

SHRI VISHWAKARMA SKILL UNIVERSITY

Dudhola, Palwal



QUANTUM PHYSICS

Experiment:- SUPERCONDUCTORS AND THE SUPERCONDUCTING QUANTUM INTERFERENCE DEVICE (SQUID):

Submitted by:

Kapil(22BTC35123)

Karan(22BTC35124)

Kartik(22BTC35125)

Khushboo(22BTC35126)

Kirti(22BTC35127)

Kunal(22BTC35128)

Kunal Sood(22BTC35129)

Lakshay(22BTC35130)

Lalit(22BTC35131)

Lalit Sharma(22BTC35132)

Manmohan(22BTC35133)

Submitted to:

Dr. Divyanshu Bhatnagar

(Skill Assistant Professor)

SUPERCONDUCTORS AND THE SUPERCONDUCTING QUANTUM INTERFERENCE DEVICE (SQUIDS):

Introduction:

Brief overview of superconductors and their properties:

Superconductors are materials that exhibit zero electrical resistance below a critical temperature. When cooled below this critical temperature, certain materials can conduct electric current without any loss of energy due to resistance. This unique property makes superconductors valuable for various applications, including power transmission, magnetic levitation, high-speed computing, and particle accelerators.

Superconducting Quantum Interference Device (SQUID):

A Superconducting Quantum Interference Device (SQUID) is a highly sensitive magnetometer that utilises the unique properties of superconductors to detect and measure extremely weak magnetic fields. It consists of a superconducting loop interrupted by one or more Josephson junctions, which are weak links between two superconducting regions.

The key principle behind SQUID operation is the quantum interference of superconducting electron pairs. When an external magnetic field passes through the SQUID loop, it induces changes in the magnetic flux threading the loop. These changes can be detected by the SQUID, which is extremely sensitive to even minute variations in the magnetic field.

SQUIDs are used in a wide range of applications, such as medical diagnostics (e.g., magnetoencephalography and magnetocardiography), geophysical exploration, non-destructive testing, and fundamental research in areas like quantum computing and quantum information processing.

Superconductors and SQUIDs have revolutionised various fields of science and technology, enabling advancements that were previously impossible. Ongoing research continues to explore new superconducting materials, higher critical temperatures, and improved SQUID designs, leading to even more exciting applications in the future.

Experimental Setup:

List of materials and equipment used in the experiment:

Superconducting Materials:

Superconducting wire or thin films (e.g., niobium, niobium nitride, YBCO) Substrate material (e.g., silicon, sapphire) for supporting the superconducting film

Cryogenic Equipment:

Liquid helium (L He) or cry cooler for cooling the experiment to cryogenic temperatures Cryostat or cryogenic dewar for housing the experimental setup Temperature controller for maintaining stable temperatures

Magnetic Field Generation and Control:

Electromagnets or permanent magnets for generating magnetic fields Magnetic field shielding materials (e.g., mu-metal) to minimize external magnetic interference Magnetic field measurement devices (e.g., Hall probes, fluxgate magnetometers) for calibrating and verifying the magnetic field intensity

Electrical Components and Instruments:

Power supply for providing electrical current to the superconducting elements Cryogenic-compatible wiring and connectors for electrical connections Resistors, capacitors, and inductors for constructing electrical circuits Lock-in amplifiers for signal detection and measurement Digital multimeters for voltage and current measurements Oscilloscope for visualizing electrical signals

Fabrication Tools (for SQUID fabrication):

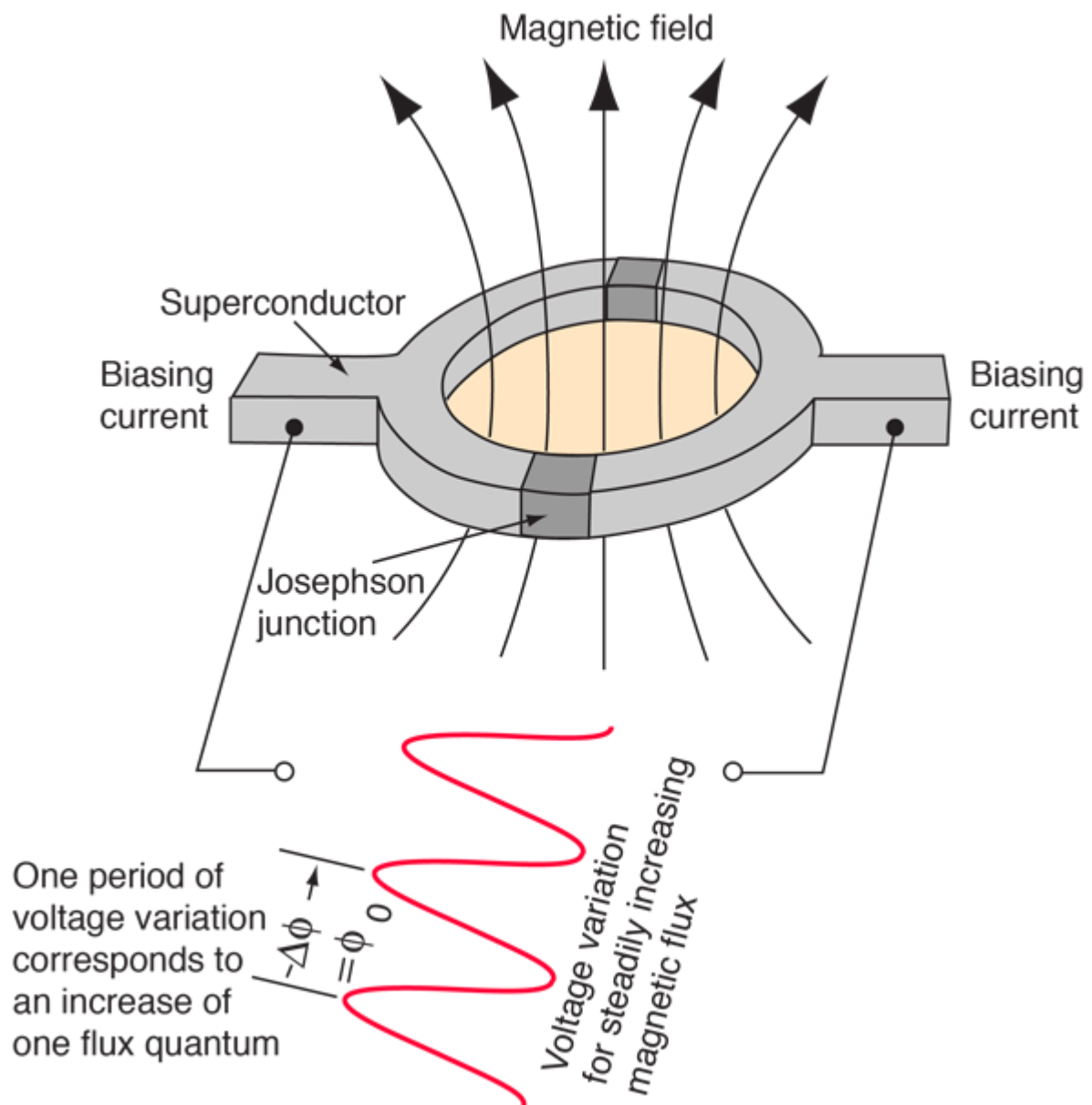
Photolithography equipment for creating patterns on the substrate Deposition systems (e.g., sputtering, evaporation) for depositing superconducting films Etching chemicals or reactive ion etching (RIE) system for defining the SQUID structure Electron beam lithography system for precise patterning (if applicable) Probe station for electrical characterization of the fabricated SQUID

Data Acquisition and Analysis:

Computer or data acquisition system for recording and storing experimental data Software for data analysis, visualization, and plotting (e.g., Python with libraries such as NumPy, SciPy, and Matplotlib).

Safety Equipment:

Personal protective equipment (PPE) such as gloves, safety glasses, and lab coats Safety interlocks and emergency shutdown mechanisms for cryogenic and high-power systems.



Here's how a SQUID works:

Principle of Operation: A SQUID consists of a superconducting loop interrupted by one or two Josephson junctions. Josephson junctions are created by placing a thin insulating barrier between two superconducting materials. These junctions allow supercurrent (a current of pairs of electrons) to flow without any resistance.

Flux Sensitivity: When a magnetic field is applied to a SQUID, it induces a change in the magnetic flux threading the superconducting loop. This change in flux causes a change in the supercurrent flowing through the SQUID. The SQUID is designed such that even tiny changes in flux can be detected as changes in the supercurrent, making it highly sensitive.

Operating in the Quantum Regime: The SQUID operates in the quantum regime, utilizing the wave-like nature of supercurrent. It can detect changes in the magnetic flux down to the level of individual magnetic flux quanta, known as fluxons or flux quanta. This allows for extremely precise measurements of magnetic flux.

Readout: The SQUID is connected to a superconducting circuit that acts as a feedback loop. The supercurrent passing through the SQUID generates a voltage that is measured and fed back to the circuit. By maintaining the SQUID in a specific operating mode, known as the flux-locked loop, the feedback circuit keeps the magnetic flux constant. Any change in the magnetic field results in a corresponding change in the SQUID's supercurrent, which is detected and used to measure the magnetic flux.

SQUIDs are used in various scientific and technological applications requiring high-precision magnetic field measurements. They find use in areas such as biomagnetism, geophysics, material characterization, and quantum information processing. The ability of SQUIDs to measure extremely weak magnetic fields with remarkable sensitivity has made them an invaluable tool in many fields of research.

- **Procedure for measuring the critical temperature of a superconductor:**

The following is a general procedure for measuring the critical temperature (T_c) of a superconductor:

Sample Preparation:

Obtain a representative sample of the superconducting material, ensuring it is clean and free from contaminants. Shape the sample into a suitable form for measurements (e.g., wire, thin film, pellet), depending on the experimental setup.

Setup the Experimental Apparatus:

Set up the cryogenic system (e.g., cryostat, dewar) and ensure it is properly connected and functioning. Install any necessary electrical connections, such as leads or electrodes, to the superconducting sample. Temperature Calibration: Calibrate the temperature measurement system (thermocouples, resistance thermometers, or other temperature sensors) using reference temperatures or standards. Ensure the temperature measurement system is properly connected to the sample and that the readings are accurate and stable.

Cooling and Temperature Stabilization:

Start the cooling process using liquid helium (LHe) or cryocooler, depending on the setup, to lower the temperature gradually. Monitor the temperature until it reaches a suitable range below the expected T_c of the superconducting material. Allow sufficient time for the temperature to stabilize and reach thermal equilibrium.

Resistance Measurement:

Set up a suitable electrical circuit to measure the resistance of the superconducting sample. Apply a small known current to the sample using a current source or power supply. Measure the voltage across the sample using a digital multimeter or other voltage measurement device. Record the resistance value at different temperature intervals, gradually increasing the temperature.

Critical Temperature Determination:

Plot a graph of the resistance versus temperature for the superconducting sample. Analyze the data and identify a sudden drop in resistance to or near zero. This drop indicates the transition to the superconducting state. The temperature at which this drop occurs is the estimated critical temperature (T_c) of the superconductor.

Reversibility Test (Optional):

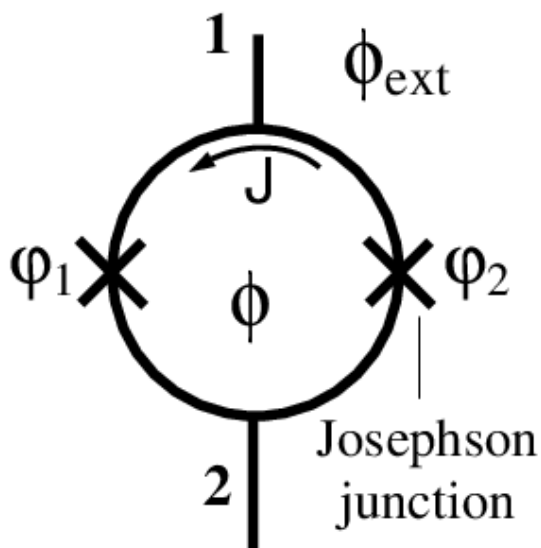
Perform a reversibility test by raising the temperature of the sample above the estimated T_c and then cooling it back down. Observe if the resistance returns to its normal, non-superconducting state upon cooling. If so, it confirms the T_c measurement.

Data Analysis and Conclusion:

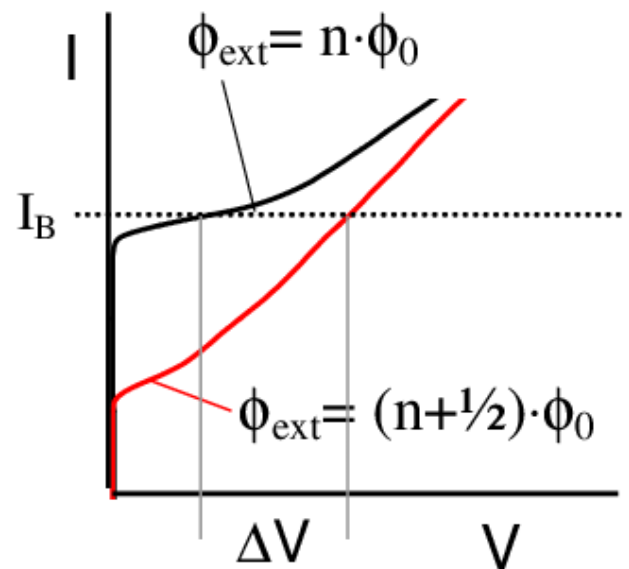
Analyze the data collected during the experiment, including the resistance-temperature plot and any additional measurements. Calculate the average critical temperature (T_c) based on the obtained values.

Compare the measured T_c with the known literature values for the superconducting material to assess the accuracy of the measurement. Draw conclusions and summarize the results obtained from the experiment.

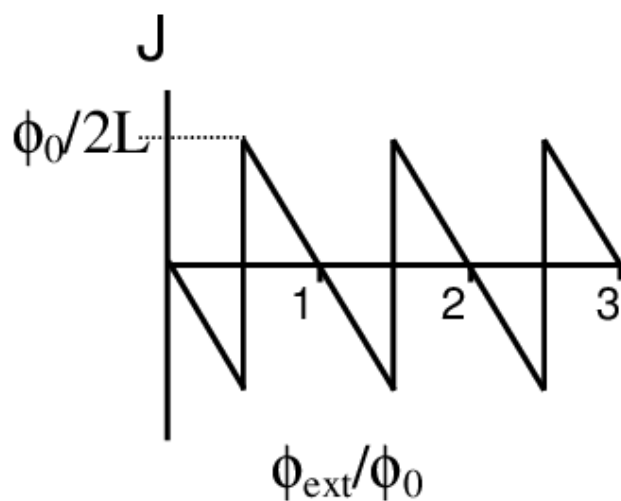
A DC SQUID



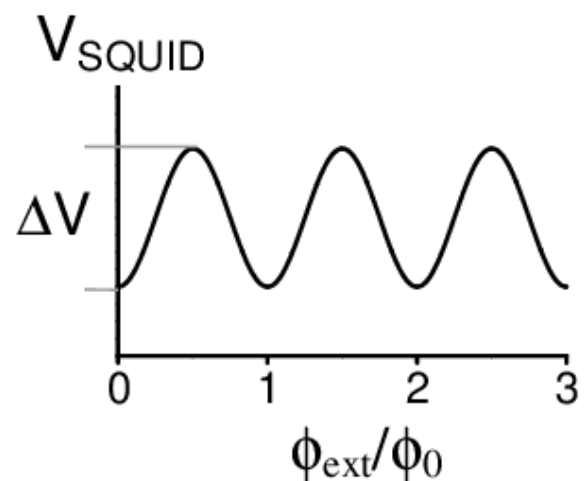
B critical current from 1 to 2



C circulating current J



D $V_{\text{SQUID}}\text{-}B$ oscillations



- **Applications of Superconductors and SQUIDs:**

Magnetic Resonance Imaging (MRI): Superconducting magnets are used in MRI machines to generate high-intensity magnetic fields for medical imaging. The strong magnetic fields produced by superconducting magnets enhance the resolution and quality of MRI scans.

Particle Accelerators: Superconducting radiofrequency cavities are employed in particle accelerators to accelerate charged particles to high energies. Superconducting materials allow for efficient energy transfer and reduce power dissipation, enabling the construction of more powerful and compact accelerators.

Energy Transmission and Storage: Superconducting power cables offer significantly lower energy losses compared to traditional copper cables, making them ideal for long-distance power transmission. Superconducting energy storage devices, such as superconducting magnetic energy storage (SMES) systems, provide high-capacity energy storage with fast response times.

Quantum Computing: Superconducting qubits are used as the building blocks for quantum computing systems. The superconducting properties of certain materials allow for the creation and manipulation of quantum states, enabling quantum information processing and potential advancements in computing power.

Sensing and Detectors:

SQUIDs are highly sensitive magnetic field detectors used in various applications. They are employed in magnetoencephalography (MEG) and magnetocardiography (MCG) for non-invasive measurement of brain and heart activity, respectively.

SQUIDs are used in geophysical exploration to detect and map subsurface mineral deposits and conduct environmental monitoring.

SQUIDs are also used in non-destructive testing and evaluation to detect flaws or defects in materials, such as in the aerospace or automotive industries.

Astronomy and Astrophysics: SQUIDs are used in cryogenic detectors for astronomical observations. They enable precise measurements of weak magnetic fields and radiation, aiding research in areas such as cosmology, astrophysics, and the study of dark matter.

Metrology and Standards:

Superconducting materials are used to create reference standards for electrical resistance and voltage, providing highly accurate measurements for metrology applications.

Josephson voltage standards utilise the quantum properties of superconductors to establish precise and reproducible voltage standards.

Fundamental Research:

Superconductors and SQUIDs are extensively used in fundamental research in condensed matter physics, exploring phenomena like superconductivity, quantum phase transitions, and quantum interference effects.