Pre Ph.D. Courses to be followed:

1. There shall be following four papers:
   Paper I: Communication skills and Seminar
   Paper II: Research Methodology
   Paper III: Elective
   Paper IV: Elective

2. At present, because of inadequate strength of the Faculty in the Physics Department course-work of Papers I & II are being carried out by research scholars of the Department in sister Department, Department of Electronics and Communication, which is permitted by UGC. For the course-work in Papers III and IV, we shall have options. All or some of these will run depending on the availability of the Faculty and the requisite number of students and their choices. The whole process of course-work, its evaluation and award of grades should be completed in six-months of joining of a research scholars. If a research scholar fails to clear one or more papers, he/she can reappear in those papers any number of times till he/she clears all the papers.

3. In the Elective Paper III, Candidate can opt for one paper out of Papers IIIA (Theoretical Techniques) & IIIB (Experimental Techniques).

4. In the Elective Paper IV, there are several options available. The student may be (*i*) given an option relevant to his/her topic by his/her supervisor, who will be responsible for teaching and evaluation of this option for the student, or, especially for those students who are involved in inter-disciplinary research, (ii) permit the student to take any of the papers from a relevant Department/Centre/Institution, in accordance with the UGC guidelines.

5. **PAPER IIIA (THEORETICAL TECHNIQUES)** shall contain the following modules:
   - **Elements of Mathematical Physics**
   - **Classical Mechanics**
   - **Quantum Mechanics**
   - **Quantum Field Theory**
   - **Statistical mechanics**
   - **Electromagnetic Theory**
   - **Group Theory**

   Study of Paper IIIA involves lectures, self-study and solving of assignments in the above modules. Examination will be conducted by a Committee of Teachers appointed by the DPC which will set a question paper of 3 hours on problems based on understanding of the above modules and will examine and award grades.

6. **Paper IIIB (EXPERIMENTAL TECHNIQUES):**

   PREPARATION OF MATERIALS: Methods of crystal growth, preparation of Amorphous Materials, Preparation of Nanomaterials, e.g., Sol-Gel techniques, chemical vapour deposition, LPCVD, sputtering, evaporation, pulsed laser deposition, electrodeposition, chemical oxidation, etc.

CHARACTERIZATION OF MATERIALS: Diffraction phenomena as applied to Solid State problems, Scattering and Absorption of X-rays, neutrons and electrons, X-ray methods for orienting crystals, applications of XRD, Diffraction from regular and faulted closed packed structures, Broadening of diffraction spots due to defects, Line profile analysis crystal structure analysis, measurement of intensities of X-ray reflection.

UV-VIS Raman Spectroscopy, LIF, LIBS, Photoluminescence, Scanning Electron Microscopy (SEM)

Electron Diffraction, LEED, RHEED, TEM, STM

EPR

7. **Paper IIIB** includes classroom teaching and exposure of research scholars to the various research labs in the Physics Department (for a period of 3-4 weeks in each Lab) and learning the experimental techniques. , followed by a presentation before a committee of teachers appointed by the DPC. A written examination will also be conducted by teachers teaching the course/appointed by DPC, who will set a question paper of 3 hours on problems based on understanding of the above experimental techniques and will examine. Grades will be awarded on the performance of the student in the presentation before the committee and in the written examination."

8. The following are the Syllabi for the Various Options for Paper IV available in the Department:

<u>Paper IV.01 (QUANTUM & NONLINEAR OPTICS AND QUANTUM INFORMATION THEORY):</u>

Polarization of Light: Randomness in amplitude and phase; Polarized light; Unpolarized Light; Partially Polarized Light; Polarized Light in Anisotropic Media and Directions of Fields E, D, B, H, propagation vector and ray.

Elements of Coherence Theory: Concept of Analytic Signal; Correlations; Coherence; Interference of partially Coherent Light; Self and Mutual Coherence; Degree of Coherence; Spatial and Temporal Coherence; Interference of Polarized Light.

Elements of Nonlinear Optics: Formal Definition and Estimation of nonlinear Susceptibilities Calculation of susceptibilities in Anharmonic Oscillator Model; Second Harmonic Generation and Phase-Matching; Pockels and Kerr Effects and Faraday Rotation. Frequency Conversion; Parametric Amplification and Oscillation; Four-wave Mixing; Phase-Conjugation.

<u>Elementary Quantum Mechanics</u>: Schrodinger, Heisenberg and Dirac Pictures; Density Operator Formalism; Pure and Mixed States; Orthogonal States.

Quantum Optics: Problems on annihilation and creation operators and their normal, antinormal and symmetric orderings; Coherent States; Various representations of density Operators; Non-Classical radiation; Squeezing, Sub-Poissonian Statistics and Antibunching.

Quantum Information Theory: Qubits, Qutrits, Ququats and Qudits; Separability and Entanglement in Two-Qubit Pure State; Negativity and Concurrence; Elementary Idea of Separability and Concurrence of Mixed States; Elementary Ideas of Entropy, Mutual Information and Quantum Discord

Paper IV.02 (Chaos & Factals):

Discrete, Continuous, Linear and Non-Linear Dynamical Systems. Phase Space, Trajectories, Critical Points (equilibria); Classification of Critical Points in 2D. Linear Stability Analysis; Stable, Unstable and Center manifolds. Attractors: Fixed point, Limit Cycle, higher dimensionalAttractors, Bifurcation. 1 D Maps: Shit Tent, Logistic Maps. Periodic Doubling Route to Chaos,

Intermittency, Lyapunov Exponent, Sensitive Dependence on lnitial Conditions. Chaos -definition and examples of Chaos, Characteristic of Chaos, Lorenz Equations, Buttery Effect,

Fractals ~ Introduction, Fractals examples, Dimension of Self ~ Similar Fractals, Box-Dimension, Pointwise and Correlation Dimension.

Paper IV.03 (Chaos-based Secure Communications):

Secure Communication system: Phase Space based Coding, Spread Spectrum Communication: Direct Sequence Spread Spectrum, Chaotic Sequence Spread Spectrum. Synchronization of Chaotic Systems: Peeora and Carroll Complete Replacement Technique, Partial Replacement Technique, Error Feedback Control Technique, Active Control Technique, Backstepping Synchronization Technique, Generalized Projective Synchronization Technique, Coherent (Chaotic Communication Techniques: Chaotic Masking, Antipodal Chaos Shin Keying, Chaotic On Off Keying (COOK) with Coherent Decoder, Chaotic Shitt Keying (CSK) with Coherent Decoder, Parameter Adaptation. Non-Coherent Chaotic Communication: Chaotic On Off Keying (COOK) with Non-Coherent Decoder, Chaotic Shift Keying (CSK) with Non-Coherence l)itTerential Chaos Shift Keying (DCSK),Decodcr Correlation Delay Shift Keying (CDSK), Quadrature Chaos Shift Keying (QCSK). Standard Cryptology: Cryptosystem, Secret-Key Cryptosystcm, Public-Key Cryptosystem,
Hybrid Cryptosystem, Cryptanalysis, Cryptological Aspects of'Cl1aotic Communication.

Paper IV.04 (EPR) :

Electron Paramagnetic Resonance (EPR): Orbital and spin moments, spin Hamiltonian, information gained from EPR, systems studied by EPR, microwave generators (klystron, Gunn diode), isolator, magic T, resonant cavity, attenuator, crystal detector, Q and frequency changes at resonance, noise sources, signal-to-noise ratio, microwave power, choice of modulation frequency and amplitude, magnet scan, scanning rate and response time, characteristics of spectral lineshapes, experimental details of magnetic field modulation apparatus, standard samples.

Experimental Techniques of EPR.

Paper IV.05 (Spectroscopy-I) :

Atomic & Molecular Spectroscopy: Interaction of light and matter, Heisenberg uncertainty principle, thermal equilibrium, absorption and emission of light, the electromagnetic spectrum, spectrograph and detection system (CCD and ICCD), excitation source in spectroscopy.

Atomic Spectroscopy: Radiations from atoms and their selection rules, spectra of atoms with two valance electron and vector atom model, spectral line broadening and high resolution spectroscopy, effect static field on spectral line(Zeeman's effect, Stark effect), fine structure, hyperfine structure.

Molecular Spectroscopy : Vibration and rotation of di-atomic molecules, harmonic and anharmonic consideration of di-atomic molecules, rigid and non-rigid rotator, transitions and selection rules for di-atomic molecules, infrared spectroscopy, Raman effect and its application, Florescence.

Lasers Theory and its application: Introduction, Einstein's prediction the 3 process, differences between spontaneous and stimulated emission, Einstein relation, conditions for large stimulated emission, condition for light amplification , line-shape function, population inversion, pumping, pumping method, active medium, meta stable states, line broadening, two level system, 3 level and 4 level lasers, properties of lasers, kind of lasers classification of lasers, laser beam characteristics, techniques for control of laser output (Q-switching, mode locking), Modern applications of lasers (Raman, LIBS, Laser Fluorescence etc.).

Concept of Plasma, applications of Boltzmann and Saha-Boltzmann equation in spectroscopy, calculation of electron number density and plasma temperature.

Paper IV.06 (Spectroscopy-II):

Advance Spectroscopy Techniques

A. ICP-OES, ICP-MS, AAS, LIF, LIBS, CD, Raman Spectroscopy, PES, AES, XRF
B. Steady State and Time Resolved Fluorence Spectroscopy
C. Fourier Transform Spectrtoscopy
D. UV-VIS-IR Spectroscopy
E. Confocal Microspectroscopy and Time Resolved Microspectroscopy
F. Synchrotron Based Spectroscopy Techniques (XRF, IR, Photophysics, Vacuum Ultraviolet Spectroscopy)
G. Imaging Spectroscopy (Fluorescence, Raman, IR, and X-Rays imaging, Microtomography)
H. Microspectroscopy and Nanospectroscopy (Microscopy and Nanoscopy)
I. Radoichemical Techniquies: GM Counter, Scintillation Counter, Autoradiography

Basic Spectroscopy and Advance Spectroscopy Techniques

A. Radiation Sources: d c and a c arc, spark, discharge, electrodeless discharge lamp (EDL), high temperature graphite furnace, laser, synchrotron etc

B. Production methodologies: (i) Absorption, emission, fluorescence techniques/spectroscopy, (ii)Line, band, and continuous spectrum
C. Spectral analysis methodologies: (i) Data reduction methods/techniques, (ii) Curve fitting methods/techniques, (iii) Simulation methods/techniques
D. Rotational and Vibrational Analysis, Franck Condon Factor and its computation, Perturbation and Deperturbation, Pre-dissociation Phenomena, Rydberg atoms and Rydberg States
E. Steady State and Time Resolved Fluorescence Spectroscopy
F. Fourier Transform Spectroscopy (UV-VIS-IR)
G. Confocal Microspectroscopy and Time Resolved Microspectroscopy
H. Nanospectroscopy/ Nanoscopy
I. Synchrotron Based Spectroscopy Techniques (XRF, IR, Photophysics, Vacuum Ultraviolet Spectroscopy)

<u>Paper IV.07 (Particle Physics, Relativistic Heavy Ion Collision and Quark Gluon Plasma (QGP)):</u>

Particle Physics: Symmetries and Conservations Laws, Charge Conjugation, Parity and Time-Reversal Symmetries, Quark-Model, SU(2) and SU(3) Symmetry, Structure of Quarks and its Consequences

Basic Understanding of QCD color interaction, QCD Lagrangian and running coupling constant of QCD(α_s), Color confinement and Asymptotic freedom

Thermal Field Theory: Understanding of Heavy Ion Collision Physics, Energy Consideration in Lab. Frame and Centre of Mass frame.

Basic understanding of finite temperature field theory, Calculation of Partition function for Bosonic and Fermionic fields.

Effective potential and understanding of the phase transition, order parameter, first order and second order phase transitions, Basic understanding of Quark-Hadron phase transition.

<u>Paper IV.08 (Physics of Materials-I):</u>

Physics of New Materials and Experimental Techniques: Low-dimensional systems; Physics of Semiconductors Nanomaterials and, Introduction and Classification of Organic Semiconductors, Photo-active materials, Organic-Inorganic Hybrid Materials, New Materials, Applications of nanomaterials: molecular electronics, nanoelectronics and nano-biotechology, Radiation induced modifications in materials.

Vacuum Techniques and Sample Preparation: Vacuum chamber; types of pumps; gauges, controls and leak detection techniques; sample preparation methods. Thin Films and their deposition methods: Thermal evaporation, Sputtering, laser deposition method

Signal Processing: Signal transmission and impedance matching; noise sources; signal noise optimization; pre-amplifiers, amplifiers and pulse shaping.

Materials Characterization Techniques and Instrumentation: X- Ray Diffractometry (XRD), Instrument Configuration for Powder Diffraction,

Single crystal versus powder crystal XRD, Thin Film XRD Methods, Stress and Texture by XRD, Structure determination from X-ray powder diffraction data, X-Rays Photoelectron Spectroscopy (XPS), X-Rays Fluorescence Spectroscopy,
Basics of Scanning Probe microscopy and Instrumentation, Scanning Electron Spectroscopy (SEM), Transmission Electron Spectroscopy (TEM).
Optical Spectroscopic Techniques and Instrumentation: UV-Visible, Infrared and Raman spectroscopy applications; Photoluminescence: Steady State and Time Resolve Photoluminescence Spectroscopy, Ultrasonics and Impedance spectroscopy, EPR, Recent advanced techniques in LASER spectroscopy LIBS

Paper IV.09 (Physics of Materials-II) :

Nanomaterials and their Properties

S.No.	Topics
1	Introduction to nanotechnology and the two approaches (bottom up and top down) followed for the synthesis of nanomaterials.
2	Synthetic methodologies
	i) Sol-gel.
	ii) Micromulsion.
	iii) CVD,PVD,Molecular beam epitaxy.
	iv) Vapor (solution)-liquid-solid growth, (VLS or SLS).
	v) Spary Pyrolysis.
	vi) Template based synthesis.
	vii) Lithography.
3	Various kind of Nanostructures
	i) Carbon fullerenes and CNT.
	ii) Metal and metal oxide nanowires.
	iii) Self assembly of nanostructures.
	iv) Core-shell nanostructures.
	v) Nanocomposites.
4	Physical Properties of nanomaterials
	i) Photocatalytic.
	ii) Dielectric.
	iii) Magnetic.
	iv) Optical.
	v) Mechanical.

5.	Overview of characterisation of nanomaterials	
	i)	X-Ray diffraction spectroscopy
	ii)	Scanning electron microscopy, Transmission electron microscopy, Atomic force microscopy
	iii)	UV-Visible spectroscopy, Fourier transform infrared spectroscopy

Fundamental concepts of Semiconductors Physics

S.No.	Topics
1.	Review of semiconductor physics: Band Structure of metals, insulators and semiconductors, E-K diagram, Density of States, Fermi Level Intrinsic and extrinsic semiconductors,
2.	Introduction of solid state materials: Crystal structures, Point group, Bravais lattices, Reciprocal lattices, Defects in Solids,
3.	Semiconductor devices: Photo diodes, Photo transistors, Gas Sensors, Solar Cells
4.	Thermal properties of Solids: Classical, Einstein and Debye theory of specific heat Vibrations of Crystal lattices,
5.	Superconductivity, Meissner effect, BCS theory, High Tc Superconductors,

<u>Paper IV.10 (Physics of Materials-III):</u>

Physics of New Materials and Principles of Semiconductor Devices: Low-dimensional systems; Physics of Semiconductors, Nanomaterials and Molecular Materials, Emergence of Bandstructure, Density of States, Energy Bands, Introduction and Classification of Organic Semiconductors, Photo-active materials, Organic-Inorganic Hybrid Materials, New Materials, Applications of nanomaterials: molecular electronics, nanoelectronics.

Principles of Semiconductor Devices: Carrier Concentration in Semiconductors, Recombination- Generation, Bulk recombination, Carrier Transport, Electrostatics of P-N junction diodes, Non-ideal effects, Continuity equations, Surface Recombination/Generation, Photovoltaics, Design and characterization of Solar Cells, illumination and temperature sensitivity, Energy losses, Emerging Organic-Inorganic hybrid Photovolatics. Light Emitting Diodes (LEDs), Photo Detectors (PDs).

<u>Paper IV.11 (Ultrasonics):</u>

Materials: Introduction, Synthesis and Characterization Techniques: Introduction to Material Science, Types of Materials – Metals and alloy, ceramics, Composites, Intermetallics, Liquid Crystals and Nano-materials, Emergence of Nanotechnology, Historic Background, System classification confined to one two or three dimensions and their effect on properties, Bottom-up and Top-down approaches.

Synthesis and stabilization of nanoparticles: Chemical reduction, Sonochemical methods and Physics methods.

X-ray diffraction, Powder method, Scanning electron microscopy (SEM), Transmission Electron Microscopy (TEM), UV/Vis and FTIR spectroscopy, Acoustic Spectroscopy, Acoustic Microscopy.

Nanotechnology applications: Biomedical application of nanostructures based materials, Light emitting semiconducting quantum dots, Heat transfer managements, Temperature dependent study of advanced materials

Ultrasonics: A Technique of Material Characterization:

1. Introduction
2. Ultrasonic wave: Sources of ultrasonic wave; characteristics of ultrasonic wave; Detection of ultrasonic wave
3. Material characterization techniques (NDT and DT)
4. Classification of ultrasonic application and testing
5. Ultrasonic NDT as a material characterization:
    - 5.1 Ultrasonic Velocity – Ultrasonic velocity related parameters and its theoretical evaluation; measurement techniques of ultrasonic velocity.
    - 5.2 Ultrasonic attenuation – Source of ultrasonic attenuation; Measurement techniques of ultrasonic attenuation; Properties characterized with ultrasonic attenuation
6. Ultrasonic attenuation and velocity in different materials

<u>Paper IV.12 (Ion Beam in Materials Science):</u>

<u>Ion Beam in Materials Synthesis, Modifications and Characterization:</u> Overview of accelerator types, Interaction of particles with matter, cross section, survival probability, free path length, Energy loss of Mev Ions in Solids: Interaction of a particle with a free electron gas, electronic stopping cross section. Nuclear and Electronic energy loss. Theories of Energy transfer from Ion to matter: Thermal Spike, Coulomb Explosion, Lateral Mass Transport. Simulation of range distribution by Monte-Carlo methods (SRIM/TRIM). Ion implantation, radiation damage and structure change, ion beam mixing, radiation enhanced diffusion

Detection and Controls systems: Transition radiation, detector characteristics (sensitivity, response, efficiency, dead time), gas detectors, calorimeters, semiconductor detectors, interface buses for control instrumentation, CAMAC

Ion Beam in materials Characterization: Elastic recoil detection analysis (ERDA), Particle- Induced X-Ray Emission (PIXE), Rutherford Backscattering Spectroscopy (RBS).

Paper IV.13 (Shock Wave Physics):

Elements of gasdynamics: wave motion, classical theory of shock waves, shock tubes, structure and basic properties of shock waves in gases, radiative phenomena in shock waves due to strong explosions, MHD shocks, shock waves in nano-fluids and solids, relativistic shock waves, some self-similar processes in gasdynamics, computational techniques: root finding, interpolation, extrapolation, integration, solution of differential equations using RK4 and other predictor-corrector methods**.**

Shockwavedynamics: one-dimensional unsteady motion of a gas, piston problem, blast wave, shock propagation theories: some initial studies in ideal gas and relativistic fluids, exact analytic solutions of gasdynamic and MHD equations involving shocks, converging shock waves, simulation techniques and applications of shock waves in medicine and astrophysics**.**

Paper IV.14 (Plasma Physics) :

Basics of Plasmas: Plasma as a state of matter, Debye length, Plasma frequency, Collisions, deconductivity, ac conductivity, conductivity tensor. Plasma Production and Measurements: DC discharge, RF discharge, Photo-ionization, Tunnel ionization, Avalanche breakdown, Laser produced plasmas, Langmuir probe.

Plasma Confinement and Fusion Devices: Single particle motion in magnetic field, Motion in crossed electric and magnetic fields, Motion in inhomogeneous and curved magnetic fields, Magnetic moment invariance, Mirror confinement, Fusion reactions, Lawson criterion, Tokamak, Laser driven fusion.

Applications: Laser driven charged particle acceleration, Laser ablation of materials, Space plasmas.

Plasma Waves and Instabilities: Waves in Plasmas: Electromagnetic waves, Langmuir wave, Ion acoustic waves, Surface plasma waves, Ionospheric propagation, Electrostatic waves in magnetized plasmas.

Electromagnetic waves in magnetized plasmas, Lower hybrid and upper hybrid waves, Whistler waves, Alfven wave, Electron Bernstein wave, Ion Bernstein wave, Electron cyclotron wave, Ion cyclotron wave, Medium and short wave communication.

Instabilities: Linear and parametric instabilities, Two stream instability, Weibel instability, Rayleigh Taylor instability, Cerenkov free electron laser, Stimulated Raman scattering, Stimulated Brillouin scattering, Oscillating two stream instability, Modulational instability, Filamentation instability, Landau damping.

9. Grades will be awarded in accordance with the choice based credit system.