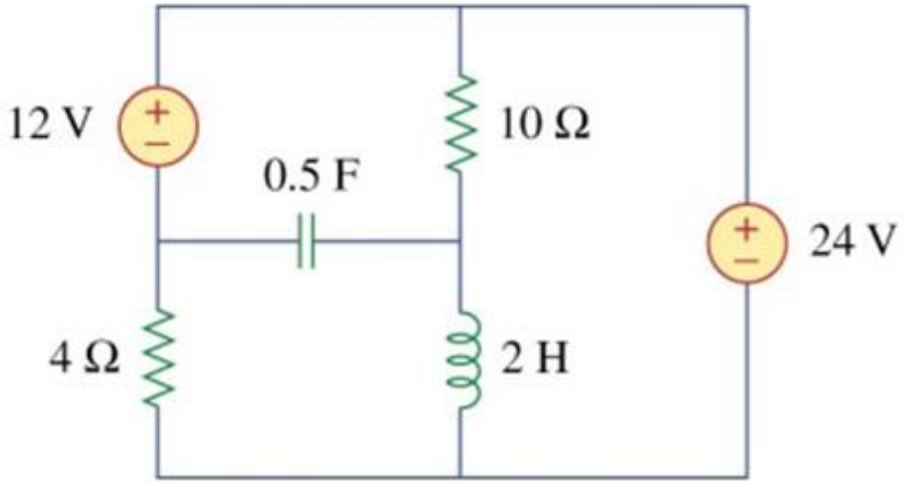
Introduction to Electrical Circuits

Motivation

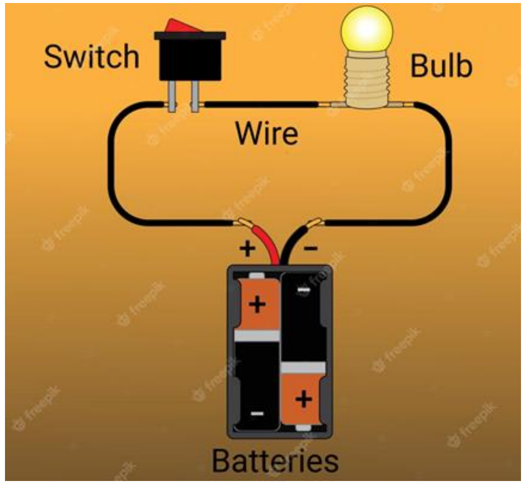
Electrical circuits seem to be everywhere!

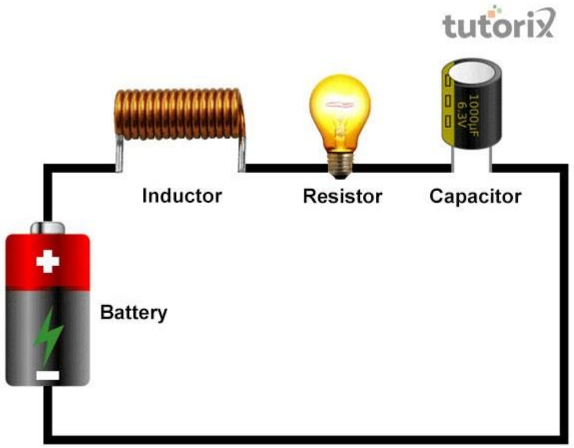
Electric Circuit

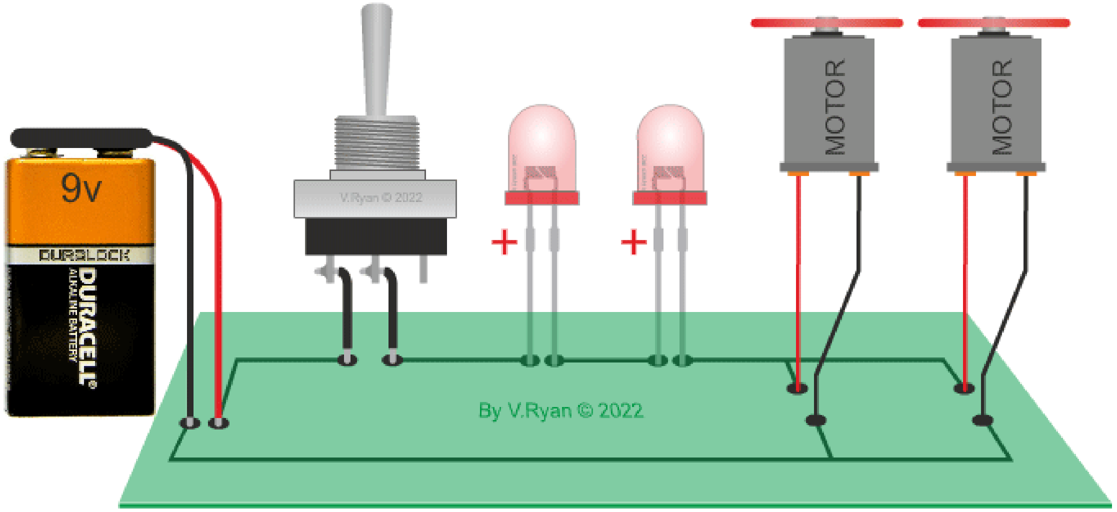
- *Electricity:* physical phenomenon arising from the existence and interaction of electric charge.
- *Electric circuit:* interconnection of electrical components linked together in a closed path to allow electric charge to flow.



A Simple Circuits





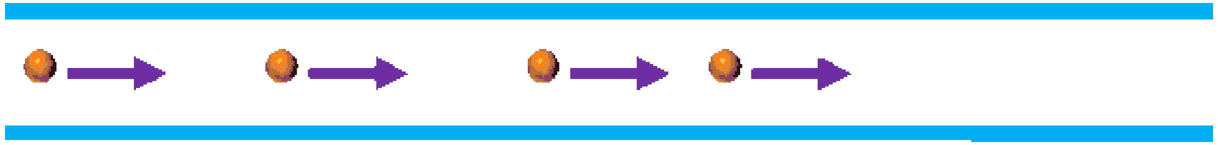


Electric Current (Charges in Motion!)

- **Current:** net flow of charge across any cross section of a conductor, measured in Amperes (Andre-Marie Ampere (1775-1836), a French mathematician and physicist)

- Current can be thought of as the rate of change of charge:

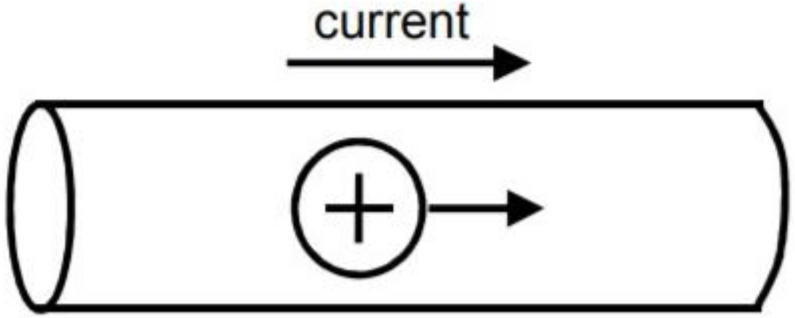
$$i = \frac{dq}{dt}$$



Electric Current

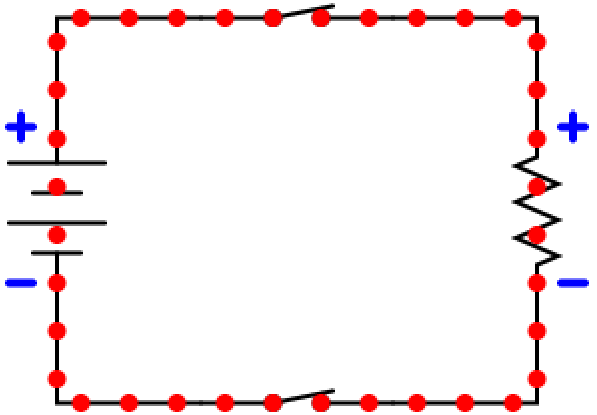
- Originally scientists (in particular Benjamin Franklin (1706-1790) an American scientist and inventor) thought that current is only due to the movement of positive charges.

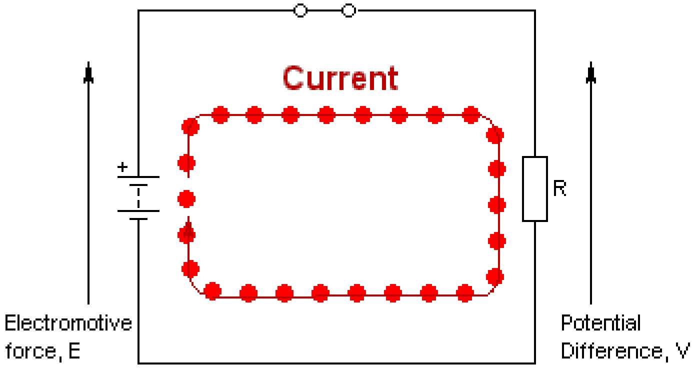
- Thus the direction of the current was considered the direction of movement of positive charges.

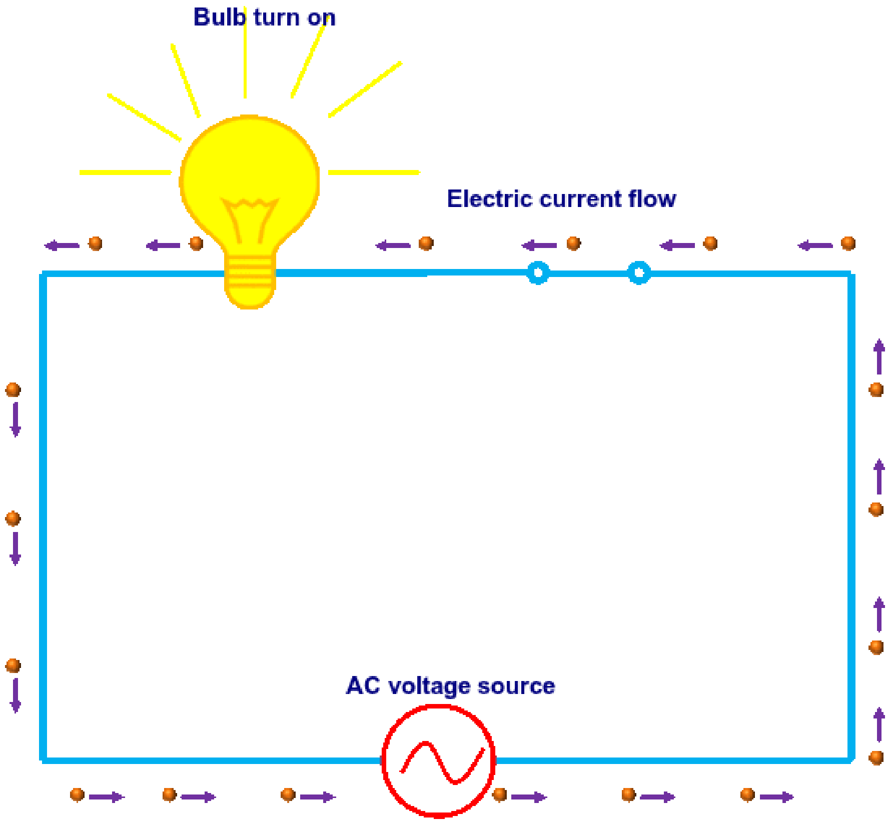


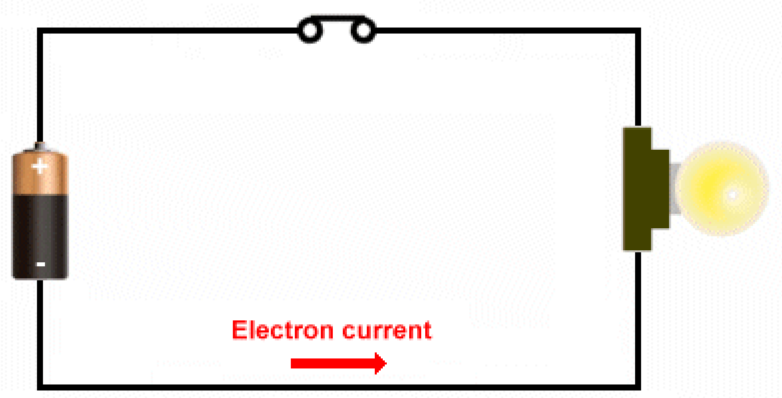
Direction of Current

Direction of electron motion



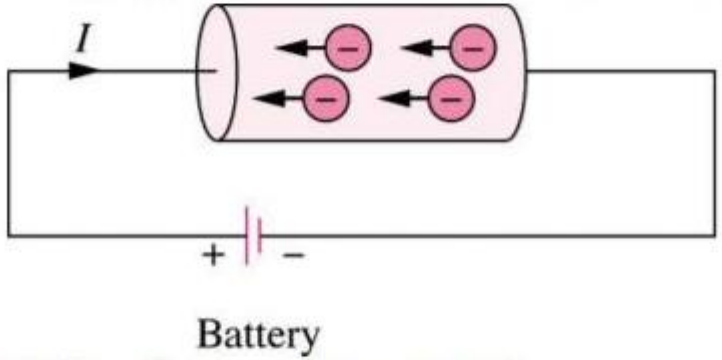




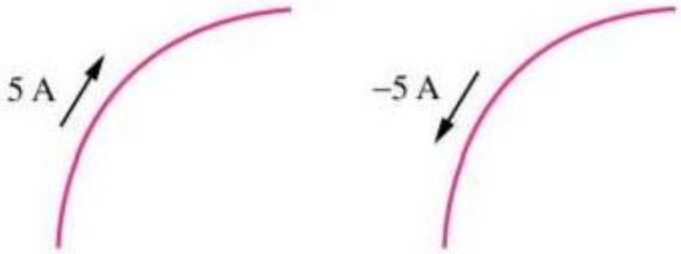


Electric Current

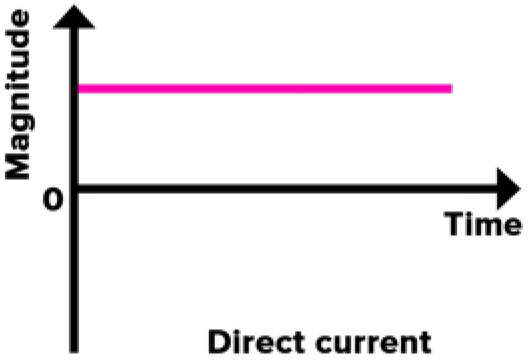
- In reality in metallic conductors current is due to the movement of **electrons**, however, we follow the universally accepted convention that current is in the direction of positive charge movement.

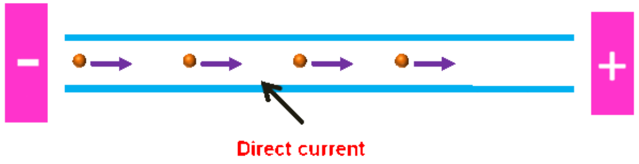


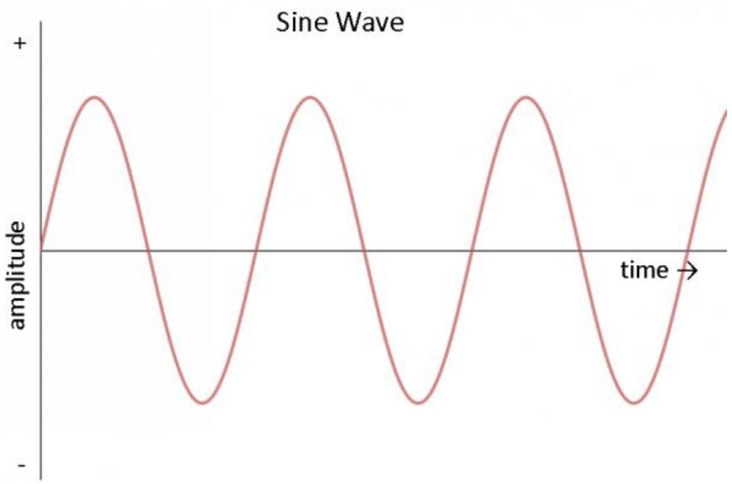
- Two ways of showing the same current:

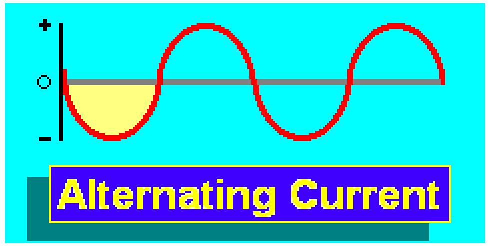


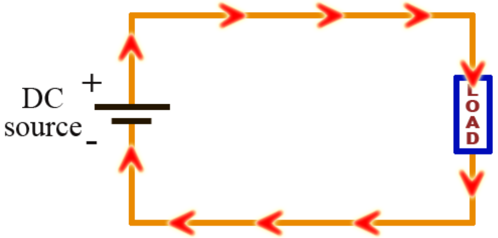
Two Important Types of Currents



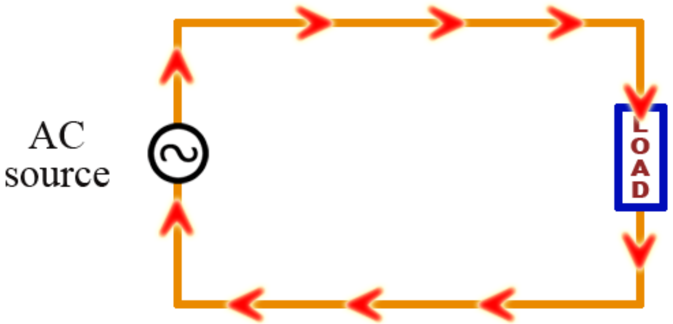






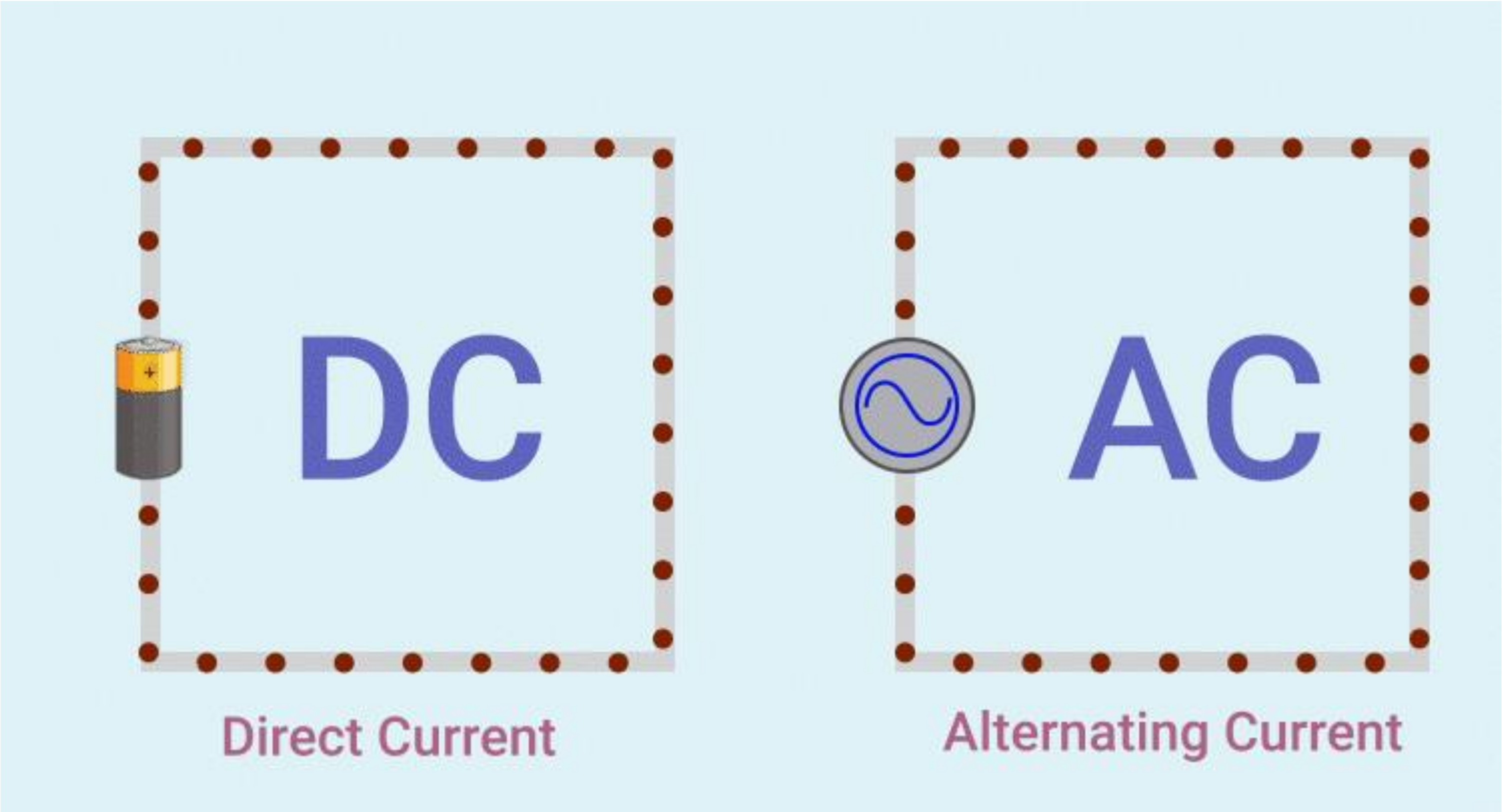


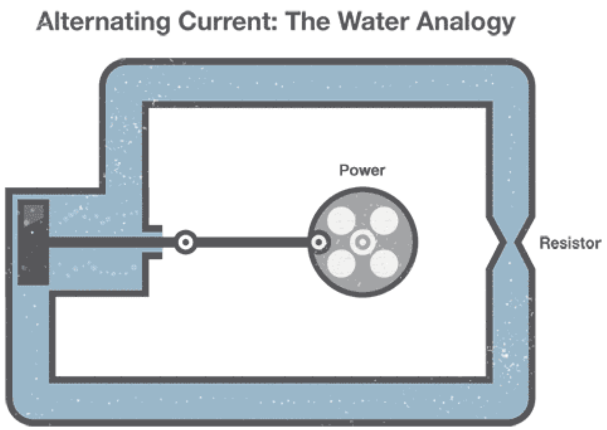
Direct Current

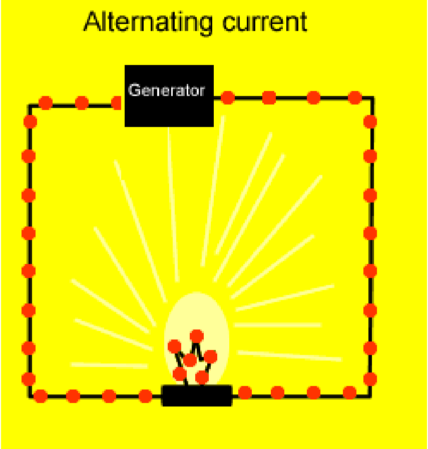


Alternating Current

Two Important Types of Currents

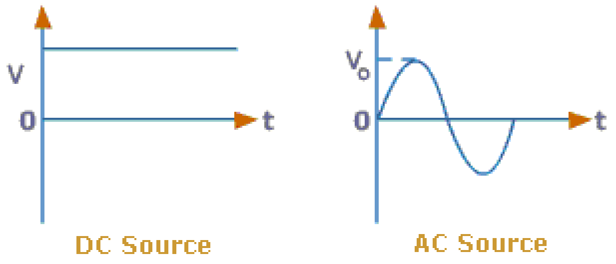




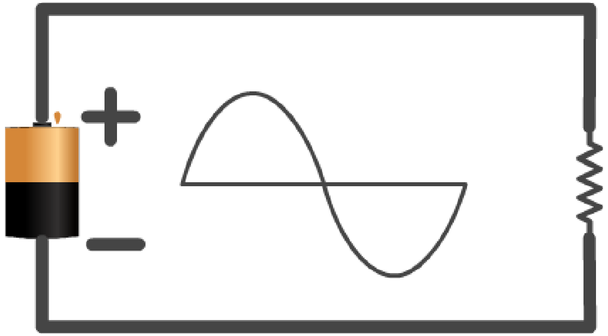


Voltage (Separation of Charges)

- **Voltage** (electromotive force, or potential) is the energy required to move a unit charge through a circuit element, and is measured in Volts (Alessandro Antonio Volta (1745-1827) an Italian Physicist).



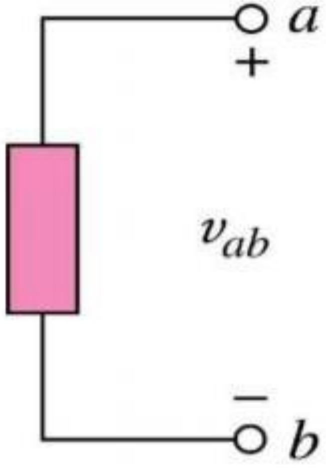
$$v = \frac{dW}{dq}$$

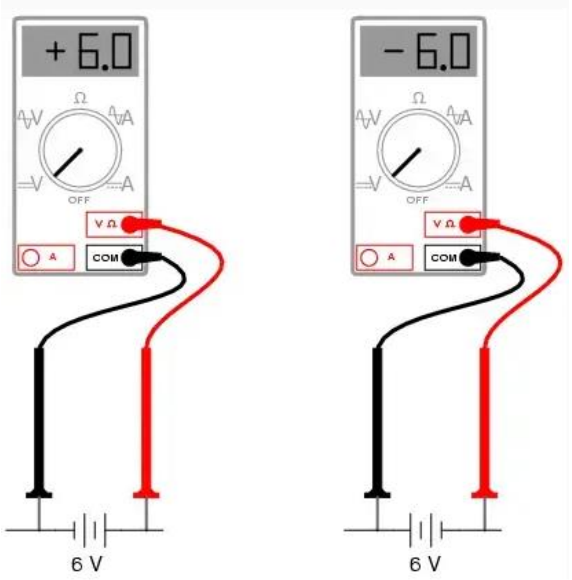


- Similar to electric current, there are two important types of voltage: DC and AC

Voltage Polarity

- The plus (+) and minus (-) sign are used to define voltage polarity.
- The assumption is that the potential of the terminal with (+) polarity is higher than the potential of the terminal with (-) polarity by the amount of voltage drop.

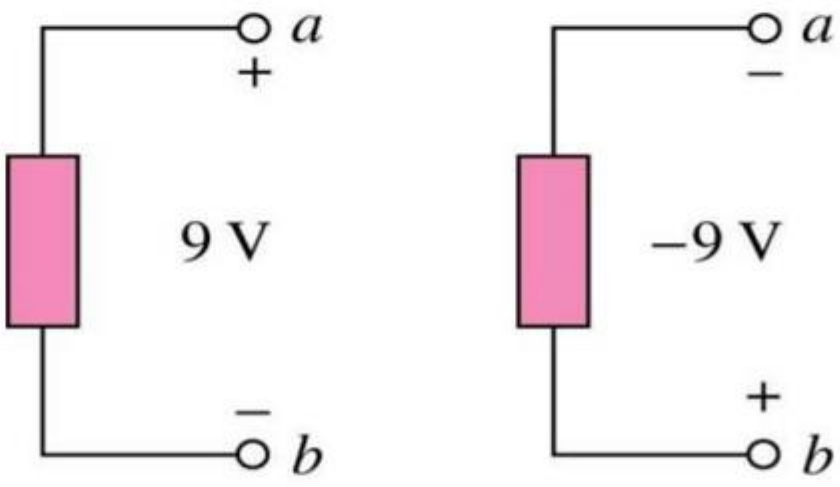




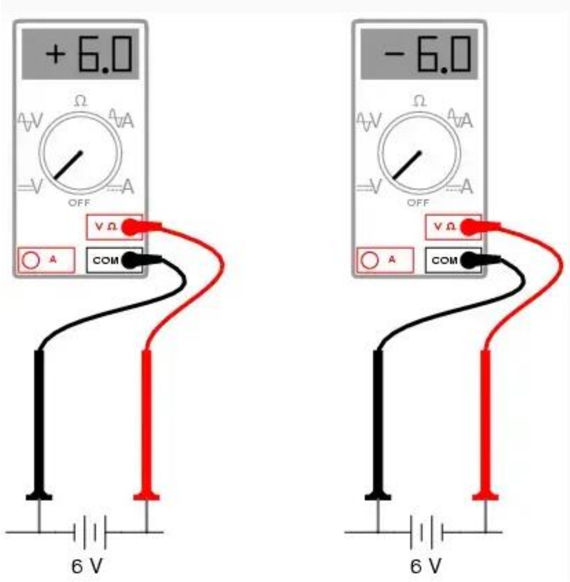
- The polarity assignment is somewhat arbitrary! Is this a scientific statement?!! What do you mean by arbitrary?!!!

Voltage Polarity

- Figures (a) and (b) are two equivalent representation of the same voltage:



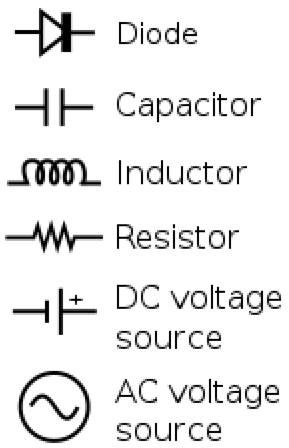
(a) (b)



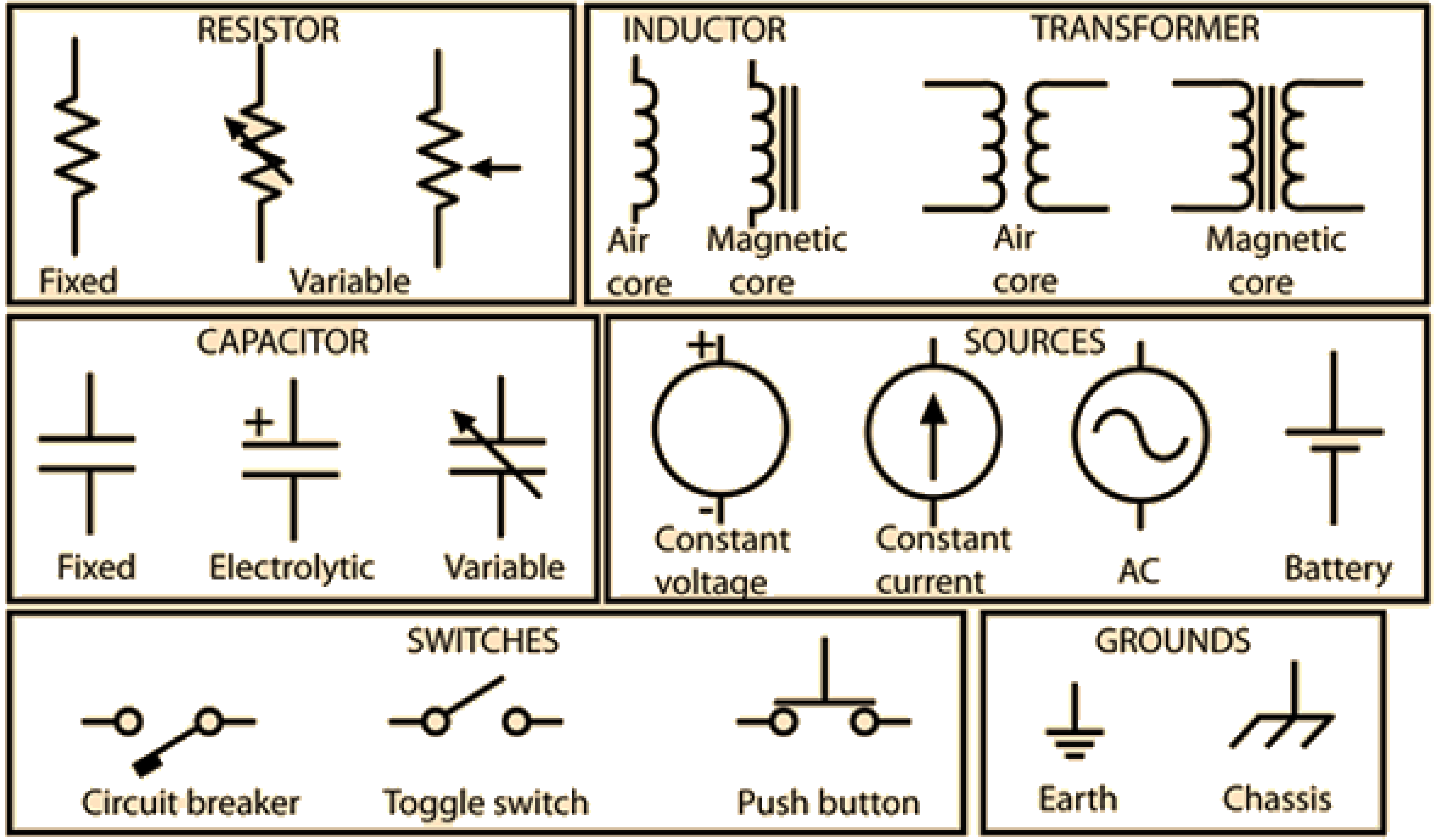
- Both show that the potential of terminal a is 9V higher than the potential of terminal b.

Circuit Elements

- Circuit components can be broadly classified as being either **active** or **passive**.
- An active element is capable of generating energy.
  - Example: current or voltage sources
- A passive element is an element that does not generate energy, however, they can either consume or store energy.
  - Example: resistors, capacitors, and inductors

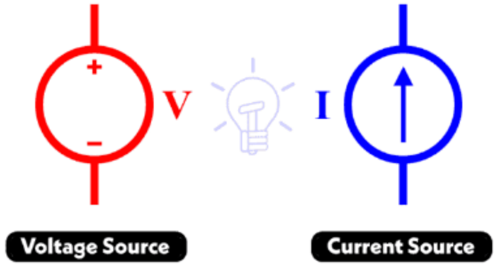


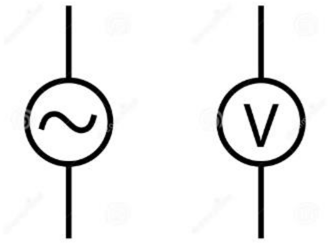
Basic Circuit Elements

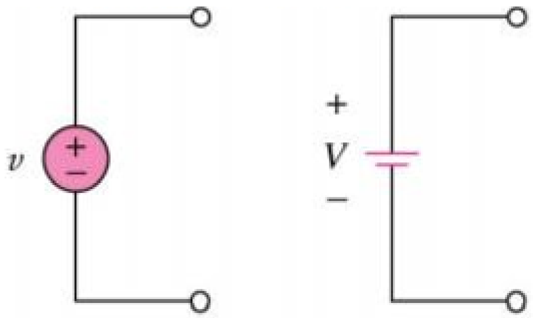


Ideal Voltage and Current Sources

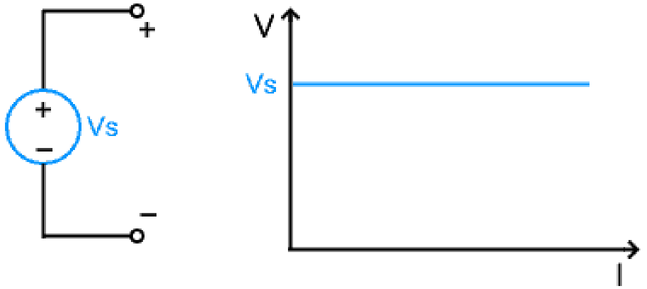
- Independent sources: An (ideal) independent source is an active element that provides a specified voltage or current that is independent of other circuit elements and/or how the source is used in the circuit.
- Symbol for independent voltage source
  (a) Used for constant or time-varying voltage
  (b) Used for constant voltage (dc)



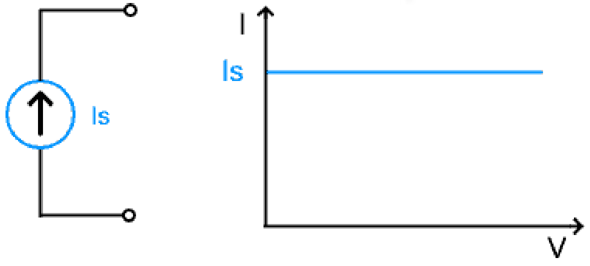




(a) (b)



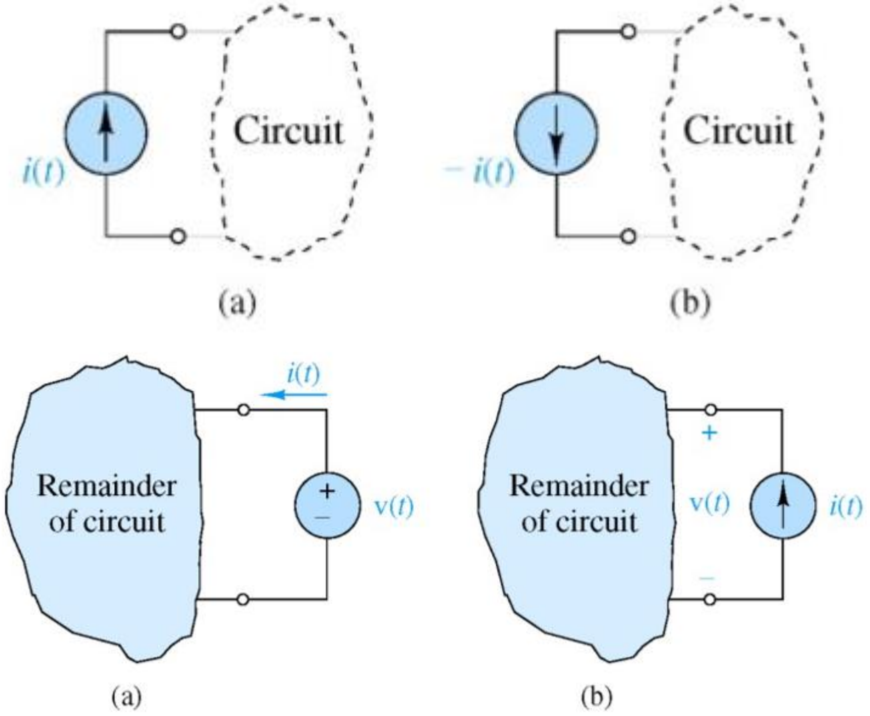
Ideal Voltage Source



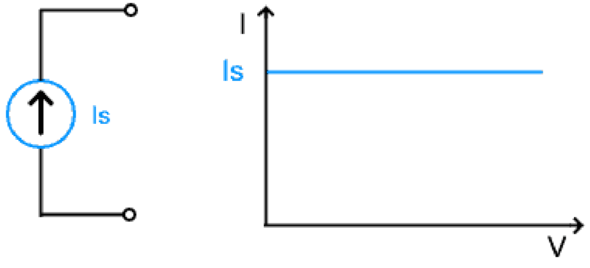
Ideal Current Source

Ideal Voltage and Current Sources

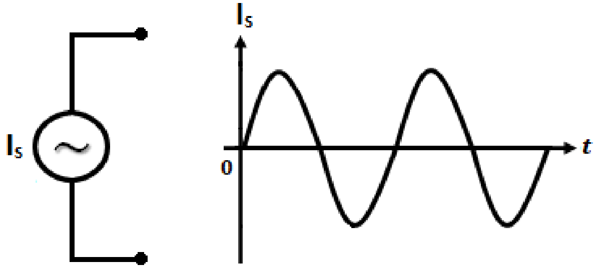
- Equivalent representation of ideal independent current sources whose current *i(t)* is maintained under all voltage requirements of the attached circuit:



Common Voltage and Current Source Labeling



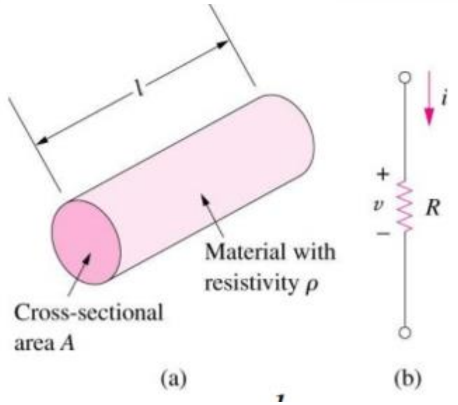
Ideal Current Source



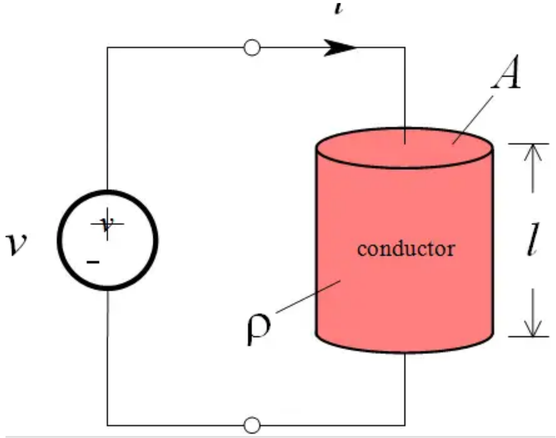
Alternating Current Source

Resistance

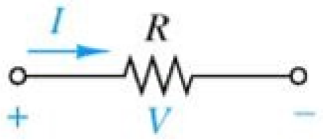
- Different material allow charges to move within them with different levels of ease. This physical property or ability to resist current is known as resistance.



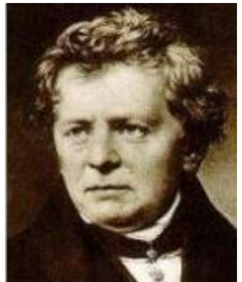
- The resistance of any material with a uniform cross-sectional area A and length l is inversely proportional to A and directly proportional to l.



$$R \propto \frac{l}{A} \qquad R = \rho \frac{l}{A}$$

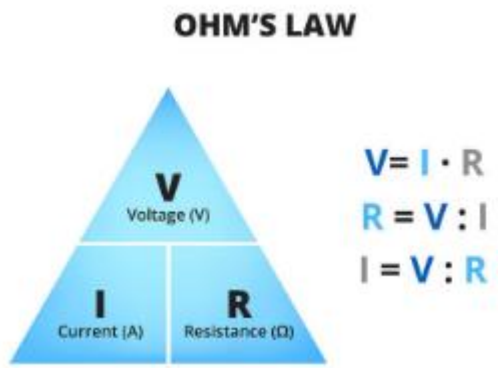


- The constant of the proportionality is the resistivity of the material, i.e., ρ
- A conductor designed to have a specific resistance is called a resistor.
- In honor of George Simon Ohm (1787-1854), a German physicist, the unit of resistance is named Ohm (Ω).



Ohm's Law

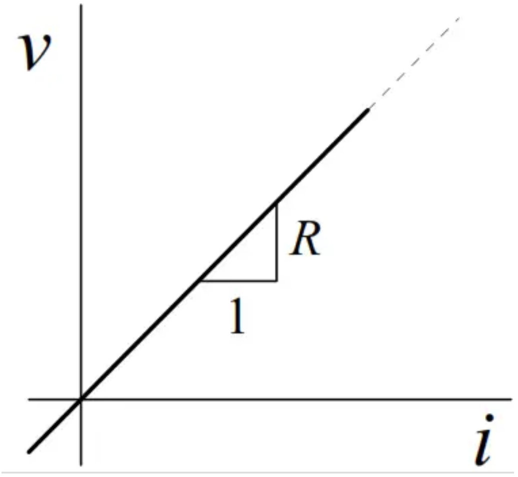
- The voltage *v* across a resistor is directly proportional to the current *i* flowing through the resistor. The proportionality constant is the resistance of the resistor, i.e., $v(t) = Ri(t)$



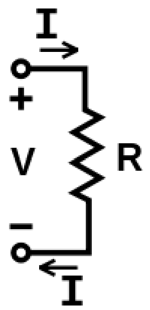
- One can also write: $$i(t) = \frac{1}{R}v(t) \Rightarrow i(t) = Gv(t)$$

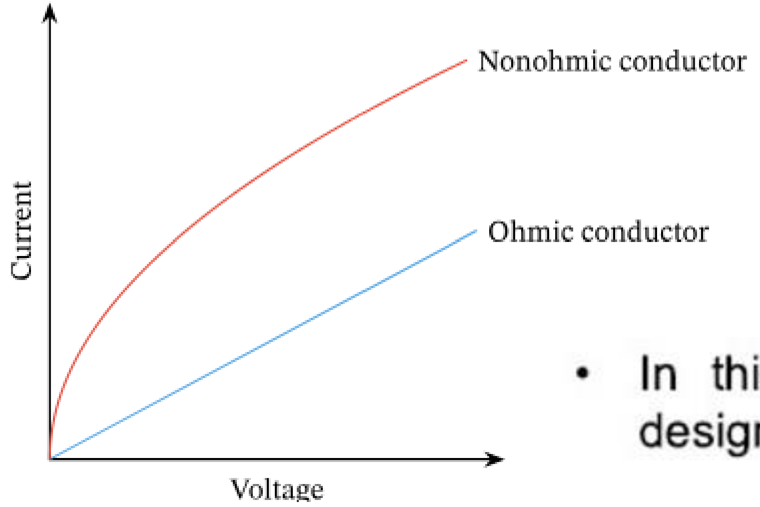
- Instantaneous power dissipated in a resistor

$$p(t) = v(t)i(t) = \frac{v^2(t)}{R} = Ri^2(t)$$



$$I = \frac{V}{R}$$





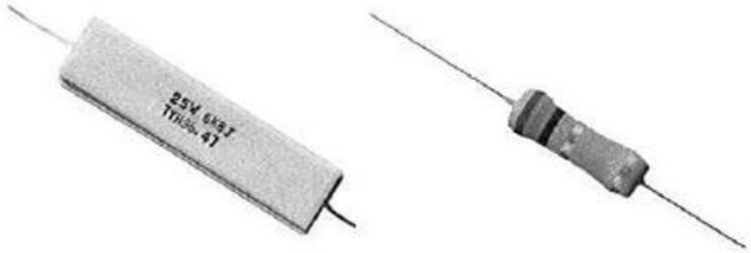
- In this course, we assume that all the elements that are designated as resistors are linear (unless mentioned otherwise)

Fixed and Variable Resistors

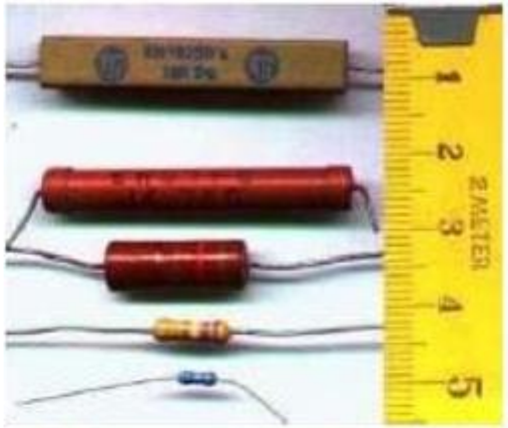
- Fixed resistors have a resistance that remains constants.
- Two common type of fixed resistors are:

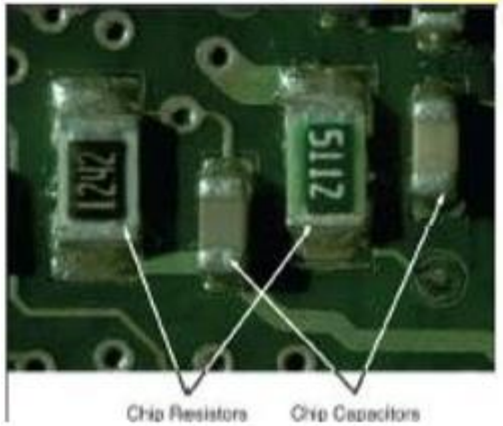
  (a) wirewound

  (b) composition (carbon film type)



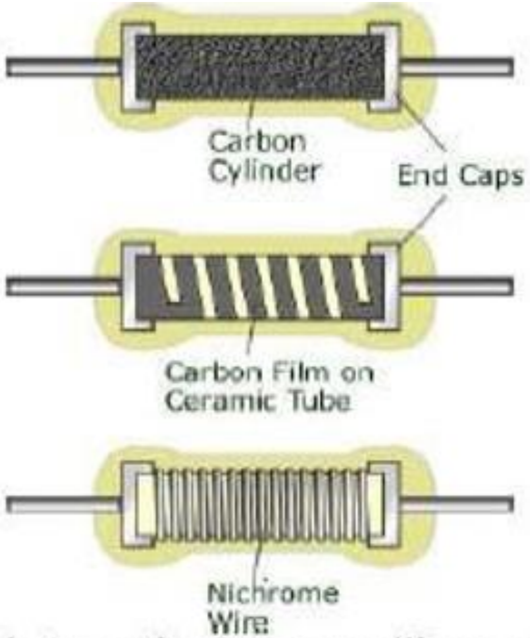
(a) (b)





Fixed Resistors

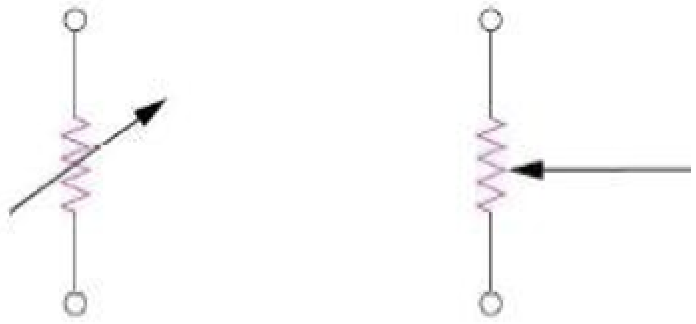
- Inside the resistor



- A common type of resistor that you will work with in your labs:
- It has 4 color-coded bands (3 for value and one for tolerance)
  - How to read the value of the resistor?

Variable Resistors

- Variable resistors have adjustable resistance and are typically called potentiometer (or pot for short).
- Potentiometers have three terminals one of which is a sliding contact or wiper.

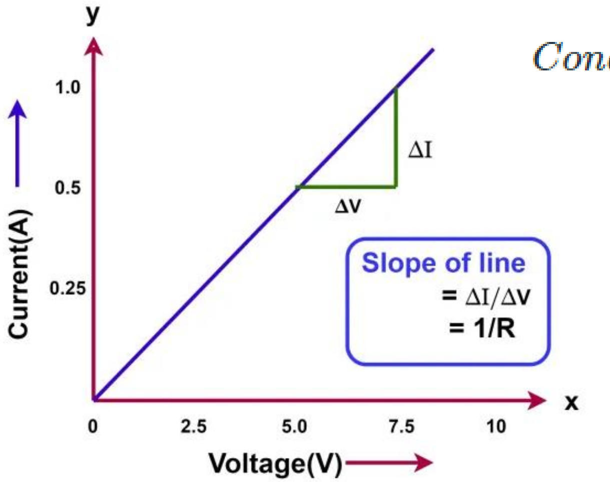


(a) (b)

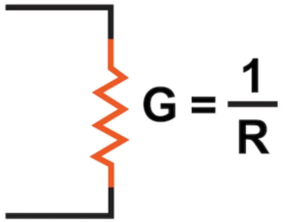
Conductance

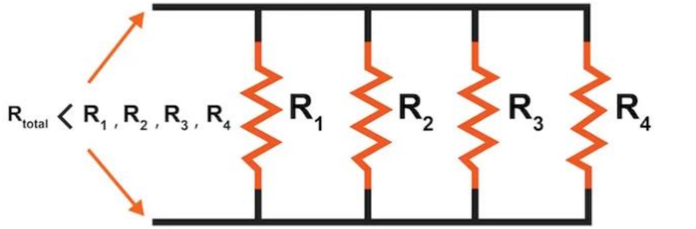
- G=1/R is called the conductance of the element and is measured in siemens (S) or mho (℧) .
- Conductance is the ability of an element to conduct current.
- A device with zero (no) resistance has infinite conductance and a device with infinite resistance has zero conductance.

German inventor Ernst Werner von (1816-1892)

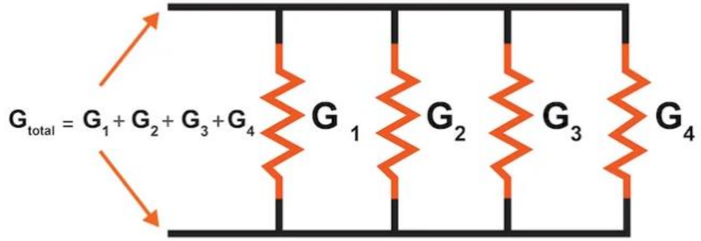


$$Conductance\ (S) = \frac{1}{Resistance\ (\Omega)}$$



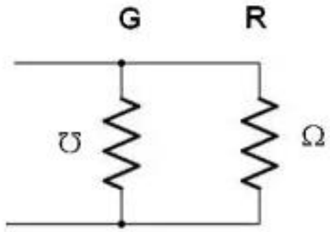


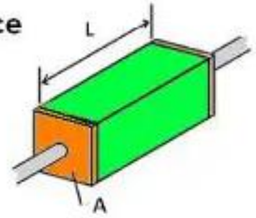
$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$



$$R_{total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}}$$

Conductance and resistance





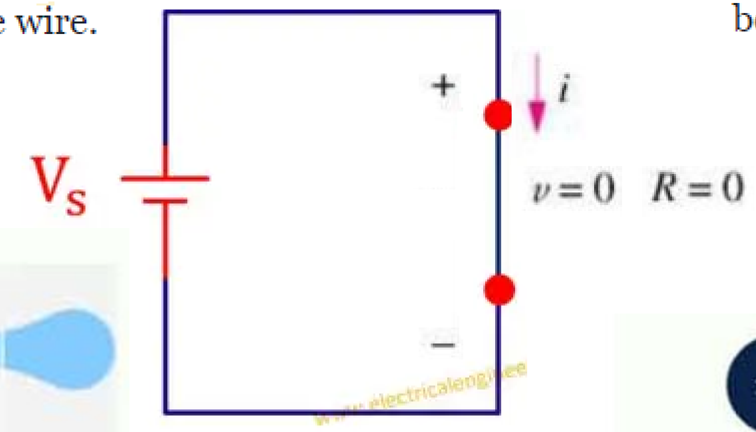
G = 1/R =I/V

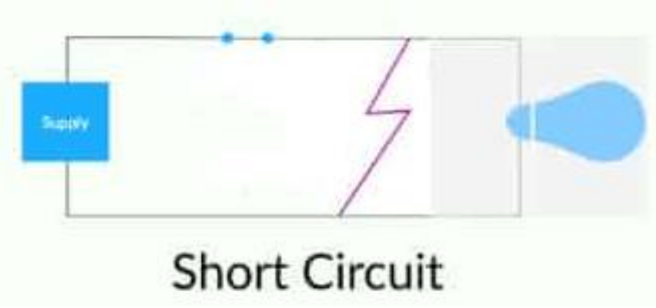
G = (A σ)/L

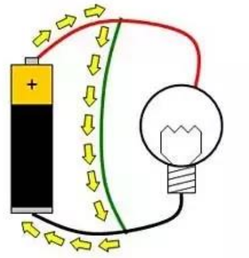
Short Circuit and Open Circuit

- A device with zero resistance is called short circuit and a device with zero conductance (i.e., infinite resistance) is called open-circuit.

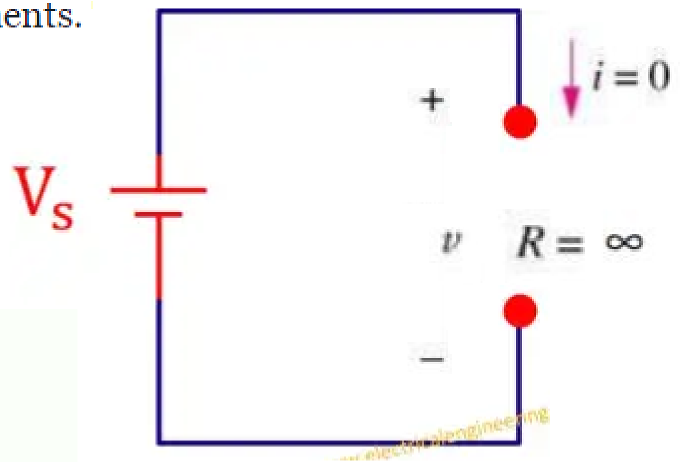
A ***short circuit*** is the one where components are connected with a very small or zero resistance wire.

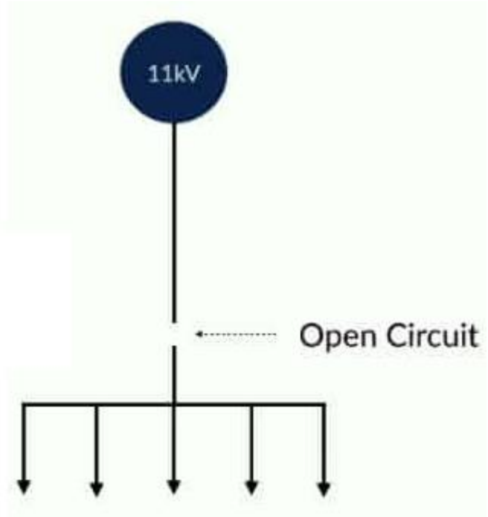


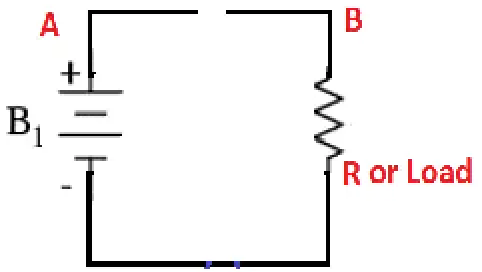




An ***open circuit*** is the one having a disconnection between components.

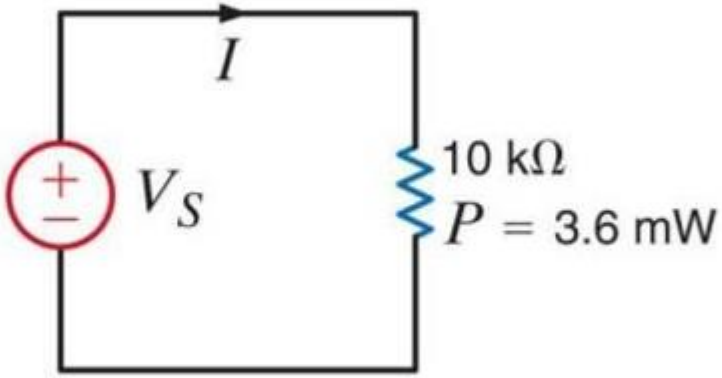




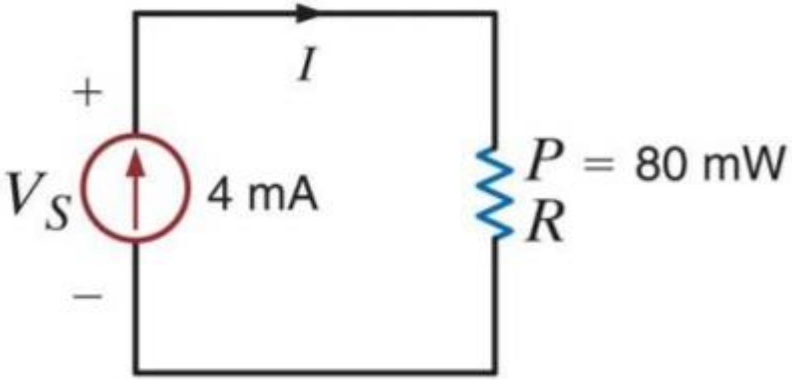


Examples

- The power absorbed by the 10-kΩ resistor in the following circuit is 3.6 mW. Determine the voltage and the current in the circuit.



- Given the following network, find *R* and V_S.



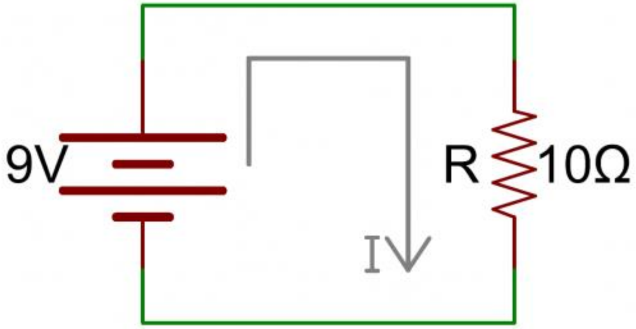
Electrical Power & Energy

- ## Electrical Power

- The rate of change of (expending or absorbing) energy per unit time, measured in Watts (James Watt (1736-1819) a Scottish inventor and mechanical engineer)

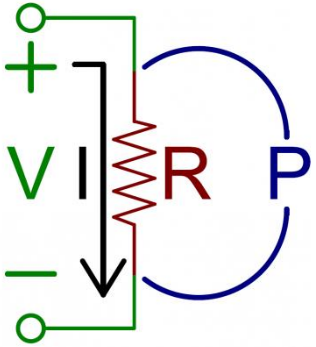
$$p = \frac{dW}{dt} = \frac{dW}{dq} \times \frac{dq}{dt} = vi \qquad watt = W = \frac{joule}{second} = \frac{J}{s}$$

$$power = volts \times amperes = \frac{joules}{\cancel{coulomb}} \times \frac{\cancel{coulomb}}{second} = watt$$



$$I = \frac{V}{R} = \frac{9\,V}{10\,\Omega} = 0.9\,A = 900\,mA$$

$$P = I \times V = 9\,V \times 0.9\,A = 8.1\,W$$



$$P = I^2 \times R$$

$$P = \frac{V^2}{R}$$

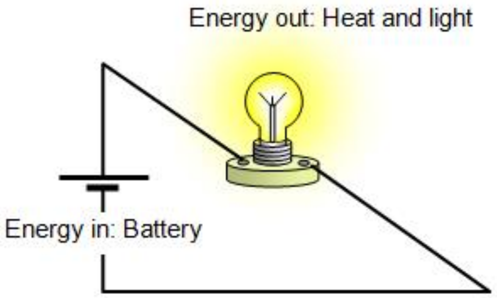
$$P = VI$$

Electrical Power & Energy

- **Electrical Energy**
- is the ability of an electrical circuit to produce work by creating an action. This action can take many forms, such as thermal, electromagnetic, mechanical, electrical, etc.

- Energy absorbed or supplied by an element from time t_0 to time $t>t_0$

$$W = W(t_0, t) = \int_{t_0}^{t} p(\tau)d\tau = \int_{t_0}^{t} v(\tau)i(\tau)d\tau$$



- **Example**
- A 100 Watt light bulb is illuminated on for one hour only. How many joules of electrical energy have been used by the lamp.

Electrical Energy = Power × Time

Electrical Energy = 100 × (60×60)

W = 360,000 joules (360 kJ)

- **Example**
- How much energy does a 1200 W dishwasher use when it runs for 30 minutes (1800s)?

Electrical Energy = Power × Time

Electrical Energy = 1200 × (30×60)

W = 2160,000 joules (2160 kJ) (2.16 MJ)

Classification of Circuit Components

- One common classification for circuit components is to group them in two major groups:

1) Passive components or passive elements

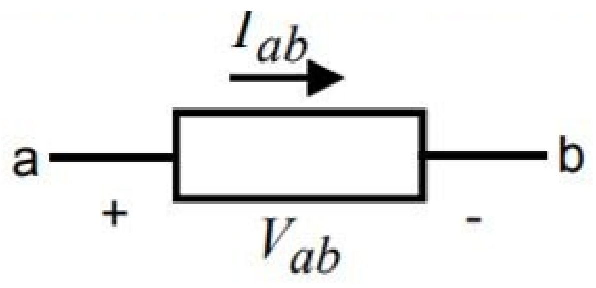
   Components or elements that absorb power.

2) Active components or active elements

   Components that are not passive! that is, components that deliver power.

Passive Sign Convention

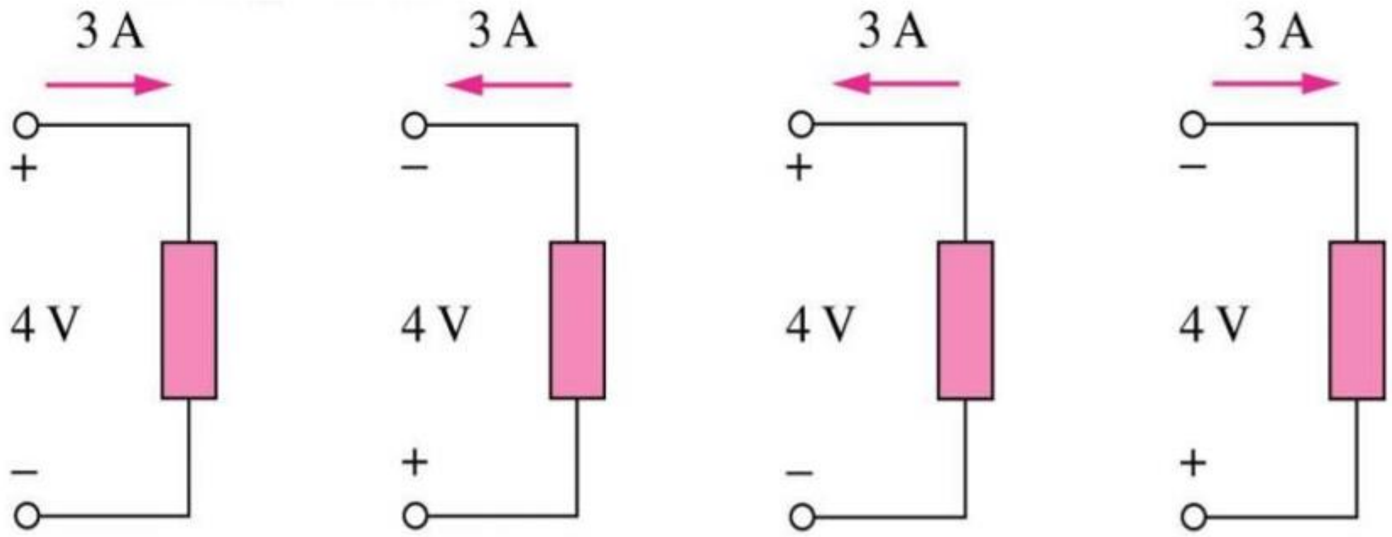
- For calculating absorbed power: The power absorbed by any circuit element with terminals A and B is equal to the voltage drop from A to B multiplied by the current through the element from A to B, i.e., $P = V_{ab} \times I_{ab}$



- With this convention if $P \geq 0$, then the element is absorbing (consuming) power. Otherwise (i.e., $P < 0$) is absorbing negative power or actually generating (delivering) power.

Passive Sign Convention

- Calculate the power absorbed or supplied by each of the following elements:

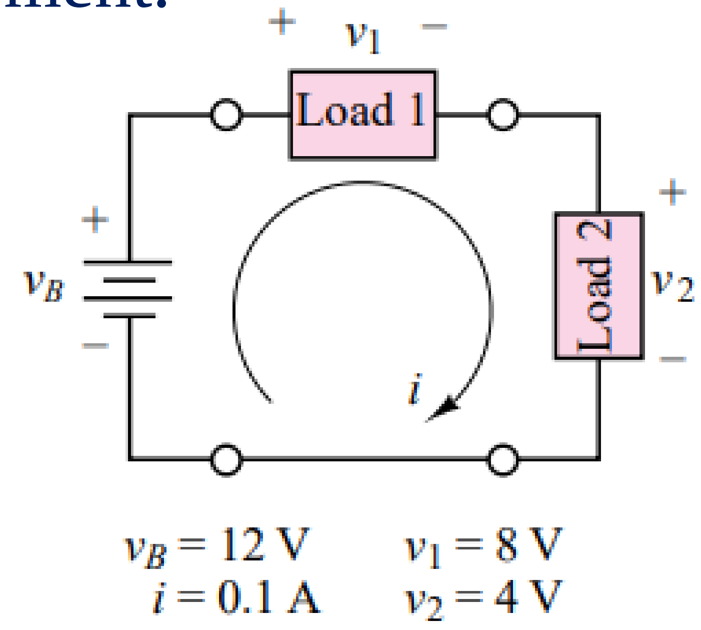


Assign polarities to all passive elements (resistors and other loads); for passive elements, current always flows into the positive terminal.

Compute the power dissipated by each element according to the following rule: If positive current flows into the positive terminal of an element, then the power dissipated is positive (i.e., the element absorbs power); if the current leaves the positive terminal of an element, then the power dissipated is negative (i.e., the element delivers power).

Example

- Find: Power dissipated or generated by each element.



$$P_B = -v_B \times i = -12\text{ V} \times 0.1\text{ A} = -1.2\text{ W}$$

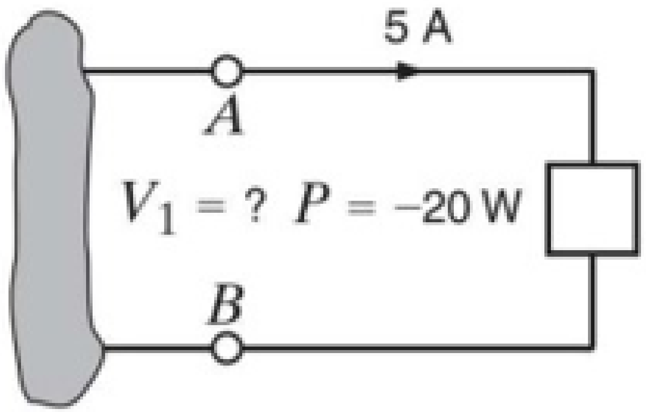
- that is, the battery generates 1.2 watts (W).
- The power dissipated by the two loads will be a positive quantity in both cases, since current flows from plus to minus:

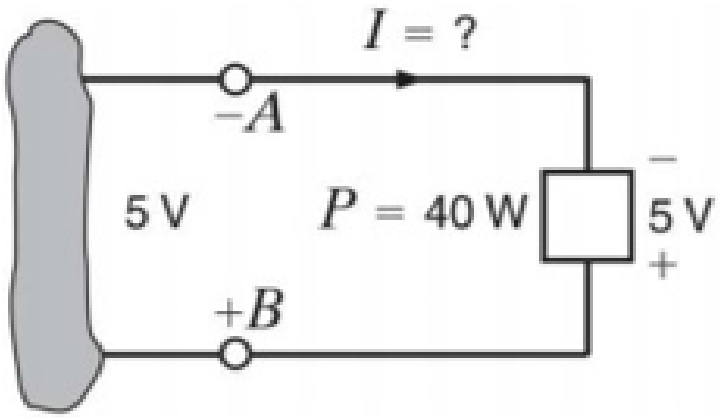
$$P_1 = v_1 \times i = 8\text{ V} \times 0.1\text{ A} = 0.8\text{ W}$$

$$P_2 = v_2 \times i = 4\text{ V} \times 0.1\text{ A} = 0.4\text{ W}$$

Example

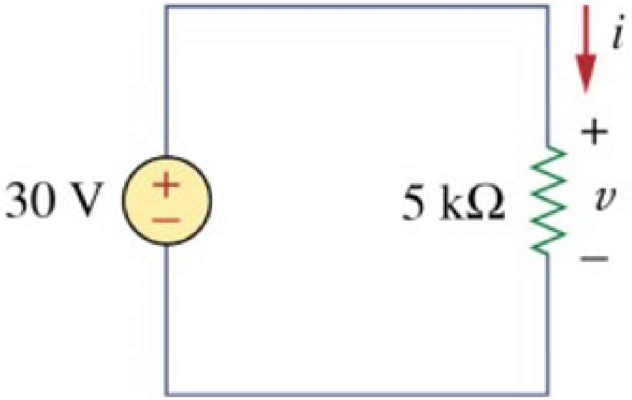
- Determine the unknown voltage or the unknown current.



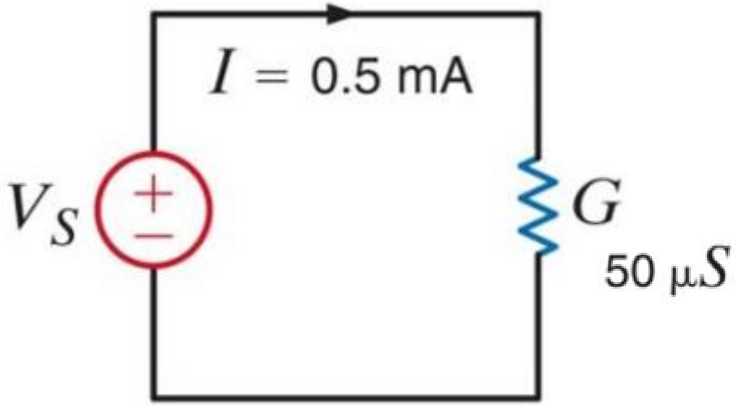


Example

In the circuit shown, calculate the current (i), the conductance (G) and power (p) dissipated in the load (resistor).

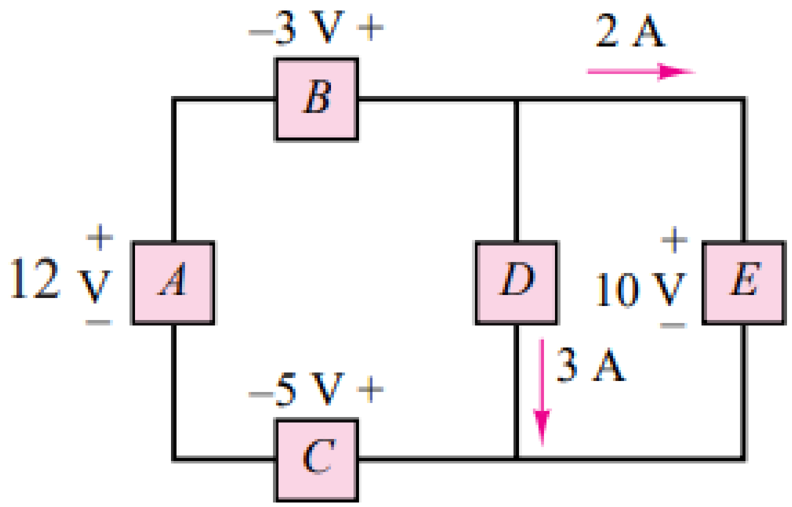


- Given the following circuit, find the value of the voltage source and the power absorbed by the resistance.



Example

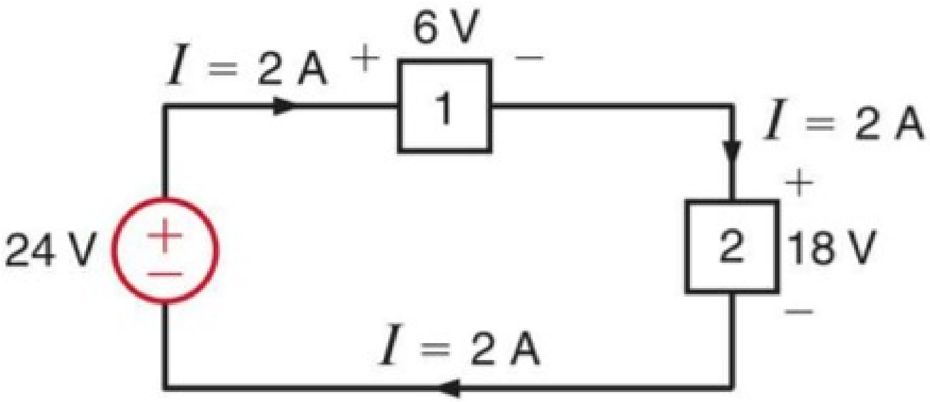
- Determine which components are absorbing power and which are delivering power. Is conservation of power satisfied? Explain your answer.



A supplies (12 V)(5 A) = 60 W
B supplies (3 V)(5 A) = 15 W
C absorbs (5 V)(5 A) = 25 W
D absorbs (10 V)(3 A) = 30 W
E absorbs (10 V)(2 A) = 20 W
Total power supplied = 60 W + 15 W = 75 W
Total power absorbed = 25 W + 30 W + 20 W = 75 W
Total power supplied = Total power absorbed, so conservation of power is satisfied

Example

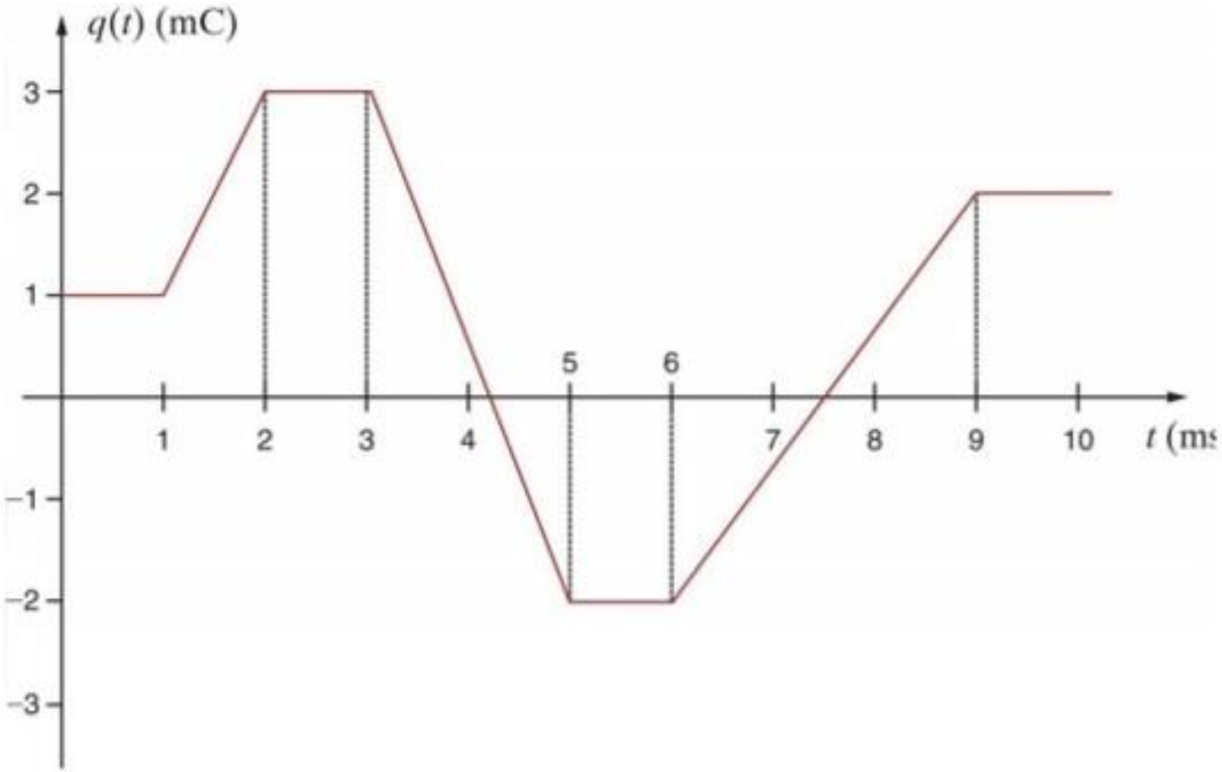
- Determine the power absorbed or supplied by the elements of the following network:

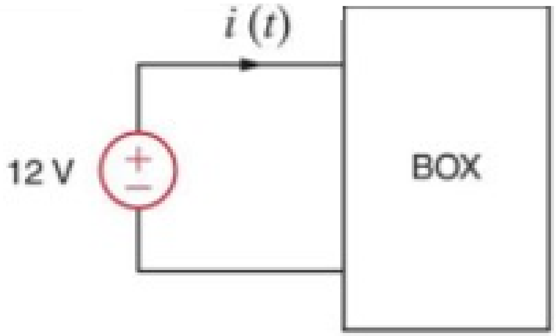


A resistor absorbs an instantaneous power of p=20cos$^2 t$ mW when connected to a voltage source v=10cos t V. Find i and R.

Example

- The charge that enters the BOX is shown below. Calculate and sketch the current flowing into the BOX and the power absorbed by the BOX between 0 and 10 milliseconds.





Example

- A third-generation iPod® with a 630 mAh Lithium-ion battery is to be recharged from a high-power USB port supplying 150 mA of current. At the beginning of the recharge, 7.8 C of charge are stored in the battery. The recharging process halts when the stored charge reaches 35.9 C. How long does it take to recharge the battery?