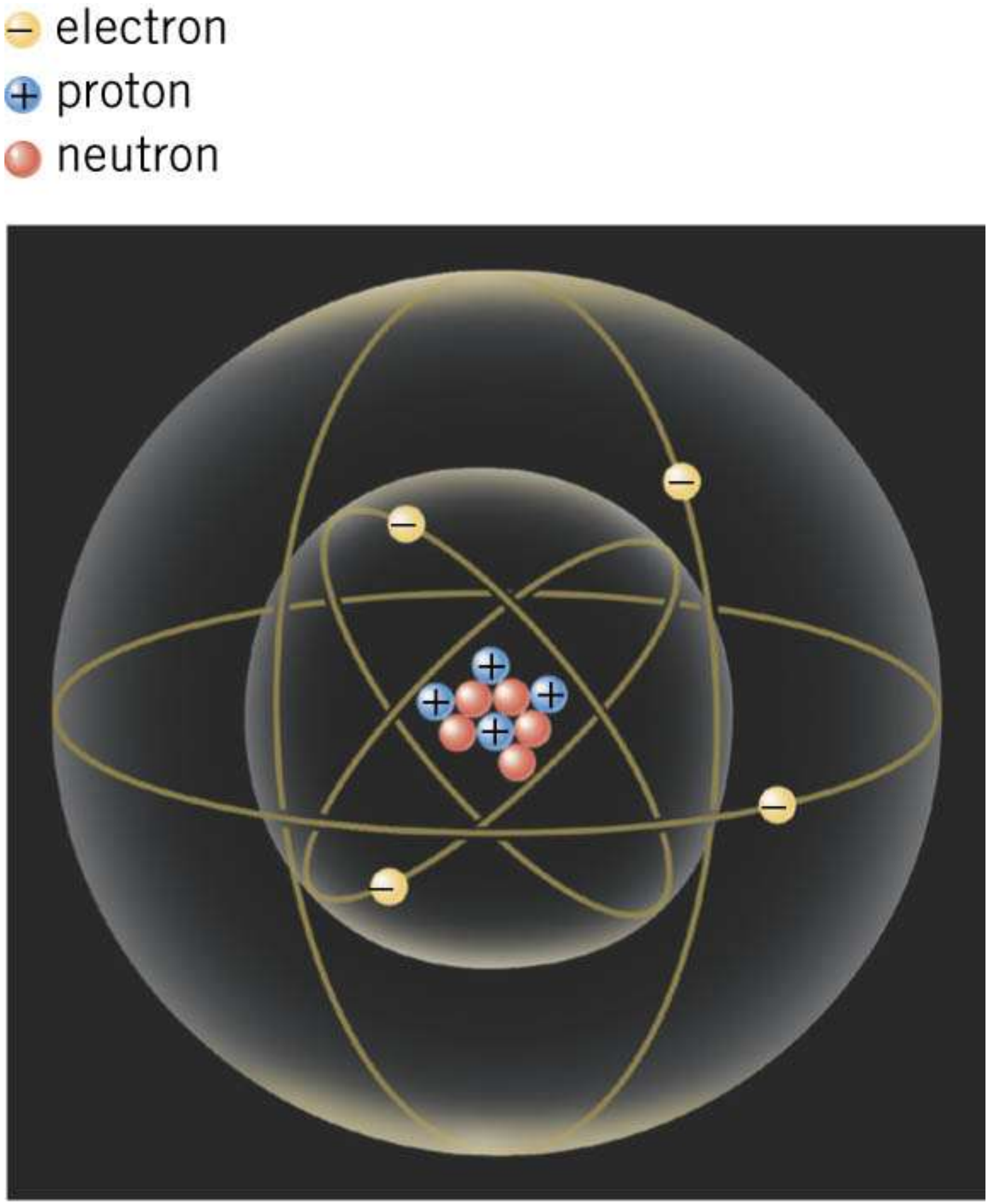
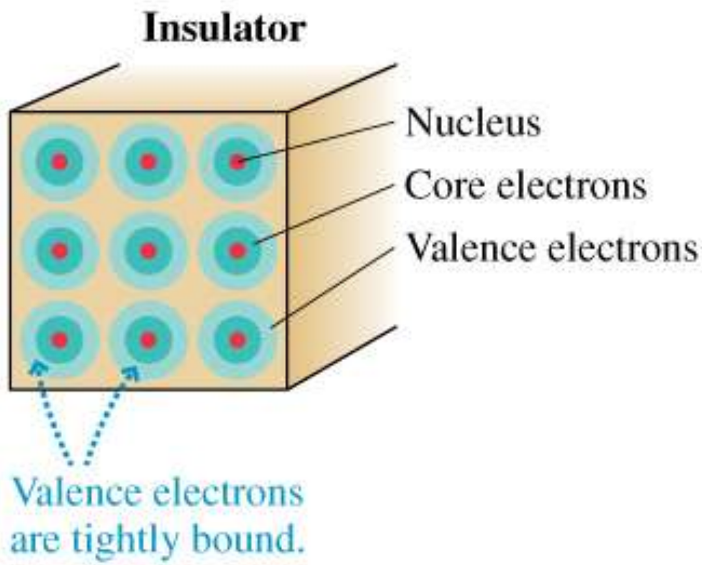
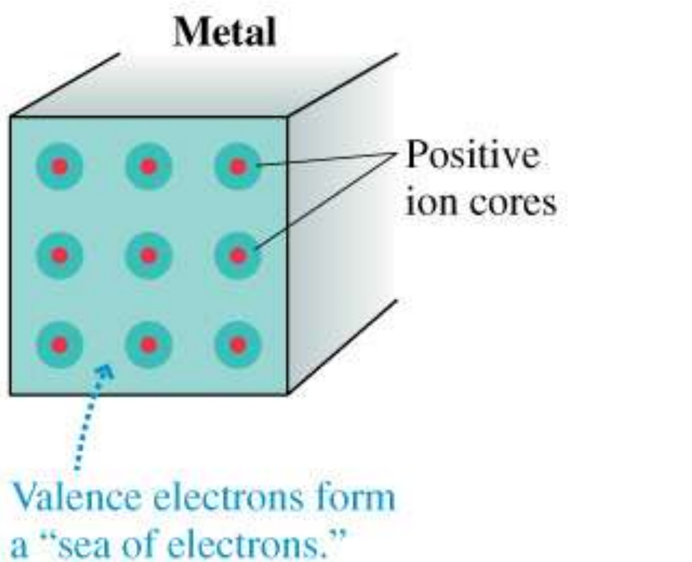
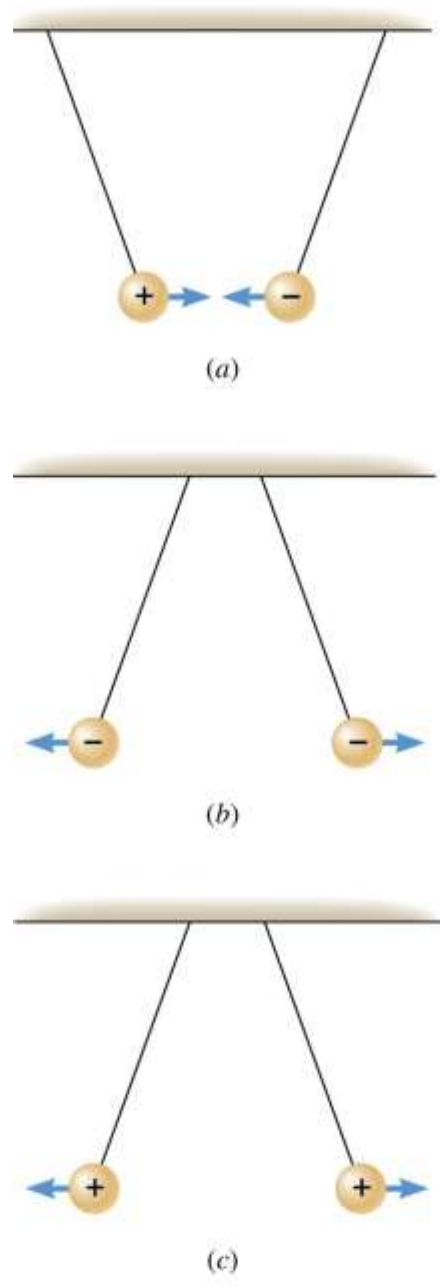
Electric Charge, Energy, and Potential Difference

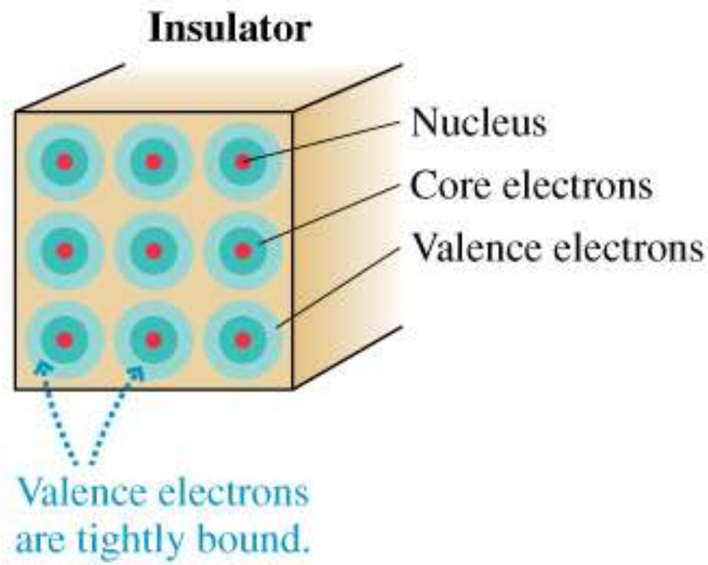


Outer or "valence" electrons determine chemical and electrical properties of solids.

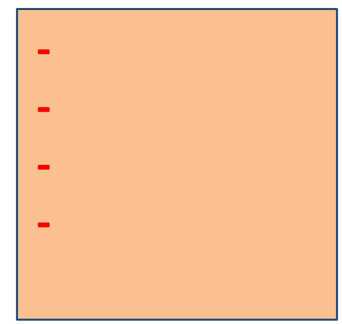

Insulator
Nucleus
Core electrons
Valence electrons
Valence electrons
are tightly bound.

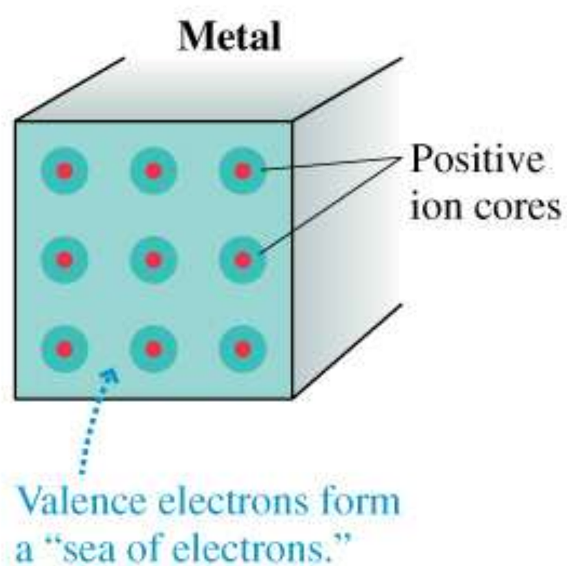

Metal
Positive
ion cores
Valence electrons form
a "sea of electrons."


+
−
(a)
−
−
(b)
+
+
(c)

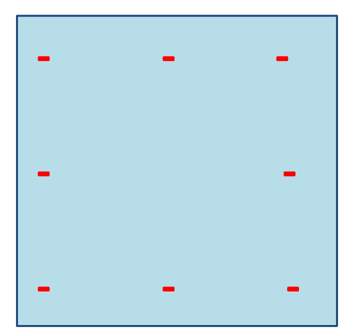


Add charge to an insulator and it stays where it is put.





Add charge to a conductor and it spreads out.



F

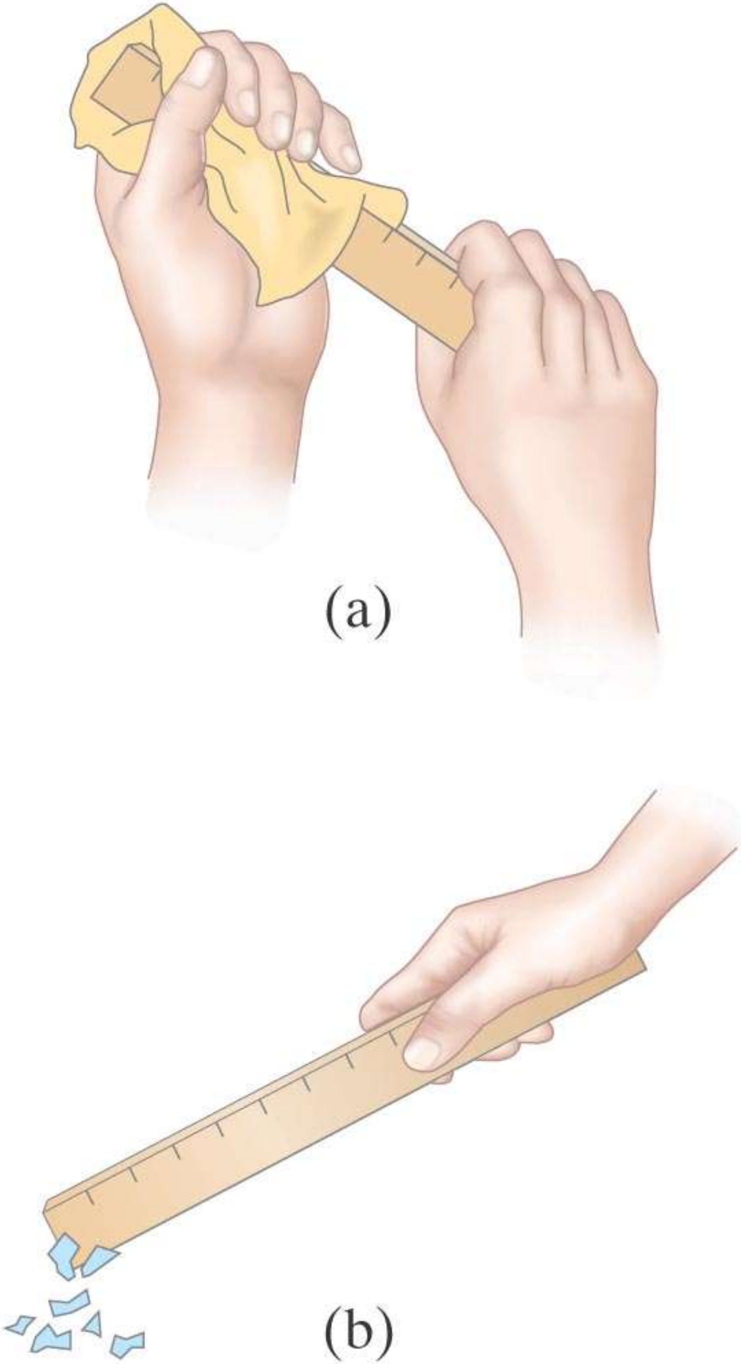
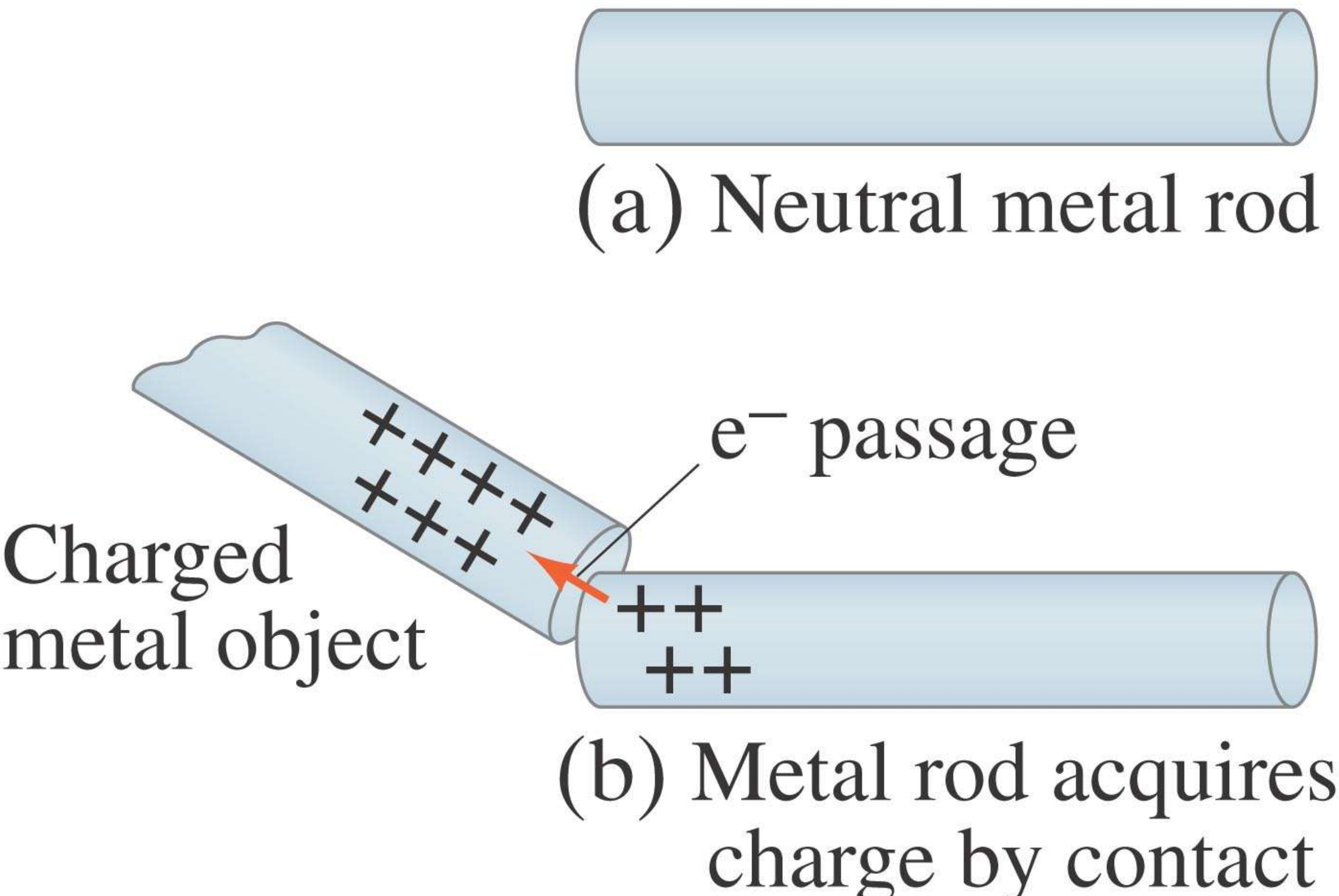
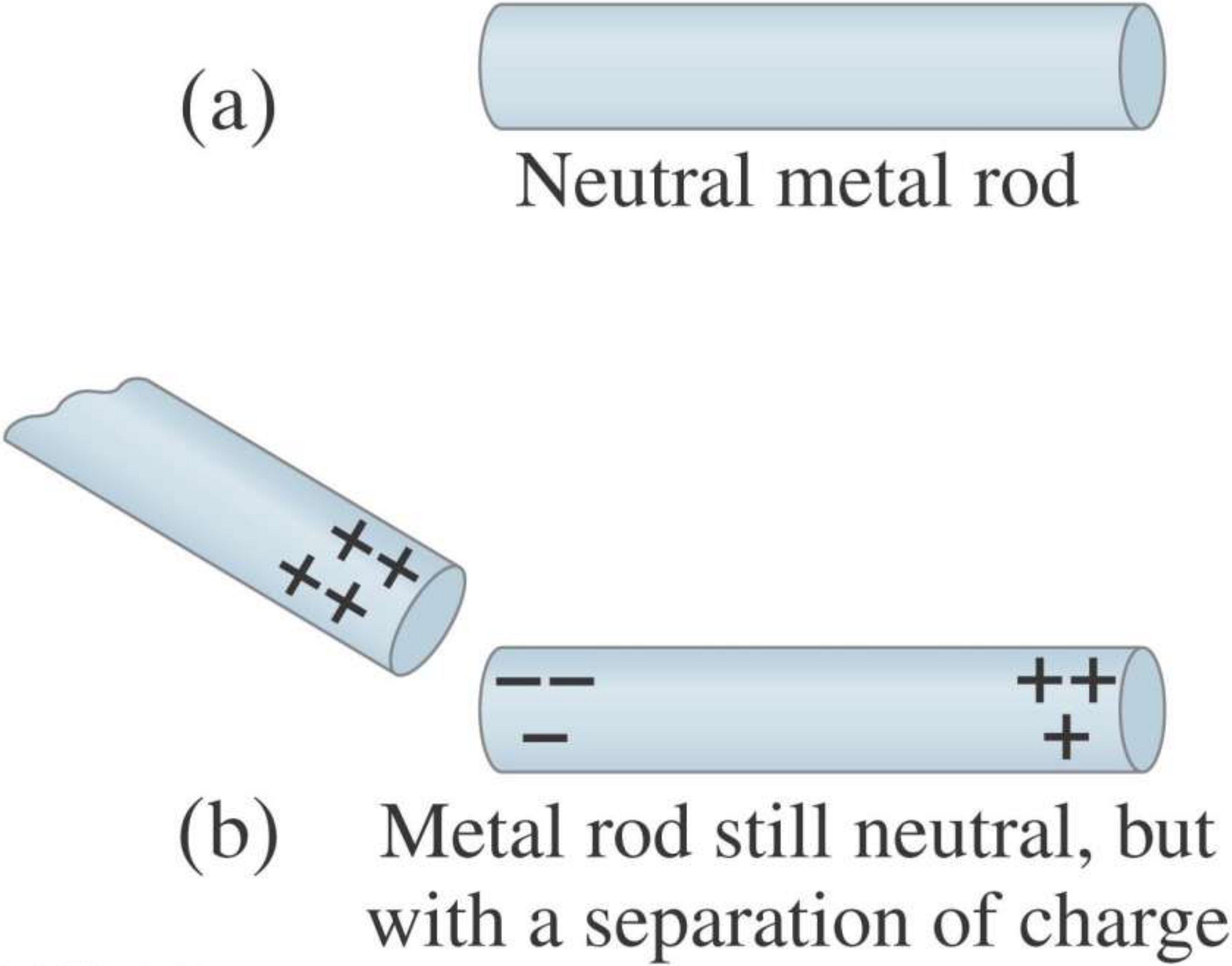


Figure 21.6



(a) Neutral metal rod
e⁻ passage
Charged metal object
++
++
(b) Metal rod acquires charge by contact

Figure 21.7



(a)
Neutral metal rod
(b)
Metal rod still neutral, but with a separation of charge

Figure 21.8

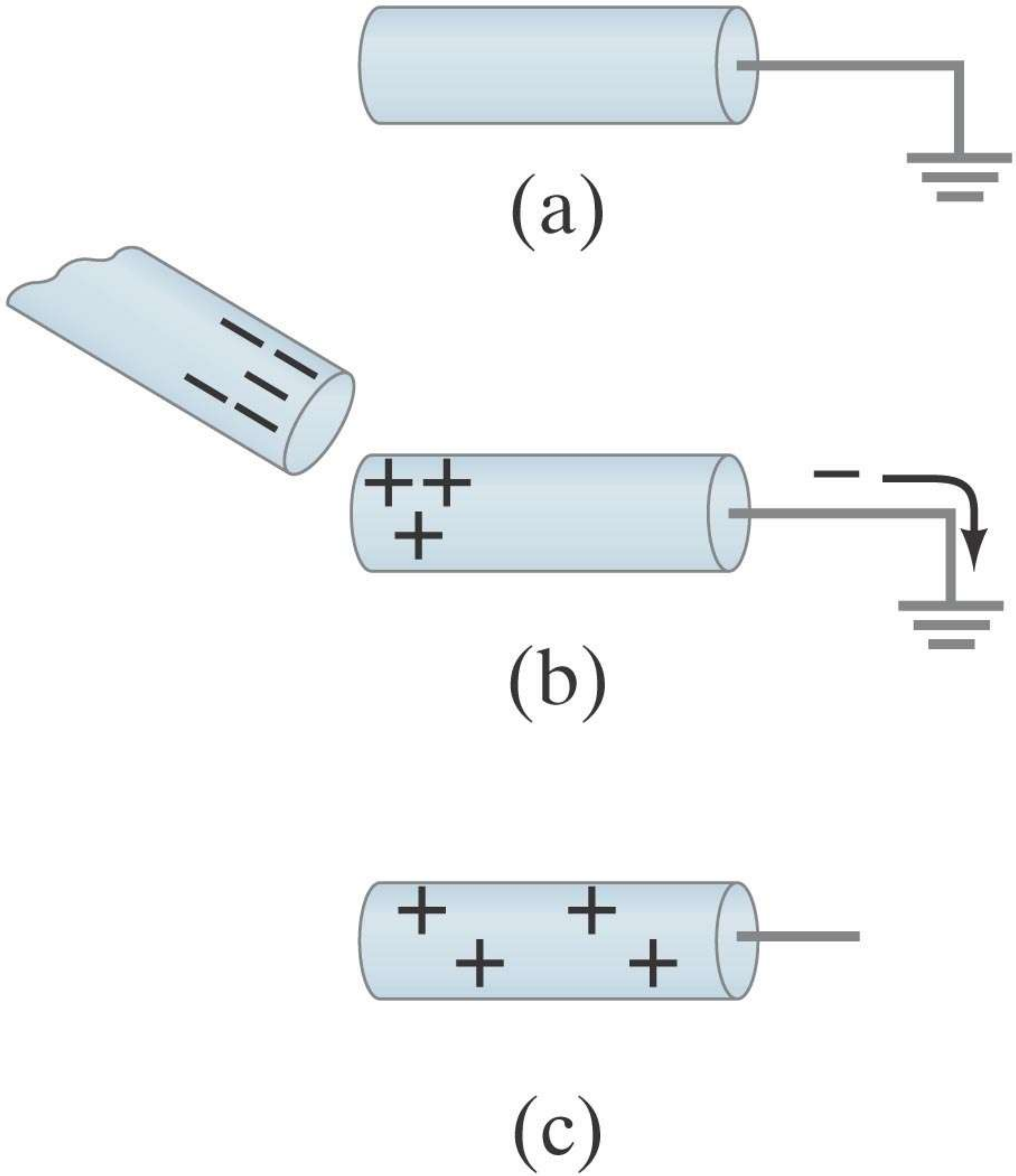
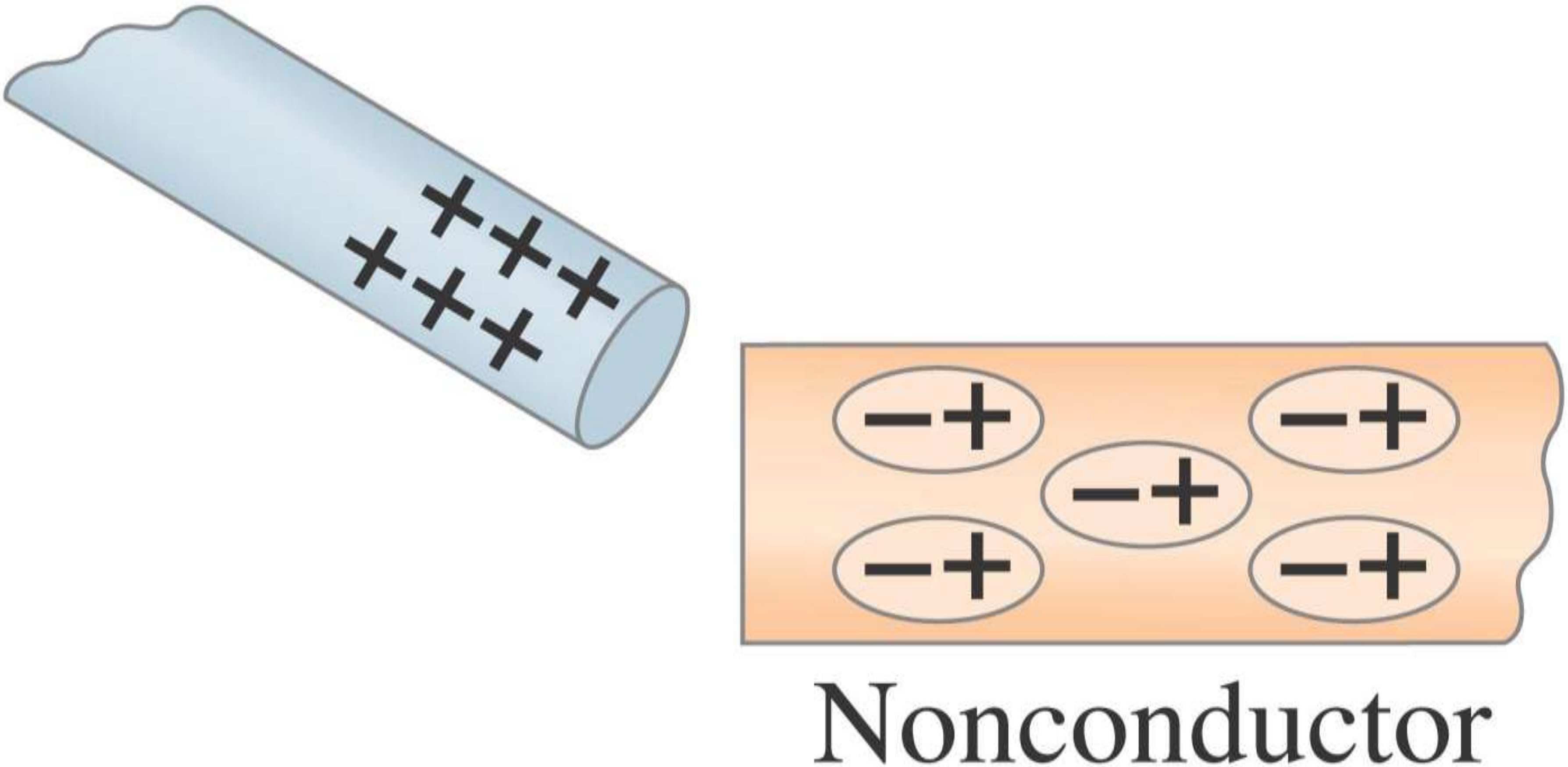
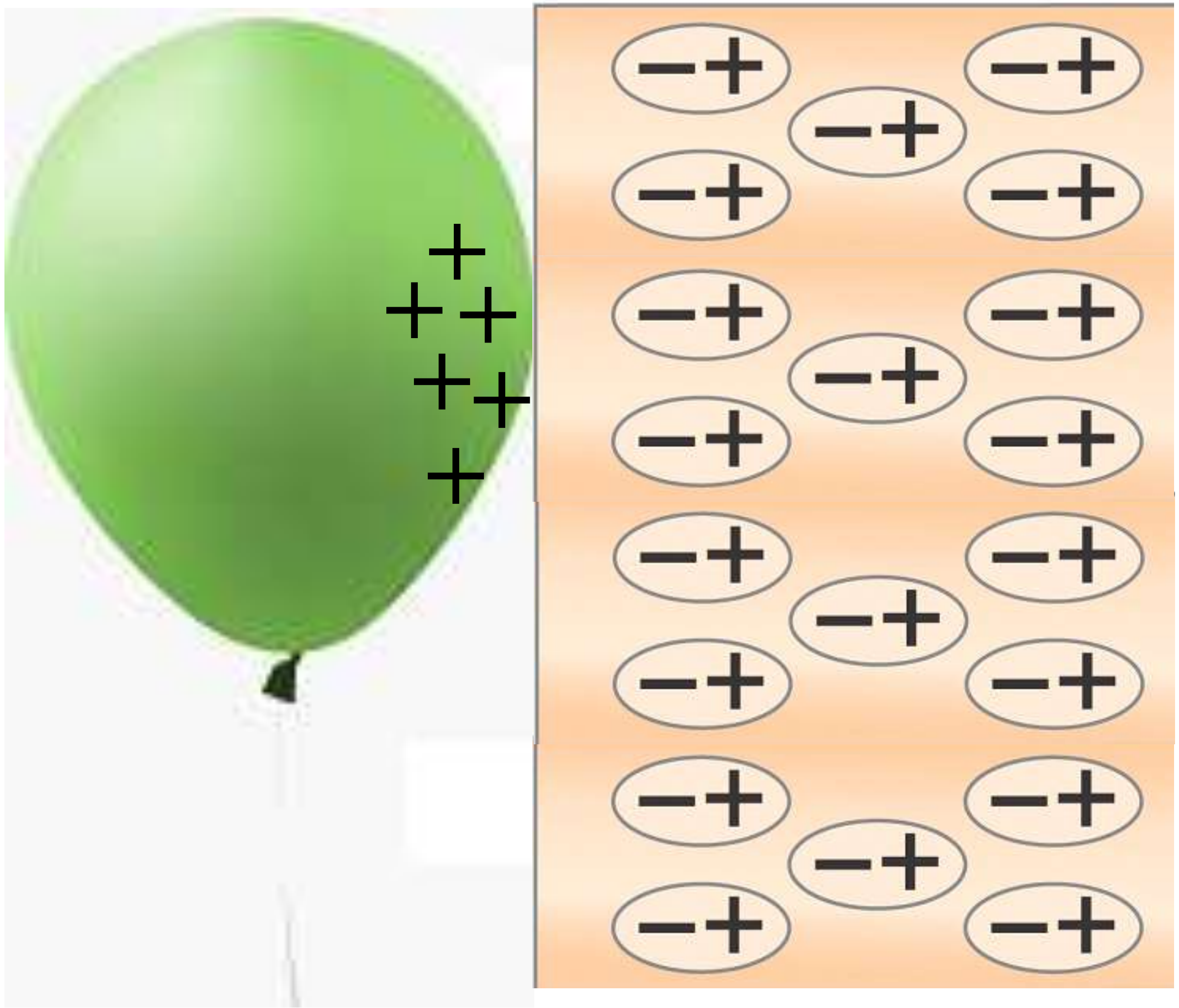


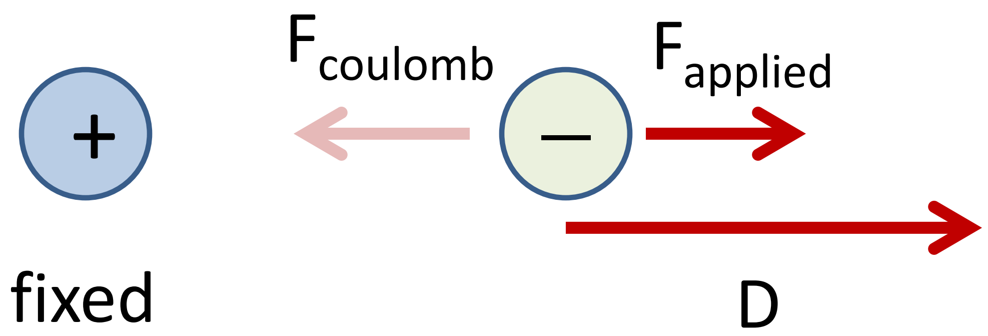
Figure 21.9





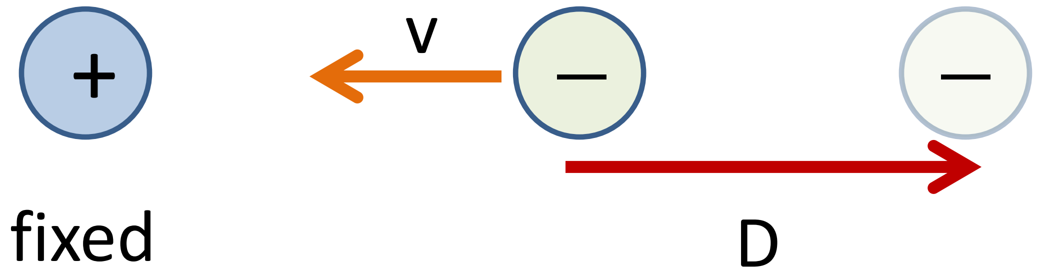
Surface of wall

Charge and Energy



- It takes energy to separate a + & – charge (must do work!)
- Note $W \neq F_{applied}$ D since F varies with position

- If I release – charge, it moves to + charge



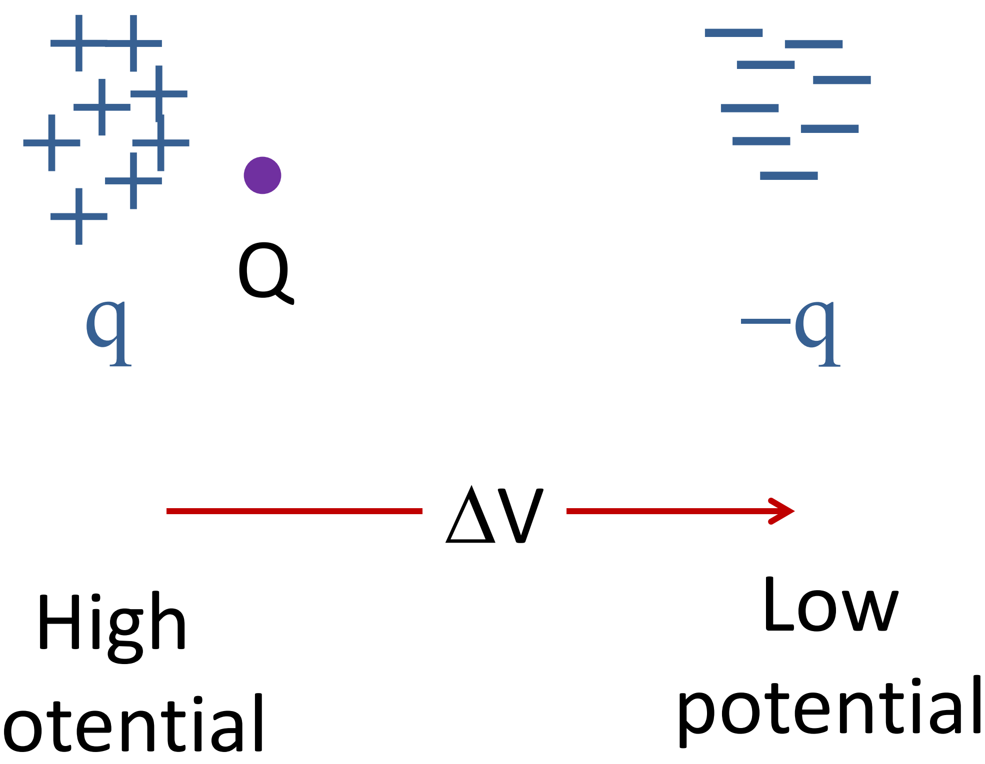
- We say electrostatic potential energy is converted to kinetic energy.

Separated charge $\Rightarrow$ Stored Energy

- Separating one valence from an otherwise neutral atom, takes only a small amount or work/energy
- But we usually move billions or more!

- Instead of PE, we use *potential difference* (also called *voltage difference*, or just plain *voltage*)

$$\Delta V = \frac{Work\ done\ in\ separating\ charge}{q}$$
$$= \frac{Energy\ of\ separated\ charge}{q}$$

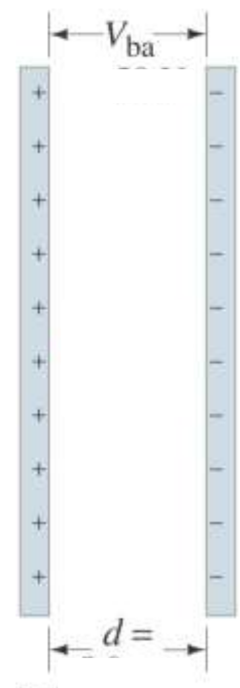


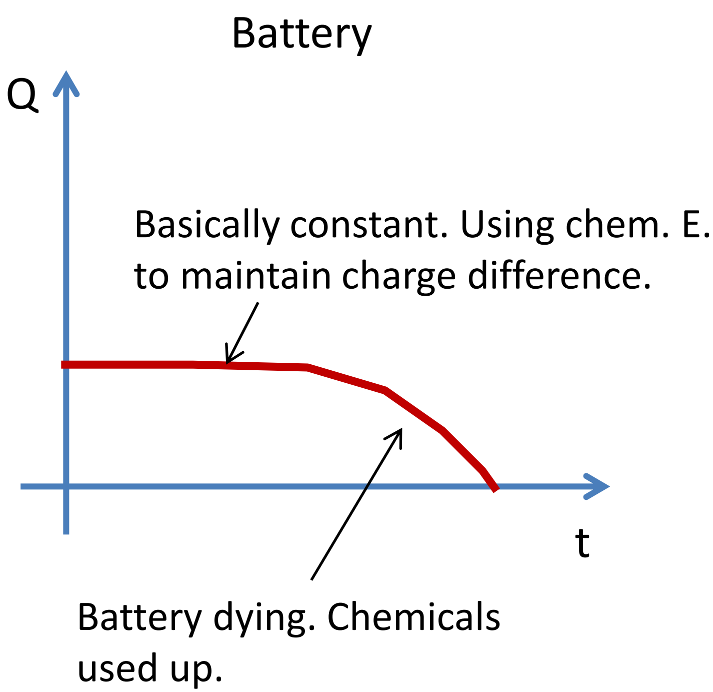
The work done on a small charge Q by a potential difference ΔV is **W = QΔV**

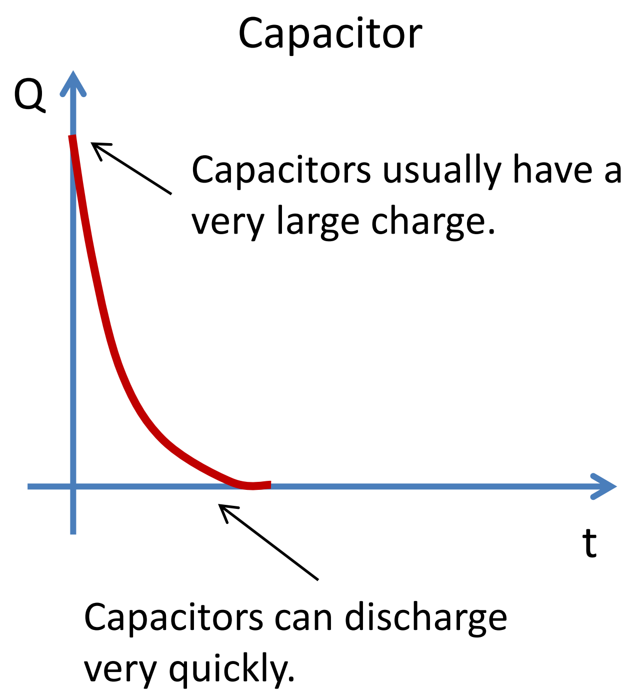
Questions

DC Circuits

- We have two common ways to create/store a charge difference: batteries and capacitors.
- Charge stays in place b/c air is an insulator (usually!). If you put provide a conducting path from one side to other, charge will flow (have a current).

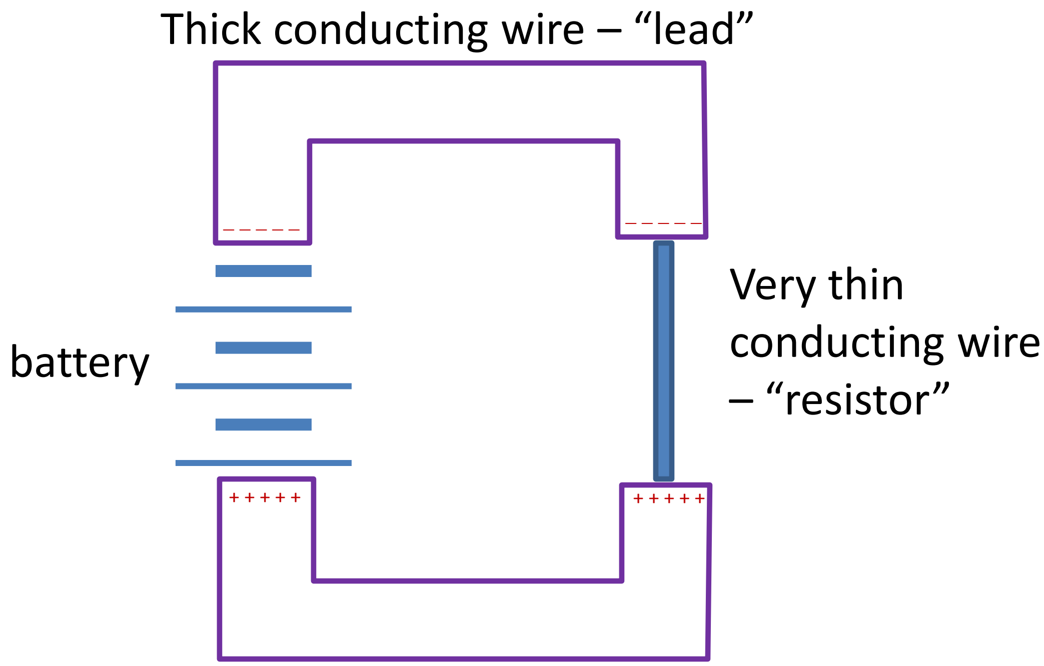






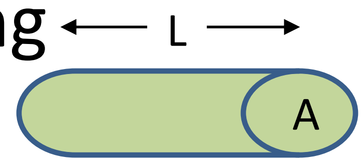
- For an ideal battery we assume a constant ΔV

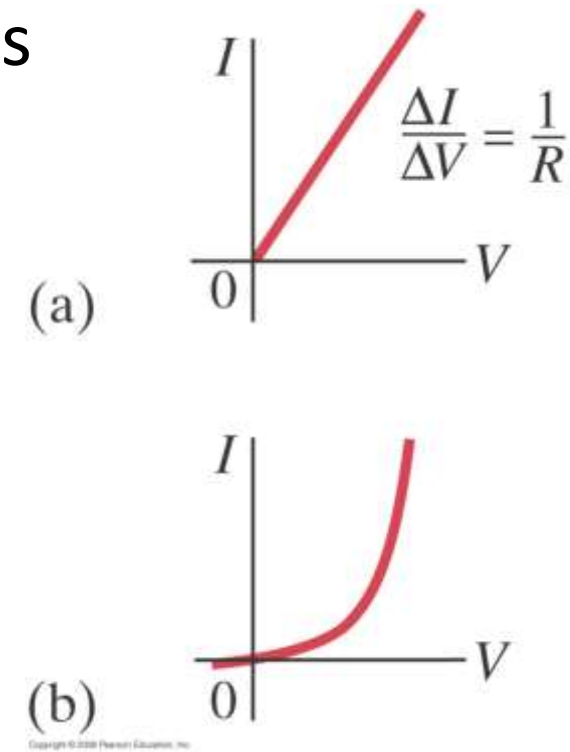
Controlling Current Size - Resistance

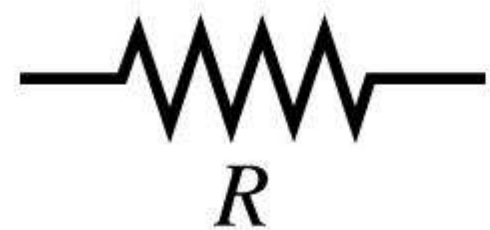


- Resistor "chokes" current
- Charge difference and $\therefore \Delta V$ across resistor
- $I = \Delta q / \Delta t$ (1 Amp = 1 C/s)
- Electron (negative) current or conventional (positive) current

- Resistance is defined R = ΔV / I or ΔV = I R (Ohm's Law). Note 1 Ω = 1 V / A
- Plot ΔV vs I. If linear have resistor.
- Resistance dissipates electron KE as heat (collisions between electron and atoms in metal transfer KE to atoms) – Joule Heating
- R = ρL/A
- Resistivity ρ is a characteristic of a conductor
- Bulky plastic or ceramic wrapping helps dissipate heat to air without melting resistor

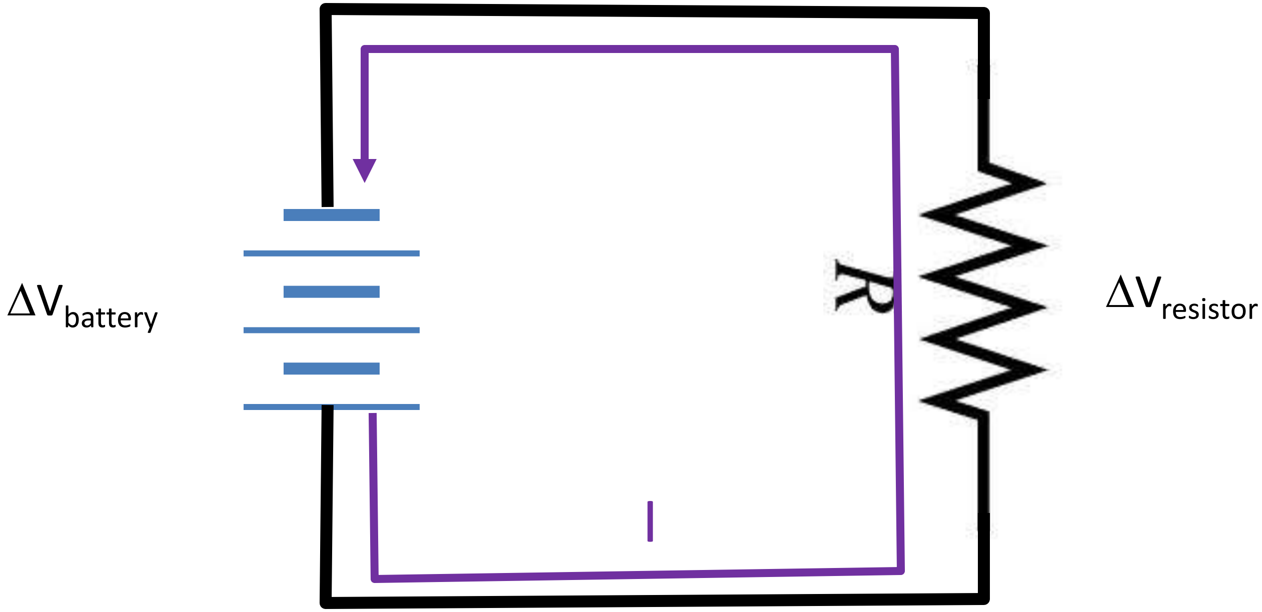






Energy and Circuits

- Power = Energy / time (1 watt = 1 J /s)
- $P = (\Delta q\ \Delta V) / \Delta t = \Delta V\ (\Delta q / \Delta t) = \Delta V\ I$
- Two ideas and Ohm's Law let's us understand any circuit
- Conservation of Charge
  - Current out of a battery must come back (electrons don't disappear)
- Conservation of Energy
  - Power supplied by batteries in must equal power dissipated by resistors

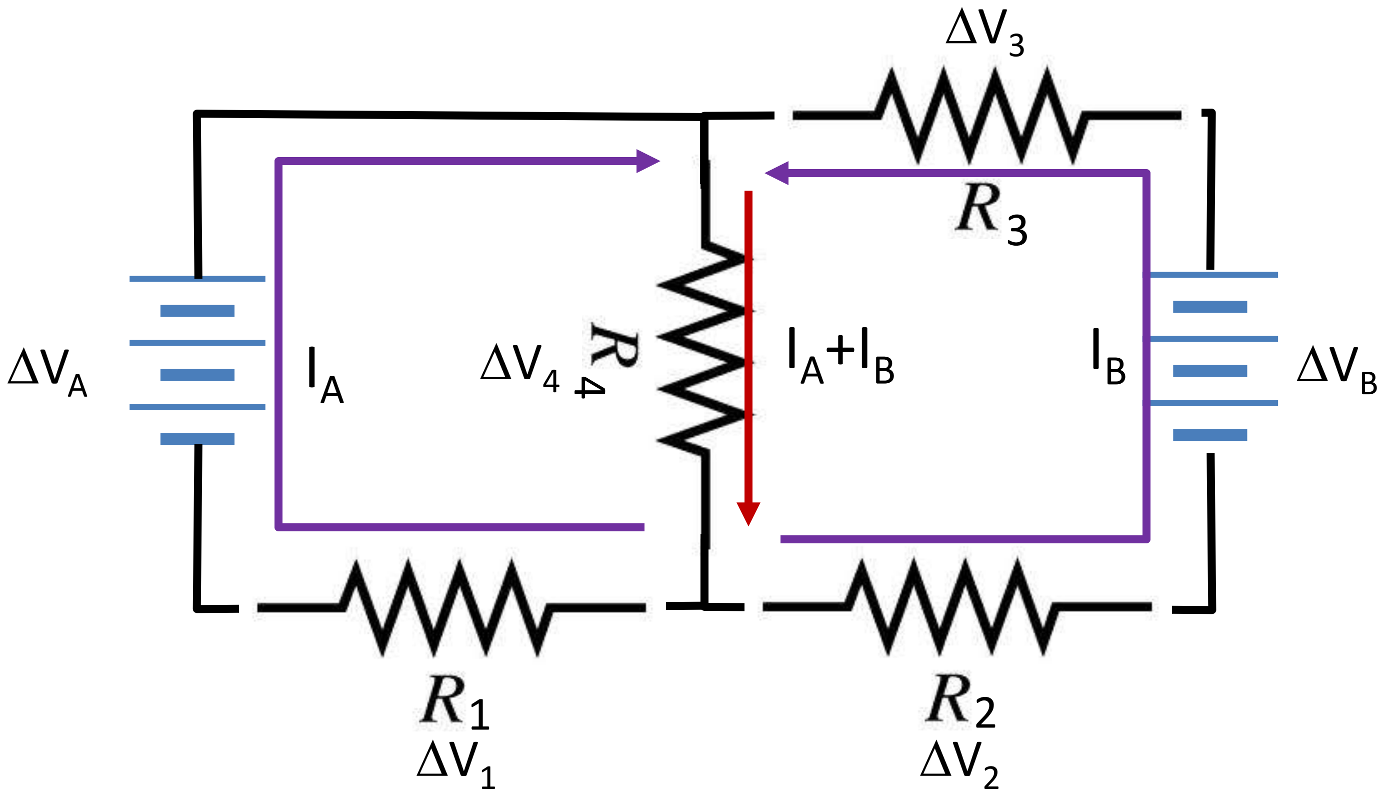


$$P_{in} = P_{out}$$

$$\Delta V_{battery} \times I = \Delta V_{resistor} \times I$$

$$\Delta V_{battery} = \Delta V_{resistor}$$

Ohm's Law: $I = \Delta V_{battery} / R$



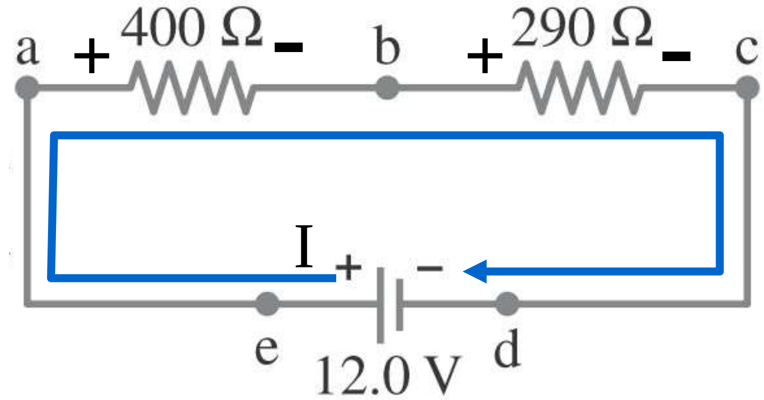
$$P_A + P_B - P_1 - P_2 - P_3 - P_4 = 0$$

$$I_A\Delta V_A + I_B\Delta V_B - I_A\Delta V_1 - I_B\Delta V_2 - I_B\Delta V_3 - (I_A+I_B)\Delta V_4 = 0$$

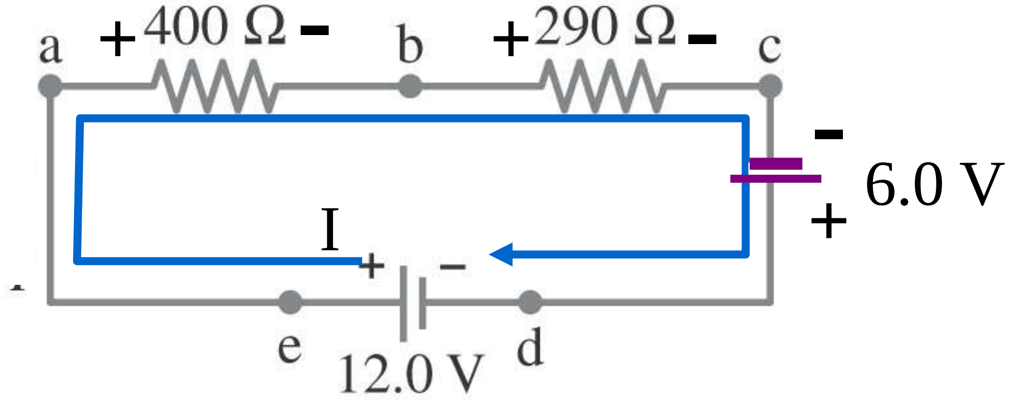
$$I_A(\Delta V_A - \Delta V_1 - \Delta V_4) + I_B(\Delta V_B - \Delta V_2 - \Delta V_3 - \Delta V_4) = 0$$

$$\Delta V_A - \Delta V_1 - \Delta V_4 = 0 \ \ \& \ \ \Delta V_B - \Delta V_2 - \Delta V_3 - \Delta V_4 = 0$$

KR1: Sum of voltage drops around a loop is zero.



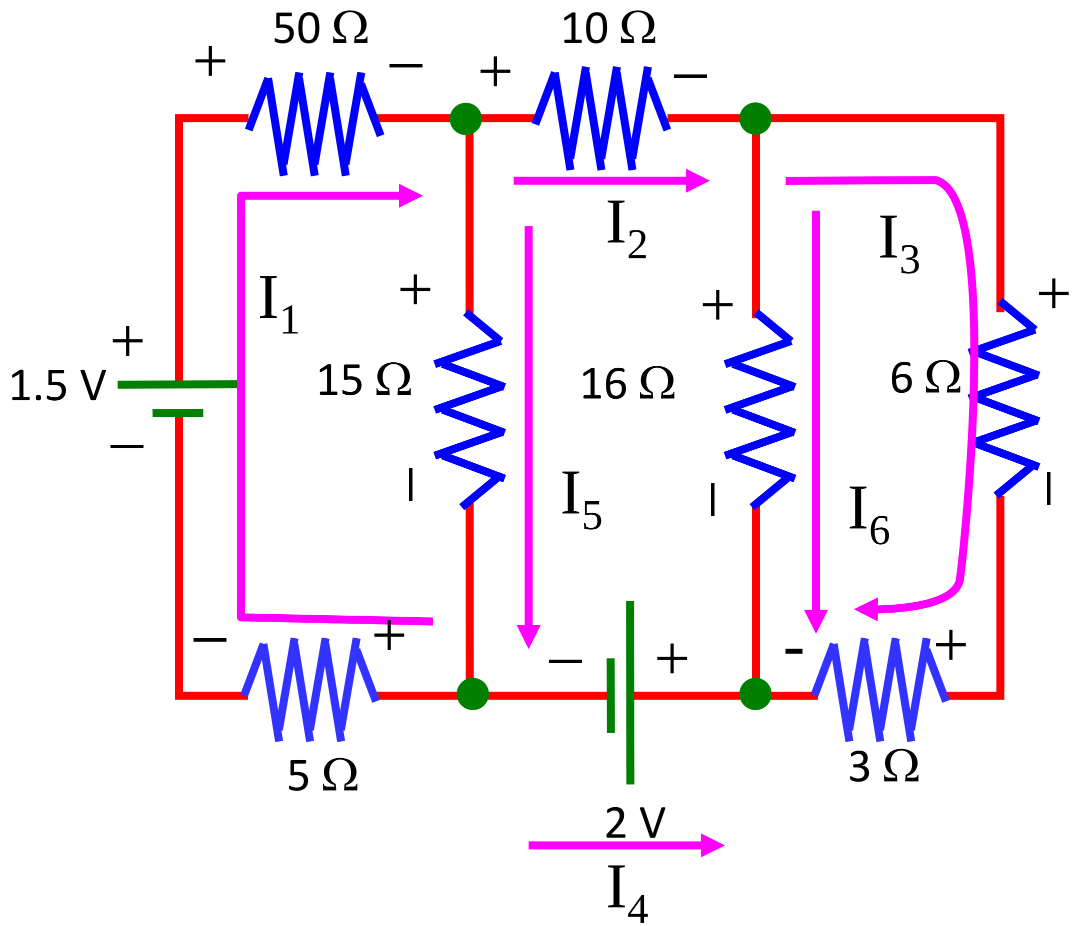
(a)



(a)

Using Kirchhoff's Rules

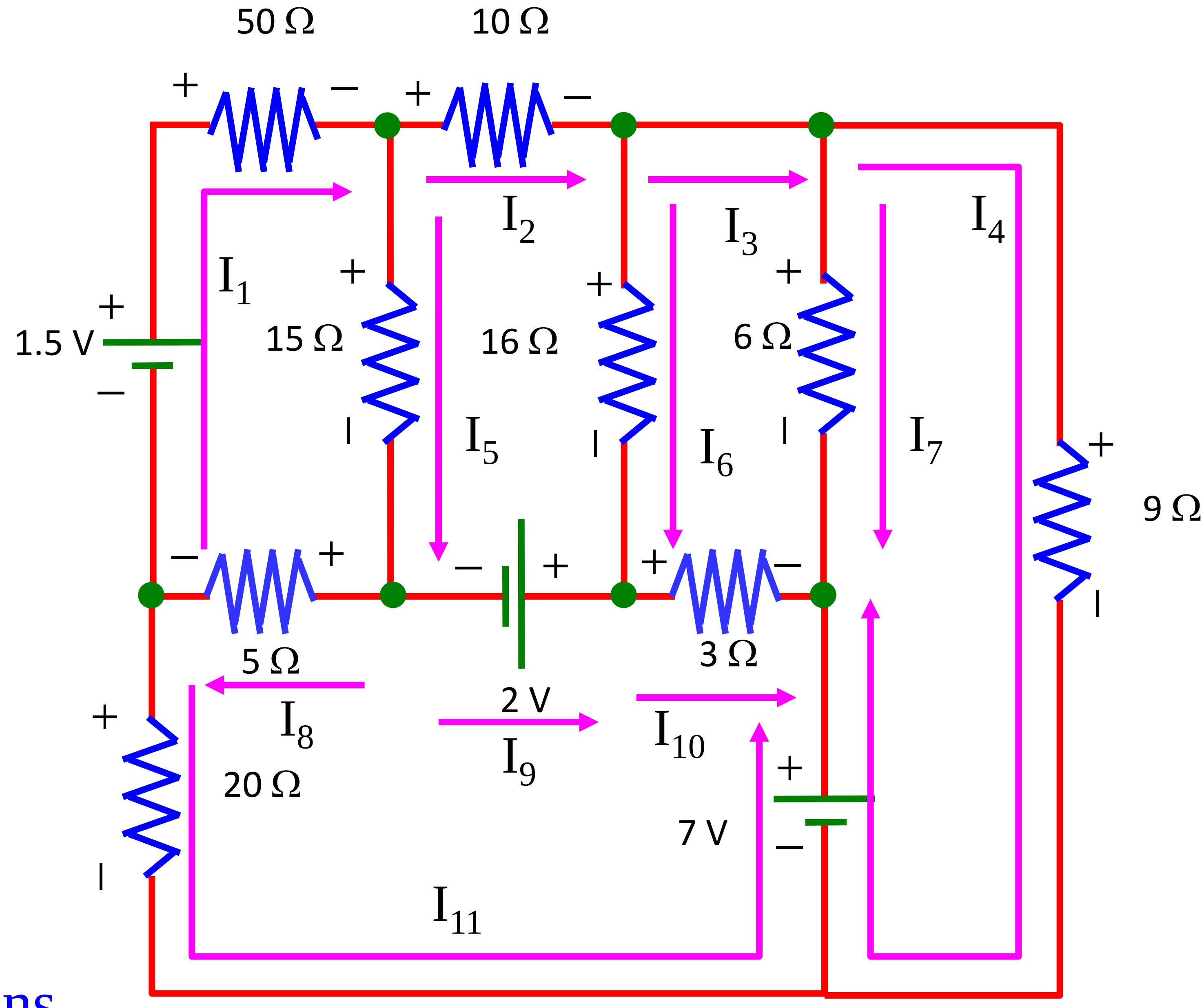
- We use conventional (+) current
- Node/Junction: 3 or more wires join
- Branch: Path from one node to next
  - Assume one current and direction per branch
  - Current flows from high (+) to low (-)
  - $\Delta V = -IR$ if go in direction of current
  - $\Delta V = +IR$ if go opposite to current
- Sum of ΔV's around loop = 0 (KR1)
- Current into node = current out (KR2)



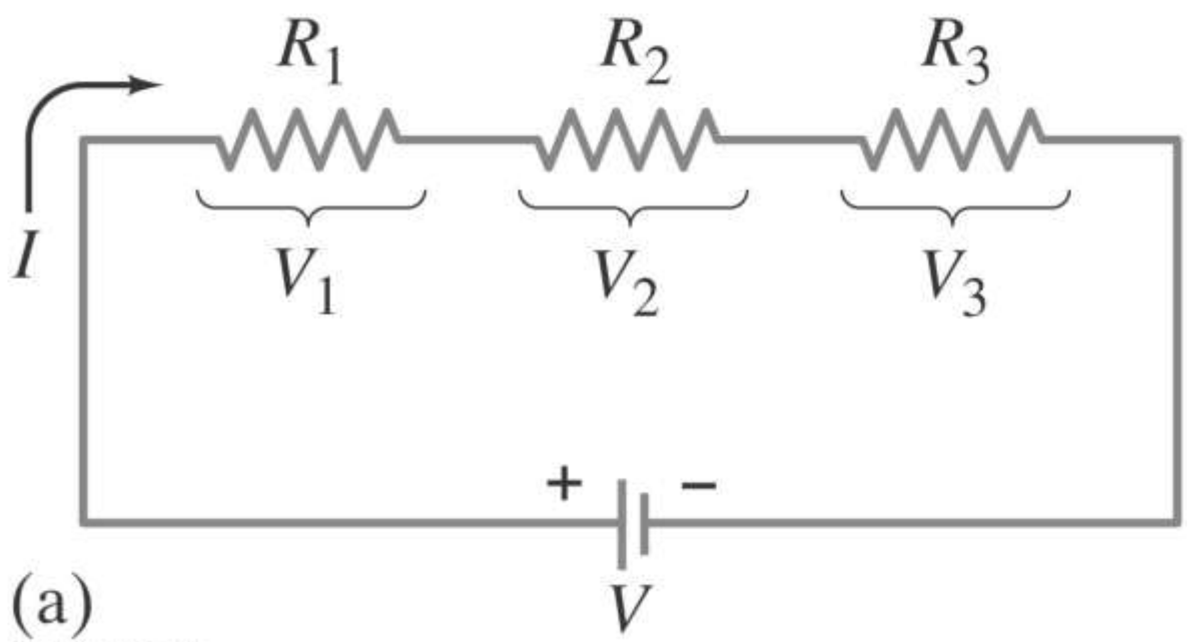
$$1.5 - 50I_1 - 15I_5 - 5I_1 = 0 \qquad I_1 = I_2 + I_5$$

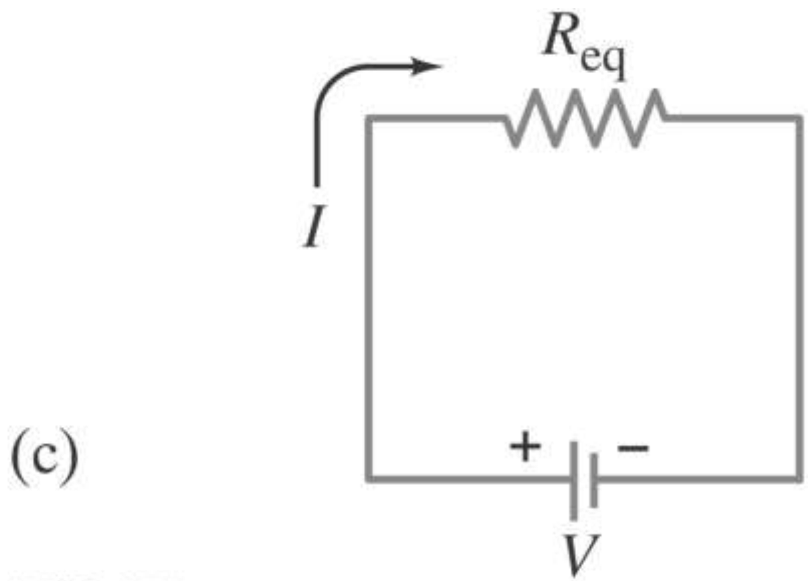
$$2 + 16I_6 + 10I_2 - 15I_5 = 0 \qquad I_2 = I_3 + I_6$$

$$-6I_3 - 3I_3 + 16I_6 = 0 \qquad I_6 + I_3 + I_4 = 0$$

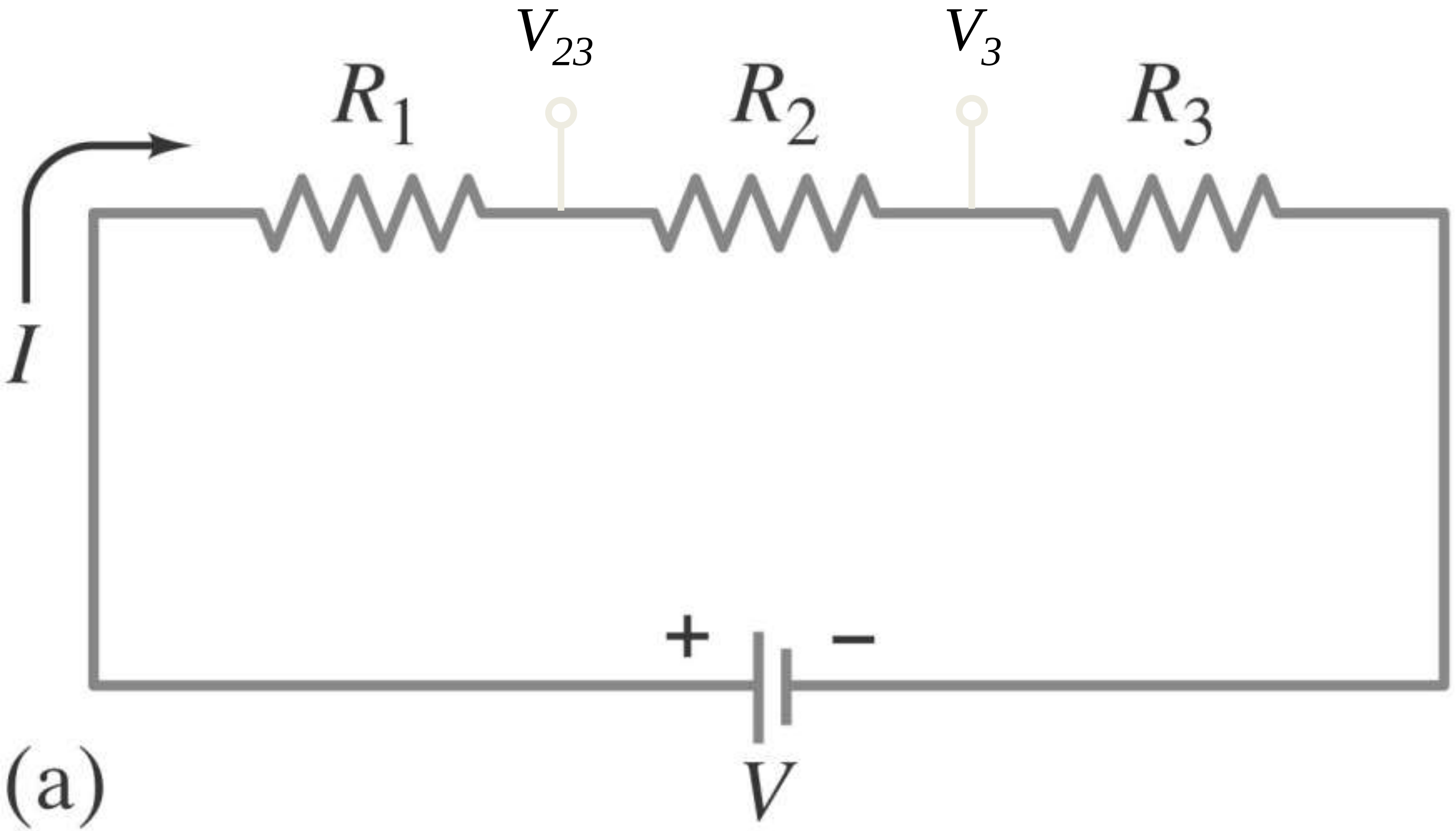

50 Ω
10 Ω
+
−
+
−
I_1
I_2
I_3
I_4
1.5 V
15 Ω
16 Ω
6 Ω
I_5
I_6
I_7
9 Ω
5 Ω
3 Ω
2 V
I_8
I_9
I_{10}
20 Ω
7 V
I_{11}

Questions



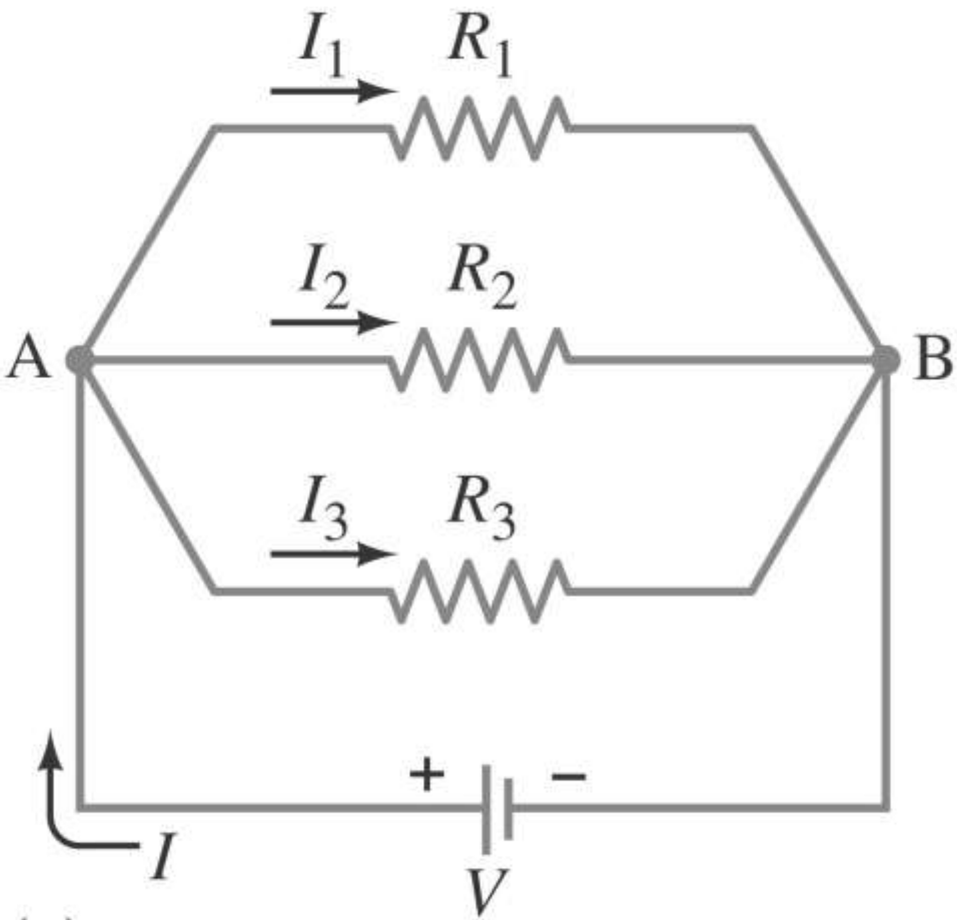


Equivalent
Series
Resistor

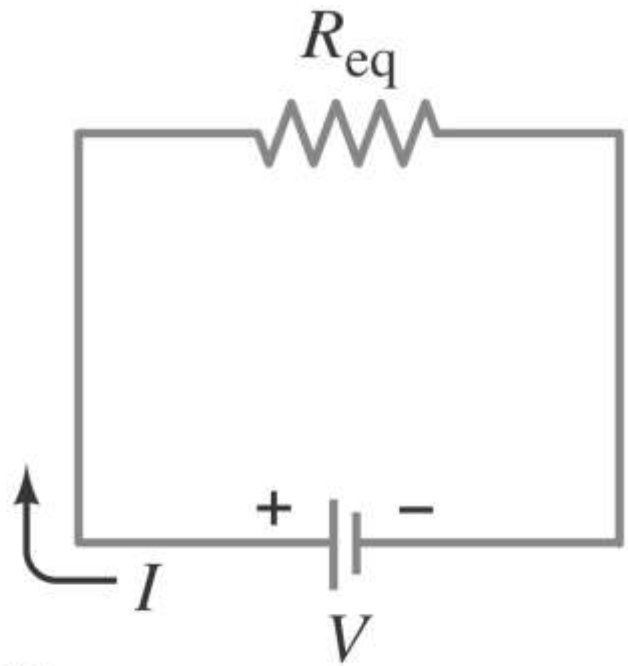


Voltage Divider

Equivalent Parallel Resistor



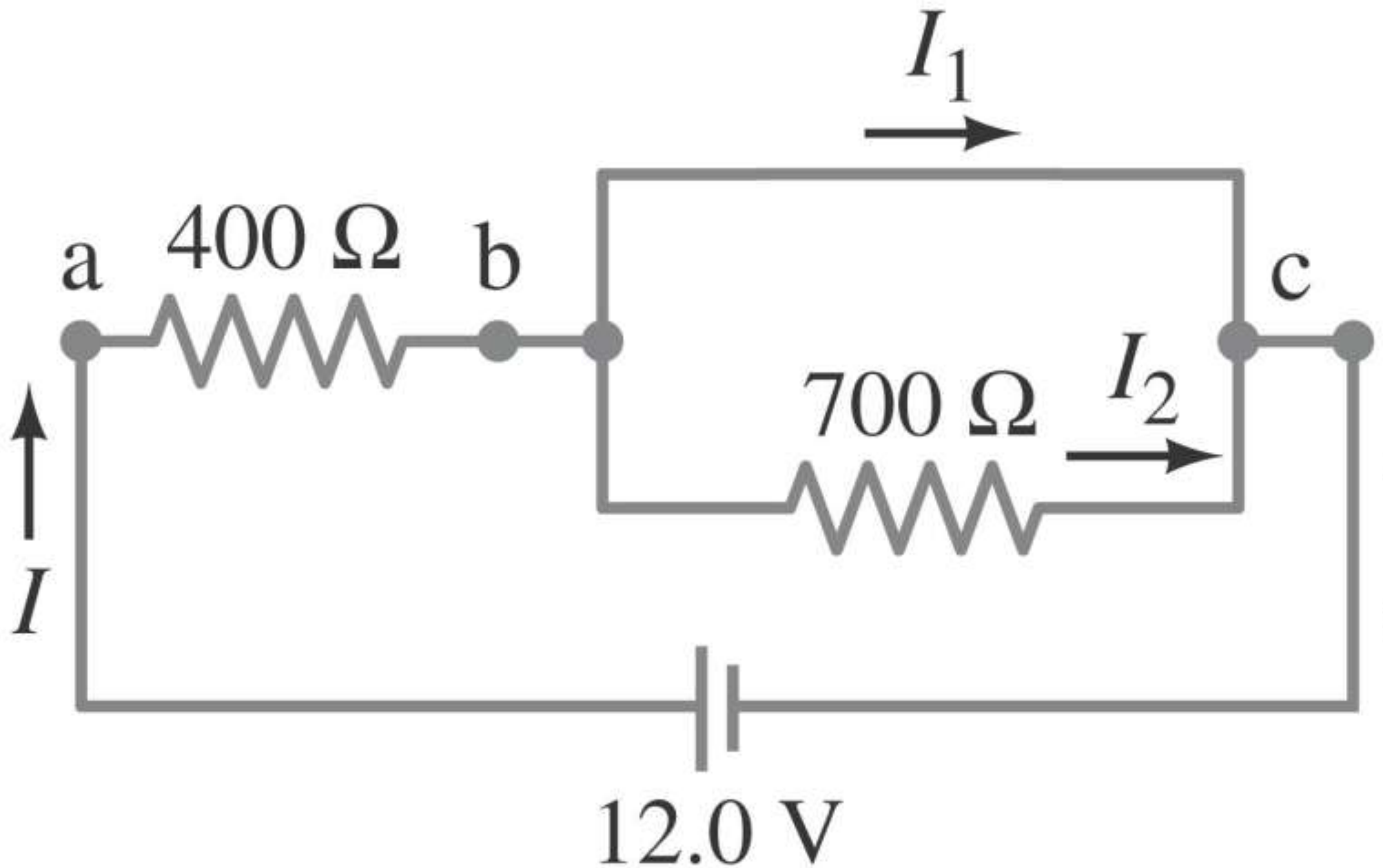
(a)



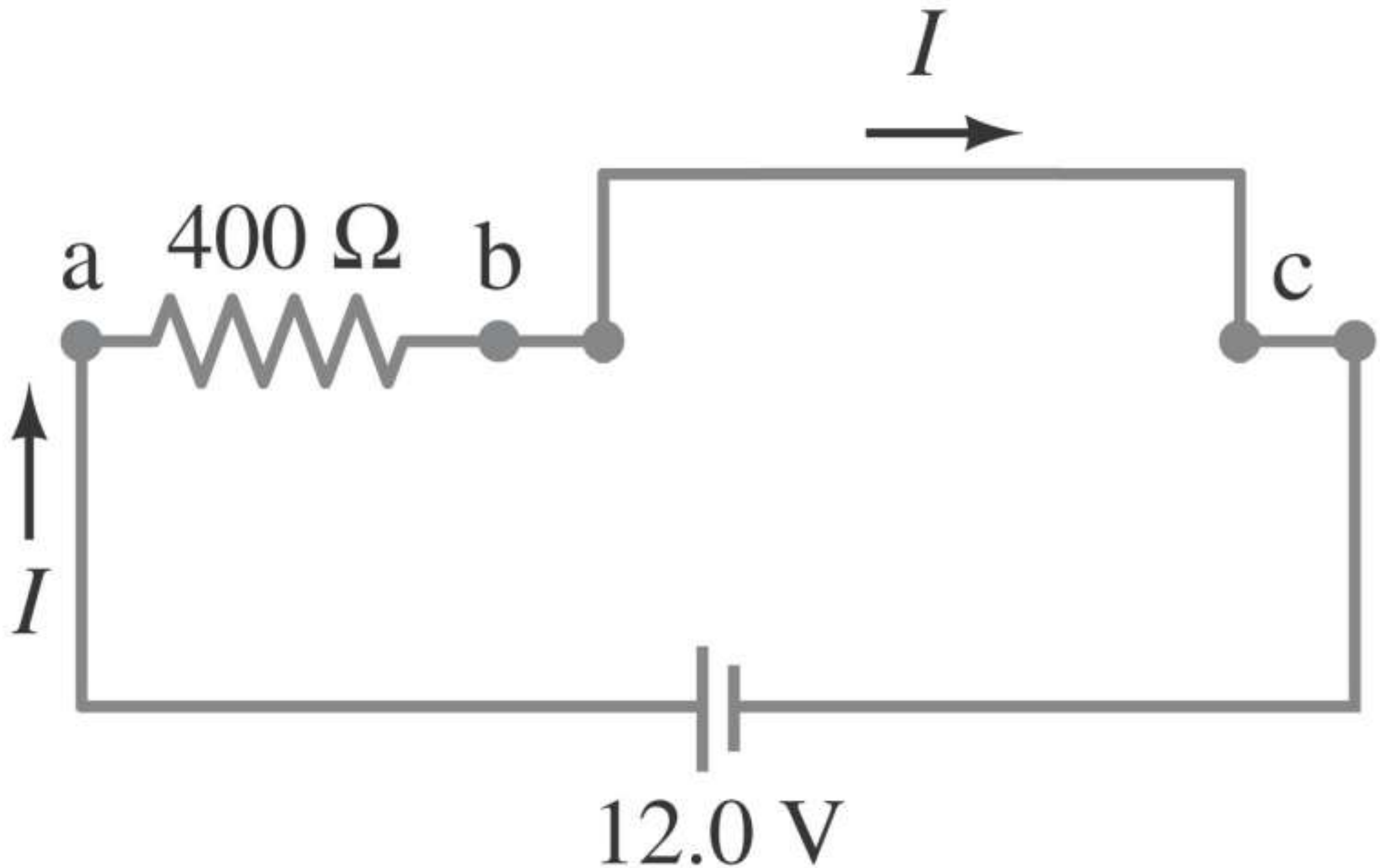
Short Circuit

A resistor(s) in a branch is shorted if you can go from one node/junction on one side to the other side by a route that has no resistors or batteries.

No current flows through the shorted resistor.

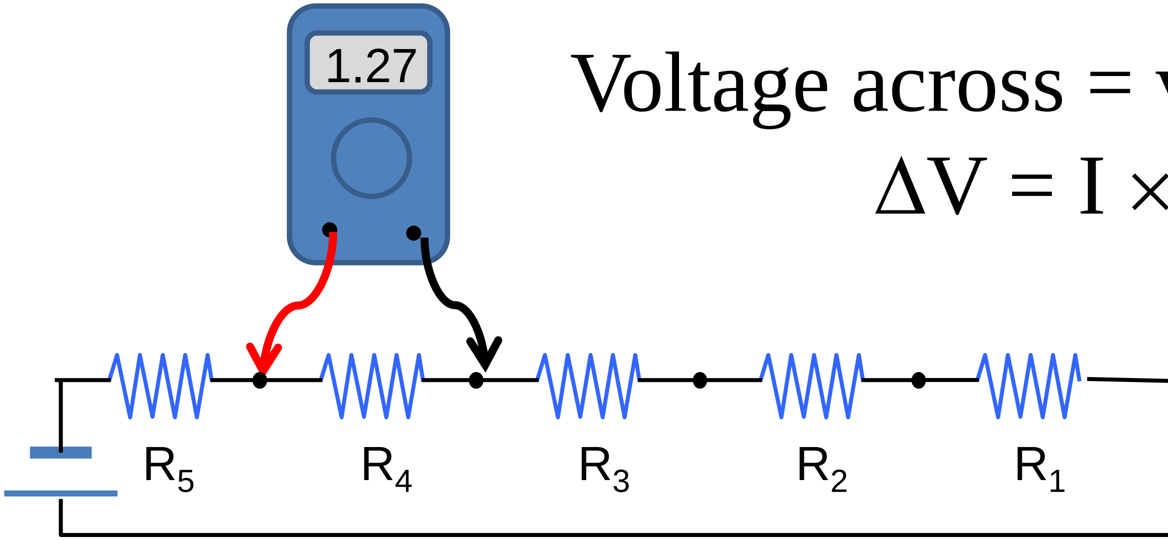


(a)



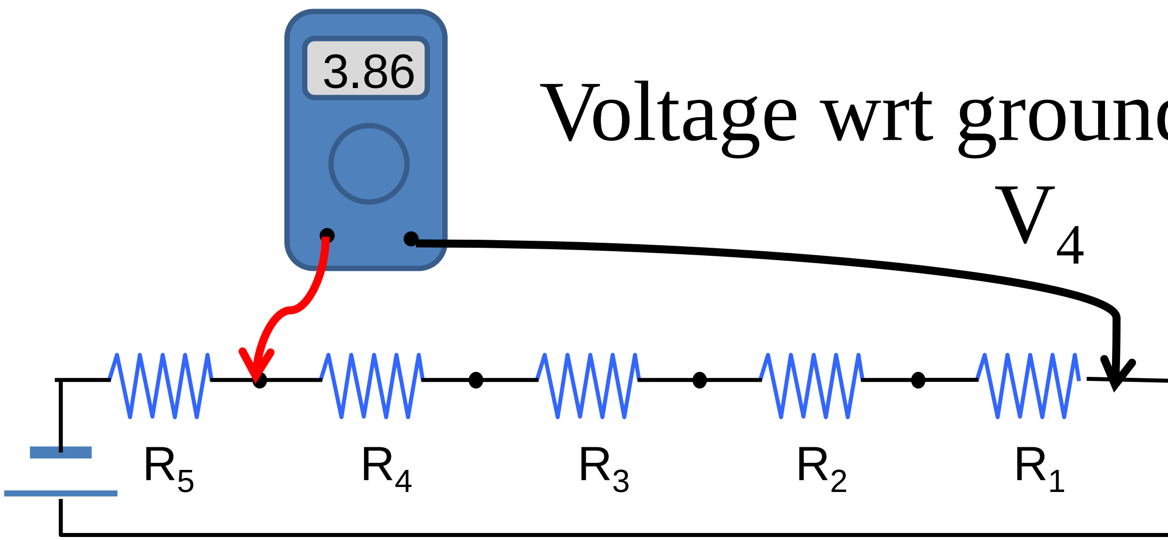
(a)

Questions



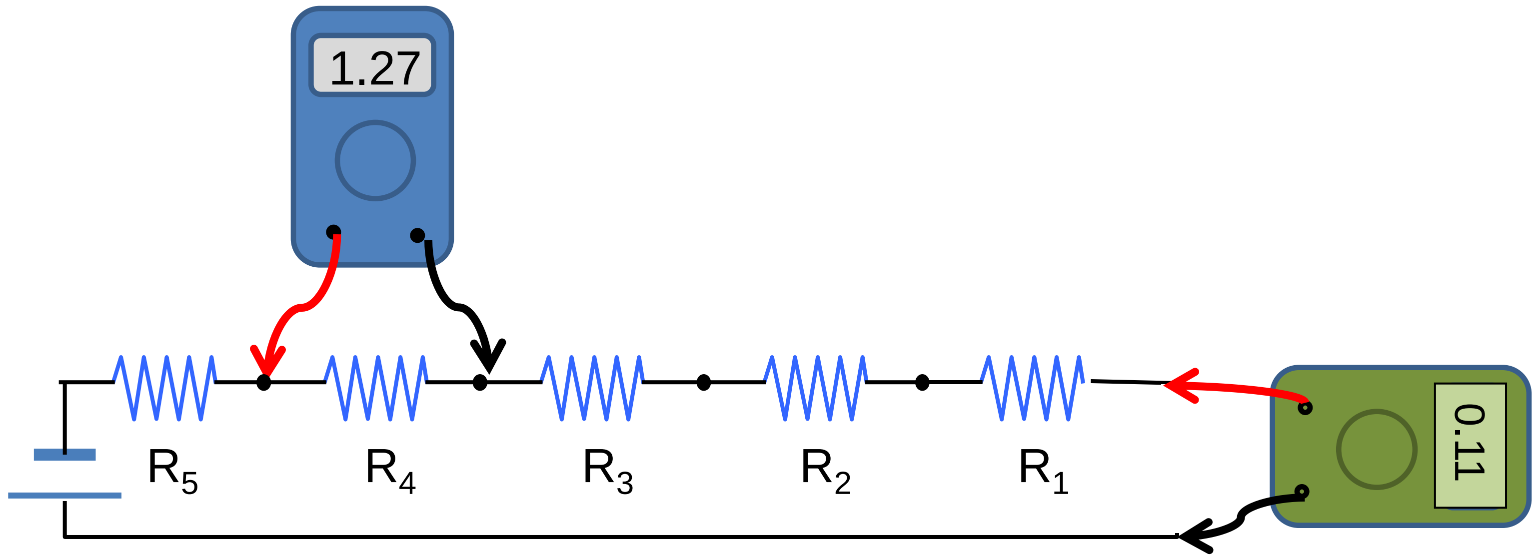
Voltage across = voltage drop

$$\Delta V = I \times R_4$$



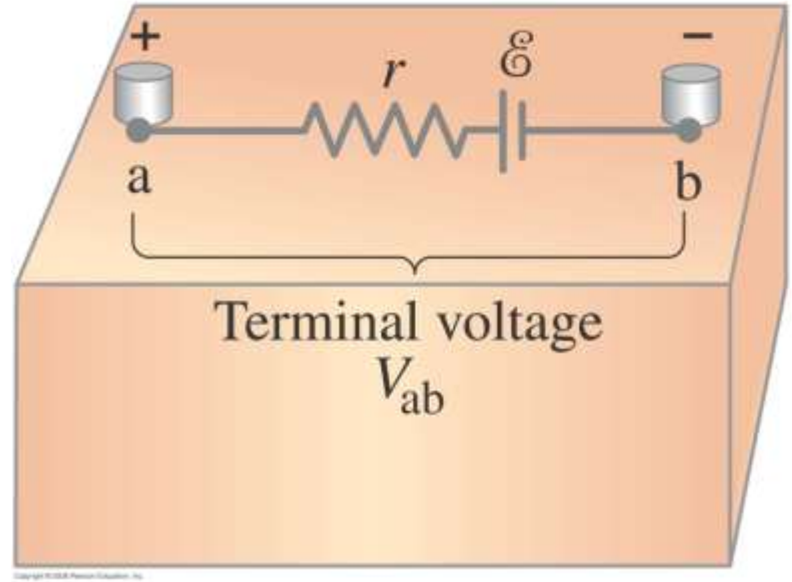
Voltage wrt ground = voltage V_4

One point, often the – side of a battery, is taken as reference or ground or 0 Volts.



- Voltmeters connect in parallel
- $R_{voltmeter}$ must be >> R_4 for accurate reading
- Ammeters connect in series
- $R_{ammeter}$ must be << $R_5 + \ldots + R_1$ for accurate reading.

“Real” Battery



- $\Delta V_{battery} = \varepsilon - I\,r$
- EMF ε is fixed
- r increases as battery dies
- Voltmeter cannot tell you if battery dead ($I \cong 0$ since $R_{voltmeter}$ is huge, voltmeter only reads ε)