**Experiment No : ** EM3

Experiment Name: Verifying Ohm's law and measuring specific resistances

Objective:

1. Verifying Ohm's law and determining the resistances.
2. Measuring the voltage and the current on four *constantan* wires with different cross-sectional areas.
3. Measuring the voltage and the current on two *constantan* wires with different lengths.
4. Measuring the voltage and the current on *constantan* and *messing* wires.

Keywords: Resistivity, resistance, voltage, current, Ohm's law

Theory:

We can relate current to the motion of the charge carriers by describing a microscopic model of conduction in a metal. Consider the current in a conductor of cross-sectional area A (Figure 3.1).

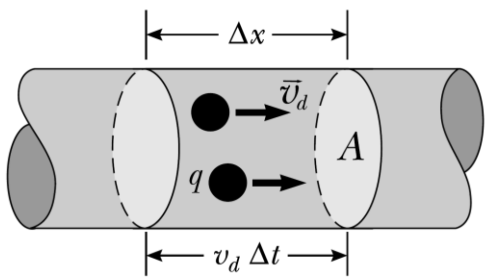

Figure 3.1: A section of a uniform conductor of cross-sectional area A.

The volume of a section of the conductor of length Δx (the gray region shown in Fig. 3.1) is $A\Delta x$. If n represents the number of mobile charge carriers per unit volume (in other words, the charge carrier density), the number of carriers in the gray section is $nA\Delta x$. Therefore, the total charge ΔQ in this section is

$$\Delta Q = number\ of\ carriers\ in\ section \times charge\ per\ carrier = (nA\Delta x)q \qquad 3.1$$

where q is the charge on each carrier. If the carriers move with a speed v_d, the displacement they experience in the x direction in a time interval Δt is $\Delta x = v_d \Delta t$. Let us choose Δt to be the time interval required for the charges in the cylinder to move through a displacement whose magnitude is equal to the length of the cylinder. This time interval is also required for all of the charges in the cylinder to pass through the circular area at one end. With this choice, we can write ΔQ in the form

$$\Delta Q = (nAv_d\Delta t)q \qquad 3.2$$

If we divide both sides of this equation by Δt, we see that the average current in the conductor is

$$I_{av} = \frac{\Delta Q}{\Delta t} = nqv_dA \qquad 3.3$$

We know that the electric field inside a conductor is zero. However, this statement is true only if the conductor is in static equilibrium. The purpose of this section is to describe what happens when the charges in the conductor are not in equilibrium, in which case there is an electric field in the conductor.

Consider a conductor of cross-sectional area A carrying a current *I*. The current density *J* in the conductor is defined as the current per unit area. Because the current $I = nqv_dA$, the current density is

$$J \equiv \frac{I}{A} = nqv_d \qquad 3.4$$

where *J* has SI units of A/m^2. This expression is valid only if the current density is uniform and only if the surface of cross-sectional area A is perpendicular to the direction of the current. In general, the current density is a vector quantity:

$$\vec{J} = nq\vec{v}_d \qquad 3.5$$

From this equation, we see that current density is in the direction of charge motion for positive charge carriers and opposite the direction of motion for negative charge carriers.

A current density $\vec{J}$ and an electric field $\vec{E}$ are established in a conductor whenever a potential difference is maintained across the conductor. In some materials, the current density is proportional to the electric field:

$$\vec{J} = \sigma\vec{E} \qquad 3.6$$

where the constant of proportionality σ is called the conductivity of the conductor. Materials that obey Equation 3.6 are said to follow Ohm's law, named after Georg Simon Ohm (1789–1854). More specifically, Ohm's law states that for many materials (including most metals), the ratio of the current density to the electric field is a constant σ that is independent of the electric field producing the current.

Materials that obey Ohm's law and hence demonstrate this simple relationship between $\vec{E}$ and $\vec{J}$ are said to be *ohmic*. Experimentally, however, it is found that not all materials have this property. Materials and devices that do not obey Ohm's law are said to be *nonohmic*. Ohm's law is not a fundamental law of nature but rather an empirical relationship valid only for certain materials.
We can obtain an equation useful in practical applications by considering a segment of straight wire of uniform cross-sectional area A and length *l*, as shown in

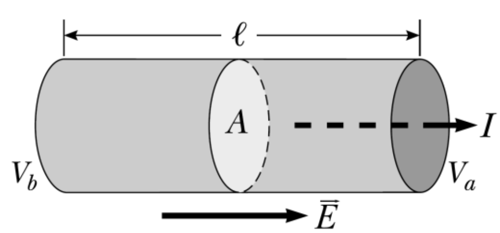

Figure 3.2: A uniform conductor of length *l* and cross-sectional area *A*. A potential difference $\Delta V = V_b - V_a$ maintained across the conductor sets up an electric field $\vec{E}$, and this field produces a current *I* that is proportional to the potential difference.

In Figure 3.2, a potential difference $\Delta V = V_b - V_a$ is maintained across the wire, creating in the wire an electric field and a current. If the field is assumed to be uniform, the potential difference is related to the field through the relationship

$$V_a - V_b = -\int_a^b \vec{E} \cdot d\vec{s} = E\int_0^l dx = El \Rightarrow \Delta V = El \qquad 3.7$$

Therefore, we can express the magnitude of the current density in the wire as

$$J = \sigma E = \sigma \frac{\Delta V}{l} \qquad 3.8$$

Because $J = I/A$, we can write the potential difference as

$$\Delta V = \frac{l}{\sigma} J = \left(\frac{l}{\sigma A}\right) I = RI \qquad 3.9$$

The quantity $R = l/\sigma A$ is called the resistance of the conductor. We can define the resistance as the ratio of the potential difference across a conductor to the current in the conductor:

$$R \equiv \frac{\Delta V}{I} \qquad 3.10$$

We will use this equation over and over again when studying electric circuits. From this result we see that resistance has SI units of volts per ampere. One volt per ampere is defined to be one ohm (Ω):

$$1\Omega \equiv \frac{1V}{1A} \qquad 3.11$$

This expression shows that if a potential difference of 1 V across a conductor causes a current of 1 A, the resistance of the conductor is 1Ω. The inverse of conductivity is resistivity ρ:

$$\rho = \frac{1}{\sigma} \qquad 3.12$$

where ρ has the units ohm-meters (Ω.m). Because $R = l/\sigma A$, we can express the resistance of a uniform block of material along the length l as

$$R = \rho \frac{l}{A} \qquad 3.13$$

Raymond A. Serway, John W. Jewett, Physics for Scientists and Engineers, 6^{th} ed., Thomson Brooks/Cole (2004).