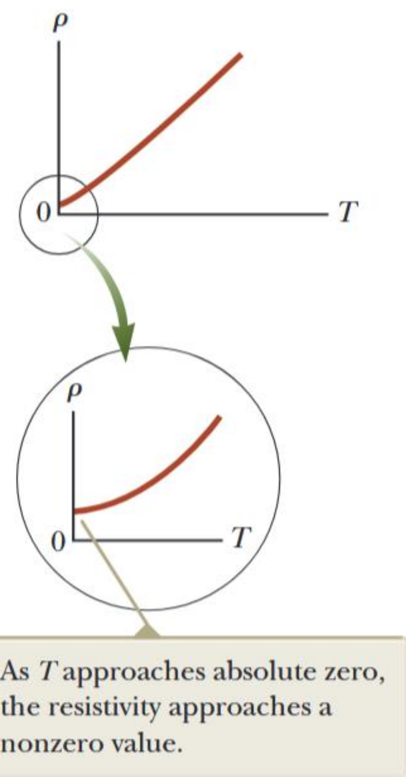
27-4 Resistance and Temperature

1. Introduction

- Electrical resistance (R) is a measure of how much a material **opposes or resists the flow of electric current**.
- The resistance of a material **changes with temperature** due to variations in atomic vibrations and electron scattering.
- This temperature dependence is crucial in designing electrical circuits, power transmission lines, and electronic sensors.



2. Resistivity and Temperature Dependence

- **Resistivity (ρ)** is an intrinsic property of a material that determines how much it resists current flow.
- The relationship between resistivity and temperature is given by:

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

where:

- ρ = resistivity at temperature T (**Ω·m**)
- ρ_0 = resistivity at reference temperature T_0 (usually **20°C or 0°C**)
- α = **temperature coefficient of resistivity** (**°C^{-1}**)
- T, T_0= temperatures in **°C**

Understanding α:

- **For metals**: $\alpha>0$, meaning resistivity **increases** with temperature.
- **For semiconductors and insulators**: $\alpha<0$, meaning resistivity **decreases** with temperature.

Material	Resistivity at 20°C (Ω·m)	Temperature Coefficient (α\alpha) (°C^{-1})
Copper (Cu)	1.68×10^{-8}	3.9×10^{-3}
Aluminum (Al)	2.65×10^{-8}	4.0×10^{-3}
Silver (Ag)	1.59×10^{-8}	3.8×10^{-3}
Silicon (Si)	6.4×10^{26}	-75×10^{-3}

3. Derivation of Resistance-Temperature Relationship

We know that **resistance** is related to **resistivity** by:

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

where:

- R = resistance (**Ω**)
- ρ = resistivity (**Ω·m**)
- *l* = conductor length (**m**)
- A = cross-sectional area (**m²**)

Substituting ρ:

Using the equation for resistivity:

$$R = [\rho_0(1 + \alpha(T - T_0))]\frac{l}{A}$$

Since ***l* and A are constant**, we simplify:

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

where:

- $R_0 = \rho_0 \frac{l}{A}$ is the resistance at the reference temperature T_0.
- This equation shows that **resistance increases linearly with temperature** for most conductors.

4. Superconductors and Thermistors

A. Superconductors

- Some materials exhibit **zero resistance** below a critical temperature (Tc).
- This is called **superconductivity** and is used in **MRI machines, maglev trains, and quantum computing**.

B. Thermistors

- **Thermistors** are semiconductor devices with a **high negative α\alpha**.
- Used in **temperature sensors** since their resistance changes significantly with temperature.

5. Example Problems

Problem 1: Change in Resistance with Temperature

Given: A **copper wire** has a resistance of **10.0 Ω** at **20°C**. Find its resistance at **100°C**. (Given: $\alpha(Cu)=3.9\times10^{-3}$ °C).

Problem 2: Change in Resistivity

Given: A silver wire has a resistivity of **1.59×10^{-8} Ω·m** at **20°C**. Find its resistivity at **100°C**. (Given: $\alpha(Ag)=3.8\times10^{-3}$ °C).

---

6. Applications of Temperature-Dependent Resistance

✅ **Electrical Wiring:** High-voltage power lines use materials with low α\alpha to reduce energy losses.
✅ **Temperature Sensors:** Thermistors in medical devices and thermostats.
✅ **Superconductors:** Used in MRI machines, fusion reactors, and particle accelerators.
✅ **Electronic Circuits:** Some components (e.g., resistors) are designed to minimize temperature effects.

Option:

Example: Plotting Resistance vs. Temperature

This script calculates and plots the resistance of **copper** as a function of temperature using the equation:

Python Code:

================

```
import numpy as np

import matplotlib.pyplot as plt

# Given values

R0 = 10  # Resistance at reference temperature (Ω)

T0 = 20  # Reference temperature (°C)

alpha_copper = 3.9e-3  # Temperature coefficient for copper (°C⁻¹)

# Define temperature range

T = np.linspace(-50, 200, 100)  # From -50°C to 200°C

# Calculate resistance at each temperature

R = R0 * (1 + alpha_copper * (T - T0))

# Plot the graph

plt.figure(figsize=(8, 5))

plt.plot(T, R, label="Copper", color='b')

plt.axvline(x=T0, color='r', linestyle='--', label="Reference Temp (20°C)")

# Labels and title

plt.xlabel("Temperature (°C)")

plt.ylabel("Resistance (Ω)")

plt.title("Resistance vs. Temperature for Copper")

plt.legend()

plt.grid(True)

plt.show()
```