PHY121-Applied Physics for Engineers

Current, Resistance and Ohm's law

LECTURE # 14

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Current and Resistance

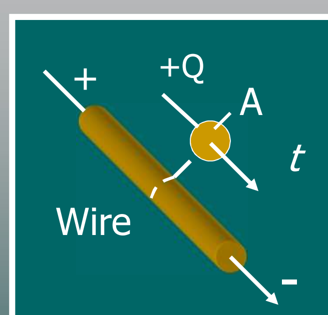
Objectives: After completing this module, you should be able to:

- Define electric current and electromotive force.
- Write and apply Ohm's law to circuits containing resistance and emf.
- Define resistivity of a material and apply formulas for its calculation.
- Define and apply the concept of temperature coefficient of resistance.

Electric Current

Electric current I is the rate of the flow of charge Q through a cross-section A in a unit of time t.

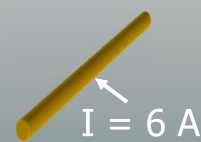
$$\boxed{I = \frac{Q}{t}} \qquad \boxed{1\ \text{A} = \frac{1\ \text{C}}{1\ \text{s}}}$$



One ampere A is charge flowing at the rate of one coulomb per second.

Example 1. The electric current in a wire is 6 A. How many electrons flow past a given point in a time of 3 s?

$$I = \frac{q}{t}; \quad q = It$$



q = (6 A)(3 s) = 18 C

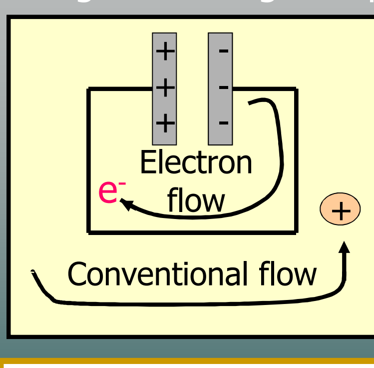
Recall that: 1 e^- = 1.6 x 10^{-19} C, then convert:

$$18\text{ C} = (18\text{ C})\left(\frac{1\text{e}^-}{1.6 \text{ x } 10^{-19}\text{C}}\right) = 1{,}125 \text{ x } 10^{20}\text{electrons}$$

In 3 s: 1.12 x 10^{20} electrons

Conventional Current

Imagine a charged capacitor with $Q = CV$ that is allowed to discharge.



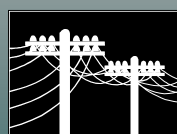
Electron flow: The direction of e^- flowing from – to +.

Conventional current: The motion of +q from + to – has same effect.

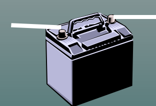
Electric fields and potential are defined in terms of +q, so we will assume conventional current (even if electron flow may be the actual flow).

Electromotive Force

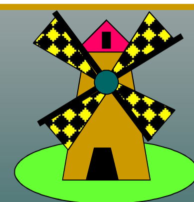
A source of electromotive force (emf) is a device that uses chemical, mechanical or other energy to provide the potential difference necessary for electric current.



Power lines

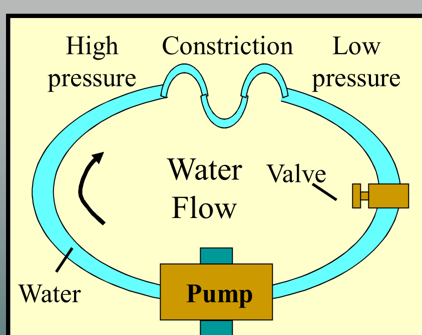


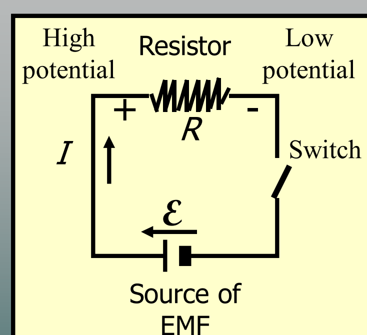
Battery



Wind generator

Water Analogy to EMF



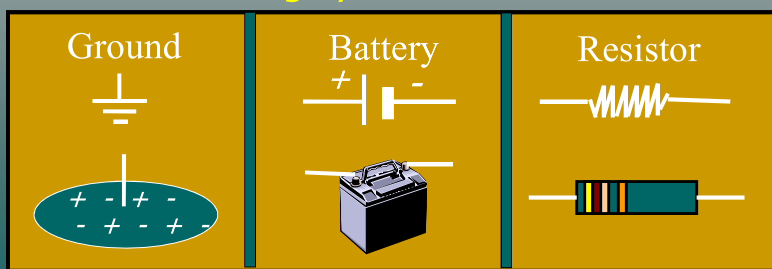


The source of emf (pump) provides the voltage (pressure) to force electrons (water) through electric resistance (narrow constriction).

Electrical Circuit Symbols

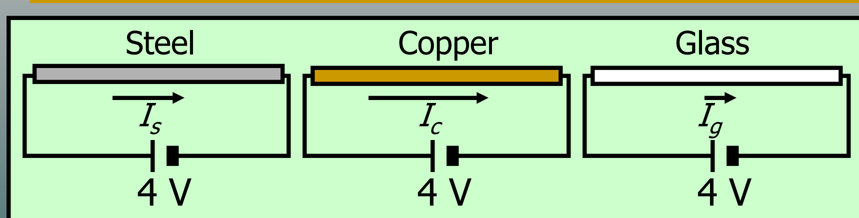
Electrical circuits often contain one or more resistors grouped together and attached to an energy source, such as a battery.

The following symbols are often used:



Electric Resistance

Suppose we apply a constant potential difference of 4 V to the ends of geometrically similar rods of, say: steel, copper, and glass.



The current in glass is much less than for steel or iron, suggesting a property of materials called electrical resistance R.

Ohm's Law

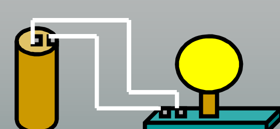
Ohm's law states that the current I through a given conductor is directly proportional to the potential difference V between its end points.

$$\boxed{Ohm's\ law: \quad I \propto V}$$

Ohm's law allows us to define resistance R and to write the following forms of the law:

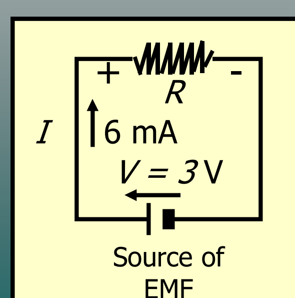
$$I = \frac{V}{R}; \qquad V = IR; \qquad R = \frac{V}{I}$$

Example 2. When a 3-V battery is connected to a light, a current of 6 mA is observed. What is the resistance of the light filament?



$$R = \frac{V}{I} = \frac{3.0\ \text{V}}{0.006\ \text{A}}$$

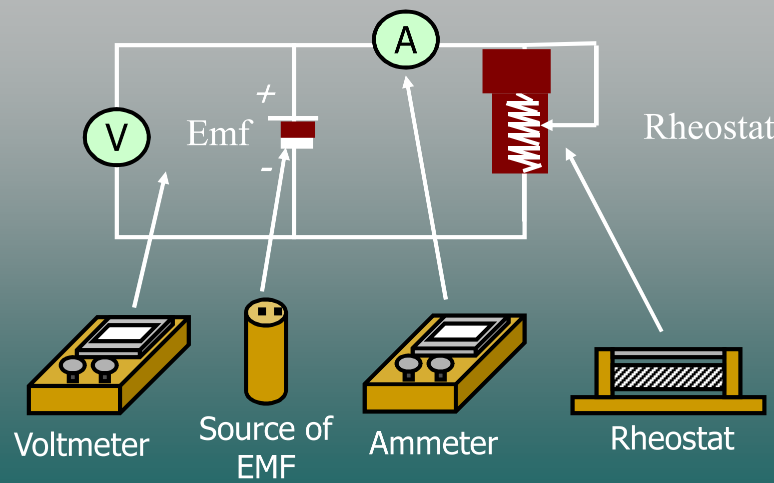
$$\boxed{R = 500\ \Omega}$$



The SI unit for electrical resistance is the ohm, Ω:

$$\boxed{1\ \Omega = \frac{1\ \text{V}}{1\ \text{A}}}$$

Laboratory Circuit Symbols



Factors Affecting Resistance

1. The length L of the material. Longer materials have greater resistance.

2. The cross-sectional area A of the material. Larger areas offer LESS resistance.

Factors Affecting R (Cont.)

3. The temperature T of the material. The higher temperatures usually result in higher resistances.

R_o

$R > R_o$

4. The kind of material. Iron has more electrical resistance than a geometrically similar copper conductor.

Copper Iron

$R_i > R_c$

Resistivity of a Material

The *resistivity* ρ is a property of a material that determines its electrical resistance *R*.

Recalling that *R* is directly proportional to length *L* and inversely proportional to area *A*, we may write:

$$R = \rho \frac{L}{A} \quad \text{or} \quad \rho = \frac{RA}{L}$$

The unit of resistivity is the ohm-meter ($\Omega \cdot m$)

Example 3. What length L of copper wire is required to produce a 4 mΩ resistor? Assume the diameter of the wire is 1 mm and that the resistivity ρ of copper is $1.72 \times 10^{-8}\ \Omega\cdot\text{m}$.

$$A = \frac{\pi D^2}{4} = \frac{\pi (0.001\text{ m})^2}{4}$$

$A = 7.85 \times 10^{-7}\text{ m}^2$

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

$$L = \frac{RA}{\rho} = \frac{(0.004\ \Omega)(7.85 \times 10^{-7}\text{m}^2)}{1.72 \times 10^{-8}\Omega\cdot\text{m}}$$

Required length is: $\boxed{L = 0.183\text{ m}}$

Temperature Coefficient

For most materials, the resistance R changes in proportion to the initial resistance R_o and to the change in temperature Δt.

Change in resistance: $\boxed{\Delta R = \alpha R_0 \Delta t}$

The temperature coefficient of resistance, α is the change in resistance per unit resistance per unit degree change of temperature.

$$\alpha = \frac{\Delta R}{R_0 \Delta t}; \quad \text{Units: } \frac{1}{\text{C}^0}$$

Example 4. The resistance of a copper wire is 4.00 mΩ at 20^0C. What will be its resistance if heated to 80^0C? Assume that α = 0.004 /C°.

R_o = 4.00 mΩ; Δt = 80°C – 20°C = 60 C°

$$\Delta R = \alpha R_0 \Delta t; \quad \Delta R = (0.004/\mathrm{C}^0)(4\ \mathrm{m}\Omega)(60\ \mathrm{C}^0)$$

$\boxed{\Delta R = 1.03\ \mathrm{m}\Omega}$ $R = R_o + \Delta R$

R = 4.00 mΩ + 1.03 mΩ

$\boxed{R = 5.03\ \mathrm{m}\Omega}$

Electric Power

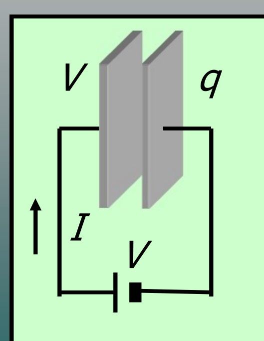
Electric power P is the rate at which electric energy is expended, or work per unit of time.

To charge C: Work = qV

$$P = \frac{Work}{t} = \frac{qV}{t} \quad \text{and} \quad I = \frac{q}{t}$$

Substitute $q = It$, then:

$$P = \frac{VI\cancel{t}}{\cancel{t}} \Rightarrow \boxed{P = VI}$$



Calculating Power

Using Ohm's law, we can find electric power from any two of the following parameters: current I, voltage V, and resistance R.

Ohm's law: $V = IR$

$$\boxed{P = VI; \quad P = I^2R; \quad P = \frac{V^2}{R}}$$

Example 5. A power tool is rated at 9 A when used with a circuit that provides 120-V. What power is used in operating this tool?

$P = VI = (120\text{ V})(9\text{ A})$ $\quad \boxed{P = 1080\text{ W}}$

Example 6. A 500-W heater draws a current of 10 A. What is the resistance?

$$P = I^2R; \quad R = \frac{P}{I^2} = \frac{500\text{ W}}{(10\text{ A})^2} \qquad \boxed{R = 5.00\ \Omega}$$

Summary of Formulas

Electric current:

$$I = \frac{Q}{t}$$

$$1\ \text{A} = \frac{1\ \text{C}}{1\ \text{s}}$$

Ohm's Law

$$I = \frac{V}{R}; \qquad V = IR; \qquad R = \frac{V}{I}$$

$$\text{Resistance:} \quad 1\ \text{ohm} = \frac{1\ \text{volt}}{1\ \text{ampere}}$$

Summary (Cont.)

Resistivity of materials:

$$R = \rho\frac{L}{A} \quad \text{or} \quad \rho = \frac{RA}{L}$$

Temperature coefficient of resistance:

$$\Delta R = \alpha R_0 \Delta t$$

$$\alpha = \frac{\Delta R}{R_0 \Delta t}; \quad \text{Units: } \frac{1}{\text{C}^0}$$

Electric Power *P:*

$$P = VI; \quad P = I^2R; \quad P = \frac{V^2}{R}$$

CONCLUSION: Chapter 27 Current and Resistance