UNIT-5(SUPERCONDUCTIVITY)

07 August 2025 11:26 PM

INTRODUCTION

54. SUPERCONDUCTIVITY

What is Superconductivity?

- **Superconductivity** is a phenomenon where certain materials **completely lose electrical resistance** when cooled below a specific **critical temperature (Tc)**.
- In this state, **electrical current can flow without any energy loss**.

Key Features of Superconductors:

- **Zero electrical resistance**: Perfect conduction of electricity.
- **Meissner Effect**: Superconductors **expel magnetic fields** from their interior, making them perfectly diamagnetic.
- **Critical Temperature (Tc)**: The temperature **below which** the material becomes superconducting.
- **Critical Magnetic Field (Hc):** A magnetic field **above which superconductivity is destroyed**.

- **Critical Current (Ic):** Maximum current the superconductor can carry without losing superconductivity.

Types of Superconductors:

1. **Type I Superconductors**
   - Exhibit **complete Meissner effect**.
   - Sharp transition from normal to superconducting state.
   - Usually pure metals (e.g., mercury, lead).
2. **Type II Superconductors**
   - Partial Meissner effect.
   - Allow magnetic field to penetrate in quantized vortices.
   - Include alloys and high-temperature superconductors (e.g., YBCO).

Applications of Superconductivity:

- **Magnetic levitation trains (Maglev)**
- **MRI machines** in hospitals
- **Superconducting quantum computers**

- **Power cables** with zero energy loss
- **Particle accelerators** (like CERN)
- **SQUIDs** (Superconducting Quantum Interference Devices) for precise magnetic measurements

Here is a clear and easy-to-understand explanation of the **General Properties of Superconductors**, in your preferred format:

55. GENERAL PROPERTIES OF SUPERCONDUCTORS

1. Zero Electrical Resistance

- When cooled below their **critical temperature (Tc)**, superconductors show **absolutely zero resistance**.
- Electric current can flow **indefinitely** without any loss.

2. Meissner Effect

- A superconductor **expels all magnetic fields** from its interior when it enters the superconducting state.
- This makes it a **perfect diamagnet** (magnetic field B = 0 inside).
- This is a key difference between a perfect conductor and a superconductor.

3. Critical Temperature (Tc)

- Each superconductor has a specific **temperature below which** it becomes superconducting.

Examples:

- **Mercury (Hg):**
  $T_c \approx 4.2\,\mathrm{K}$
- **YBCO (Yttrium Barium Copper Oxide):**
  $T_c \approx 90\,\mathrm{K}$
  → A **high-T_c** ceramic superconductor

4. Critical Magnetic Field (Hc)

- Superconductivity is destroyed if the applied magnetic field exceeds a certain value called the **critical field**.
- The value of Hc **decreases with increasing temperature**.

5. Critical Current Density (Jc)

- If the current flowing through a superconductor exceeds a certain limit, it **loses its superconductivity**.
- This limit is known as **critical current density**.

6. Perfect Diamagnetism

- Due to the Meissner effect, superconductors show **complete repulsion of magnetic fields**.

- **Magnetic Susceptibility $\chi = -1$**
  - In the superconducting state, a material **completely expels magnetic fields** from its interior — this is known as the **Meissner effect**.
  - This perfect diamagnetism means the **magnetic susceptibility** becomes:

$$\boxed{\chi = -1}$$

  - This indicates:
    - The material **repels all magnetic field lines**.
    - **Magnetic flux density** $B = 0$ inside the superconductor, even if an external magnetic field is applied.

7. Energy Gap

- In the superconducting state, there is a small **energy gap** between the ground state and the excited state of electrons.
- This gap explains why **thermal vibrations do not scatter electrons**.

8. Persistent Currents

- A current induced in a superconducting loop can **circulate forever** without decaying.

9. Isotope Effect

- Tc changes with the **mass of the isotopes** in the material.
- This shows that **lattice vibrations (phonons)** play a role

in superconductivity.

56. MEISSNER EFFECT

What is the Meissner Effect?

- The **Meissner Effect** is the phenomenon where a superconductor **expels all magnetic field lines from its interior** when cooled below its **critical temperature (Tc)**.
- This means a superconductor becomes a **perfect diamagnet** (magnetic field B=0B = 0 inside).

Key Points:

- It was discovered by **Walther Meissner and Robert Ochsenfeld** in **1933**.
- Happens **only in superconductors**, not in ordinary perfect conductors.
- Even if a magnetic field is applied **before cooling**, the superconductor will expel it **once it becomes superconducting**.

Magnetic Field Behavior:

- **Normal state**: Magnetic field passes through the material.

- **Superconducting state**: Magnetic field is **pushed out** of the material completely.

Mathematical Expression:

$$B = \mu_0(H + M) = 0 \Rightarrow M = -H$$

- Where:
  - B = magnetic flux density (inside the superconductor)
  - μ_0 = permeability of free space
  - H = applied magnetic field
  - M = magnetization

Importance:

- Confirms that superconductivity is **not just perfect conduction**, but a **completely new state of matter**.
- Used in **magnetic levitation (Maglev)** and **SQUID devices**.

57. TYPE I AND TYPE II SUPERCONDUCTORS

What are Type I and Type II Superconductors?

Superconductors are classified into two types based on how they **respond to magnetic fields**:

TYPE I SUPERCONDUCTORS

- These are **pure elemental superconductors** (like Mercury, Lead, Tin).
- They show a **sharp transition** from the normal state to the superconducting state.
- They exhibit **complete Meissner effect** — expel magnetic fields totally until a critical magnetic field is reached.

Key Properties:

- **Single critical magnetic field (Hc)**
- **Perfect diamagnetism ($\chi = -1$)**
- **Low critical field strength**
- **Used less in practical applications due to low Tc**

Examples:

- Mercury (Hg), Lead (Pb), Tin (Sn)

TYPE II SUPERCONDUCTORS

- These are usually **metal alloys or complex compounds**.
- They allow **partial penetration** of magnetic fields in a mixed state between two critical fields.

- Show **incomplete Meissner effect** — magnetic flux enters in **quantized vortices**.

Key Properties:

- Two critical magnetic fields: **Lower critical field (Hc1)** and **Upper critical field (Hc2)**
- Between Hc1 and Hc2: **Mixed state (vortex state)**
- **Higher critical temperatures (Tc)**
- **Stronger magnetic field tolerance**
- **Used in practical applications** like MRI, maglev trains

Examples:

- Niobium-Titanium (NbTi), YBCO (Yttrium Barium Copper Oxide), BSCCO

58. BCS THEORY (QUALITATIVE)

What is BCS Theory?

- Proposed by **Bardeen, Cooper, and Schrieffer** in 1957.
- Explains **why materials become superconducting** at low temperatures.

Main Ideas:

- In a superconductor, **electrons do not act alone**.

- They form **Cooper pairs** — two electrons weakly bound via lattice vibrations (phonons).
- These pairs move through the lattice **without resistance** because they do not scatter off atoms.
- The energy needed to break a Cooper pair is called the **energy gap**.
- This explains **zero resistance** and the **Meissner effect**.

59. INTRODUCTION TO HIGH-Tc SUPERCONDUCTORS

What are High-Temperature Superconductors?

- These are materials that become superconducting at **much higher temperatures** than conventional superconductors.
- Typically, they are **ceramic compounds** of copper and oxygen (called **cuprates**).

Features:

- **Critical temperature (Tc)** above **77 K** (the boiling point of liquid nitrogen).
- Examples:
  - **YBCO –** Yttrium Barium Copper Oxide (Tc ≈ 92 K)

- **BSCCO –** Bismuth Strontium Calcium Copper Oxide

- Do not follow traditional BCS theory exactly.
- Used with **liquid nitrogen cooling**, which is cheaper than liquid helium.

60. APPLICATIONS OF SUPERCONDUCTORS

1. Magnetic Levitation (Maglev Trains)

- Superconductors repel magnets strongly (Meissner effect), allowing **frictionless high-speed trains**.

2. MRI Machines

- Used to generate **strong, stable magnetic fields** for medical imaging.

3. Superconducting Wires

- Carry **very high currents** with **zero power loss**.
- Useful in **power grids and transformers**.

4. Particle Accelerators

- Used in **Large Hadron Collider (LHC)** to bend and accelerate particles.

5. SQUIDs (Superconducting Quantum Interference Devices)

- Ultra-sensitive magnetic field detectors used in **geophysics** and **medicine**.

6. Quantum Computers

- Superconducting materials are used to make **qubits**, the basic units of quantum computers.