King Saud University
College of Science
Physics & Astronomy Dept.

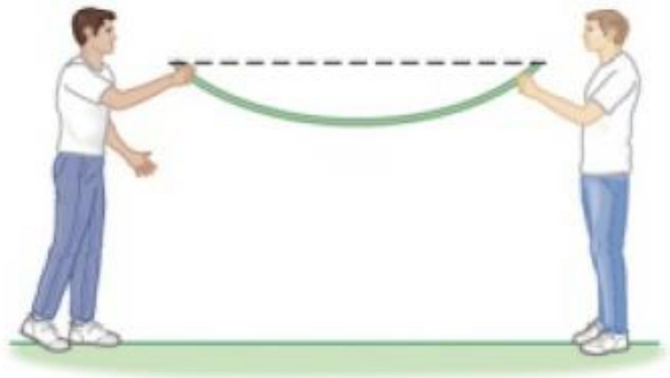
PHYS 111 (GENERAL PHYSICS 2)
CHAPTER 27: Current and Resistance
LECTURE NO. 6

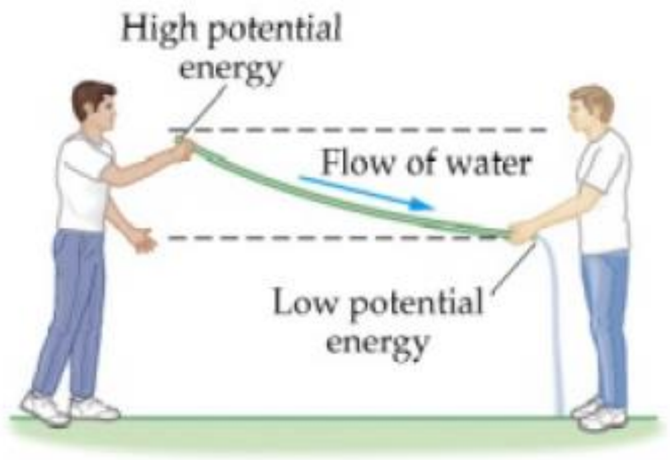
Presented by Nouf Alkathran

27.1 Electric Current

Water Flow as Analogy for Electric Current

- Water can flow quite freely through a garden hose, but if both ends are at the same level (a) there is no flow. If the ends are held at different levels (b), the water flows from the region where the gravitational potential energy is high to the region where it is low.


(a)

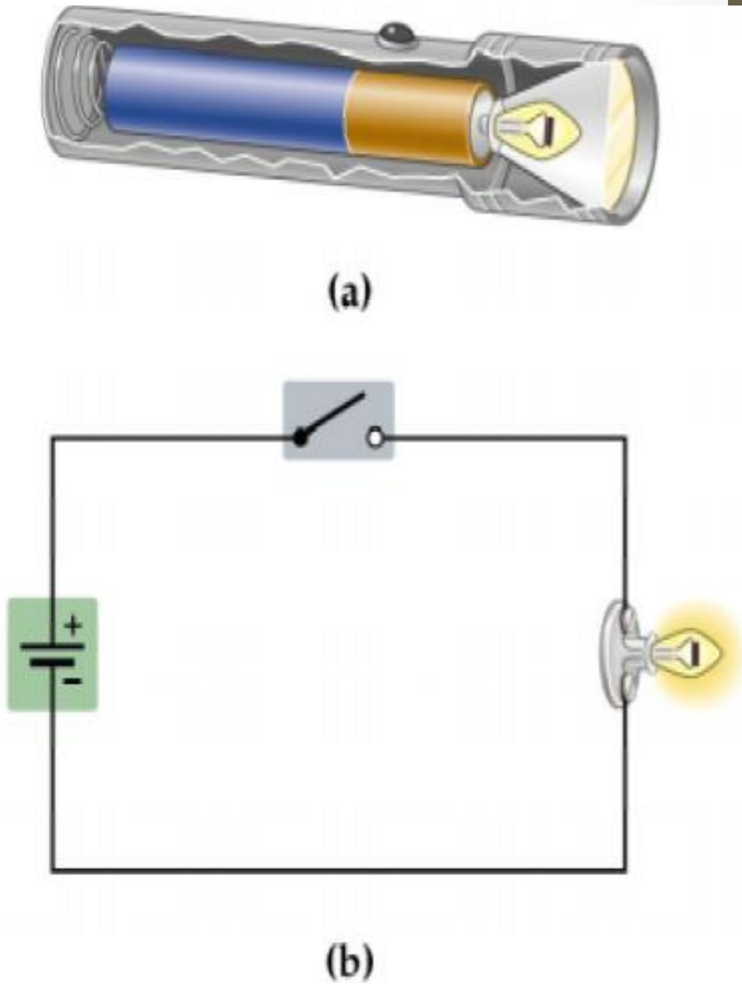


(b)

27.1 Electric Current

A Simple Electrical Circuit

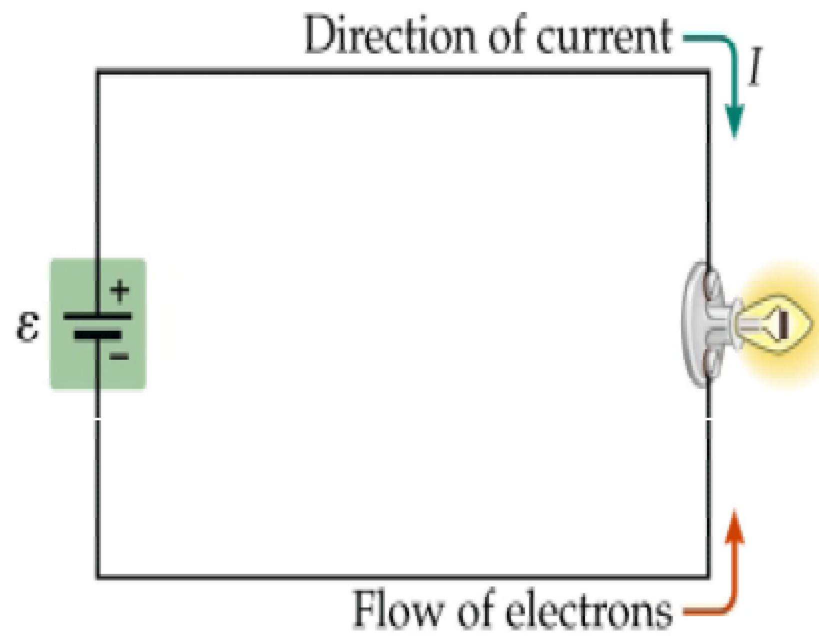
- (a) A simple flashlight, consisting of a battery, a switch, and a light bulb.
- (b) When the switch is in the open position the circuit is "broken," and no charge can flow. When the switch is closed electrons flow through the circuit, and the light glows.



27.1 Electric Current

Direction of Current and Electron Flow

- In the flashlight circuit, electrons flow from the negative terminal of the battery to the positive terminal. The direction of the current, I, is just the opposite: from the positive terminal to the negative terminal.



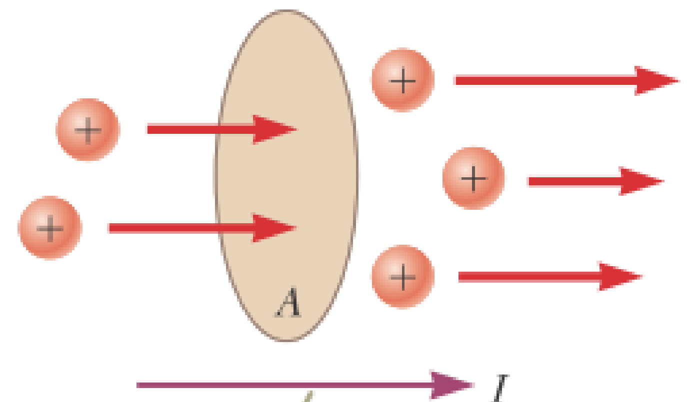
27.1 Electric Current

The current is defined as the rate at which charge flows through this surface. If ΔQ is the amount of charge that passes through this surface in a time interval Δt, the average current I_{avg} is equal to the charge that passes through A per unit time:

$$I_{\text{avg}} = \frac{\Delta Q}{\Delta t}$$

Where:

- I is the current
- Q is charge in coulomb
- T is time in second



The direction of the current is the direction in which positive charges flow when free to do so.

27.1 Electric Current

The SI unit of current is the ampere (A):

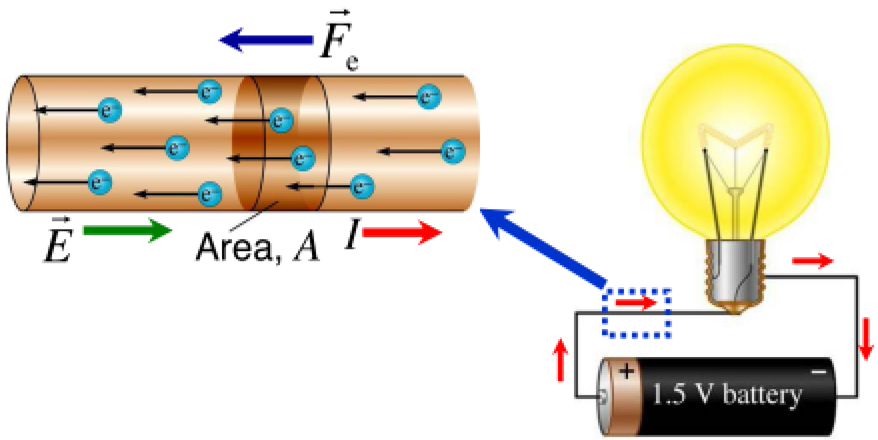
$$1\ \mathrm{A} = 1\ \mathrm{C/s}$$

That is, 1 A of current is equivalent to 1 C of charge passing through a surface in 1 s.

1 A is quite a large current. Household currents are usually as large as several amps.

27.1 Electric Current

- Consider a simple closed circuit consists of wires, a battery and a light bulb as shown in Figure



- Direction of electric field

or electric current :

Positive to negative terminal

- Direction of electron flows

Negative to positive terminal

- The electron accelerates because of the electric force acted on it.

27.1 Electric Current

Microscopic Model of Current

- Consider the current in a cylindrical conductor of cross-sectional area A, and length Δx, then the volume of the conductor $V = A\,\Delta x$.
- If n represents the number of mobile charge carriers per unit volume .
- The number of carriers in the segment is $nA\,\Delta\,x$
- Therefore, the total charge $\Delta\,Q$ in this segment is

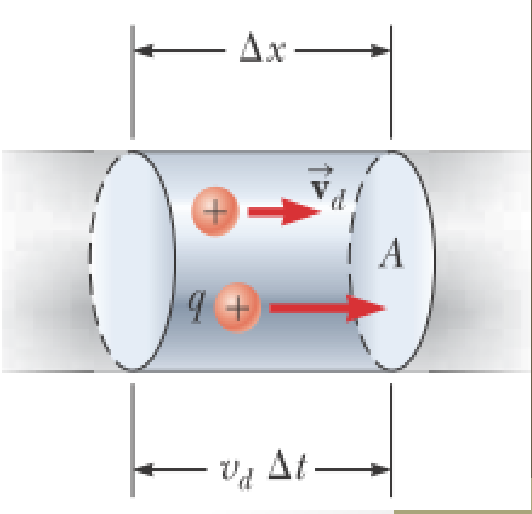
$$\Delta Q = (\mathrm{nA}\Delta x)q$$

- If the carriers move with a velocity (v_d), we can write ΔQ as

$$\Delta Q = (\mathrm{nA}v_d\Delta t)q$$

- Dividing both sides of this equation by Δt

$$\frac{\Delta Q}{\Delta t} = (\mathrm{nA}v_d)q = I_{avg}$$



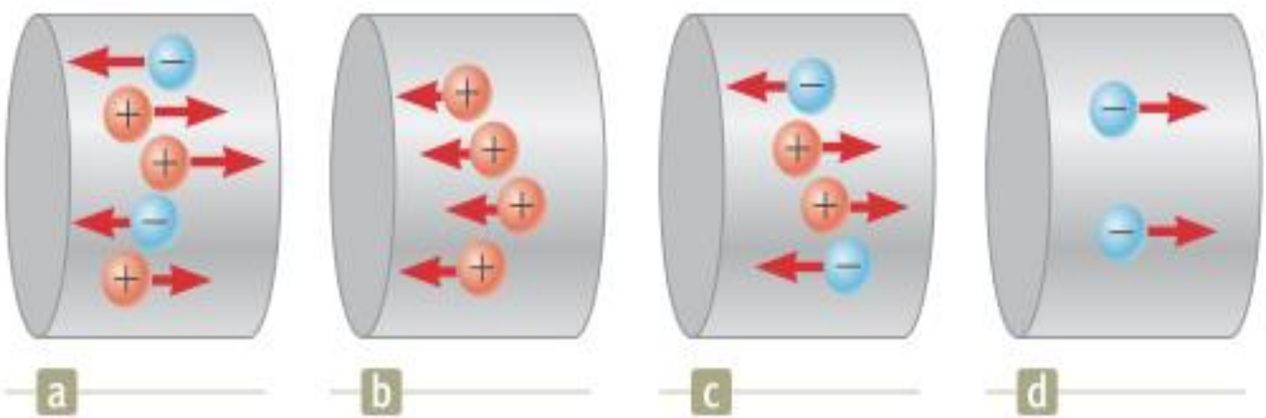
27.1 Electric Current

- The total charge Q of the free electrons that pass through the area A along the conductor is

$$Q = Ne$$
$$Q = (nAL)e$$

27.1 Electric Current

Quick Quiz 27.1 Consider positive and negative charges moving horizontally through the four regions shown in Figure 27.4. Rank the current in these four regions from highest to lowest.



27.2 Resistance

Ohm's law

- States that the potential difference across a metallic conductor is proportional to the current flowing through it if its temperature is constant.
- $V \propto I$ where T = constant

then

$$\boxed{V = IR}$$

where R : resistance of a conductor.

27.2 Resistance

- **Resistance (R):** is defined as a ratio of the potential difference across an electrical component to the current passing through it.

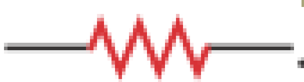
$$\boxed{R = \frac{V}{I}}$$

Where:

V :potential difference (voltage)

I :current

- It is a measure of the component is opposition to the flow of the electric charge.
- It is a scalar quantity and its unit is ohm (Ω) or V A^{-1}
- In general, the resistance of a metallic conductor increases with temperature.

(Resistors are designated by the circuit symbol .)

27.2 Resistance

Resistivity (ρ)

- **Resistivity, ρ :**is defined as the resistance of a unit cross-sectional area per unit length of the material.

$$\rho = \frac{RA}{l}$$

where l : length of the material

A : cross - sectional area

- It is a scalar quantity and its unit is ohm meter (Ω m)
- It is a measure of a material is ability to oppose the flow of an electric current.
- It also known as specific resistance.
- Resistivity depends on the type of the material and on the temperature.
- A good electric conductors have a very low resistivities and good insulators have very high resistivities.

27.2 Resistance

Conductivity(σ)

- is defined as the reciprocal of the resistivity of a material.

$$\sigma = \frac{1}{\rho}$$

- It is a scalar quantity and its unit is Ω-1 m-1

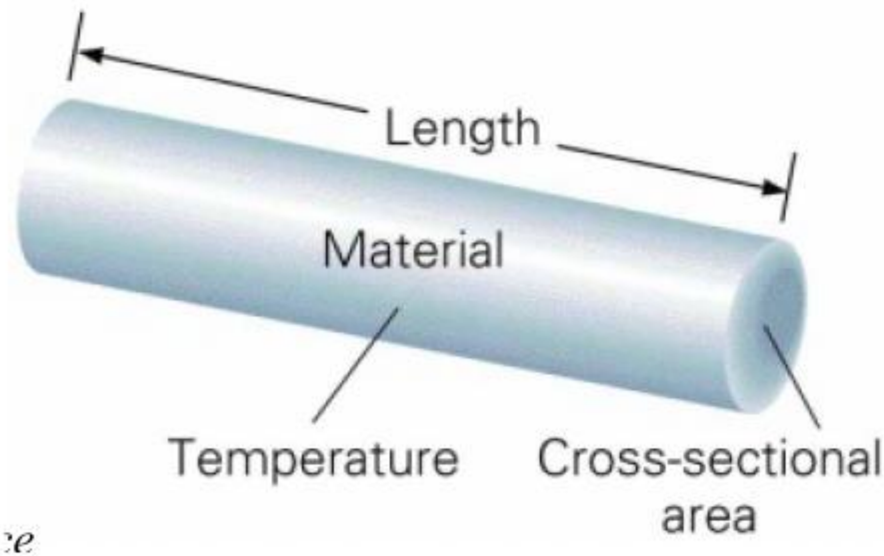
27.2 Resistance

The Factors of Resistance

- Resistance of a wire depends on:

1. The material (ρ) -resistivity
2. The Area (A)
3. The length (L)
4. The temperature (T)

$$R = \rho \frac{L}{A}$$



Just like water in a pipe. Narrow , long pipes have high resistance

27.2 Resistance

Quick Quiz 27.2

A cylindrical wire has a radius r and length ,. If both r and , are doubled, does the resistance of the wire (a) increase, (b) decrease, or (c) remain the same?

27.2 Resistance

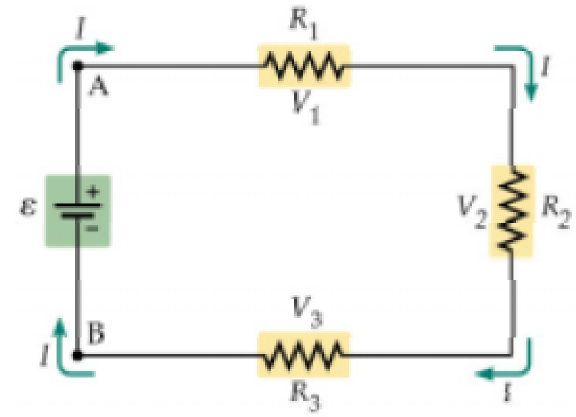
<u>Combination of cells</u>

- Series Resistors
- Parallel Resistors

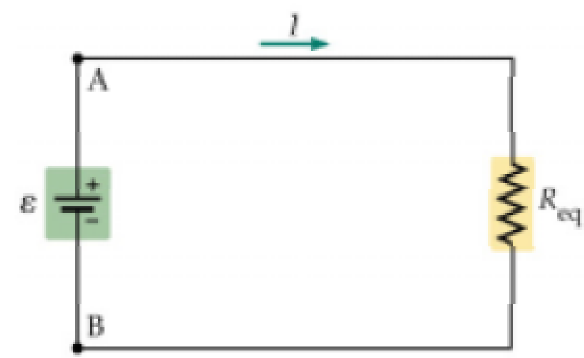
1. Series Resistors

- (a) Three resistors, R1, R2, and R3, connected in series. Note that the same current I flows through each resistor.
- (b) The equivalent resistance:

Req = R1 + R2 + R3 has the same current flowing through it as the current I in the original circuit.

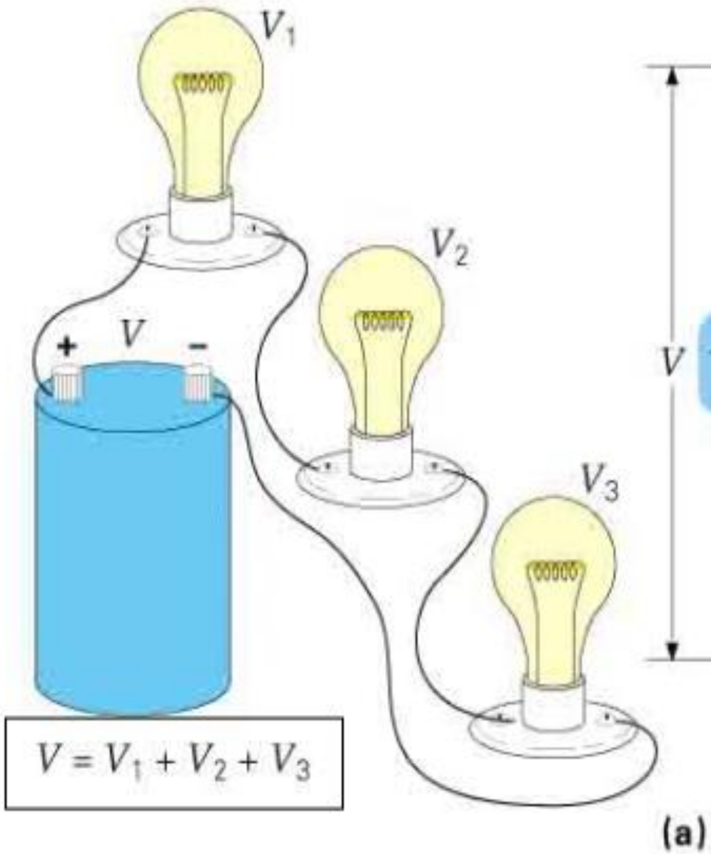


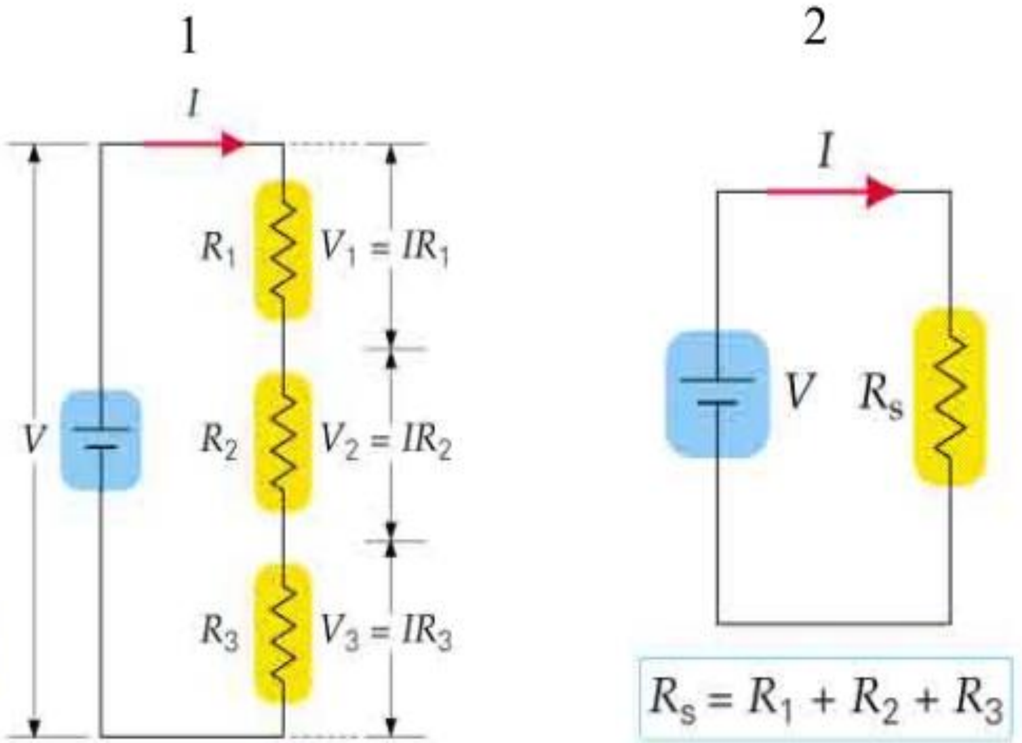
(a)



(b)

1. Series Resistors

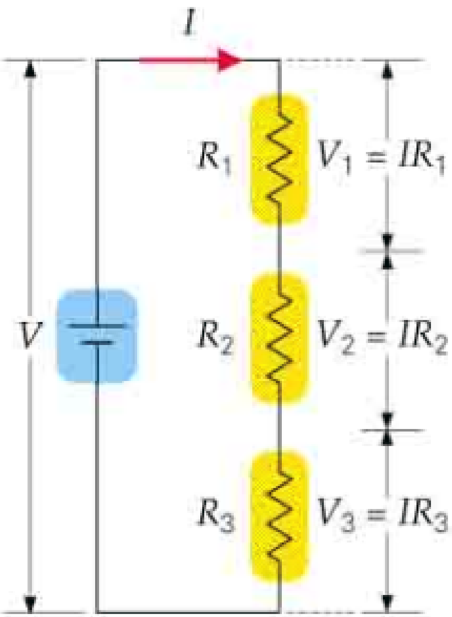




Circuit 1 IS EQUIVALENT to circuit 2.

1. Series Resistors

In a series circuit the current is the same at each point in the circuit.



Circuits are EQUIVALENT

$$\boxed{R_s=(R_1+R_2+R_3)}$$

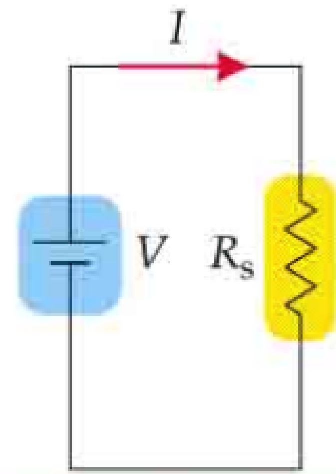
$V1=IR_1$

$V_2=IR_2$

$V_3=IR_3$

$V=V_1+V_2+V_3$

$=I(R_1+R_2+R_3)$



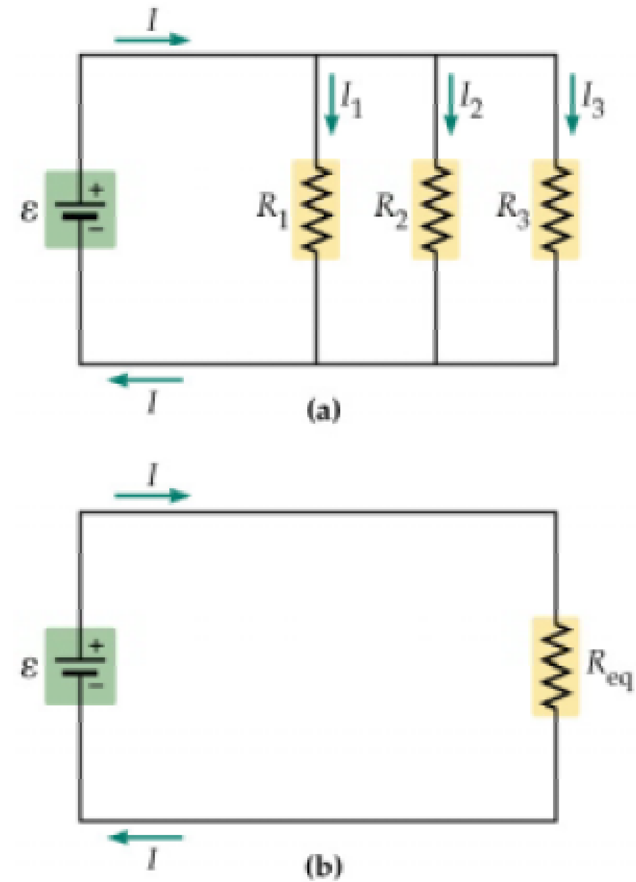
$$R_s = R_1 + R_2 + R_3$$

V=IRs

2. Parallel Resistors

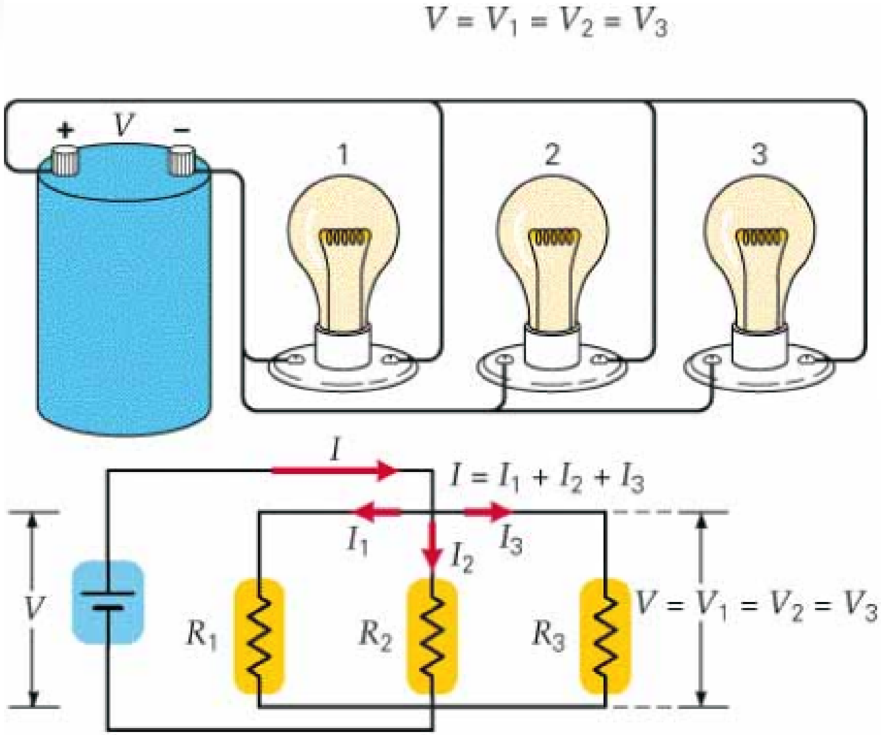
- (a) Three resistors, R_1, R_2, and R_3, connected in parallel. Note that each resistor is connected across the same potential difference, E.
- (b) The equivalent resistance:

$1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3$ has the same current flowing through it as the total current I in the original circuit.

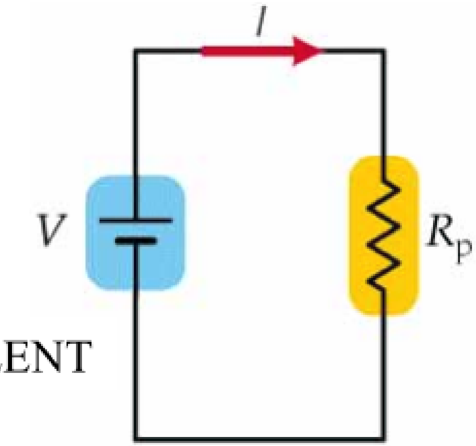


Note: The equivalent parallel resistance, R_P, is ALWAYS less than any of the individual resistances.

2. Parallel Resistors



Circuits are EQUIVALENT



$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

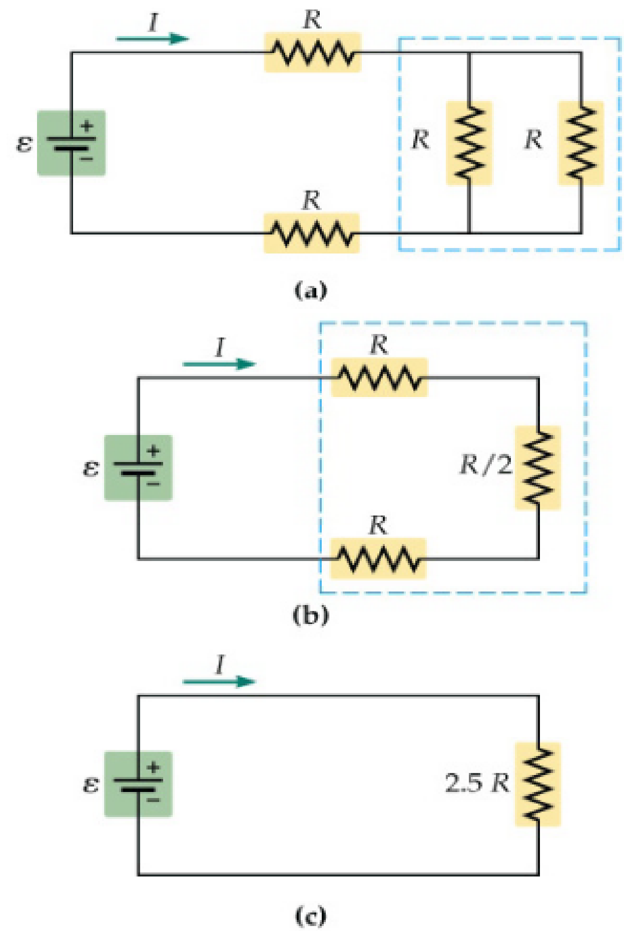
$V=V_1=V_2=V_3$
$=I_1R_1=I_2R_2=I_3R_3$

$I=I_1+I_2+I_3$
$=V/R_1+V/R_2+V/R_3$
$=V(1/R_1+1/R_2+1/R_3)$

$I=V/Rp$

Analyzing a complex circuit of resistors

- (a) The two vertical resistors are in parallel with one another, hence they can be replaced with their equivalent resistance, R/2.
- (b) Now, the circuit consists of three resistors in series. The equivalent resistance of these three resistors is 2.5 R.
- (c) The original circuit reduced to a single equivalent resistance.



27.4 Resistance and Temperature

The resistivity of a conductor varies approximately linearly with temperature according to the expression:

$$\rho = \rho_0[1 + \alpha(T - T_0)]$$

where ρ is the resistivity at some temperature T (in degrees Celsius), ρ_0 is the resistivity at some reference temperature T_0 (usually taken to be 20°C), and $\alpha$is the temperature coefficient of resistivity.

The temperature coefficient of resistivity can be expressed as

$$\alpha = \frac{1}{\rho_0}\frac{\Delta\rho}{\Delta T}$$

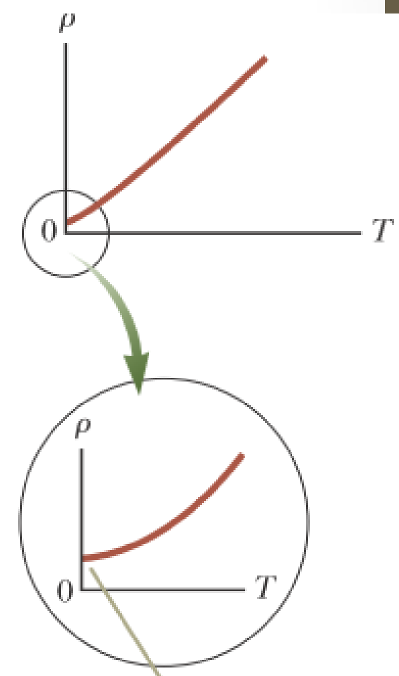
where $\Delta\rho = \rho - \rho_0$is the change in resistivity in the temperature interval $\Delta T = T - T_0$.

27.4 Resistance and Temperature

Notice that the unit for α is degrees $Celsius^{-1}$ [($°C^{-1}$).
Because resistance R is proportional to resistivity ρ, the variation of resistance of a sample is:

$$R = R_0[1 + \alpha(T - T_0)]$$

where R is the resistance at some temperature T (in degrees Celsius), R_0 is the resistivity at some reference temperature T_0



As T approaches absolute zero, the resistivity approaches a nonzero value.

27.6 Electrical Power

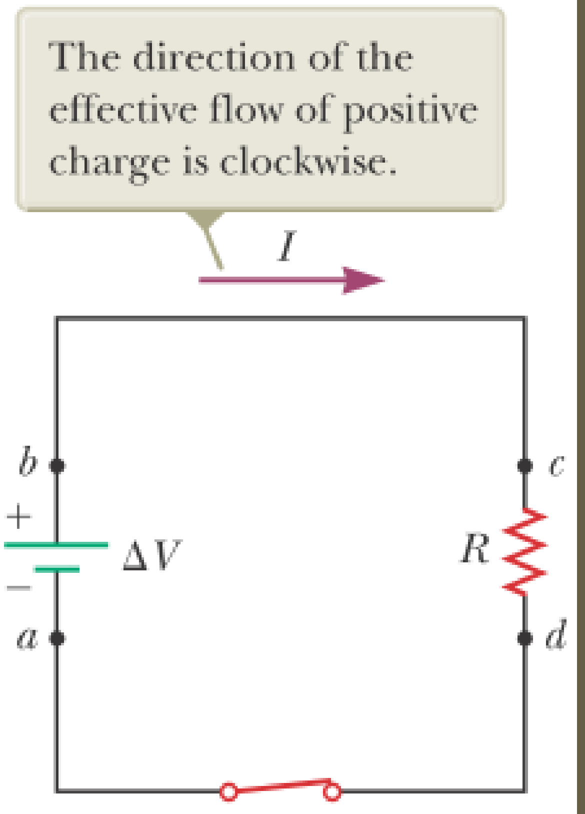
$$\Delta U = q\,\Delta V$$

Let's now investigate the rate at which the electric potential energy of the system decreases as the charge Q passes through the resistor:

$$\frac{dU}{dt} = \frac{d}{dt}(Q\,\Delta V) = \frac{dQ}{dt}\Delta V = I\,\Delta V$$

Therefore, the power P, representing the rate at which energy is delivered to the resistor, is

$$P = I\,\Delta V$$



27.6 Electrical Power

We can express the power delivered to the resistor in the alternative forms

$$P = I^2R = \frac{(\Delta V)^2}{R}$$

When I is expressed in amperes (A), ΔV in volts (V), and R in ohms (Ω), the SI unit of power is the watt (W).
1 W = 1 A/V
1W = 1 J/s

The process by which energy is transformed to internal energy in a conductor of resistance R is often called joule heating; this transformation is also often referred to as an I^2R loss.

27.6 Electrical Power

Figure 27.12 These power lines transfer energy from the electric company to homes and businesses. The energy is transferred at a very high voltage, possibly hundreds of thousands of volts in some cases. Even though it makes power lines very dangerous, the high voltage results in less loss of energy due to resistance in the wires.

Lester Lefkowitz/Taxi/Getty Images

Example 27.4 Power in an Electric Heater

An electric heater is constructed by applying a potential difference of 120 V across a Nichrome wire that has a total resistance of 8.00 V. Find the current carried by the wire and the power rating of the heater.

Solution:

$$I = \frac{\Delta V}{R} = \frac{120\ \text{V}}{8.00\ \Omega} = \boxed{15.0\ \text{A}}$$

$$P = I^2R = (15.0\ \text{A})^2(8.00\ \Omega) = 1.80 \times 10^3\ \text{W} = \boxed{1.80\ \text{kW}}$$

Summary

- Definition of Resistance
- Ohm's Law
- Resistivity and Conductivity
- Combinations of resistors; parallel & series
- Resistance and Temperature
- Electric Power, Loss

The End