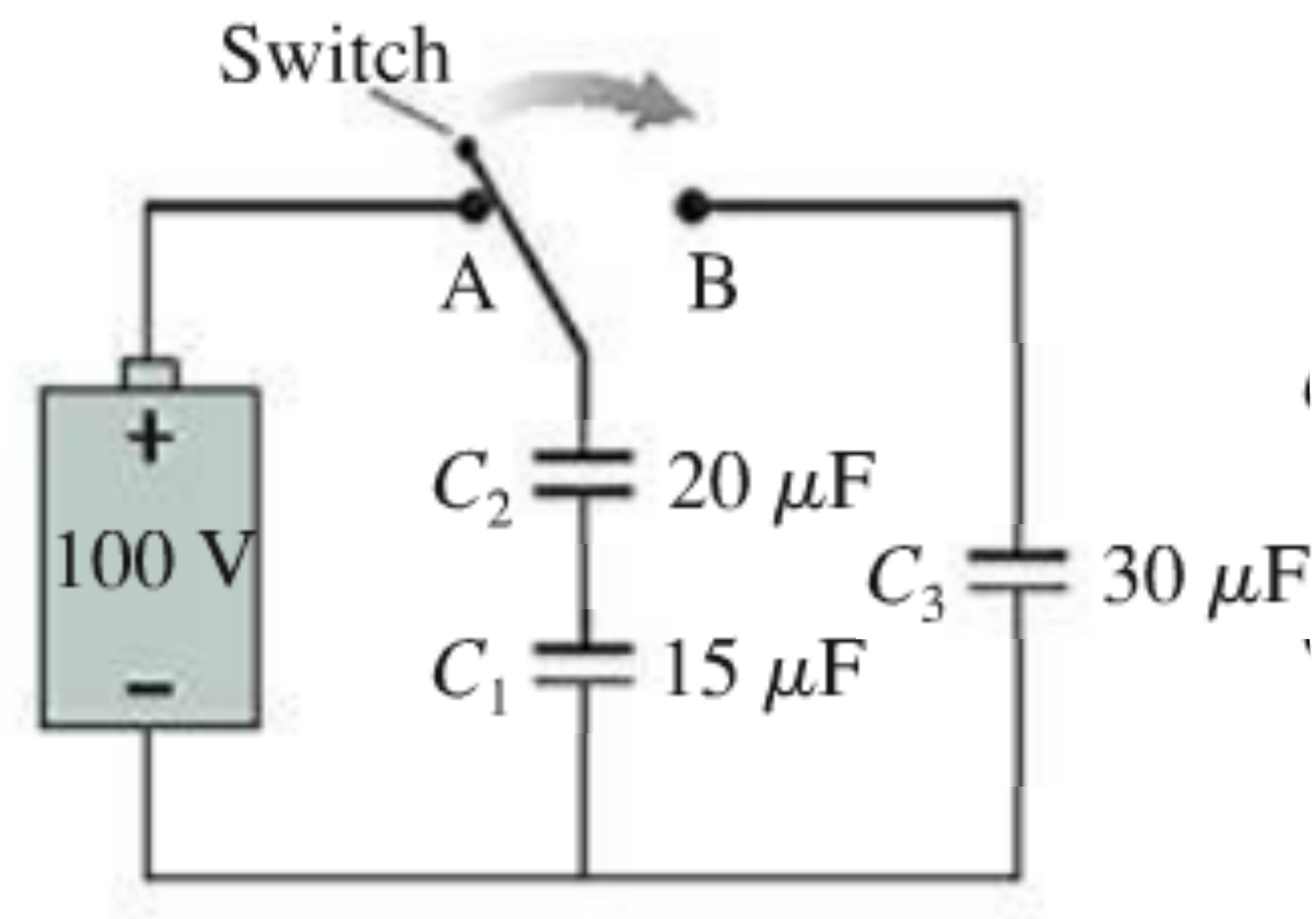
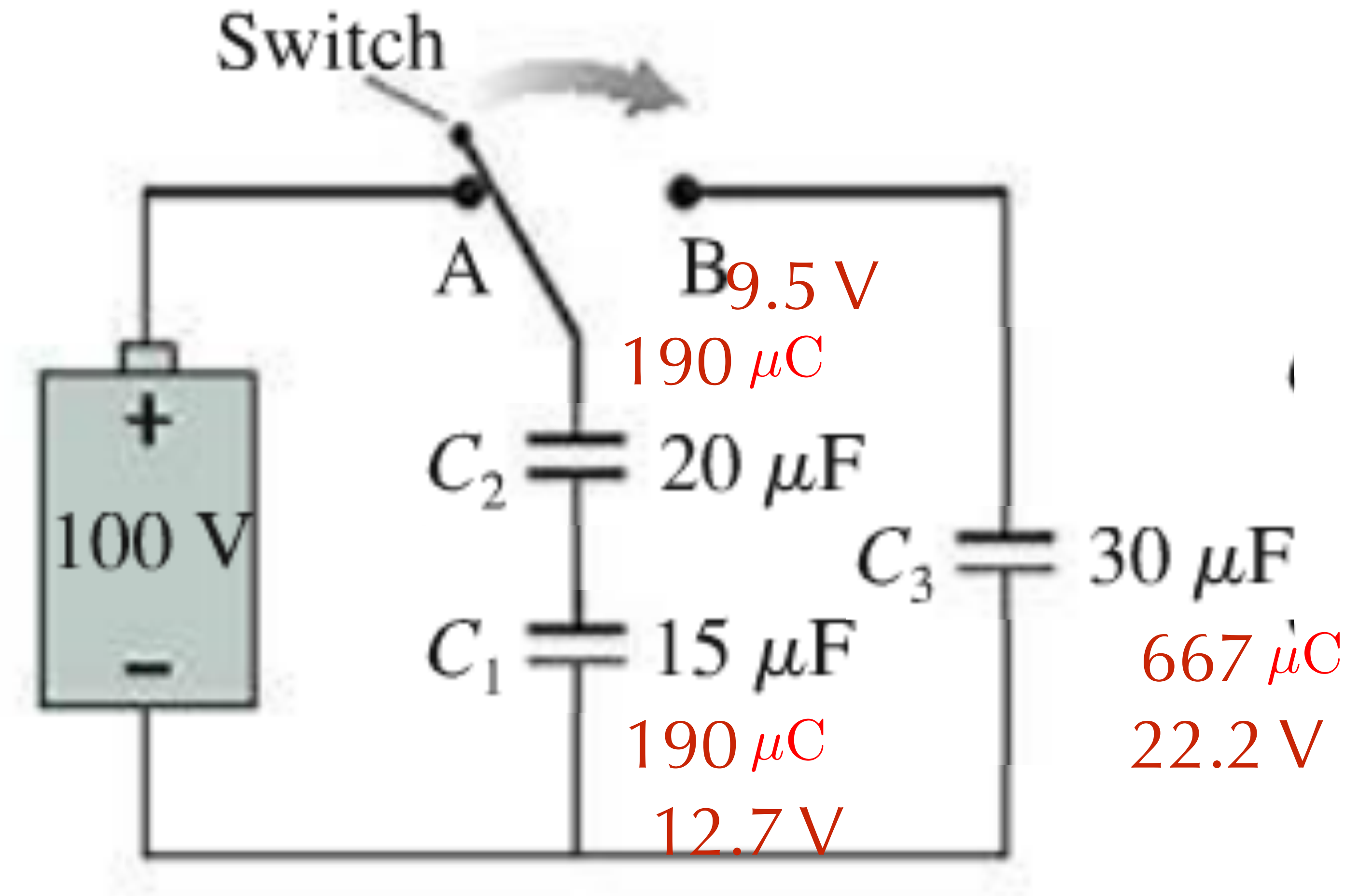
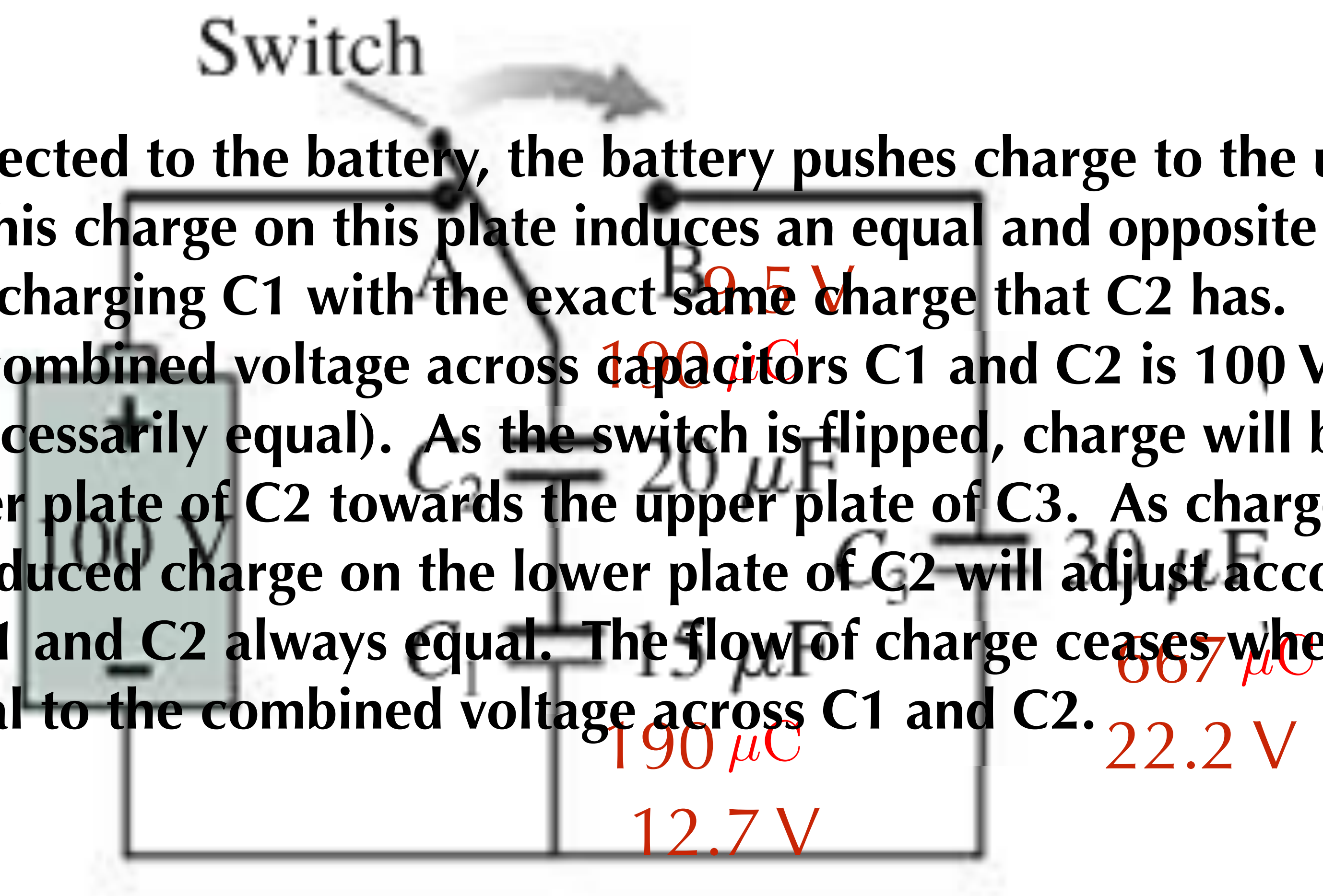

PH 220
Lance Nelson


Switch
A
B
+
100 V
−
C_2 20 μF
C_1 15 μF
C_3 30 μF



Switch
A
B
9.5 V
190 μC
C_2
20 μF
100 V
+
–
C_3
30 μF
C_1
15 μF
667 μC
22.2 V
190 μC
12.7 V

When the switch is connected to the battery, the battery pushes charge to the upper plate of C2. The presence of this charge on this plate induces an equal and opposite charge on the opposing plate, thus charging C1 with the exact same charge that C2 has. The charge stops flowing when the combined voltage across capacitors C1 and C2 is 100 V(note that these voltages are not necessarily equal). As the switch is flipped, charge will begin to flow away from the upper plate of C2 towards the upper plate of C3. As charge leaves the upper plate of C2, the induced charge on the lower plate of C2 will adjust accordingly keeping the charge on C1 and C2 always equal. The flow of charge ceases when the voltage across C3 is equal to the combined voltage across C1 and C2.



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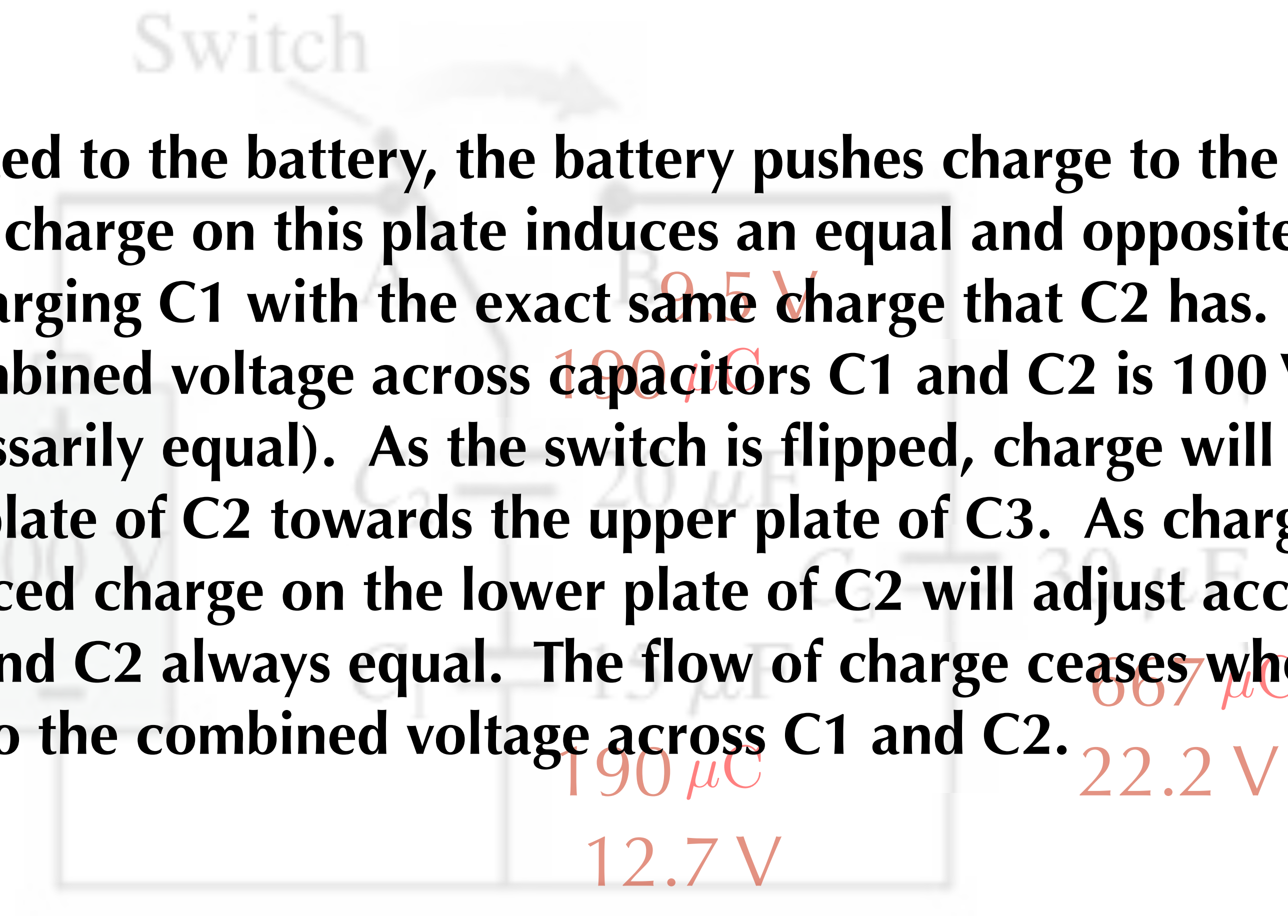
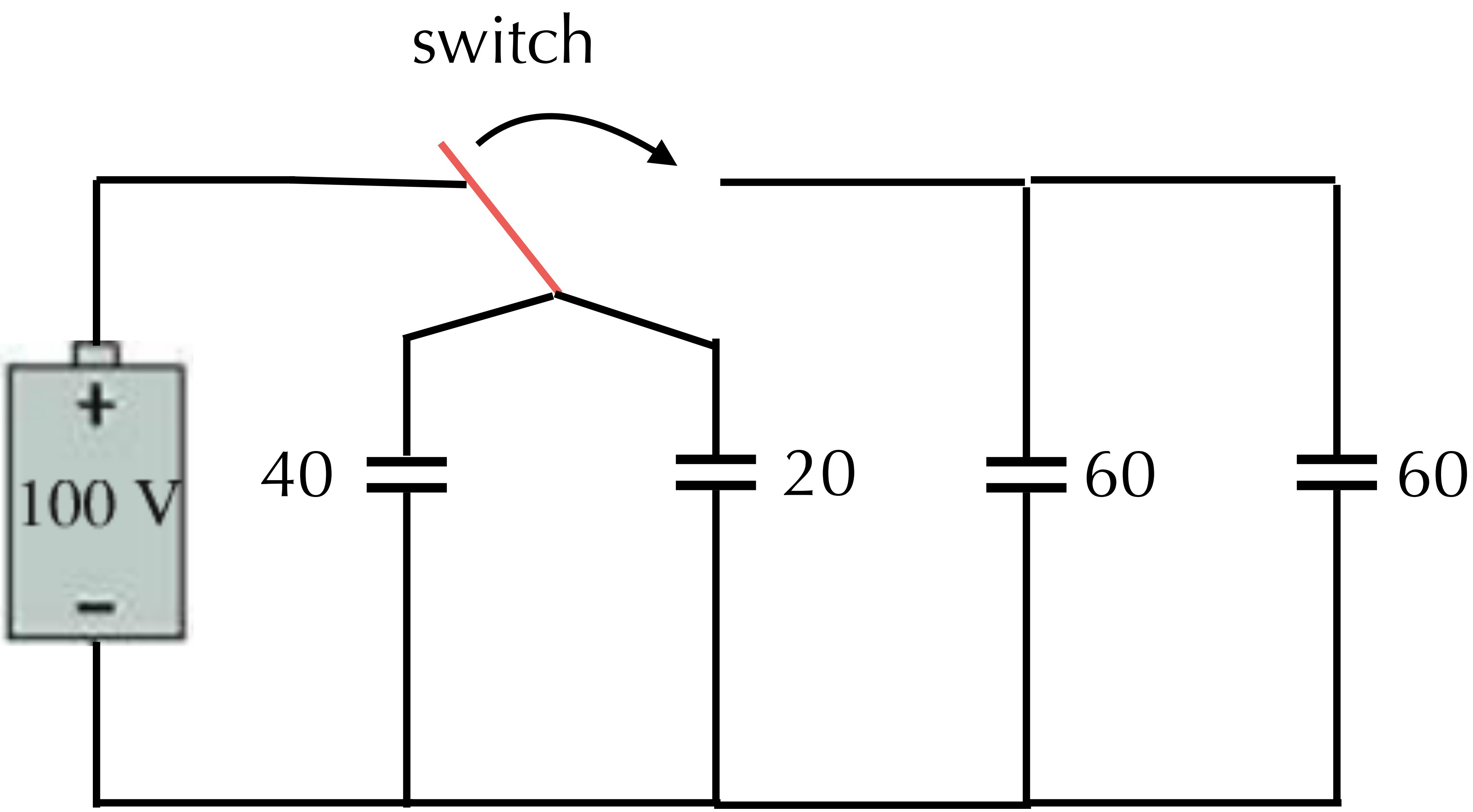
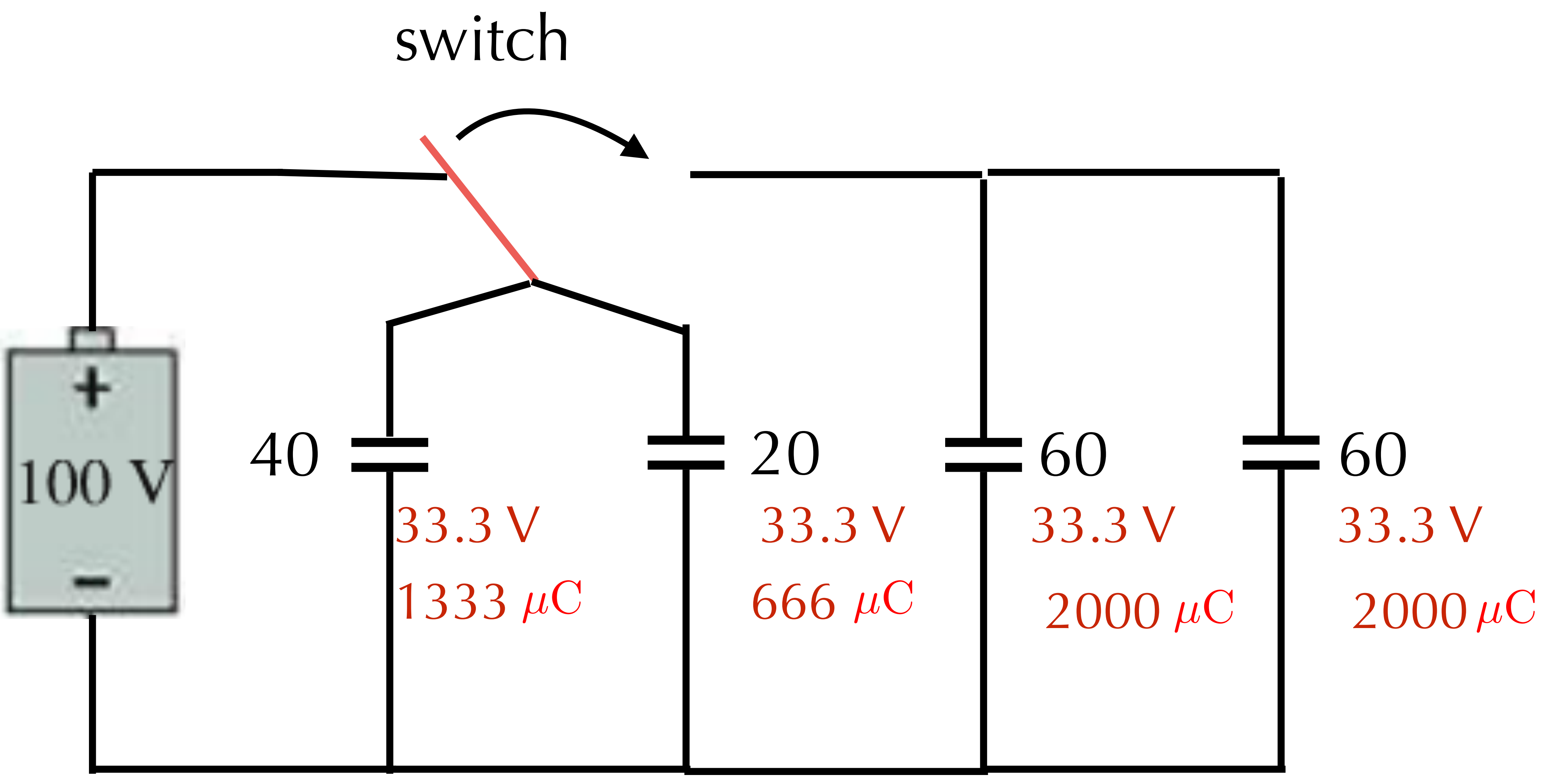



switch
100 V
40
20
60
60

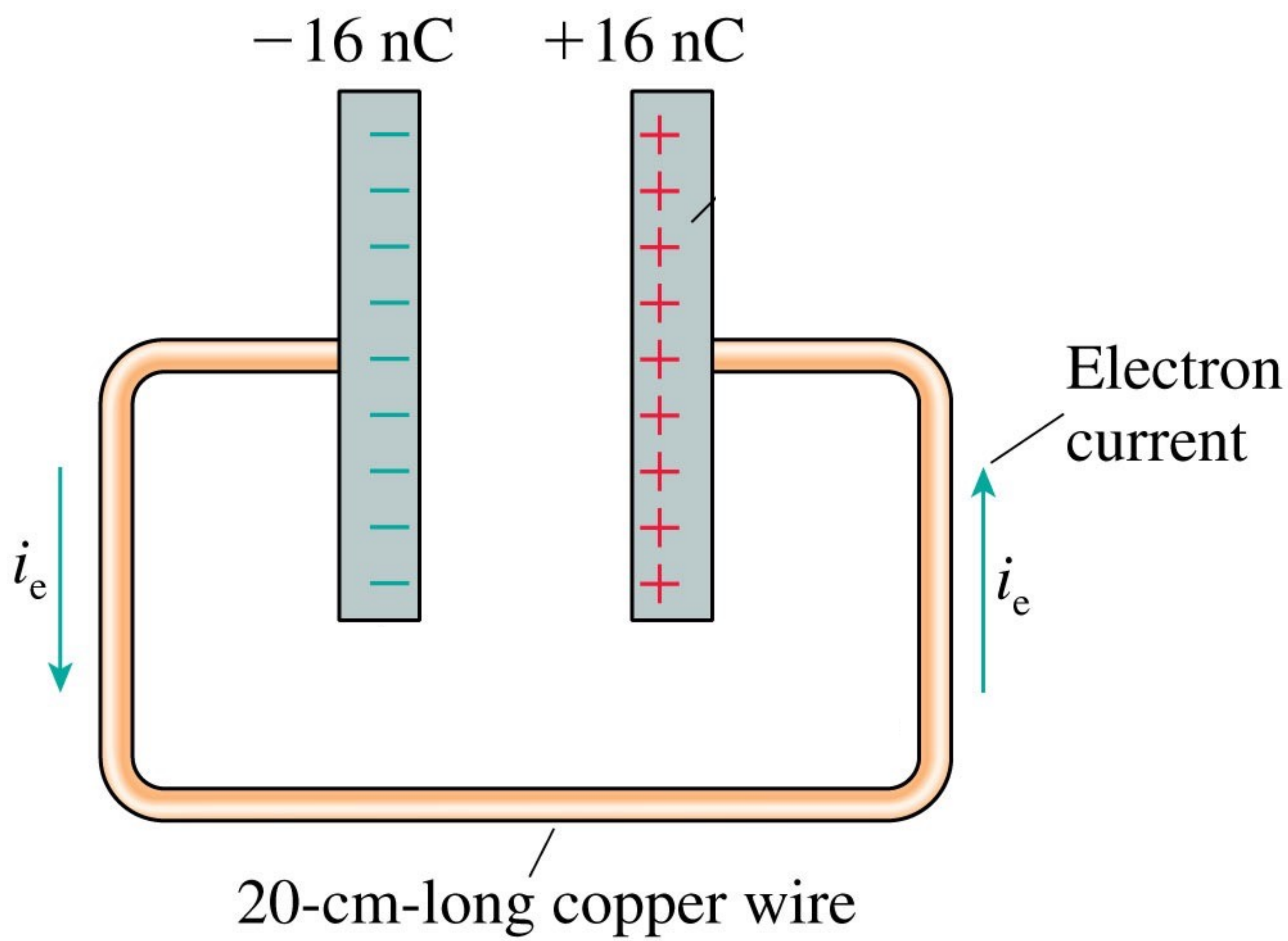

switch
100 V
40
33.3 V
1333 μC
20
33.3 V
666 μC
60
33.3 V
2000 μC
60
33.3 V
2000 μC

Discharging a capacitor

Typical drift velocities are on the order:

$$v_d = 10^{-4} \text{ m/s}$$

If the wire were 20 cm long, how long would it take for a single electron to get to the positive plate?



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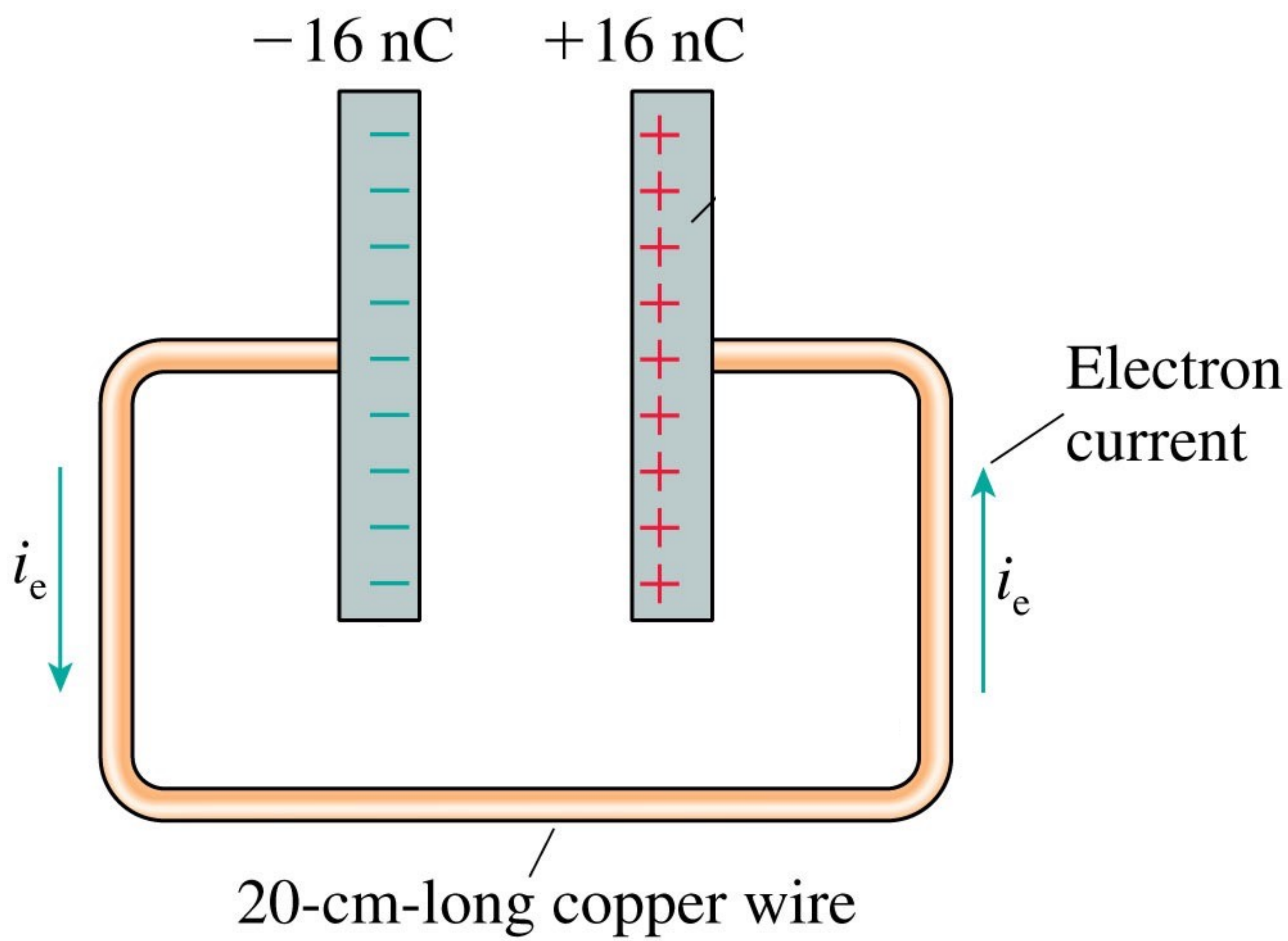

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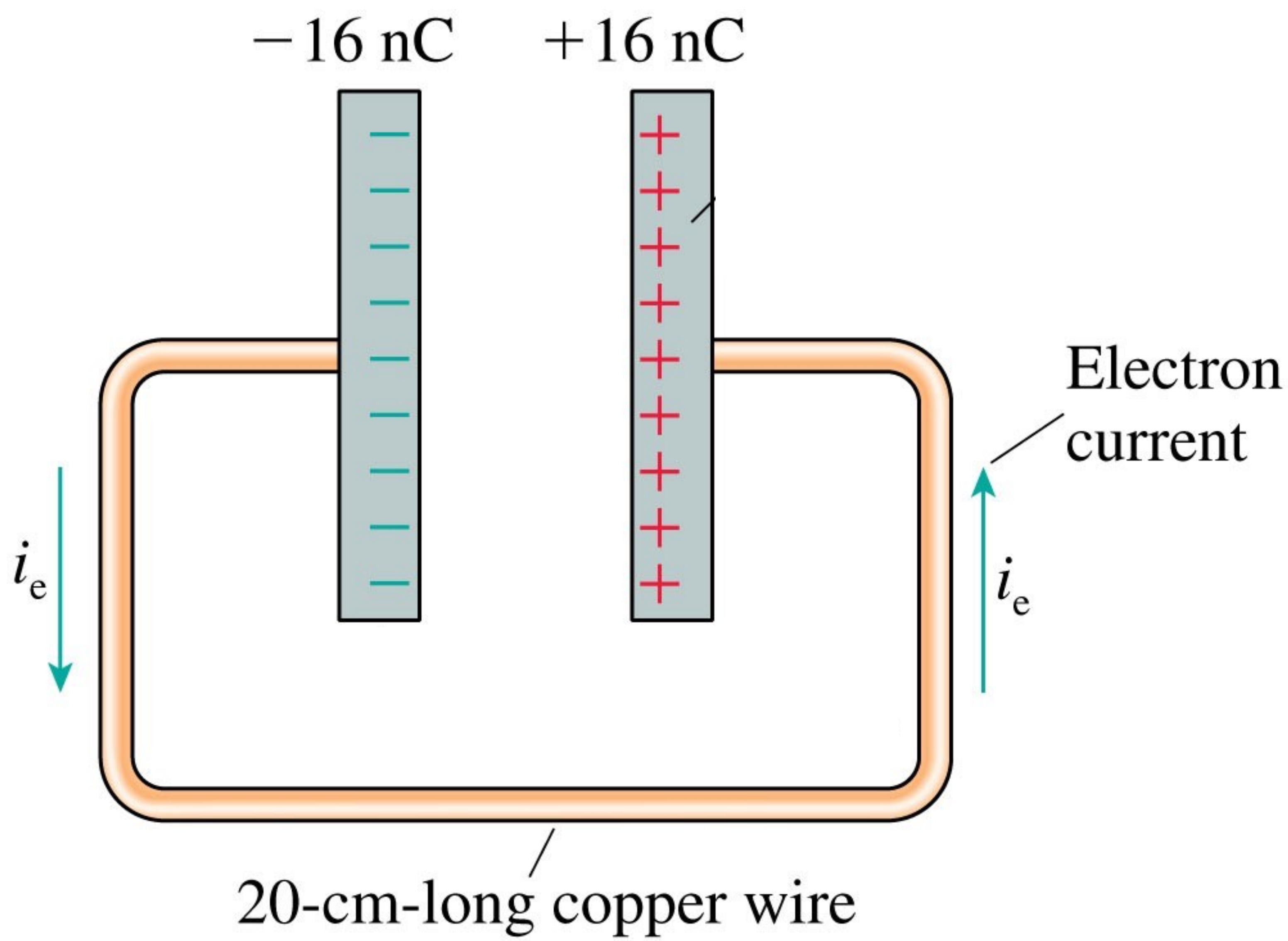
$$2000\ \mathrm{s}$$

What???



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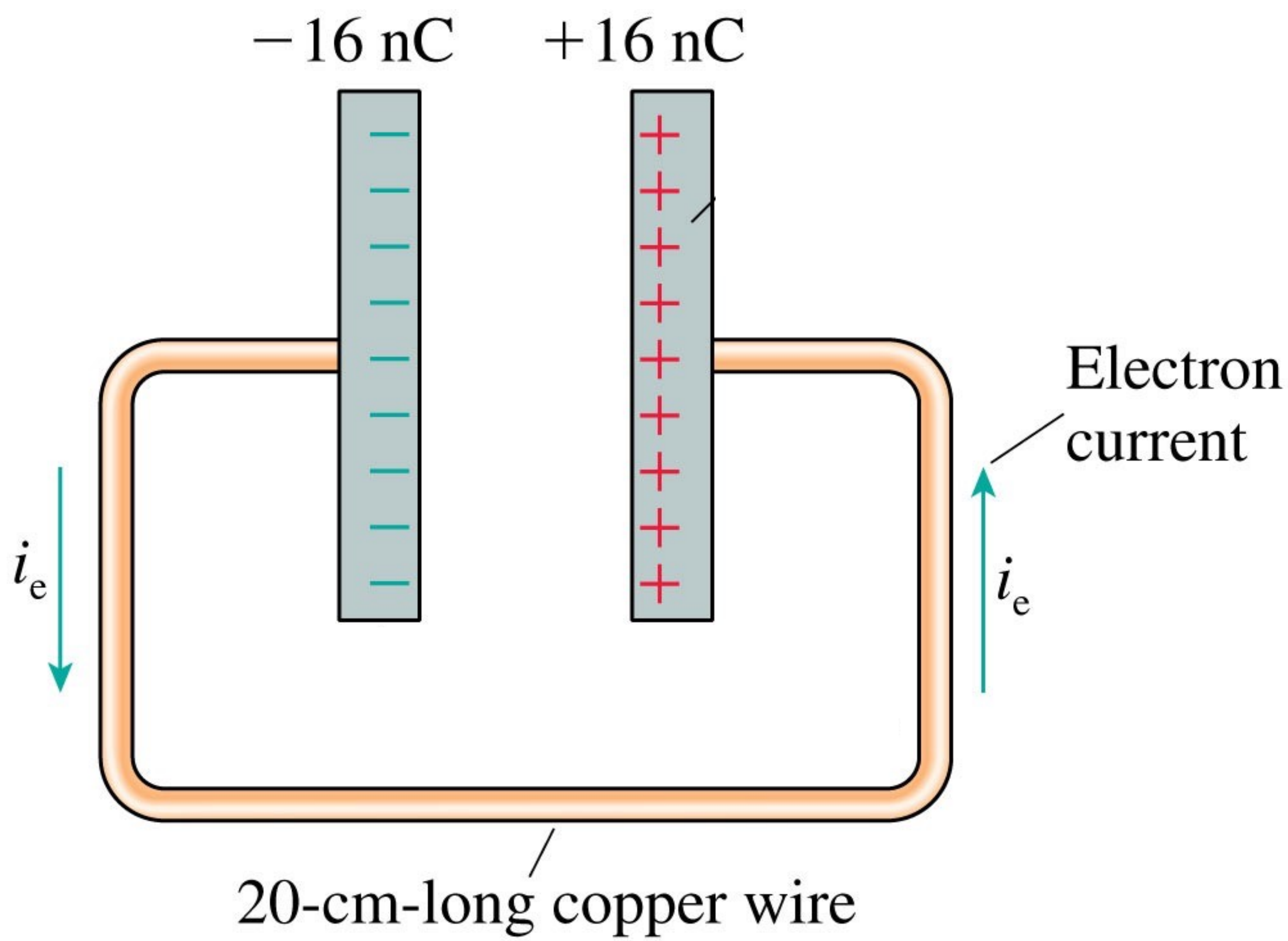
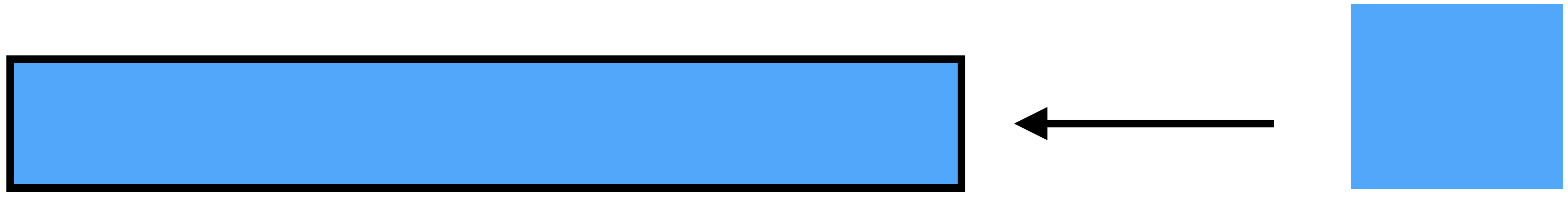


2000 s What???

Capacitors discharge nearly instantaneously!

Water-in-pipe analogy

How long will it take for this amount of water to emerge from the left side?



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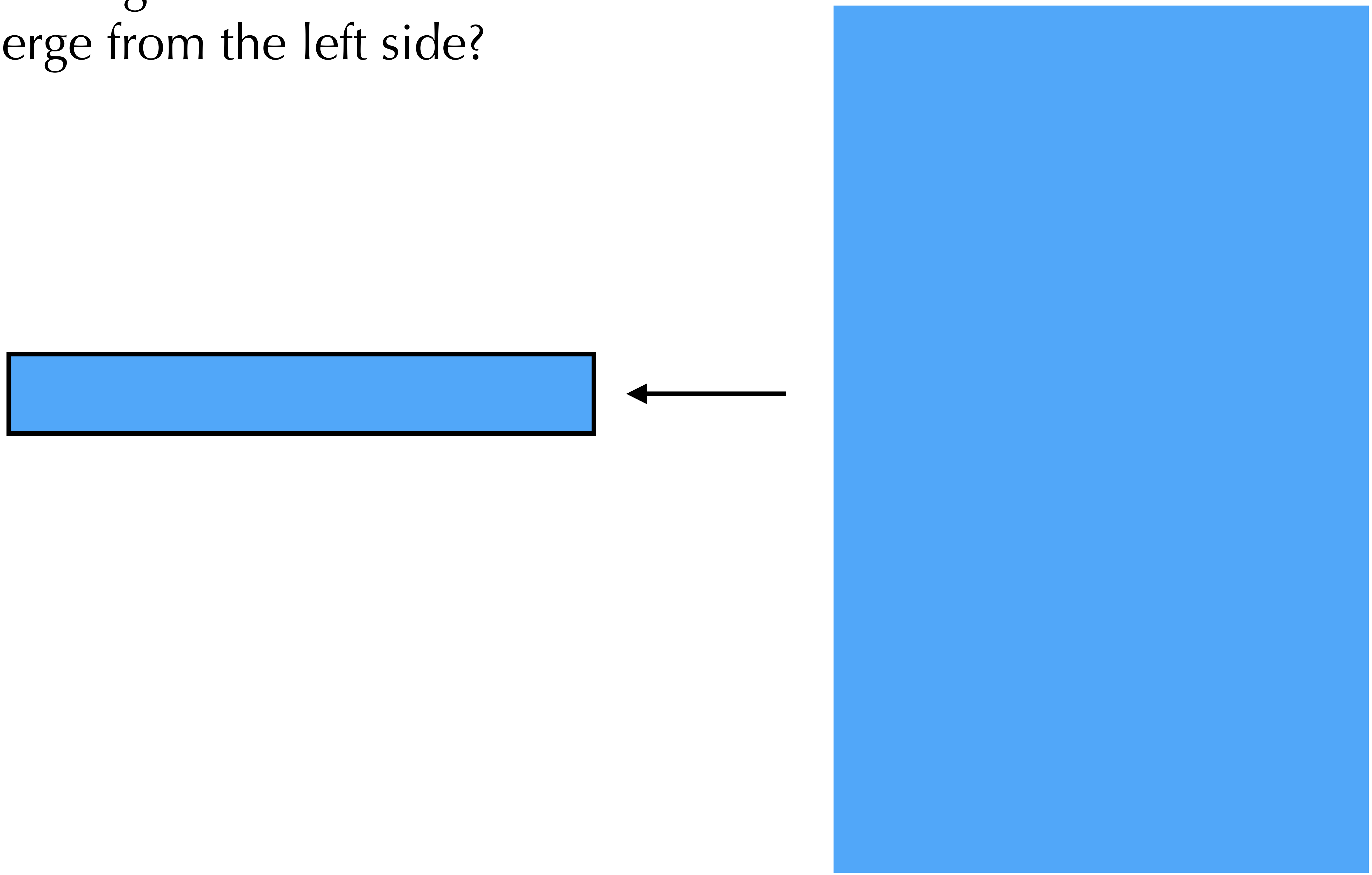
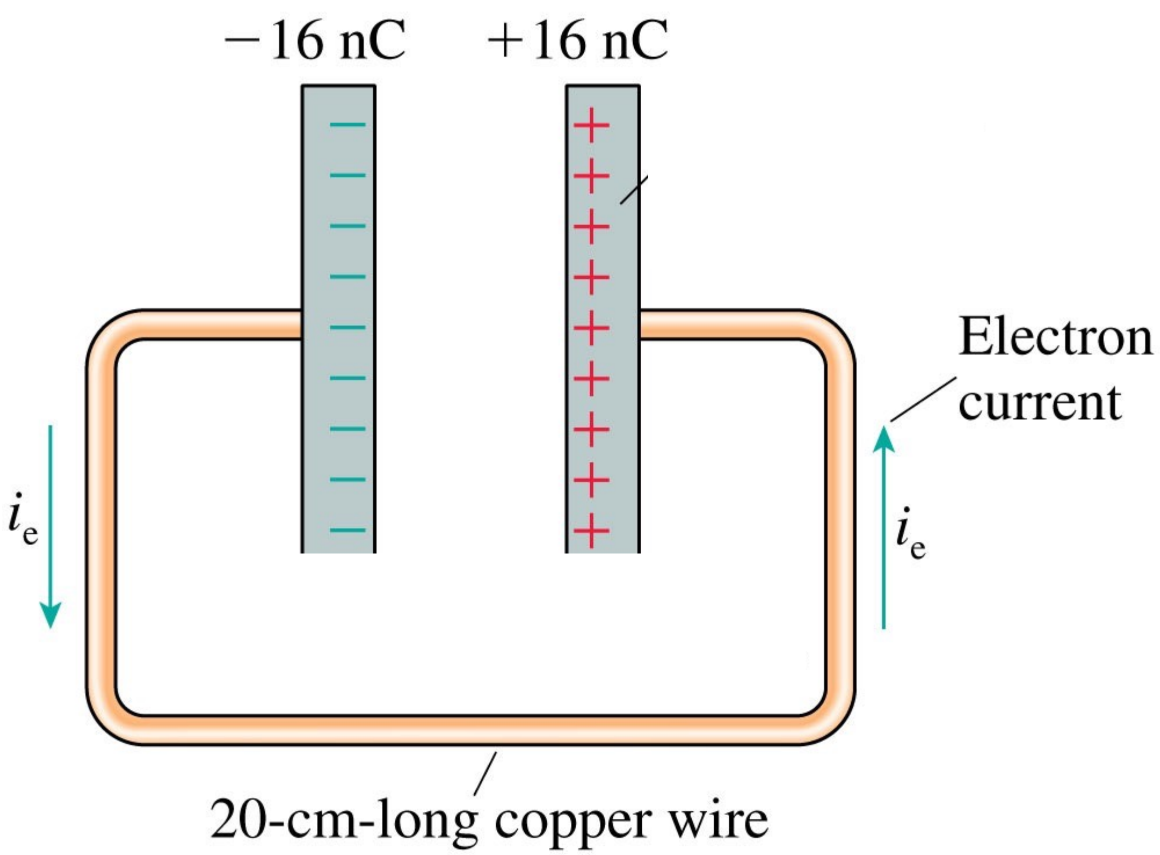
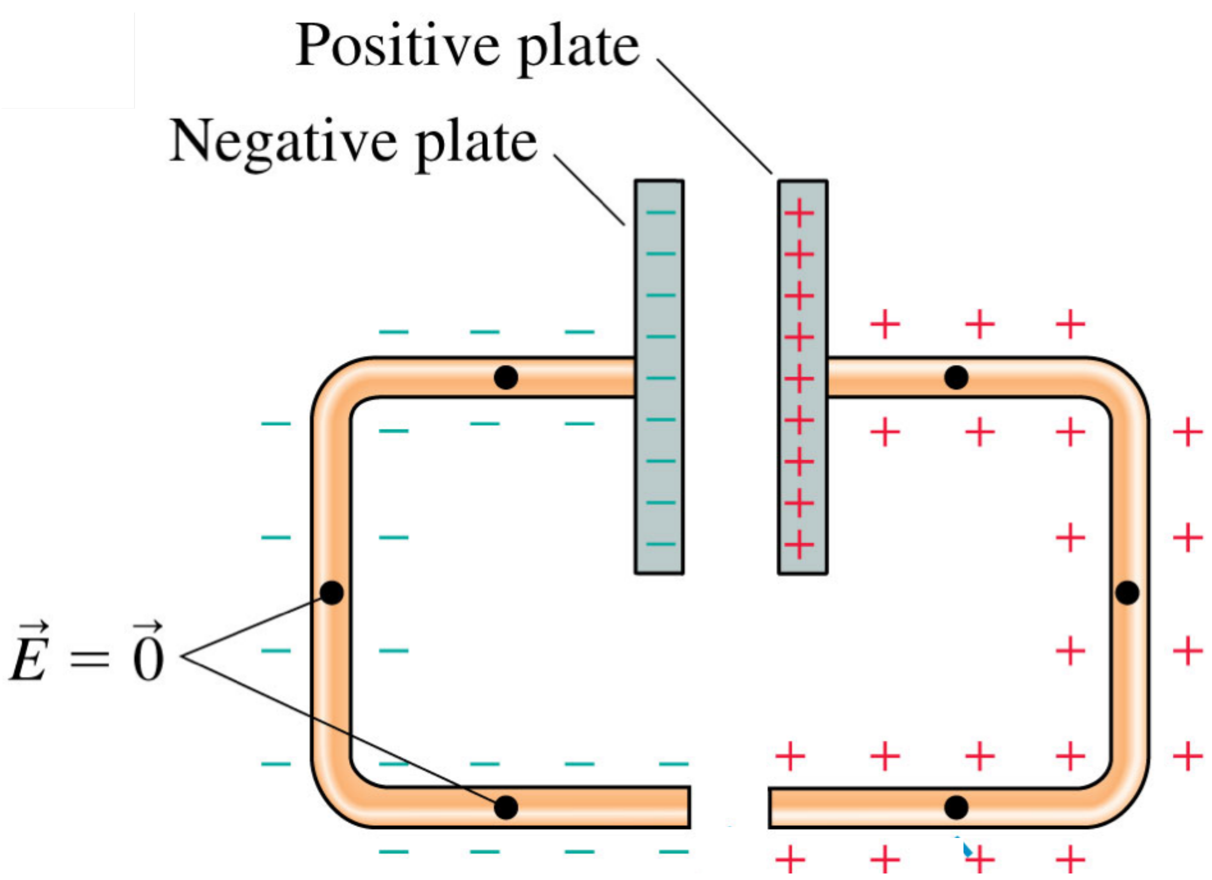


5×10^{22}

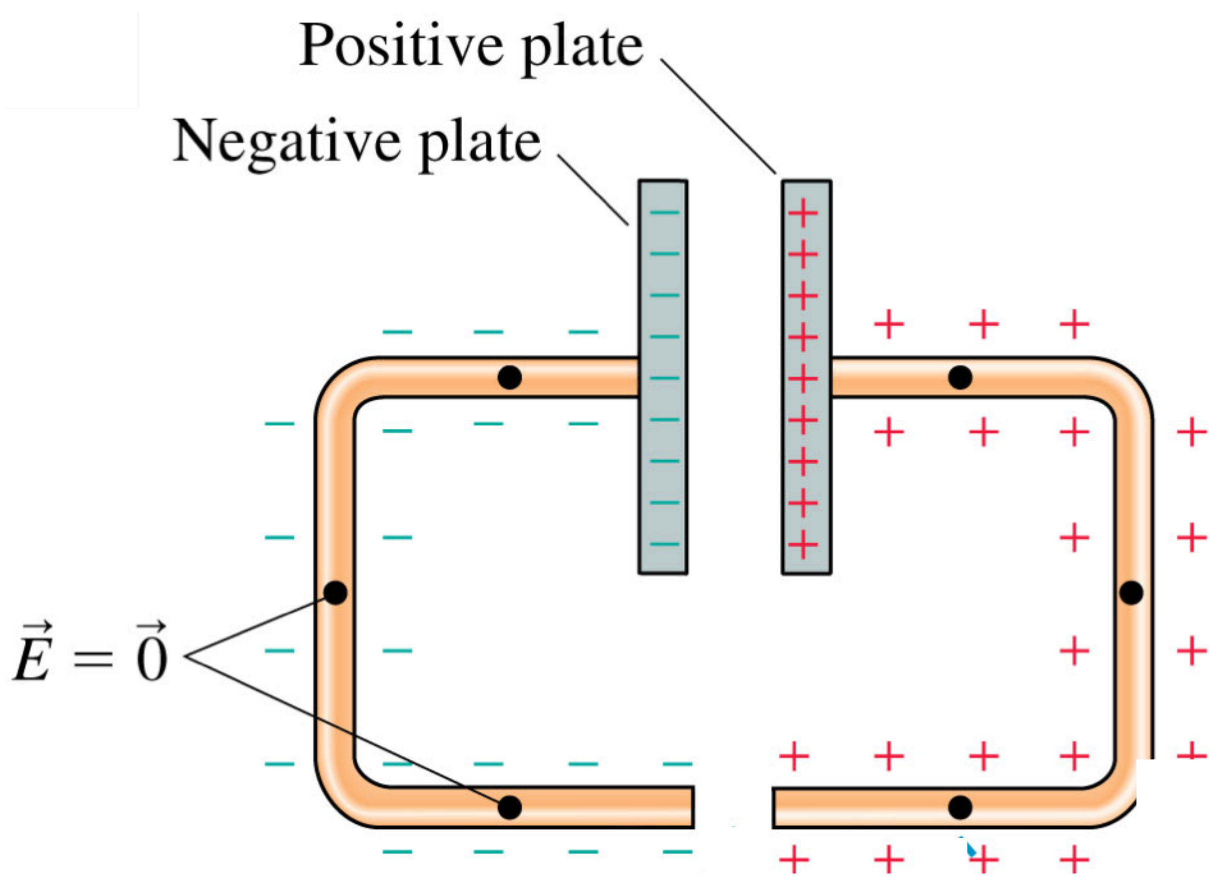
10^{11}

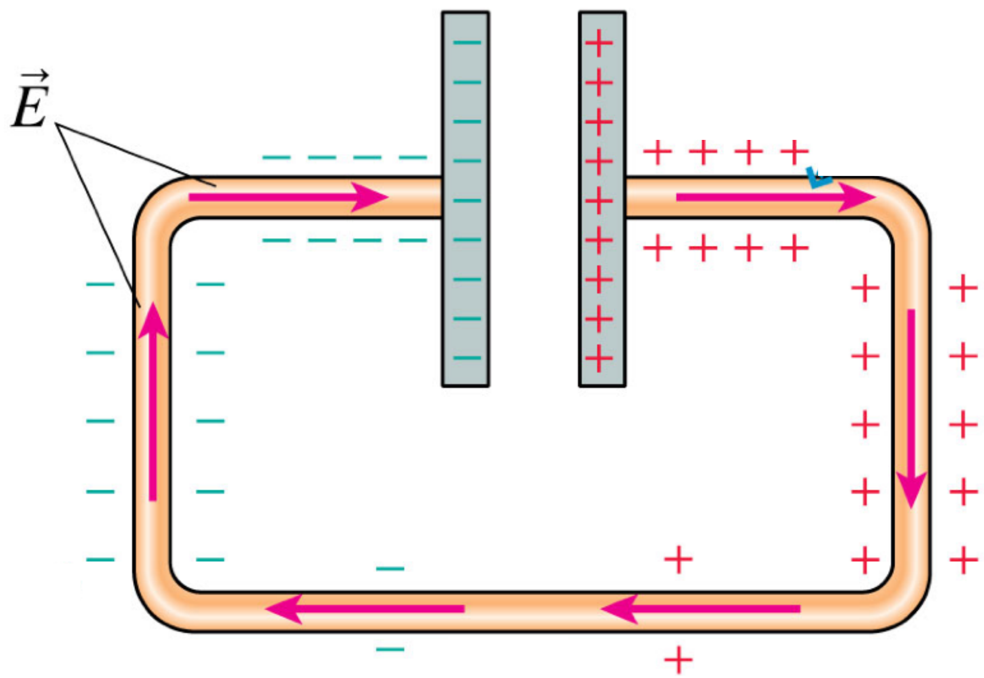


Conceptualizing Current

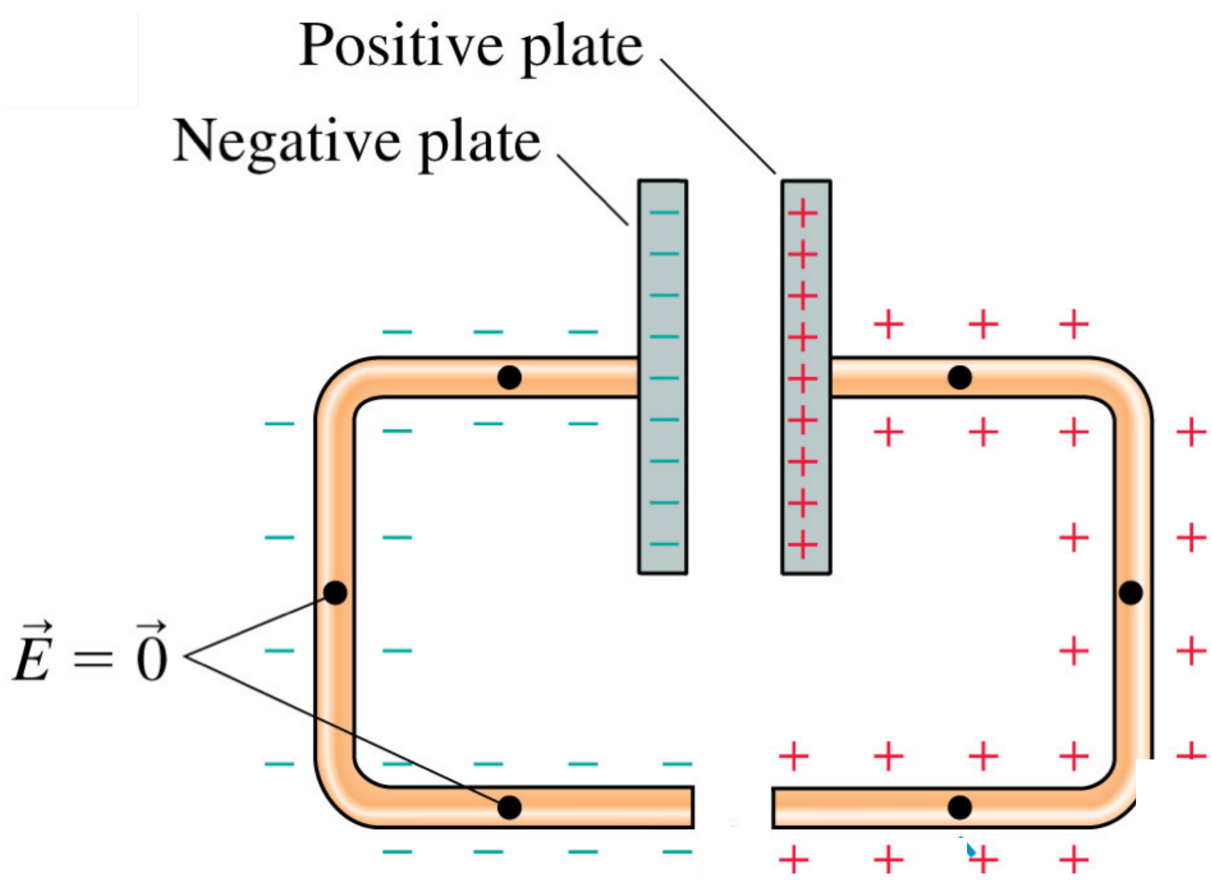


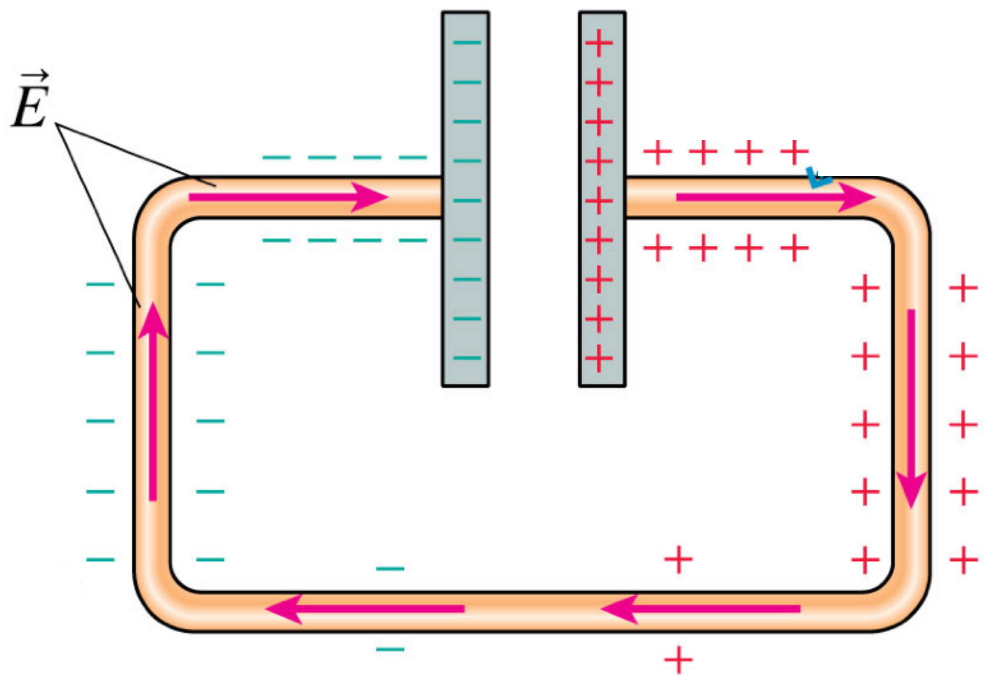
Conceptualizing Current

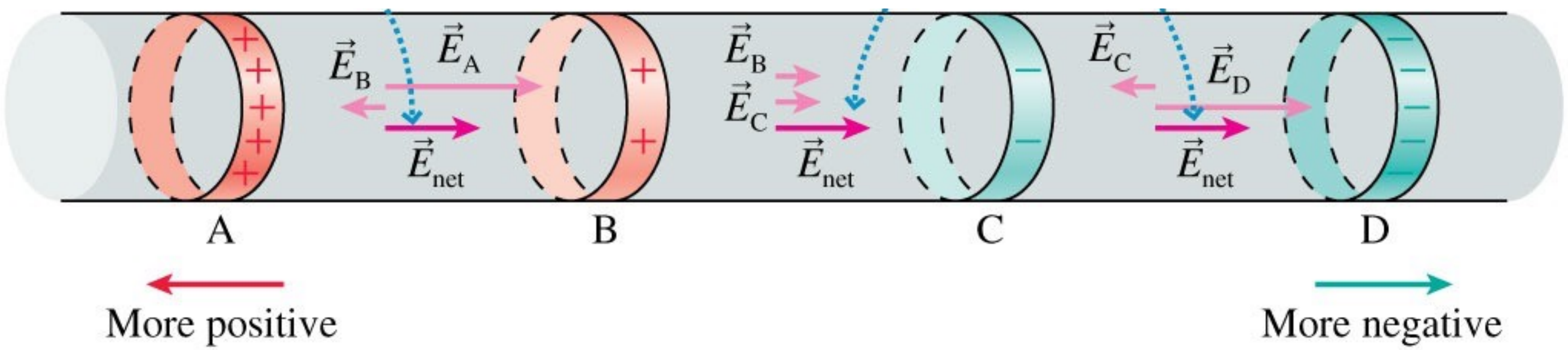




Conceptualizing Current

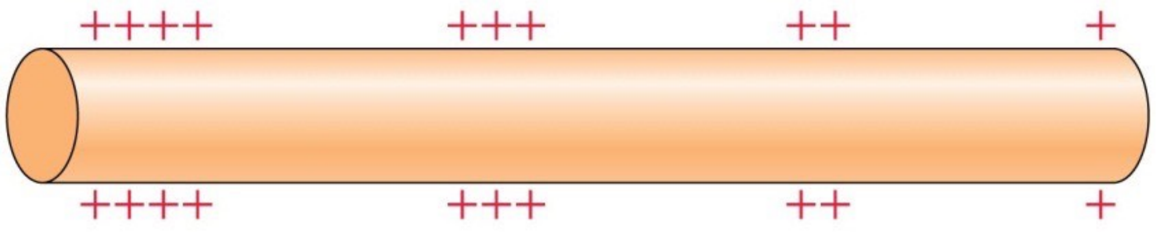






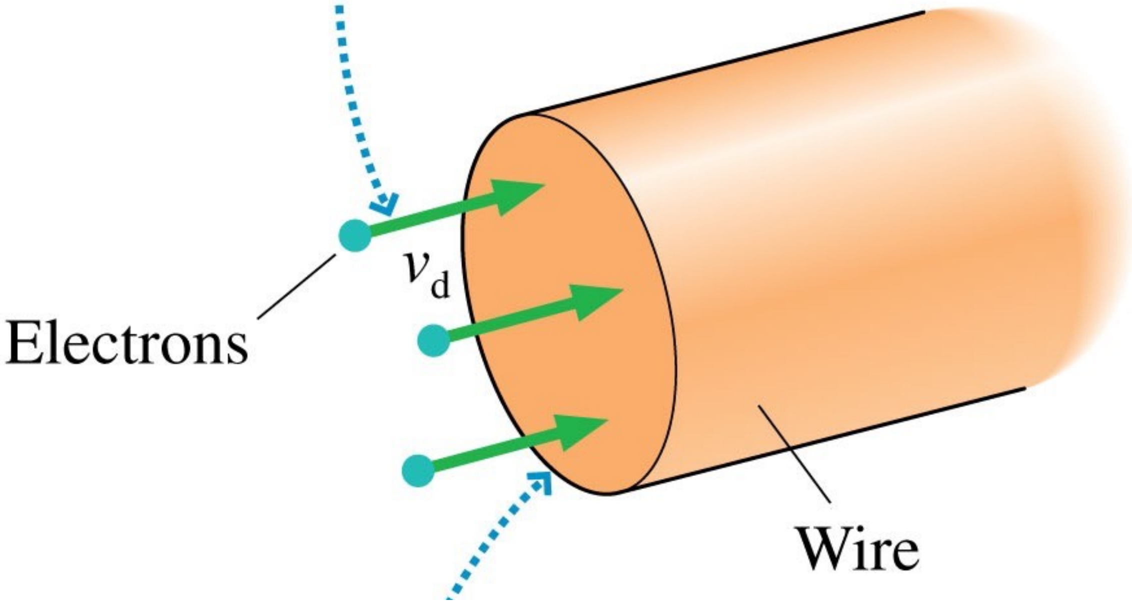
Question #28

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



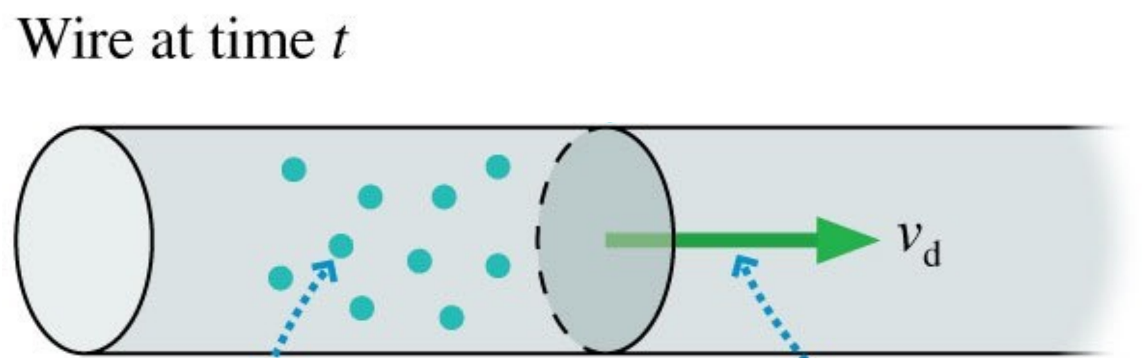
A. Drift to the right.
B. Move downward.
C. Move upward.
D. Drift to the left.
E. On average, remain at rest.

Current

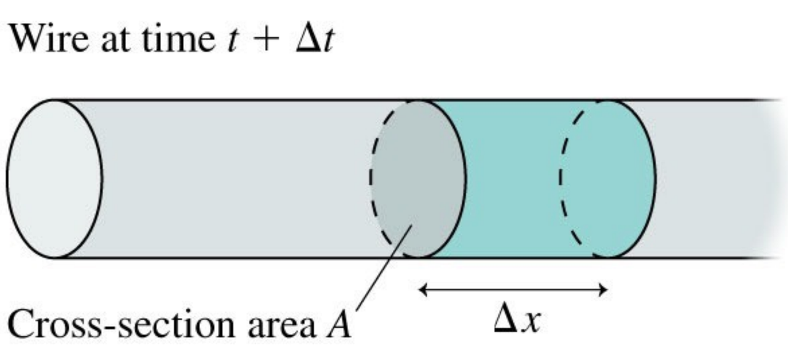


$$i_e = \frac{N_e}{\Delta t}$$

$$N_e = i_e \Delta t$$



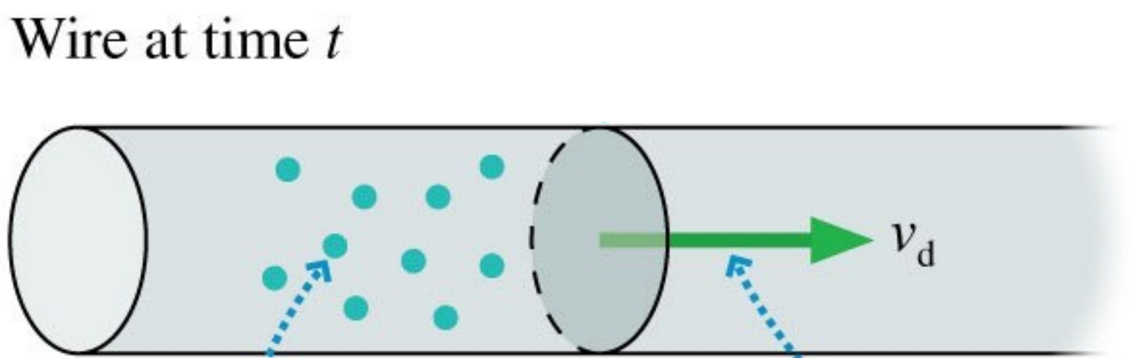
Wire at time t
v_d

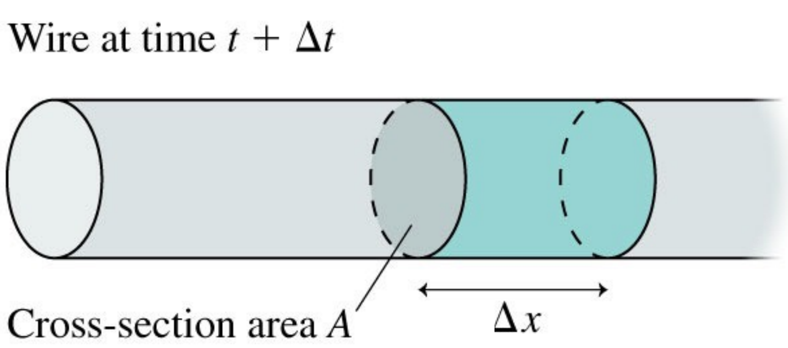


Wire at time $t + \Delta t$
Cross-section area A
Δx

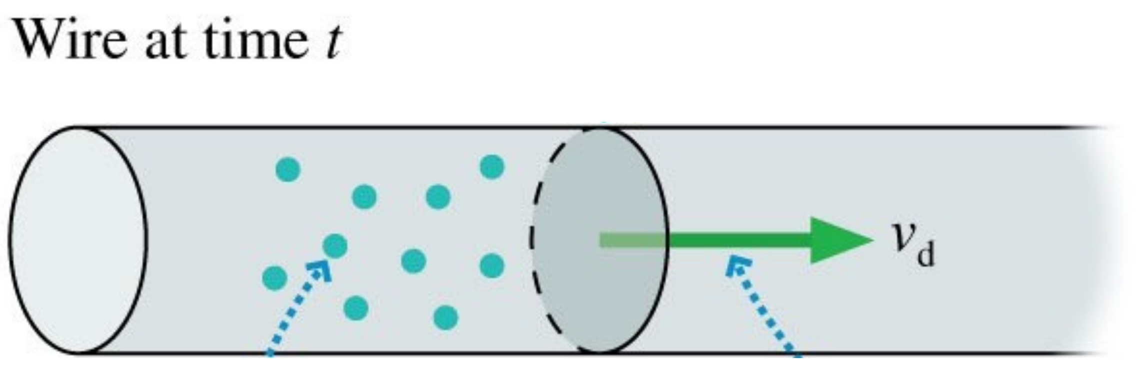
$$N_e = i_e \Delta t$$

$$N_e = n_e V$$



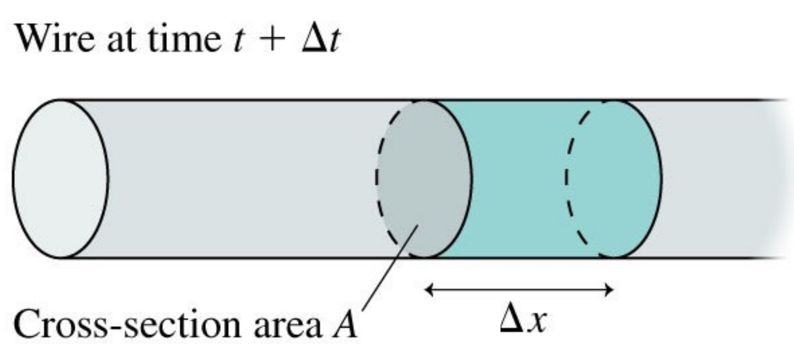


$$N_{\mathrm{e}} = i_{\mathrm{e}} \Delta t$$



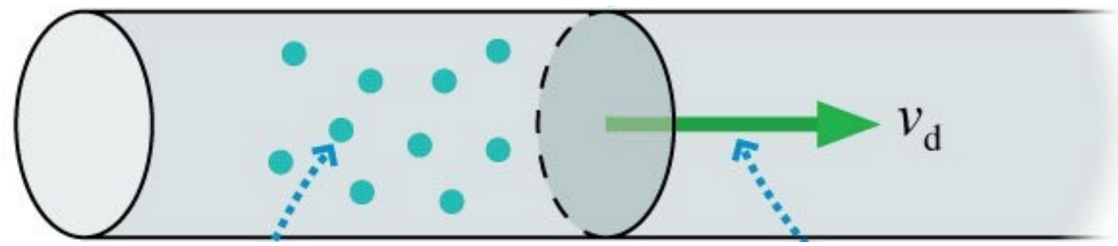
$$N_e = n_e V$$

$$= n_e A \Delta x$$



$$N_e = i_e \Delta t$$

Wire at time t

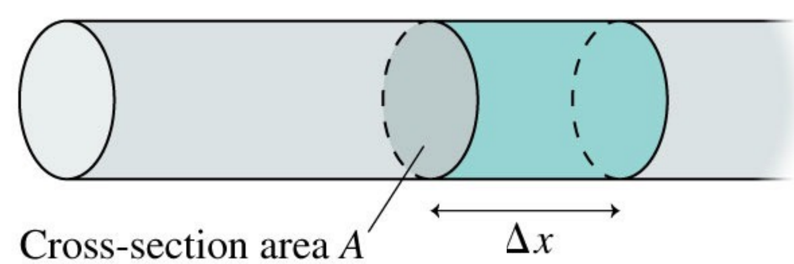


$$N_e = n_e V$$

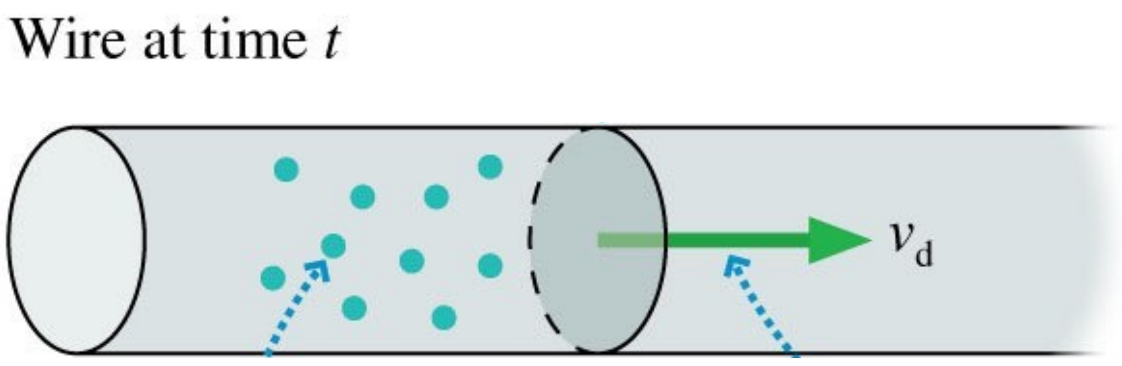
$$= n_e A \Delta x$$

$$= n_e A v_d \Delta t$$

Wire at time $t + \Delta t$



$$N_e = i_e \Delta t$$



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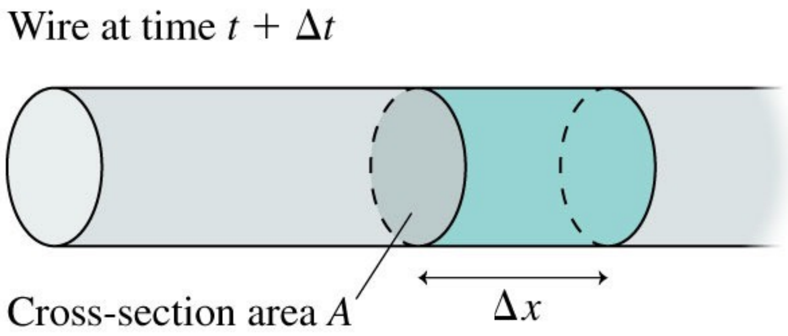

$$i_e = n_e A v_d$$

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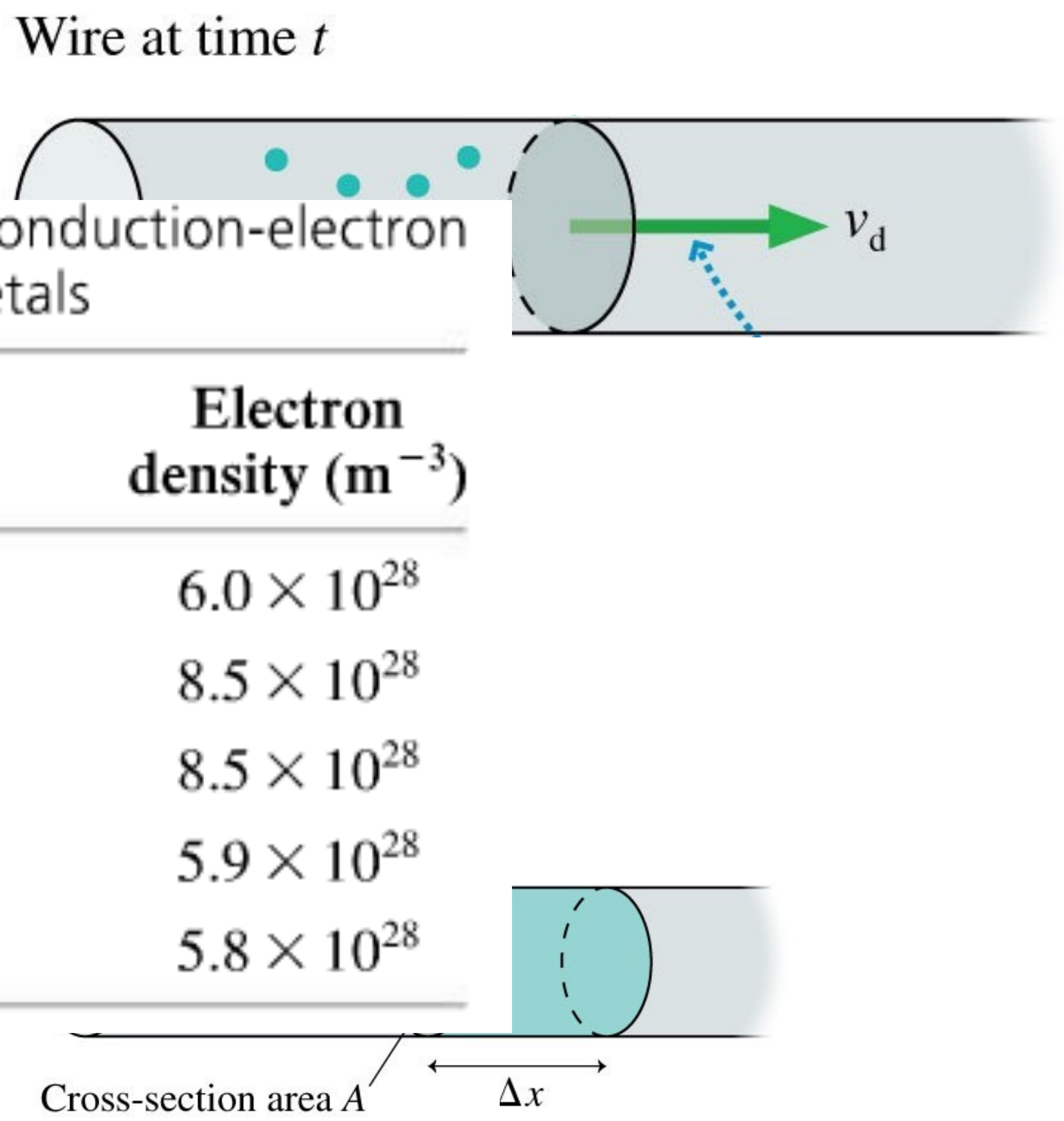
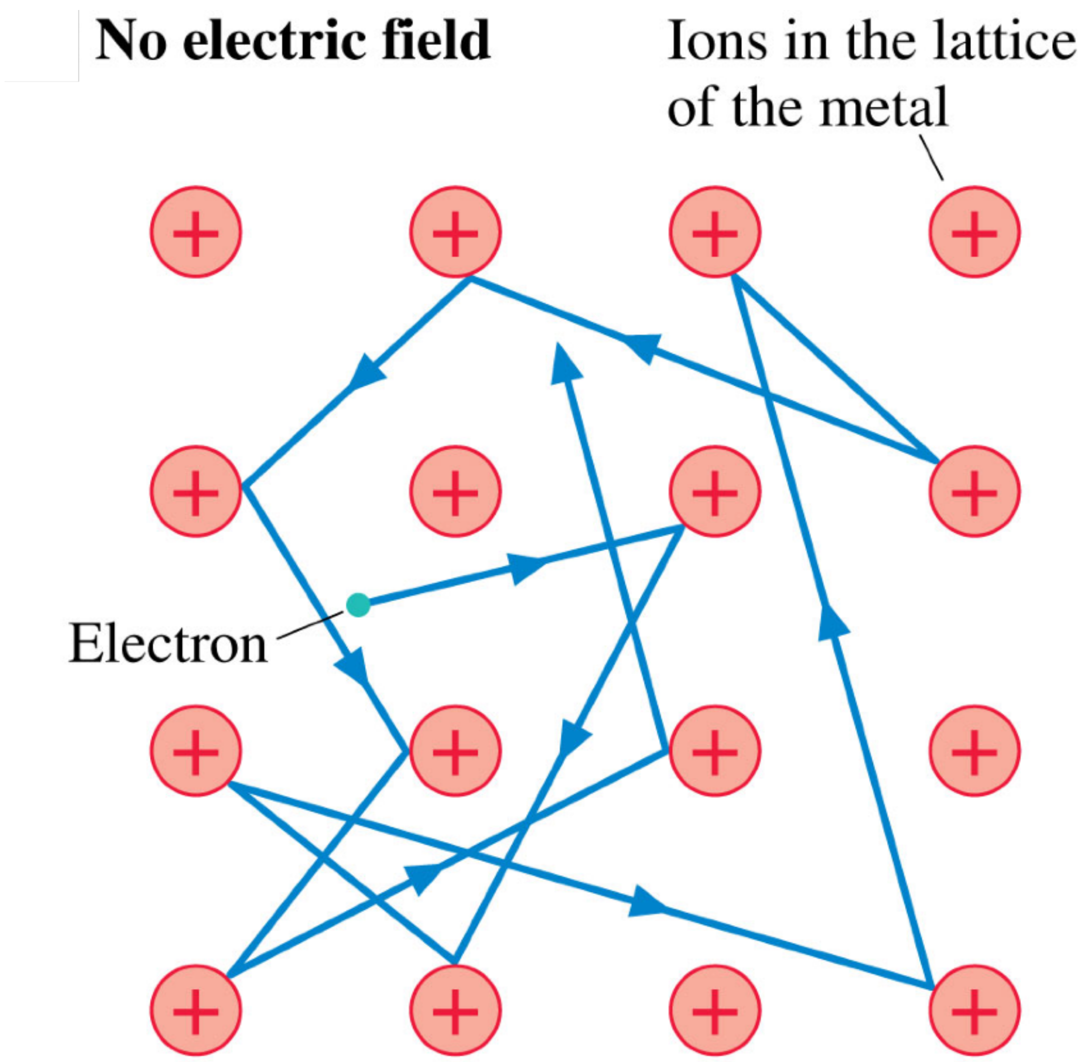


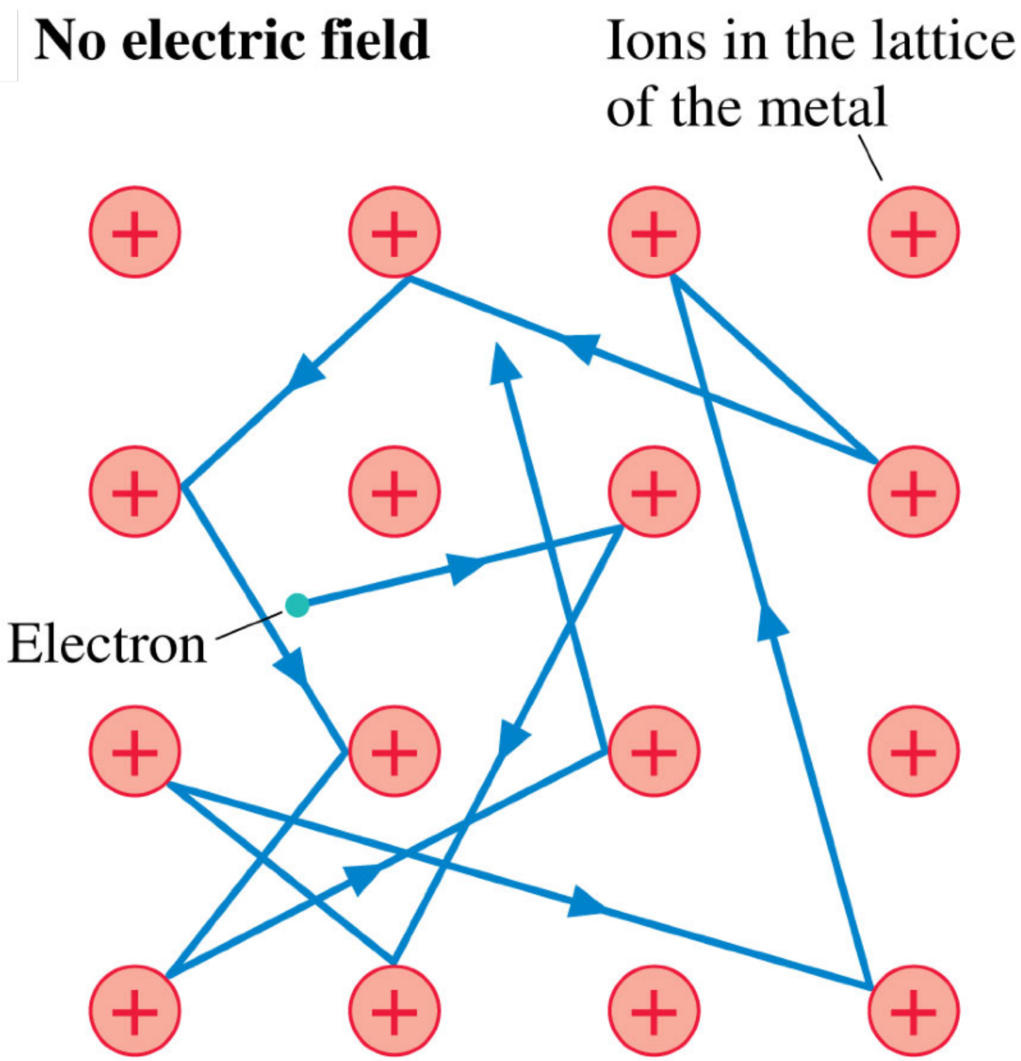
TABLE 30.1 Conduction-electron density in metals

Metal	Electron density (m^{-3})
Aluminum	6.0×10^{28}
Copper	8.5×10^{28}
Iron	8.5×10^{28}
Gold	5.9×10^{28}
Silver	5.8×10^{28}

Model of Conduction

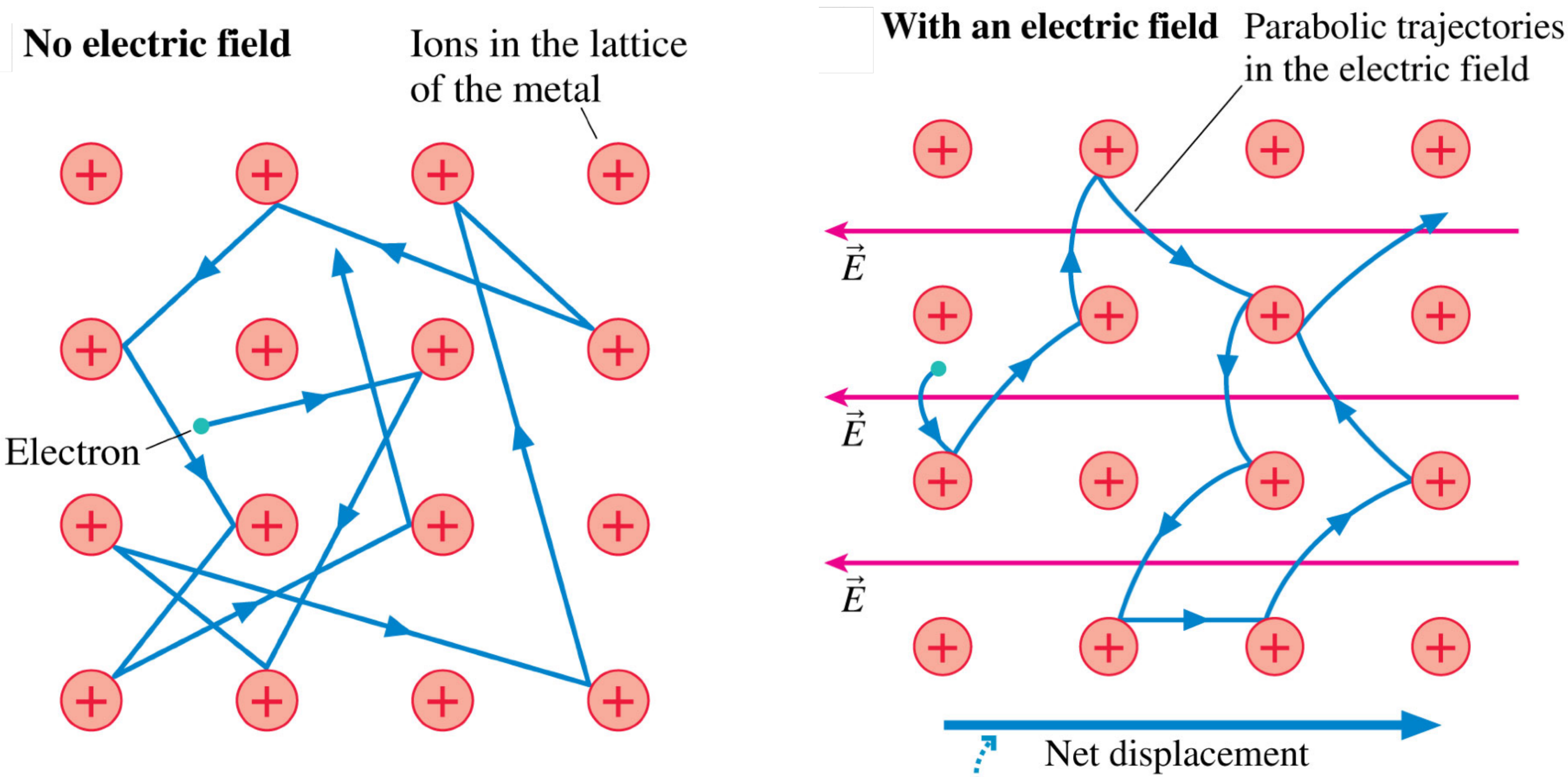


Model of Conduction



What will the trajectories look like when an E field is present?

Model of Conduction



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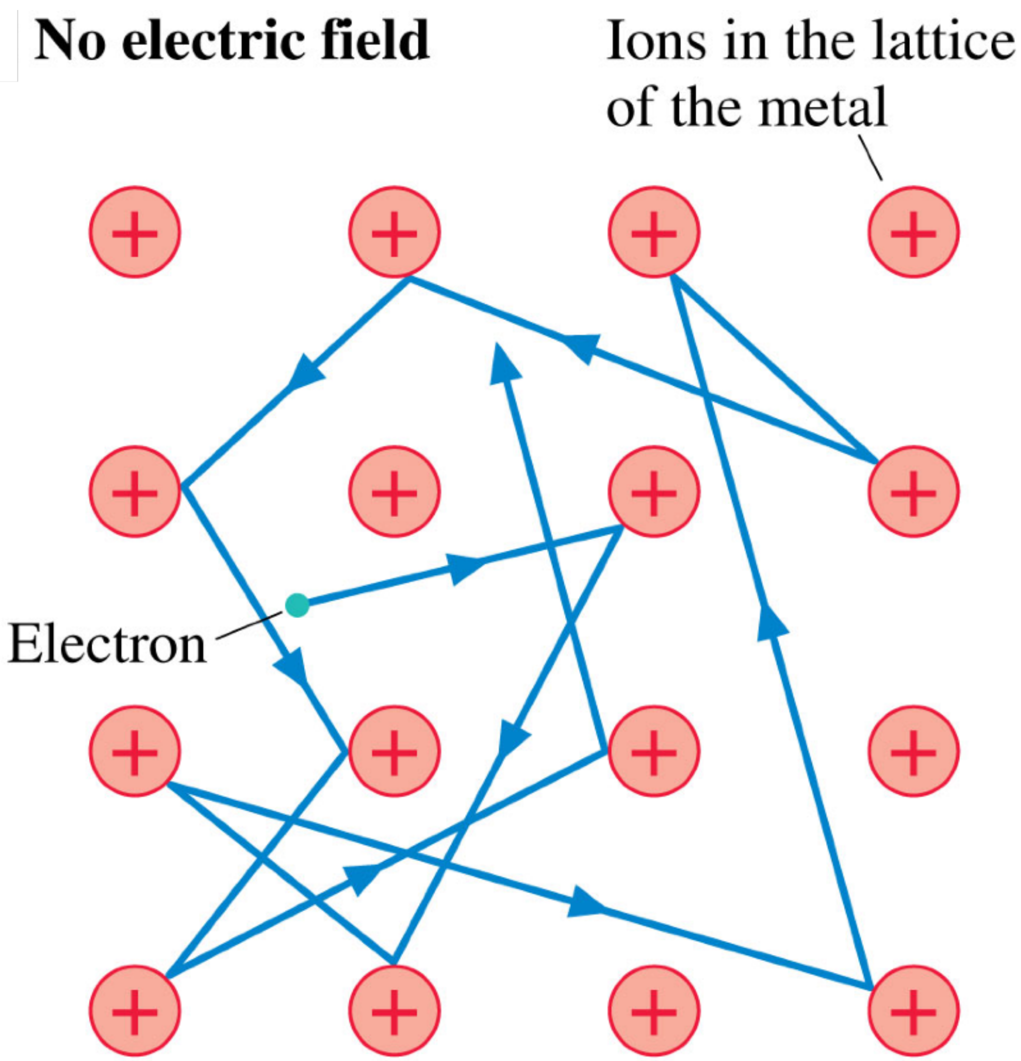
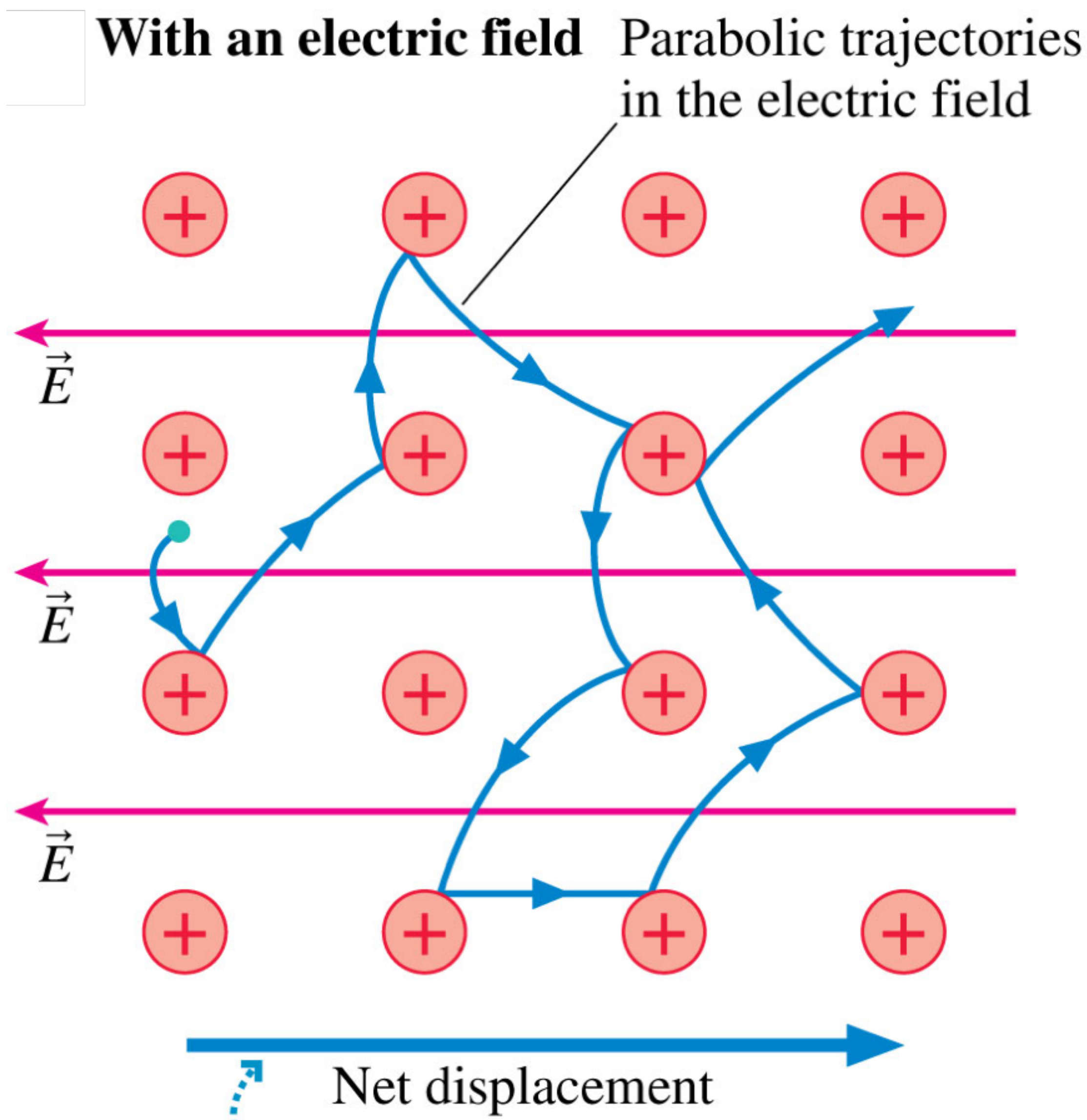
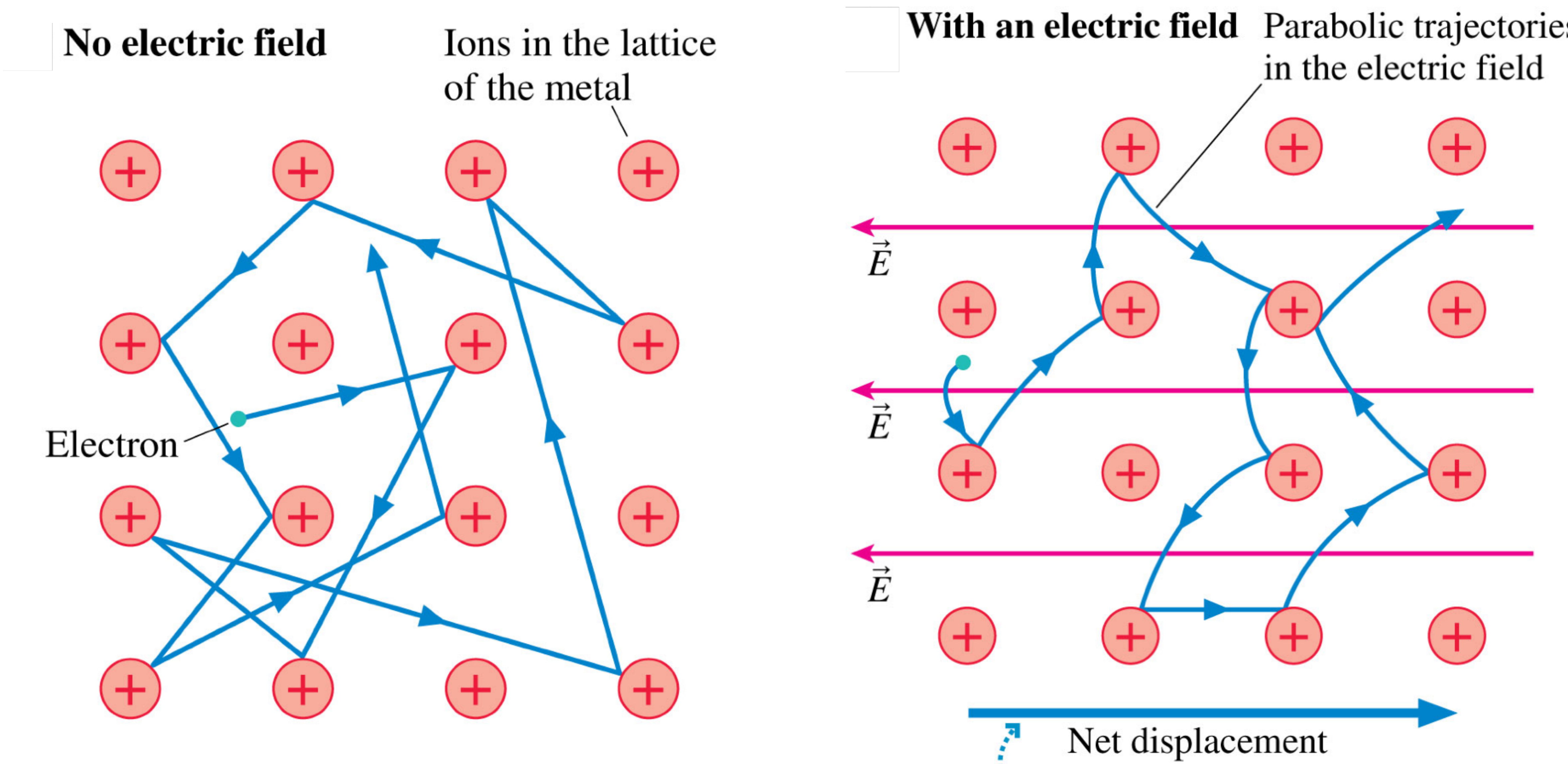




What will the trajectories look like when an E field is present?

Write an expression for the acceleration of the electrons in between collisions

Model of Conduction

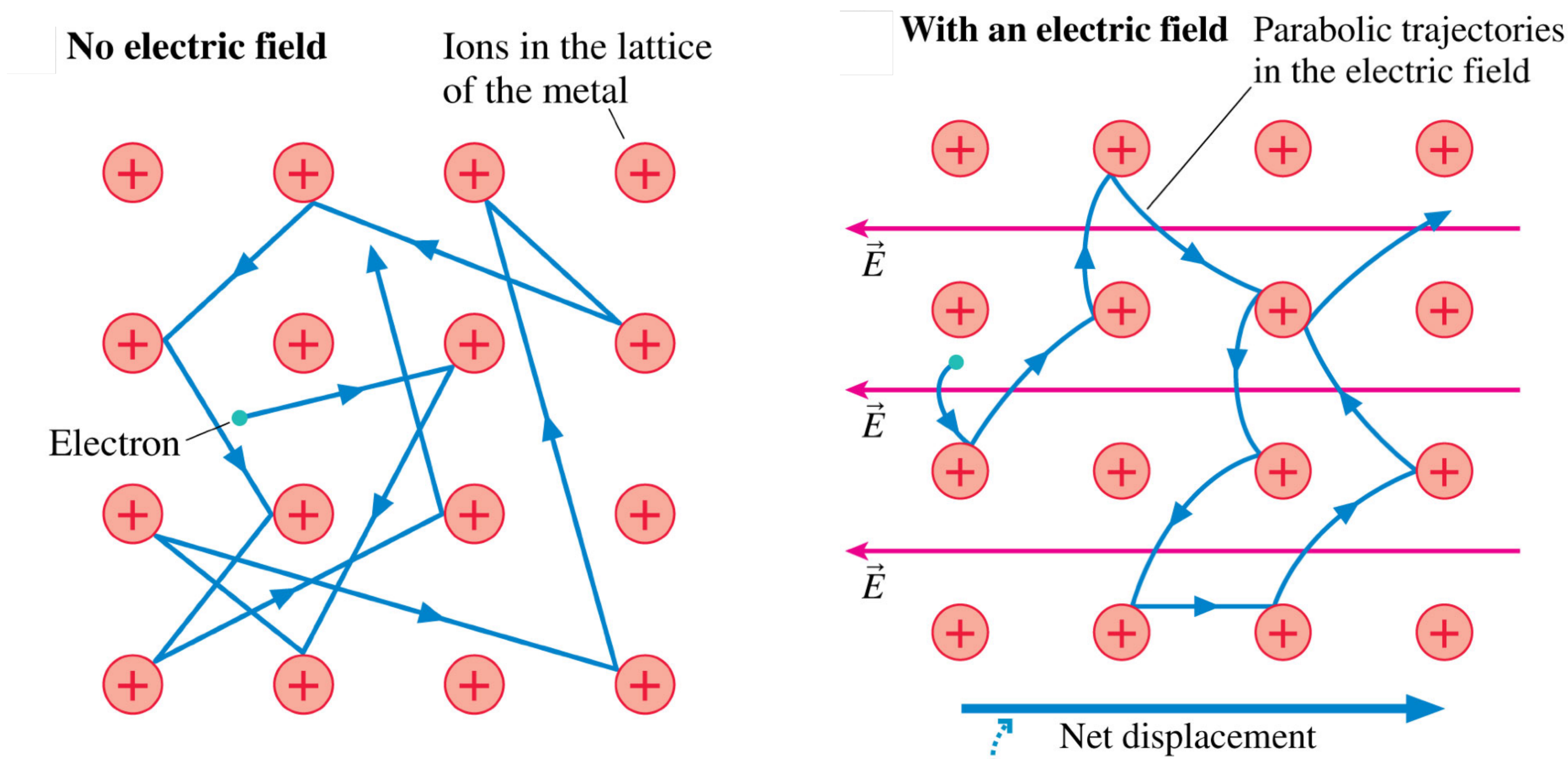


What will the trajectories look like when an E field is present?

Write an expression for the acceleration of the electrons in between collisions

$$a = \frac{eE}{m}$$

Model of Conduction



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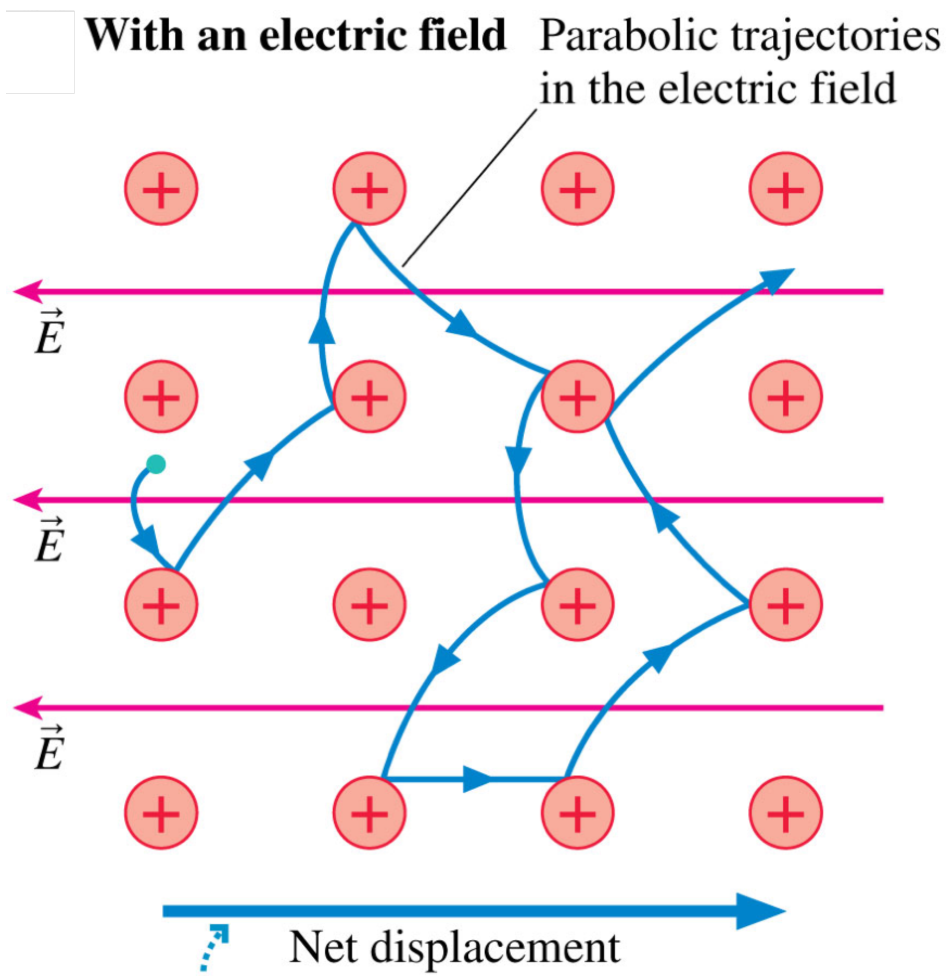
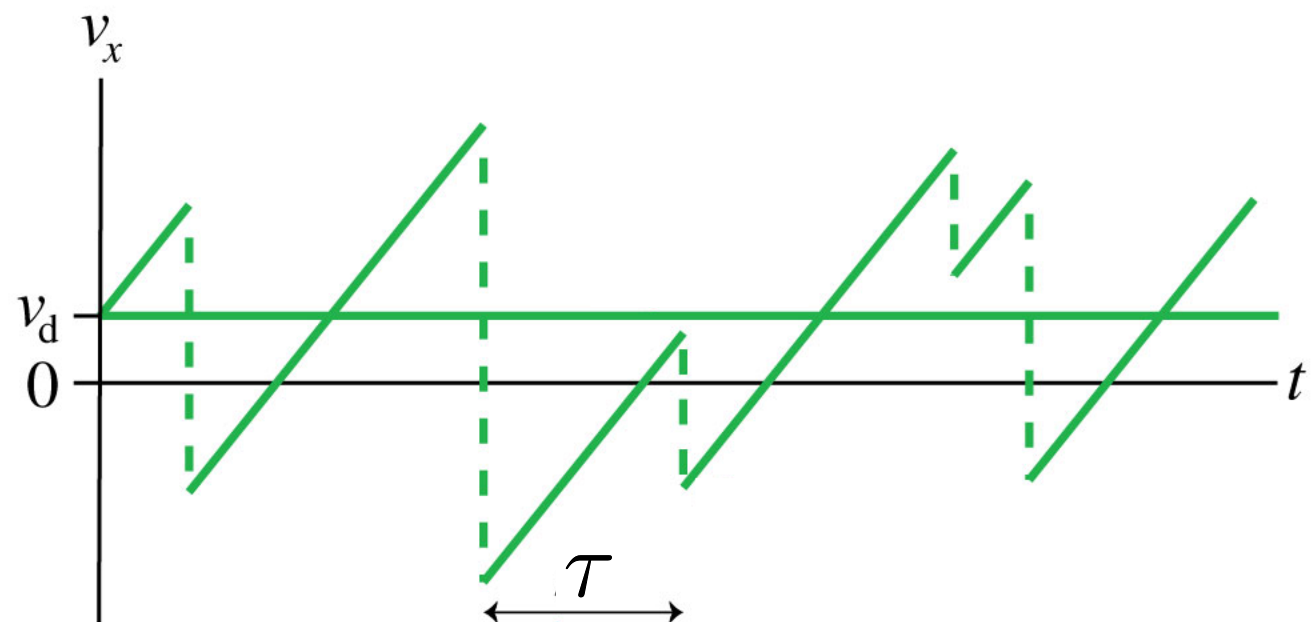
$$v_d = \frac{eE}{m}\tau$$





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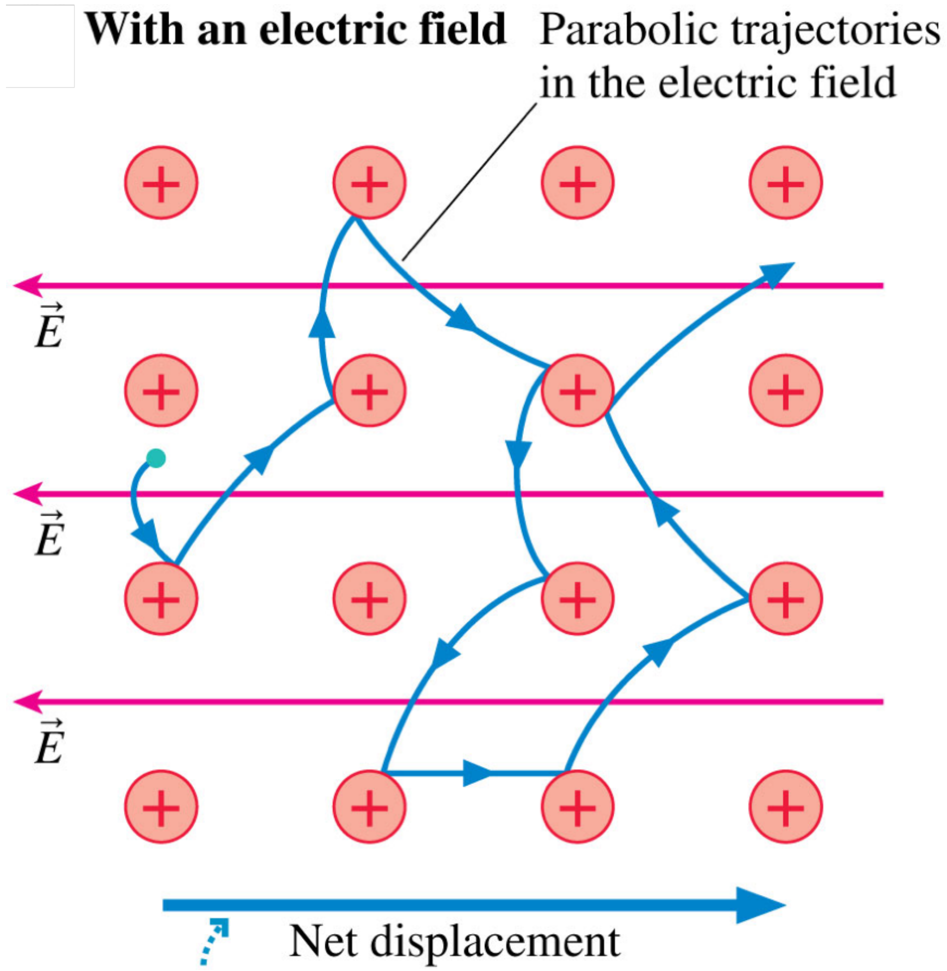
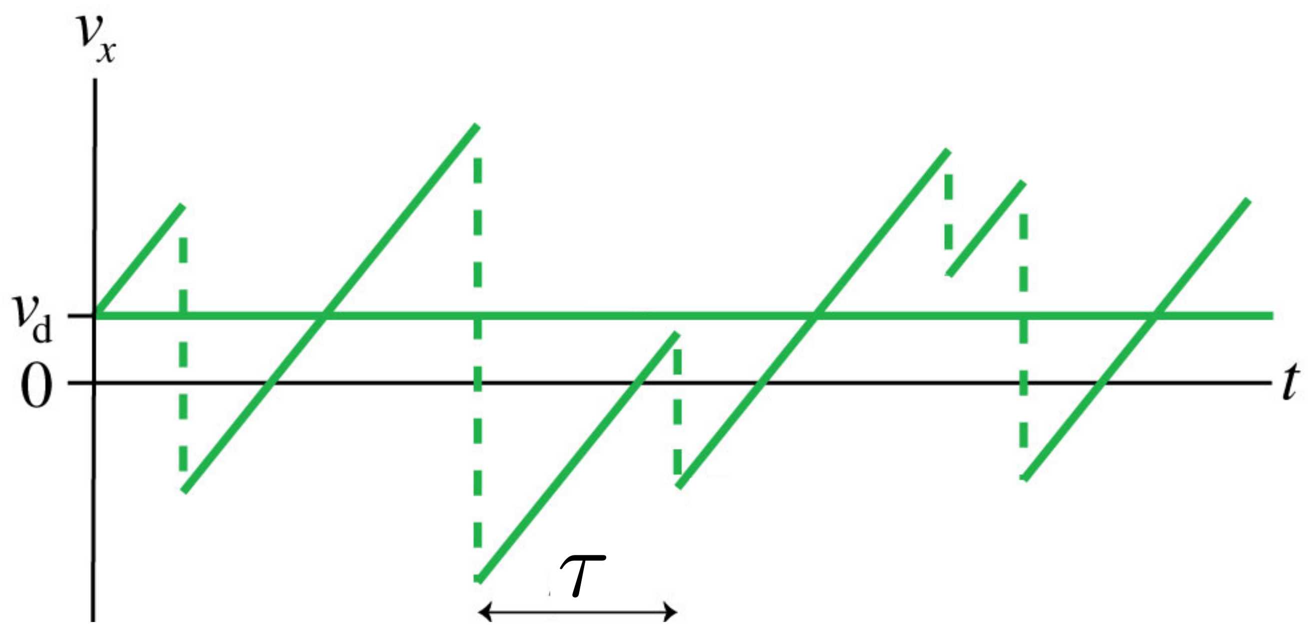
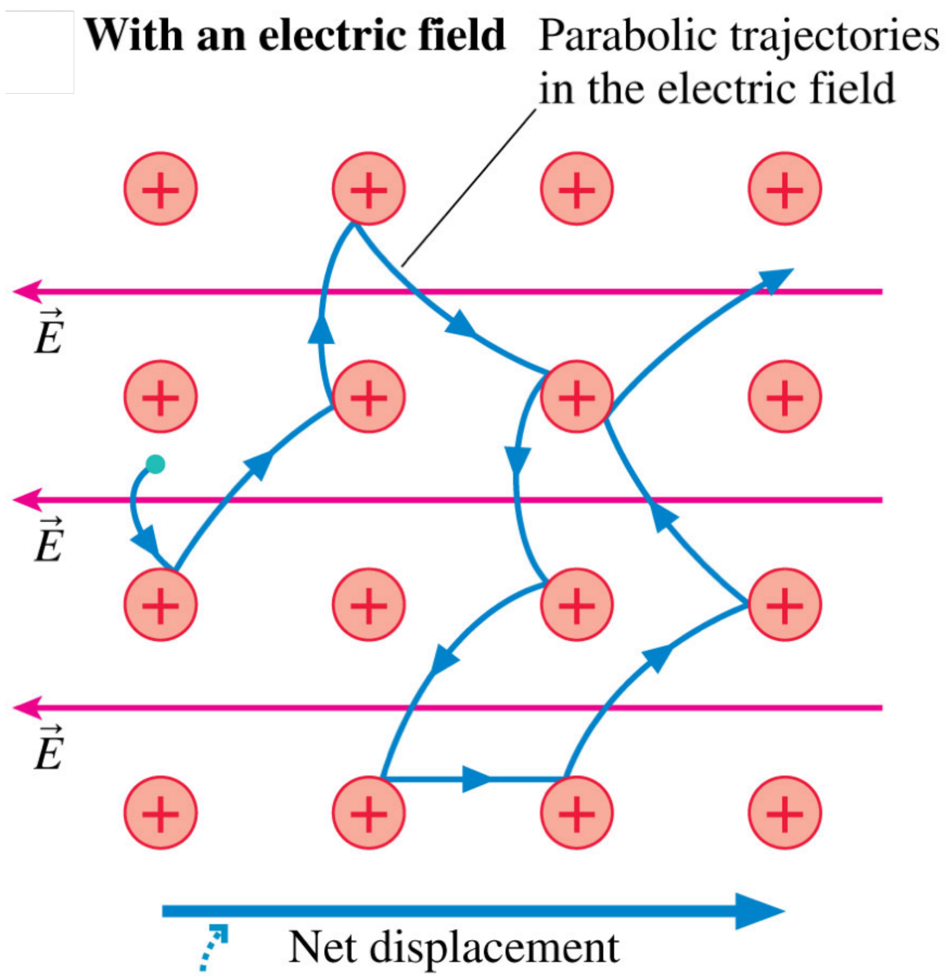
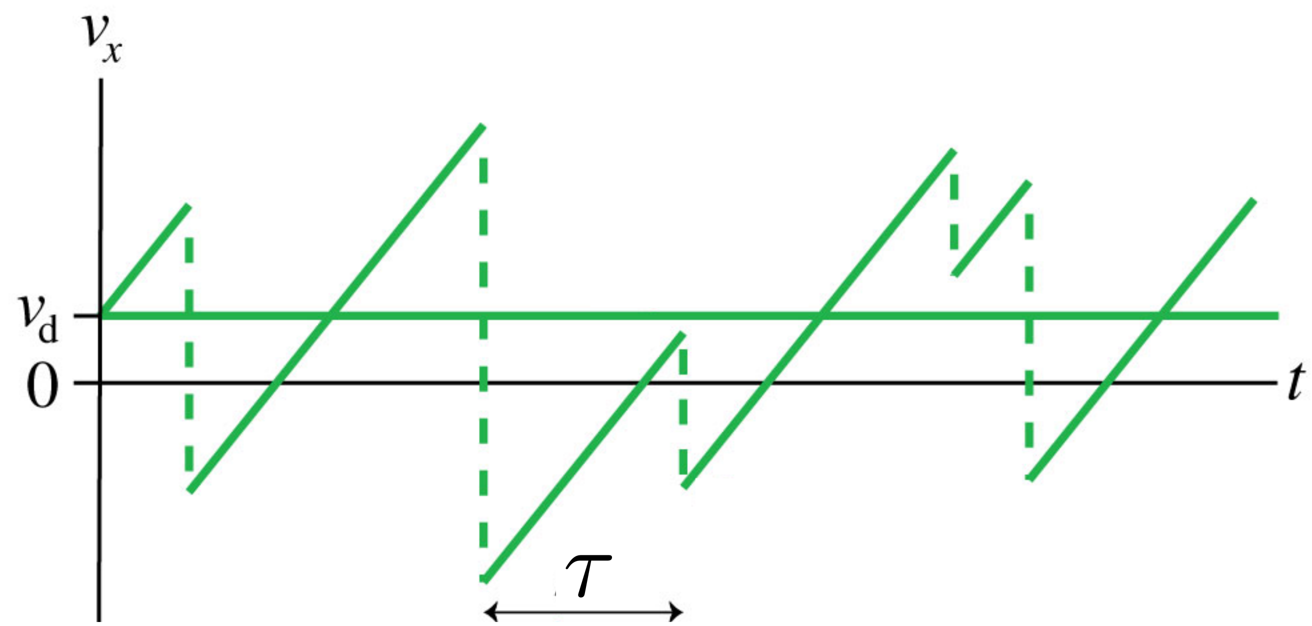




$$v_d = \frac{eE}{m}\tau$$

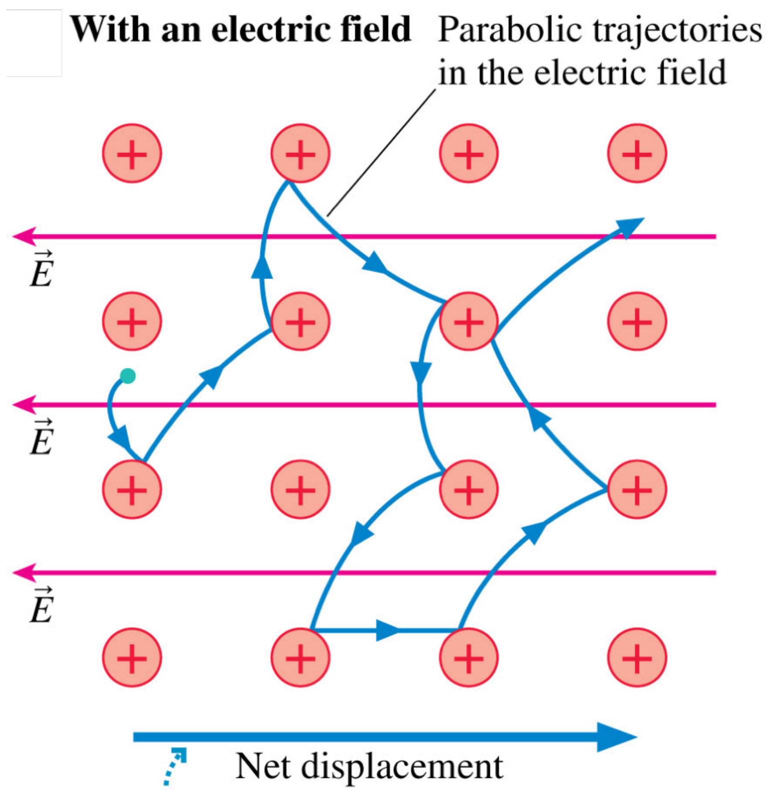
$$\boxed{i_e = \frac{n_e A e E \tau}{m}}$$





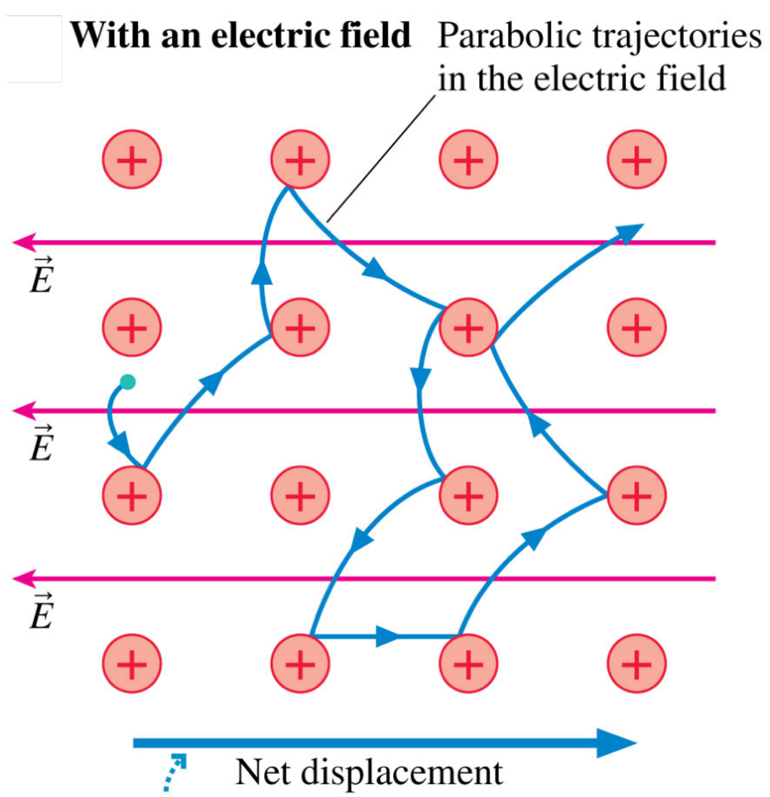
$$v_d = \frac{eE}{m}\tau \qquad i_e = n_e A v_d$$

$$\boxed{i_e = \frac{n_e A e E \tau}{m}}$$



$$i_e = \frac{n_e A e E \tau}{m}$$

Perform a unit analysis on this expression. What are the units of i_e?



$$i_e = \frac{n_e A e E \tau}{m}$$

# of electrons/time

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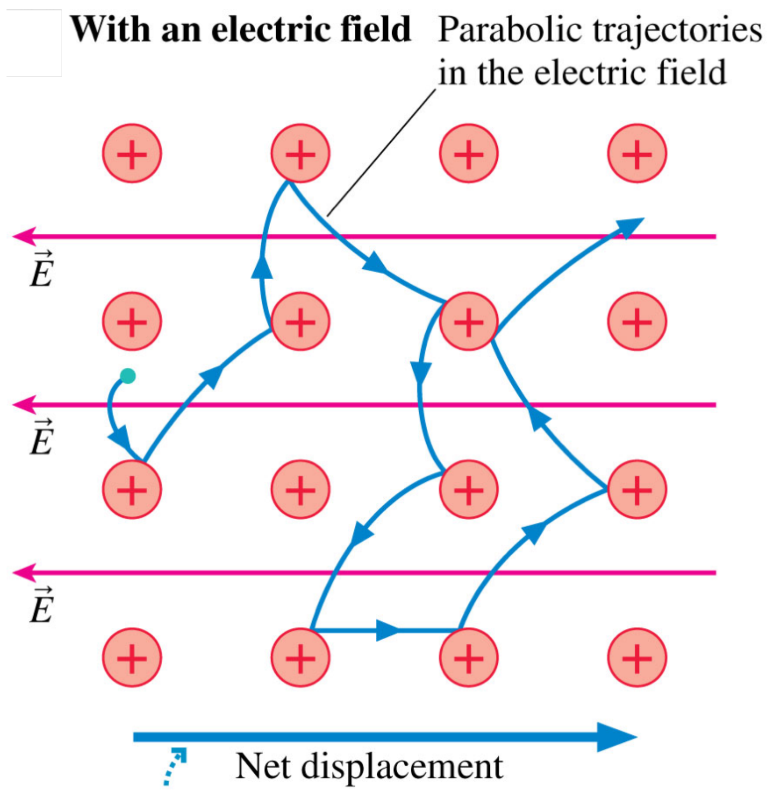

$$i_e = \frac{n_e A e E \tau}{m}$$

# of electrons/time

$$I = \frac{dQ}{dt} = \frac{n_e A e^2 E \tau}{m} = \frac{n_e A e^2 \tau}{m} E$$

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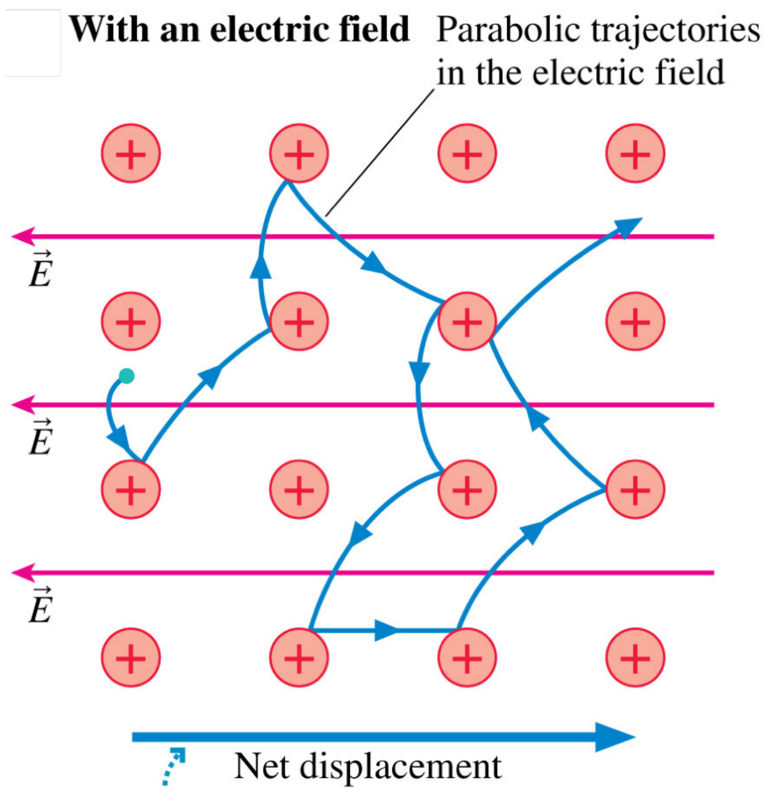

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charge/time

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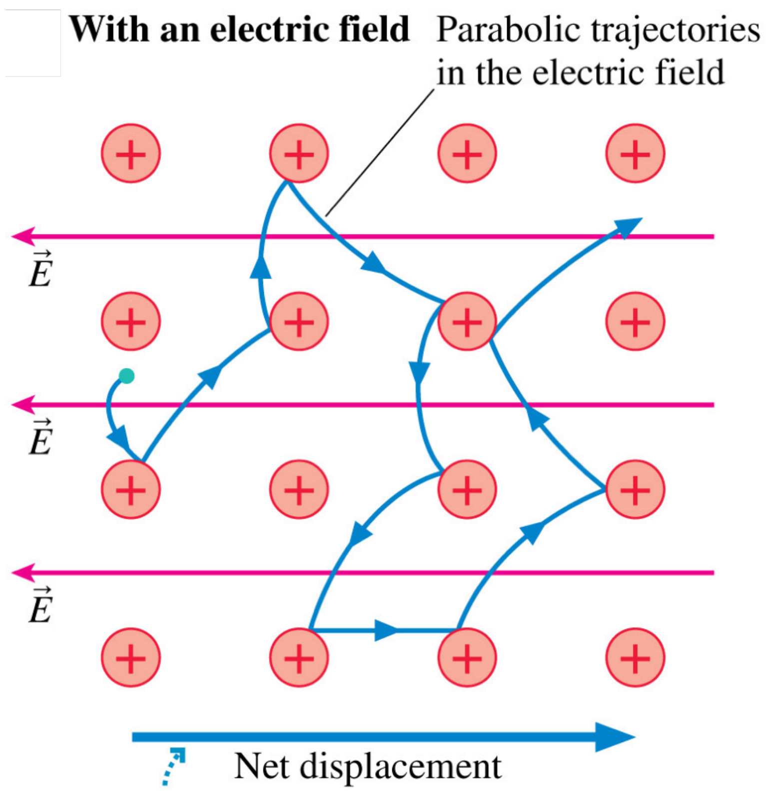

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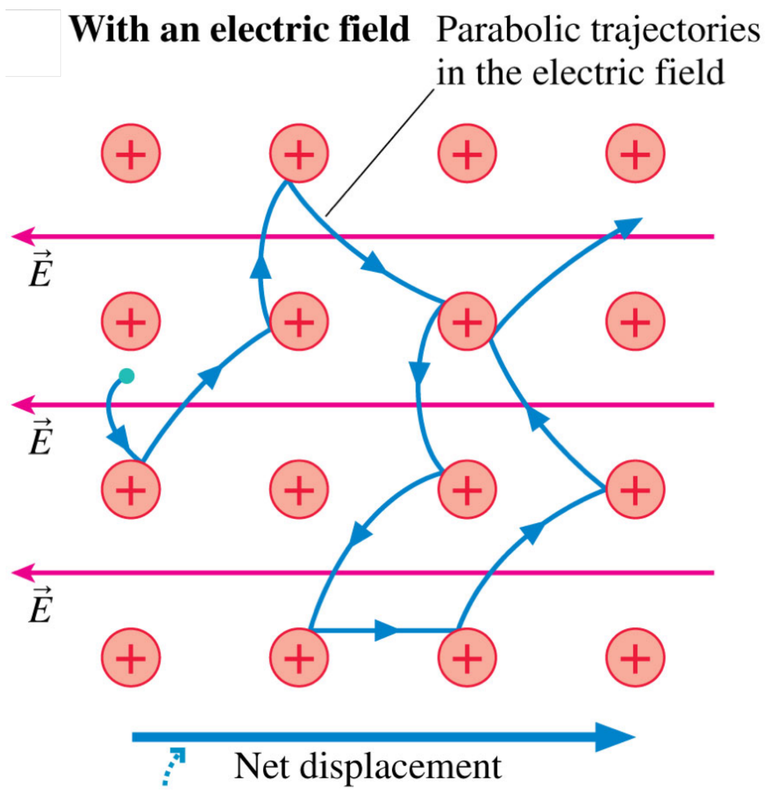
# of electrons/time

$$I = \frac{dQ}{dt} = \frac{n_e A e^2 E \tau}{m} = \frac{n_e A e^2 \tau}{m} E$$

charge/time

Perform a unit analysis on this expression. What are the units of i_e?

$$J = \frac{I}{A} = \frac{n_e e^2 \tau}{m} E$$



$$i_e = \frac{n_e A e E \tau}{m}$$

# of electrons/time

$$I = \frac{dQ}{dt} = \frac{n_e A e^2 E \tau}{m} = \frac{n_e A e^2 \tau}{m} E$$

charge/time

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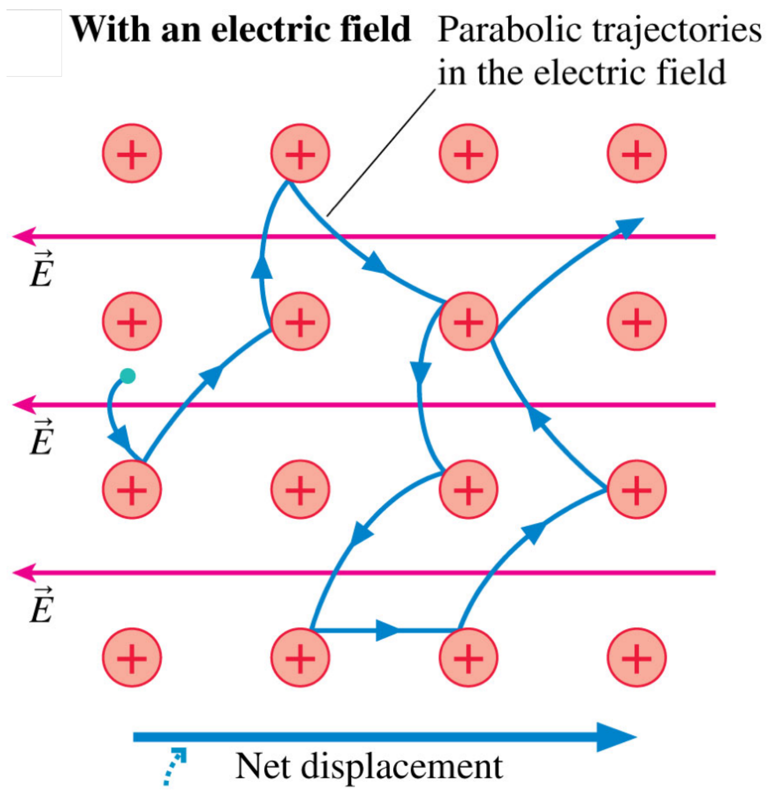

$$i_e = \frac{n_e A e E \tau}{m}$$ # of electrons/time

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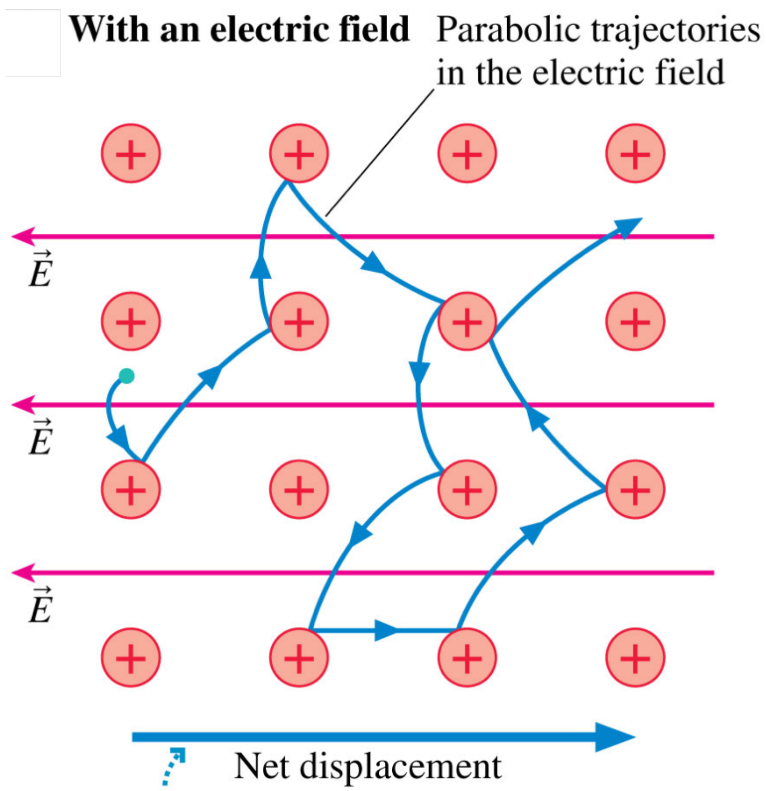
charge/time

Perform a unit analysis on this expression. What are the units of i_e?

$$J = \frac{I}{A} = \boxed{\frac{n_e e^2 \tau}{m}} E$$

$$= \sigma E$$ conductivity



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charge/time

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$$J = \frac{I}{A} = \boxed{\frac{n_e e^2 \tau}{m}} E$$

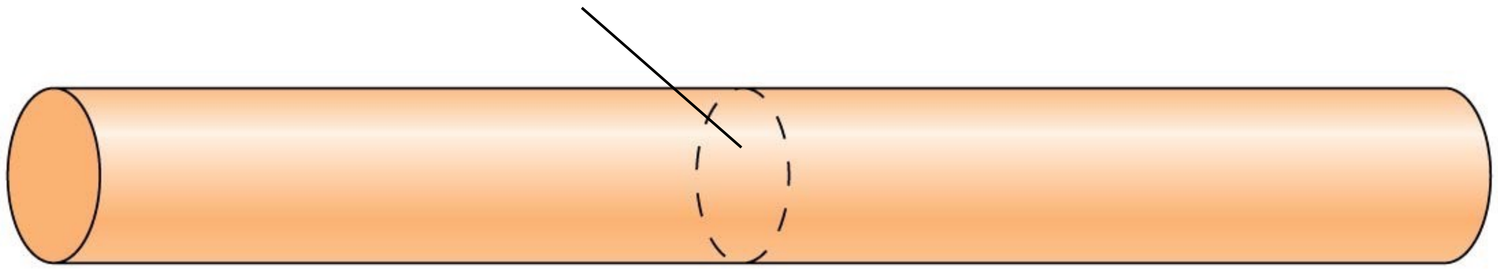
$$= \sigma E$$ conductivity

$$= \frac{1}{\rho} E$$ resistivity

Question #29

Every minute, 120 C of charge flow through this cross section of the wire.

The wire's current is

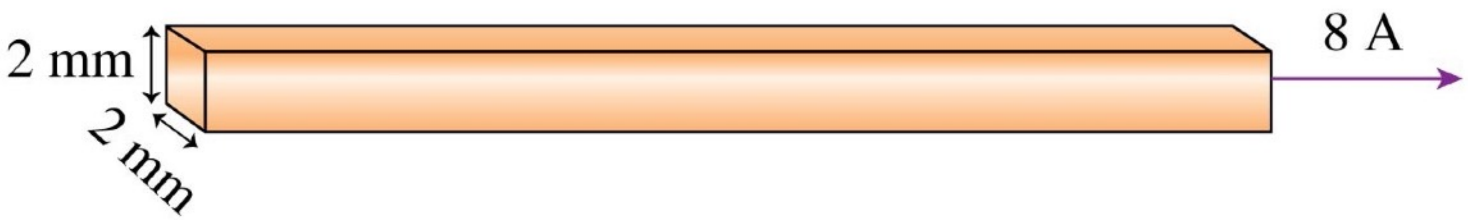


B. 240 A.
C. 120 A.
D. 60 A.
E. 2 A.

Question #30

The current density in this wire is

A. 4×10^6 A/m^2.
B. 2×10^6 A/m^2.
C. 4×10^3 A/m^2.
D. 2×10^3 A/m^2.
E. Some other value.

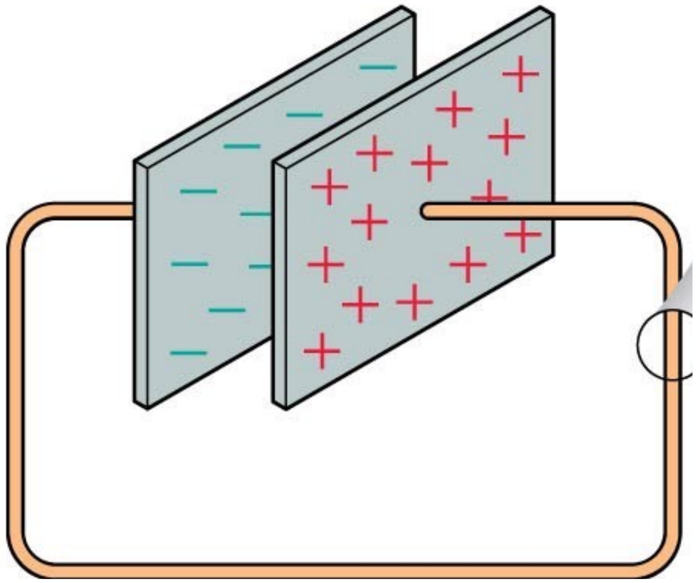


Question #31

Which direction is the current?

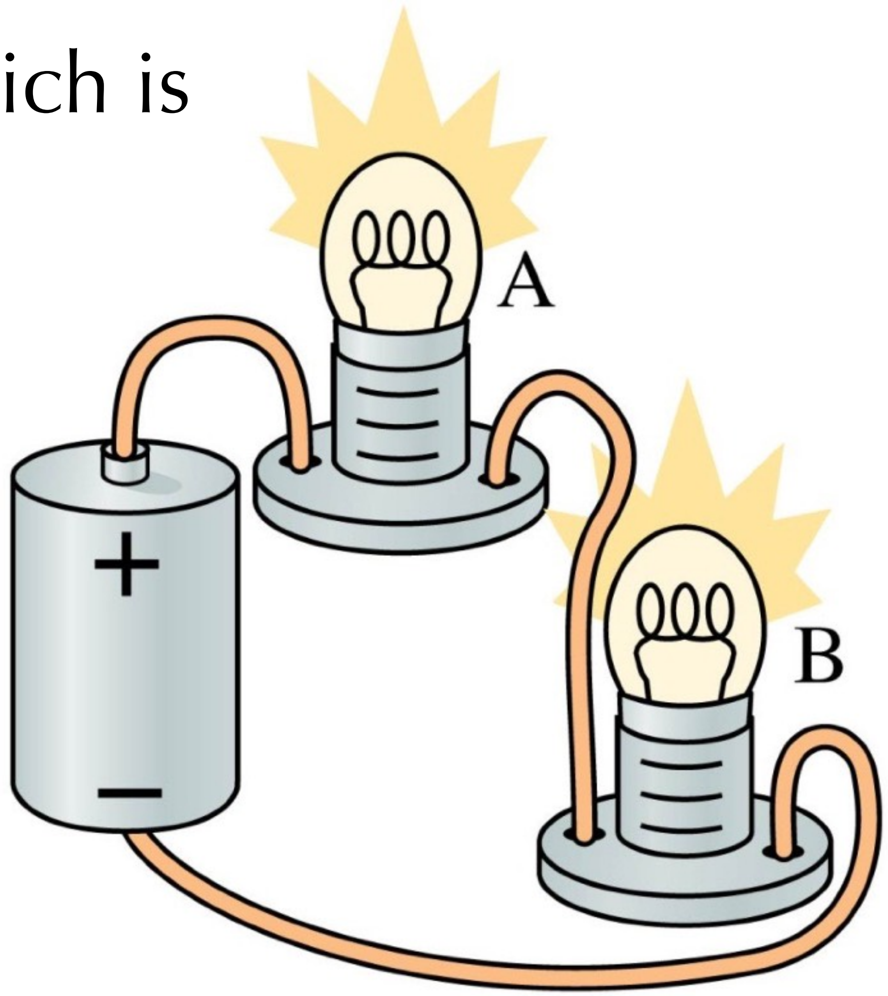
a) counterclockwise

b) clockwise



Question #32

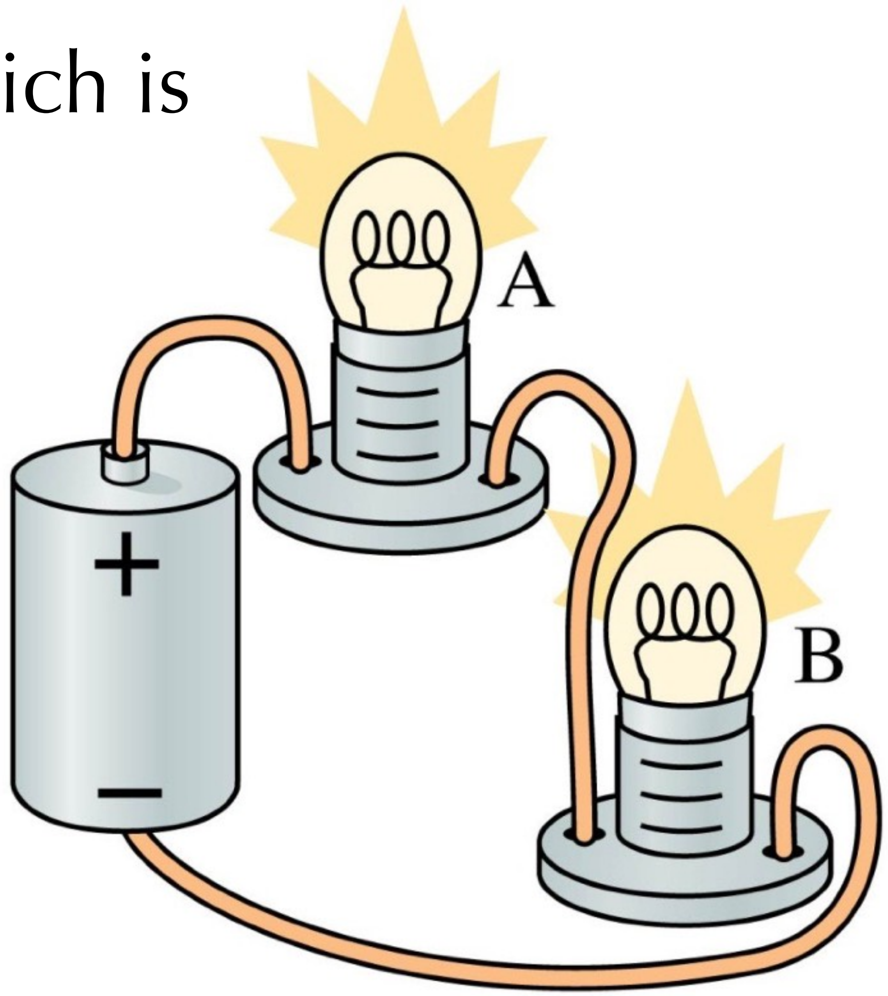
A and B are identical lightbulbs connected to a battery as shown. Which is brighter?



A. Bulb A.
B. Bulb B.
C. The bulbs are equally bright.

Question #32

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

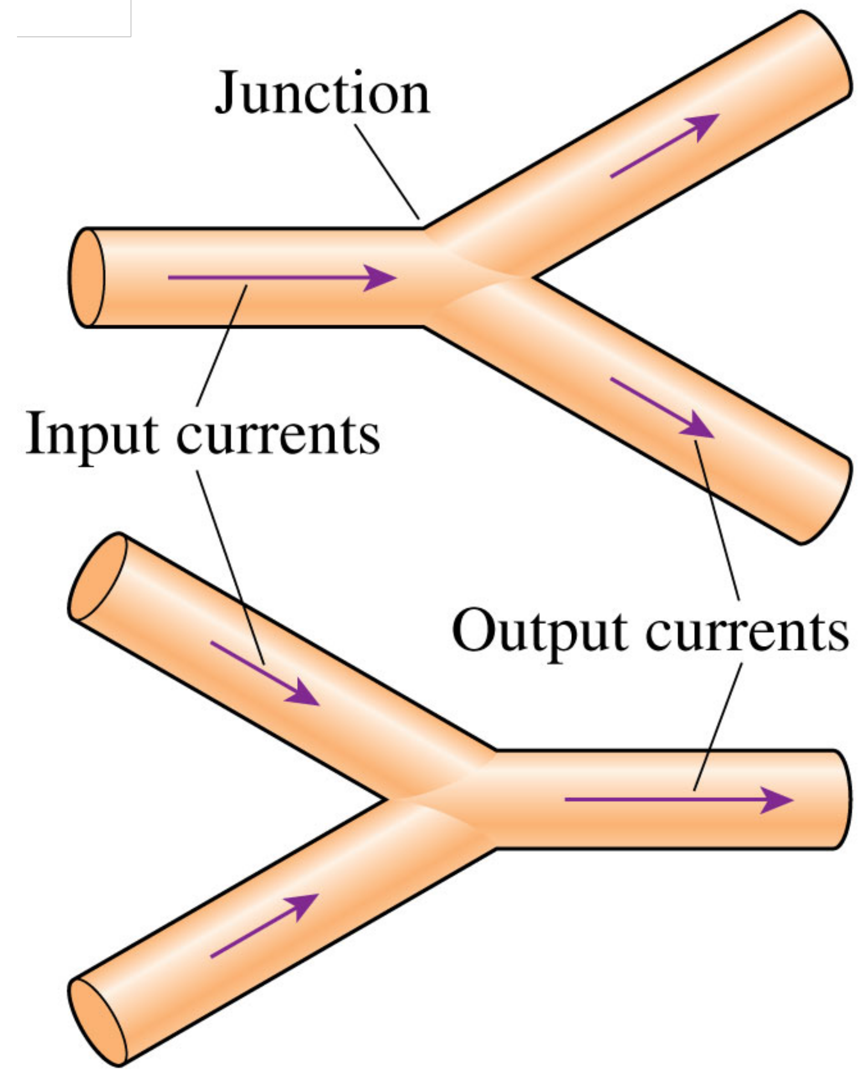


A. Bulb A.
B. Bulb B.
C. The bulbs are equally bright.

conservation of current.

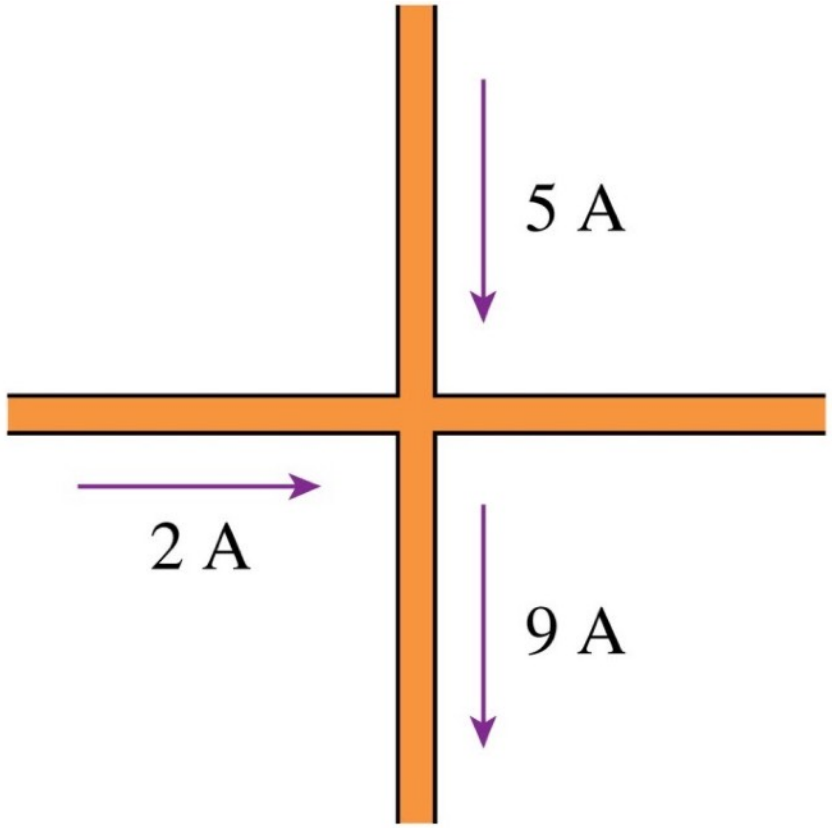
Kirchoff's Junction Law

$$\sum I_{\text{in}} = \sum I_{\text{out}}$$



Question #33

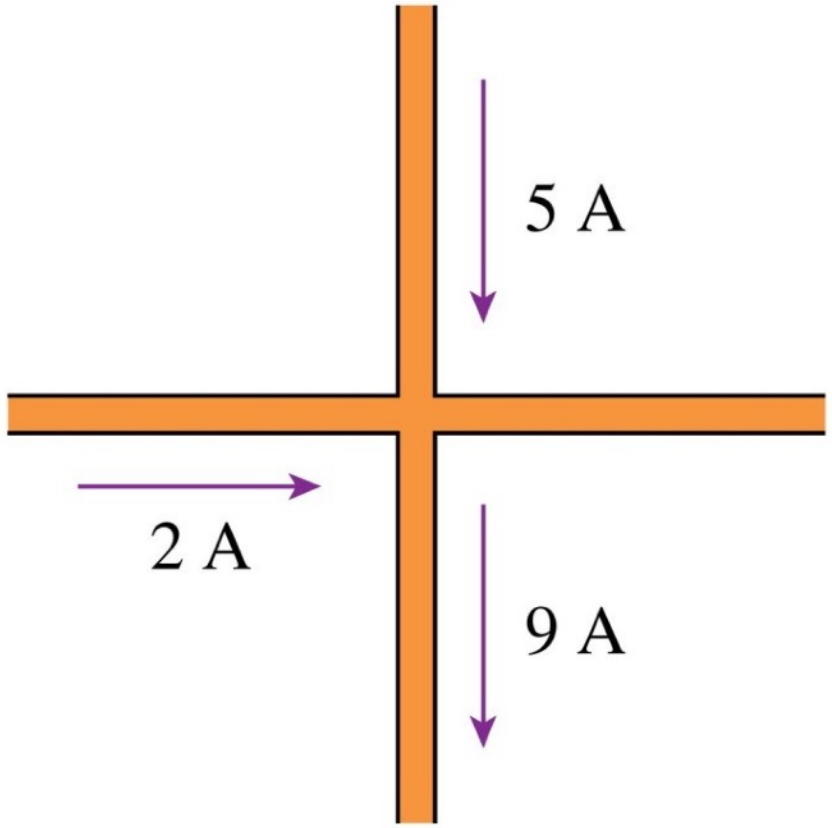
The current in the fourth wire is



A. 2 A to the left.
B. 4 A to the left.
C. 2 A to the right.
D. 16 A to the right.
E. Not enough information to tell.

Question #33

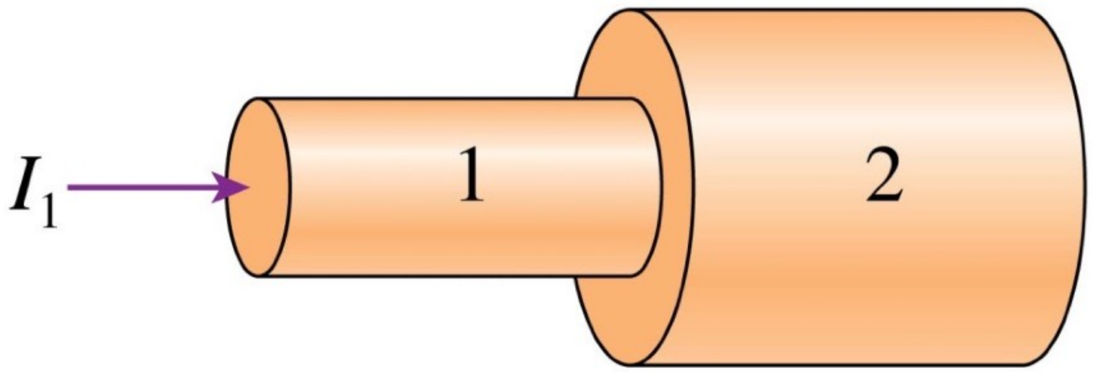
The current in the fourth wire is



A. 2 A to the left.
B. 4 A to the left.
C. 2 A to the right.
D. 16 A to the right.
E. Not enough information to tell.

Question #34

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?



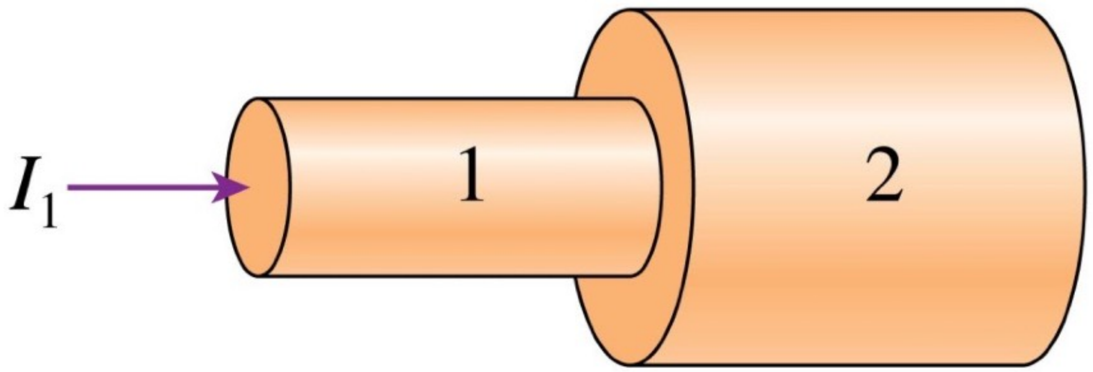
B. $I_1 > I_2$.

C. $I_1 < I_2$.

D. $I_1 = I_2$.

Question #35

Both segments of the wire are made of the same metal. Current I_1 flows into segment 1 from the left. How does current density J_1 in segment 1 compare to current density J_2 in segment 2?



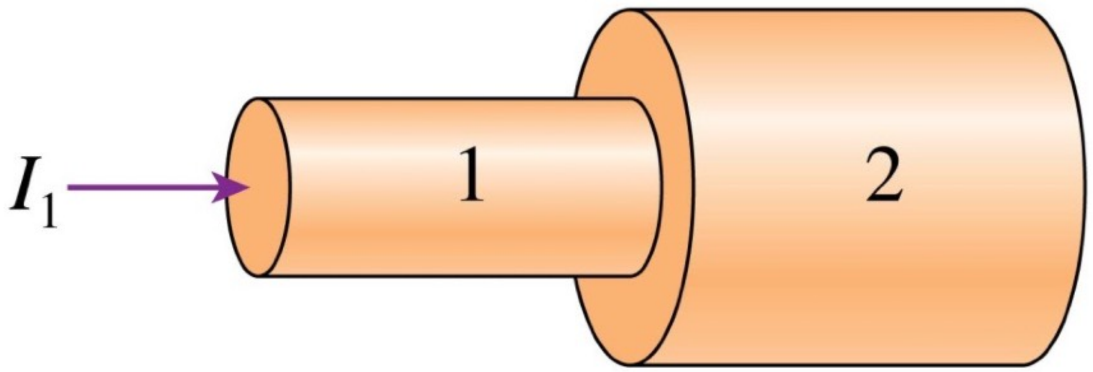
B. $J_1 = J_2$.

C. $J_1 < J_2$.

D. $J_1 > J_2$.

Question #35

Both segments of the wire are made of the same metal. Current I_1 flows into segment 1 from the left. How does current density J_1 in segment 1 compare to current density J_2 in segment 2?



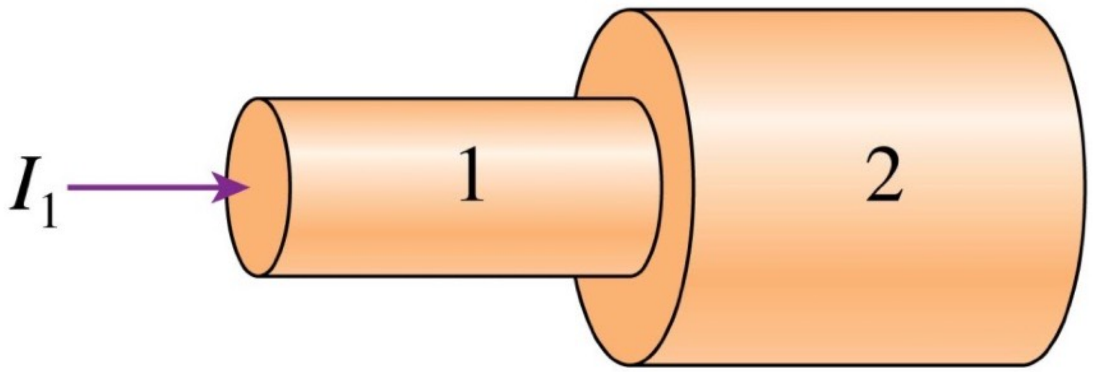
B. $J_1 = J_2$.

C. $J_1 < J_2$.

D. $J_1 > J_2$. smaller cross section

Question #36

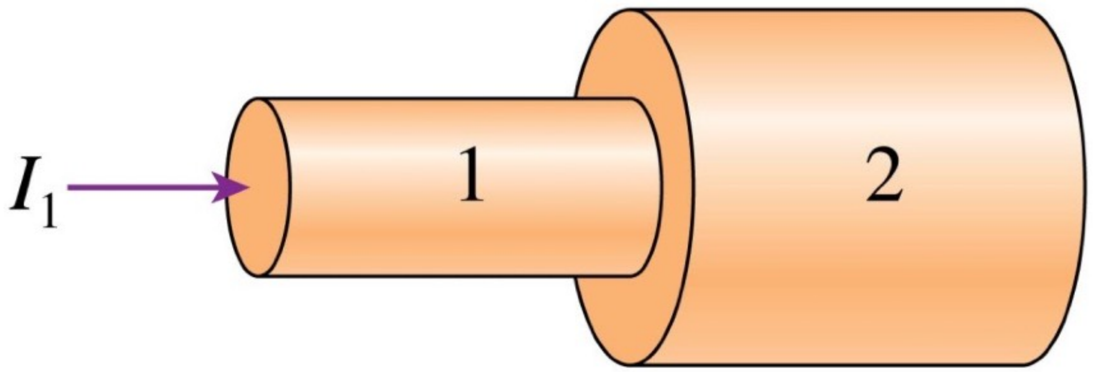
Both segments of the wire are made of the same metal. Current I_1 flows into segment 1 from the left. How does the electric field E_1 in segment 1 compare to the electric field E_2 in segment 2?



A. $E_1 < E_2$.
B. $E_1 = E_2$ but not zero.
C. $E_1 > E_2$.
D. Both are zero because metal is a conductor.
E. There's not enough information to compare them.

Question #36

Both segments of the wire are made of the same metal. Current I_1 flows into segment 1 from the left. How does the electric field E_1 in segment 1 compare to the electric field E_2 in segment 2?



A. $E_1 < E_2$.

B. $E_1 = E_2$ but not zero.

C. $E_1 > E_2$. how is this possible?

D. Both are zero because metal is a conductor.

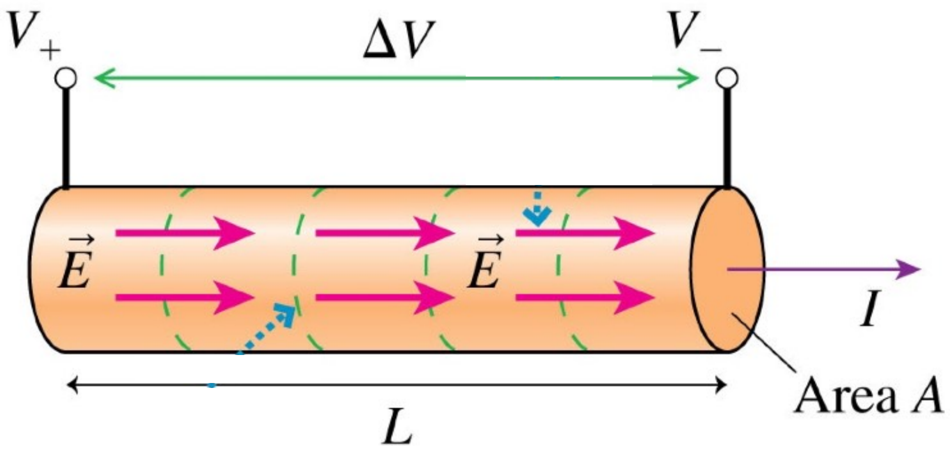
E. There's not enough information to compare them.

Ohm's Law

recall that…

$$E = \frac{\Delta V}{L}$$

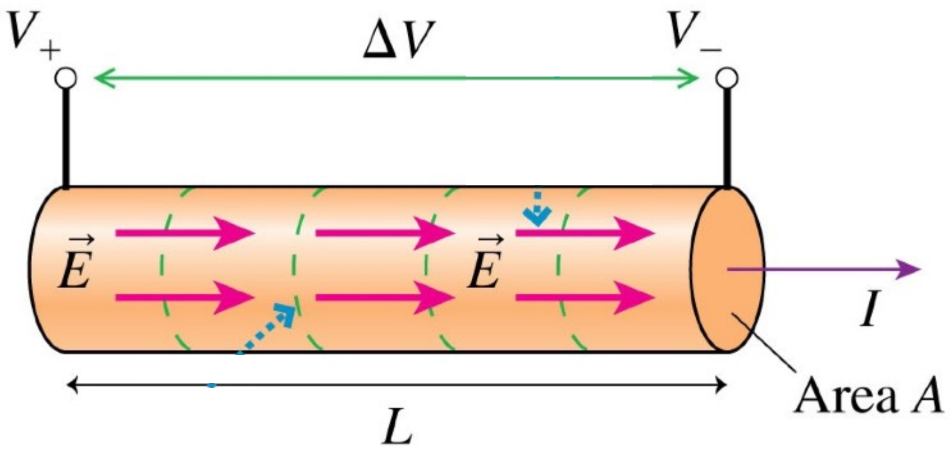
$$J = \frac{I}{A} = \frac{1}{\rho}E$$



Ohm's Law

recall that...

$$E = \frac{\Delta V}{L}$$



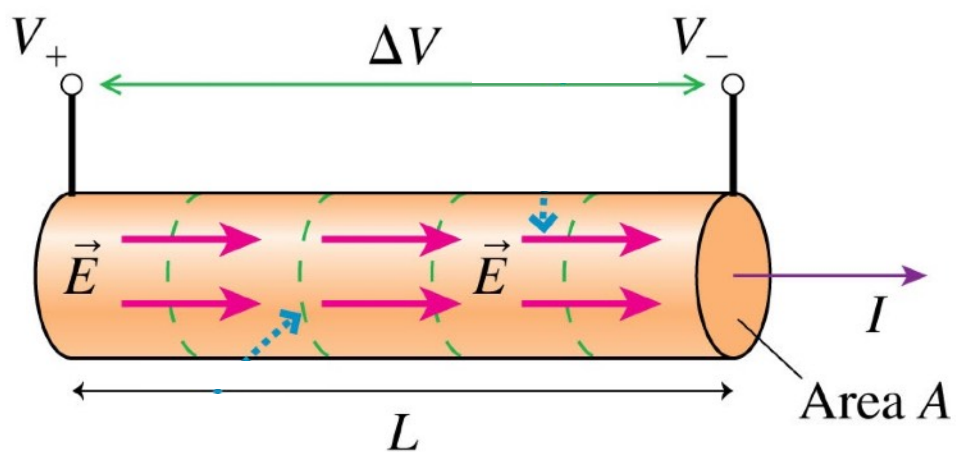
$$J = \frac{I}{A} = \frac{1}{\rho} E$$

rearrange...

Ohm's Law

recall that…

$$E = \frac{\Delta V}{L}$$



$$J = \frac{I}{A} = \frac{1}{\rho}E$$

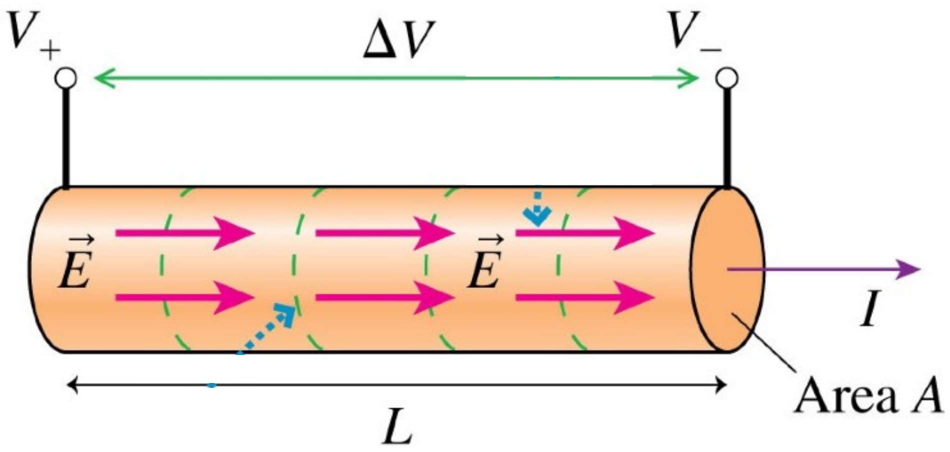
rearrange…

$$I = \frac{A}{\rho}E$$

Ohm's Law

recall that...

$$E = \frac{\Delta V}{L}$$



$$J = \frac{I}{A} = \frac{1}{\rho} E$$

rearrange...

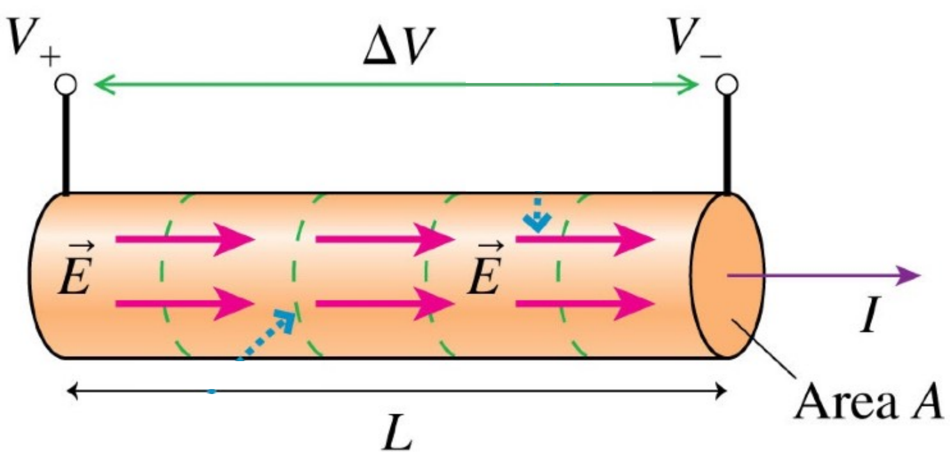
$$I = \frac{A}{\rho} E$$

$$= \frac{A \Delta V}{\rho L}$$

Ohm's Law

recall that...

$$E = \frac{\Delta V}{L}$$



$$J = \frac{I}{A} = \frac{1}{\rho}E$$

rearrange...

$$I = \frac{A}{\rho}E$$

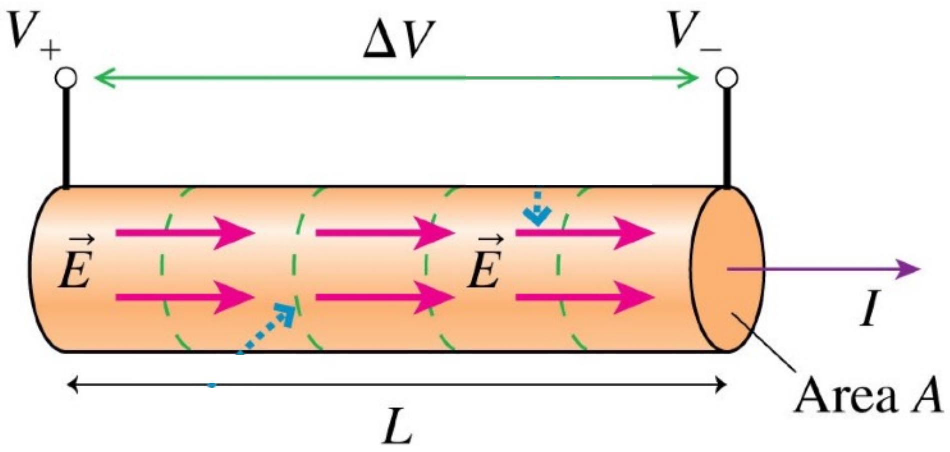
$$= \frac{A\Delta V}{\rho L}$$

$$= \frac{\Delta V}{R}$$

Ohm's Law

recall that...

$$E = \frac{\Delta V}{L}$$



$$\boxed{I = \frac{\Delta V}{R}}$$

$$J = \frac{I}{A} = \frac{1}{\rho} E$$

rearrange...

$$I = \frac{A}{\rho} E$$

$$= \frac{A \Delta V}{\rho L}$$

$$= \frac{\Delta V}{R}$$

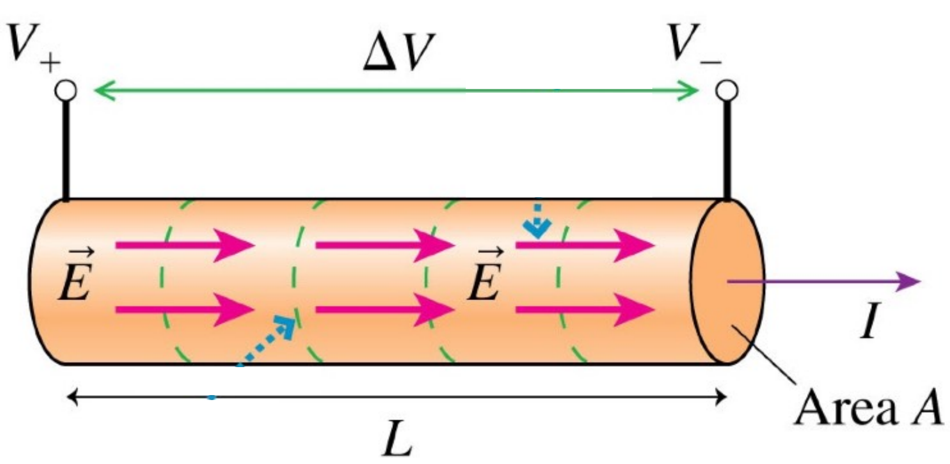
Ohm's Law

recall that...

$$E = \frac{\Delta V}{L}$$

$$J = \frac{I}{A} = \frac{1}{\rho}E$$

rearrange...



$$I = \frac{A}{\rho}E$$

$$= \frac{A\Delta V}{\rho L}$$

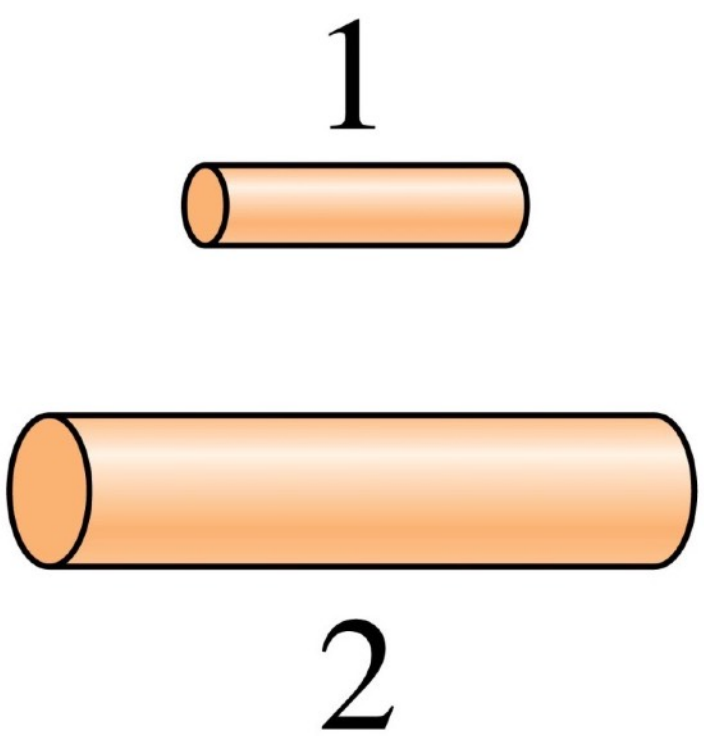
$$= \frac{\Delta V}{R}$$

$$\boxed{R = \frac{\rho L}{A}}$$

$$\boxed{I = \frac{\Delta V}{R}}$$

Question #37

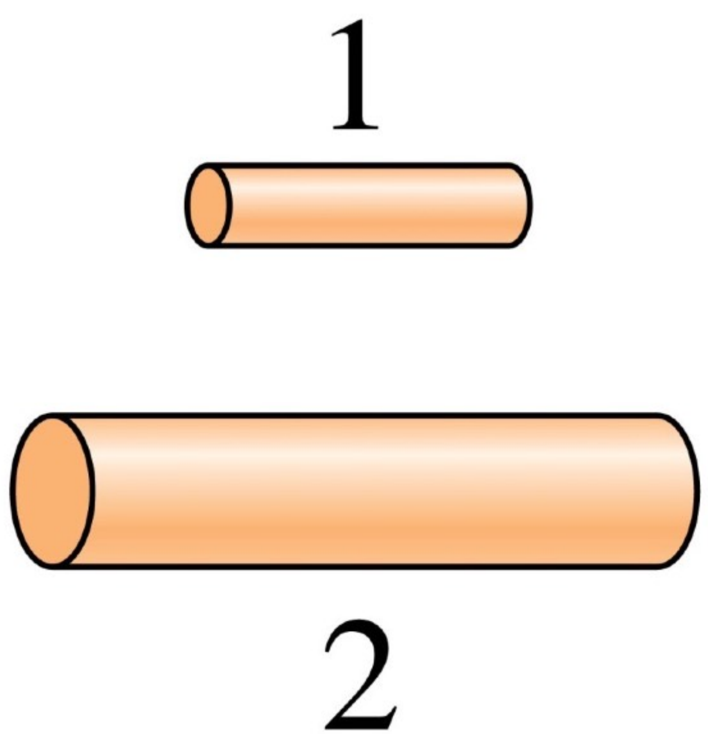
Wire 2 is twice the length and twice the diameter of wire 1. What is the ratio R_2/R_1 of their resistances?



A. 1/4.
B. 2.
C. 1.
D. 1/2.
E. 4.

Question #37

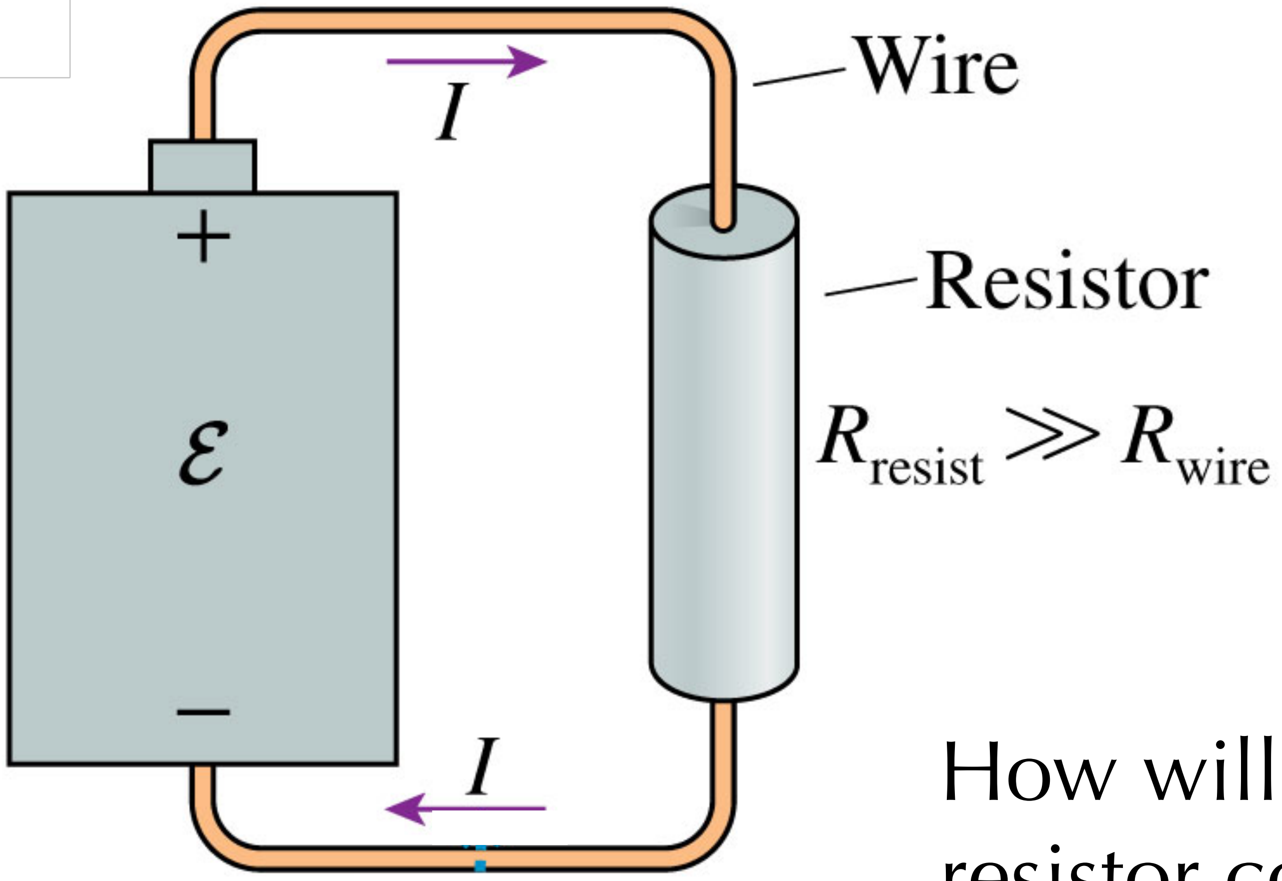
Wire 2 is twice the length and twice the diameter of wire 1. What is the ratio R_2/R_1 of their resistances?



A. 1/4.
B. 2.
C. 1.
D. 1/2.
E. 4.

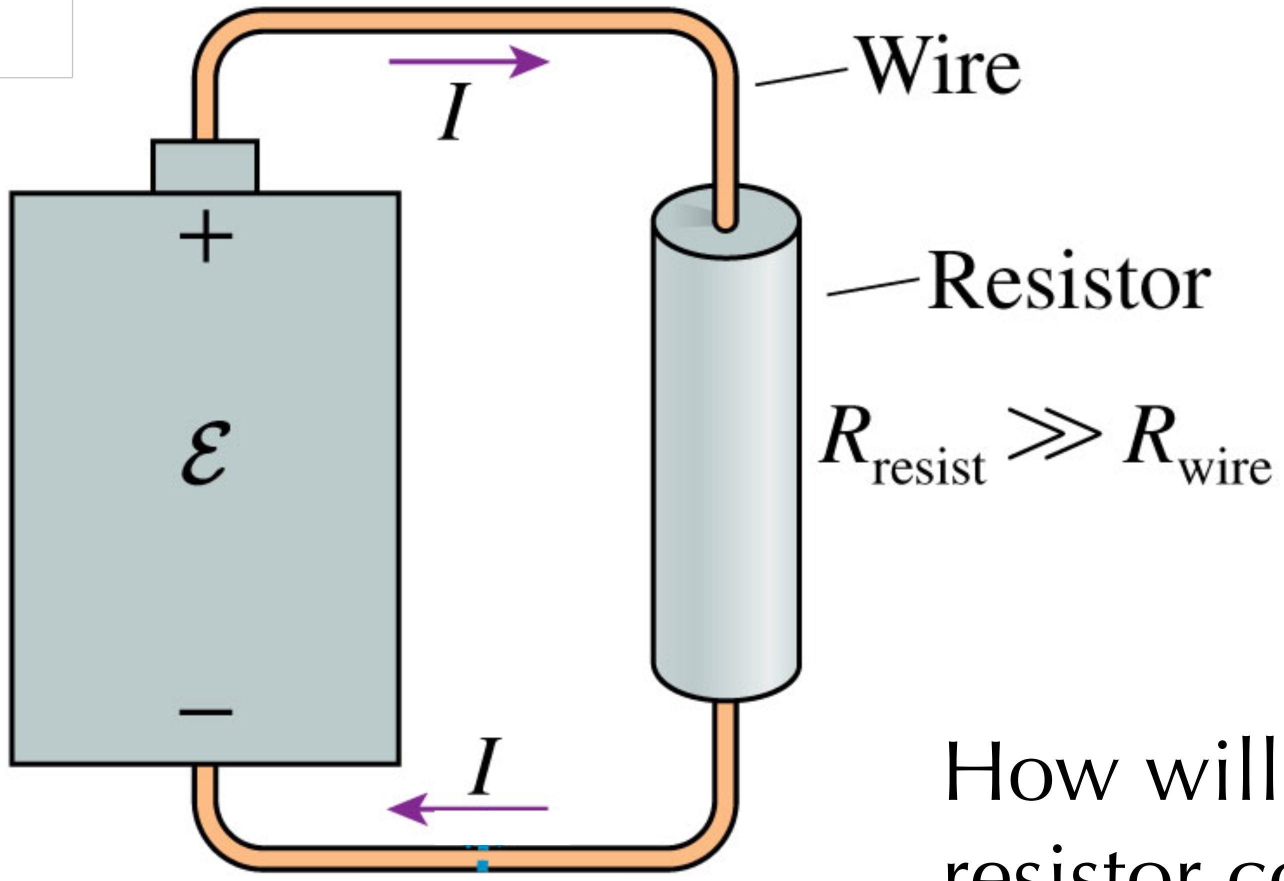
$$R = \frac{\rho L}{A}$$

Resistance is specific to the geometry of the material, not just the type of material.



How will the voltage drop across the resistor compare to the voltage drop across the wire leading to the resistor?

How is this possible?

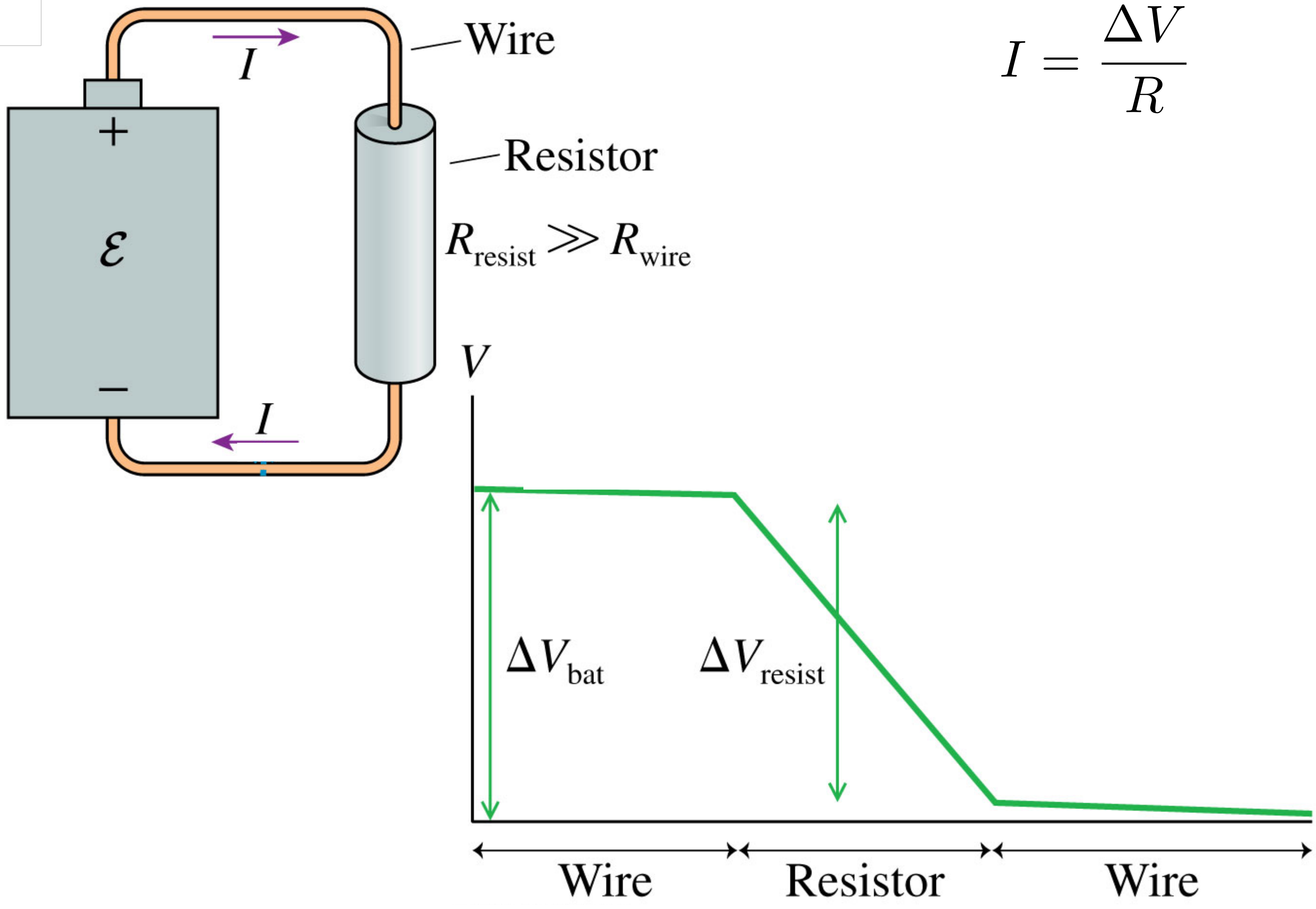


$$I = \frac{\Delta V}{R}$$

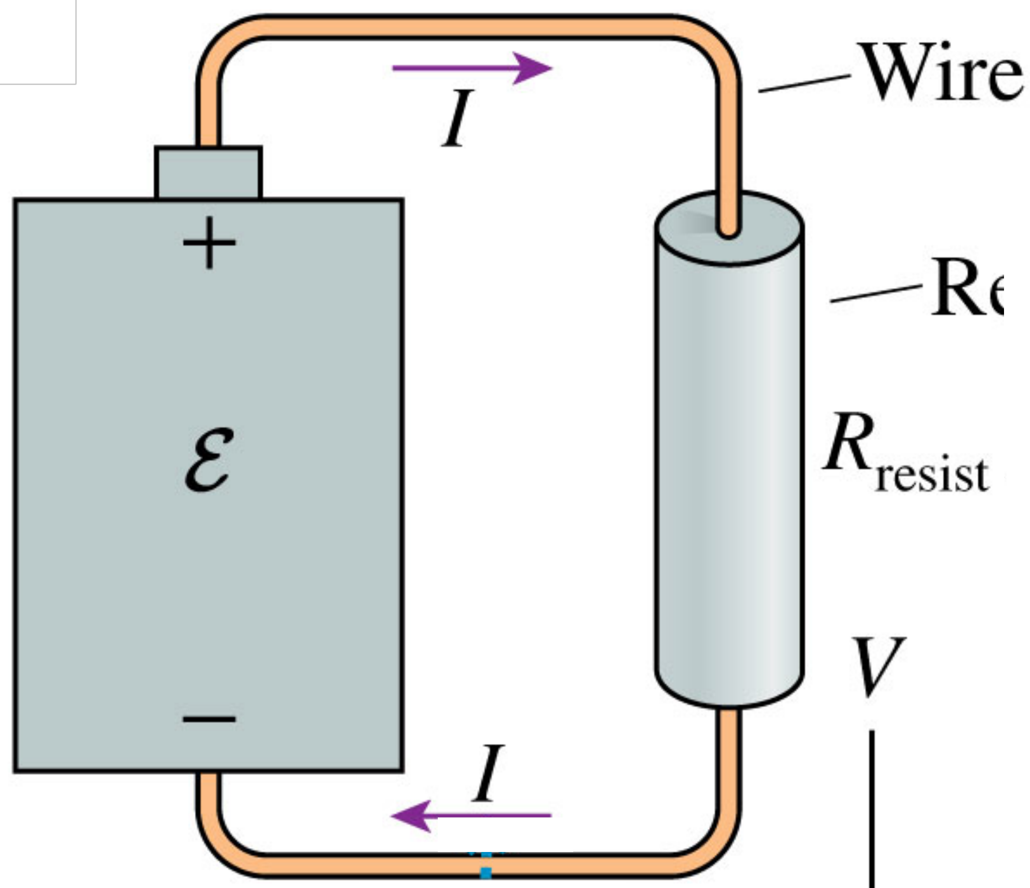
How will the voltage drop across the resistor compare to the voltage drop across the wire leading to the resistor?

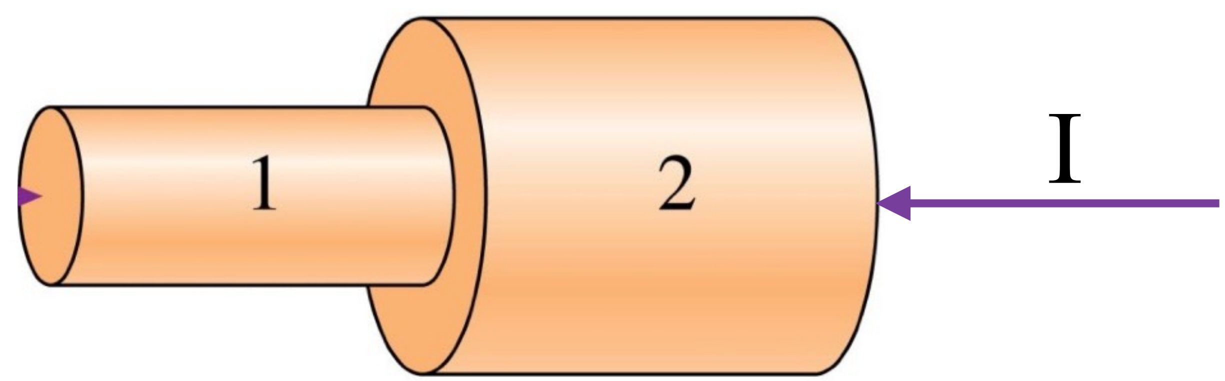
How is this possible?

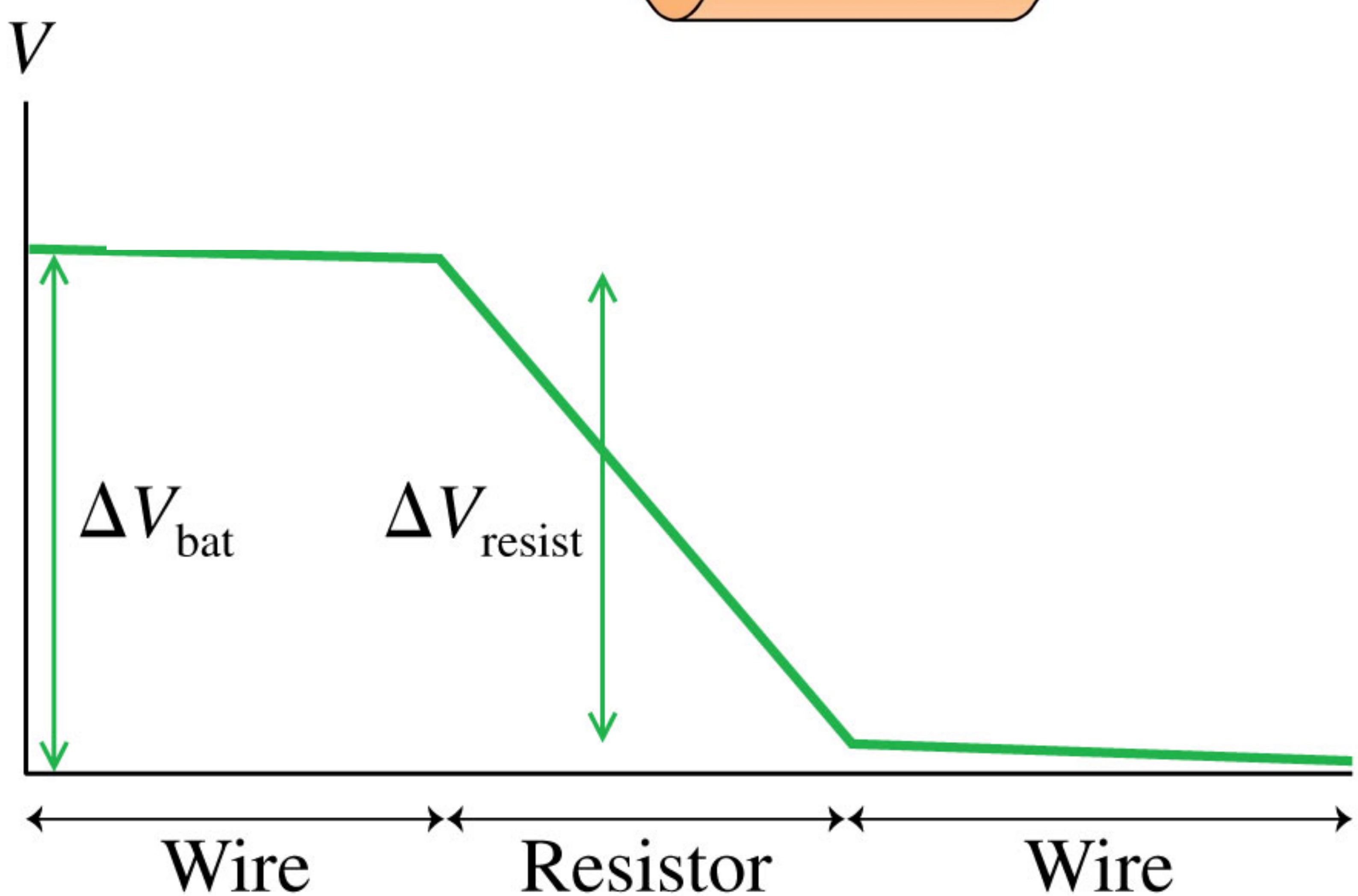
$$I = \frac{\Delta V}{R}$$

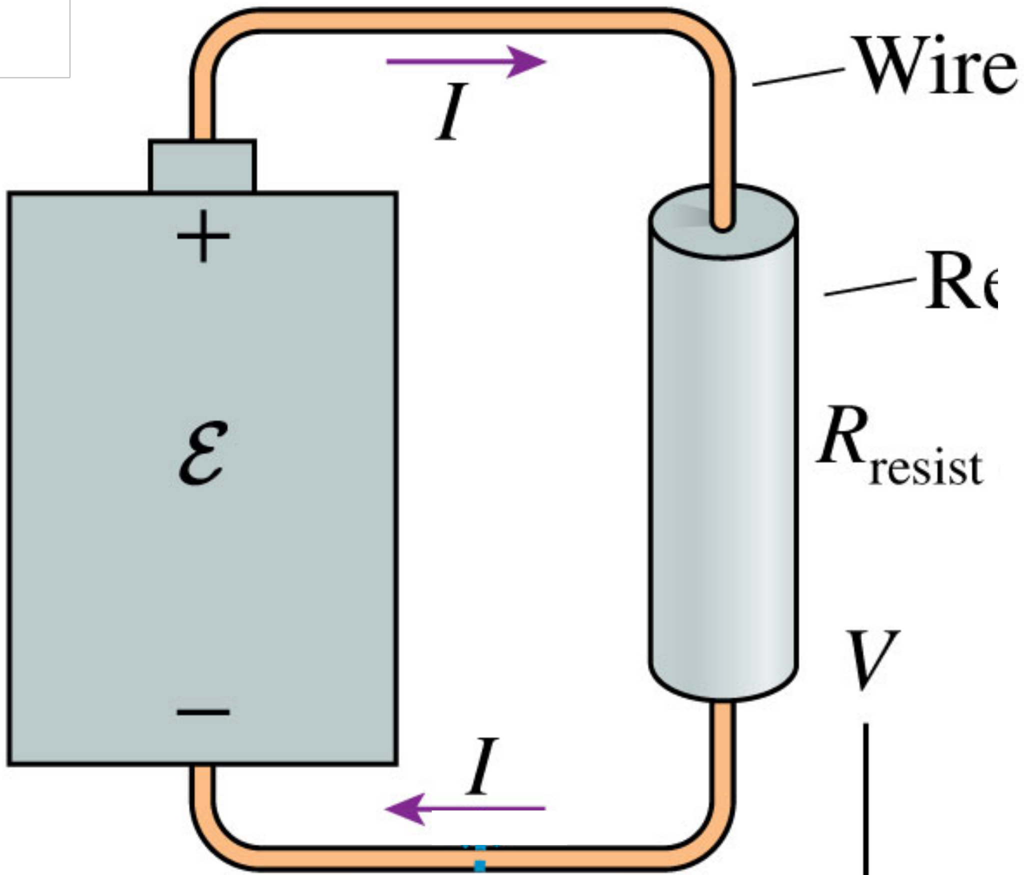


$$I = \frac{\Delta V}{R}$$

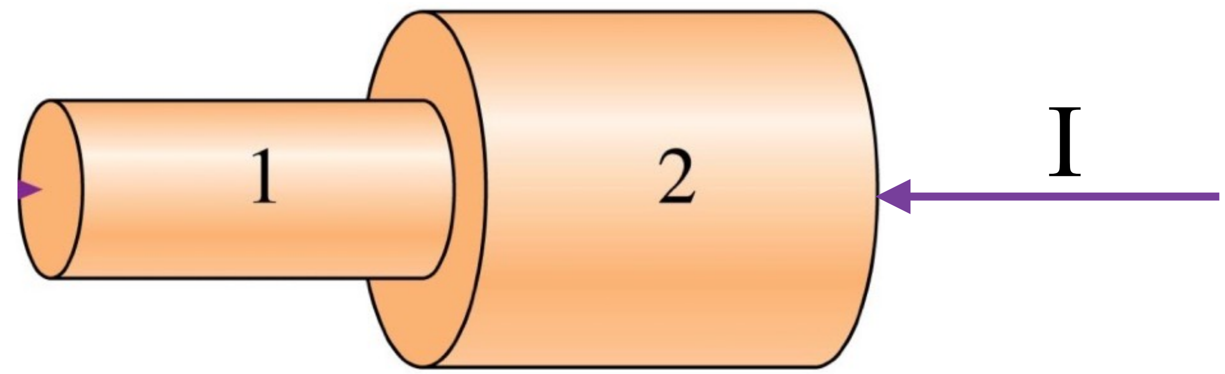


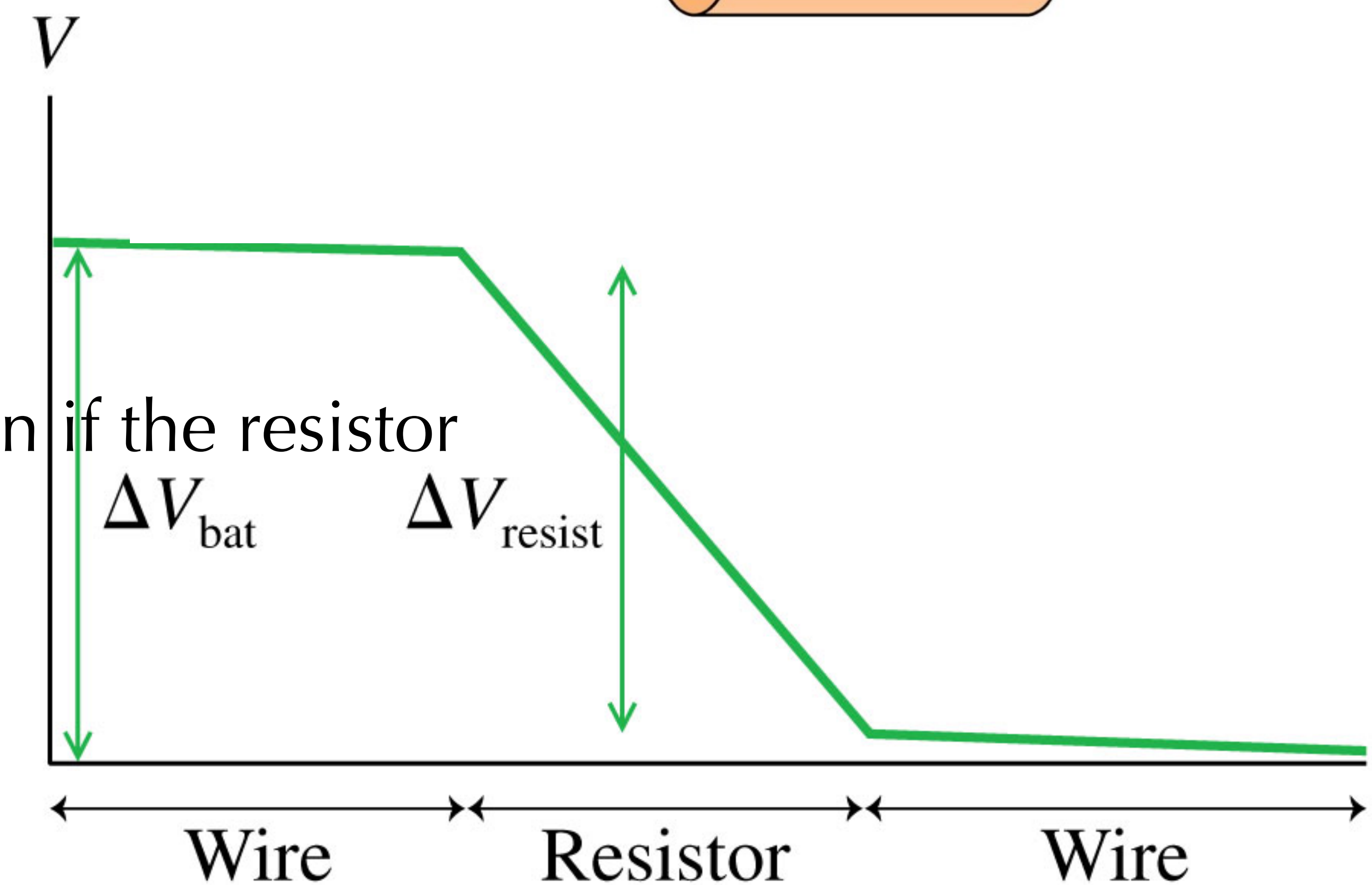




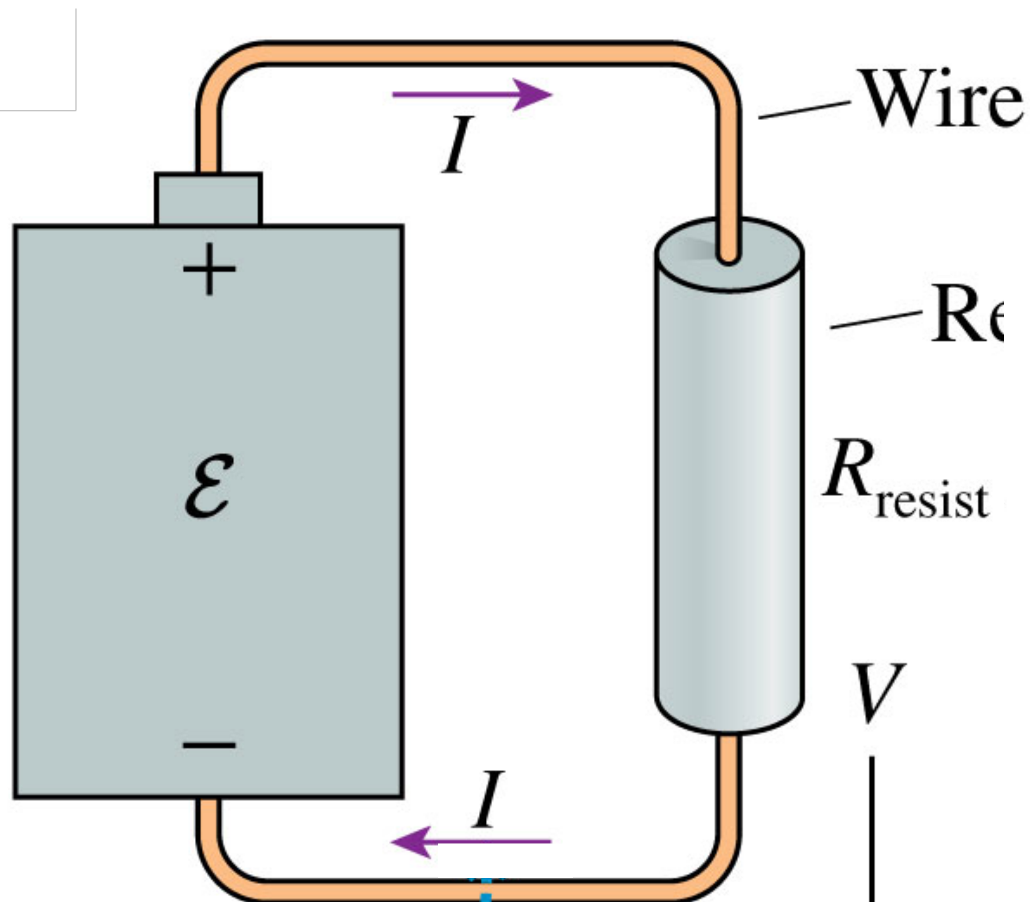


$$I = \frac{\Delta V}{R}$$

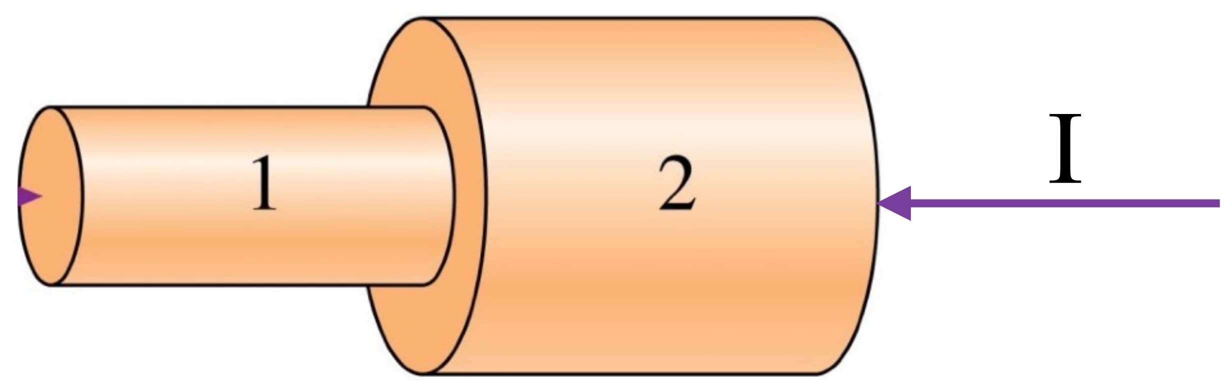


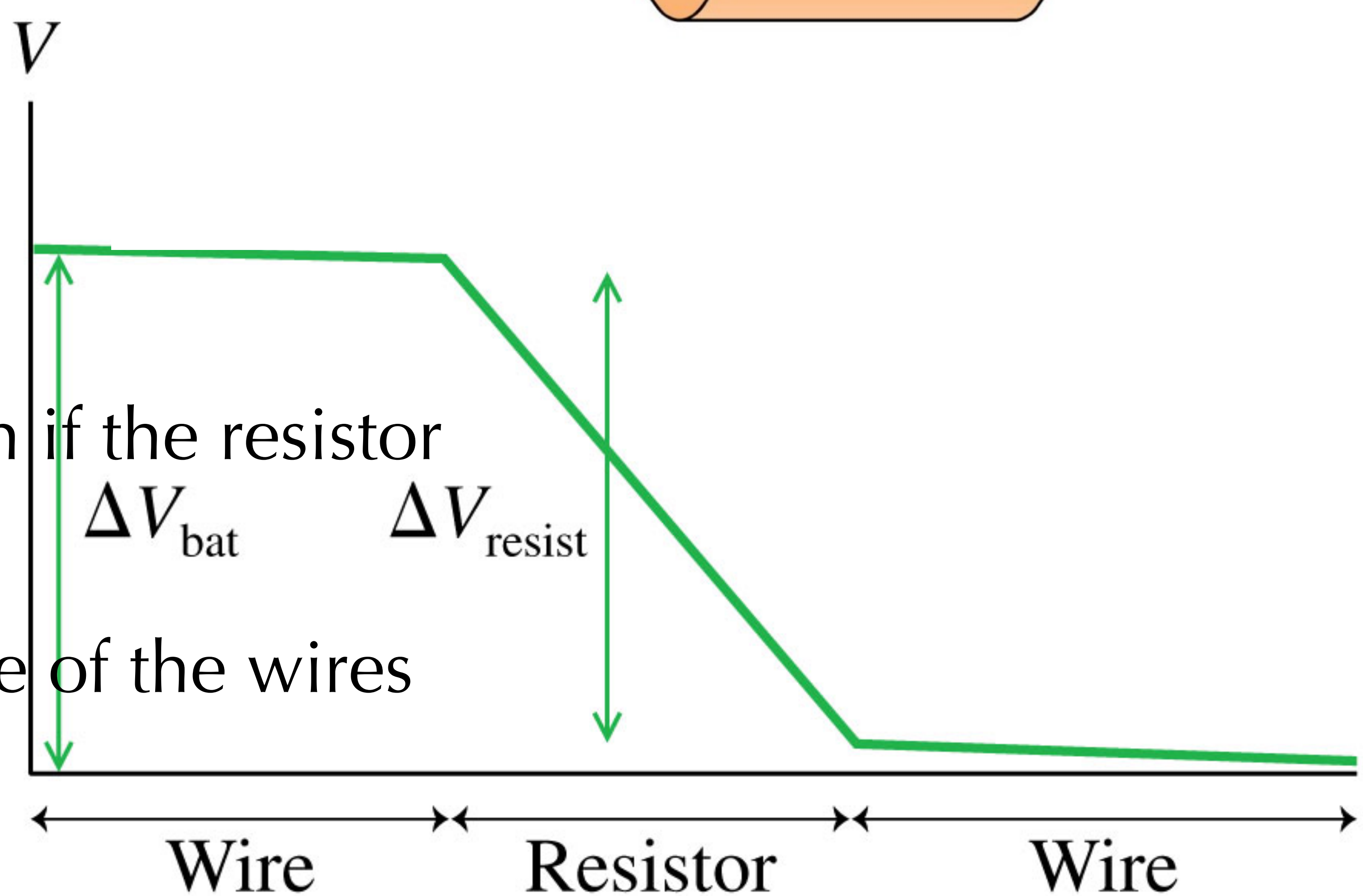


What would happen if the resistor was removed?



$$I = \frac{\Delta V}{R}$$





What would happen if the resistor was removed?

What if the resistance of the wires were not small?

An electric utility company supplies a customer's house from the main power lines (120 V) with two copper wires, each of which is 50.0 m long and has a resistance of 0.108 Ohms per 300 m. Find the voltage at the customer's house for a load current of 110 A.

Draw a circuit diagram for this problem and try to provide a conceptual(no math) description of what is being asked.

Equations so far

$$v_d = \frac{eE}{m}\tau$$

$$C = \frac{\epsilon_0 A}{d}$$

$$i_e = \frac{n_e A e E \tau}{m}$$

$$\kappa \equiv \frac{E_0}{E}$$

$$J = \sigma E$$

$$\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

$$R = \frac{\rho L}{A}$$

$$C = \frac{Q}{\Delta V_{\text{C}}}$$

$$I = \frac{\Delta V}{R}$$

$$\sum I_{\text{in}} = \sum I_{\text{out}}$$

$$U_C = \frac{Q^2}{2C} = \frac{1}{2}C(\Delta V_C)^2$$

$$C_{\text{eq}} = C_1 + C_2 + C_3 + \ldots$$

$$i_e = n_e A v_d$$

Equations so far

1
$$i_e = n_e A v_d$$

2
$$C_{\text{eq}} = C_1 + C_2 + C_3 + \ldots$$

3
$$C = \frac{\epsilon_0 A}{d}$$

4
$$J = \sigma E$$

5
$$C = \frac{Q}{\Delta V_{\text{C}}}$$

6
$$R = \frac{\rho L}{A}$$

7
$$I = \frac{\Delta V}{R}$$

8
$$\kappa \equiv \frac{E_0}{E}$$

9
$$v_d = \frac{eE}{m}\tau$$

10
$$i_e = \frac{n_e A e E \tau}{m}$$

11
$$\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

12
$$U_C = \frac{Q^2}{2C} = \frac{1}{2} C (\Delta V_C)^2$$

13
$$\sum I_{\text{in}} = \sum I_{\text{out}}$$