Indian Institute of Technology, Kanpur

Proposal for a New Course

1. Course No: A **600 level elective** number requested. PHY656
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 (λ). Electrodynamic Response of Superconductors (AC / DC response and high frequency	**6**

		response (dissipation) – Discussion of Applications). Complex Conductivity and Two fluid Model. Type I 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**	Exploring the Thermodynamics aspects of Superconductors in Zero field and in finite applied field. Tc as a phase transition. Order of the SC phase transition in zero and applied magnetic field. Type I and Type II superconductors, Concepts of Critical Fields. Thermal Conductivity of Superconductors. Discussion of some important Experiments Related to the thermodynamic response of superconductors. Evidence of Energy Gap in DOS.	**5**
4.	**Origins of BCS theory and Tunneling phenomena related to superconductors**	Ultrasonic attenuation experiment and evidence of presence of gap in DOS. Measurements of Surface 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 Pair occupation Probabilities, Evaluation of the Ground State energy. Calculation of Excited State energy and Energy Gap, DOS, Temperature Dependence of Gap, Tc relation to the gap. Concept of Coherence length (ξ). Tunneling experiments, Normal – Normal tunneling, Normal-Insulator-Superconductor Tunneling. Brief discussion of Andreev Reflections.	**9**
5.	**Ginzburg Landau Theory of Superconductivity**	Phase coherence in superconductors and the concept of an Order parameter for SC. Discussion of the Ginzburg Landau (GL) free energy formalism and its application to SC, the two differential equations arising from minimizing the GL free energy and the emergence of λ_{GL} and ξ_{GL}. Proximity effect (N-SC boundary and GL solution around it). Type II superconductivity, Flux Quantization Phenomena, Experiment which led to evidence of flux quantization, Discussion of the Vortex Structure in Type II superconductor, Linearlized GL equation, Abrikosov vortex state, dependence of H_{c1} and H_{c2} on λ_{GL} and ξ_{GL} and their temperature dependence. Vortex state phenomena, applications, effect current on vortices and dissipation in SC. Vortex Dynamics, Nanostructured superconductors.	**8**
6.	**Josephson Effect, Junctions and Applications**	Superconducting Phase and Josephson Tunneling, The Josephson Critical current and Josephson Relations. Short one-dimensional Weak links and the Nature of IV of such Josephson Junctions in zero field and applied field. AC and DC Josephson Effect, Deriving the equations for the Josephson current in the presence of Magnetic flux (parallels with Diffraction phenomena), Quantum Interference Phenomena, Introduction and Discussion of the Superconducting Quantum Interference Device (SQUID). SQUID based Applications. RCSJ Model	**8**
		Total number of lectures:	**40**

C) Pre-requisites: Phy412, Phy431, Phy432, Phy543

D) Short summary for including in the Courses of Study Booklet: 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 (SBanerjee).

Dated: 8/3/24 DPGC Convener (PHY): ____________

The course is approved / not approved

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Chairman, SPGC Abhijeet Keotiey 21/4/24

Dated: ____________