

ECE2150J Intro to Circuits

Chapter 1 Basic Concepts

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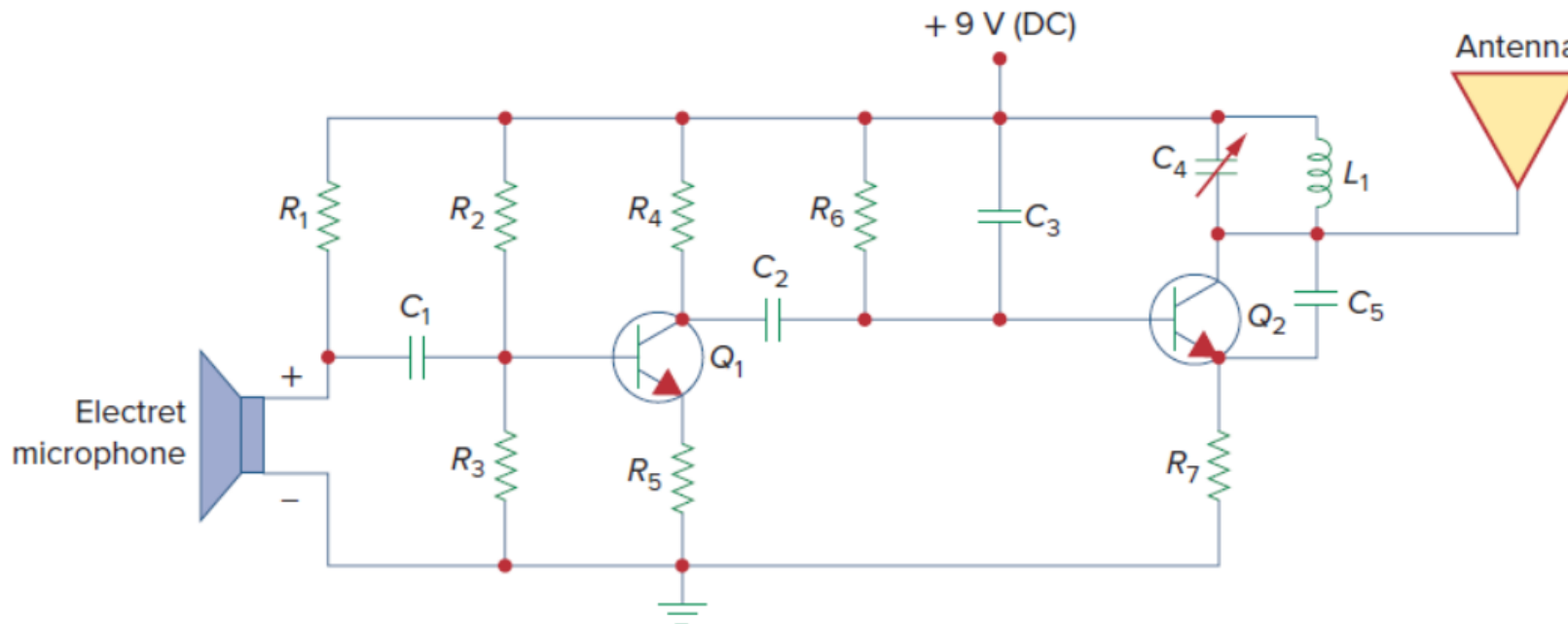
1.1 Introduction

- **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.

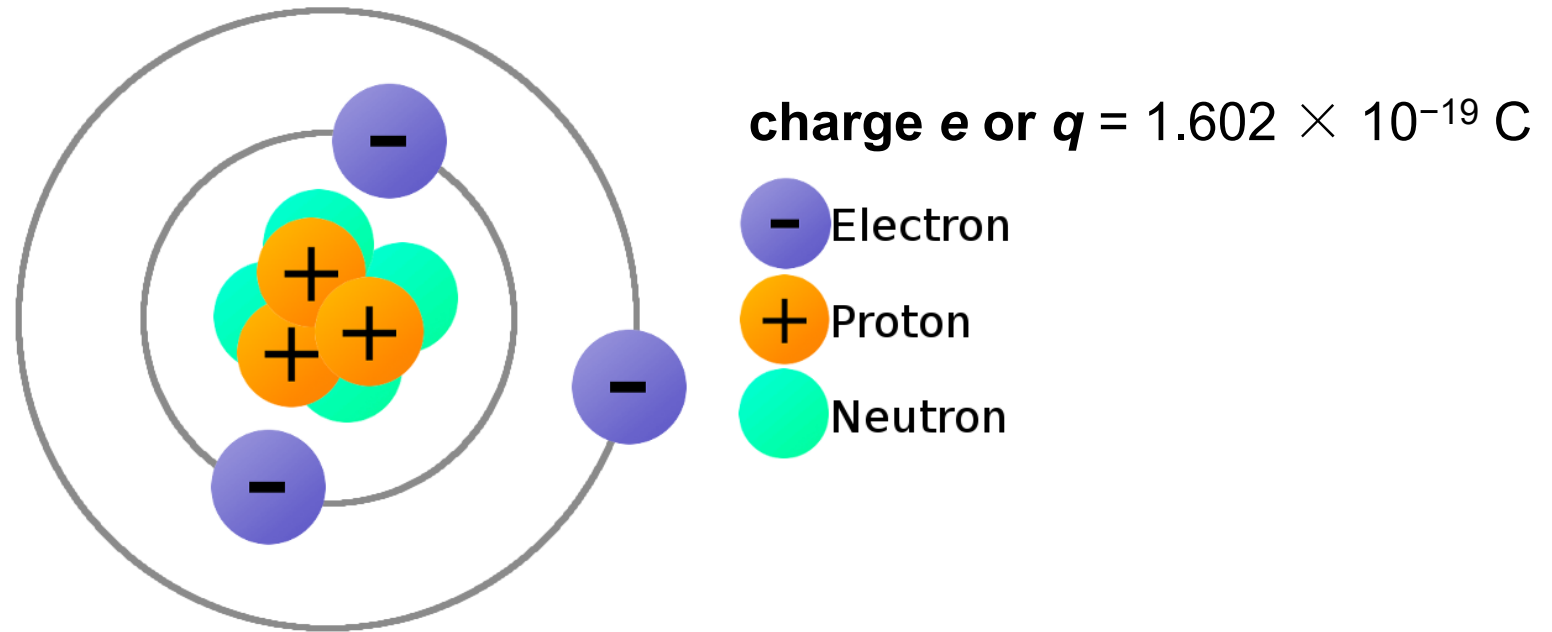
- In electrical engineering, we are often interested in **transferring energy** from one point to another.
- This requires an **interconnection of electrical devices**. Such interconnection is referred to as an **electric circuit**, and each component of the circuit is known as an **element**.

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



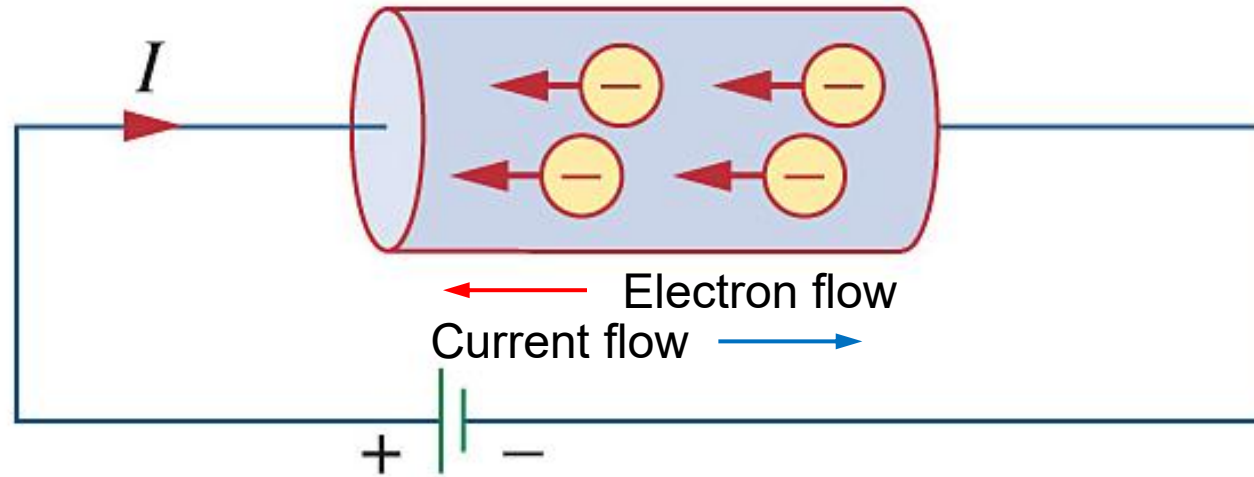
- The concept of electric charge is the underlying principle for explaining all electrical phenomena.
- The most basic quantity in an electric circuit is the **electric charge**.

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

$$1 \text{ C } (6.24 \times 10^{18} \text{ electrons}) = 1 \text{ A} \times 1 \text{ s.}$$

- 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).

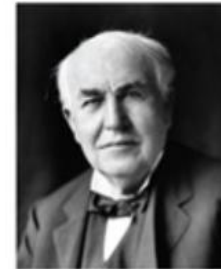
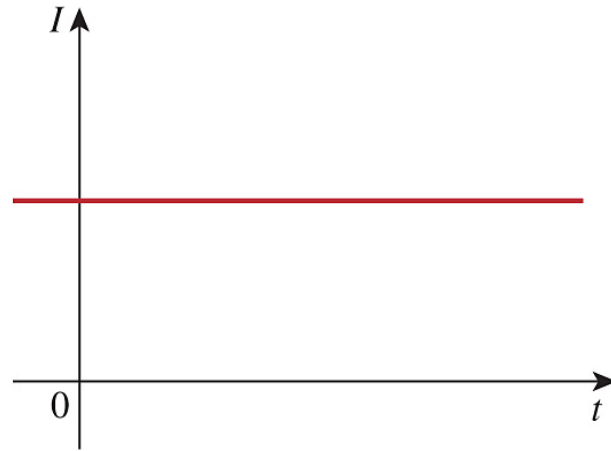
Mathematically, the relationship between current i [amperes (A)], charge q , and time t
*1 A = 1 C/sec

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

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

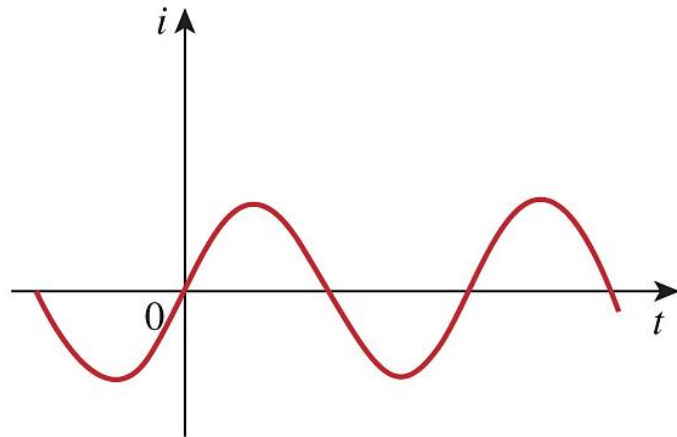
$$Q \triangleq \int_{t_0}^t i \, dt$$

- *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.

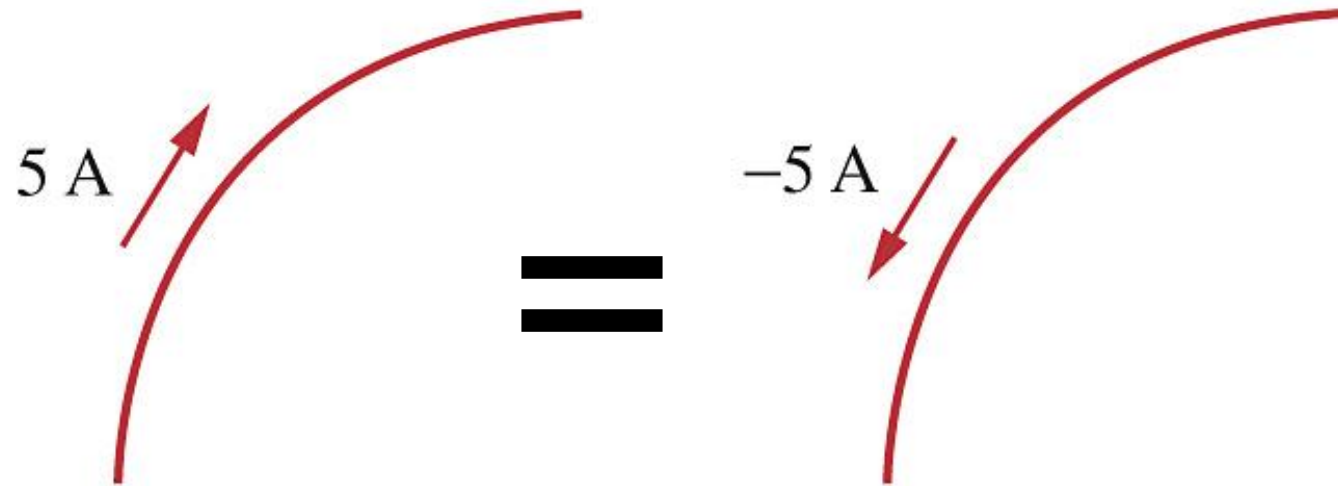


George
Westinghouse
1846-1914



Nikola
Tesla
1856-1943

- The direction of current (1D) 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

***Current flow in two-dimensional surface**

In a 2D plane, current does not choose a single path like clockwise. Instead, it spreads out to take **all possible paths simultaneously**: current takes all paths in inverse proportion to the resistance.

We will consider that all the wires are in the 1D form.

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 :

$$\begin{aligned} Q &= \int_0^2 i dt = \int_0^1 2 dt + \int_1^2 2t^2 dt = 2t \Big|_0^1 + 2 \frac{t^3}{3} \Big|_1^2 \\ &= 2 + \frac{14}{3} \approx 6.667 \text{ (C)} \end{aligned}$$

1.4 Voltage

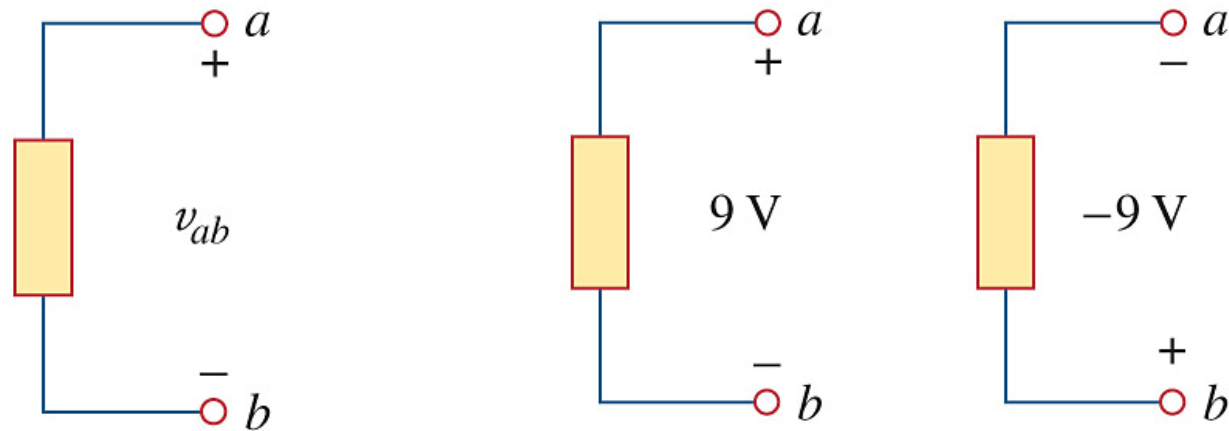
- Voltage (or potential difference) is the **energy (or work) required** to move a unit charge through an element, measured in volts (V).

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

$$v_{ab} \triangleq \frac{dw}{dq} \quad \text{where } w \text{ is energy in joules (J) and } q \text{ is charge in coulombs (C)}$$

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

- 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.

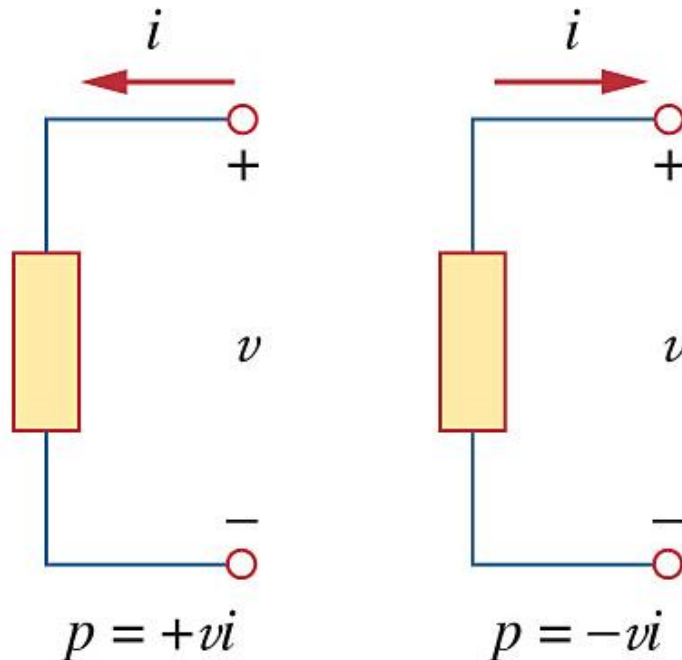
1.5 Power and Energy

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

$$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi \quad w \text{ is energy in joules (J)}$$

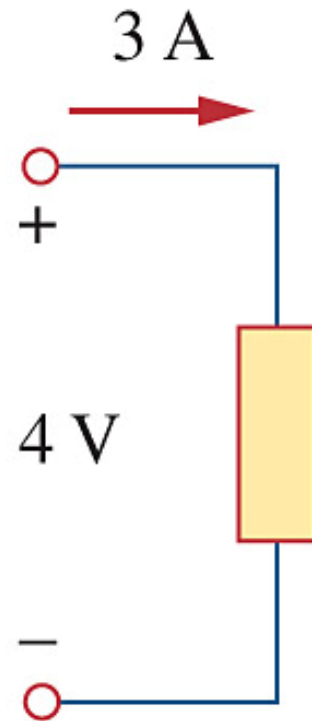
Passive sign convention:

- 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**.

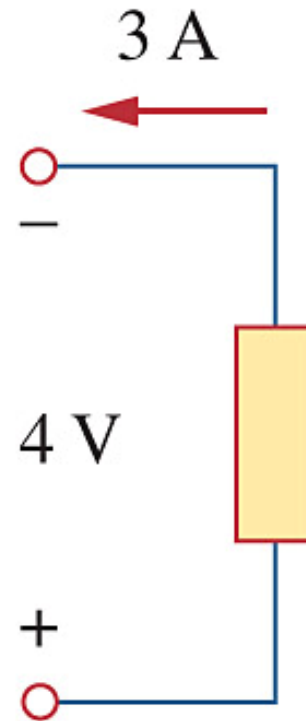


*Unless otherwise stated, we **follow the passive sign convention** from now on.

example

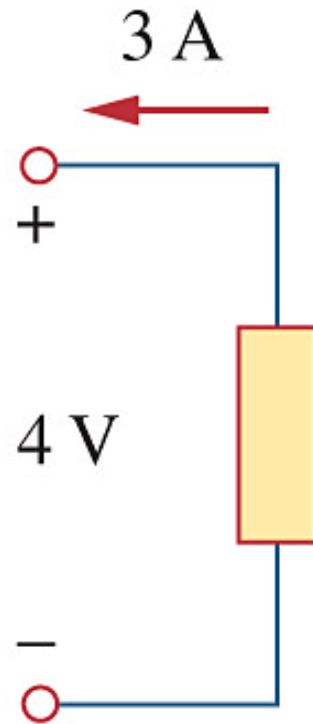


(a) Absorbing power
(b) Supplying power

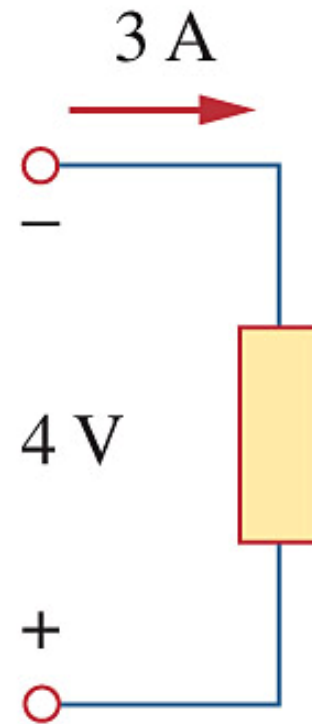


(a) Absorbing power
(b) Supplying power

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

$$w = \int_{t_0}^t p dt = \int_{t_0}^t v i dt$$

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) $v =$

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

Hint: $p = vi$

Solution :

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

$$\begin{aligned} p &= vi = 2i^2 = 2(5 \cos 60\pi t)^2 = 50 \cos^2 60\pi t \\ &= 50 \cos^2 (60\pi \times 5 \times 10^{-3}) \approx 17.27 \text{ (W)} \end{aligned}$$

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

$$\begin{aligned}
v &= 10 + 5 \int_0^t i dt = 10 + 5 \int_0^t 5 \cos 60\pi t dt \\
&= 10 + \frac{25}{60\pi} \sin 60\pi t \Big|_0^t = 10 + \frac{5}{12\pi} \sin 60\pi t \\
&= 10 + \frac{5}{12\pi} \sin(60\pi \times 5 \times 10^{-3}) \approx 10.1073 \text{ (V)} \\
i &= 5 \cos 60\pi t = 5 \cos(60\pi \times 5 \times 10^{-3}) \\
&\approx 2.9389 \text{ (A)} \\
p &= vi = 10.1073 \times 2.9389 \approx 29.70 \text{ (W)}
\end{aligned}$$

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

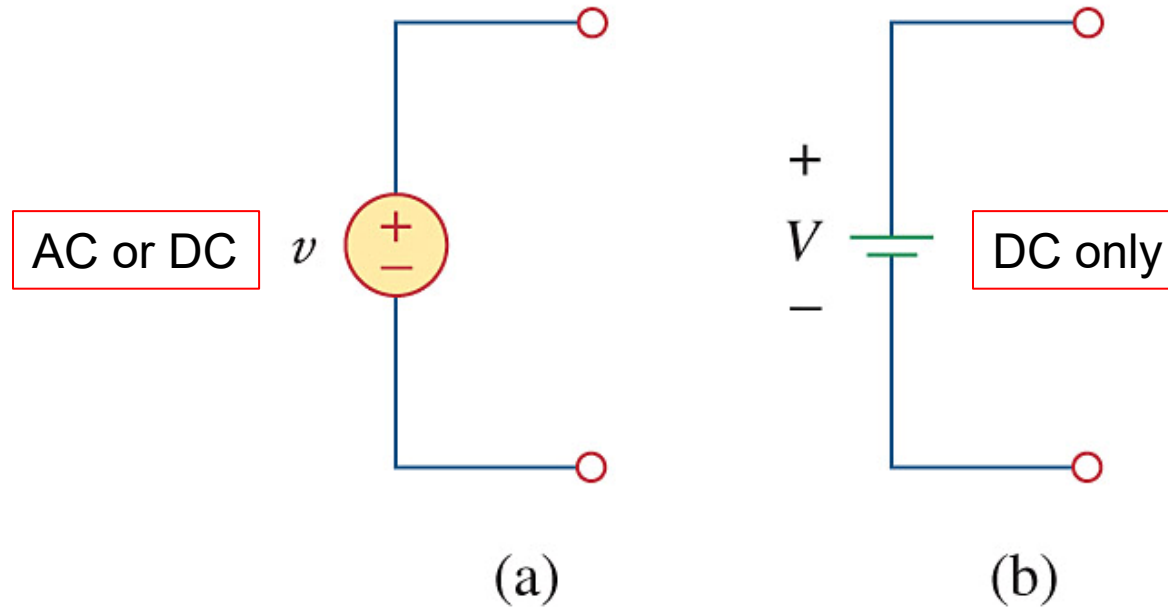


Figure 1.11 Symbols for independent voltage sources:

(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

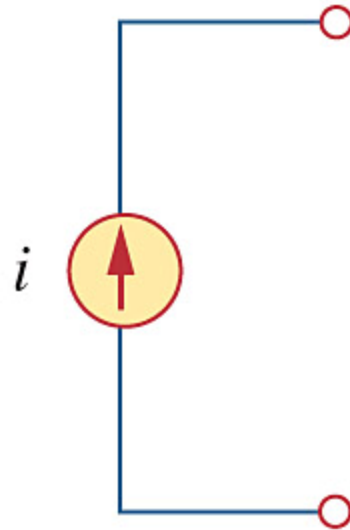
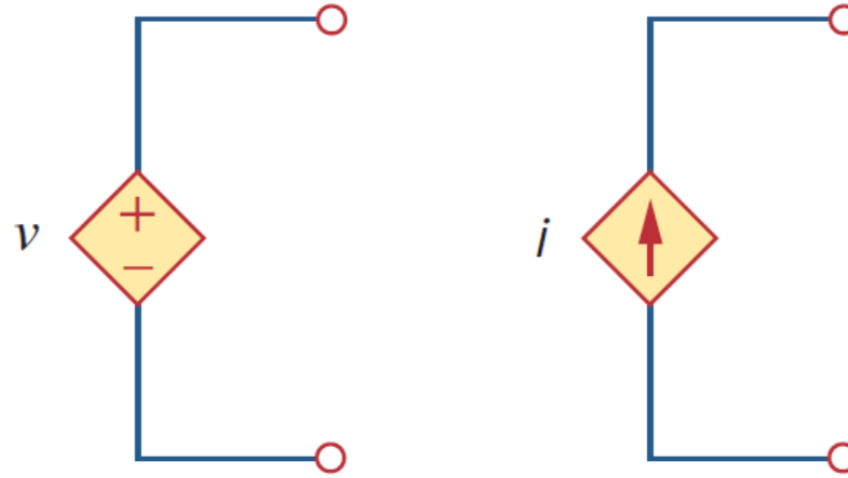


Figure 1.12 Symbols for independent current source.

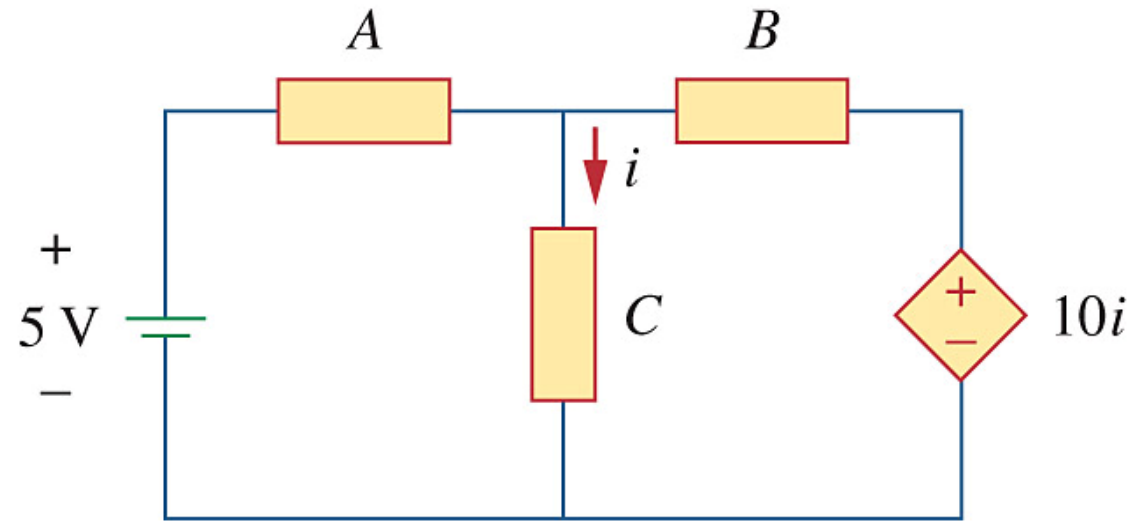
i is fixed at a specified value, v can be any value

- **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)

1.20 Find V_o and the power absorbed by each element in the circuit of Fig. 1.31.

