ECE2150J Introduction to Circuits

Chapter 1 Basic Concepts

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1.1 Introduction

- **Electric circuit theory** and **electromagnetic theory** are the two fundamental theories upon which all branches of electrical engineering are built.
- The basic electric circuit theory course is the most important course for an electrical engineering student, and always an excellent starting point for a beginning student in electrical engineering education.
- Circuit theory is also valuable to students specializing in other branches.

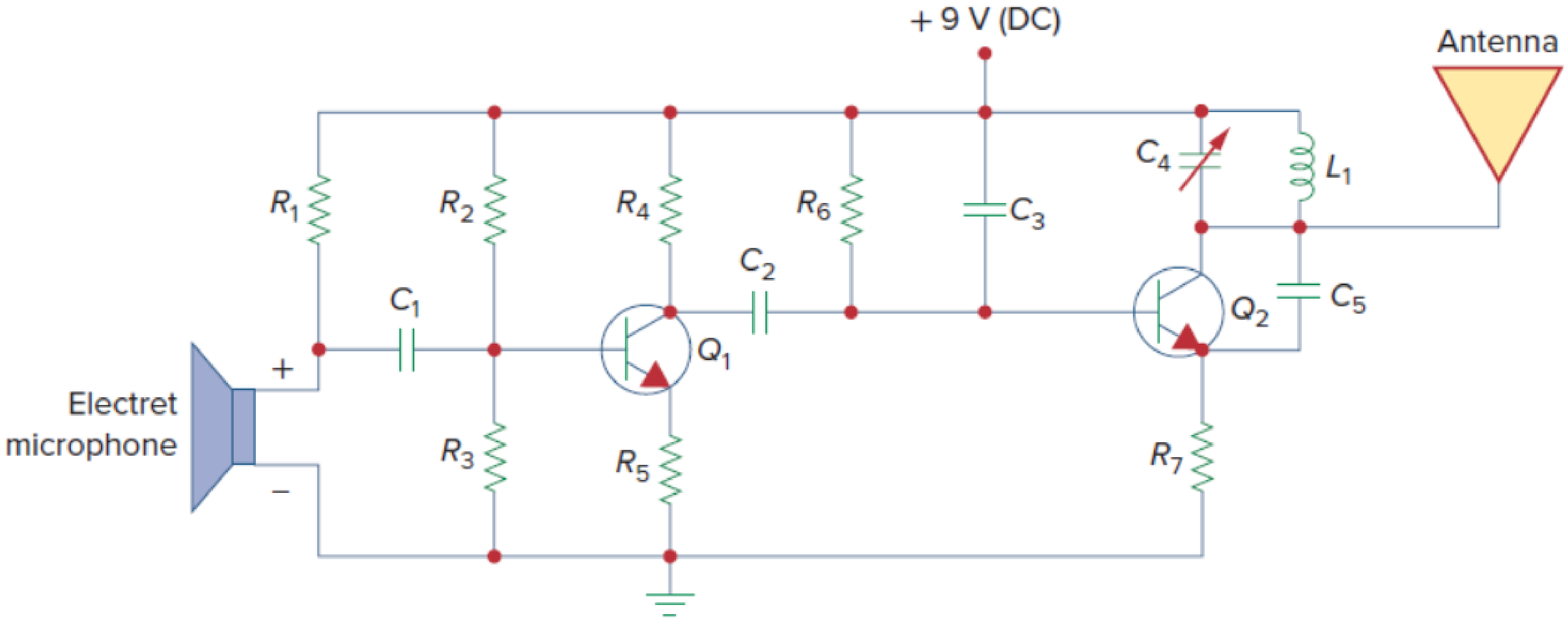
- In electrical engineering, we are often interested in **transferring energy** from one point to another.

- 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**.

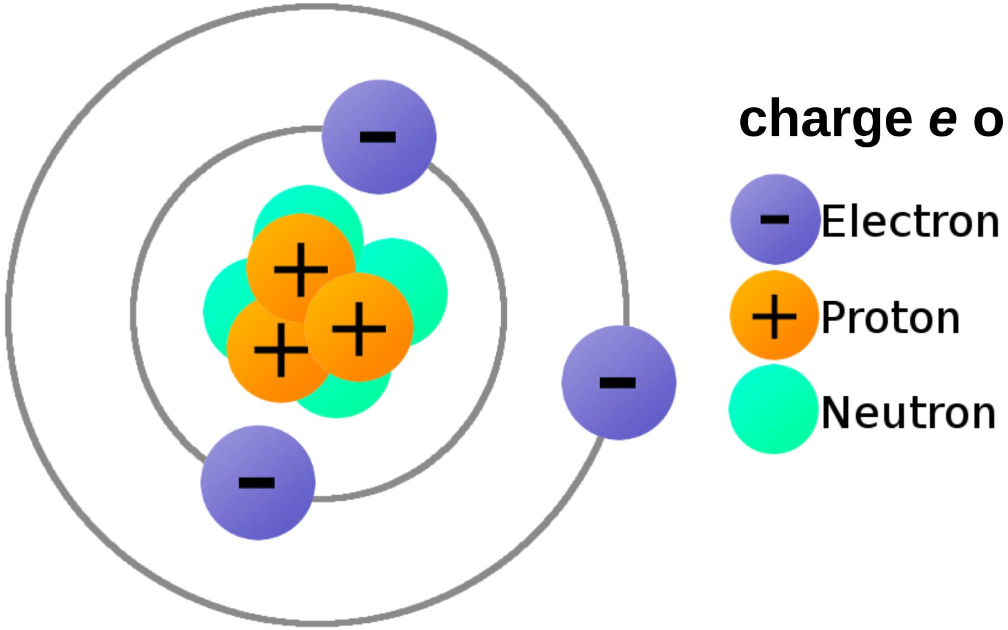
Our major concern in this course is the **analysis of the circuits**.

– How does it respond to a given input?

– How do the interconnected elements and devices in the circuit interact?



1.3 Charge and Current



charge *e* or *q* = 1.602×10^{-19} C

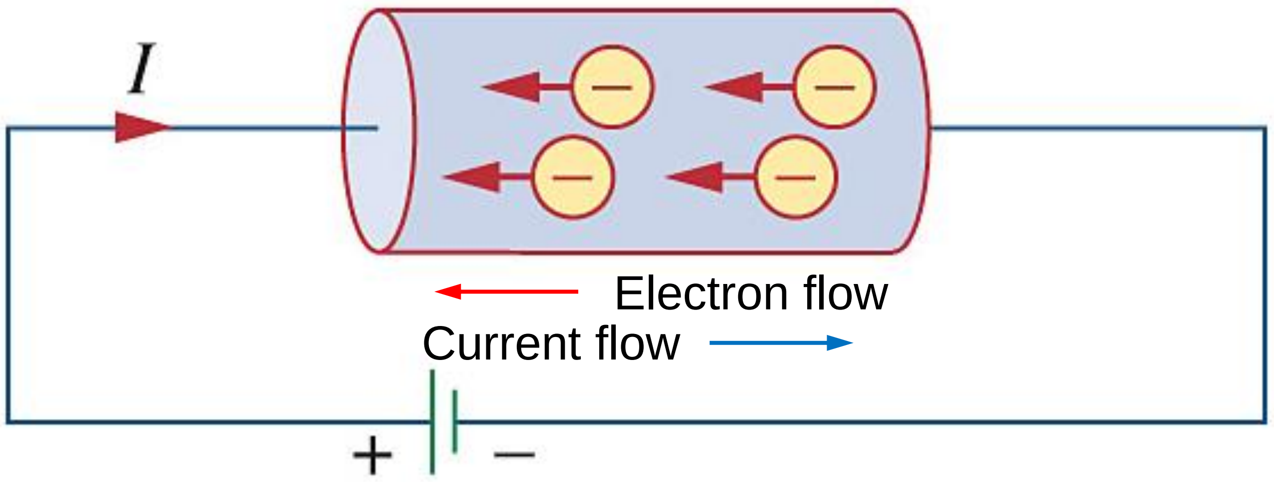
- The concept of electric charge is the underlying principle for explaining all electrical phenomena.
- The most basic quantity in an electric circuit is the **electric charge**.

- Charge is **an electrical property of the atomic particles** of which matter consists, measured in coulombs (C)

  1 C (6.24×10^{18} electrons) = 1 A x 1 s.

- 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.



Electric conduction is **due to negatively charged electrons**. However, we follow the universally accepted convention **that current is the net flow of positive charges**.

Electric current (i) is the **time rate of change of charge**, measured in amperes (A).

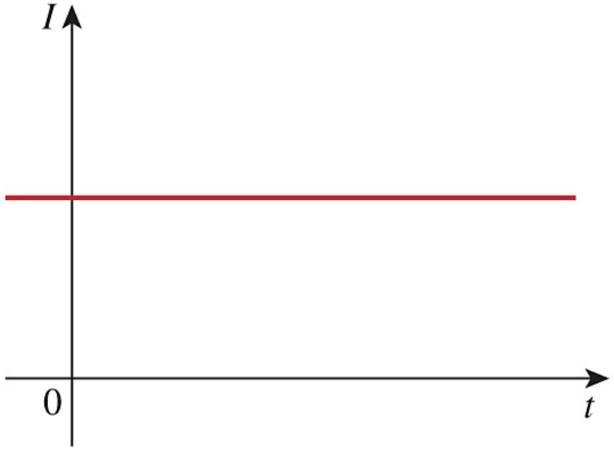
Mathematically, the relationship between current i [amperes (A)], charge q, and time t
*1 A = 1 C/sec

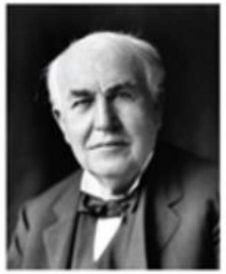
$$i \triangleq \frac{dq}{dt}$$

The charge transferred between time t_0 and t is obtained by integrating both sides

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

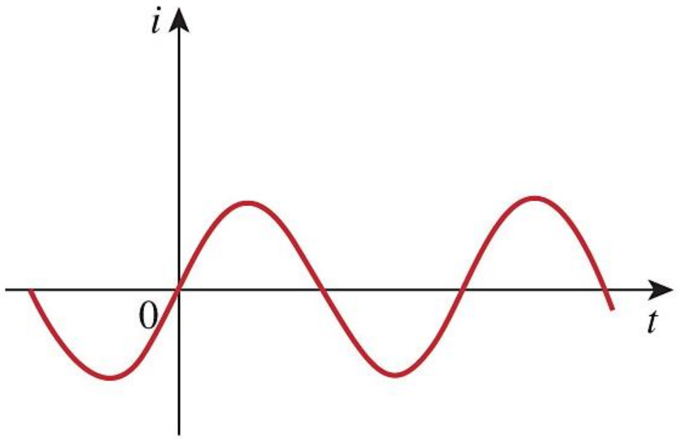
- *Direct current* (DC) is the unidirectional flow of electric charge, i.e. a current that remains constant with time.

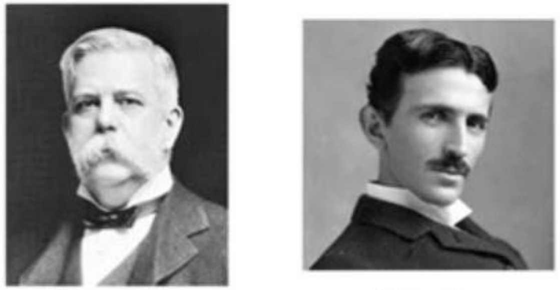




Thomas Edison 1847-1931

- In *alternating current* (AC), the movement of electric charge periodically reverses direction, i.e. a current that varies sinusoidally with time.



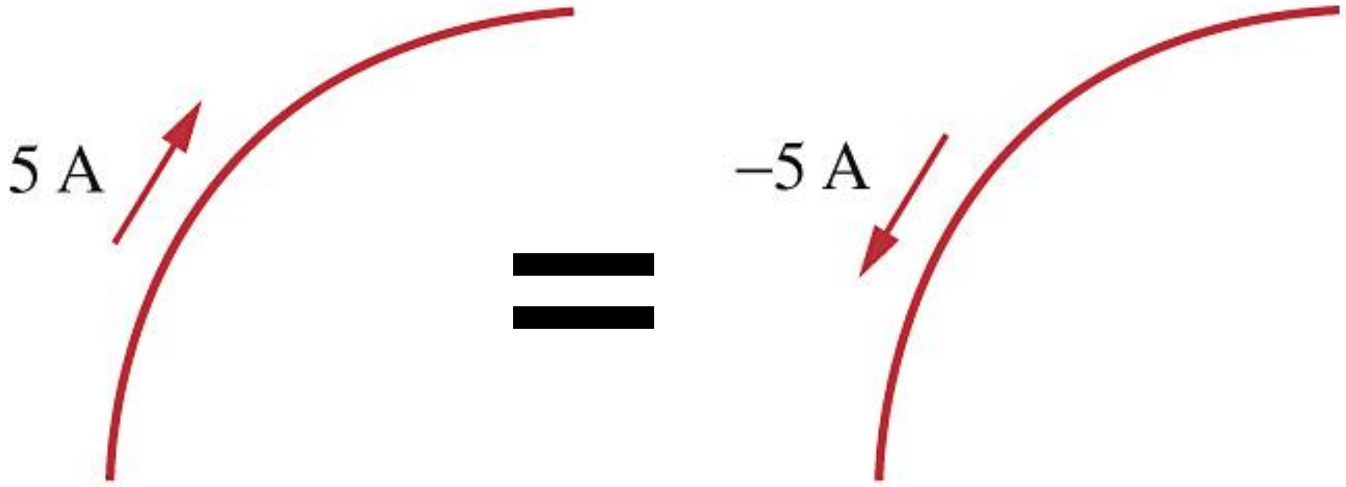


George Westinghouse 1846-1914

Nikola Tesla 1856-1943

https://www.energy.gov/articles/war-currents-ac-vs-dc-power

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



5 A of current is flowing clockwise =
-5 A of current is flowing counter-clockwise

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).

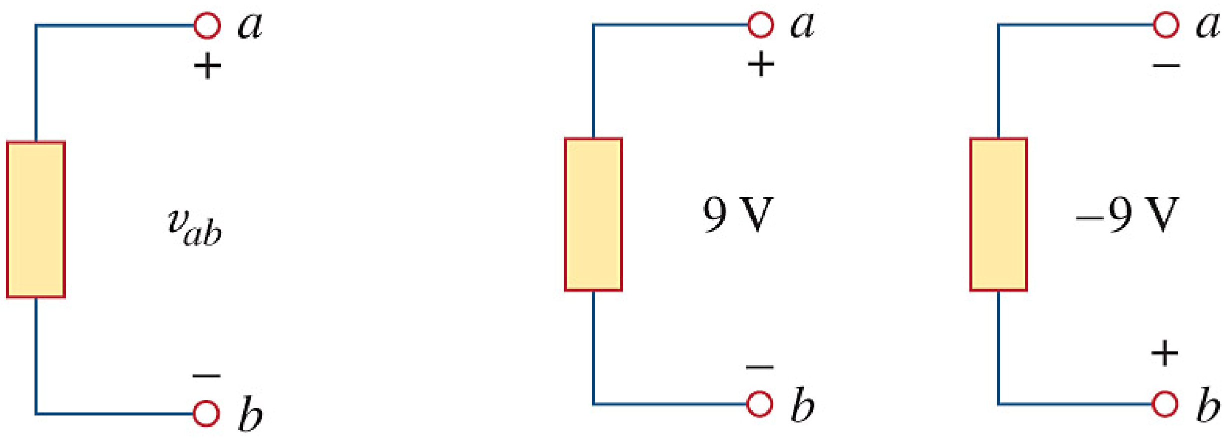
Mathematically, the voltage between two points a and b in an electric circuit is

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

where w is energy in joules (J) and
q is charge in coulombs (C)

$$1 \text{ volt} = 1 \text{ joule/coulomb} = 1 \text{ newton-meter/coulomb}$$

- The plus (+) and minus (-) signs are used to define **reference direction or polarity** of the voltage.



$$v_{ab} = -v_{ba}$$

- 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

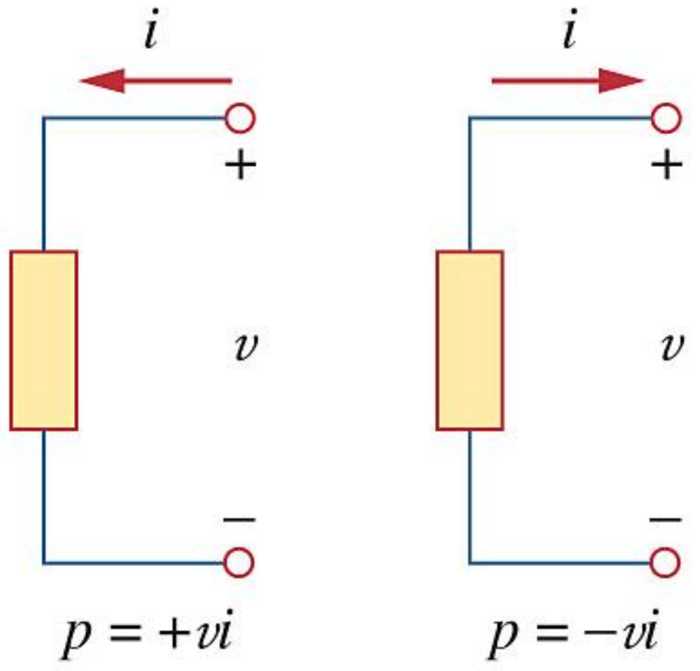
- **Power** is the time rate of expending or absorbing energy, measured in **watts (W)**.
- The power $p = vi$ is a **time-varying** quantity and is called the instantaneous power.

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

w is energy in joules (J)

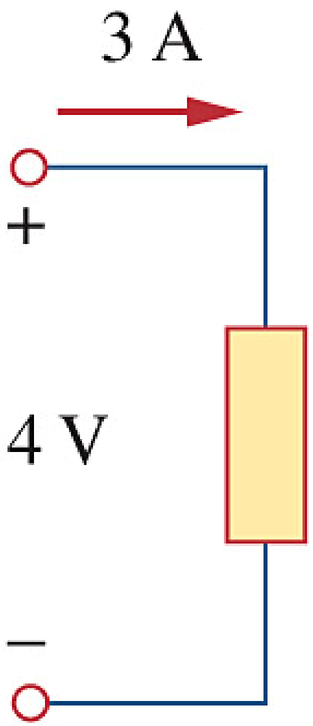
Passive sign convention:

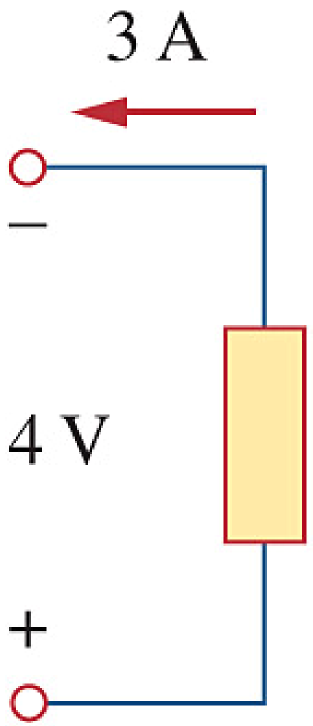
- When **the current enters through the positive terminal** of **an element**
- $p = +vi > 0$ implies that the element is **consuming power**.
- $p = -vi < 0$ implies that the element is **supplying power**.



*Unless otherwise stated, we **follow the passive sign convention** from now on.

example





(a) Absorbing power
(b) Supplying power

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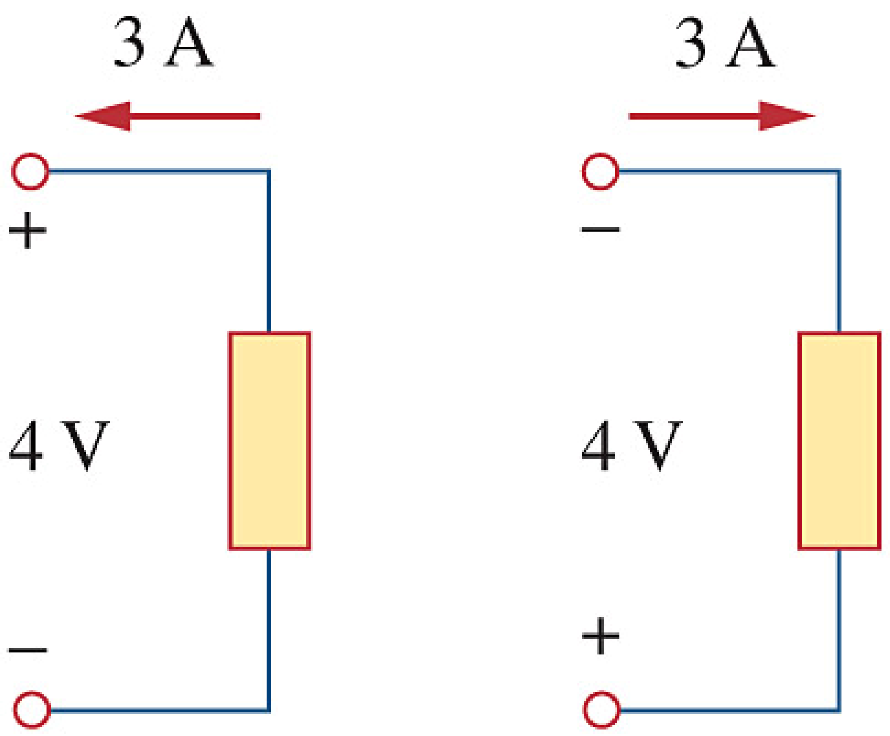
example



(a) Absorbing power
(b) Supplying power

(a) Absorbing power
(b) Supplying power

- 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

$i = 5\cos 60\pi t$ A

and the voltage is (a) $v = 2i$ V, (b) $v = \left(10 + 5\int_0^t i\,dt\right)$ V.

Hint: p = vi

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:

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

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

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

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

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

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

1.6 Circuit Elements

- There are two types of elements found in electric circuits
  - **Passive elements:** devices that cannot generate electric energy, such as, resistors, capacitors, inductors.
  - **Active elements**: devices capable of generating electric energy, such as, 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/current source** is an active element that provides a **specified voltage/current** that is completely independent of other circuit elements.

Independent voltage source

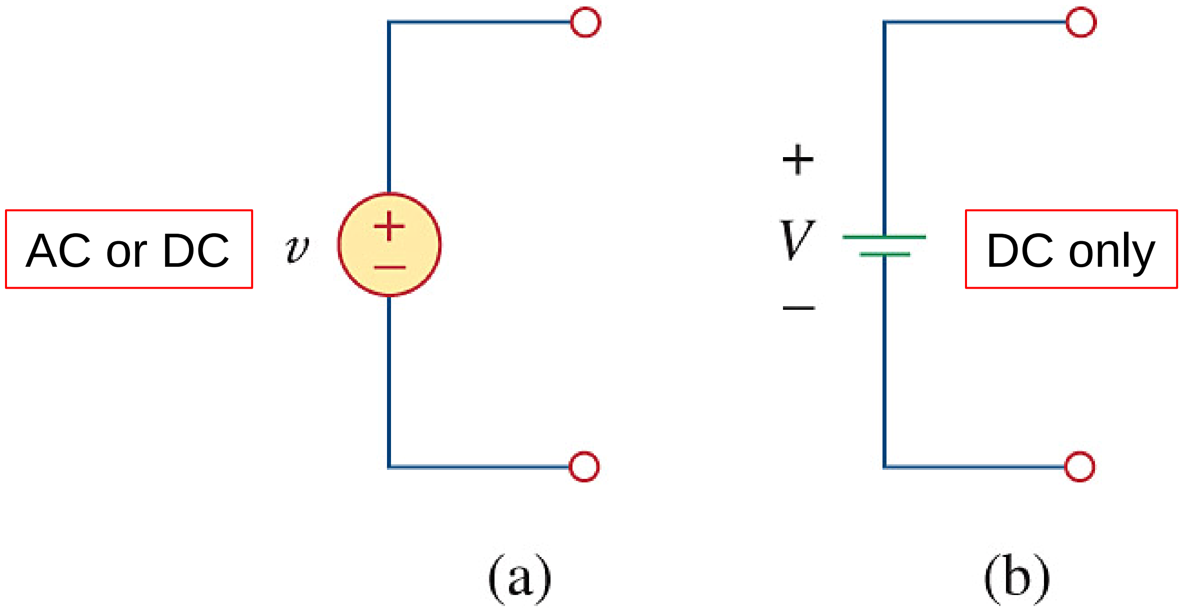


Figure 1.11 Symbols for independent voltage sources:

(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

Independent current source

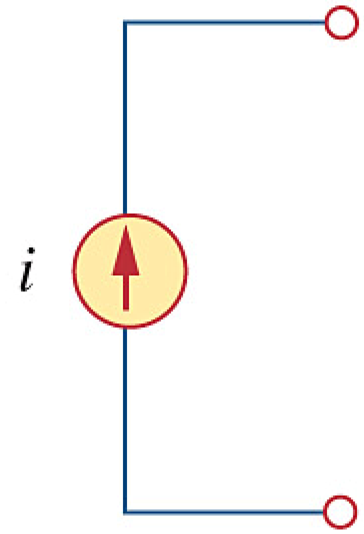
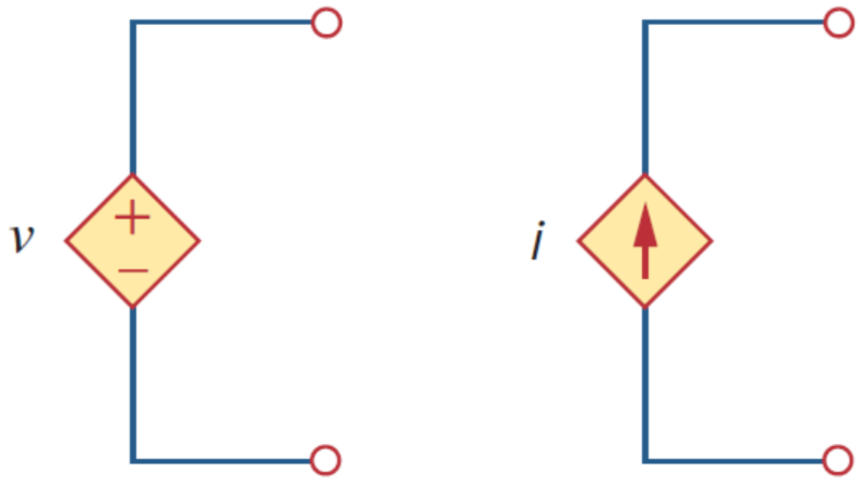


Figure 1.12 Symbols for independent current source.

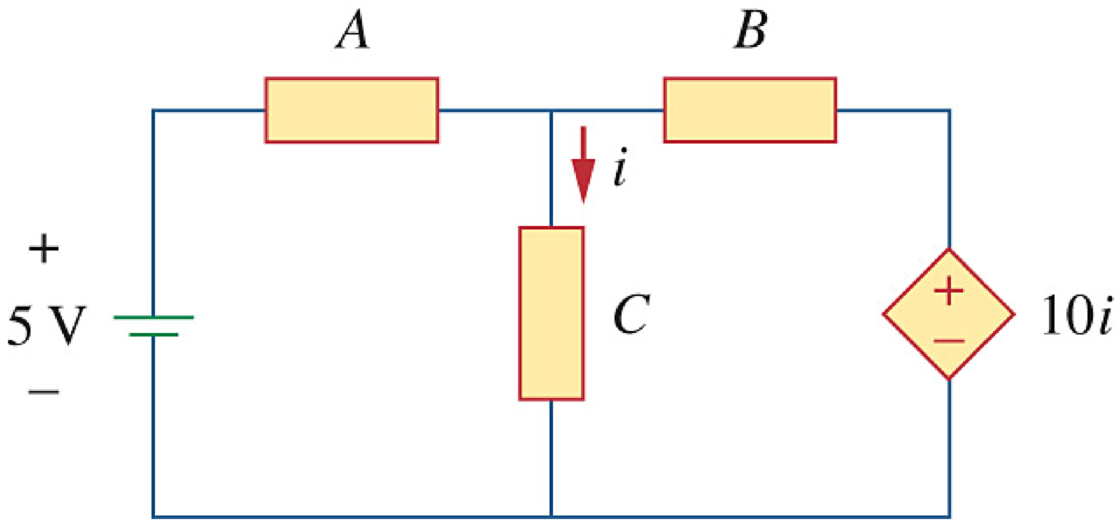
***i* is fixed at a specified value, *v* can be any value**

- **An ideal dependent (or controlled) source** is an active element in which the source quantity is **controlled by another voltage or current**, for example, the value of a voltage or current elsewhere in the circuit. e.g., op-amp, transformers, transistors, etc.



- 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)

Example



(a) A voltage-controlled voltage source (VCVS)

(b) A current-controlled voltage source (CCVS)

(c) A voltage-controlled current source (VCCS)

(d) A current-controlled current source (CCCS)

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

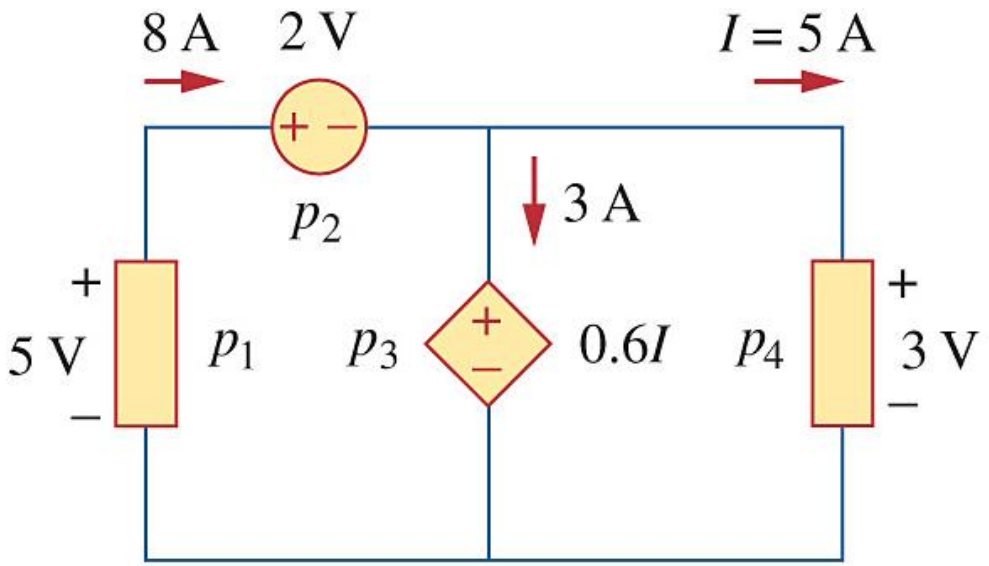


Figure 1.16

Solution : We apply the passive sign convention.

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

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

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

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