Syllabus for Ph.D. Course

Subject: Physics

PAPER	CONTENT
Paper-III **Any Four Unit**	Unit-1-Quantum Mechanics-GM Unit-2-Statistical Physics Unit-3-Atomic and Molecular Physics Unit-4- Nuclear and particle Physics Unit-5-Electronics Unit-6-Condensed Matter Physics Unit-7-Introduction to Gravitation and Cosmology Unit-8- Art and Science of Happiness (PS) Unit-9-Quantum Information Science Unit-10-Fundamentals of Remote Sensing and Photogrammetry (PS) Unit-11-Biophysics (PS) Unit-12- History of Indian Science and Technology (PS+PP)
Paper-IV **(Elective)** **Any Two**	Elective-1-Science and Technology of Nanomaterials (AG+PS) Elective-2-Dark matter and Dark energy (GM) Elective-3- Quantum Field Theory and Beyond (GM) Elective-4- Quantum Optics and Quantum Information (PP) Elective-5: Nuclear & Particle Physics (GM) Elective-6: Advanced statistical mechanics (SM) Elective-7: Advanced condensed matter physics (PP+SM) Elective-8: Environment, Technology and Society in Asia (PS) Elective-9: Environmental Impact Assessment (PS) Elective-10: Applications of RS & GIS (PS)

Paper -III: General Physics

ANY FOUR UNIT TO BE TAUGHT

Unit-1-Quantum Mechanics-

(a) Non-Relativistic - Schrödinger equation and its applications, Theory of angular momentum, Perturbation theory, Quantum harmonic oscillator, Coherent States, Quantum theory of Scattering, S-matrix Theory.

(b) Relativistic - Introduction, The Klein-Gordon equation, Particles and antiparticles, Bohr-Sommerfeld Semiclassical solution of the Coulomb problem, The Dirac equation and the Clifford algebra, Dirac matrices, Covariant form of the Dirac equation, Equations of motion, Spin, Free particle solutions.

(c) Basic concepts of Quantum Field Theory.

Unit-2-Statistical Physics

Foundation of Statistical mechanics, Elements of ensemble theory – a system in Microcanoncial, Canonical and Grand Canonical ensembles, Partition functions applications of ensemble theory Maxwell - Boltzman, Bose-Einstein, Fermi-Dirac distributions.

Unit-3- Atomic and Molecular Physics

Electronic spectra, Radiative transitions, Applications of Laser in spectroscopy, Basic idea of two-photon processes and frequency up conversion.

Unit-4-Nuclear and Particle Physics

Nuclear forces, Nuclear Models, Beta decay Fermi theory, parity violation, Symmetry and conservation laws, Special Unitary Symmetries and Quark model.

Unit -5- Electronics

Linear integrated circuits, Operational amplifier and its applications. MEMS, NEMS, Integrated photonics

Unit-6-Condensed Matter Physics

(a) Semiconductors: Band structure of common semiconductors; effective mass theory, intrinsic and extrinsic semiconductor - statistics of electron-hole carriers and Fermi energy;

dynamics of electrons and holes; generation and recombination processes; surface recombination; Shockley-Reed mechanism of recombination; lifetime of carriers; Hall effect and Hall Coefficient for two carrier types, origin of positive Hall coefficient for metals, modification of Hall coefficient for velocity distribution of carriers.

(b) Magnetism: Quantum theory of dia, paramagnetism, transition and rare-earth elements, Ferromagnetic, anti-ferromagnetic and Ferri-magnetic order, molecular fields, direct and indirect exchange interaction, Heisenberg and Ising model, domain theory, Bloch wall, spin waves, magnons, magnetic resonance, principle and application of NMR, EPR, ESR.

(c) Superconductivity: Review of experimental results, London-Pippard theory, penetration depth, coherence length, electron-phonon interaction, Cooper pair, BCS theory, energy gap, transition temperature, Ginzburg Landau theory, Flux quantization, Critical Current density, SQUID, superconducting devices, recent advances on high Tc superconductors.

Unit-7- Introduction to Gravitation and Cosmology

An introduction to general relativity as a theory of gravitation with applications to cosmology. Includes: principles of special and general relativity, tensor calculus in curved spacetime, Einstein's field equations, Schwarzschild solution, experimental tests of general relativity, black holes, standard cosmological models, unresolved cosmological issues, gravitational waves.

Unit-8- Art and Science of Happiness:

We will look at current theories on happiness and positive psychology as well as practical implications of those theories for our own lives. We will explore the concept of happiness, different cultural definitions of happiness, and the connection between happiness, optimism, and meaning. Practical strategies for creating more opportunities for happiness in our lives and for learning how to deal more effectively with sources of unhappiness will be explored. Weekly class discussions will be supplemented with speakers, movie clips, in-class exercises, and student presentations about their interviews with others about views on happiness. Every student will choose a different type of meditation to present each week as part of the hands-on focus of this class.

Unit-9-Quantum Information Science:

Quantum algorithms. Simon's algorithm, The prime factorization algorithm, Grover's search algorithm, Mathematical models of quantum computation, their relationships to each other, and to physical systems. Quantum error correcting codes, Quantum cryptography, Quantum fault tolerance.

Unit-10- Fundamentals of Remote Sensing and Photogrammetry:

Definition, History, Development, Stages in RS-EMR, EMR Spectrum, Theories of EMR, Types of RS and Laws of Radiation, basic of solar radiation, Interaction of EMR, Spectral Signature, Platforms, Sensors, Orbits, Aerial Photography, Aerial Photo and Image Interpretation.

Unit-11- Biophysics:

Crystallography, Crystallization, Data collection, Phasing by molecular replacement, Model-building & refinement, Advanced NMR, Biomolecular structure determination, Dynamics, Paramagnetic NMR, ESR, spin-labeling & solid-state NMR, Microscopy, Light microscopy - Theory; Fluorescence, Confocal & Correlative, Electron microscopy Theory of transmission EM; Biological application, Tomography & 3D single-particle reconstruction, Analysis of structure, Databases & Homology modeling, Energy minimization; Poses & Docking, Electrostatics - potentials & pKs, Molecular Dynamics, Simulated Annealing, Normal modes, Enhanced sampling / acceleration, Mass Spectrometry, Theory & instrumentation, Foot printing & dynamics

Unit-12-History of Indian Science and Technology:

Introduction- Logic and methodology of Indian sciences, overview of Indian contributions to sciences, overview of Indian contributions to technology, Astronomy- Development of astronomy in India, Pancanga: Indian calendrical computations, The distinct features of Indian planetary models, Computation of eclipses: Its simplicity, elegance and efficiency, Observational astronomy in India, Mathematics- overview of the development of mathematics in India, Mathematics contained in Sulbasutras, Combinatorial aspects of the Chandassastra, Solutions to the first and second order indeterminate equations, Weaving mathematics into beautiful poetry: Bhaskaracarya, The evolution of sine function in India, The discovery of calculus by Kerala astronomers, Ayurveda- History of Ayurveda, Rational foundations of Ayurveda, Textual sources in Ayurveda, Ayurveda and allied disciplines, Approach to health and disease in Ayurveda – 2 lectures, Approach to diet and nutrition in Ayurveda, Ayurveda and modern medicine, Ayurveda and Yoga, Technological development in India-Agriculture, origin and development, Ancient crops, Traditional practices, Water management-overview, Harappan water management, Other case studies, Medieval Water structures, Pottery-overview, Technical aspects, Silpasastra- Architecture and Construction, Construction Technology, Metallurgy- Copper/Bronze/Zinc, Iron and Steel Technology in India

PAPER-IV: ELECTIVES (Any two)

Elective-1-Science and Technology of Nanomaterials

Introduction-Origin of Nanotechnology, Forces at nanoscale- classification of nanostructures, The quantum mechanics at nanoscale- Quantum confinement, Size-effect, Physical and chemical properties of nanomaterials, applications of nano-structured materials.

Synthesis of Nanomaterials-Bottom-up approach and Top-down approach with examples. Various fabrication and synthesis techniques such as Ball Milling, Chemical bath Deposition, Electrodeposition, Sol-Gel, Physical Vapor Deposition, Pulsed Laser Deposition, Molecular Beam Epitaxy.

Thin films-Properties, Preparation -Thermal Vapour Deposition, Chemical Vapour Deposition, laser ablation, Molecular Beam Epitaxy, study of surface topography by multiple beam interferometry, conditions for accurate determination of step height and film thickness Fizeau fringes, Electrical conductivity of thin films, difference of behaviour of thin films from bulk material, expression for electrical conductivity for thin film

Characterization of Nanomaterials

Diffraction techniques: X-ray Diffraction (XRD) – Crystallinity, particle/crystallite size determination and structural analysis. Microscopic techniques: Scanning Electron Microscopy (SEM)–Morphology, grain size and EDX; Transmission Electron Microscopy (TEM) – Morphology, particle size and electron diffraction, Selected Area Electron Diffraction (SAED). Scanning probe techniques: Scanning Tunneling Microscopy (STM) –surface imaging and roughness; Atomic Force Microscopy (AFM) -surface imaging and roughness; other scanning probe techniques. Spectroscopic techniques: Photoluminescence –Emission (PL) and Excitation (PLE) spectroscopy; Infrared (IR), Fourier Transform infrared (FTIR) Spectroscopy and Raman spectroscopy; X-ray Absorption (XAS), UV-Visible spectroscopy.

Carbon nanostructures

Allotropes of Carbon, Graphene, Properties of Graphene, Applications of Graphene, Carbon nanotubes, Structure, Types of Carbon nanotubes, Synthesis of Carbon nanotubes, Applications of Carbon nanotubes.

References:

1. Introduction to Nanotechnology, Poole & Owners, Wiley India Pvt Ltd, 2007.
2. Nanotechnology: A Crash Course, Raul J. Martin-Palma, Akhilesh Lakhtakia, SPIE Publications, 2010.
3. Handbook of Nanophysics – Principles and Methods: By Klaus D. Sattler; CRC Press, 2010
4. Nanostructures and Nanomaterials: Synthesis, Properties, and Applications, Cao; World Scientific Publishing Company, 2011.
5. Introduction to Nanoscience and Nanotechnology, Chattopadhyay & Banerjee, PHI Learning Pvt. Ltd., 2009.
6. Chemistry of Nanomaterials: Synthesis, Properties and Applications, Rao, Muller & Cheetham, Wiley VCH.

Elective-2-Dark matter and Dark energy

I. Introductory Overview-Prologue: The Modern Renaissance of Cosmology, Historical Introduction: cosmologies of the past, Cosmology and religion.

II. The Birth of Modern Cosmology-Expansion of the Universe, The Cosmological Principle: homogeneity & isotropy, Olbers's Paradox, Cosmology according to Newton, Alternative Cosmologies: did the Big Bang really happen?

III. Cosmology according to Einstein-Understanding Gravity: Einstein's theory of General Relativity, Curved Spacetime from Black Holes to the Universe, Einstein cosmology: geometry and destiny

IV. Measuring the Universe-The Expansion Rate and the Age of the Universe, Evidence for Dark Matter and the Density of the Universe, he Accelerating Universe, Dark Energy, the Cosmological Constant problem, and all That

V. The Hot Big Bang-The Cosmic Microwave Background Radiation, Big Bang Nucleosynthesis: the Origin of the Elements, Relic Particles: Neutrinos and Weakly Interacting Massive Particles (WIMPS): Cold and Hot Dark Matter Candidates

VI. The Early Universe-Symmetries and Unified Theories, Baryogenesis: the Origin of Matter, The Very Early Universe: String Theory, Quantum Gravity, etc,

VII. The Inflationary Universe-The Horizon and Flatness problems, he Inflationary scenario, Quantum mechanics and the Origin of Structure in the Universe

VIII. The Formation of Structure in the Universe-Gravitational instability as the engine of Structure Formation, The Cold Dark Matter Paradigm, Simulating the growth of structure

IX. Testing Models of Structure Formation: New Methods to Measure Cosmological Parameters, Anisotropies of the Cosmic Microwave Background, Galaxy Redshift Surveys, Weak Gravitational Lensing

References

1. Timothy Ferris, The Whole Shebang (Touchstone Books, 1997)
2. Brian Greene, The Elegant Universe
3. Craig Hogan, The Little Book of the Big Bang
4. Joseph Silk, A Short History of the Universe (Scientific American books)
5. Alan Guth and Alan Lightman, The Inflationary Universe
6. Andrew Liddle, An Introduction to Modern Cosmology
7. Eric Linder, First Principles of Cosmology
8. P.J.E. Peebles, Principles of Physical Cosmology
9. J. Peacock, Cosmological Physics

Elective-3- Quantum field theory

Introduction to quantum field theory. The reasons for the development of quantum field theory in a conceptual and a history of science context and possible limitations of a quantum field theoretical description. The formalism of quantum field theory: field quantisation; field-theoretical description of identical particles; Klein--Gordon equation; Lagrange formalism for fields; symmetries, Noether's theorem and conservation laws; Poincare invariance and related discrete symmetries; Lorentz group and its representations; Dirac and Majorana fields; path integrals (functional integrals); scattering theory; perturbation theory and Feynman diagrams; introduction to the concept of renormalisation. The course provides the necessary mathematical and theoretical background for problems in current research of nuclear and particle physics. It also provides a basic working knowledge for the mathematical tool of functional integrals, which are used in wide areas of modern science ranging from particle physics to mathematical finance.

References

1. Ryder, Quantum Field Theory

2. Barger & Phillips, Collider Physics

3. Peskin & Schroeder, Quantum Field Theory

4. Palash Pal and A Lahiri, Quantum Field Theory, Narosa

5. Mandle, Quantum Field Theory

Elective-4: Quantum Optics and Quantum Information

Introduction and background of Quantum Optics and Quantum Information, Review of classical optics and Quantum Mechanics, Atom-light interactions – semiclassical, Quantized electromagnetic fields – photons and photodetection, Harmonic oscillator quantization; Number states, Coherent states, and Squeezed states;

Interaction of Light and Matter - the Two-Level Atom: Rabi-Oscillations, Density Matrix, Energy and Phase Relaxation, Homogeneous and Inhomogeneous Broadening and Related Effects, Rate Equations, Dispersion, Absorption and Gain, Lambda-type and V-type atomic systems, Electromagnetically induced Transparency, Coherent population trapping

Quantum information processing – introduction, qubits, circuits, gates

Quantum cryptography, Bell and GHZ states, Dense coding, teleportation

1. **References**

2. Quantum Optics by Scully and Zubairy
3. Quantum Optics by Girish S Agarwal
4. Quantum Optics for Beginners, by Zbigniew Ficek and Mohamed Ridza Wahiddin
5. Introductory Quantum Optics, by C. C. Gerry and P. L. Knight
6. Elements of Quantum Optics by Pierre Meystre & Murray Sargent III
7. Mathematical Methods of Quantum Optics by Ravinder R. Puri
8. Quantum Computation and Quantum Information by Nielsen and Chuang
9. Quantum Computer Science : An Introduction by N. David Mermin
10. Quantum Information Theory by M. M. Wilde

Elective-5: Nuclear & Particle Physics

This course covers the phenomenology and experimental foundations of particle and nuclear physics including the fundamental forces and particles and composites. Topics include: Interactions of particles with matter, and detectors, SU(2), SU(3), models of mesons and baryons, QED, weak interactions, parity violation, lepton-nucleon scattering, and structure , functions, QCD, gluon field and color, W and Z fields, electro-weak unification, the CKM matrix, Nucleon-nucleon interactions, properties of nuclei, single and collective particle models, Electron and hadron interactions with nuclei, Relativistic heavy ion collisions, and transition to quark-gluon plasma.

References

1. Griffith, Introduction to Particle Physics
2. Perkins, High Energy Physics

3. Halgen & Martin, Quarks & Leptons
4. M.P. Khanna- Introduction to Particle Physic

Elective-6: Advanced statistical mechanics

Overview-Coldea experiment. Ising model, phases. Symmetry breaking. Classical Ising transition. MFT. Fluctuations: classical chain at T>0. Coldea article, Quantum Ising model. Quantum transition. Fermionization. Critical phenomena. Scaling. Continuum field theory. Renormalization group and scaling, Elementary excitations. Domain walls versus spin flips. Effect of other chains Hyejin Ju's notes on Monte Carlo (caveat emptor), Finish Coldea experiment. Begin frustrated magnets and ice. Spin and water ice, Spin ice. Spin liquid and correlations. Pinch points and monopoles, Finish spin ice. Begin order by disorder lecture domino model and J1-J2 model, Quantum critical points in metals - Hertz theory. Upper critical dimension. Above the upper critical dimension, Hertz theory for antiferromagnet in d=3, Beyond the Landau paradigm.

References

1. R. K. Pathria, Statistical Mechanics
2. K. Huang, Introduction to Statistical Mechanics
3. Silvio R. A. Salinas, Introduction to Statistical Mechanics.
4. F. Reif, Fundamentals of Statistical and Thermal Physics.
5. Kadanoff, Statistical Mechanics. World Scientific.
6. R. Kubo, Statistical Mechanics. (Collection of problems)

Elective-7: Advanced condensed matter physics

(1) Fermi Liquid Theory (FLT) -- Conceptual background -- physics of electronic repulsion, Fermi liquid parameters, renormalization of physical observables in the framework of FLT. Possible breakdown of FLT, e.g. in (a) low dimensions, (b) Strong correlations.

(2) Strongly correlated electronic systems -Mott insulators, Metal-Insulator transition etc. Hubbard Model as a minimal model for studying strong correlations, Notions of wigner crystal, spin-charge separation etc.

(3) Superconductivity (SC) -- Microscopic theory (BCS), density of states and Meissner effect within the BCS framework. Beyond BCS theory and a bit of high Tc phenomenology, SC from strong correlation in contrast with electron-phonon SC in metals.

(4) Basics of Quantum Magnetism -- Hubbard Model and magnetism, Stoner Ferromagnetism, Superexchange and Antiferromagnetism, Mermin-Wagner theorem.

(5) Disorder and Localization Physics-extended vs. localized state, weak, and strong localization, scaling theory of localization.

(6) Interacting Bosonic system and superfluidity -- Feynman theory, Mean field, treatment, GP equation, superfluid density vs. condensate fraction, super solidity.

(7) Brief intro to QHE

(8) Basics of Bosonization and low dimensional systems

References

1. Fundamentals of Condensed Matter Physics- Marvin L. Cohen & Steven G. Louie.
2. Basic Aspects of the Quantum Theory of Solids: Order and excitations-, Daniel I. Khomskii.
3. Modern Condensed Matter Physics- Steven M. Girvin and Kun Yang.
4. Introduction to Many-Body Physics, P. Coleman.
5. Advanced Solid State Physics- Philip Phillips.
6. Quantum Theory of Many-Particle Systems, Fetter & Wallecka.

Elective-8: Environment, Technology and Society in Asia

This course examines the dynamic relationship among environment, technology and society in Asia. During the first seven weeks, the students would be exposed to the major theoretical, conceptual and analytical frameworks for the study of interactions between society and technology. Themes covered during this period will include: what is technology? How has our understanding of technology evolved over the years? How society's influence on the environment was/is mediated through the use of various technologies? In the last seven weeks, the course will focus on case studies from Asian regions/countries to develop a nuanced understanding of major environmental challenges/issues in Asia. The course will draw upon theoretical and empirical literature from multiple disciplines, such as science and technology studies, environmental studies, economic sociology, and development studies.

References

1. Routledge Handbook of Environment and Society in Asia, Paul G. Harris, Graeme Lang · 2014
2. Establishing a Resource-circulating Society in Asia, Tohru Morioka, Keisuke Hanaki, Yūichi Moriguchi
3. Introducing East Asia: History, Politics, Economy and Society, Carin Holroyd

Elective-9: Environmental Impact Assessment

The purpose of this course is to discuss the impact of developmental activities on environment, social and health sectors and effects of a future development activity on biodiversity, arable land, forest, waterbodies, etc. and ecosystem services. It thrives to identify and assess the physical, biological and socio-economic effects of a development in a form that permits a practical and rational decision to be made. The objective of environmental impact interpretation and assessment is to make available information on the environmental repercussions before commencement using past and current satellite data, climatic data, etc. The course will discuss the need of EIA and evaluation system. The application of RS & GIS technologies in EIA will be taught.

References

1. Environmental Impact Assessment, R R Barthwal
2. Introduction To Environmental Impact Assessment, John Glasson, Riki Therivel, Andrew Chadwick
3. Environmental Impact Assessment, Charles H. Eccleston

Elective-10: Applications of RS & GIS

The course will deal with the application of geospatial technologies such as Remote Sensing, GIS, Global Navigation Satellite Systems, and Information and Communication Technology for natural resources management. Some of the key resources such as vegetation (forests, biodiversity, etc.), animals (insects, birds, mammals, etc.), fresh water (rivers, ponds, lakes, biodiversity, etc.), soil (sand, dunes, wasteland, ushar, ravines, etc.), snow, Ice, glaciers, atmosphere – environment (air, gases, etc.) have been impacted raising concern of their sustainability for posterity. Satellite data has been used world-wide to map and monitor these natural resources and phenomenon and try to understand the impact of human activities. This course will focus on the application of satellite data for mapping and monitoring different types of natural resources for information generation for appropriate decision making.

References

1. GIS and ArcGIS by Bradley A. Shellito
2. Historical GIS: technologies, methodologies and scholarship by Ian N. Gregory; Paul S. Ell.
3. Integration of GIS and Remote Sensing by Victor Mesev Book
4. Introduction to geospatial technologies by Bradley A. Shellito Book
5. Qualitative GIS: a mixed methods approach by Sarah Elwood; Meghan S. Cope,
6. Understanding place: GIS and mapping across the curriculum by Diana Stuart Sinton; Jennifer J. Lund