Electricity

Lecture Notes: Current Electricity

3.5 Drift of Electrons and the Origin of Resistivity

Concept of Drift Velocity:

- **Drift Velocity (v_d)**: The average velocity attained by charged particles, such as electrons, in a material due to an electric field. Unlike the random thermal motion, drift velocity is directional.

Relation Between Drift Velocity and Electric Field:

- **Electric Field (E)**: When an electric field is applied to a conductor, it exerts a force on the free electrons, causing them to accelerate.
- **Formula**: The drift velocity v_d is given by $v_d = \frac{eE\tau}{m}$, where e is the charge of the electron, E is the electric field, τ is the average time between collisions (relaxation time), and m is the mass of the electron.

Origin of Resistivity in Materials:

- **Collisions**: Electrons moving through a conductor collide with the fixed ions in the lattice, losing energy in the process. These collisions are the primary cause of electrical resistance.
- **Resistivity (ρ)**: A material property that quantifies how strongly a given material opposes the flow of electric current. The resistivity is given by $\rho = \frac{m}{ne^2\tau}$, where n is the number density of free electrons.

Mobility of Charge Carriers:

- **Mobility (μ)**: The drift velocity per unit electric field, given by $\mu = \frac{v_d}{E} = \frac{e\tau}{m}$. It measures how quickly electrons can move through a conductor when an electric field is applied.
- **Units**: The SI unit of mobility is $\mathrm{m^2V^{-1}s^{-1}}$.

3.6 Limitations of Ohm's Law

Situations Where Ohm's Law Does Not Apply:

- **Non-Linear V-I Characteristics**: Ohm's Law states that $V = IR$, implying a linear relationship between voltage (V) and current (I). However, in some materials and devices, the V-I relationship is not linear.

Examples of Non-Ohmic Materials and Devices:

- **Diodes**: Semiconductor devices that allow current to flow in one direction only. The V-I characteristic curve of a diode is non-linear.

- **Transistors**: Semiconductor devices used to amplify or switch electronic signals, exhibiting non-linear V-I relationships.
- **Thermistors**: Resistive components whose resistance changes significantly with temperature, resulting in non-linear V-I characteristics.

3.7 Resistivity of Various Materials

Classification of Materials Based on Resistivity:

- **Conductors**: Materials with low resistivity, allowing easy flow of electric current (e.g., silver, copper).
- **Semiconductors**: Materials with intermediate resistivity, which can be modified by adding impurities (e.g., silicon, germanium).
- **Insulators**: Materials with high resistivity, preventing the flow of electric current (e.g., glass, rubber).

Table of Resistivities for Common Materials:

- **Examples**:
    - Silver: $\rho \approx 1.6 \times 10^{-8}\ \Omega\text{m}$
    - Copper: $\rho \approx 1.7 \times 10^{-8}\ \Omega\text{m}$
    - Aluminum: $\rho \approx 2.7 \times 10^{-8}\ \Omega\text{m}$
    - Silicon: $\rho \approx 2300\,\Omega\text{m}$
    - Glass: $\rho \approx 10^{10} - 10^{14}\ \Omega\text{m}$

Explanation of Temperature Dependence of Resistivity:

- **Metals**: Resistivity increases with temperature due to increased collision frequency of electrons with the lattice ions.
- **Semiconductors**: Resistivity decreases with temperature as more charge carriers are generated.

3.8 Temperature Dependence of Resistivity

Mathematical Relationship Between Resistivity and Temperature:

- **Formula**: For conductors, $\rho_T = \rho_0[1 + \alpha(T - T_0)]$, where ρ_T is the resistivity at temperature T, ρ_0 is the resistivity at a reference temperature T_0, and α is the temperature coefficient of resistivity.

Graphical Representation of Resistivity vs. Temperature:

- **Conductors**: Typically show a linear increase in resistivity with temperature.
- **Semiconductors**: Show an exponential decrease in resistivity with increasing temperature.

Practical Examples and Calculations:

- **Example Calculation**: A copper wire has a resistivity of $1.7 \times 10^{-8}\ \Omega\text{m}$ at 20°C. If the temperature coefficient of resistivity is $0.0039\ {}^\circ\text{C}^{-1}$, find the resistivity at 100°C.
    - **Solution**: $\rho_{100°C} = 1.7 \times 10^{-8}\ \Omega\text{m}[1 + 0.0039(100 - 20)] = 1.7 \times 10^{-8}\ \Omega\text{m} \times 1.312 = 2.23 \times 10^{-8}\ \Omega\text{m}.$