Ve215 Introduction to Circuits

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Chapter 1

Basic Concepts

1.1 Introduction

- The basic electric circuit theory course is the most important course for an electrical engineering student.
- Circuit theory is also valuable to students specializing in other branches.

- In electrical engineering, we are often interested in transferring energy from one point to another. To do this requires an interconnection of electrical devices. Such interconnection is referred to as an *electric circuit*, and each component of the circuit is known as an *element*.
- Our major concern in this course is the analysis of the circuits.

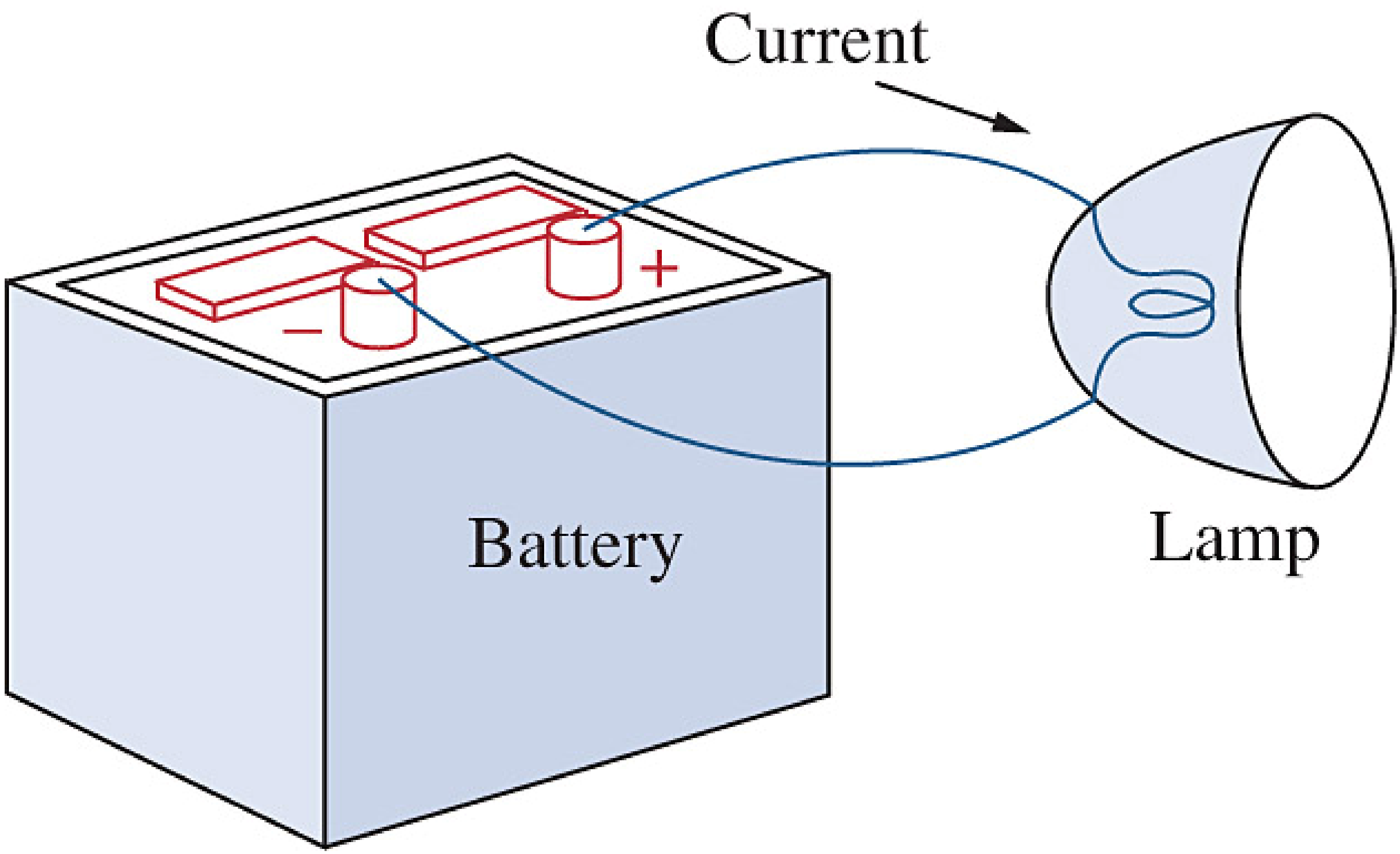


Figure 1.1 A simple electric circuit.

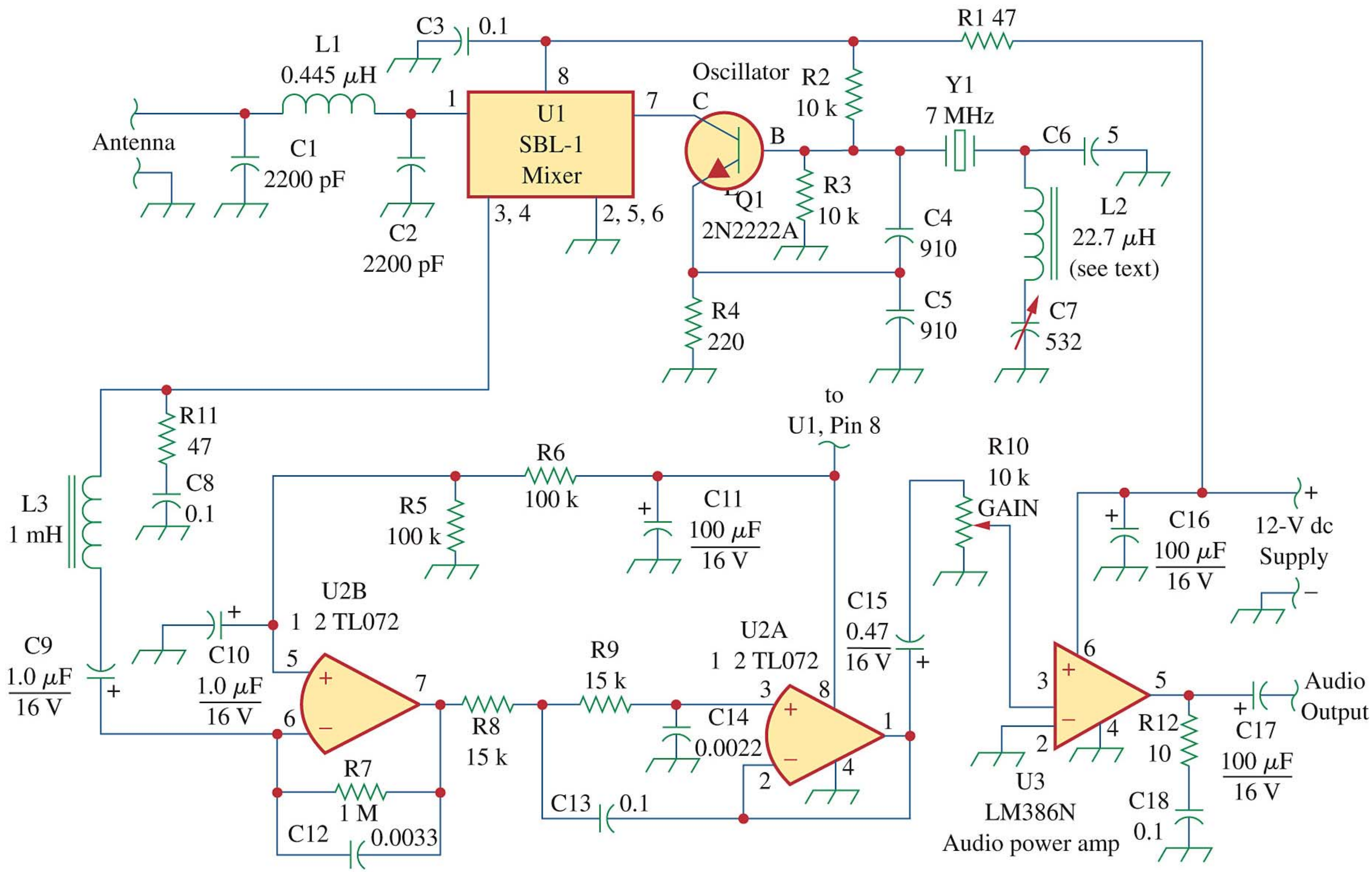


Figure 1.2 Electric circuit of a radio receiver.

1.3 Charge and Current

- *Sears and Zemansky's University Physics*: We can't say what electric charge is. Electric charge, like mass, is one of the fundamental attributes of the particles of which matter is made.
- The textbook: Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C). Coulomb = ampere x second.

- Each atom consists of electrons, protons and neutrons.
  - 1 electron = 1.602E-19 Coulombs
  - 1 Coulomb = 1/1.602E-19 = 6.24E18 electrons

- The *law of conservation of charge* states that charge can neither be created nor destroyed, only transferred. Thus the algebraic sum of the electric charges in a system does not change.

- Electric current is a flow of electric charge through a conductive medium.

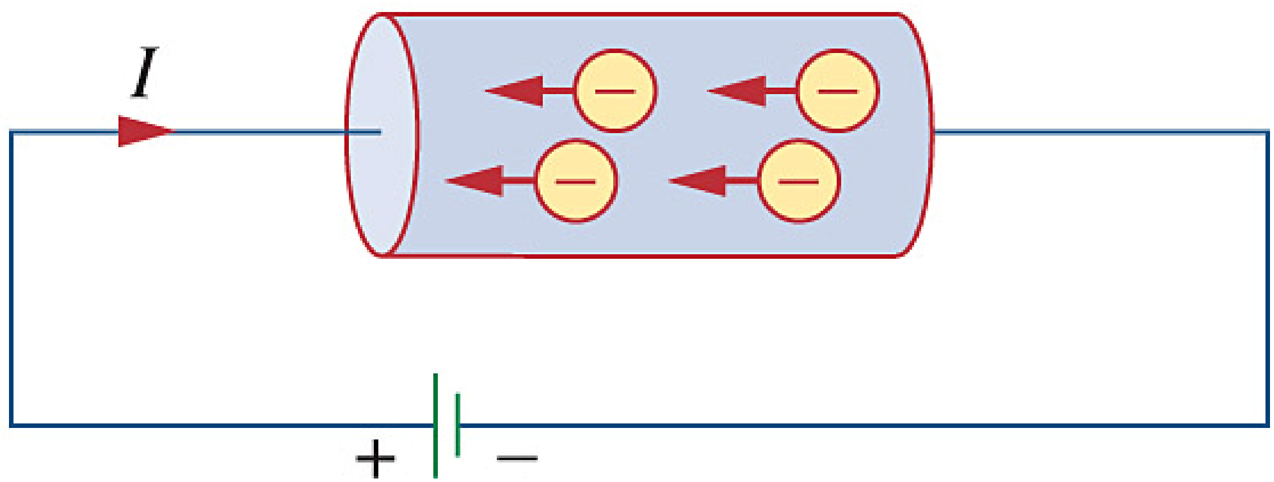


Figure 1.3 Electric current due to flow of electric charge in a conductor.

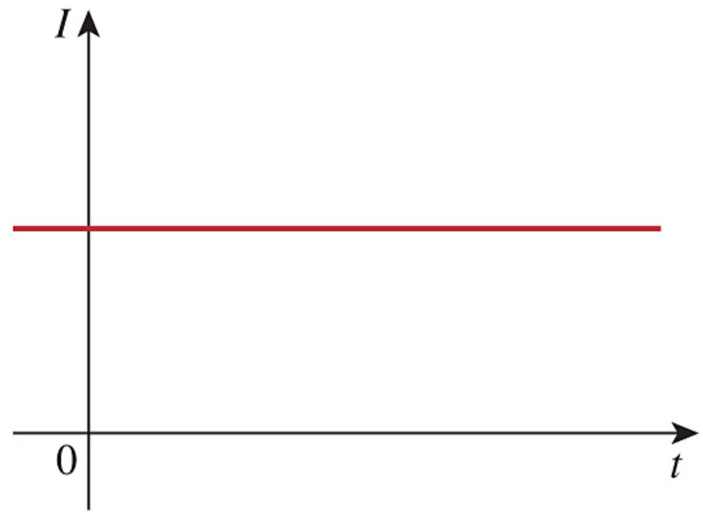
Mathematically, the relationship between current i, charge q, and time t is

$$i = \frac{dq}{dt}$$

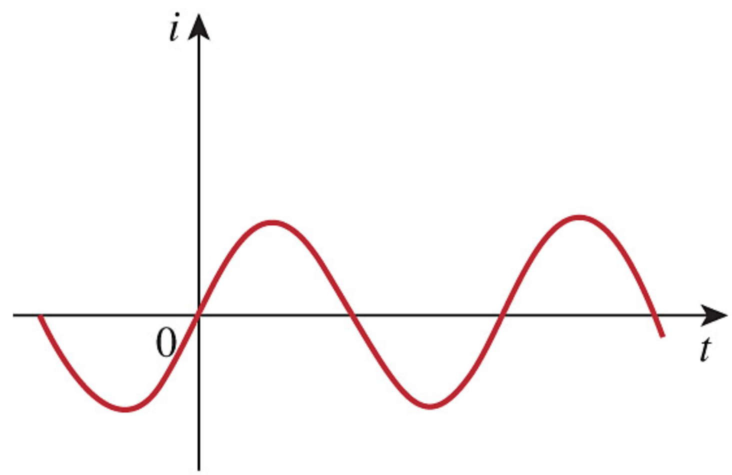
The charge transferred between time t_0 and t is

$$Q = \int_{t_0}^{t} i\,dt$$

- *Direct current* (DC) is the unidirectional flow of electric charge.
  - The textbook: A direct current (dc) is a current that remains constant with time.
- In *alternating current* (AC), the movement of electric charge periodically reverses direction.
  - The textbook: An alternating current (ac) is a current that varies sinusoidally with time.



(a)



(b)

Figure 1.4 two common types of current (a) direct current (dc), (b) alternating current (ac).

- The direction of current is conventionally taken as the direction of positive charge movement.

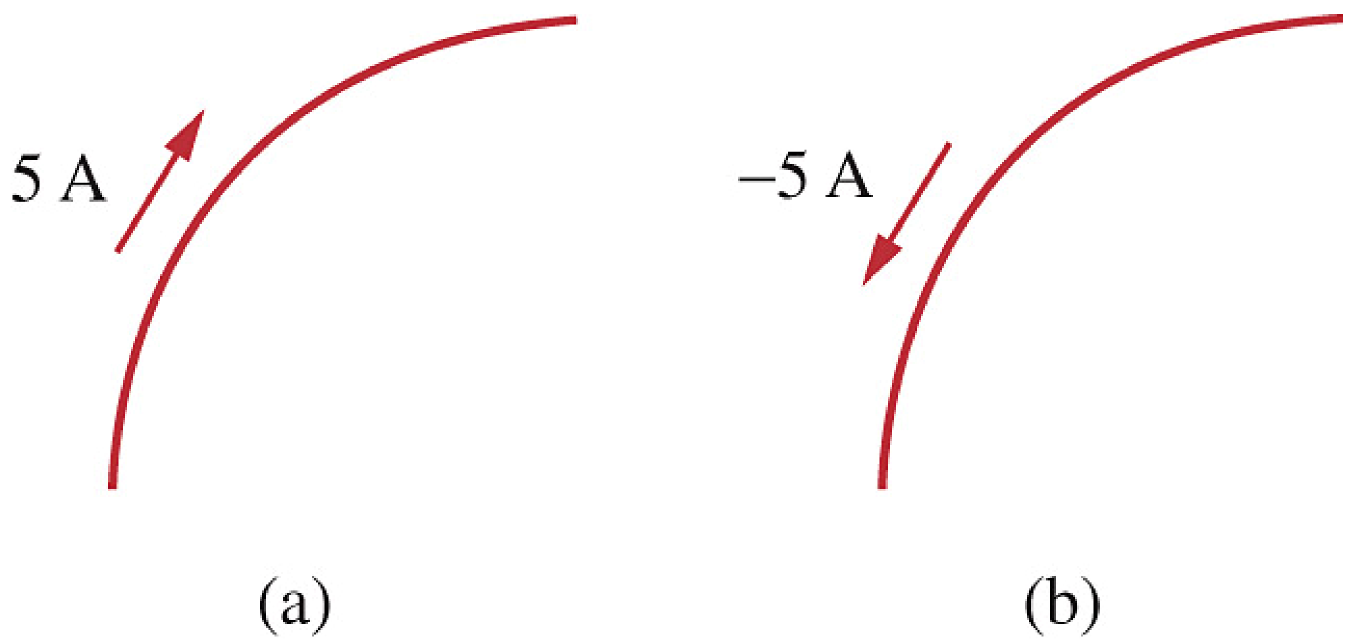


Figure 1.5 Conventional current flow: (a) positive current flow, (b) negative current flow.

Practice Problem 1.3 The current flowing through an element is

$$i = \begin{cases} 2 \text{ A}, & 0 < t < 1 \text{ s} \\ 2t^2 \text{ A}, & t > 1 \text{ s} \end{cases}$$

Calculate the charge entering the element from $t = 0$ to $t = 2$ s.

Solution :

$$Q = \int_0^2 i dt = \int_0^1 2dt + \int_1^2 2t^2 dt = 2t\Big|_0^1 + 2\frac{t^3}{3}\Bigg|_1^2$$

$$= 2 + \frac{14}{3} \approx 6.667 \text{ (C)}$$

1.4 Voltage

- Voltage (or potential difference) is the energy (or work) required to move a unit charge through an element, measured in volts (V).

Mathematically, the voltage between two points a and b in an electric circuit is

$$v_{ab} = \frac{dw}{dq}$$

- In Figure 1.6, the plus (+) and minus (-) signs are used to define reference direction or polarity of the voltage.

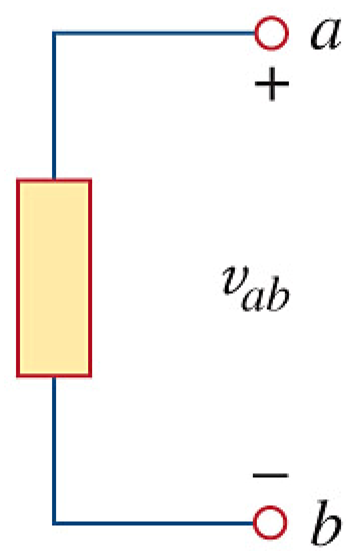


Figure 1.6 Polarity of voltage v_{ab}.

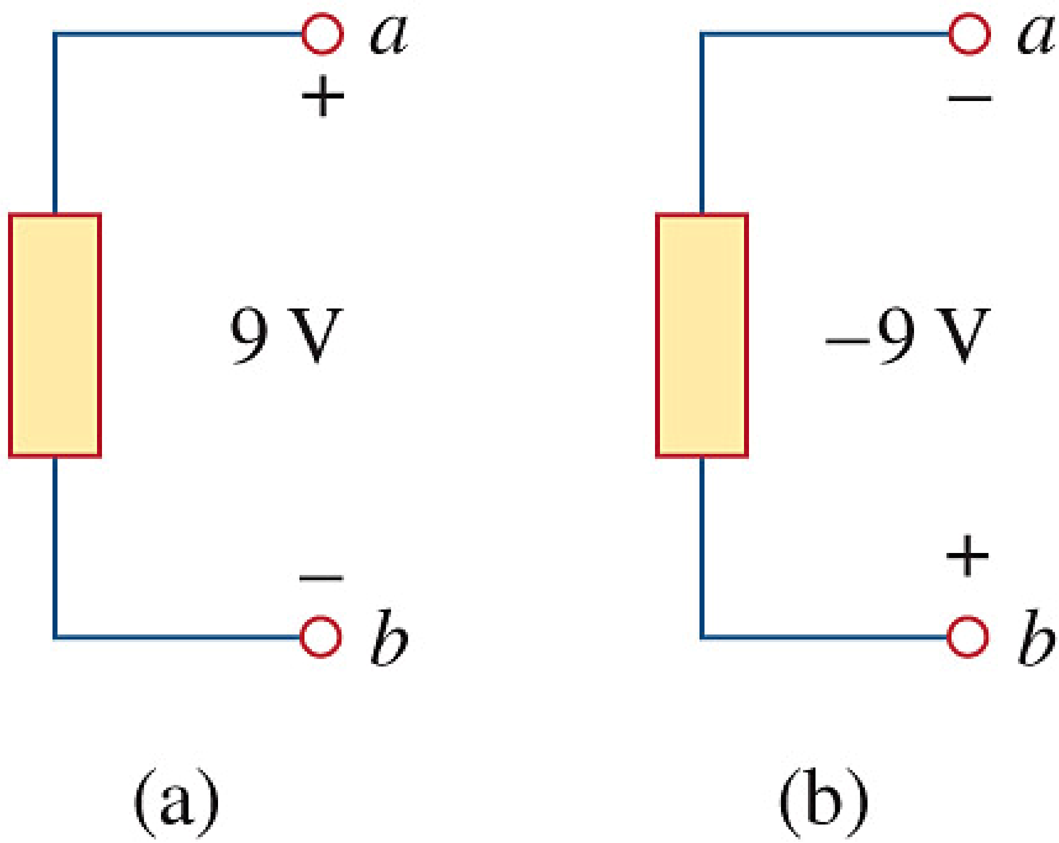


Figure 1.7 Two equivalent representations of the same voltage v_{ab} : (a) point a is 9 V above point b, (b) point b is -9 V above point a.

- Current and voltage are the two basic variables in electric circuits. The common term *signal* is used for an electric quantity such as a current or a voltage (or even electromagnetic wave) when it is used for conveying information.

1.5 Power and Energy

- Power is the time rate of expending or absorbing energy, measured in watts (W).

The instantaneous power absorbed by an element is the product of the voltage across the element and the current through it.

$$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi$$

- Passive sign convention:
  - When the current enters through the positive terminal of an element and $p = +vi$.
  - If the current enters through the negative terminal, $p = -vi$.

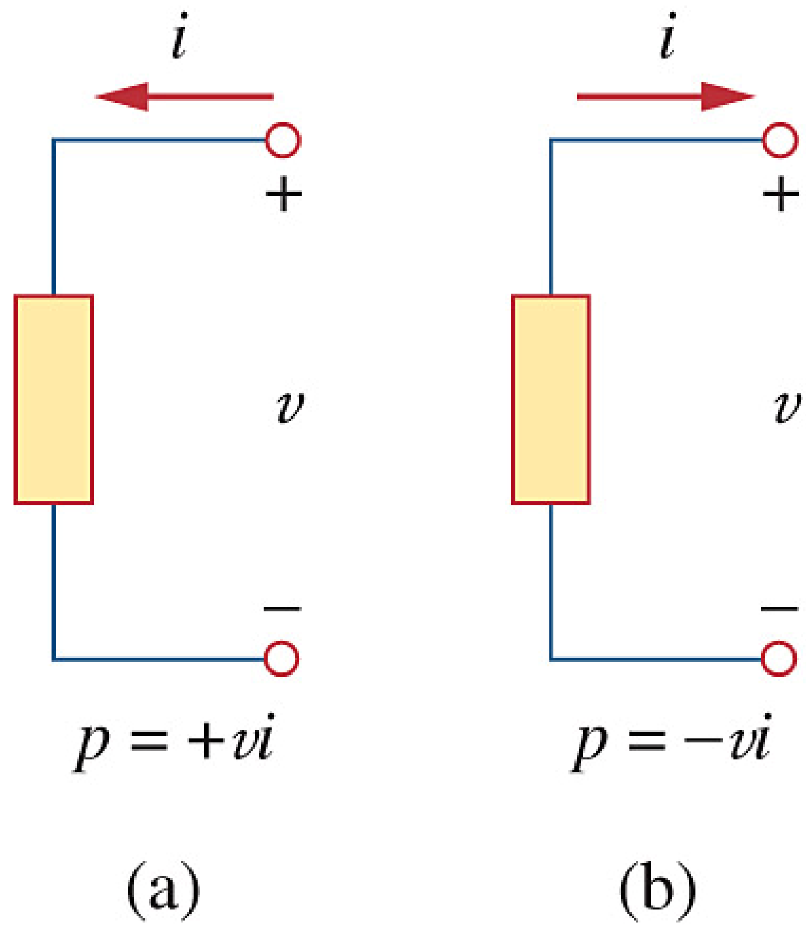


Figure 1.8 Reference polarities for power using the passive sign convention: (a) absorbing power, (b) supplying power.

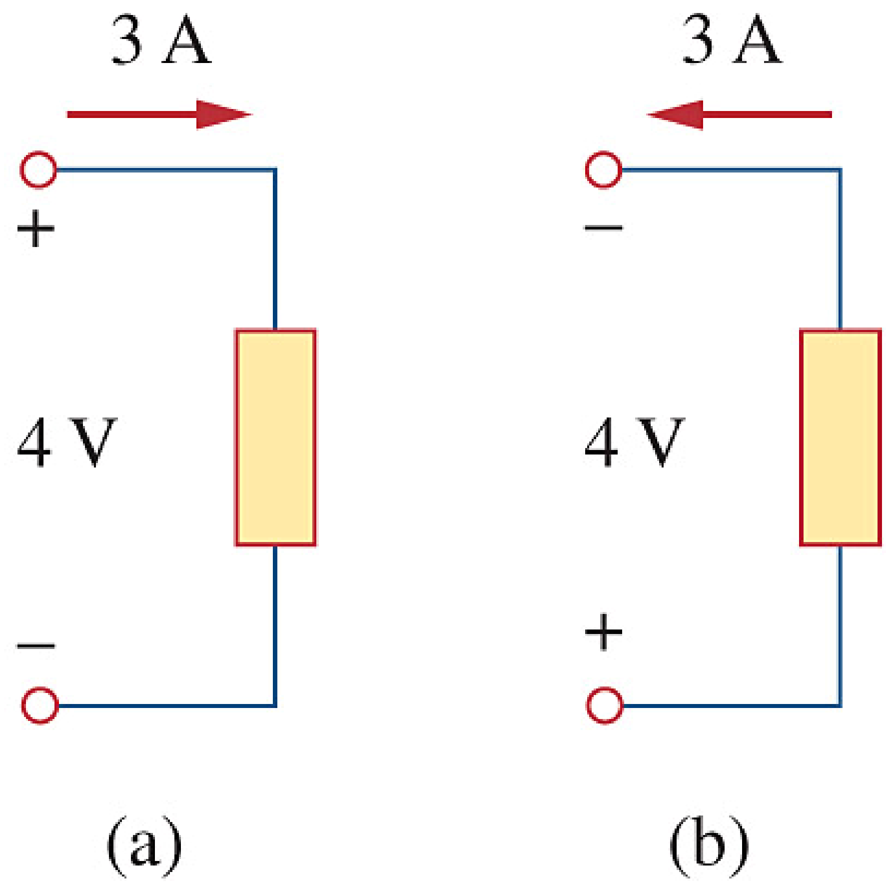


Figure 1.9 Two cases of an element with an absorbing power of 12 W.

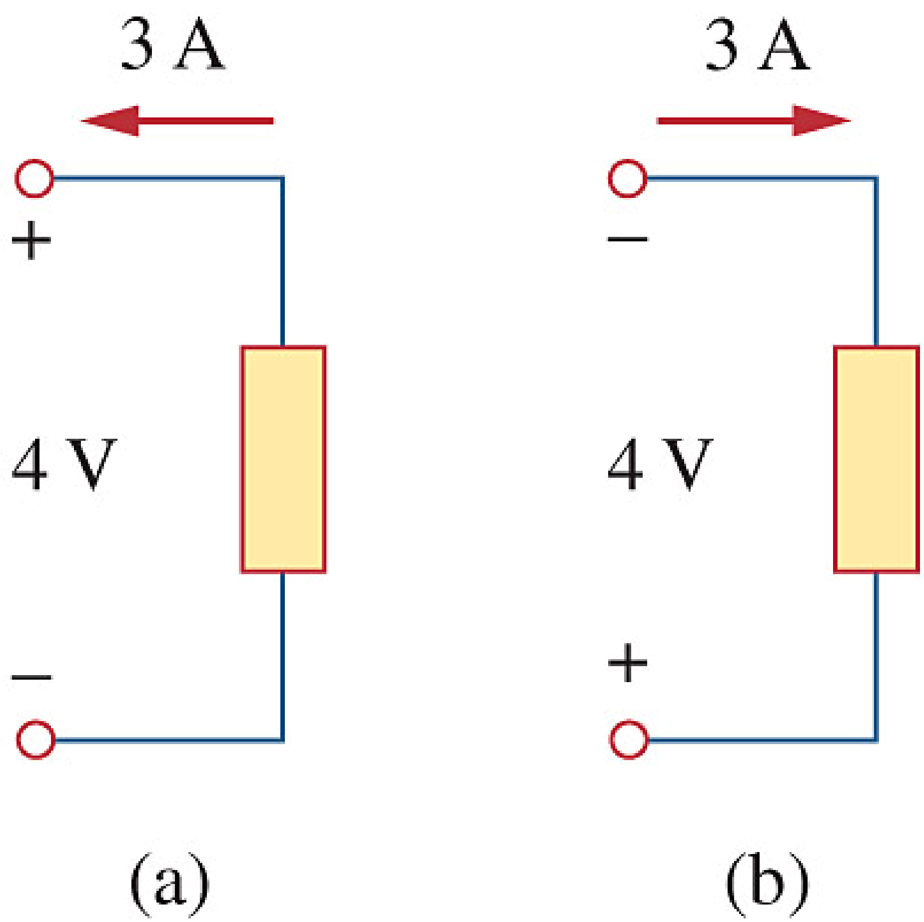


Figure 1.10 Two cases of an element with a supplying power of 12 W (or absorbing power of -12 W).

- In fact, the law of conservation of energy must be obeyed in any electric circuit. For this reason, the algebraic sum of power in a circuit, at any instant of time, must be zero:

$$\sum p = 0$$

- Energy is the capacity to do work, measured in joules (J).

The energy absorbed by an element from time t_0 to time t is

$$w = \int_{t_0}^{t} p\,dt = \int_{t_0}^{t} vi\,dt$$

Practice Problem 1.5 Find the power delivered to an element at $t = 5$ ms if the current entering its positive terminal is

$$i = 5\cos 60\pi t \text{ A}$$

and the voltage is (a) $v = 2i$ V, (b) $v =$

$$\left(10 + 5\int_0^t i\,dt\right) \text{ V}.$$

Solution :

(a) The power delivered to (or absorbed by) the element is 17.27 W:

$$p = vi = 2i^2 = 2\left(5\cos 60\pi t\right)^2 = 50\cos^2 60\pi t$$

$$= 50\cos^2(60\pi \times 5\times 10^{-3}) \approx 17.27 \text{ (W)}$$

(b) The power delivered to the element is 29.70 W:

$$v = 10 + 5\int_0^t i\,dt = 10 + 5\int_0^t 5\cos 60\pi t\,dt$$

$$= 10 + \frac{25}{60\pi}\sin 60\pi t\Big|_0^t = 10 + \frac{5}{12\pi}\sin 60\pi t$$

$$= 10 + \frac{5}{12\pi}\sin(60\pi \times 5 \times 10^{-3}) \approx 10.1073\ \text{(V)}$$

$$i = 5\cos 60\pi t = 5\cos(60\pi \times 5 \times 10^{-3})$$

$$\approx 2.9389\ \text{(A)}$$

$$p = vi = 10.1073 \times 2.9389 \approx 29.70\ \text{(W)}$$

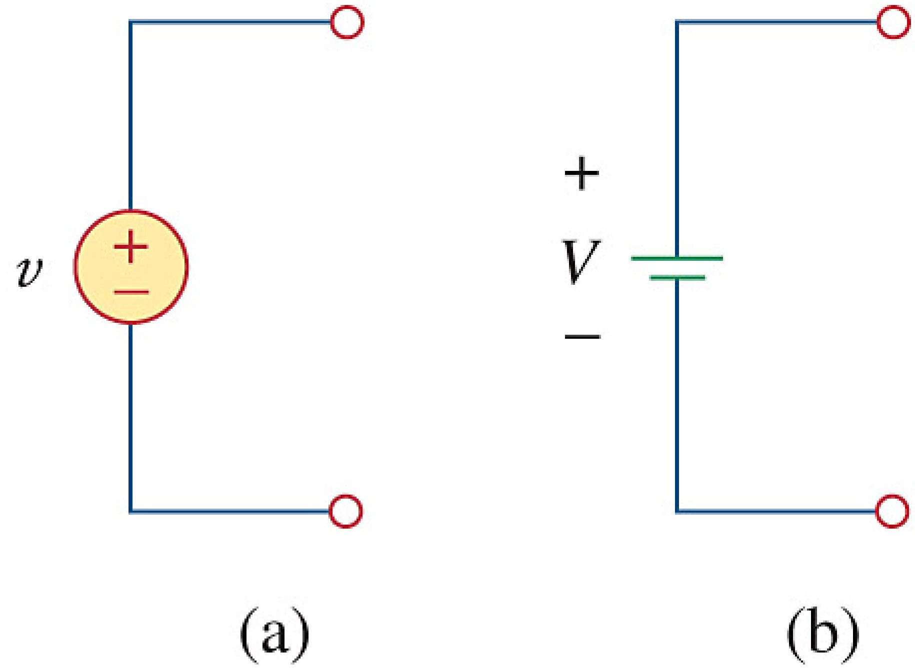
1.6 Circuit Elements

- There are two types of elements found in electric circuits
  – Passive elements model physical devices that cannot generate electric energy: resistors, capacitors, inductors, …
  – Active elements model devices capable of generating electric energy: generators, batteries, operational amplifiers, …

- The most important active elements are voltage or current sources. There are two kinds of sources
  - Independent sources
  - Dependent sources

- An ideal independent voltage source is an active element that provides a specified voltage that is completely independent of other circuit elements.
- An ideal independent current source is an active element that provides a specified current that is completely independent of other circuit elements.

AC or DC



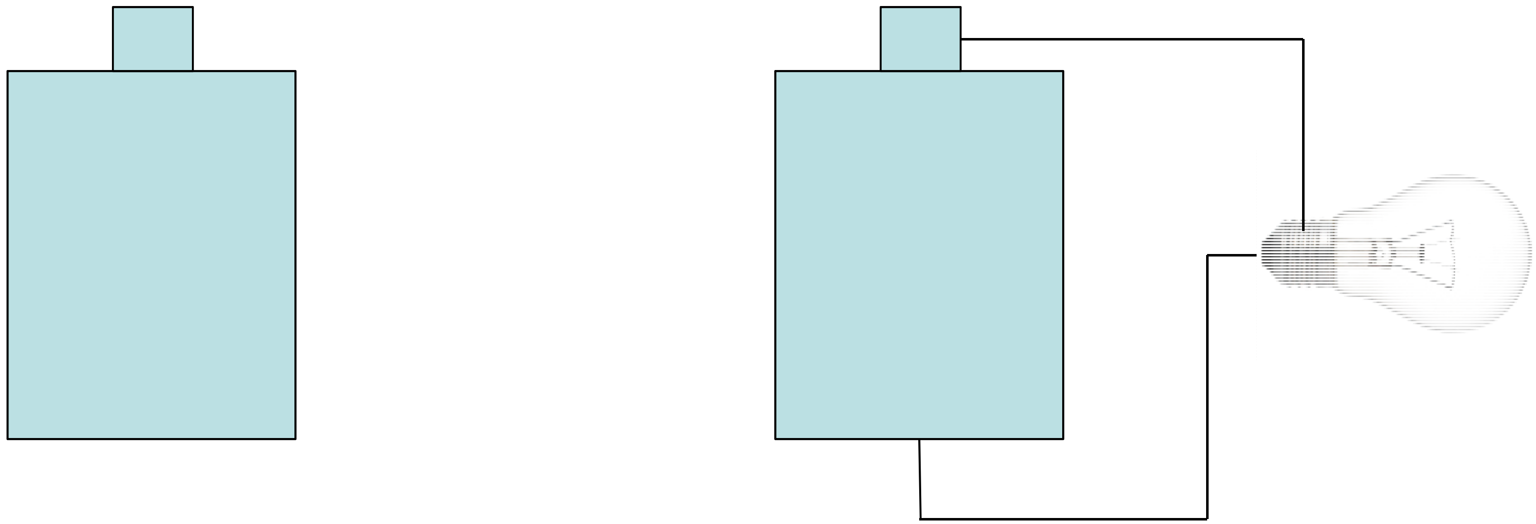
DC only

Figure 1.11 Symbols for independent voltage sources:

(a) used for constant or time-varying voltage source,

(b) used for constant voltage source.

v is fixed at a specified value, i can be any value



Same or different voltages?

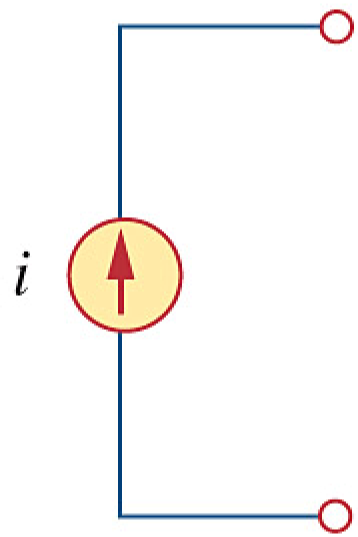


Figure 1.12 Symbols for independent current source.

i is fixed at a specified value, v can be any value

- An ideal dependent (or controlled) source is an active element in which the source quantity is controlled by another voltage or current. In other words, a dependent source establishes a voltage or current whose value depends on the value of a voltage or current elsewhere in the circuit. You cannot specify the value of a dependent source unless you know the value of the voltage or current on which it depends.
- E.g., op-amp, transformers, transistors, etc.

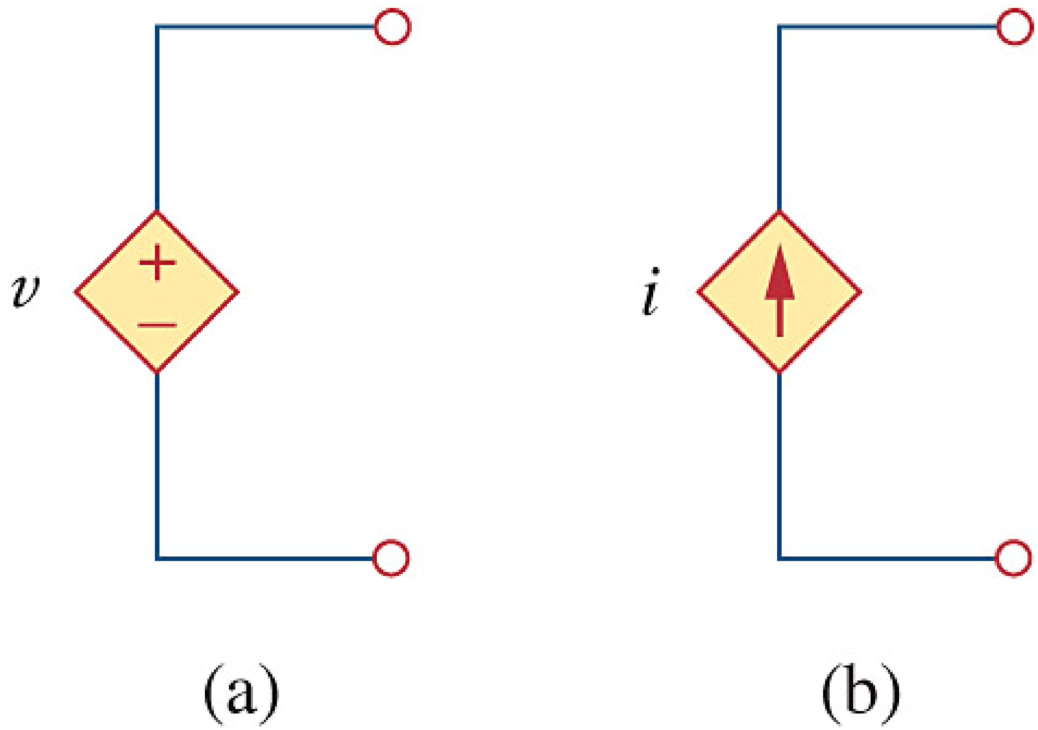


Figure 1.13 Symbols for (a) dependent voltage source, (b) dependent current source.

- There are four possible types of dependent sources
  - A voltage-controlled voltage source (VCVS)
  - A current-controlled voltage source (CCVS)
  - A voltage-controlled current source (VCCS)
  - A current-controlled current source (CCCS)

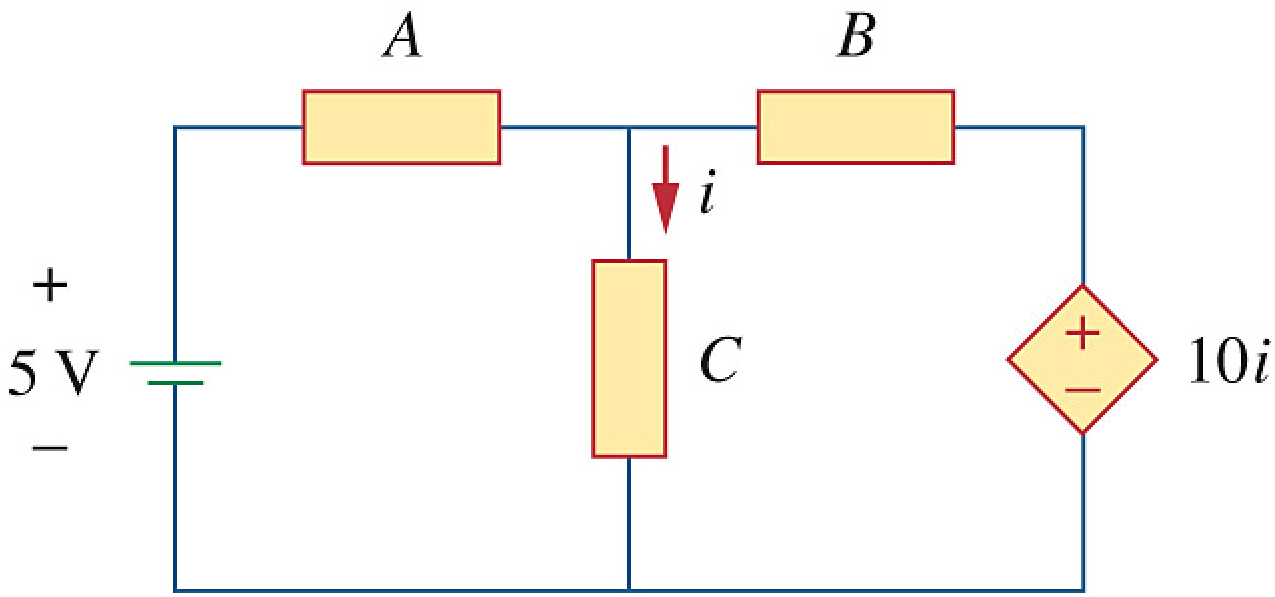


Figure 1.14 An example CCVS.

Practice Problem 1.7 Compute the power absorbed or supplied by each component of the circuit Figure 1.16.

Solution : We apply the passive sign convention.

$$p_1 = 5 \times (-8) = -40 \text{ (W)}$$

$$p_2 = 2 \times 8 = 16 \text{ (W)}$$

$$p_3 = (0.6 \times 5) \times 3 = 9 \text{ (W)}$$

$$p_4 = 3 \times 5 = 15 \text{ (W)}$$

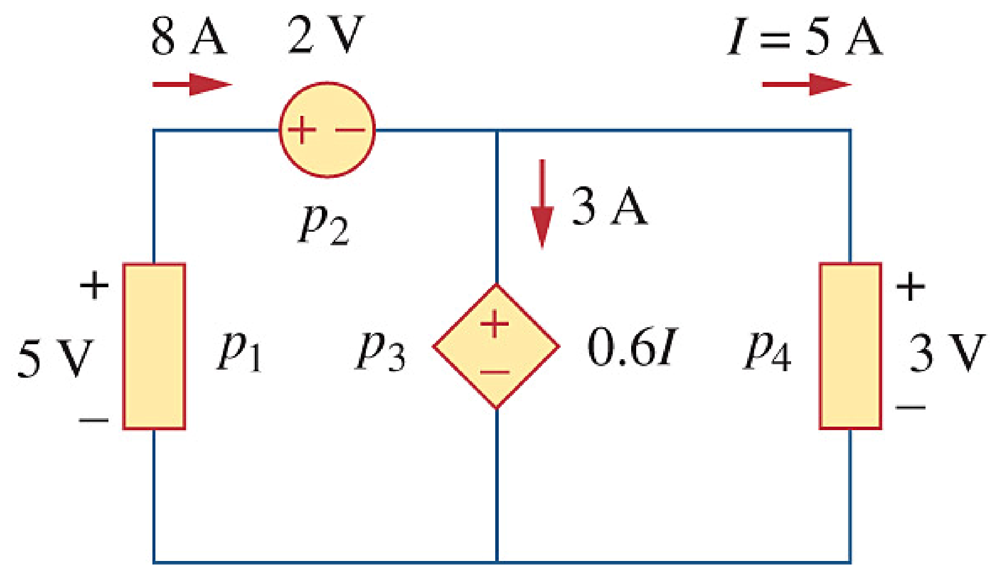


Figure 1.16

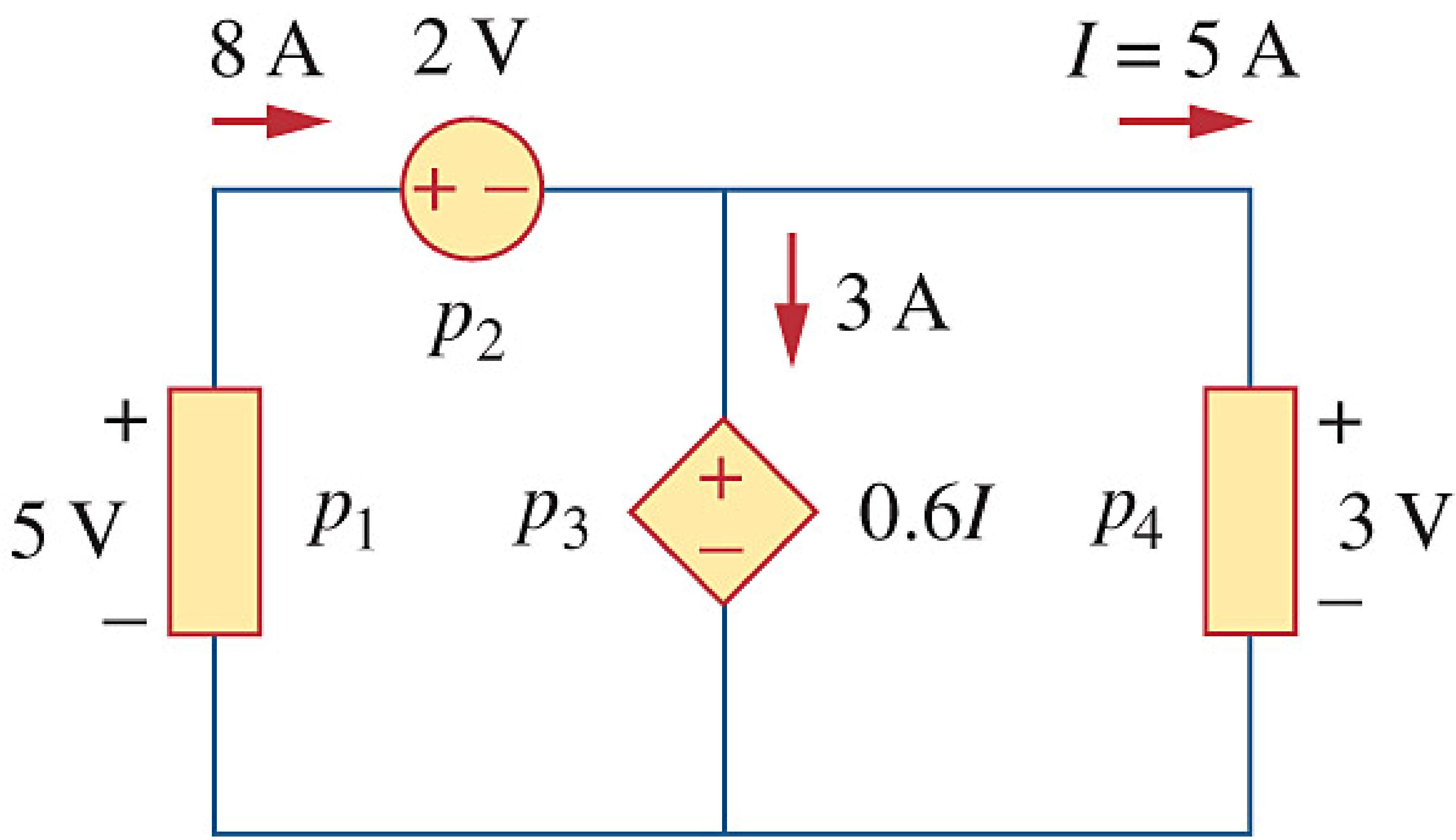


Figure 1.16