Resistance and Ohm's Law

If you maintain an electric potential difference, or voltage V, across any conductor, an electric current occurs. In general, the magnitude of the current depends on the potential difference. For any particular material, the ratio of the applied voltage to the resulting current is defined to be the **resistance** R:

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

Resistance can be thought of as the ability of a material to resist the flow of charge when it is subject to a potential difference. An **insulator** allows only a small amount of current to pass for a particular voltage, and thus has a large resistance. A **conductor** allows a large amount of current to pass for the same voltage, and thus has a small resistance.

Note: The unit of resistance is the **Ohm** (Ω).

$$1 \text{ ohm} = \frac{1 \text{ volt}}{\text{ampere}}$$

In many types of materials, the value of the resistance is **not** constant. That is, the ratio of the applied voltage to the resulting current changes as the applied voltage changes.

In some special cases, the value of the resistance is constant. That is, the ratio of the applied voltage to the resulting current remains constant as the applied voltage changes. For these materials, the graph of I vs. V results in a straight line. This relationship may be expressed as

$$V = IR \qquad \text{where } R \text{ is a constant}$$

This equation is known as **Ohm's Law**.

To determine if a material obeys Ohm's law or not, we must examine the relationship between I and V (usually by graphing). If the relationship is linear, then the material obeys Ohm's law.

Electric components manufactured especially for their resistance are called **resistors**.

Example 1

The filament of a light bulb is a resistor in the form of a thin piece of wire. The wire becomes hot enough to emit light because of the current in it. A flashlight uses two $1.5\ V$ batteries (effectively a single $3.0\ V$ battery) to provide a current of $0.40\ A$ in the filament. Determine the resistance of the glowing filament.

Resistivity

By working with wires of different thicknesses and lengths, Ohm found that the amount of current transmitted by a wire for a given potential difference was directly proportional to the cross-sectional area of the wire and inversely proportional to its length.

Ohm had already shown that the current was inversely proportional to the resistance (Ohm's law). When these observations are combined, we find that the resistance of a wire must be proportional to its length L and inversely proportional to its cross-sectional area A.

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

The constant of proportionality ρ is the electric **resistivity**. The unit of resistivity is the ohm-meter $(\Omega \cdot m)$. The value of the resistivity depends on the type of material. The table below lists the resistivity of some common materials:

Material	**Resistivity at** $20°C$ $(\Omega \cdot m)$
Conductors	
Aluminum	2.65×10^{-8}
Copper	1.72×10^{-8}
Gold	2.24×10^{-8}
Iron	9.71×10^{-8}
Nichrome	100×10^{-8}
Platinum	10.6×10^{-8}
Silver	1.59×10^{-8}
Tungsten	5.65×10^{-8}
Semiconductors	
Carbon (graphite)	1.5×10^{-5}
Germanium (pure)	5×10^{-1}
Silicon (pure)	3×10^{3}
Insulators	
Glass	$10^{7} - 10^{10}$
Quartz	7.5×10^{17}

Note: The resistivity of most metals increases as temperature increases.

Example 2

What is the electric resistance of an iron wire $0.50\ m$ long with a diameter of $1.3\ mm$ if the resistivity of iron is $9.71 \times 10^{-8}\ \Omega \cdot m$?

Example 3

A piece of copper wire has a cross section of $4.0\ mm^2$ and a length of $2.0\ m$.

a. What is the electric resistance of the wire at $20°C$?

b. What is the potential difference across the wire when it carries a current of $10\ A$?

Circuits Worksheet # 2

Assume resistors obey Ohm's law unless stated otherwise.

1. What is the potential difference across a $220\ \Omega$ resistor when a current of $3.50\ A$ flows through it?

2. What is the current drawn by a $470\ \Omega$ resistor when a potential difference of $25.0\ V$ is maintained across it? ($53.2\ mA$)

3. A $40\ W$ electric lamp draws a current of $0.33\ A$ when operated with a potential difference of $120\ V$. What is the resistance of the lamp?

4. A three cell flashlight draws a current of $0.60\ A$. What is the operating resistance of the light bulb if each cell provides a potential of $1.0\ V$ when delivering this current? ($5.0\ \Omega$)

5. A piece of Nichrome wire passes a current of $0.853\ A$ when a potential of $1.64\ V$ is applied. What is the resistance of the wire?

6. What is the resistance of a resistor through which $8.0 \times 10^4\ C$ flow in one hour if the potential difference across it is $12\ V$? ($0.54\ \Omega$)

7. The current through an electronic device is measured for several voltages across the device. When the potential difference is $0\ V$, $0.50\ V$, $0.75\ V$, the current is $0\ A$, $0.010\ A$, and $0.015\ A$, respectively. Does the device obey Ohm's law? (**Hint**: Make a graph of the data and examine it.)

8. The current through an electronic device is measured for several voltages across the device. When the potential difference is $1.7\ V$, $7.6\ V$, $20\ V$, $45\ V$, the current is $0.075\ A$, $0.15\ A$, and $0.22\ A$, $0.35\ A$, respectively. Does the device obey Ohm's law? (**Hint**: Make a graph of the data and examine it.) (no)

9. What is the difference between resistance and resistivity?

10. Calculate the resistance of a piece of 20-gauge copper wire $2.00\ m$ long. The cross-sectional area of 20-gauge wire is $0.5176\ mm^2$. ($6.65 \times 10^{-2}\ \Omega$)

11. A piece of 20-gauge wire one meter long has an electric resistance of $0.19\ \Omega$. Calculate its resistivity and identify the composition of the wire from the values given in the table. ($9.8 \times 10^{-8}\ \Omega \cdot m$, iron)

12. Calculate the electric resistance of an iron rod $2.00\ m$ long, assuming that its cross-sectional area is $0.90\ mm^2$. ($2.16 \times 10^{-7}\ \Omega$)

13. Calculate the resistance of a Nichrome wire $0.50\ mm$ in diameter and $1.25\ m$ long. ($6.4\ \Omega$)

14. The light-duty extension cords that are routinely sold for household use are made from 18-gauge copper wire. Cords for higher current usage are often made from 16-gauge wire. Compute the resistances of wires $5.00\ m$ long. The cross-sectional area of 18-gauge wire is $0.8231\ mm^2$, and that of 16-gauge wire is $1.309\ mm^2$. ($1.04\times10^{-7}\ \Omega$, $6.57\times10^{-8}\ \Omega$)

15. When aluminum is used for electrical wire, it is common to use a larger-diameter wire than would be necessary for copper. Compare the resistance of 16-gauge aluminum wire with that of 18-gauge copper wire of equal length by finding the ratio of their resistances. (0.969)