PHYS 104
1ST semester 1439-1440

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Lecture 19

Chapter 28

Direct Current Circuits

28.3 Kirchhoff's Rules

- It is not possible to reduce a circuit to a single loop. The procedure for analyzing more complex circuits is greatly simplified if we use two principles called **Kirchhoff 's rules:**

1. **Junction rule.** The sum of the currents entering any junction in a circuit must equal the sum of the currents leaving that junction:

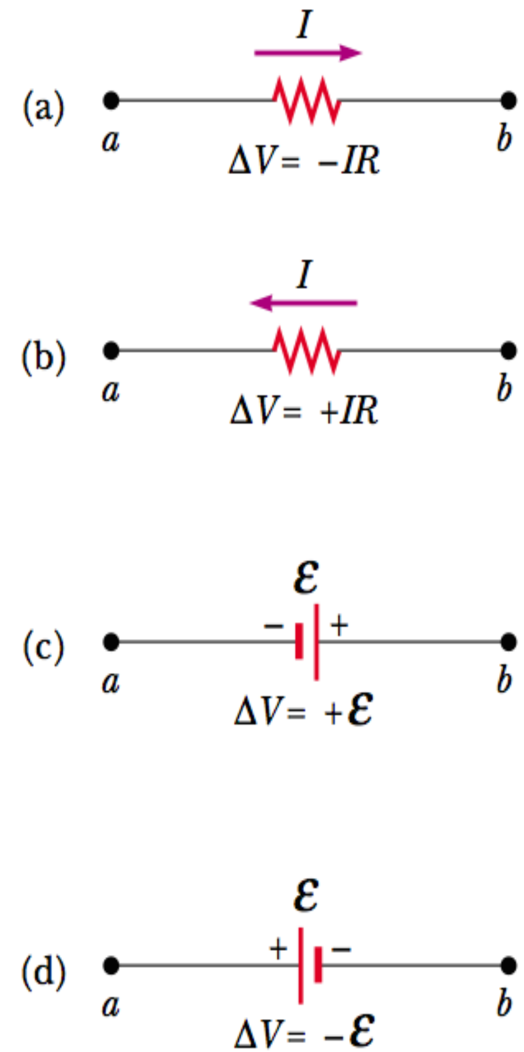
$$\sum I_{\text{in}} = \sum I_{\text{out}} \qquad (28.9)$$

2. **Loop rule.** The sum of the potential differences across all elements around any closed circuit loop must be zero:

$$\sum_{\substack{\text{closed}\\ \text{loop}}} \Delta V = 0 \qquad (28.10)$$

28.3 Kirchhoff's Rules

- **Loop rule**
- Rules for determining the potential differences across a resistor and a battery:



(a) Because charges move from the high-potential end of a resistor toward the low-potential end, if a resistor is traversed in the direction of the current, the potential difference ΔV across the resistor is $-IR$

(b) If a resistor is traversed in the direction *opposite* the current, the potential difference ΔV across the resistor is $+IR$.

(c) If a source of emf (assumed r=0) is traversed in the direction of the emf (from – to +), the potential difference ΔV is $+\varepsilon$. The emf of the battery increases the electric potential as we move through it in this direction.

(d) If a source of emf (assumed r=0) is traversed in the direction opposite the emf (from + to -), the potential difference ΔV is $-\varepsilon$. The emf of the battery reduces the electric potential as we move through it.

Example 28.9 Applying Kirchhoff's Rules

Interactive

Find the currents I_1, I_2, and I_3 in the circuit shown in Figure 28.17.

Solution Conceptualize by noting that we cannot simplify the circuit by the rules of adding resistances in series and in parallel. (If the 10.0-V battery were taken away, we could reduce the remaining circuit with series and parallel combinations.) Thus, we categorize this problem as one in which we must use Kirchhoff's rules. To analyze the circuit, we arbitrarily choose the directions of the currents as labeled in Figure 28.17. Applying Kirchhoff's junction rule to junction *c* gives

$$(1) \qquad I_1 + I_2 = I_3$$

We now have one equation with three unknowns—I_1, I_2, and I_3. There are three loops in the circuit—*abcda, befcb,* and *aefda*. We therefore need only two loop equations to determine the unknown currents. (The third loop equation would give no new information.) Applying Kirchhoff's loop rule to loops *abcda* and *befcb* and traversing these loops clockwise, we obtain the expressions

$$(2) \qquad abcda \quad 10.0\text{ V} - (6.0\ \Omega)I_1 - (2.0\ \Omega)I_3 = 0$$

$$(3) \quad befcb \quad -14.0\text{ V} + (6.0\ \Omega)I_1 - 10.0\text{ V} - (4.0\ \Omega)\ I_2 = 0$$

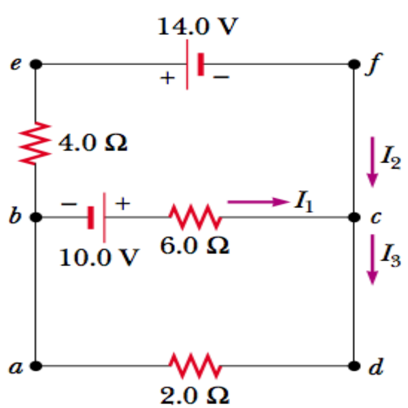


Figure 28.17 (Example 28.9) A circuit containing different branches.

Note that in loop *befcb* we obtain a positive value when traversing the 6.0-Ω resistor because our direction of travel is opposite the assumed direction of I_1. Expressions (1), (2), and (3) represent three independent equations with three unknowns. Substituting Equation (1) into Equation (2) gives

$$10.0\text{ V} - (6.0\ \Omega)I_1 - (2.0\ \Omega)\ (I_1 + I_2) = 0$$

$$(4) \qquad 10.0\text{ V} = (8.0\ \Omega)I_1 + (2.0\ \Omega)I_2$$

Dividing each term in Equation (3) by 2 and rearranging gives

$$(5) \qquad -12.0\text{ V} = -(3.0\ \Omega)I_1 + (2.0\ \Omega)I_2$$

Subtracting Equation (5) from Equation (4) eliminates I_2, giving

$$22.0\text{ V} = (11.0\ \Omega)I_1$$

$$I_1 = \boxed{2.0\text{ A}}$$

Using this value of I_1 in Equation (5) gives a value for I_2:

$$\begin{aligned}(2.0\ \Omega)I_2 &= (3.0\ \Omega)I_1 - 12.0\text{ V} \\ &= (3.0\ \Omega)(2.0\text{ A}) - 12.0\text{ V} = -6.0\text{ V}\end{aligned}$$

$$I_2 = \boxed{-3.0\text{ A}}$$

Finally,

$$I_3 = I_1 + I_2 = \boxed{-1.0\text{ A}}$$

To finalize the problem, note that I_2 and I_3 are both negative. This indicates only that the currents are opposite the direction we chose for them. However, the numerical values are correct. What would have happened had we left the current directions as labeled in Figure 28.17 but traversed the loops in the opposite direction?

Example 28.10 A Multiloop Circuit

(A) Under steady-state conditions, find the unknown currents I_1, I_2, and I_3 in the multiloop circuit shown in Figure 28.18.

Solution First note that because the capacitor represents an open circuit, there is no current between *g* and *b* along path *ghab* under steady-state conditions. Therefore, when the charges associated with I_1 reach point *g*, they all go toward point *b* through the 8.00-V battery; hence, $I_{gb} = I_1$. Labeling the currents as shown in Figure 28.18 and applying Equation 28.9 to junction *c*, we obtain

$$(1) \qquad I_1 + I_2 = I_3$$

Equation 28.10 applied to loops *defcd* and *cfgbc*, traversed clockwise, gives

$$(2) \qquad defcd \quad 4.00\ \text{V} - (3.00\ \Omega)I_2 - (5.00\ \Omega)I_3 = 0$$

$$(3) \qquad cfgbc \quad (3.00\ \Omega)I_2 - (5.00\ \Omega)I_1 + 8.00\ \text{V} = 0$$

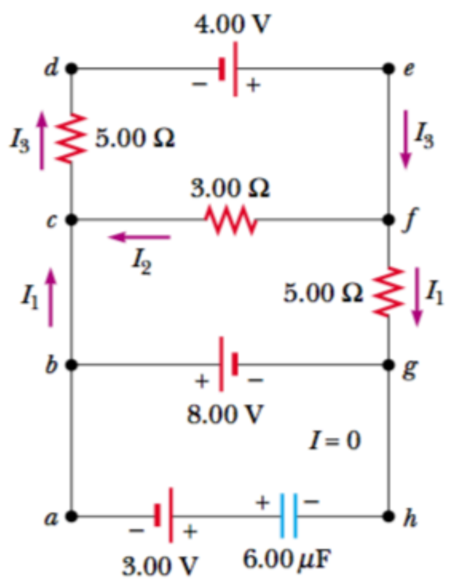


Figure 28.18 (Example 28.10) A multiloop circuit. Kirchhoff's loop rule can be applied to *any* closed loop, including the one containing the capacitor.

From Equation (1) we see that $I_1 = I_3 - I_2$, which, when substituted into Equation (3), gives

$$(4) \qquad (8.00\ \Omega)I_2 - (5.00\ \Omega)I_3 + 8.00\ \text{V} = 0$$

Subtracting Equation (4) from Equation (2), we eliminate I_3 and find that

$$I_2 = -\frac{4.00\ \text{V}}{11.0\ \Omega} = \boxed{-0.364\ \text{A}}$$

Because our value for I_2 is negative, we conclude that the direction of I_2 is from *c* to *f* in the 3.00-Ω resistor. Despite this interpretation of the direction, however, we must continue to use this negative value for I_2 in subsequent calculations because our equations were established with our original choice of direction.

Using $I_2 = -0.364$ A in Equations (3) and (1) gives

$$I_1 = \boxed{1.38\ \text{A}} \qquad I_3 = \boxed{1.02\ \text{A}}$$

Chapter 29

Magnetic Field

Introduction

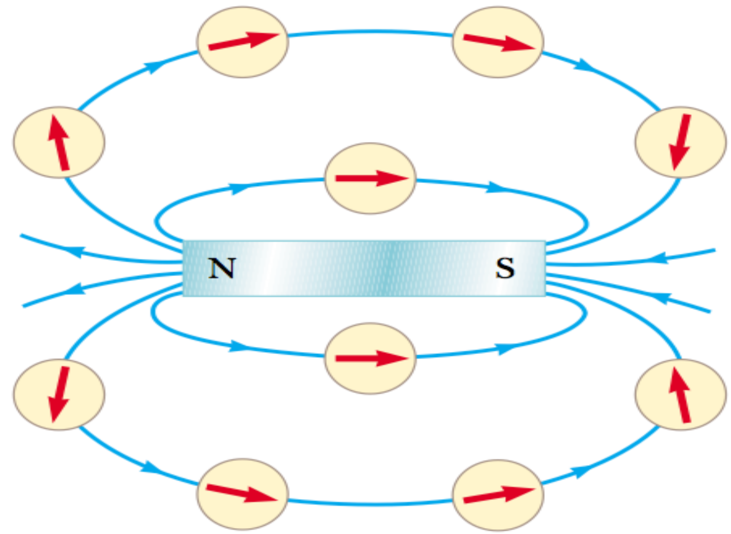
- Every magnet, regardless of its shape, has two poles, called ***north*** (N) and ***south*** (S) poles, that exert forces on other magnetic poles similar to the way that electric charges exert forces on one another.
- That is, like poles (N–N or S–S) repel each other, and opposite poles (N–S) attract each other.
- A single magnetic pole has never been isolated. That is, magnetic poles are always found in pairs.

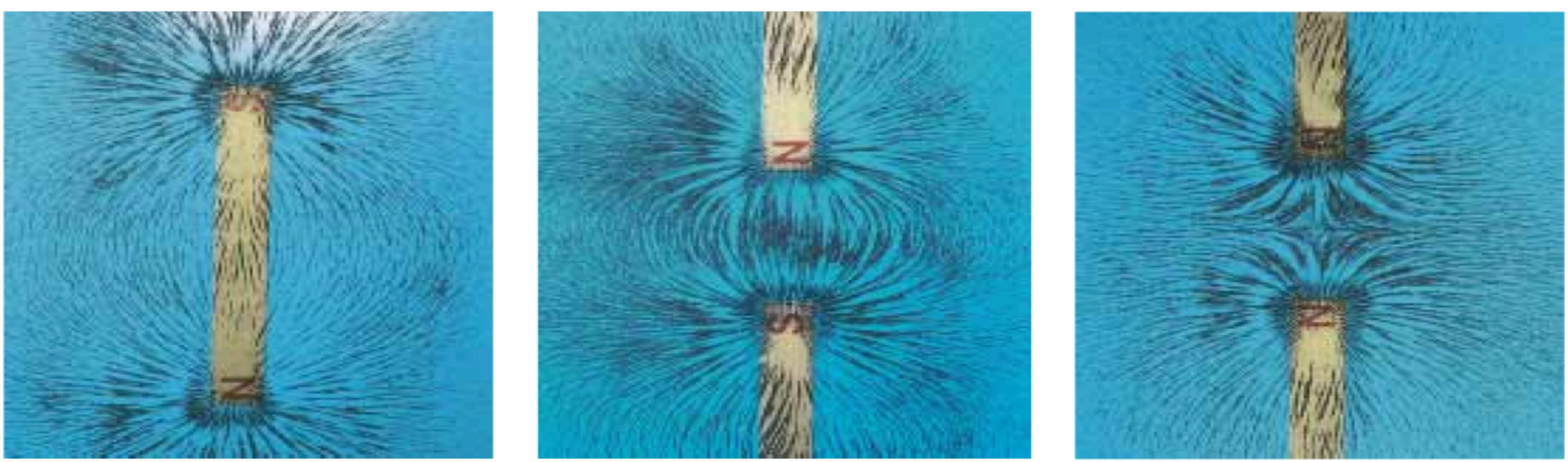
29.1 Magnetic Fields and Forces

- The region of space surrounding any *moving* electric charge also contains a magnetic field.
- A magnetic field also surrounds a magnetic substance making up a permanent magnet.
- The symbol **B** has been used to represent a magnetic field.
- The direction of the magnetic field **B** at any location is the direction in which a compass needle points at that location.
- we can represent the magnetic field by drawing the *magnetic field lines*.

29.1 Magnetic Fields and Forces

- The magnetic field lines of a bar magnet can be traced with the aid of a compass.
- The magnetic field lines outside the magnet point away from north poles and toward south poles.





(a) (b) (c)

29.1 Magnetic Fields and Forces

- We can define a magnetic field **B** at some point in space in terms of the magnetic force $\mathbf{F}_B$ that the field exerts on a charged particle moving with a velocity **v**, which we call the test object.

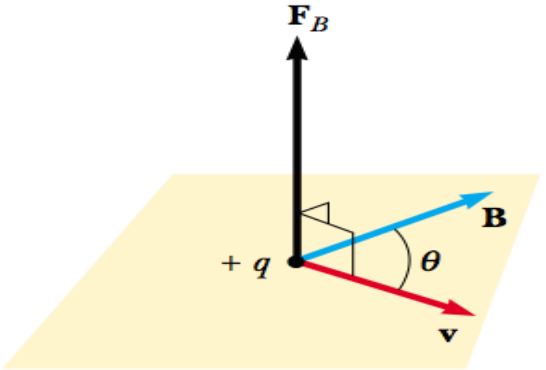
- **Properties of the magnetic force on a charge moving in a magnetic field B:**
  - The magnitude F_B of the magnetic force exerted on the particle is proportional to the charge q and to the speed v of the particle.
  - The magnitude and direction of $\mathbf{F}_B$ depend on the velocity of the particle and on the magnitude and direction of the magnetic field **B**.
  - When a charged particle moves parallel to the magnetic field vector, the magnetic force acting on the particle is zero.

29.1 Magnetic Fields and Forces

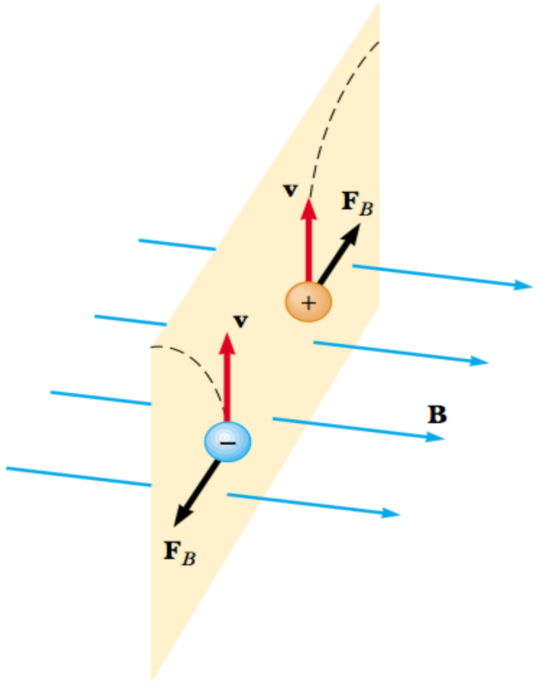
- When the particle's velocity vector makes any angle θ ≠ 0 with the magnetic field, the magnetic force acts in a direction perpendicular to both **v** and **B**; that is, F_B is perpendicular to the plane formed by v and B (Fig. a).

- The magnetic force exerted on a positive charge is in the direction opposite the direction of the magnetic force exerted on a negative charge moving in the same direction (Fig. b).

- The magnitude of the magnetic force exerted on the moving particle is proportional to sin θ, where θ is the angle the particle's velocity vector makes with the direction of **B**.



(a)



(b)