Physics 122 – Class #23 – (4/7/15)

- Announcements / Equation Abuse
- Resistance and Resistivity
- Drude Model of Conduction
- Series and Parallel Circuits
- RC Circuits

Homework assignment from Hell

Week of 4/6/2015

Read ALL OF Chapter 31

Mastering Physics HW-OL-10 (Current) is posted.

MP includes problems: 30.9, 30.13, 19, 20, 21, 34, 43, 44, 46, 49

[Due Thursday 4/9/2015 at 11:59 pm]

Mastering Physics HW-OL-11 (Circuits) is posted.

MP includes problems (CH30): 30.23, 30.53 (EC), 30.55,

(CH31): 31.7, 31.8, 31.10, 31.11, 31.19, 20, 21, 28, 30, 31, 32, 34, 35, 36

(CH32): 32.9, 32,10, 14, 33, 34, 35, 36

[Due Sunday 4/19/2015 at 11:59 pm]

Art by Carlos.S americaslastdays.blogspot.com

Physicists are nice people

Physicists are nice people

- We only torture wires, and transistors, and vacuums, and motors and “samples” …
- We also abuse equations.
  - Given any equation you can
  - Multiply it, Add to it, rearrange it, integrate it, differentiate it, exponentiate it, subtract other equations from it, divide other equations by it …
- We also abuse calculus and frequently “multiply” by dt

Why are half of you skipping recitation??

- Free points
- We're doing the homework
- Working in groups

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Material	Resistivity ($\Omega \cdot m$)
Metallic conductors (20°C)	
Aluminum	2.65×10^{-8}
Copper	1.68×10^{-8}
Gold	2.24×10^{-8}
Iron	9.71×10^{-8}
Mercury	9.84×10^{-7}
Silver	1.59×10^{-8}
Ionic solutions (in water, 18°C)	
1-molar $CuSO_4$	3.9×10^{-4}
1-molar HCl	1.7×10^{-2}
1-molar NaCl	1.4×10^{-4}
H_2O	2.6×10^{5}
Blood, human	0.70
Seawater (typical)	0.22
Semiconductors (pure, 20°C)	
Germanium	0.47
Silicon	23.0
Insulators	
Ceramics	10^{11}–10^{14}
Glass	10^{10}–10^{14}
Polystyrene	10^{15}–10^{17}
Rubber	10^{13}–10^{16}
Wood (dry)	10^{8}–10^{14}

Resistance in terms of Resistivity ρ

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

$$\rho = \frac{1}{\sigma}$$

The femoral artery is the large artery that carries blood to the leg. What is the resistance of a 20-cm-long column of blood in a 1.0 cm diameter femoral artery? The conductivity of blood is

$$\sigma_{blood} = 0.63 \frac{1}{(\Omega \cdot m)}¿$$

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

$$\rho = \frac{1}{\sigma}$$

If you make a resistor with a length of copper wire of square cross-section with side 1 mm, how long a wire do you need to make a 3.2 Ohm resistor? $\rho_{copper} = 1.6 \times 10^{-8}\,\Omega \cdot m$

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

(A) 200,000 m

(B) 160,000 m

(C) 3.2 m

(D) 100 m

(E) 200 m

The Current Density in a Wire

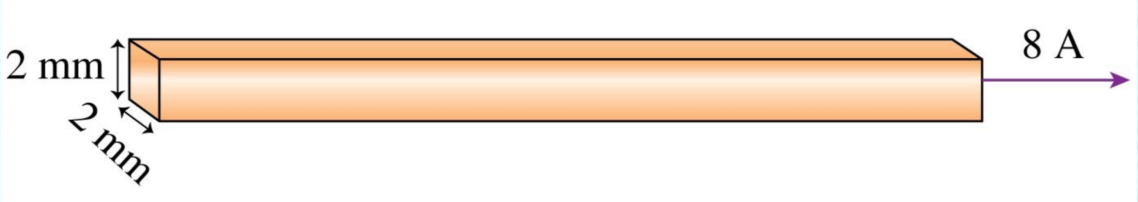
The **current density** J in a wire is the current per square meter of cross section:

$$J = \text{current density} \equiv \frac{I}{A} = n_e e v_d$$

The current density has units of A/m^2.

Clicker

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.

A cylindrical tube of seawater carries a total electric current of 350 mA. If the electric field in the water is 21 V/m, what is the diameter of the tube?

$$I = J A$$

$$J = \sigma E$$

Possible Confusion about Ch. 30-31

$$J = \sigma E \qquad E = \frac{\sigma}{\epsilon_0}$$

Sigma means conductivity in first formula, and surface charge density in second.

In Chapter 30, we calculate resistance of a wire:

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

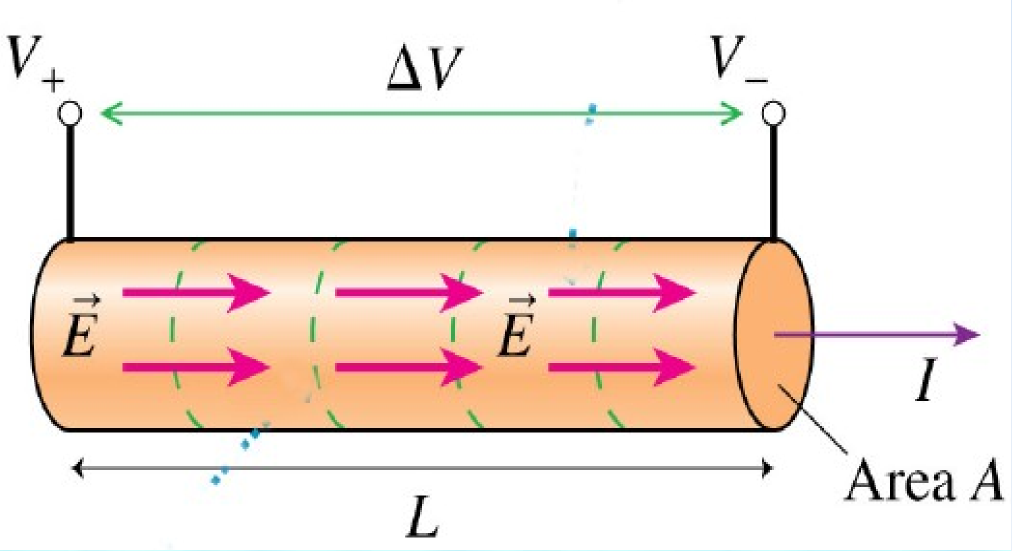
In Chapter 31, wires are assumed to have no resistance (only “resistors” have resistance)

Electric field in home wire?

You are using a cheap extension cord made of #14 copper wire (which has a $2\ \mathrm{mm}^2$ cross sectional area). What is the electric field in the wire when you light a 100 Watt bulb?

$$\rho_{copper} = 1.6 \times 10^{-8}\ \Omega \cdot \mathrm{m}$$

Going from Microscopic to Human Scale



$$\vec{J} = \sigma \vec{E}$$

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

Definition of Voltage for constant Electric field

$$J = \frac{I}{A}$$

Definition of Current density

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

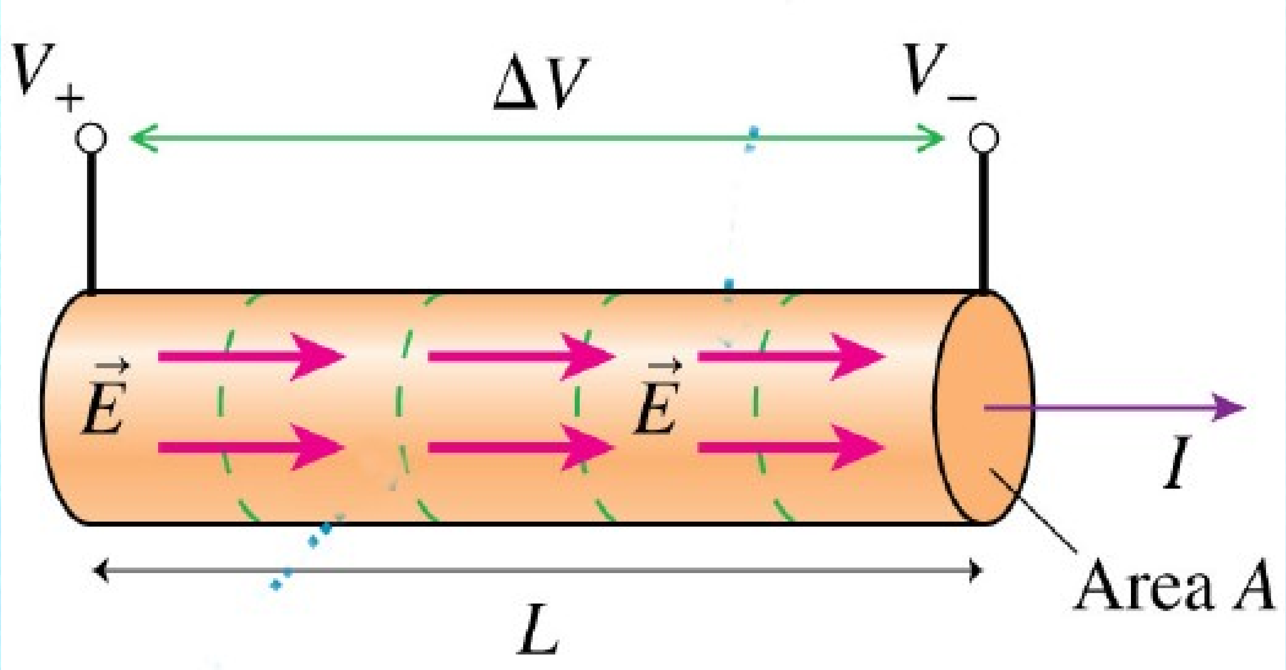
Relation between resistance And resistivity

$$V = IR$$

Engineers form of Ohm's Law

Going from Microscopic to Human Scale

$$\vec{J} = \sigma \vec{E} \qquad E = \frac{V}{L} \qquad J = \frac{I}{A} \qquad R = \frac{L}{\sigma A} \rightarrow \sigma = \frac{L}{RA}$$



$$\frac{I}{A} = \frac{L}{RA} \frac{V}{L}$$

$$I = \frac{1}{R} V \rightarrow V = IR \quad \text{Ohm's Law}$$

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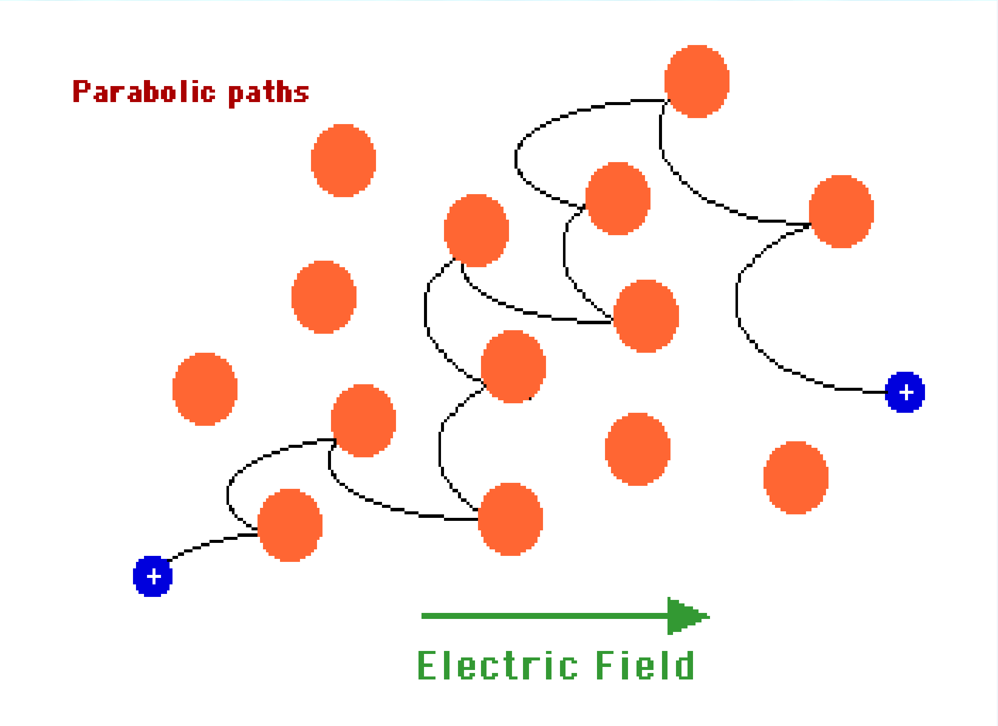
Microscopic view of resistivity

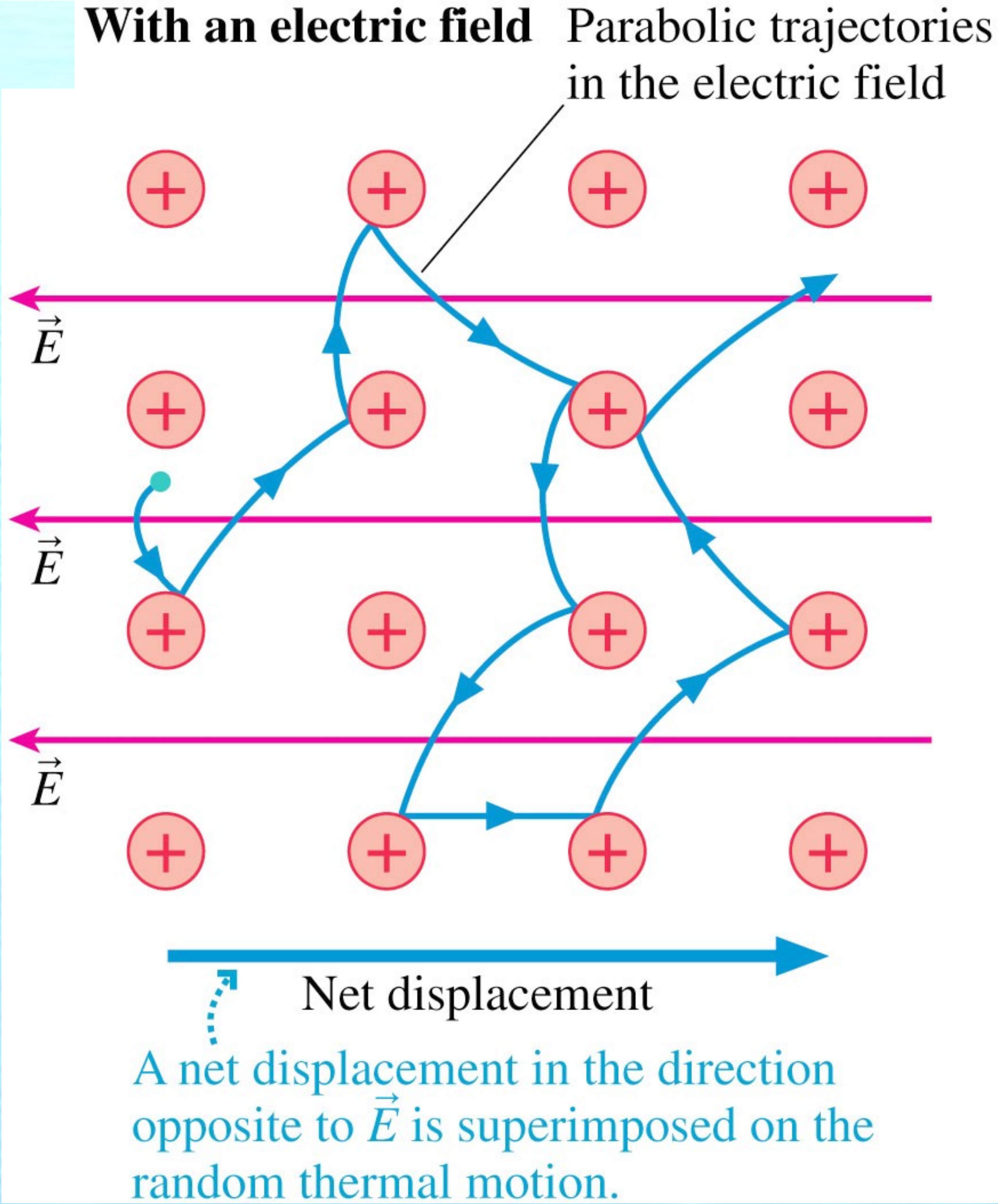
”Free electron gas” model (also called Drude model) of a metal.

You can derive Ohm's law by assuming a metal is a box full of loose electrons that bump into “scattering centers” every τ seconds.



Microscopic view of resistivity

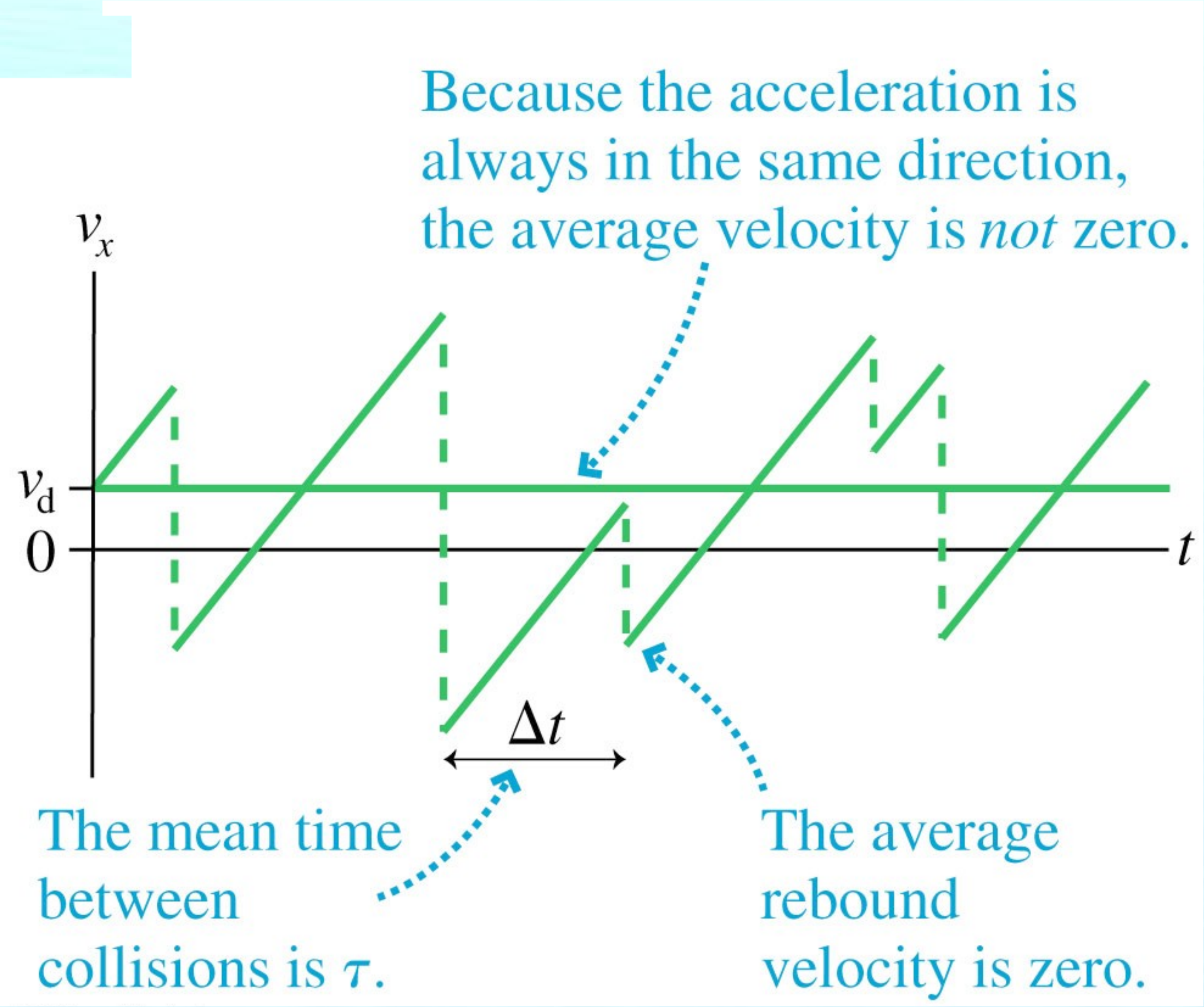
- In the presence of an electric field, the electric force causes electrons to move along parabolic trajectories between collisions.
- Because of the curvature of the trajectories, there is a slow net motion in the "downhill" direction.

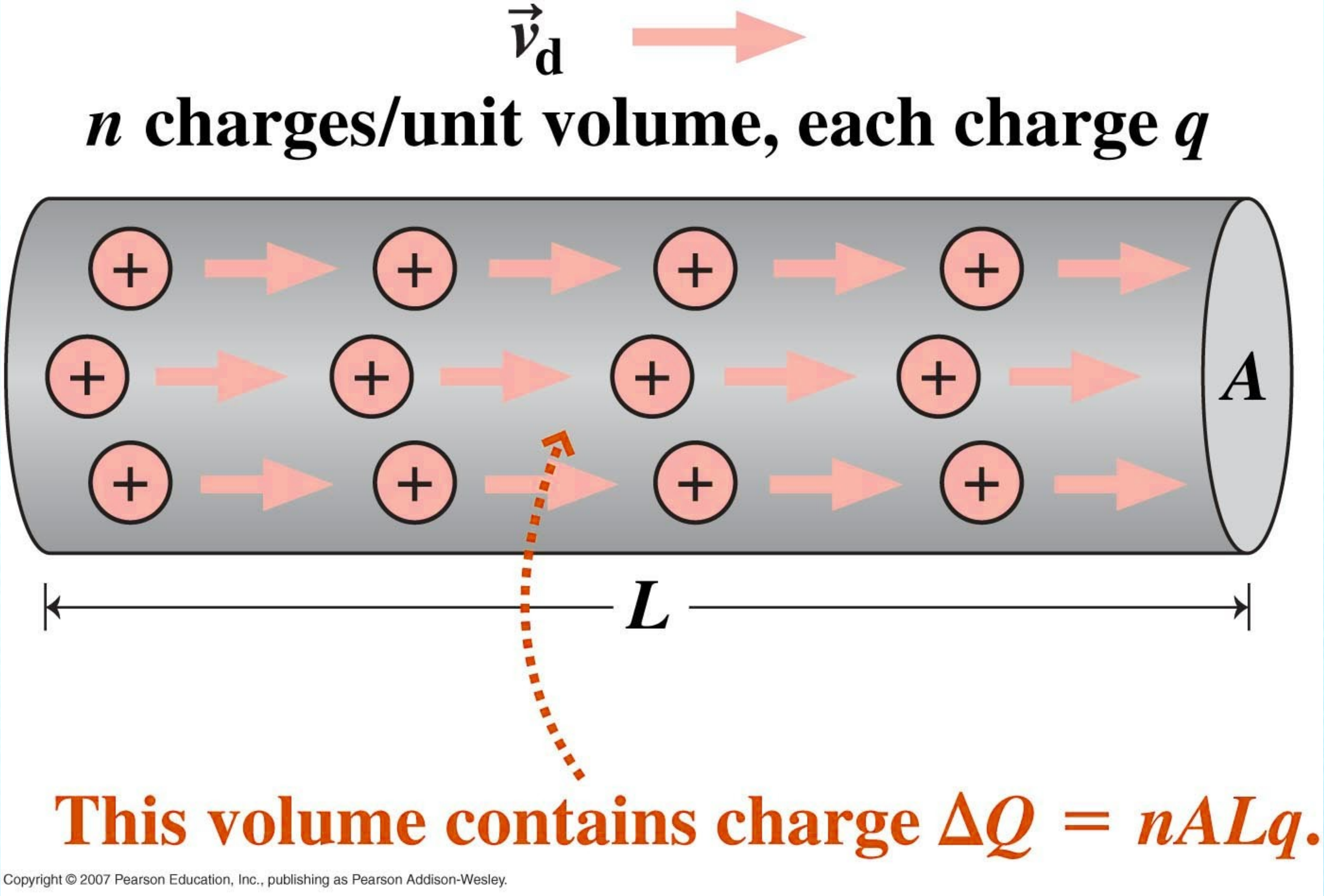


Drude Model of Resistance

- The graph shows the speed of an electron during multiple collisions.
- The average drift speed is

$$v_d = \frac{e\tau}{m}E$$





$$\Delta Q = n A \vec{v}_d \Delta t \; q$$

$$\vec{J} = n q \vec{v}_d$$

$$I = n q \vec{v}_d A$$

$$I = \vec{J} \cdot \vec{A}$$

Drude Model of Conductance

You can derive Ohm's law by assuming a metal is a box full of loose electrons that bump into “scattering centers” every τ Seconds. (Tau is < 1 picosecond for most solids at room temp.)

$$\vec{J} = n q \vec{v}_d = n q a \tau = \frac{n q^2 \tau}{m} \vec{E} = \sigma \vec{E}$$

Derived electrical resistance from Classical Mechanics!

$$\sigma = \frac{n q^2 \tau}{m}$$

In semiconductor, n is small, so rho is larger than a conductor. τ

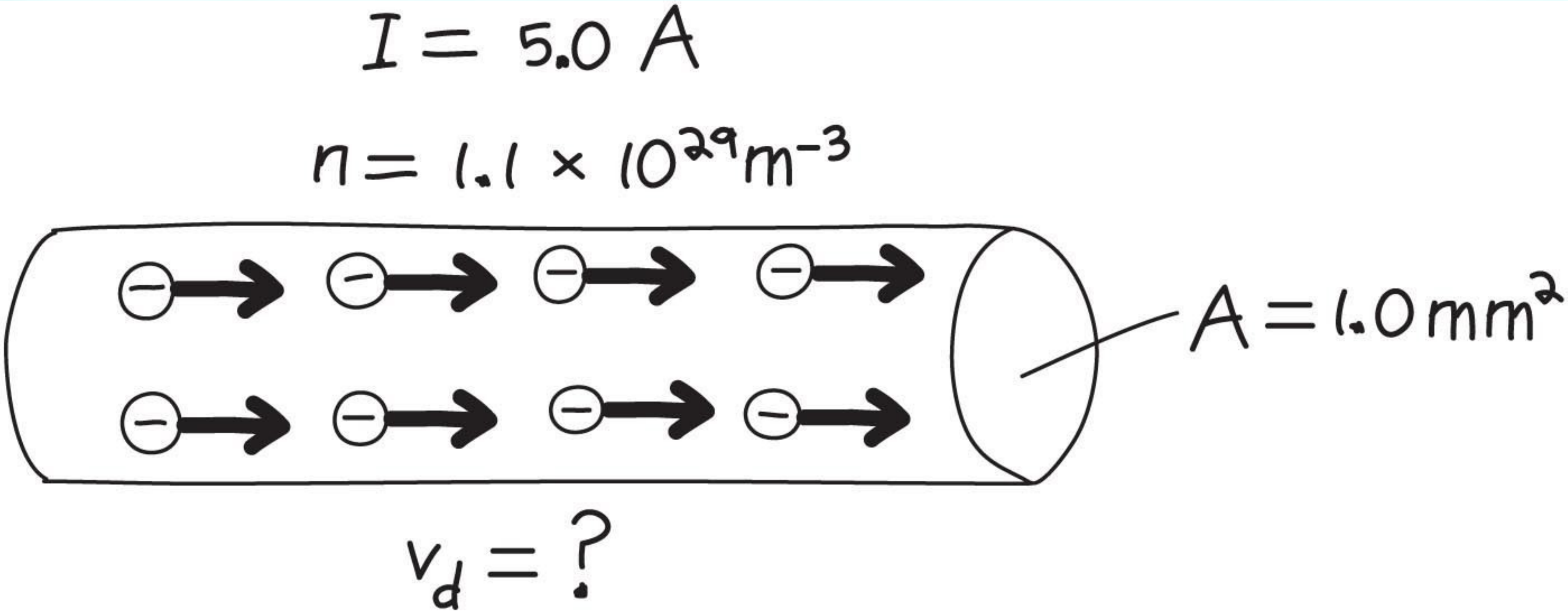
In insulator, n is nearly zero.

$$\rho = \frac{m}{n q^2 \tau}$$

In ionic conductor, m is larger (ions not electrons) so conductivity is Lower.

A semiconductor may be "doped"

Typical drift velocity



$$I = n\,q\,\vec{v}_d\,A$$

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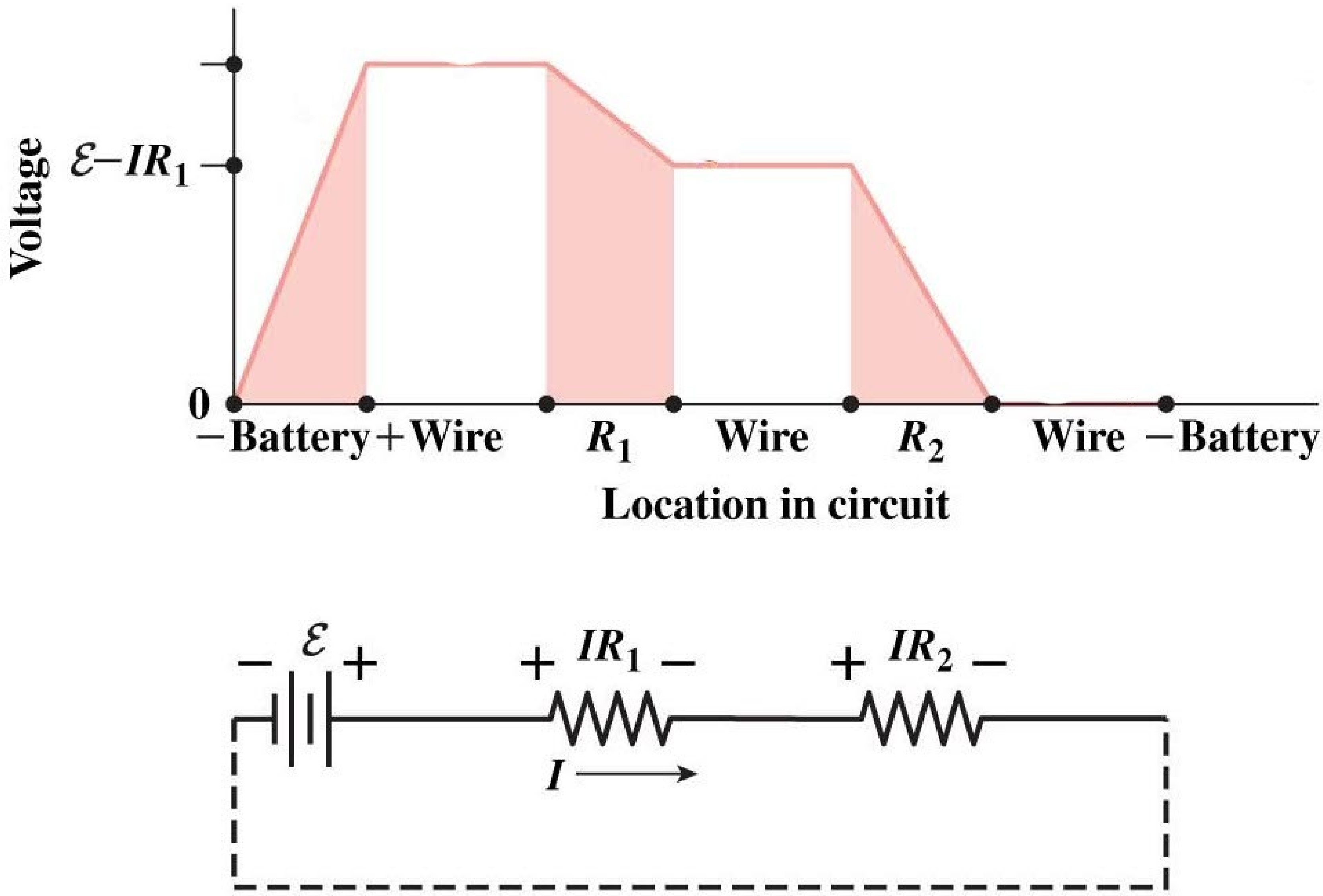
Series circuits:

Same current in every part of circuit

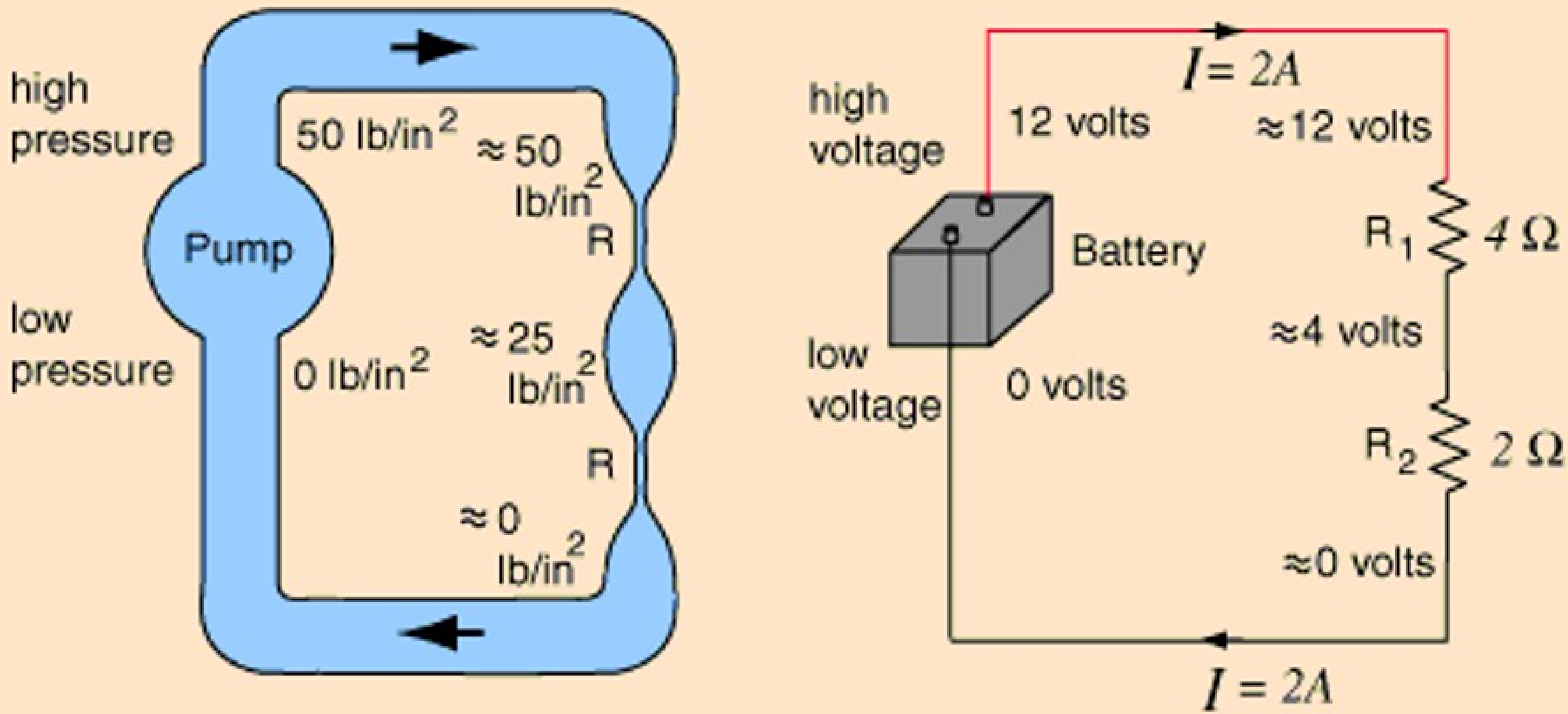
Voltage drops at every resistor



Series circuits:

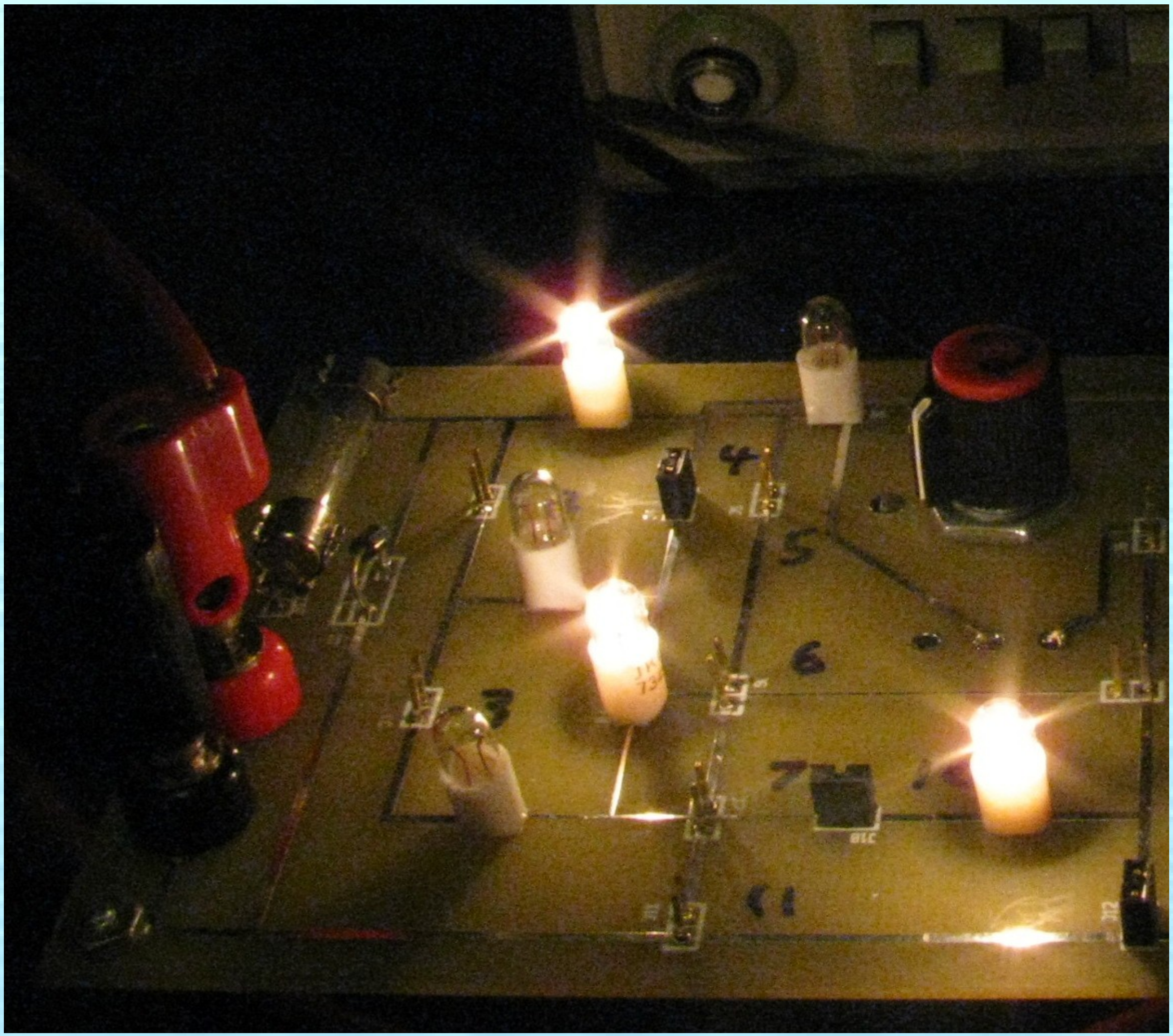
Same current in every part of circuit.

Voltage drops at every resistor.



Series circuits:

All light bulbs equally bright …

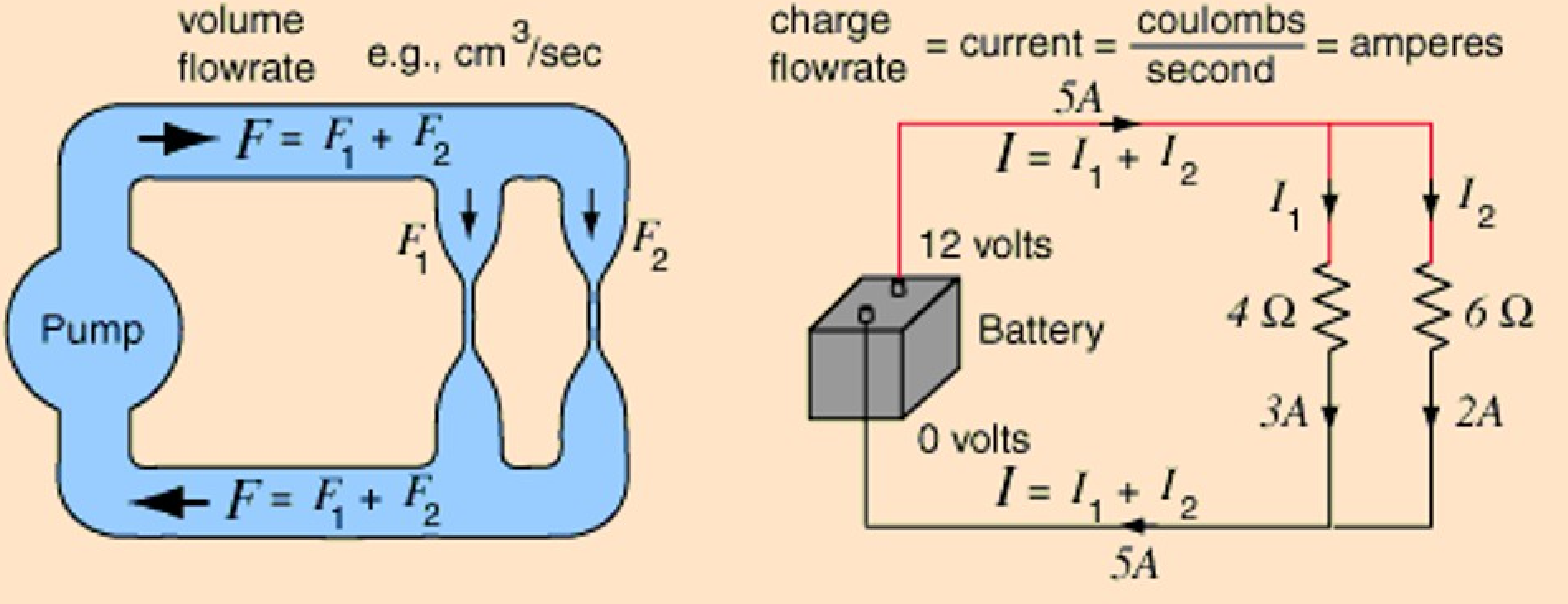


Parallel circuits:

Same voltage drop across resistors.

Current splits between resistors.

$$\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$



Parallel circuits:

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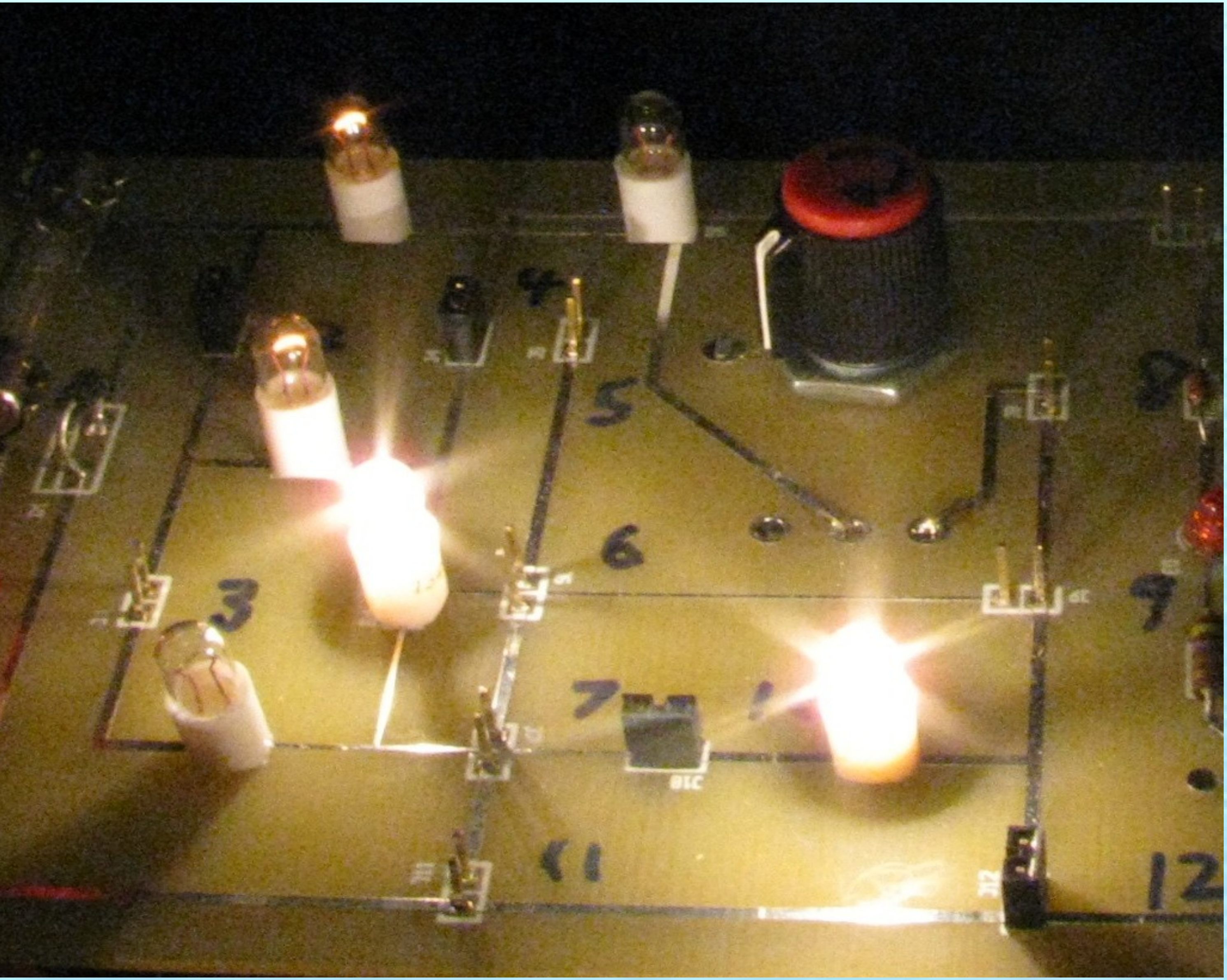
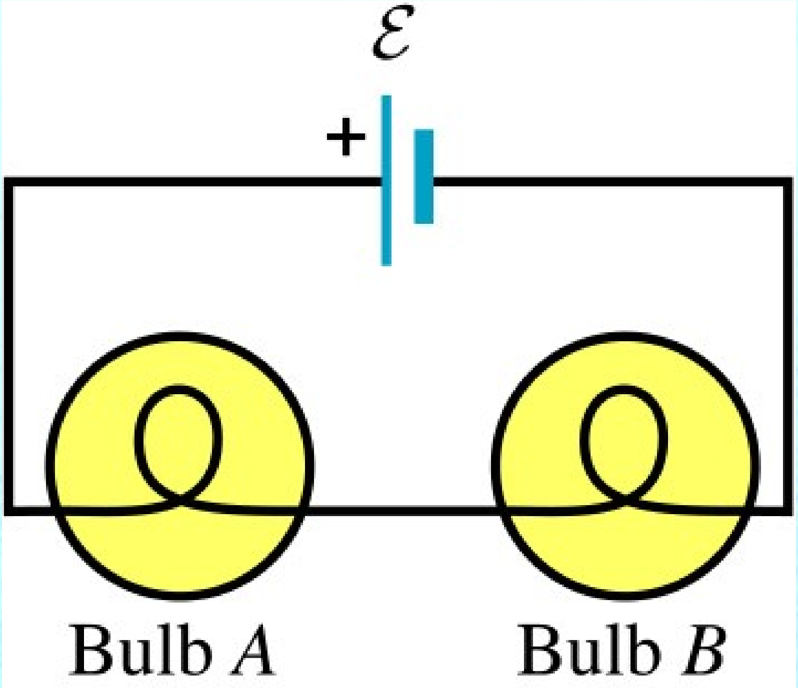


Clickers: A 2.0 Ω resistor is in series with a 6.0 Ω resistor. If the 2.0 Ω resistor has a current of 1.0 Amp, what is the current through the 6.0 Ω resistor?

[A] also 1.0 Amp
[B] 0.333 Amp
[C] 6.0 Amps
[D] 3.0 Amps
[E] Need more information to decide.

In the circuit shown, the two bulbs *A* and *B* are identical. Compared to bulb *A*,



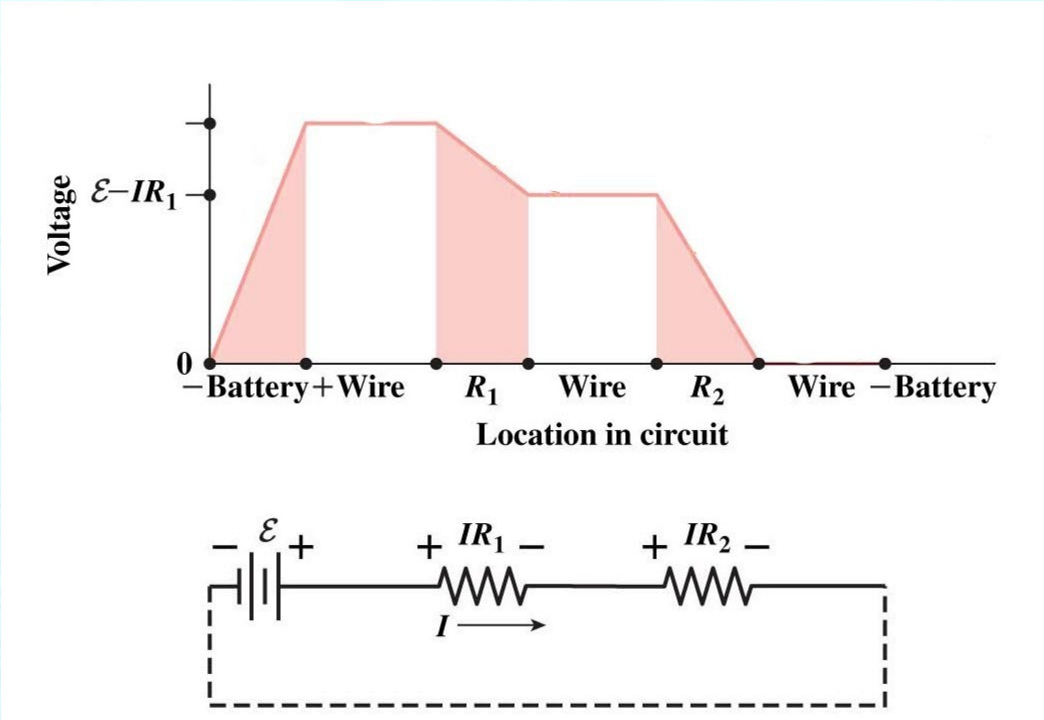
A. bulb *B* glows more brightly

B. bulb *B* glows less brightly

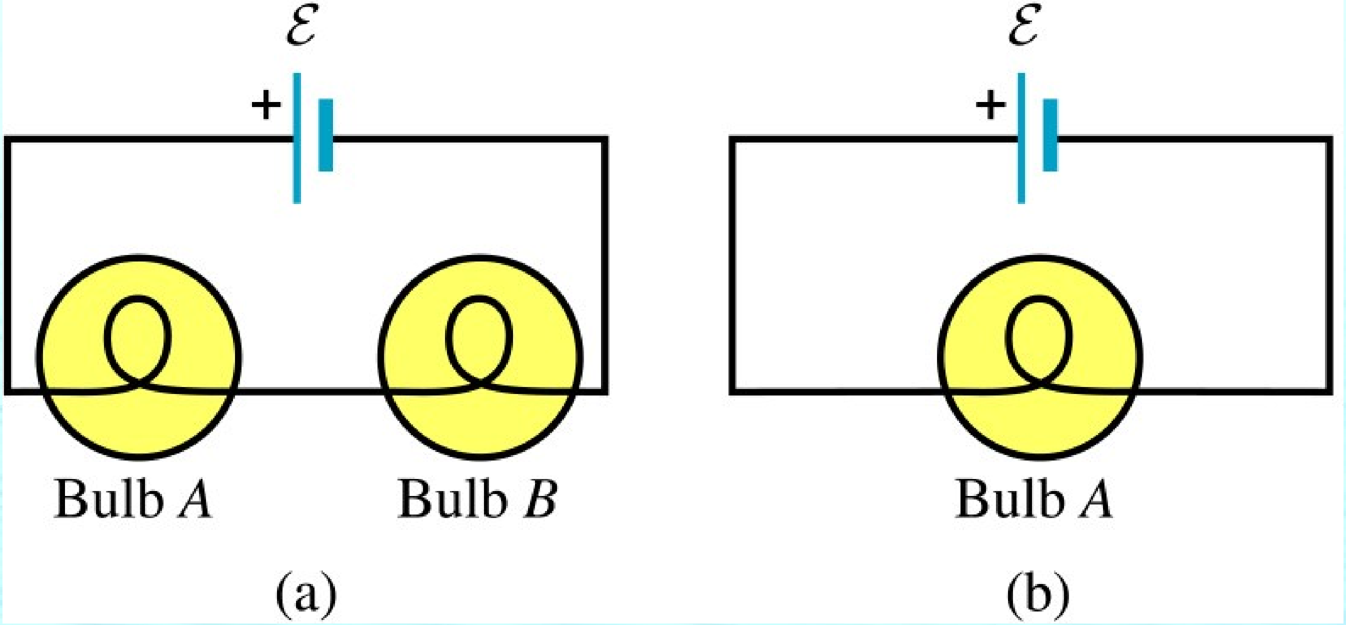
C. bulb *B* glows just as brightly

D. answer depends on whether the mobile charges in the wires are positively or negatively charged

pHeT



http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc



In the circuit shown in (a), the two bulbs *A* and *B* are identical. Bulb *B* is removed and the circuit is completed as shown in (b). Compared to the brightness of bulb *A* in (a), bulb *A* in (b) is

A. brighter

B. less bright

C. just as bright

D. any of the above

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RC Circuits

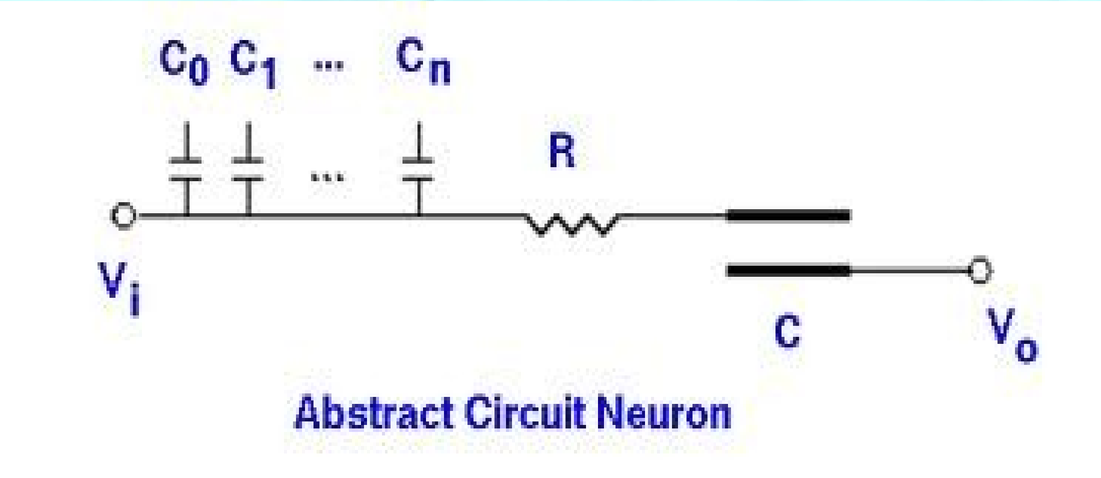
A circuit with both a resistor and a capacitor in it is called an "RC-circuit".

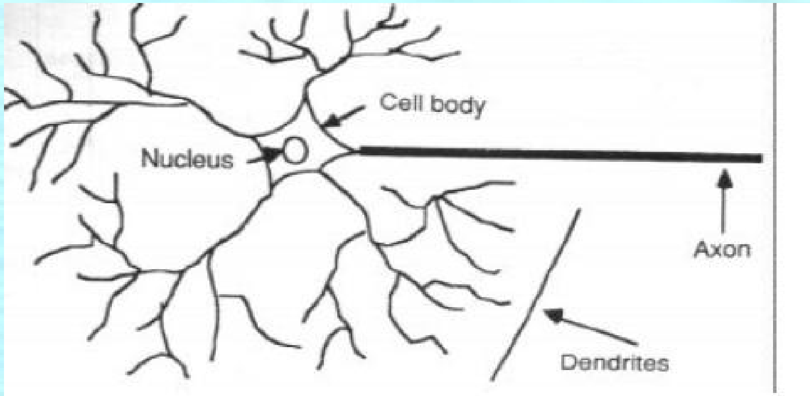
A circuit of pure resistors comes to equilibrium in less than a picosecond.

RC circuits have a characteristic time $(\tau = RC)$ Before they reach equilibrium.

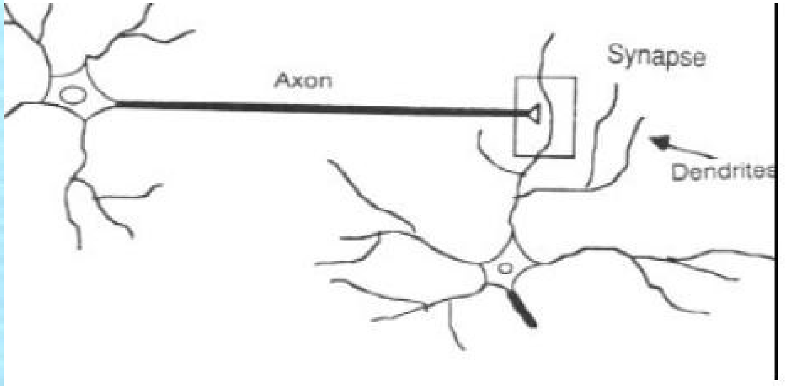
For the Biology majors …
(or anyone with neurons)

Try Googling "RC model of a neuron".

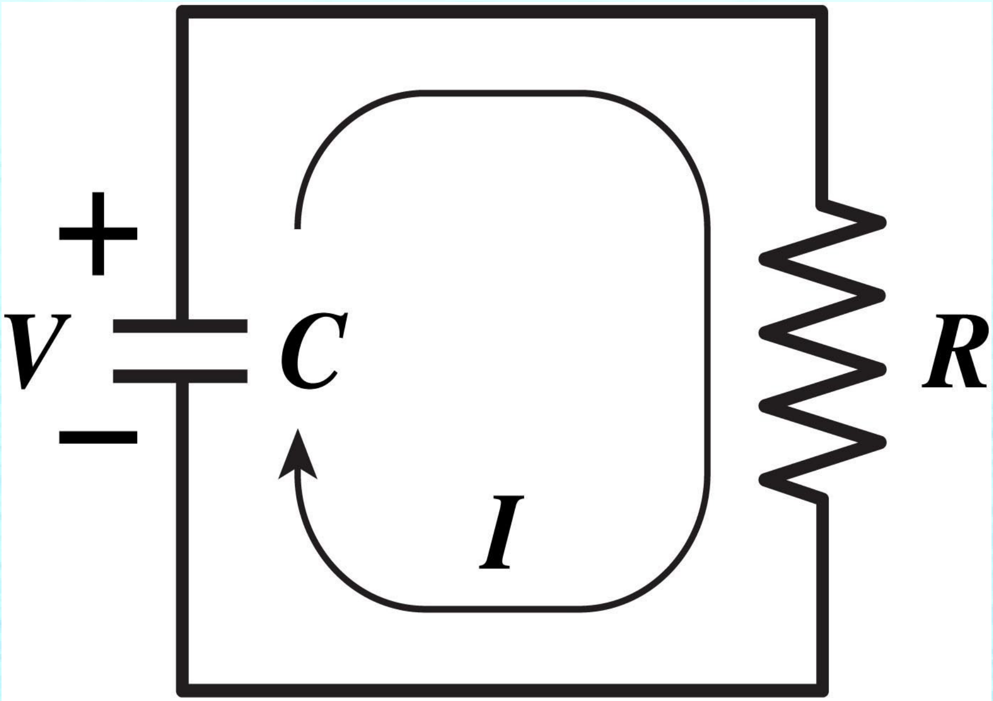




Components of a Biological Neuron



The Synapse



If capacitor begins charged --->

$$Q_C = Q_0 e^{-t/RC}$$

$$V_C = V_0 e^{-t/RC}$$

$$I = I_0 e^{-t/RC}$$

Is an Ohm Farad really a second?

$$Q = CV \rightarrow C = \frac{Q}{V} \rightarrow [\text{Farad}] = \frac{[\text{Coul}]}{[\text{Volt}]}$$

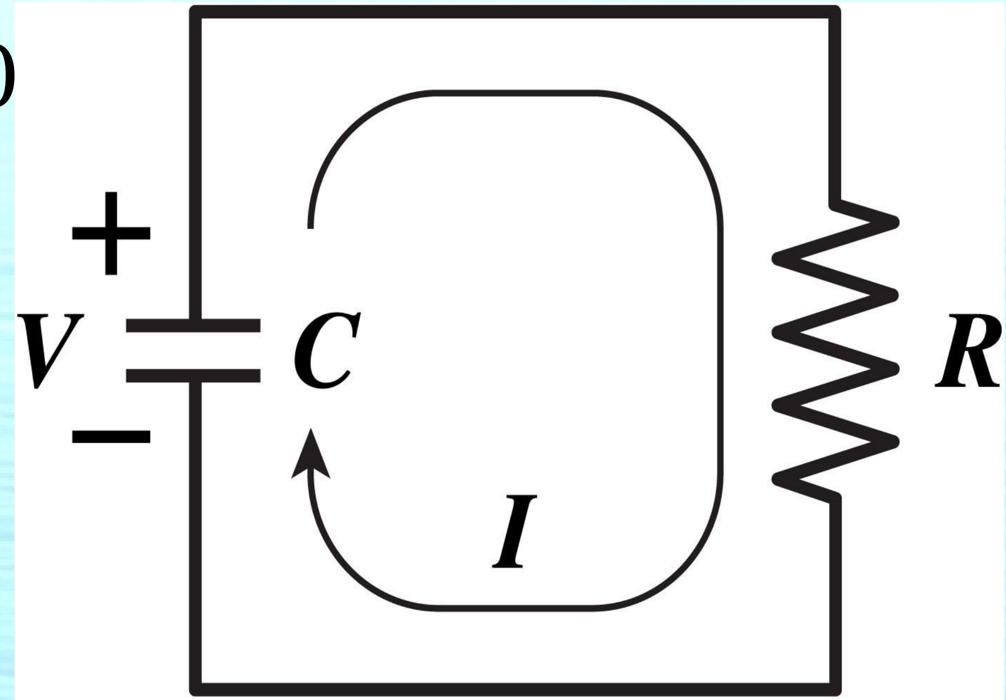
$$V = IR \rightarrow R = \frac{V}{I} \rightarrow [\text{Ohm}] = \frac{[\text{Volt}]}{[\text{Amp}]}$$

$$RC = [\text{Ohm}][\text{Farad}] = \frac{[\text{Volt}]}{[\text{Amp}]} \times \frac{[\text{Coul}]}{[\text{Volt}]}$$

$$RC = \frac{[\text{Coulomb}]}{[\text{Amp}]} = \frac{[\text{Coul}]}{[\text{Coul/second}]} = \text{seconds}!¿$$

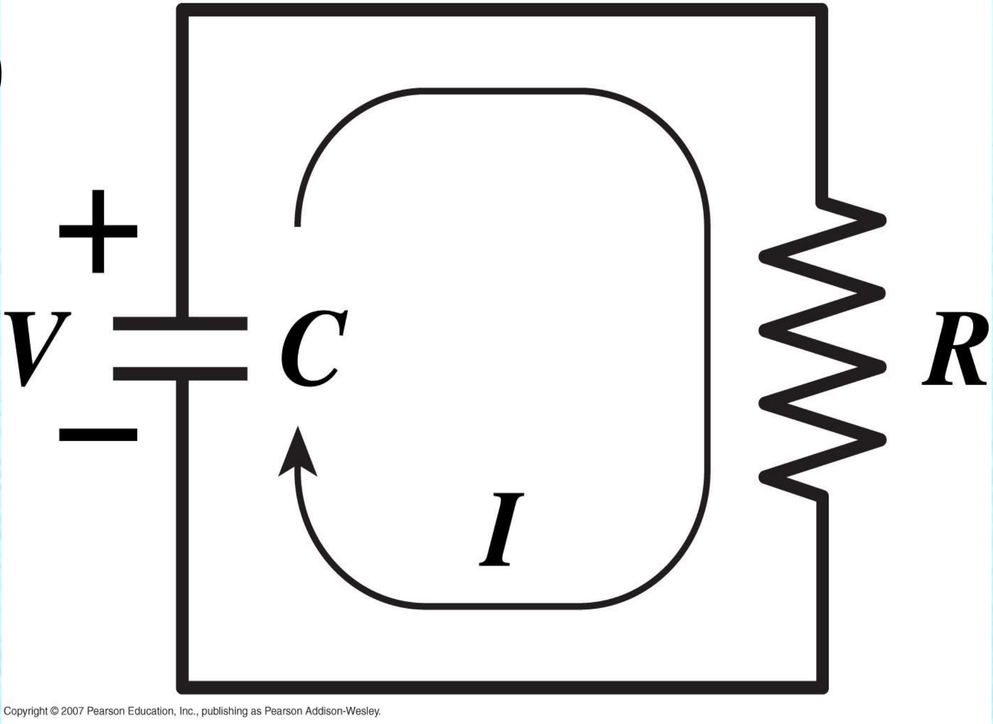
If capacitor begins charged …

$$V + IR = 0 \rightarrow \frac{Q}{C} + \frac{dQ}{dt}R = 0$$



If capacitor begins charged ...

$$V + IR = 0 \rightarrow \frac{Q}{C} + \frac{dQ}{dt}R = 0$$



$$\frac{dQ}{dt} = -\frac{Q}{RC}$$

$$\frac{dQ}{Q} = -\frac{dt}{RC}$$

$$\int \frac{dQ}{Q} = -\frac{1}{RC}\int dt$$

$$\ln Q = -\frac{t}{RC}$$

$$Q = Q_0 e^{-t/RC}$$

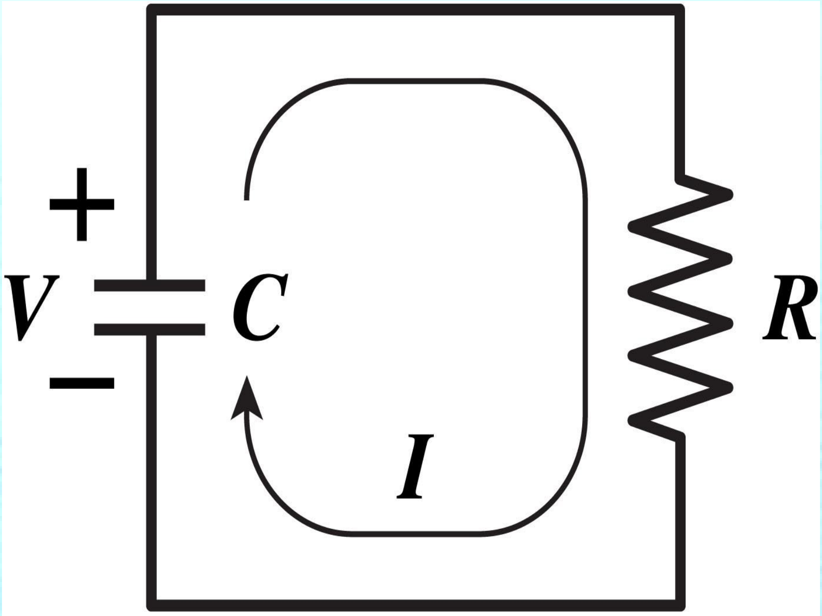
$$V_C = \frac{Q_0}{C} e^{-t/RC}$$

What is I(t)?

Given $Q(t)=Q_0 e^{-t/RC}$

And $I(t)=\frac{-dQ}{dt}$

What is $I(t)$?



$[A]\ Q_0 e^{-t/RC}$

$[B]\ Q_0 RC e^{-t/RC}$

$[C]\ -Q_0 RC e^{-t/RC}$

$[D]\ \frac{1}{RC} e^{-t/RC}$

$[E]\ \frac{Q_0}{RC} e^{-t/RC}$

RC Circuits

RC circuits have a characteristic time $(\tau = RC)$
Before they reach equilibrium. Note that R and C never appear alone

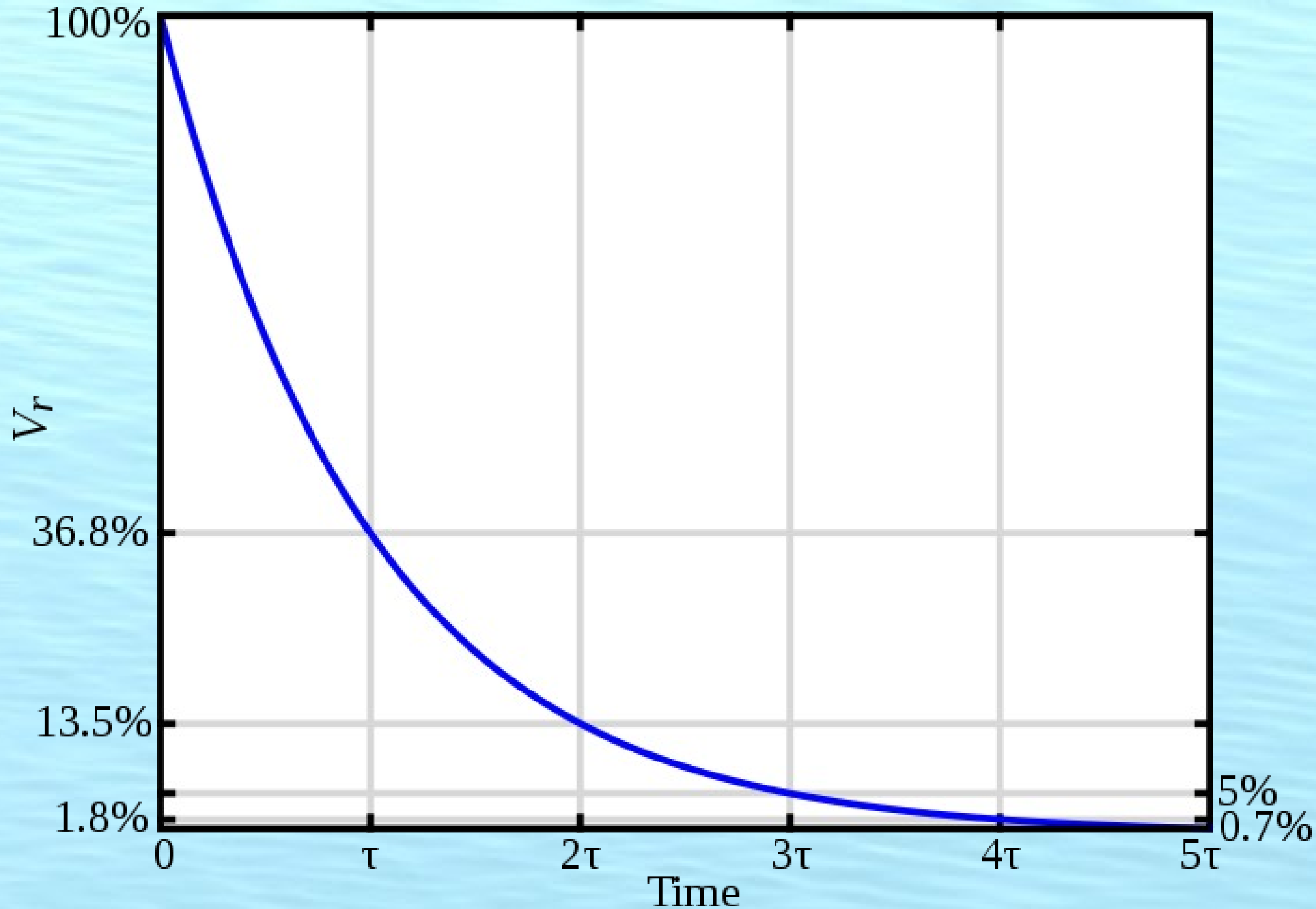
$$Q = Q_0 e^{-t/RC}$$

$$I = I_0 e^{-t/RC}$$

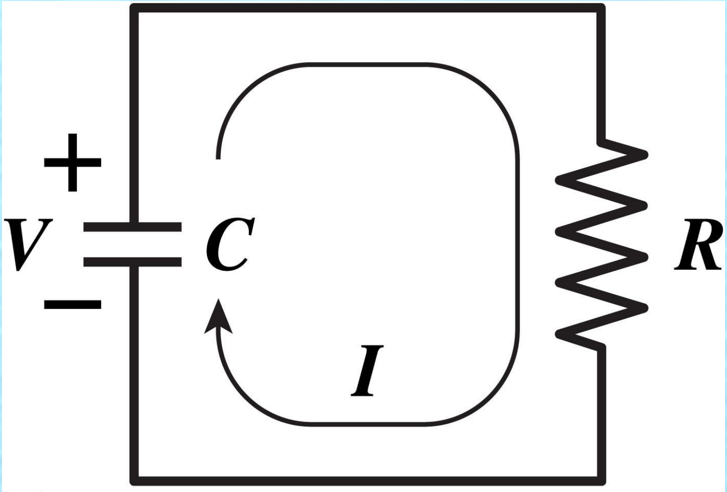
$$I = -\frac{Q_0}{RC} e^{-t/RC}$$

$$V_C = V_0 e^{-t/RC}$$

$$V_C = \frac{Q_0}{C} e^{-t/RC}$$



A 200 kΩ resistor is in series with C=10 μF. A t=0, the voltage on the capacitor is 8 V. What is the voltage on the capacitor and the current through the resistor after 1 sec, 2 sec and 4 seconds?



A 200 kΩ resistor is in series with $C = 10\ \mu F$.
A t=0, the voltage on the capacitor is 8 V.
What is the voltage on the capacitor and the current through the resistor after 1 sec, 2 sec and 4 seconds?

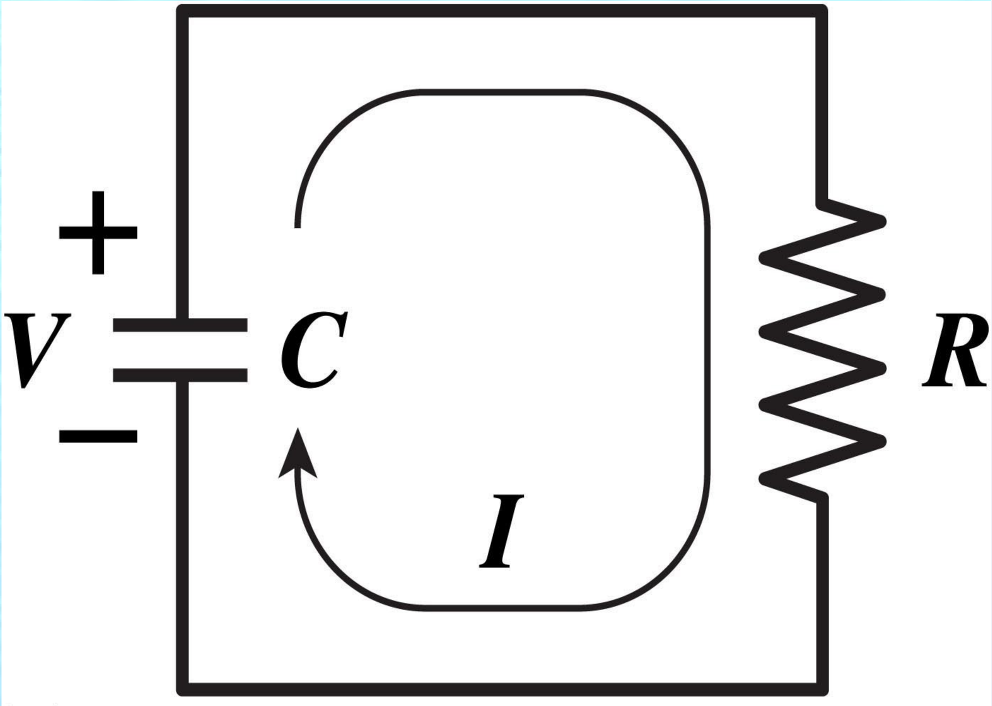
$$I = I_0 e^{-t/RC} \qquad I = \frac{V_0}{R} e^{-t/RC}$$

$$V = V_0 e^{-t/RC}$$

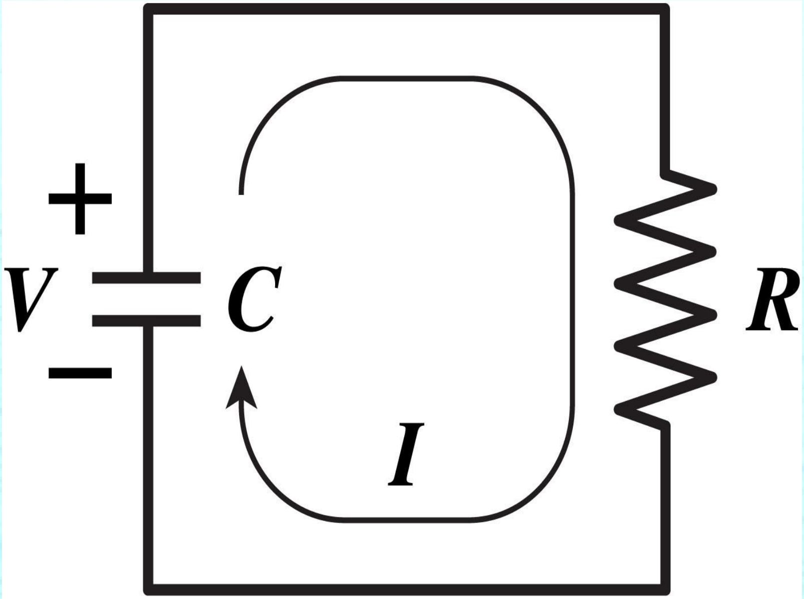
$$RC = (2.0 \times 10^5\ \Omega)(1.0 \times 10^{-5}\ F)$$

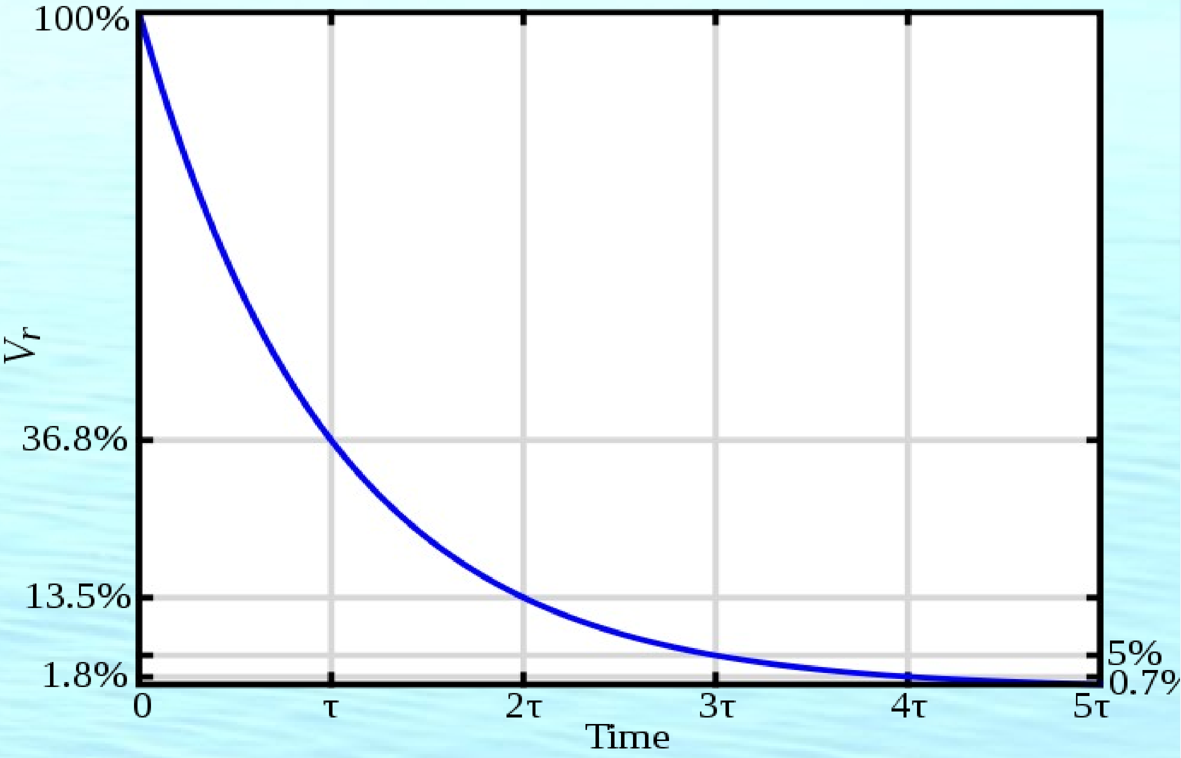
$$V(4) = 8e^{-4.00s/2.00s}\ \text{Volts}$$

$$V(4) = 8 \times 0.135 = 1.08\ \text{Volts}$$



Time for pHeT (AC Circuits Lab)





In this circuit, where capacitor begins charged --->

$$V_C = V_0 e^{-t/RC}$$

$$I = I_0 e^{-t/RC}$$

Find the resistance needed in an RC circuit to discharge a 20 μF capacitor
to 55% of full charge in 140 ms.

Find the resistance needed in an RC circuit to discharge a $20\ \mu F$ capacitor to 55% of full charge in 140 ms.

$$Q_C = Q_0 e^{-t/RC}$$

$$0.55\, Q_0 = Q_0 e^{-t/RC}$$

$$0.55 = e^{-t/RC}$$

$$\ln(0.55) = \ln\left(e^{-t/RC}\right)$$

$$-0.597 = \frac{-t}{RC}$$

$$R = \frac{t}{0.597\, C}$$

$$R = \frac{1.40 \times 10^{-1}\ s}{0.597 \cdot 2.0 \times 10^{-5}\ F}$$

$$R = 11.74\ k\Omega$$

RC Circuits Demo