Chapter 1 Basic Concepts

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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.

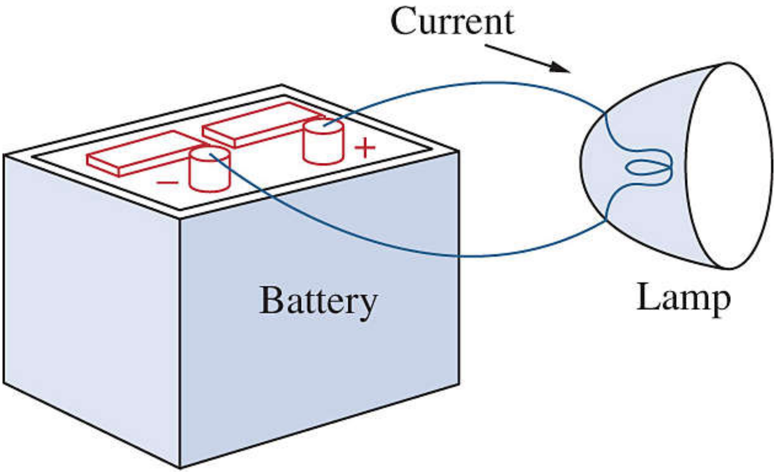


Figure 1.1 A simple electric circuit.

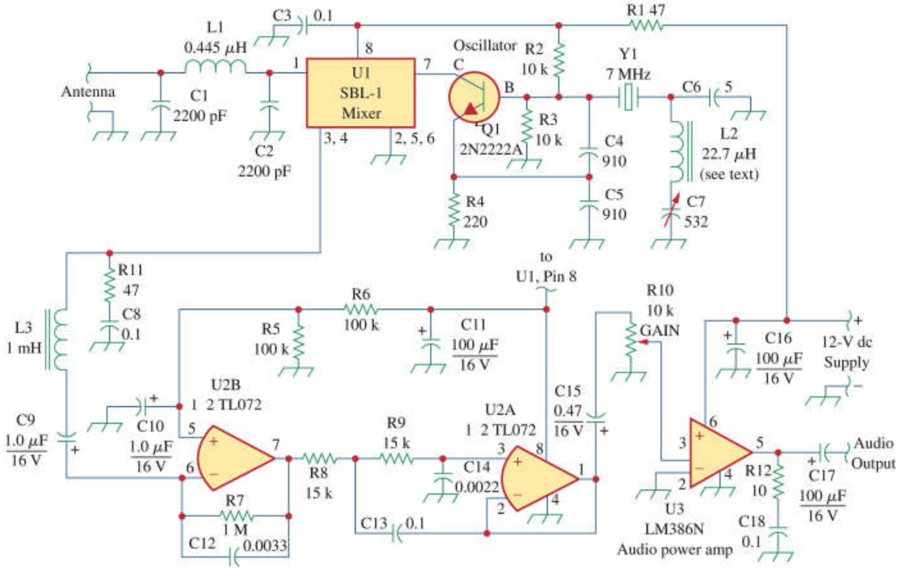


Figure 1.2 Electric circuit of a radio receiver.

1.3 Charge and Currents

- 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.

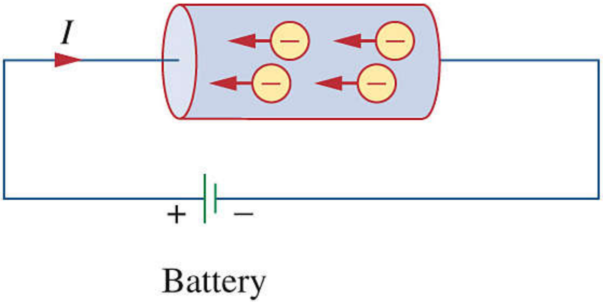


Figure 1.3 Electric current due to flow of electric charge in a conductor.

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.

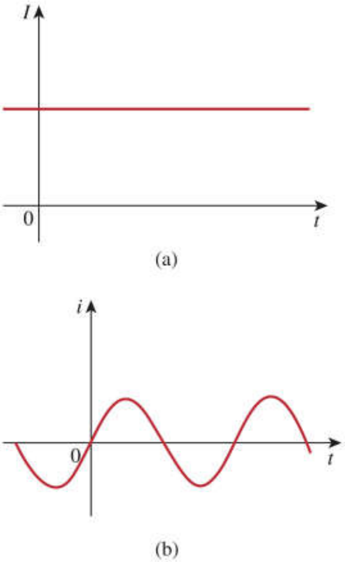


Figure 1.4 two common types of current (a) direct current (dc), (b) alternating current (ac).

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

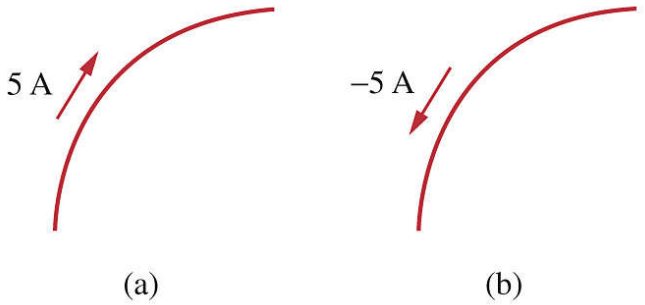


Figure 1.5 Conventional current flow: (a) positive current flow, (b) negative current flow.

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 :

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

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

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.

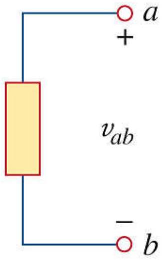


Figure 1.6 Polarity of voltage v_{ab}.

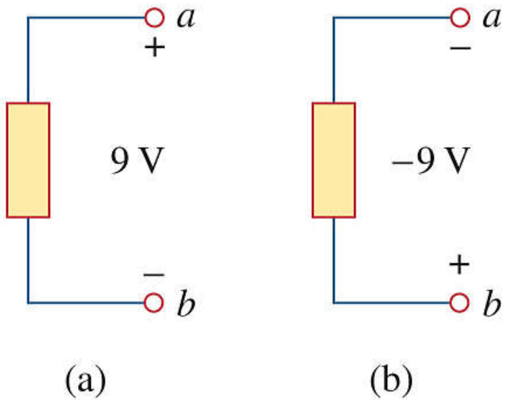


Figure 1.7 Two equivalent representations of the same voltage v_{ab} : (a) point a is 9 V above point b, (b) point b is -9 V above point a.

- 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.

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

- 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, $p = -vi$.

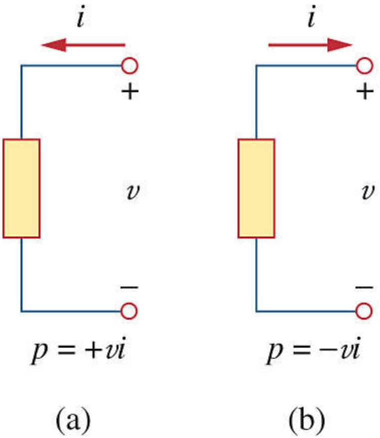


Figure 1.8 Reference polarities for power using the passive sign convention: (a) absorbing power, (b) supplying power.

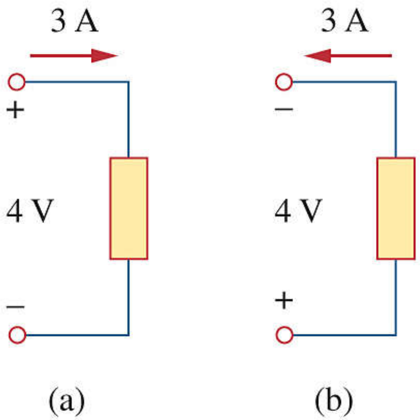


Figure 1.9 Two cases of an element with an absorbing power of 12 W.

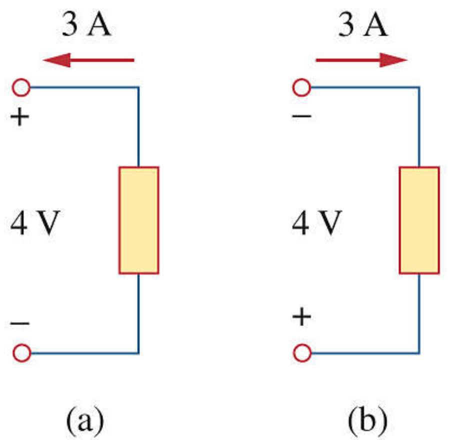


Figure 1.10 Two cases of an element with a supplying power of 12 W (or absorbing power of -12 W).

- 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) $v = \left(10 + 5\int_0^t i\,dt\right)$ 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. E.g., resistors, capacitors, inductors, …
  - Active elements model devices capable of generating electric energy. E.g., 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.

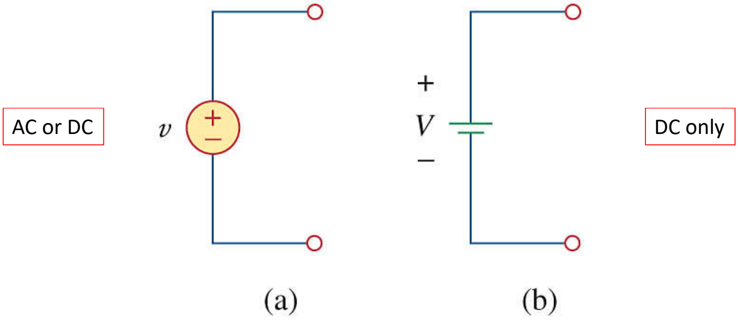
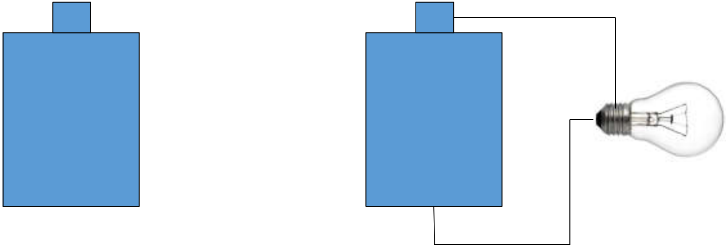


Figure 1.11 Symbols for independent voltage sources:
(a) used for constant or time-varying voltage source,
(b) used for constant voltage source.

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



Same or different voltages?

Ideal independent or non-ideal independent

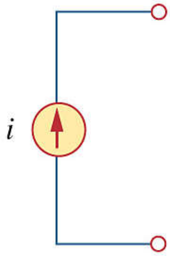


Figure 1.12 Symbols for independent current source.

***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.

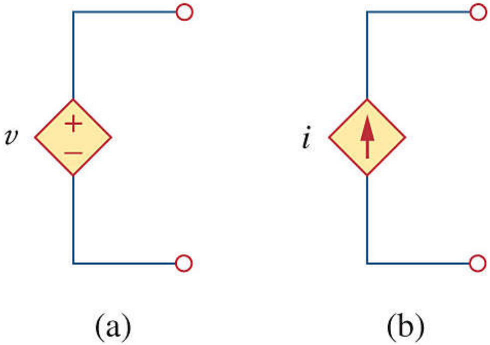


Figure 1.13 Symbols for (a) dependent voltage source, (b) dependent current source.

- 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)

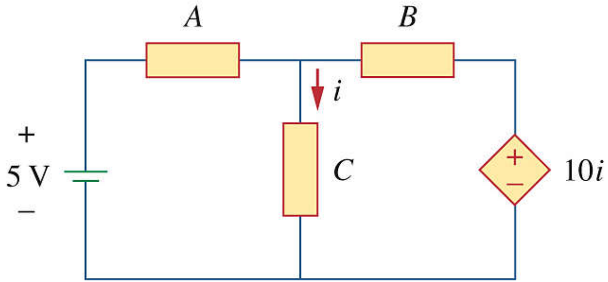


Figure 1.14 An example CCVS.

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.

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

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

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

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

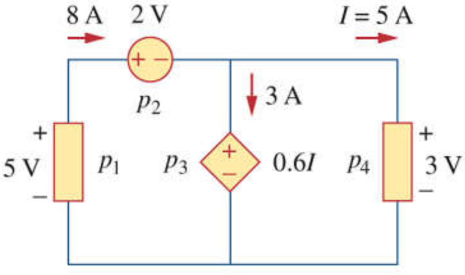


Figure 1.16

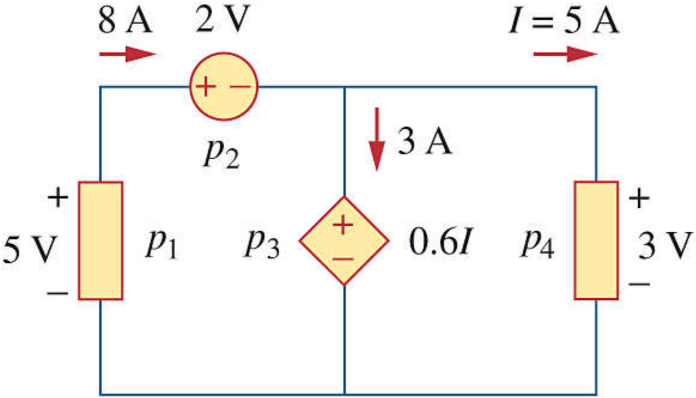


Figure 1.16