## Indian Institute of Technology, Kanpur

## **Proposal for a New Course**

1. Course No: A 600 level elective number requested.

Pny656

2. Course Title: Superconductivity and Applications

3. No. of Lectures per week: 2 of 75 mins each or 3 (L) of 50 mins each, Tutorial: 0 (T), Laboratory: 0 (P), Additional Hours[0-2]: 0 (A),

Credits (3\*L+2\*T+P+A): 09

**Duration of Course: Full Semester** 

4. Proposing Department/IDP: PHY.

Other Departments/IDPs which may be interested in the proposed course: MSE

Other faculty members interested in teaching the course: -

5. Proposing Instructor: Satyajit Banerjee (Phy)

6. Course Description:

1. A) Objectives: This PG level elective course will attempt to summarize the vast field of superconductivity and its applications. It will discuss different aspects of superconductivity from both theoretical and experimental point of view. I will discuss seminal experiments associated with this phenomenon which led to its advancement. The initial part of the course will discuss classical aspects of superconductors, followed by a study of their thermodynamic and magnetic properties and electrodynamic response. An overview of the diverse and modern (emerging) aspects of superconductors along with discussion of new aspects related to phenomena of superconductivity in new emerging materials in the field, devices applications, will be discussed. The course will discuss the BCS theory and develop the gap equation near Tc and discuss various thermodynamic quantities within the purview of the microscopic theory. Ginzburg Landau theory for superconductivity, Abrikosov vortex state, pinning and vortex phases and phase transition in these phases, current voltage relationship of a type II superconductor in the presence of a magnetic field. Study of tunneling phenomenon in N-I-S or S-I-S junctions, associated Andreev reflection issues, Josephson effect junctions and their applications (SQUID), Superconductivity and vortex physics at nanoscales and device applications and experiments related to superconductivity will be introduced and discussed throughout the course at relevant points in the course. Attempts wherever possible will be made to connect some of the physics with that of superfluidity. The course will also attempt to review some of the latest developments in superconductivity and its applications.

## B) Contents:

S. No.	Broad Title	Topics	No. of Lectures
1.	Generation of low and ultra low Temperatures	General overview and introduction to thermodynamic principles related to generation of low temperatures. Discussion of Joule Thomson effect, concept of Inversion Temperature, Liquefaction of Helium, Dilution Refrigerator Principles to reach milli kelvin temperatures and ADR technique together with dilution techniques to reach down to microkelvin temperatures. Discussion of temperature measurement techniques using a variety of quantum phenomena.	4
2.	Overview of Electrodynamics of Superconductors	London's equation and the Meissner response in superconductors, Perfect Diamagnetism and related experimental signatures. Superconducting Penetration depth ( $\lambda$ ). Electrodynamic Response	6
		of Superconductors (AC / DC response and high frequency	

response (dissipation) — Discussion of Applications). Complex Conductivity and Two fluid Model. Type 1 SC and Intermediate State (for different geometries). Critical Current density in SC. Distinguishing the Superconducting Response from that of an Ideal (Prefect) Metal response. Discussion of experimental techniques used to measure the magnetization response of superconductors like VSM, Torque sensing, Pickup coil techniques, Micro-hall bar arrays and Scanning Hall. Superconducting materials both classical and modern, high temperature superconductors. Pnictide superconductors, topological superconductors.  3. Thermodynamic Response of Superconductors, Concepts of Superconductors in Zero field and in finite applied field. To as a phase transition. Order of the SC phase transition in zero and applied magnetic field. Type I and Type II superconductors, Discussion of some important Experiments Related to the thermodynamic response of superconductors. Discussion of some important Experiments Related to the thermodynamic response of superconductors. Discussion of Some important Experiments Related to the thermodynamic response of Superconductors. Source Resistance and concept of Kinetic Inductance and relation of Penetration depth. Isotope Effect. Pedagogic introduction to BSC theory of Superconductivity, Cooper Pairs, Origin of Attractive Interaction. Second quantized formulation of the BCS Hamiltonian, the BCS trial wavefunction. Cooper Pairs, Origin of Attractive Interaction. Second quantized formulation of the BCS Hamiltonian, the BCS trial wavefunction. Cooper Pairs, Origin of Attractive Interaction. Second quantized formulation of the BCS Hamiltonian, the BCS trial wavefunction. Cooper Pairs, Origin of Attractive Interaction. Second quantized formulation of the BCS Hamiltonian, the BCS trial wavefunction. Cooper Pairs of Administrative Interaction of Superconductorial Cooper Pairs of Administrative Interaction of Superconductorial Cooper Pairs of Administrative Interaction of Superconductorial Cooper Pairs (Su		
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C) Pre-requisites: Phy412, Phy431, Phy432, Phy543

D) <u>Short summary for including in the Courses of Study Booklet</u>: Introduction to the Quantum mechanical phenomena of superconductivity and its fascinating manifestation as a macroscopic quantum phenomenon. We sample some of the rich diverse properties displayed by this phenomenon and the plethora of ancillary phenomena's displayed by superconductors which have immense applications potential of which some have already been realized and used. We discuss some of these applications and devices based on superconductors which are increasingly finding use at the frontiers of Quantum technology.

## 7. Recommended books:

Introduction to Superconductivity: A. C. Rose-Innes and E. H. Rhoderick

Introduction to Superconductivity : Michael Tinkham Magnetic Flux structures in superconductors: R. P. Huebner

Theory of superconductivity: J. R. Schrieffer

Superconductivity Physics and Applications: Kristian Fossheim and Asle Sudbo

Superfluidity and Superconductivity: D. R. Tilley and J. Tilley

Experimental Techniques in Low Temperature Physics, Guy K White and Phillip J. Meeson.

Dated: 07 March 2024. Proposer: Satyajit Banerjee ( Abauju).
Dated: DPGC Convener (PHY):
The course is approved / not approved  Chairman, SPGC
Dated: