ELECTRICITY AND MAGNETISM

Topic
17

Current and Resistance
(Part I)

Content

Objectives

- Understanding the direction of charge flow in conventional current and drift velocity
- Realizing *how to measure* current(s) and voltage(s) in a circuit

17.1 Electric Current

- Charges move in a direction perpendicular to a surface of area (*cross-sectional area of a wire*) *A.*
- *The current is the rate at which charge flows through this surface.*

➢ The *direction of current* is the same as the flow of positive charge.

➢ *Negative charge flowing* to the left is equivalent to an equal amount of positive charge flowing to the right.

➢ In a *conductor*, negative electrons *moving actively* to the left are *equivalent to* positive holes migrating to the right.

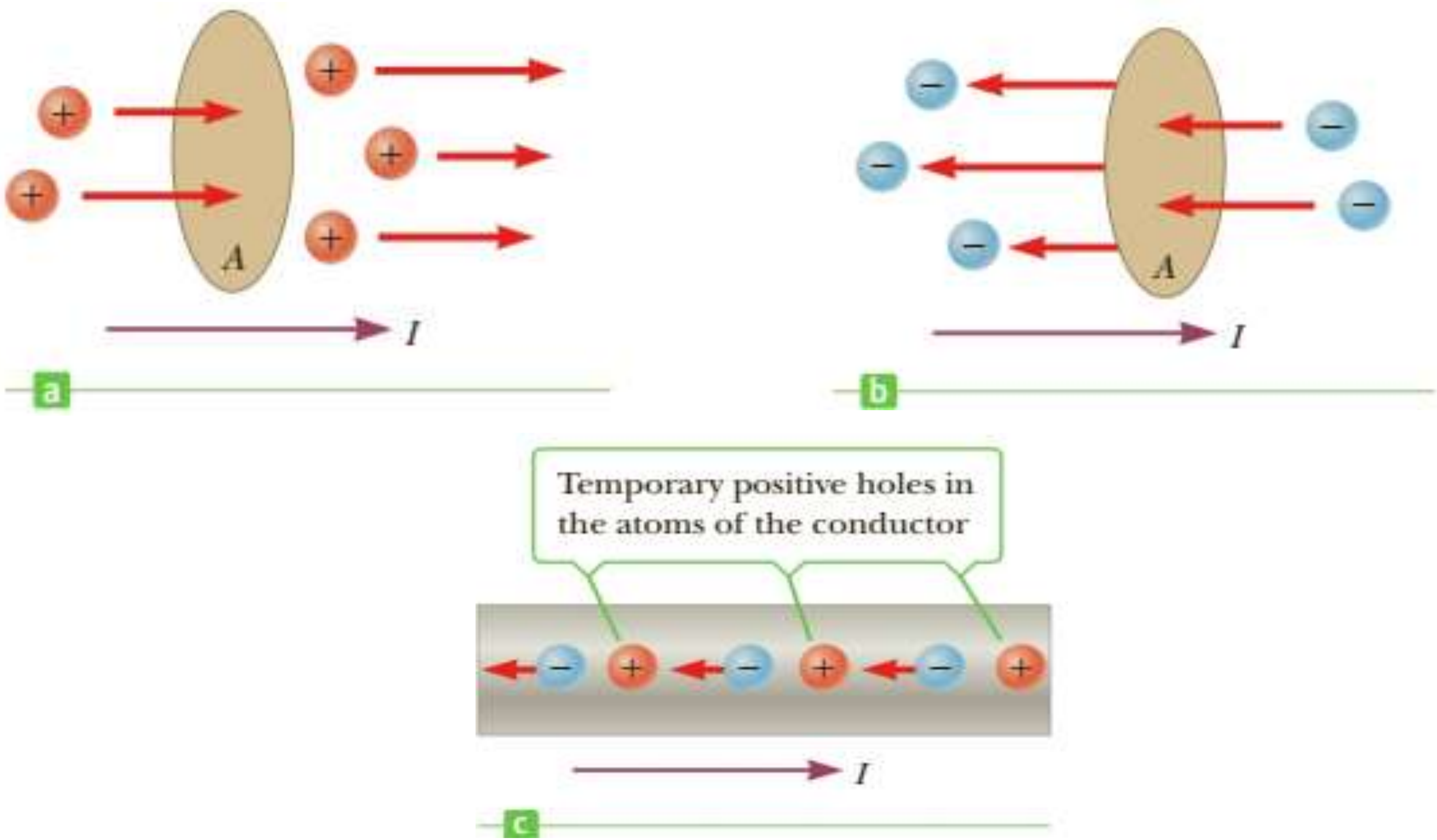


Figure1. The time rate of flow of charge through area A is the current I [Source: Ref 1]

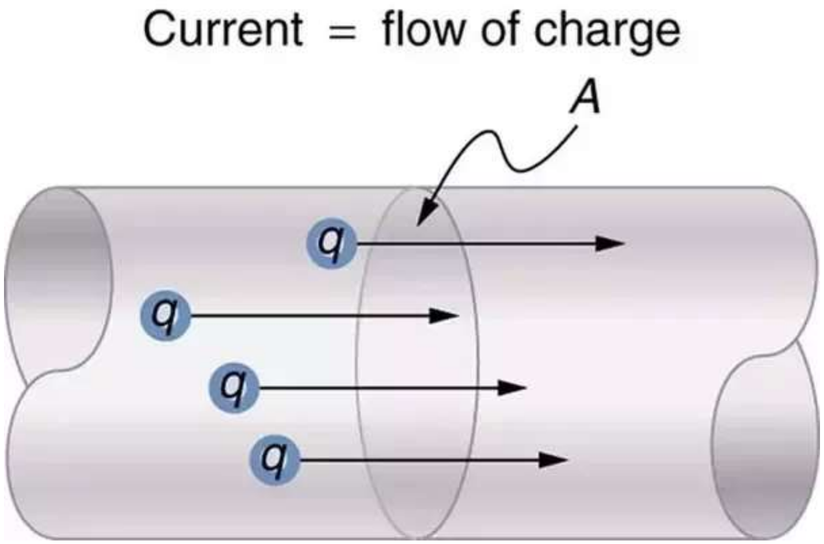


Figure 2. https://allabout-japan.com/en/article/6236/

- **Average Current:** The average current I_{av} is equal to the amount of charge ΔQ divided by the time interval Δt: $I_{av} = \frac{\Delta Q}{\Delta t}$

SI unit: coulomb/second (C/s), or the ampere (A)

The total number of electrons, $N = \frac{I_{av}\Delta t}{q}$

- **Instantaneous Current:** The instantaneous current I is the limit of the average current as the time interval goes to zero:

$$I = \lim_{\Delta t \to 0} I_{av} = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t}$$

SI unit: coulomb/second (C/s), or the ampere (A)

Example 17.1 (Pg 568): The amount of charge that passes through the filament of a certain lightbulb in 2.00 s is 1.67 C. Find **(a)** the average current in the light bulb and **(b)** the number of electrons that pass through the filament in 5.00 s. **(c)** If the current is supplied by a 12.0-V battery, what total energy is delivered to the light bulb filament during 2.00 s? What is the average power?

Solution:

(a) The average current, $I_{av} = \frac{\Delta Q}{\Delta t} = \frac{1.67}{2} = 0.835A$

(b) The total number of electrons, N $= \frac{I_{av}\,\Delta t}{q} = \frac{(0.835)(5)}{(1.6\times 10^{-19})}$

$= \mathbf{2.61 \times 10^{19}}$ **electrons**

(c) The average power, $P_{av} = \frac{\Delta U}{\Delta t} = \frac{q\Delta V}{\Delta t} = \frac{(1.67)(12)}{(2)}$

P_{av} = **10 W**

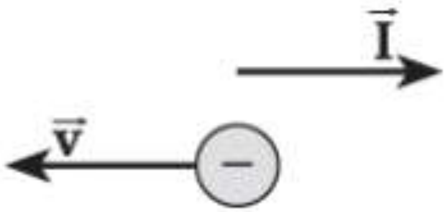
Problem 17.5 (Pg 586): If a current of 80.0 mA exists in a metal wire, (a) how many electrons flow past a given cross section of the wire in 10.0 min? (b) In what direction do the electrons travel with respect to the current?

Solution:

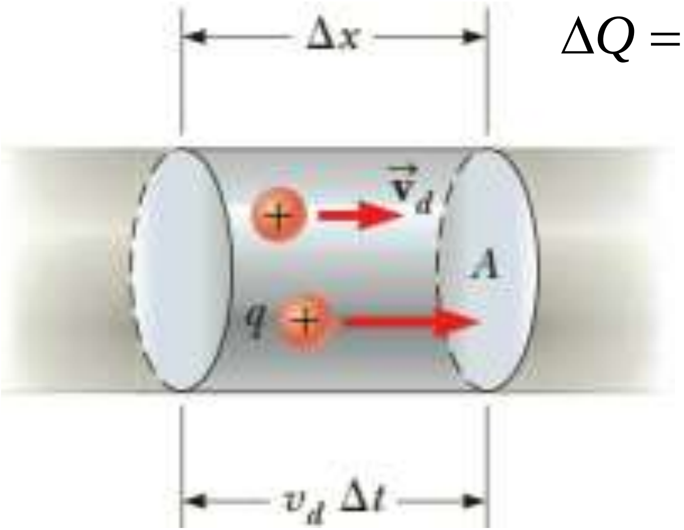
(a) The total number of electrons, $N = \dfrac{I_{av}\,\Delta t}{q} = \dfrac{(80 \times 10^{-3})\,(10 \times 60)}{(1.6 \times 10^{-19})}$

$= 3 \times 10^{20}$ electrons

(b) The negatively charged electrons move in the *direction opposite* to the conventional current flow.



17.2 A Microscopic view: Current and Drift Speed



$$\Delta Q = \text{ number of carriers} \times \text{charge per carrier} = (nA\Delta x)q$$

$$\Delta x = v_d \Delta t \quad \rightarrow \Delta Q = (nAv_d \Delta t)q$$

$$I = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = nqv_d A$$

Figure 3. A section of a uniform conductor of cross-sectional area *A*

Macroscopic currents: The motion of the microscopic charge carriers making up the current.

The mobile charge ΔQ in this element:

$$\boldsymbol{\Delta Q = \text{number of carriers} \times \text{charge per carrier} = (nA\Delta x)q}$$

The current in a conductor is related to the motion of the charge carriers by

$$\boldsymbol{I = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = nqv_d A}$$

Where, n = the number of mobile charge carriers per unit volume

q = the charge on each carrier

v_d = the drift speed of the charges

A = the cross-sectional area of the conductor.

If the carriers move with a constant average speed called the ***drift speed*** v_d, the distance they move in the time interval Δt,

$$\Delta x = v_d \Delta t$$

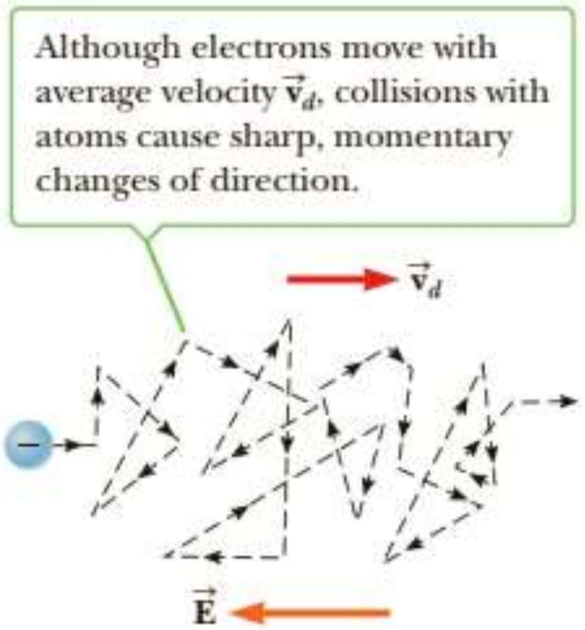


Figure 4. The zigzag motion of a charge carrier in a conductor. The drift velocity $\overrightarrow{v_d}$ is opposite the direction of the electric field.

Problem 17.6 (Pg 586): A copper wire has a circular cross section with a radius of 1.25 mm. (a) If the wire carries a current of 3.70 A, find the drift speed of electrons in the wire. (Take the density of mobile charge carriers in copper to be n =1.10 × 10^{29} electrons/m^3.) (b) For the same wire size and current, find the drift speed of electrons if the wire is made of aluminum with n = 2.11 × 10^{29} electrons/m^3.

Solution:

(a) The wire's cross-sectional area, $A = \pi r^2 = \pi(1.25)^2 = 4.91 \times 10^{-6}$ m^2

$$I = nqv_dA$$

The drift speed, $$v_d = \frac{I}{nqA}$$

$$v_d = \frac{3.7}{(1.1 \times 10^{29})(1.6 \times 10^{-19})(4.91 \times 10^{-6})}$$

$$= 4.28 \times 10^{-5}\ \text{m/s}$$

(b) Aluminum with $n = 2.11 \times 10^{29}$ electrons/m^3

$$v_d = \frac{I}{nqA}$$

$$v_d = \frac{3.7}{(2.11 \times 10^{29})(1.6 \times 10^{-19}))(4.91 \times 10^{-6})}$$

$$= 2.23 \times 10^{-5}\ \text{m/s}$$

17.3 Currents and Voltage Measurements in Circuits

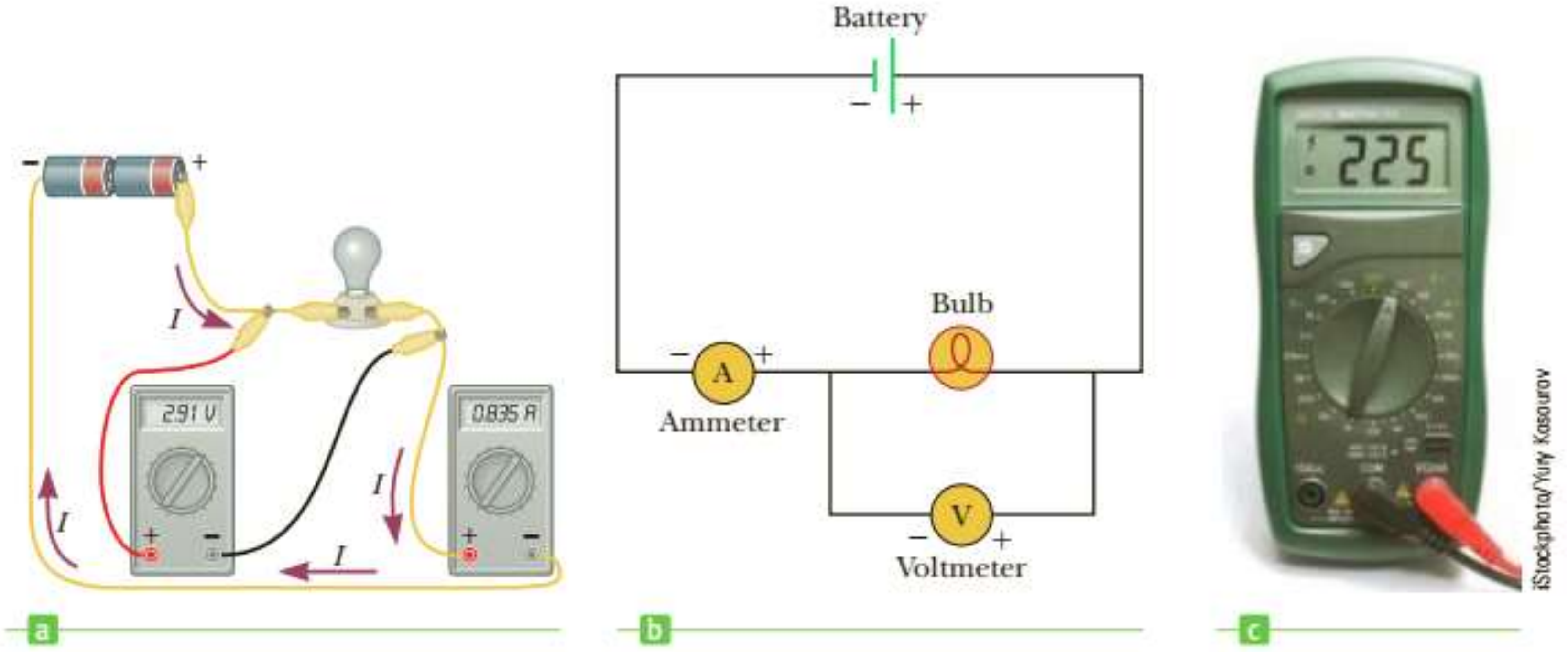
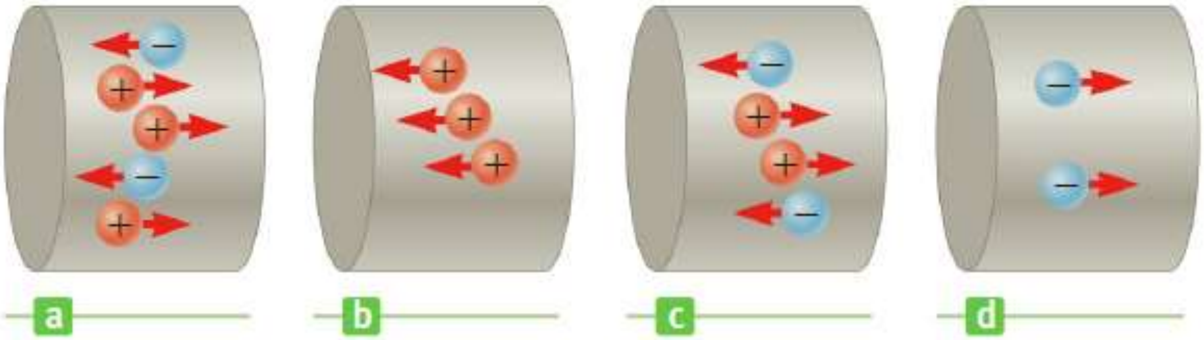


Figure 5.(a) A sketch of an actual circuit (b) A schematic diagram of the circuit shown in (a) (c) A digital multimeter

Quiz 17.1

Consider positive and negative charges all moving horizontally with the same speed through the four regions in Figure 17.2. Rank the magnitudes of the currents in these four regions from lowest to highest. (I_a is the current in Figure 17.2a, I_b the current in Figure 17.2b, etc.) (a) I_d, I_a, I_c, I_b (b) I_a, I_c, I_b, I_d (c) I_c, I_a, I_d, I_b (d) I_d , I_b, I_c, I_a (e) I_a, I_b, I_c, I_d (f) None of these



Answer. (d)

Negative charges moving in one direction are equivalent to positive charges moving in the opposite direction. Thus, I_a, I_b, I_c, I_d are equivalent to the movement of 5,3,4 and 2 charges respectively, giving $I_d < I_b < I_c < I_a$.

Quiz 17.2

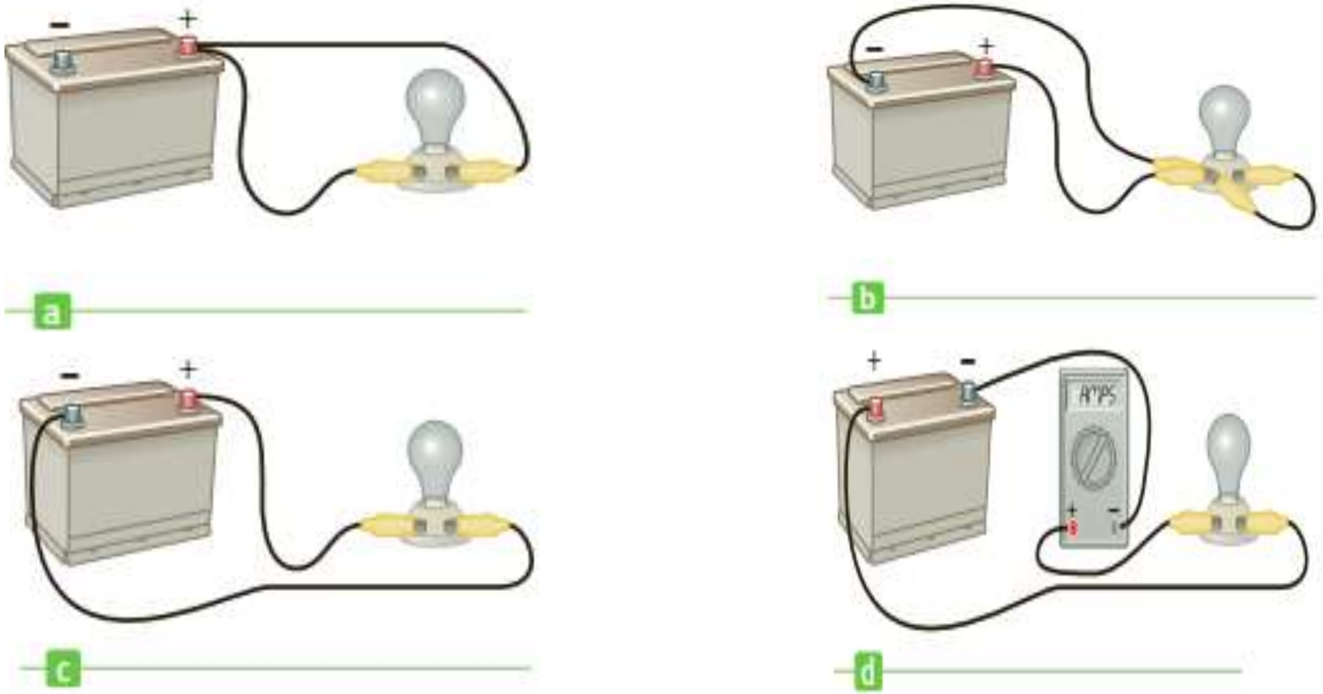
Suppose a current-carrying wire has a cross-sectional area that gradually becomes smaller along the wire so that the wire has the shape of a very long, truncated cone. How does the drift speed vary along the wire? (a) It slows down as the cross section becomes smaller. (b) It speeds up as the cross section becomes smaller. (c) It doesn't change. (d) More information is needed.

Answer. (b)

Under steady-state conditions, the current is the same in all parts of the wire. Thus, the drift velocity, $v_d = \frac{I}{nqA}$, is inversely proportional to the cross-sectional area A.

Quiz 17.3

Look at the four “circuits” shown in Figure and select those that will light the bulb.



a. a and c

b. b only

c. c and d

d. All will light the bulb.

Answer: (c). c and d. Neither circuit (a) nor circuit (b) applies a difference in potential across the bulb. Circuit (a) has both lead wires connected to the same battery terminal. Circuit (b) has a low resistance path (a “short”) between the two battery terminals as well as between the bulb terminals.

How to measure current and voltage?

Summary

❑ 17.1 Electric Current

The average electric current I_{av} in a conductor,

$$I_{av} = \frac{\Delta Q}{\Delta t}$$

The instantaneous current I,

$$I = \lim_{\Delta t \to 0} I_{av} = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t}$$

❑ 17.2 A Microscopic View: Current and Drift Speed

The current in a conductor is related to the motion of the charge carriers, $I = nqv_d A$

Learning Outcomes

- Difference between average current and instantaneous current.
- Microscopic viewing of current and drift velocity
- Understanding how to measure current and voltage by using ammeter and voltmeter ?

Reference

1. “College Physics” by Raymond A. Serway and Chris Vuille, 11^{th} Edition (Global Edition) ISBN-13: 978-1337620338.

THANK YOU!