
- C $I_1 < I_2$
- D Not enough information

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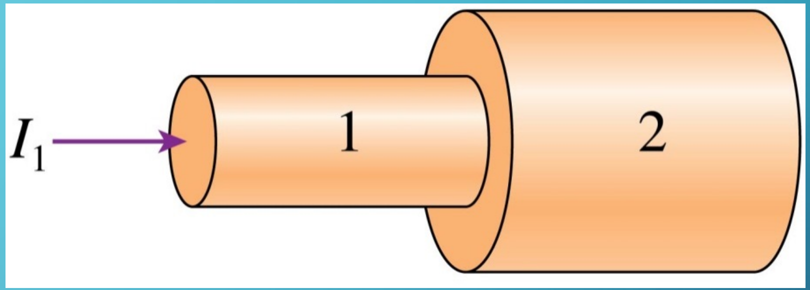

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