ECS 203 - Part 1A - For CPE2

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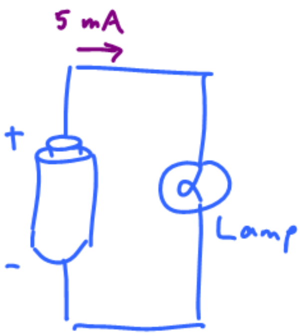
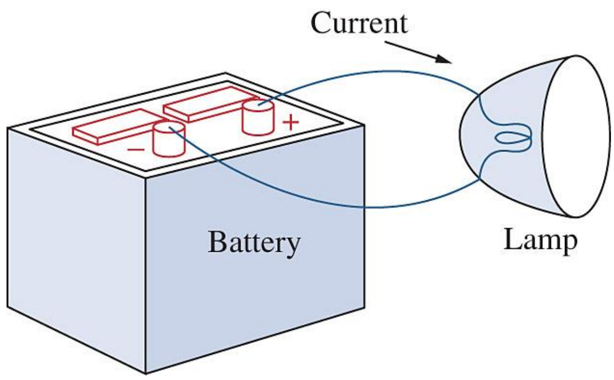
CHAPTER 1

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.





1.1. Systems 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).

- 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

- 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 1.1.2. 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,

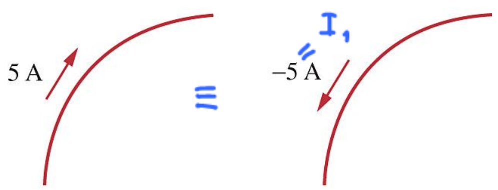
$$i(t) = \frac{d}{dt}q(t)$$

Note:

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

$$q = \int_{t_1}^{t_2} i dt$$

1.2.4. Representing current in circuit diagram:



To talk about current you need to specify two things:
① direction
② amount
These are conveyed by
ⓐ arrow
ⓑ value (positive/negative)
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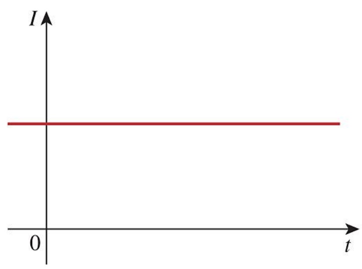
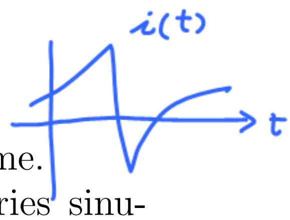
1.2.5. Two types of currents:

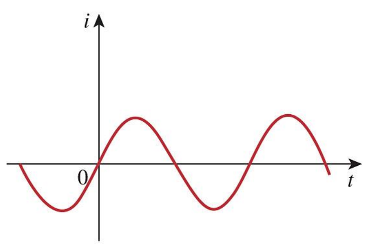
(a) A **direct current** (dc) is a current that remains constant with time.





(b) A **time-varying current** is a current that varies with time.

- An **alternating current** (ac) is a 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): the energy required to move a unit charge though an element, measured in volts (V). The voltage between two points a and b in a circuit is denoted by v_{ab} and can be interpreted in two ways:

Ex. $v_{ab} = 5$ V

(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}.

Note:

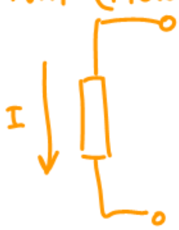
- 1 volt (V) = 1 joule/coulomb = 1 newton-meter/coulomb
- $v_{ab} = -v_{ba}$
- Mathematically,

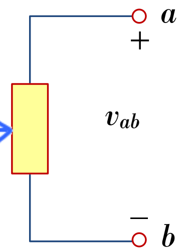
$$v_{ab} = \frac{dw}{dq}$$

(dw: energy (joule: J); dq: charge (coulomb: C))

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

1.2.8. Representing voltage in circuit diagram:

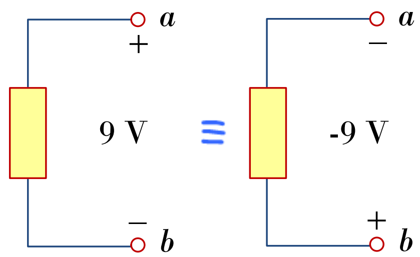




To talk about Voltage, you need to specify a) polarity (+ and −) (reference direction) b) value (positive or negative number)

The plus (+) and minus (-) signs at the points a and b are used to define reference direction (voltage polarity).

Read: $V_{ab} = 9$ V = $V_a - V_b$ "node voltages"



$V_{ba} = -9$ V = $V_b - V_a = -9$ V

1.2.9. 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 1.2.10. A dc voltage is commonly produced by a battery; ac voltage is produced by an electric generator.

1.2.11. 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.

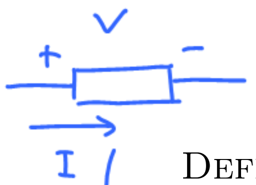
For practical purposes, we need to be able to find/calculate/measure more than the current and voltage. We all know from experience that a 100-watt bulb gives more light than a 60-watt bulb. We also know that when we pay our bills to the electric utility companies, we are paying for the electric energy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

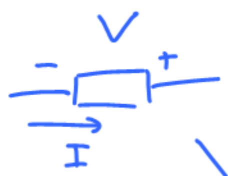
DEFINITION 1.2.12. **Power**: time rate of *absorbing* (or *expending*) energy, measured in watts (W). Mathematically, the instantaneous power

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

DEFINITION 1.2.13. Sign of power

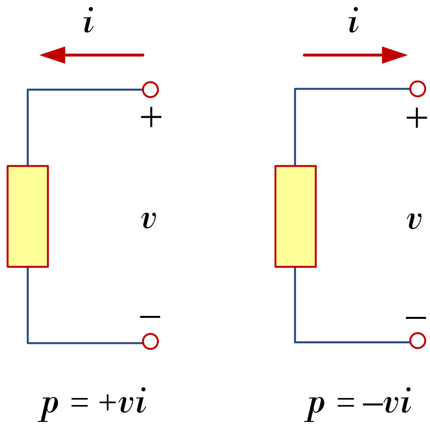
- **Plus sign**: Power is absorbed by the element. (resistor)
- **Minus sign**: Power is supplied by the element. (battery, generator)



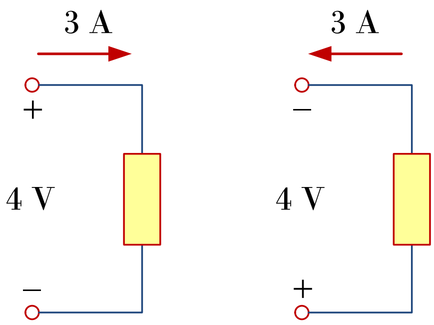


DEFINITION 1.2.14. *Passive sign convention*:

- Passive sign convention is satisfied when the current enters through the positive terminal of an element.
- If the current enters through the positive polarity of the voltage, $p = vi$.
- If the current enters through the negative polarity of the voltage, $p = -vi$.

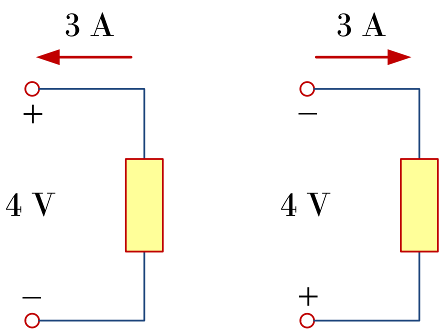


P = IV = 3×4
= 12 W



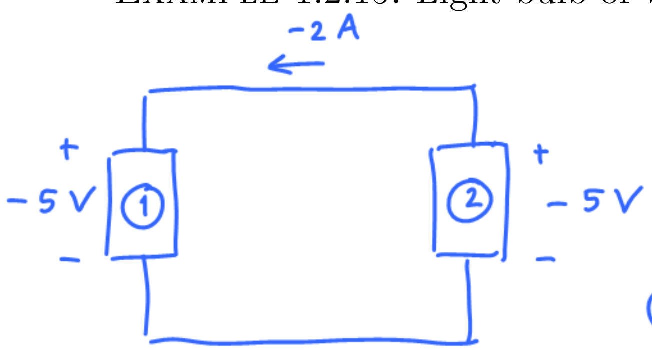
P = IV
= 3×4 = 12 W
absorbing power

P = − IV
= − 3×4 = −12 W



supplying power

Example 1.2.15. Light bulb or battery



① P = VI = (−5)(−2) = 10 W > 0

⇒ absorb power ⇒ light bulb

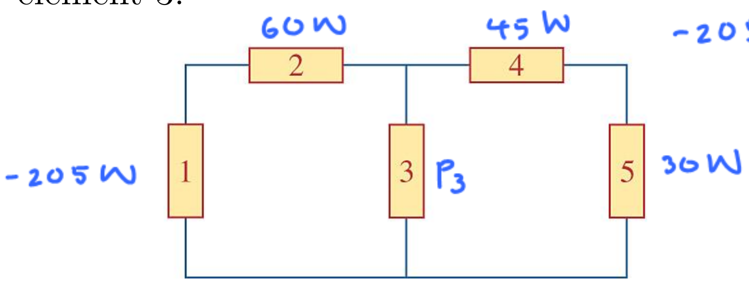
② P = − VI = −(−5)(−2) = −10 W < 0

⇒ supply power ⇒ battery

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. If $p_1 = -205$ W, $p_2 = 60$ W, $p_4 = 45$ W, $p_5 = 30$ W, calculate the power p_3 received or delivered by element 3.



$-205 + 60 + 45 + 30 + P_3 = 0$

$P_3 = 70$ W

1.2.18. **Energy**: the energy absorbed or supplied by an element from time 0 to t is

$$w = \int_0^t p\,dt = \int_0^t vi\,dt.$$

- 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:

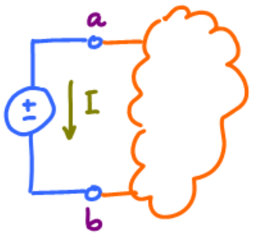
(a) **Voltage source** provides the circuit with a specified voltage (e.g. a 1.5V battery)

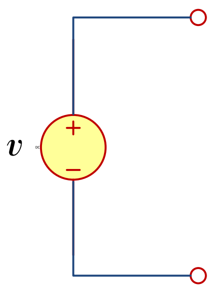
(b) **Current source** provides the circuit with a specified current (e.g. a 1A current source).

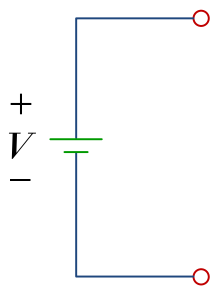
DEFINITION 1.3.3. In addition, we may characterize the voltage or current sources as:

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

Ex.

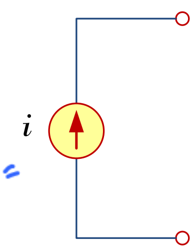






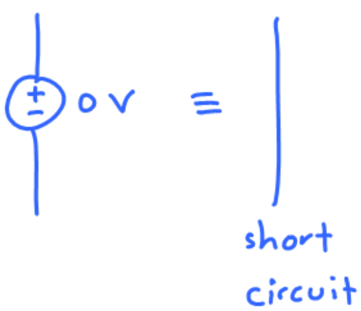
Q: What is the amount of the current I?

A: It depends on what's inside { }. The value of I will be adjusted "automatically" such that the voltage across the source is 5 V.

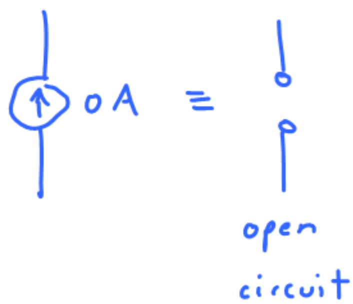


Important special cases

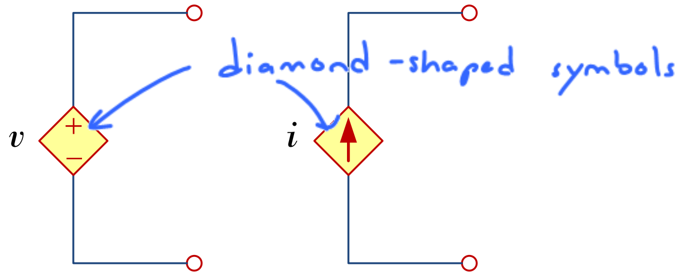
a)



b)

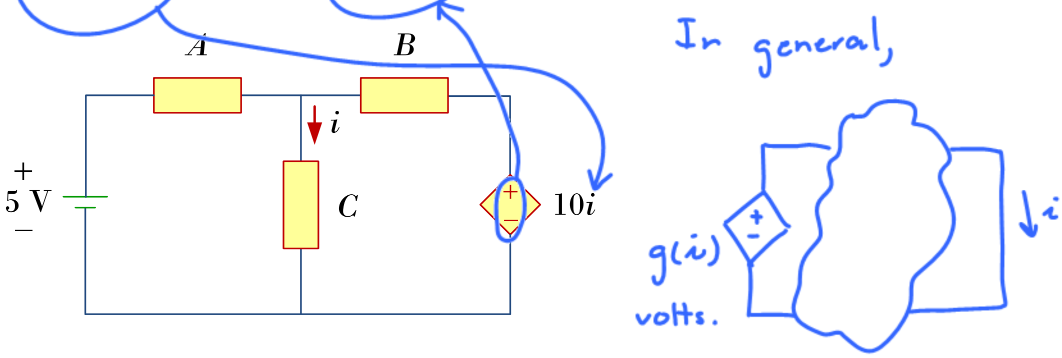


2) **Dependent source**: An active element in which the source quantity is controlled by another voltage or current.

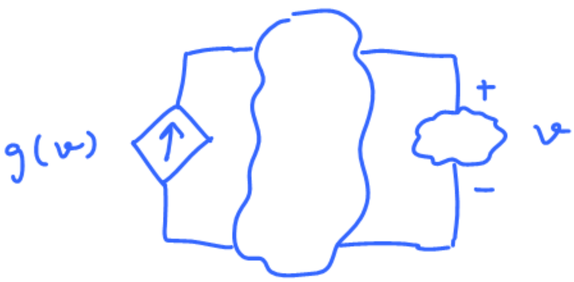


1.3.4. The key idea to keep in mind is that a voltage source comes with polarities (+ -) in its symbol, while a current source comes with an arrow, irrespective of what it depends on.

EXAMPLE 1.3.5. Current-controlled voltage source



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



1.3.7. 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.