Lecture (7)

Electricity and Magnetism I

First Stage
Department of Physics
College of Science
Al-Muthanna University
2018-2019

Dr. Ahmed Almurshedi
Ph.D., M.Sc., B.Sc.
Medical Physics

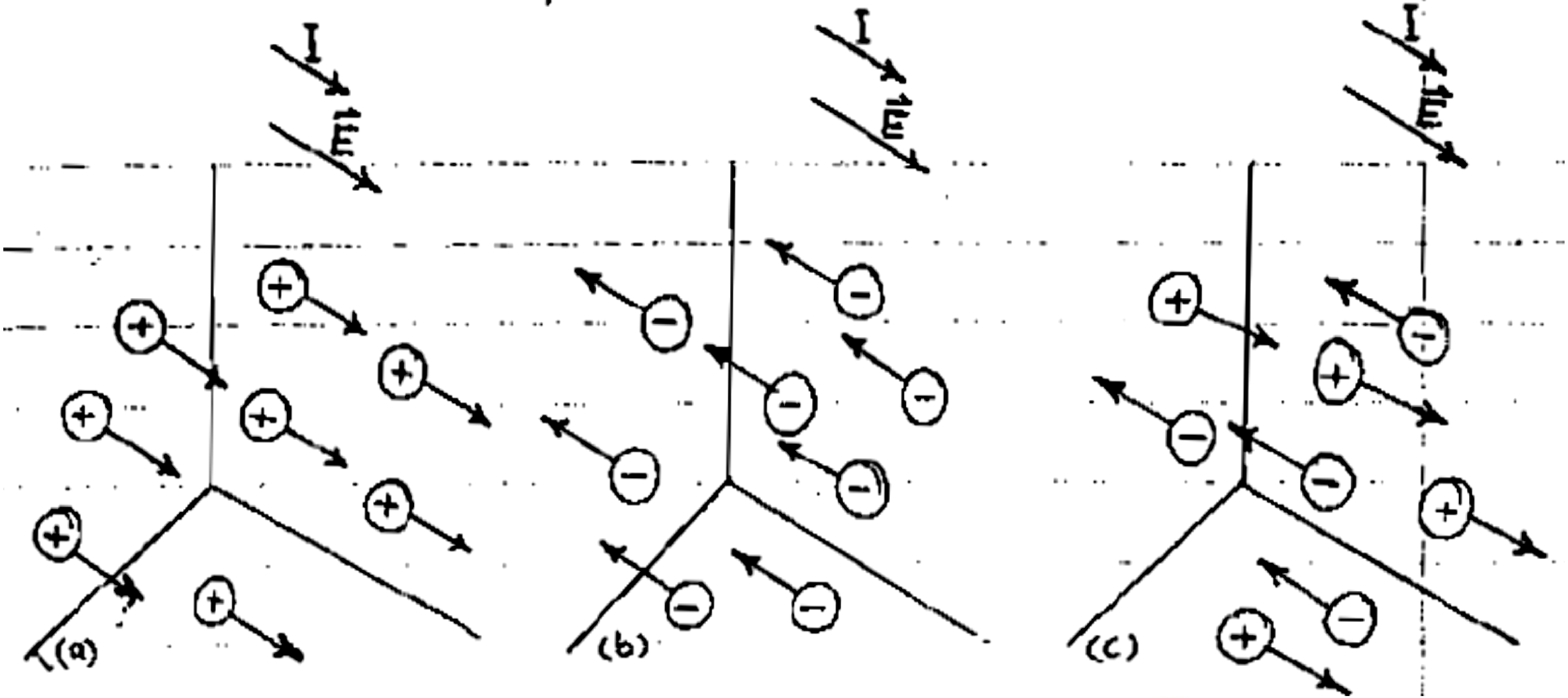
Electric Current

Current is the flow of electrical charge, i.e. amount of charge per second moving through a wire. It is a scalar, not a vector, but it has a direction positive in the direction of flow of positive charge carriers.

Charges will flow from the positive terminal to the negative terminal, but current is defined as the direction of positive charge carriers).

The direction of an electric current is assumed to be that of the motion of the positively charged particle. It is the same direction as that of the applied electric field. Which produces the motion of the charged particles (figure below a). Therefore, if a current is due to the motion of negatively charged particles. Such as electrons, the direction of the current is opposite to the actual motion of the electrons (figure below b).

The SI unit of current is Ampere (A): 1 A = 1 C/s.


I
E
(a)
(b)
(c)

Instantaneous Electric Current

If the rate at which the charge flows varies with time, the instantaneous current, I, can be found:

$$\boldsymbol{I = \frac{dq}{dt}}$$

Current Density

The current density J of a conductor is defined as the current per unit area. $\boldsymbol{J = \frac{I}{A} = nqV_d}$

Where: n is the number of charge carriers per unit volume, V_d is Drift Speed.

This expression is valid only if the current density is uniform and A is perpendicular to the direction of the current. J has SI units of $\boldsymbol{\frac{A}{m^2}}$

The current density is in the direction of the positive charge carriers.

Resistance and Resistivity

Some materials conduct electricity better than others. If we apply a given voltage across a conductor, we get a large current. If we apply the same voltage across an insulator, we get very little current (ideal: none).

The property of a material that describes its ability to conduct electric currents is called the resistivity (ρ).

The property of a particular device or object that describes it ability to conduct electric currents is called the Resistance, R.

Resistivity is a property of the material and Resistance is a property of a particular object made from that material.

If we apply an electric potential difference V across a conductor and measure the resulting current I in the conductor, we define the resistance R of that conductor as

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

The unit of resistance is volt per ampere, which is called Ohm (Ω).

$$\boldsymbol{1\,\Omega = \frac{1\,V}{1\,A}}$$

The resistance of a conductor will be 1Ω when it allows 1 A current to flow through it on application of 1 V across its material.

The resistance of conducting material is found to:

1. be directly proportional to the length l of the material,
2. be inversely proportional to the cross-sectional area of the material.
3. depend on the nature of material.
4. depend upon the temperature.

Resistivity

The conducting properties of a material are characterized in terms of its resistivity.

We define the resistivity, ρ, of a material by the ratio:

$$\boldsymbol{\rho = \frac{E}{J}}$$

E: magnitude of the applied field, J: magnitude of the current density.

The units of resistivity are:

$$\frac{\left(\frac{V}{m}\right)}{\left(\frac{A}{m^2}\right)} = \frac{V\,m}{A} = \Omega\,m$$

The resistance of an ohmic conductor is proportional to its length, L, and inversely proportional to its cross-sectional area A:

$$R = \rho\frac{L}{A} \qquad \rho : Constant\ of\ Proportionality$$

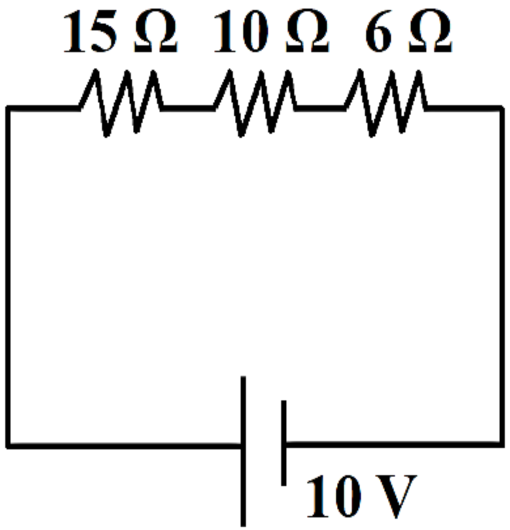
Resistors can be combined in series or parallel

Resistors in Series

When connected in series, the total resistance R_{tot} is equal to:

$$\boldsymbol{R_{tot} = R_1 + R_2 + R_3 + \cdots \qquad Resistors\ in\ Series}$$

The total resistance is always larger than any individual resistance.



Example: Calculate the total current through the circuit.

Sol.

$$\boldsymbol{R_t = R_1 + R_2 + R_3 = 15\Omega + 10\Omega + 6\Omega = 31\Omega}$$

$$\boldsymbol{I = \frac{V}{R_t} = \frac{10\ V}{31\ \Omega} = 0.32\ A}$$

Disadvantages of Series Circuits

1. When one component fails the whole circuit fails.
2. The current is the same at all points.
3. The voltage is divided between the bulbs.
4. The more bulbs added the dimmer each one is.

Resistors in Parallel

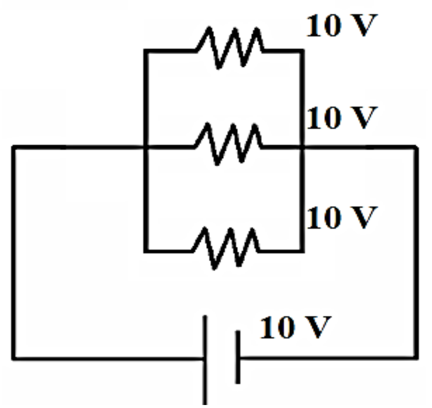
Since there is more than one possible path, the current divides itself according to the resistance of each path.

smallest resistor = more current passes

largest resistor = least current passes

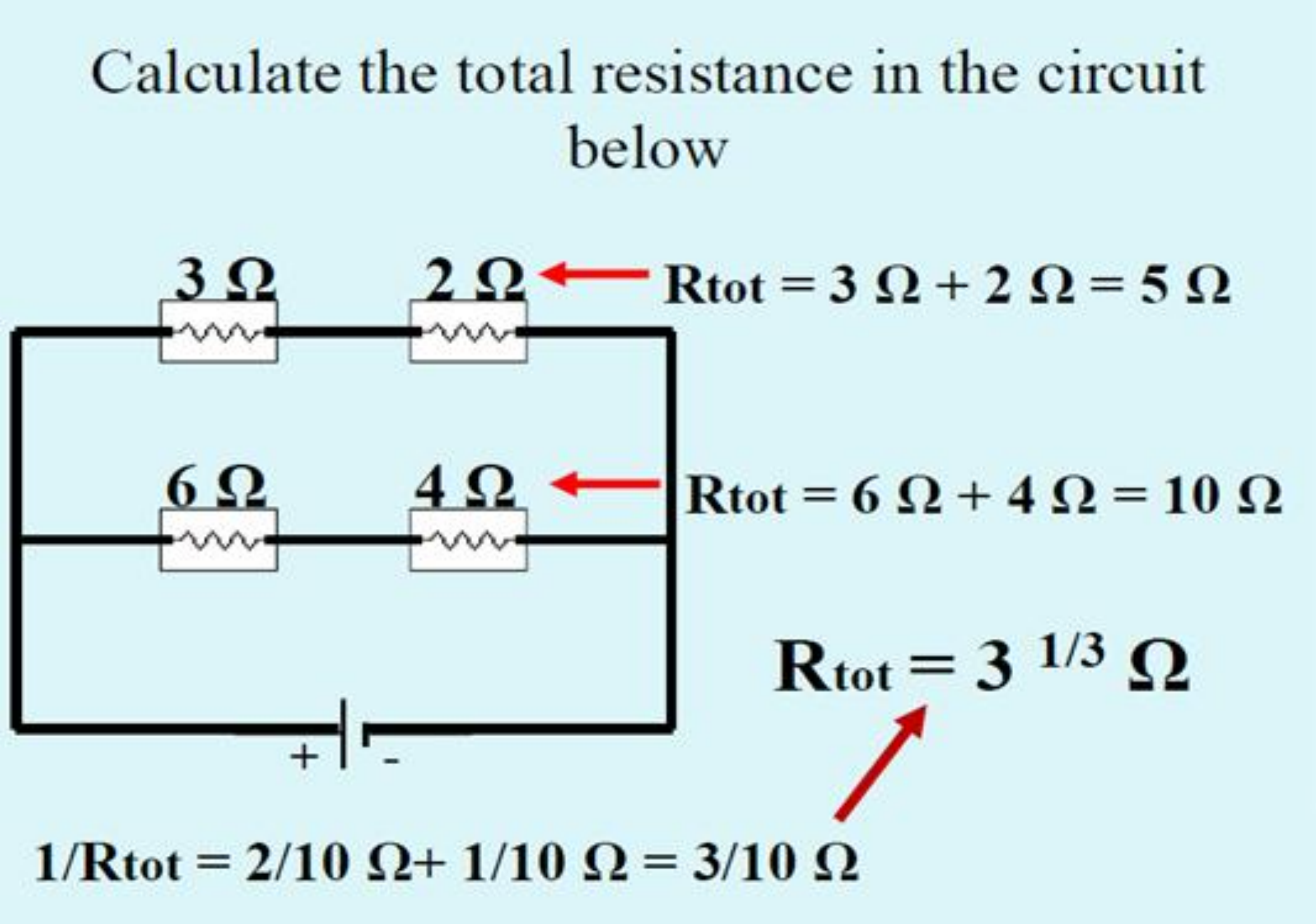
$$\frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Resistor in Parallel



The voltage across each resistor in a parallel combination is the same.

Example:



Calculate the total resistance in the circuit below

$R_{tot} = 3\ \Omega + 2\ \Omega = 5\ \Omega$

$R_{tot} = 6\ \Omega + 4\ \Omega = 10\ \Omega$

$R_{tot} = 3\ ^{1/3}\ \Omega$

$1/R_{tot} = 2/10\ \Omega + 1/10\ \Omega = 3/10\ \Omega$

Advantages of the Parallel Circuit

1. When one bulb fails the rest of the circuit continues to work.
2. The more components, the lower the resistance.
3. The total current drawn increases.
4. Voltage in each branch is the same as the supply voltage therefore bulbs in parallel will each be as bright as a single.

Ohm’s Law

Ohm’s Law explains the relationship between voltage (V), current (I) and resistance (R).

Ohm’s law, states that: For a metallic conductor at constant temperature, the ratio of the potential difference V between two points to the electric current I is constant.

This constant is called the electrical resistance R of the conductor between the two points.

Thus we may express Ohm’s law by:

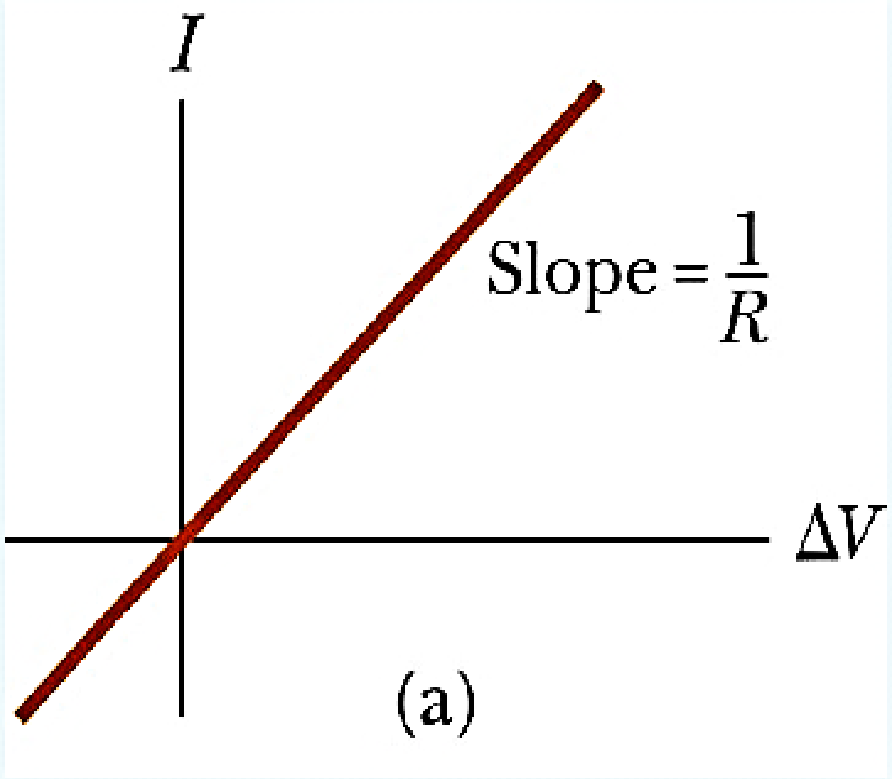
$$\boldsymbol{R = \frac{V}{I} \qquad or \qquad V = R\,I}$$

We need resistors to decrease the amount of voltage applied to a component. The value of the resistor is marked on the body using coloured rings.

Current-Voltage Relations Graph

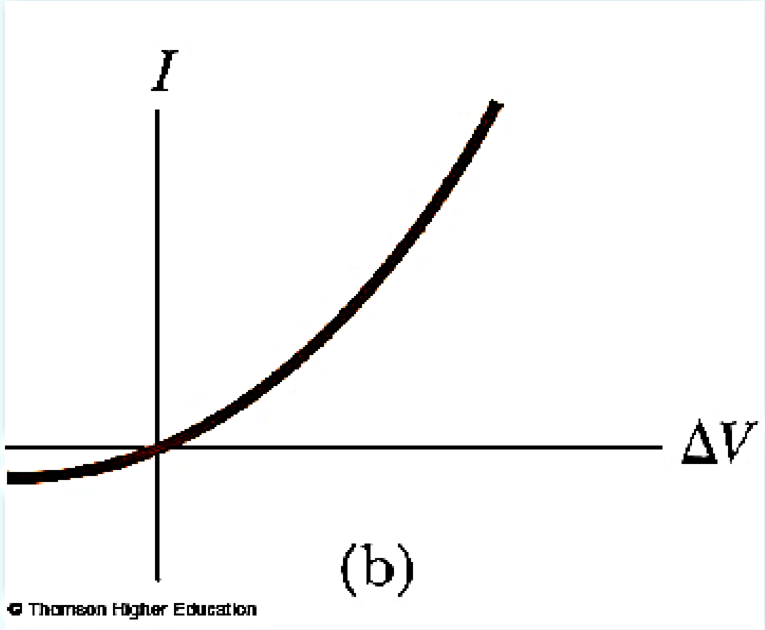
Ohmic Material, Graph

- ➢ The resistance is constant over a wide range of voltages.
- ➢ The relationship between current and voltage is linear.
- ➢ The slope is related to the resistance.



NonOhmic Material, Graph

- Nonohmic materials are those whose resistance changes with voltage or current.
- The current-voltage relationship is nonlinear.
- A junction diode is a common example of a nonohmic device.



Energy and Power

Energy (E) is the ability to do work.

Power (P) is the rate at which energy is used. Power (P) is a certain amount of energy (W) used in a certain length of time (t), expressed as follows:

$$P = \frac{Energy}{Time} = \frac{E}{t}$$

where : P = power in watts (W), E = energy in joules (J) and t = time in seconds (s)

$$E = P\,t$$

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

$$P = I\,V \qquad\qquad P = \frac{V^2}{R}$$

Example 1: A amount of energy equal to 100 J is used in 5 S. What is the power in watts.

Sol.

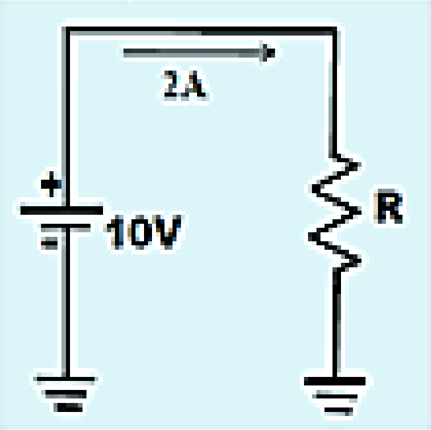
$$\boldsymbol{P = \frac{E}{t} = \frac{100\,J}{5\,s} = 20\,W}$$

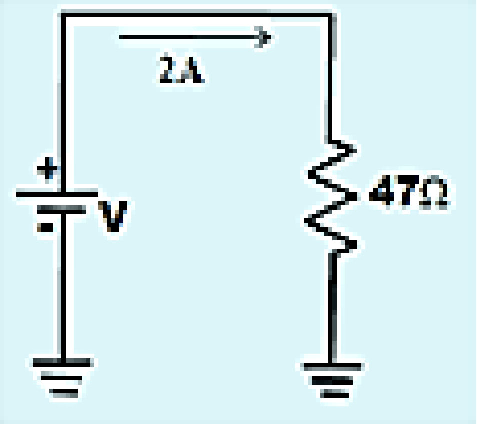
Example 3: If the voltage to a light bulb is 120 volts and the resistance of the filament is 240 ohms, how much current does the bulb use?

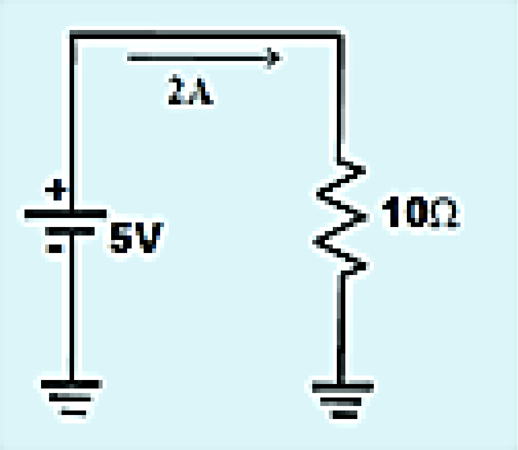
Sol.

$$\boldsymbol{I = \frac{V}{R} = \frac{120\,V}{240\,\Omega} = 0.5\,A}$$

Example 2: Calculate the power in the following three circuits.







Sol.

$$P = I\,V = (10\,V)(2\,A) = 20\,W$$

$$P = I^2\,R = (2\,A)^2\,(47\,\Omega) = 188\,W$$

$$P = \frac{V^2}{R} = \frac{(5\,V)^2}{(10\,\Omega)} = 2.5\,W$$

Example 4: A nine volt battery supplies power to a cordless curling iron with a resistance of 18 ohms. How much current is flowing through the curling iron?

Sol.

$$\boldsymbol{I = \frac{V}{R} = \frac{9\ V}{18\ \Omega} = 0.5\ A}$$