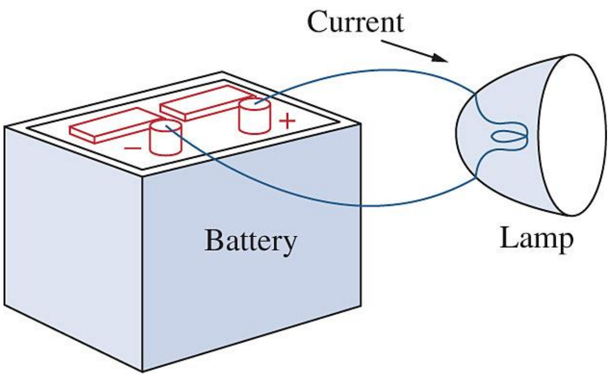
CHAPTER 1

Basic Concepts

In electrical engineering, we are often interested in communicating or 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**.

DEFINITION 1.0.1. An **electric circuit** is an interconnection of electrical elements.

- Examples of circuit elements are discussed in Section 1.3.



1.1. International System of Units

1.1.1. As engineers, we deal with measurable quantities. Our measurement must be communicated in standard language that virtually all professionals can understand irrespective of the country. Such an international measurement language is the **International System of Units** (SI).

1.1.2. In this system, there are six principal units from which the units of all other physical quantities can be derived.

Quantity	Basic Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Temperature	kelvin	K
Luminous Intensity	candela	cd

1.1.3. One great advantage of SI unit is that it uses prefixes based on the power of 10 to relate larger and smaller units to the basic unit.

Multiplier	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Example 1.1.4. Change of units:

$600,000,000 \text{ mA} \; =$

1.2. Circuit Variables

1.2.1. **Charge**: The concept of electric charge is the underlying principle for all electrical phenomena. Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C). The charge of an electron is -1.602×10^{-19} C.

- The coulomb is a large unit for charges. In 1 C of charge, there are $1/(1.602 \times 10^{-19}) = 6.24 \times 10^{18}$ electrons. Thus realistic or laboratory values of charges are on the order of pC, nC, or μC.
- A large power supply capacitor can store up to 0.5 C of charge.

1.2.2. *Law of Conservation of Charge*: Charge can neither be created nor destroyed, only transferred.

DEFINITION 1.2.3. **Current**: The time rate of change of charge, measured in amperes (A). Mathematically,

$$i(t) = \frac{d}{dt}q(t)$$

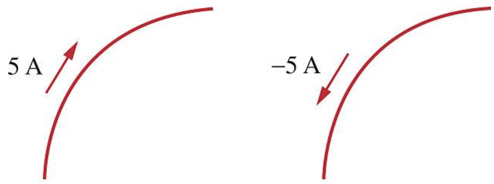
Note:

- 1 ampere (A) = 1 coulomb/second (C/s).
- The charge transferred between time t_1 and t_2 is obtained by

$$\Delta q = \int_{t_1}^{t_2} i(t)dt$$

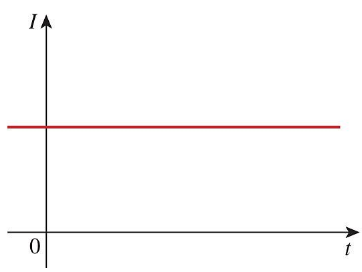
1.2.4. Representing current in circuit (schematic) diagram:

- To talk about current, we need to specify its direction and amount.
- These are conveyed by the direction of the arrow (referred to as the reference direction) and the labeled value (which can be negative if the current actually flows in the opposite direction.)



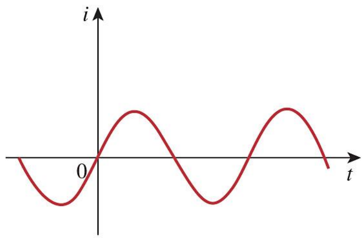
1.2.5. Two types of currents:

(a) A **direct current** (dc) is a current that remains constant with time.



- Produced by sources such as batteries, power supplies.

(b) A **time-varying current** is a current that varies with time.
- An **alternating current** (ac) is a type of time-varying current that varies sinusoidally with time.

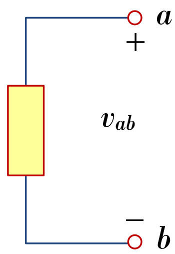


- Such ac current is used in your household, to run the air conditioner, refrigerator, washing machine, and other electric appliances.

1.2.6. By convention the symbol I is used to represent such a constant current. A time-varying current is represented by the symbol i.

Definition 1.2.7. **Voltage** (or potential difference) across an element: the energy required to move a unit charge though an element, measured in volts (V).

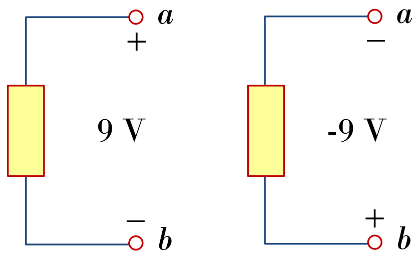
- 1 volt (V) = 1 joule/coulomb = 1 newton-meter/coulomb



- Representing voltage in circuit (schematic) diagram: To talk about voltage, we need to specify
  (a) its polarity via the plus (+) and minus (-) symbols at the two positions (points a and b in the picture above)

  (b) its value (can be a negative number)

- The voltage between two points a and b in a circuit is denoted by v_{ab} and can be interpreted in two ways:



(a) point a is at a potential of v_{ab} volts higher than point b, or
(b) the potential at point a with respect to point b is v_{ab}.

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

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

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

1.2.8. Like electric current, a constant voltage is called a **dc voltage** and is represented by V, whereas a **time-varying** voltage is represented by v. A time-varying voltage that is sinusoidal is called an **ac voltage**.

Example 1.2.9. A dc voltage is commonly produced by a battery; ac voltage is produced by an electric generator.

1.2.10. 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. Engineers prefer to call such variables ***signals*** rather than mathematical functions of time because of their importance in communications and other disciplines.

For practical purposes, we need to be able to find/calculate/measure more than the current and voltage. We all know from experience that a 100-watt bulb gives more light than a 60-watt bulb. We also know that when we pay our bills to the electric utility companies, we are paying for the electric energy consumed over a certain period of time. Thus power and energy calculations are important in circuit analysis.

Definition 1.2.11. **Power**: time rate of *absorbing* (or *expending*) energy, measured in watts (W). Mathematically, the instantaneous power

$$p = \frac{dw}{dt} = \frac{dw}{dq}\frac{dq}{dt} = vi \tag{1.1}$$

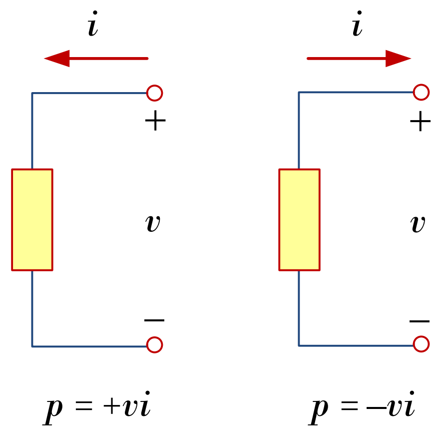
DEFINITION 1.2.12. **Passive Sign Convention** (PSC): Sign of power

(a) **Plus sign**: Power is **absorbed** (consumed) by the element. (resistor)
   - For resistor, we say the power is dissipated.

(b) **Minus sign**: Power is **supplied** by the element. (battery, generator)

1.2.13. To comply with the convention, we have to be careful when applying formula (1.1).

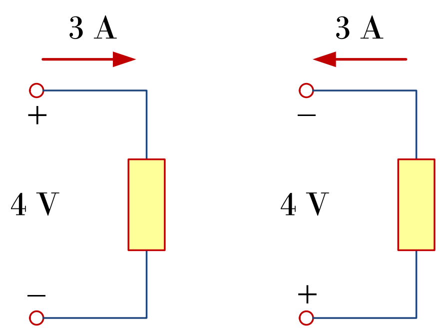
(a) If the current "enters" the element through the "positive terminal" of the voltage across this element, $p = vi$.

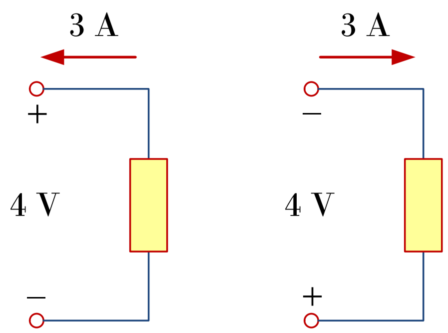


(b) If the current "enters" the element through the "negative terminal" of the voltage across this element, $p = -vi$.

Note that, here, to choose which version of the formula to apply, we only consider the direction of the current's arrow and the polarity of the voltage. We do not have to care whether the variables i and v are positive or negative.

EXAMPLE 1.2.14.



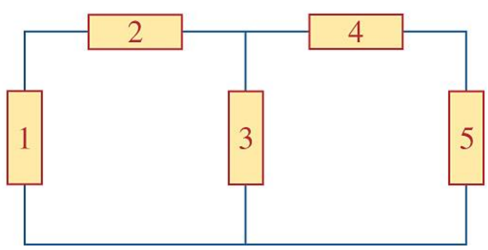


EXAMPLE 1.2.15. Light bulb or battery: which is which?

1.2.16. *Law of Conservation of Energy*: Energy can neither be created nor destroyed, only transferred.

- For this reason, the algebraic sum of power in a circuit, at any instant of time, must be zero.
- The total power supplied to the circuit must balance the total power absorbed.

EXAMPLE 1.2.17. The circuit below has five elements. Let P_k be the power "absorbed" by element k. (Although we use the word "absorbed", if P_k is negative, then element k is actually supplying power.)
If $P_1 = -205$ W, $P_2 = 60$ W, $P_4 = 45$ W, $P_5 = 30$ W,
calculate the power P_3.



1.2.18. **Energy**: the energy absorbed or supplied by an element from time $t = t_1$ to $t = t_2$ is

$$w = \int_{t_1}^{t_2} p(t)\ dt = \int_{t_1}^{t_2} v(t)i(t)\ dt.$$

- Integration suggests finding area under the curve.
- Need to be careful with negative area.

EXAMPLE 1.2.19. **Electricity bills**: The electric power utility companies measure energy in kilowatt-hours (kWh), where 1 kWh = 3600 kJ.

1.3. Circuit Elements

DEFINITION 1.3.1. There are 2 types of elements found in electrical circuits.

1) **Active elements** (is capable of generating energy), e.g., generators, batteries, and operational amplifiers (Op-amp).

2) **Passive element**, e.g., resistors, capacitors and inductors.

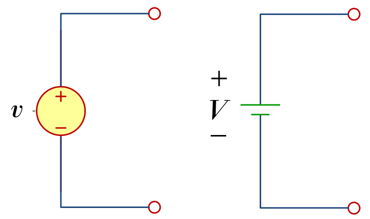
DEFINITION 1.3.2. The most important active elements are voltage and current sources:

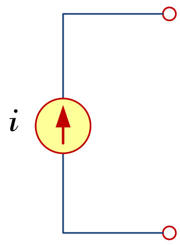
(a) **Voltage source** provides the circuit with a specified voltage (e.g. a 1.5V battery)

(b) **Current source** provides the circuit with a specified current (e.g. a 1A current source).

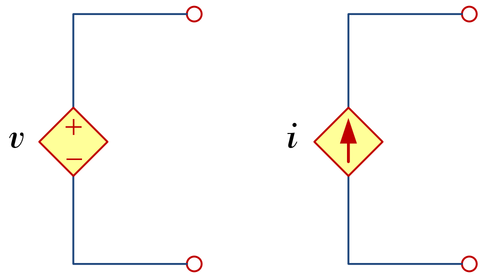
DEFINITION 1.3.3. In addition, we may characterize the voltage or current sources as:

1) **Independent source**: An active element that provides a specified voltage or current that is completely independent of other circuit elements.



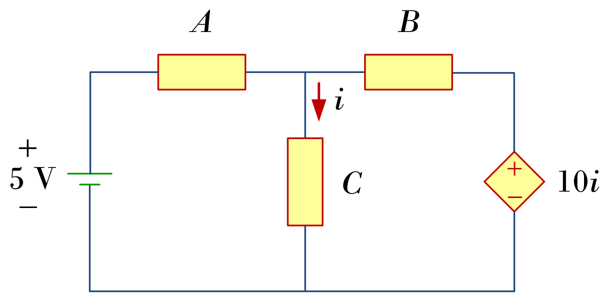


2) **Dependent source**: An active element in which the source quantity is controlled by another voltage or current.



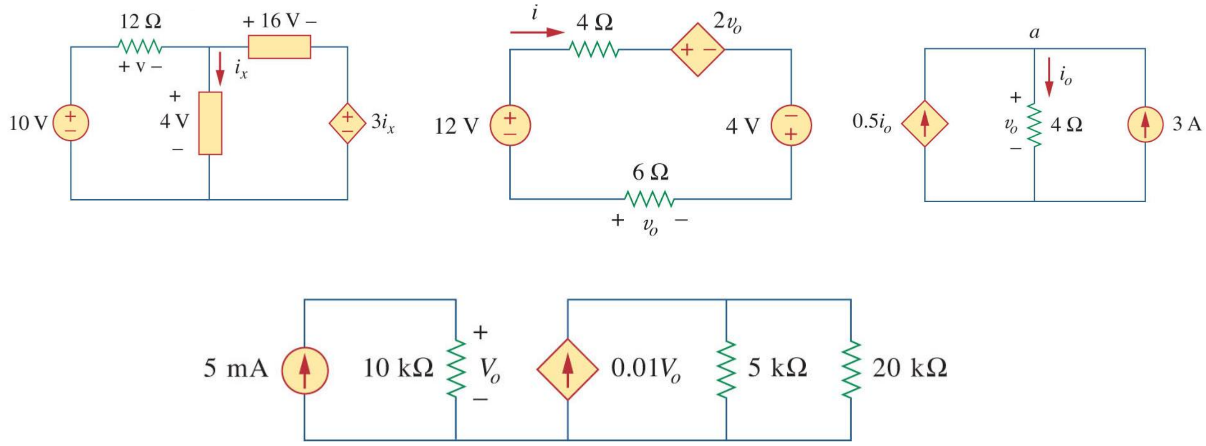
1.3.4. The key idea to keep in mind is that a voltage source comes with polarities (+ -) in its symbol, while a current source comes with an arrow, irrespective of what it depends on.

EXAMPLE 1.3.5. Current-controlled voltage source



EXAMPLE 1.3.6. Draw the general form of a voltage-controlled current source.

Example 1.3.7. Indicate the type of the dependent source in each of the circuit in the figure below.



1.3.8. Remarks:

- Dependent sources are useful in modeling elements such as transistors, operational amplifiers and integrated circuits.
- Ideal sources
  - An ideal voltage source (dependent or independent) will produce any current required to ensure that the terminal voltage is as stated.
  - An ideal current source will produce the necessary voltage to ensure the stated current flow.
  - Thus an ideal source could in theory supply an infinite amount of energy.
- Not only do sources supply power to a circuit, they can absorb power from a circuit too.
- For a voltage source, we know the voltage but not the current supplied or drawn by it. By the same token, we know the current supplied by a current source but not the voltage across it.