DEPARTMENT OF PHYSICS

INDIAN INSTITUTE OF TECHNOLOGY
(INDIAN SCHOOL OF MINES) DHANBAD

SYLLABUS

OF

PhD COURSE WORK IN PHYSICS

EFFECTIVE FROM THE SESSION
2019-20

Ph.D. (PHYSICS) COURSE STRUCTURE

SEMESTER – I

Compulsory Papers:

Sl. No.	Course Code	Course Name	L	T	P	Credit
1	PHC571	Research Methodology and Statistics	3	0	0	9
2	PHC572	Theoretical Physics	3	0	0	9
3	PHC573	Experimental Physics	3	0	0	9
4	PHC574	Numerical Methods and Simulation	3	2	0	13
5	HSI500	Research and Technical Communication	3	0	0	-

SEMESTER – II

Elective Papers (to choose at least four papers out of six):

Sl. No.	Course Code	Course Name	L	T	P	Credit
1	[*To Elect*]	Departmental Elective I†	3	1	0	11
2	[*To Elect*]	Departmental Elective II†	3	0	0	9
3	[*To Elect*]	Departmental Elective III†	3	0	0	9
4	[*To Elect*]	Departmental Elective IV†	3	0	0	9
5	[*To Elect*]	Open Elective I‡	3	0	0	9
6	[*To Elect*]	Open Elective II‡	3	0	0	9

†Departmental Electives:

Sl. No.	Course Code	Course Name	L	T	P	Credit
1	PHD571	Advanced Mathematical Methods in Physics	3	1	0	11
2	PHD572	Laser and Nonlinear Optics	3	0	0	9
3	PHD573	Physics of Semiconducting Materials and Devices	3	0	0	9
4	PHD574	Advanced Materials and Energy Devices	3	0	0	9

‡Open Electives:

Sl. No.	Course Code	Course Name	L	T	P	Credit
1	PHO571	Materials Characterization	3	0	0	9
2	PHO572	Photonics and Fibre Optics	3	0	0	9

Compulsory Papers only meant for the scholars admitted from B.Tech. degree.

Sl. No.	Course Code	Course Name	L	T	P	Credit
1	PHD501	Advanced Quantum Mechanics	3	0	0	9
2	PHD509	Advanced Condensed Matter Physics	3	0	0	9

COURSE CONTENT

SEMESTER – I

PHC571	**RESEARCH METHODOLOGY AND STATISTICS**	**(300)**
Course Philosophy	• To show the scholars roadmaps of research from the beginning to the end and their intricacies; • To inform and equip the scholars with essential knowledgebase and infrastructures for conducting research before landing up in the field.	
Learning Outcome	After completion of the course a scholar will learn how to plan research objectives and to communicate research findings, about – research procedure, necessary statistical tools, data and information resources, research utilities, good laboratory practices, ethical aspects of research.	
Unit No.	**Topics**	**No. of lectures**
	Research Methodology	
1	**Research objectives:** Types of research, Development of a research question; Science, pseudoscience and rationalism; Physical science and metaphysics; Literature survey, Identification of knowledge gaps and a research problem; Concept of novelty, Formulation and implementation of a research plan; Serendipity, creativity, discovery and innovation.	5
2	**Research process and tools:** Design of experiments, testing and characterization; Measurement - Standardization, calibration and sampling; Primary and secondary data; Computer programming, theory, modelling and simulation; Data acquisition, processing, observation, critical analysis and interpretation; Presentation of data; Reliability and reproducibility.	5
3	**Computer applications and tools:** Software for documentation, graphs, graphics, drawing and presentation.	2
4	**Search engines and databases:** Web literature search; International standards, reference data and constants.	2
5	**Library system:** Physical cataloguing of books and journals; Online catalogue search; Subscribed books and journals.	2
6	**Good laboratory practices:** Organization and cleanliness; Maintenance of laboratory records; Biological, chemical, electrical and fire safety; Safe disposal of hazardous materials; Upholding environmental and human concerns in planning and conducting experiments; Government regulations.	3
7	**Communicating research results:** Journal paper – types of available publishing services; Research proposal, Report, Thesis; Presentation in Seminar and conference; Journal abbreviations, Bibliography standards; Indices of quality assessment of publications.	3
8	**Research ethics:** Ethics code of American Psychological Association; Collaboration, cooperation and teamwork; Research outcome; Intellectual property right, Copy-right, patent,	4

	fundamentals of patent filing; Usage of pirated version of literatures and software; Plagiarism – Case Studies, Web based verification.	
	Statistics	
9	**Statistical techniques:** Mathematical tools for analysis, Statistical data treatment and evaluation; Probability and probability distributions; Sampling and sampling designs, Data analysis, Testing of hypothesis, statistical tests and analysis, Data interpretation, multivariate analysis, Model building.	5
10	**Uncertainty in measurements:** Null hypothesis; Interval estimation, Statistical significance, Central tendency and dispersion; Error Analysis.	2
11	**Analytical and numerical techniques:** Mean deviation, Root mean square deviation, Histogram, Skewness, Kurtosis, Moments, Variance, Chi-square, Correlation, Factor analysis, Mean square weighted deviation, Regression, Time series analysis.	4
12	**Statistical and graphical packages:** MS Excel, MATLAB, Microcal Origin / Sigma plot, gnu plot, xmgr – Key Features; Developing algorithms and applications, Tex.	2
Total		39

Text Books:

1. Research Methodology: The Aims, Practices and Ethics of Science, P. Pruzan, Springer, 2016
2. Research Methods for Science, M. P. Marder, Cambridge University, 2011
3. Fundamentals of Research Methodology and Statistics, Y.K. Singh, New Age, 2006

Reference Books:

1. Research Methodology: An Introduction for Science and Engineering Students; Melville and Goddard, Juta, 1996
2. Research Methods in Science and Engineering, Scott A. Gold, CRC Press, 2016

PHC572	**THEORETICAL PHYSICS**	**(300)**
Course Philosophy	• To convey the scholars some of the concepts of higher levels of physics; • To prepare them for research in advanced physical fields.	
Learning Outcome	After attending the course the scholars will have some of the advanced concepts of quantum mechanics, condensed matter physics, statistical mechanics, general theory of relativity, high energy physics and nonlinear optics, likely to be useful in forefront areas of research.	
Unit No.	**Topics**	**No. of lectures**
1	***Quantum Mechanics:*** Schrödinger Picture, **Time independent perturbation theory**: Theory and an example; S**cattering theory**: Quantum theory, Partial wave analysis (one example), Born Approximation and its validity (One example); P**ath integral formulation**: propagator, Schrödinger wave equation from path integral, eg: free particles; Introduction to second quantization; Q**uantum field theory**: quantization of scalar field and Dirac field.	8

2	***Condensed Matter Physics:*** **Electronic Structure Calculation:** Hartree-Fock Theory, Introduction to Density Functional Theory; **Correlated Electron States:** Mott Transition, Hubbard Model, Magnetic impurities and Kondo Model; **Quantum Hall effect:** Integer and fractional Hall Effect, Laughlin wave function; **Magnetism:** Mean-field approximation for Heisenberg Hamiltonian model for Ferromagnetism.	8
3	***Statistical Mechanics:*** Landau theory for phase transitions. Ising model: transfer matrix method; Onsager solution of 2-dimensional Ising model. **Non-equilibrium Statistical Mechanics**: Response function and susceptibility; fluctuation-dissipation theorem; irreversibility and the master equation; Fokker-Planck and diffusion equations.	7
4	***General Theory of Relativity:*** Equivalence principle and its applications: gravity as a curvature of space-time; geodesics as trajectories under the influence of gravitational field; generalisation to massless particles.	5
5	***High Energy Physics:*** Introduction to relativistic kinematics, Review of Experimental methods: fixed target and collider experiments, Introduction of four forces and interactions, Feynman diagrams Basics of quantum electrodynamics: Glashow-Salam-Weinberg model, Standard Model Physics.	6
6	***Nonlinear Optics:*** Nonlinear wave propagation in Anisotropic media; Second Harmonic Generation (SHG); Phase Matching Techniques; Three-Wave Interactions; Third Harmonic Generation (THG); Density Matrix and Perturbation approach to Nonlinear susceptibility.	5
Total 39		39

Text Books:

1. Introduction of Quantum Mechanics; David J. Griffiths; Pearson Education; 2010.
2. Principle of Quantum Mechanics; R. Shankar; Springer; 1994.
3. Introduction to Condensed Matter Physics; F. Duan, J. Guojun; World Scientific; 2007.
4. Statistical Mechanics: R. K. Pathria; Elsevier; 2002.
5. Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity, Steven Weinberg; Wiley; 2013.
6. Introduction to Elementary Particles; David J. Griffiths; Wiley; 2008.
7. Introduction to High Energy Physics, Donald Perkins; Cambridge University Press; 2000.
8. Nonlinear Optics, 3rd Ed; R. W. Boyd, Academic Press; 2008.

Reference Books:

1. Quantum Mechanics 2nd Ed; Bransden and Joachain; Pearson; 2000.
2. Quantum Mechanics and Path Integral; Feynmann and Hibbs, McGraw-Hill College; 1965.
3. Many-particle Physics; G. D. Mahan; Springer US; 2000; DOI: 10.1007/978-1-4757-5714-9.
4. Advanced Condensed Matter; L. M. Sander; Cambridge University Press; 2009.
5. Introduction to Phase Transitions and Critical Phenomena; H. E. Stanley; Oxford University Press; 1987.

6. Gravity: Introduction to Einstein's General Relativity; J. B. Hartle; Pearson Education, 2003.
7. Quarks and Leptons: An Introductory Course in Modern Particle Physics, Francis Halzen and Alan Martin; Wiley; 1984.
8. Nonlinear Optics, 4th Ed; N. Bloembergen, World Scientific; 1996.
9. Fundamentals of Nonlinear Optics; P. E. Powers, CRC Press; 2011

PHC573	**EXPERIMENTAL PHYSICS**	**(300)**
Course Philosophy	• To teach scholars some of the basic concepts of experimental methods of physics in research; • To prepare them for research in advanced fields of experimental physics.	
Learning Outcome	After attending the course the scholars will have some of the fundamental and higher level concepts of vacuum generation and measurement techniques, synthesis and fabrication of materials, measurements and characterization techniques, accelerator and fusion techniques, and low temperature methods likely to be useful especially in forefront areas of experimental research.	
Unit No.	**Topics**	**No. of lectures**
	Vacuum Generation and Measurement Techniques:	
1	Introduction to vacuum, gas law; Rotary vane pump, Turbomolecular pump, Cryo pump; Pirani gauge, Penning gauge.	4
	Fundamentals of Synthesis and Fabrication of Materials:	
2	Classification of powders; Synthesis of powders: Sol-gel, Hydrothermal, Combustion techniques; Synthesis of thin films: Spin-coating, Dip coating, Thermal and electron beam evaporation, Pulsed laser deposition; General concept of lithography, Photolithography, Electron beam lithography; Clean room.	6
	Introduction to Basic Measurements and Characterization Techniques:	
3	*Study of Crystal Structure:* X-ray diffraction (XRD), Transmission Electron diffraction (TED)	2
4	*Microscopic Techniques:* Optical Microscopes (Bright field, Confocal, Super-resolution), Scanning Electron Microscope, Transmission Electron Microscope, Scanning Probe Microscopes.	5
5	*Spectroscopic Techniques:* UV-Vis, Fluorescence, IR and FTIR, Photo-Acoustic, Laser Induced Breakdown, Raman, Twyman-Green interferometer as a special case of Michelson Interferometer for testing of optical components, Lateral shearing interferometers and its applications such as testing. Collimation of a lens, laser speckle techniques and its applications.	7
6	*Surface and Compositional Analysis Methods:* EDAX, XPS.	1
7	*Dielectric Characterization:* Complex impedance spectroscopy, Analysis of Nyquist plot, Various RC network schemes, Analysis of CV curves, ac conductivity, Charging-discharging cycle of capacitors.	3
8	*Electrochemical Measurements:* Different potentiometric / galvanometric techniques.	2
9	*Methods for studying electrical, magnetic, thermal properties*.	4

	Accelerator and Fusion Techniques:	
10	Pelletron, Linear accelerator, Cyclotron, Synchrotron, Tokamac; Applications in High energy physics, Materials science and Particle therapy.	3
	Low Temperature Methods:	
11	Temperature measurement and control; Cryostats and cooling methods.	2
Total		**39**

Text Books:

1. Handbook of Vacuum Science and Technology; Hoffman, Singh and Thomas; Academic Press, 1998.
2. Nanostructures and Nanomaterials - Synthesis, Properties and Applications; Guozhong Cao, World Scientific, 2004
3. Thin Film Phenomena; Chopra; McGraw-Hill; 1969
4. ASM Handbook: Volume 10: Materials Characterization; Crankovic; ASM International; 1986
5. Surface Characterization Methods: Principles, Techniques and Applications; Milling; CRC Press; 1999
6. Principles of Fluorescence Spectroscopy; J. R. Lakowicz, Third Ed., Springer, 2006.
7. Fundamentals of Molecular Spectroscopy; C. N. Banwell and E. M. McCash, 4^{th} Ed., McGraw, 2016.
8. Particle Accelerator Physics: Basic Principles and Linear Beam Dynamics; Helmut Wiedemann, Springer, 2013
9. Synchrotron Radiation; Helmut Wiedemann, Springer, 2013
10. Plasma Physics and Controlled Nuclear Fusion, K. Miyamoto, Springer, 2005
11. Experimental Techniques for Low-Temperature Measurements: Cryostat Design, Material Properties, and Superconductor Critical-Current Testing; Jack W. Ekin, Oxford, 2006.

Reference Books:

1. Materials Science of Thin Films; Milton Ohring; Academic Press; 2001.
2. Microstructural Characterization of Materials; Brandon & Kaplan; Wiley; 2008
3. Encyclopaedia of Materials Characterization - Surfaces, Interfaces, Thin Films; Brundle, Richard, Evans & Shaun; Elsevier; 1992

PHC574	**NUMERICAL METHODS AND SIMULATION**	**(320)**
Course Philosophy	• To enable the scholars about the fundamentals of MATLAB programming; • To understand the concepts of various numerical methods and simulation techniques.	
Learning Outcome	After attending the course the scholars will have the knowledge of programming fundamental, system of linear and nonlinear equations, least squares regression and curve fitting, Fourier methods, numerical calculus, stochastic systems, modelling using programming languages especially with MATLAB, and their hands on experience with MATLAB, to be useful throughout the research career and professional life.	
Unit No.	**Topics**	**No. of lectures**

1	**Programming Fundamental**: Representation of numbers on a computer; Errors in numerical solutions, round-off errors and truncation errors; Estimation of errors in numerical solution; Introduction to Computer programming.	3
2	**System of Linear equations:** Basics of Matrix algebra; Gauss elimination method; LU decomposition method; Inverse of a matrix method, Iterative methods;	4
3	**System of Nonlinear equations:** Bisection method; Newton's method; Fixed-point iteration method;	3
4	**Least Squares Regression and Curve fitting**: Numerical Curve fitting of linear equation and nonlinear equation. Curve fitting using quadratic and higher order polynomials; Interpolation; Lagrange polynomials; Newton's polynomial.	6
5	**Fourier Methods**: Square wave; General Fourier Series; Triangular wave; Discrete Fourier Transform	3
6	**Numerical Calculus: Numerical differentiation**; Finite difference approximation; Finite difference using Taylor series; Differentiation using Curve fitting;	3
7	**Numerical Calculus: Numerical integration**: Rectangle and midpoint methods; Trapezoidal method; Simpson's method; Gauss quadrature;	3
8	**Differential equations**: Ordinary Differential Equations (ODE) – Initial value problems (Euler's method, and Runge-Kutta); Boundary-value problems of ODE; Partial Differential Equations:	4
9	**Stochastic Systems**: Probability Distributions; Generating Random numbers; Monte Carlo Simulation.	3
10	**Modeling Using MATLAB/ Any Programming Language:** Introduction to Modeling; Modeling Concepts and Definitions; Review of computational science examples; Accuracy and precision in modeling; Modeling terminology; Introduction to MATLAB; MATLAB Scripts; MATLAB Arrays; Linear models; Graphing data in MATLAB; MATLAB Array Math; Advanced graphing in MATLAB; Nonlinear Functions; Nonlinear modeling examples; MATLAB I/O; MATLAB conditional statements; MATLAB loops; MATLAB functions; Curve fitting;	7
Total:		**39**

Text Books:

1. Numerical Analysis, R. L. Burden and J. D. Faires, 1993.
2. Numerical Methods for Engineers and Scientists: An Introduction with Applications Using MATLAB; Amos Gilat and Vish Subramiam

Reference Books:

1. Introduction to Dynamic Systems: Theory, Models, and Applications; D. G. Luenberger, 1979.
2. Numerical Analysis; Shantinarayan
3. Modeling and Simulation of Systems Using Matlab and Simulink; D. K. Chaturvedi, 2010

Tutorial

<table>
<tr><th>Unit No.</th><th>Topics</th><th>No. of Classes</th></tr>
<tr><td>1</td><td>Familiarize basic programs to understand the fundamental of MATLAB programming.</td><td>2</td></tr>
<tr><td>2</td><td>MATLAB program to verify the interference phenomena of two monochromatic waves.</td><td rowspan="2">1</td></tr>
<tr><td>3</td><td>MATLAB program to approximate a square wave by a series of sine and cosine functions.</td></tr>
<tr><td>4</td><td>MATLAB program for curve fitting with a linear function</td><td rowspan="2">1</td></tr>
<tr><td>5</td><td>MATLAB program for curve fitting with a nonlinear function</td></tr>
<tr><td>6</td><td>MATLAB program to obtain the interpolation using Lagrange polynomial.</td><td>1</td></tr>
<tr><td>7</td><td>MATLAB program to find the numerical derivative of finite difference method.</td><td>1</td></tr>
<tr><td>8</td><td>MATLAB program to numerically integrate the function using Trapezoidal method.</td><td rowspan="2">1</td></tr>
<tr><td>9</td><td>MATLAB program to numerically integrate the function using Simpson’s method.</td></tr>
<tr><td>10</td><td>MATLAB program to numerically integrate the function using Gauss quadrature method.</td><td>1</td></tr>
<tr><td>11</td><td>MATLAB program to solve a first order differential equation using Euler’s method.</td><td rowspan="2">1</td></tr>
<tr><td>12</td><td>MATLAB program to solve a first order differential equation using Runge-Kutta method.</td></tr>
<tr><td>13</td><td>MATLAB program to solve a second-order linear(boundary value problem) using the finite difference method.</td><td>1</td></tr>
<tr><td>14</td><td>MATLAB program to plot various probability distribution function</td><td rowspan="2">2</td></tr>
<tr><td>15</td><td>MATLAB program to generate random numbers</td></tr>
<tr><td>16</td><td>MATLAB program to estimate the value of πusing Monte Carlo Simulation method</td><td>1</td></tr>
<tr><td colspan="2">Total:</td><td>13</td></tr>
</table>

References

1. Applied Numerical Methods with MATLAB for Engineers and Scientists, 4^{th} Ed; Steven Chapra, McGraw-Hill Education, 2017
2. Essential MATLAB for Engineers and Scientists, 3rd Ed; Brian Hahn and Daniel Valentine, Elsevier (Butterworth-Heinemann)

SEMESTER II

PHD571	ADVANCED MATHEMATICAL METHODS IN PHYSICS		(310)
Course Philosophy	• To familiarize the scholars with some of the sophisticated methods of mathematics to deal with problems and applications in physics; • To specialize and equip them with some mathematical tools ready to plan and confront challenges in advanced physical fields of research.		
Learning Outcome	After completing the course the scholars will be more comfortable with extra knowledge to treat theoretical and experimental problems in physics; they will be able to employ the mathematical tools like vector operators, polynomials, boundary value problems, differential equations, special functions, integral transforms, complex variable analysis, group theory and tensor analysis.		
Unit No.	**Topics**	**No. of lectures**	**No. of tutorials**
1	**Applications of mathematical techniques in Physics problems based on the following topics:** Vector spaces - Discrete and continuous: orthogonality, operator algebra, Hermitian and unitary operators, projection operators, Matrices , eigenvalue problems and applications in Physics. Differential equations. Boundary value problems. Orthogonal polynomials, Spherical harmonics, addition theorem and multipole expansions, Integral transforms (e.g. Fourier, Laplace, etc.), Green's functions and applications to physics. Method of residues, poles and cuts in complex variables.	17	6
2	**Group theory:** Introduction, Generators of the continuous groups and discreet groups, Group representation: reducibility, equivalence, Schur's lemma. Lie groups and Lie algebras, SU(2) and SU(3). Representations of simple Lie algebras, SO(n), Lorentz group, applications to spectroscopy, condensed matter and particle physics etc.	14	4
3	**Tensor analysis:** Introduction, tensor algebra (linear combinations, direct products, contraction, Raising and lowering indices) Tensor densities, Covariant differentiation, Invariant equations and applications to physics.	8	3
Total 52		**39**	**13**

Text Books:

1. Mathematical Methods for Physicists; Arfken, Weber (Academic Press)
2. Complex Variables; A. K. Kapoor (World Scientific)
3. Matrices and Tensors in Physics; A. W. Joshi (New age international)

Reference Books:

1. Mathematical Physics: A modern introduction to its foundations; Sadri Hassani (Springer)

2. Mathematical Methods in Classical and Quantum Physics; Tulsi Dass and S. K. Sharma (University Press)
3. Mathematical Methods of Physics; Mathews-Walker (Addison-Wesley)
4. Schaum's Outlines of Vector Analysis, 2ed; Murray R. Spiegel, Seymour Lipschutz and Dennis Spellman; McGraw Hill, 2017
5. Schaum's Outlines of Theory and Problems of Vector Analysis and an Introduction to Tensor Analysis; M. R. Spiegel (McGraw Hill)
6. Green Function and Boundary Value Problems; Stakgold, Wiley

PHD572	**LASER AND NONLINEAR OPTICS**	**(300)**
Course Philosophy	To make the scholars familiar with the basics & types of lasers and their uses in different areas of science and technology.	
Learning Outcome	Scholars will be able to learn the basics & different parameters required to fabricate the lasers and their advantages and disadvantages in various fields.	
Unit No.	**Topics**	**No. of lectures**
1	**Basic principle of Laser**: Spontaneous and stimulated Emission and Absorption; Laser and its characteristics; Population inversion, Properties of Laser Beams: Monochromaticity, Coherence: first order & higher order, Directionality, Brightness, Laser speckles.	5
2	**Pumping processes**: Pumping schemes for population inversion, Optical pumping, Electrical pumping.	3
3	**Beams & Resonators**: Plane Parallel resonator, Spherical resonator, Stable and unstable resonators, Gaussian beams & propagation, Directionality.	4
4	**Types of Lasers**: Solid State Lasers: Ruby Laser and Nd-YAG Laser, Titanium sapphire laser, Semiconductor Lasers, Gas Lasers: Neutral atom gas Lasers, Ion Lasers, Molecular Gas Lasers, Excimer Lasers, Dye Lasers, Chemical Lasers, Free-electron laser.	6
5	**Applications of Lasers**: Fibre-optics, Holography, Optical data Processing, Laser surgery, Microscopy.	2
6	**Nonlinear Optics**: Introduction, Nonlinear optical processes: Second harmonic generation (SHG), Phase matching techniques, Parametric fluorescence, Parametric amplification, Three wave mixing, Sum and Difference frequency generation, Parametric oscillation, Third harmonic generation (THG), Self-phase modulation, Cross-phase modulation, Four wave mixing, Optical phase conjugation, Kerr effect, Self-focusing and Self-defocusing, Spontaneous and Stimulated Raman Scattering, Hyper-Raman effect, Higher-order Raman processes, Multiphoton processes.	19
Total		**39**

Text Books:

1. Laser Fundamentals, by William T. Silfvast, Cambridge University Press, 2008.
2. Principles of Lasers, by Orazio Svelto; Springer, 2009.

Reference Books:

1. Laser Spectroscopy: Basic Concepts and Instrumentation, by Demtroder; Springer, 2004.

2. Laser Cooling and Trapping: P. N. Ghosh
3. Nonlinear Optics, R.W. Boyd, Academic press, Elsevier, 2008.
4. Quantum Electronics, Amnon Yariv, John Wiley & Sons, 1989.
5. Fundamentals of Nonlinear Optics, P. E. Powers, CRC Press, 2011.
6. Handbook of Nonlinear Optics, R. L. Sutherland, 2003.
7. Lasers and Non-Linear Optics, B. B. Laud; New Age International, New Delhi, 1991.
8. Essentials of Lasers and Non-Linear Optics: Baruah; Pragati Prakashan; 2000.

PHD573	**PHYSICS OF SEMICONDUCTING MATERIALS AND DEVICES**	**(300)**
Course Philosophy	• To familiarize the research students about the physical principles functioning behind semiconductors and the devices made out of it; • To prepare and specialize them in the relevant areas of research, development and applications.	
Learning Outcome	The scholars will learn many aspects on the working mechanisms of band structures, doping and degeneracy, continuity equation, effect of traps and defects, impurity profiling, contacts, and devices on P-N junction, microwave, photonic, power, and high speed and high frequency for research and profession.	
Unit No.	**Topics**	**No. of Lectures**
	Physical Mechanisms	
1	Concept of band gap, electrical and optical band gaps; Direct and indirect bands in semiconductor, degenerate and non-degenerate semiconductors.	4
2	**Doping and degeneracy**: Carrier concentration in intrinsic and doped materials; Fermi level, carrier generation and recombination process.	4
3	**Semiconductor continuity equation**: recombination process, excitons, allowed, forbidden and phonon assisted optical transitions, concept of photo conductivity	4
4	Band bending, effect on bulk properties effective masses and their measurement, carrier transport and carrier lifetime.	3
5	**Effect of traps and defects**: diffusion and drift currents, variation of mobility with temperature and impurities.	3
6	Impurity profiling through capacitance measurement, junction capacitance, depletion layer formation.	2
7	**Metal semiconductor contact:** semiconductor superlattices and heterostructures.	2
	Devices	
8	**P-N junction Diodes**: Zener diodes, Avalanche diodes, Junction field effect transistors (JFETs), FETs, Schottky barrier diodes, MOSFET.	4
9	**Microwave Devices**: Tunnel Diode, MIS Tunnel Diode, MIS Switch Diode, Transferred Electron Devices (TEDs).	4
10	**Photonic Devices**: LED, LASER diodes, Photo detectors, Solar-cell.	3

11	**Power Devices**: Thyristors, Heterojunction bipolar transistor (HBT), high electron mobility transistors (HEMTs).	3
12	**High speed and high frequency devices**: Hot electron injection transistors, Resonant Tunnelling Diodes, Single electron devices.	3
Total		**39**

Text Books:
1. Introduction to Semiconductors, Smith, John Wiley, 1962
2. Physics of Semiconductor Devices; Sze; Wiley; 1969

Reference Books:
1. Semiconductor Devices Basic Principles; Singh; John Wiley;
2. Physics and Technology of Semiconductor Devices; Grove; Wiley; 1967
3. Metal/Semiconductor Schottky Barrier Junction and their Applications; Sharma; Plenum Pub Corp; 1984
4. Metal-Semiconductor Contact; Rhoderick and Williams; Oxford University Press; 1988
5. Principles of Electronic Materials and Devices; Kasap; McGraw-Hill; 2005
6. Semiconductor-Device Electronics; R. M. Warner and B. L. Grung; Holt, Rinehart, and Winston, 1991;
7. Semiconductor Devices: Physics and Technology, S. M. Sze, 3rd Ed. Wiley, (2013)
8. Semiconductor Physics and Devices, 4^{th} ed; Donald A. Neamen; McGraw Hill, 2014).

PHD574	**ADVANCED MATERIALS AND ENERGY DEVICES**	**(300)**
Course Philosophy	• To make the research students acquainted with various kinds of advanced materials and their mechanisms to be applicable for energy devices; • To prepare and specialize them in the relevant areas of advanced research, development and applications.	
Learning Outcome	The research scholars will come to know different viable materials for energy applications and their physical principles. They will also know many kinds of energy devices like optoelectronic, electrochemical, energy storage, solar cell, fuel cell devices etc.	
Unit No.	**Topics**	**No. of lectures**
	Advanced Materials	
1	Introduction to advanced materials: theories and physical mechanisms, concept of *Fermi*-energy, work function and electron affinity, equilibrium and non-equilibrium condition, linear and non-linear characteristics.	5
2	Interaction between materials of different chemical origin; organic and inorganic species; motifs and functions, bio-functional structure.	4
3	Carbon based materials: ACs, Graphenes, CNTs, MWNTs.	4
4	Conjugates and nano-conjugates of conductive polymers, co-polymers, and their hybrid electrode materials.	4
5	Organic and inorganic hole and electron transport materials, their efficiency and properties.	3
	Energy Devices	

6	Concept of energy production and storage;	2
7	Emerging trends in LEDs and optoelectronic devices;	2
8	Electrochemical capacitors and supercapacitors: principle, design and development, efficiency and properties, performance and applications;	3
9	Piezoelectric and pyroelectric devices;	1
10	Photochromic and electrochromic devices;	1
11	Magneto-hydrodynamics and magnetic fluids;	1
12	Rechargeable batteries; Solar batteries and solar charger;	2
13	Solar cells: organic, inorganic and dye sensitized;	2
14	Hydrogen production and storage using hybrid materials;	2
15	Fuel cells: SOFC, PEFC, PAFC, MCFC design, development and properties.	3
Total		**39**

Text Books:

1. Advanced Materials: Physics, Mechanics and Application; Shun-Hsyung Chang; Springer, 2014.
2. Energy Storage Devices for Electronic Systems; Nihal Kularatna; Academic Press, 2014
3. Graphene-based Energy Devices; Rashid bin Mohd Yusoff; Wiley, 2015
4. Future Solar Energy Devices; Mihaela Girtan; Springer, 2017

Reference Books:

1. Handbook of Advanced Materials: Enabling New Designs; James K. Wessel; Wiley 2004.
2. Mechanics of Advanced Materials; Vadim V. Silberschmidt; Springer, 2015.
3. Nanomaterials in Energy Devices; Jun Hieng Kiat; CRC Press, 2017.

PHO571	**MATERIALS CHARACTERIZATION**	**(300)**
Course Philosophy	• To make the scholars well conversant with useful instruments to study properties of materials for research; • To prepare and specialize them for research in advanced fields of experimental physics.	
Learning Outcome	After attending the course the scholars will have advanced analytical abilities of experimental research to characterize materials and devices based on microscopic, spectroscopic, compositional, crystalline structural, electrical, mechanical, magnetic and thermal characterization techniques.	
Unit No.	**Topics**	**No. of lectures**
	With an emphasis on the **data analysis and interpretation** of:	
1	**Microscopic techniques:** Scanning Electron Microscope (SEM), Transmission electron microscope (TEM), Atomic force microscopy (AFM), Scanning tunnelling microscopy (STM).	6
2	**Spectroscopic techniques:** Spectrophotometry, Fourier Transform Infra-Red (FTIR) and Dispersive IR spectroscopy, Raman spectroscopy, Photoluminescence, Nuclear Magnetic Resonance (NMR), Electron Paramagnetic Resonance, Ellipsometry.	8

3	**Compositional characterization techniques:** X-ray and Ultra-violet Photoelectron Spectroscopy (XPS & UPS), Energy Dispersive X-ray analysis (EDAX), Rutherford Backscattering Spectroscopy (RBS), Inductively Coupled Plasma Mass Spectrometry (ICPMS).	6
4	**Crystalline Structure characterization techniques**: Rietveld refinement of XRD patterns using FullProf software. Transmission electron diffraction (TED), Reflection high energy electron diffraction (RHEED)	4
5	**Electrical characterization techniques:** Measurement of resistivity by four-probe method, Impedance and ferroelectric measurements.	3
6	**Characterization of Mechanical Properties:** Micro/Nanoindenter, Nanoindentation and scratch tests by AFM, Frictional Force Microscopy.	4
7	**Magnetic characterization techniques:** Vibrating Sample Magnetometer (VSM), Superconducting Quantum Interference Device (SQUID) based magnetic properties measurement system (MPMS), Magnetic Force Microscopy (MFM).	5
8	**Thermal characterization techniques:** Differential Scanning Calorimeter (DSC), Thermo-Gravimetric and Differential Thermal Analyzer (TG-DTA).	3
Total		**39**

Text Books:

1. ASM Handbook: Volume 10: Materials Characterization; Crankovic; ASM International; 1986
2. Encyclopedia of Materials Characterization - Surfaces, Interfaces, Thin Films; Brundle, Richard, Evans & Shaun; Elsevier; 1992

Reference Books:

1. Microstructural Characterization of Materials; Brandon & Kaplan; Wiley; 2008
2. Surface Characterization Methods: Principles, Techniques and Applications; Milling; CRC Press; 1999
3. Characterization of Semiconductor Materials - Principles and Methods; McGuire; William Andrew Publishing/Noyes; 1989

PHO572	**PHOTONICS AND FIBRE OPTICS**	**(300)**
Course Philosophy	• To familiarize the research students about the fundamentals aspects in the fields photonics and fibre optics; • To prepare and specialize them in the relevant areas of research and development.	
Learning Outcome	The scholars will be benefitted to know some special topics on photonics, display devices, and fibre optics and devices for research and profession.	
Unit No.	**Topics**	**No. of lectures**
1	**Photonics:** Lens Design and Characterization, Image Processing, Laser sources, Up-conversion laser, Optical limiting, non-linear frequency conversion.	10
2	**Display devices**: LEDs, OLEDS and LCDs, Photo detectors: PIN	10

	photo detector, Avalanche photodiode; Photonic band gap material, Photonic crystal fibre; Crystal Optics: Wave propagation in Anisotropic media, Birefringence, electro-optic and magneto-optic effect.	
3	**Fibre Optics:** Wave propagation in Planer waveguide and cylindrical waveguides, Optical fibre-types, Optical fibre materials, $LiNbO_3$, design and basic characteristics; Fibre optic communication system: Concepts of WDM, DWDM; Repeaters and optical amplifiers; Fibre optic sensors: Intensity modulated sensors, Phase modulated sensors, Spectrally modulated sensors, Optical temperature Sensor, Mach- Zehnder interferometer.	19
Total		**39**

Text Books:

1. Photonics: Optical Electronics in Modern Communications; Amnon; Oxford University Press; 2007
2. An Introduction to Fiber Optics; Ghatak and Thyagarajan; Cambridge University Press; 1998

Reference Books:

1. Optical Fiber Communication: Principles and Practice; Senior; Pearson; 2010
2. Fiber Optics and Optoelectronics; Khare; Oxford University Press; 2004

PHD501	**ADVANCED QUANTUM MECHANICS**	**(300)**
Course Philosophy	To introduce the concept of advanced concepts of quantum mechanics	
Learning Outcome	On successful completion of this course, a student should be conversant with the concepts of scattering theory, relativistic quantum mechanics and the idea of quantum field theory	
Unit No.	**Topics**	**No. of lectures**
1	**Scattering Theory:** Scattering amplitude and cross-section, Partial wave analysis and application to simple cases; Integral form of scattering equation, Born approximation validity. The optical theorem.	9
2	**Relativistic Quantum Mechanics:** The Klein-Gordon equation. The Dirac equation. Dirac matrices, spinors. Magnetic Moment and Spin of electron; Positive and negative energy solutions, physical interpretation. Nonrelativistic limit of the Dirac equation.	10
3	**Identical Particles:** Symmetric and antisymmetric wave functions: Bosons and Fermians. symmetrization postulates, Pauli's exclusion Principle. Spin-statistics connection, self consistent field approximation:Slater determinant, HartreeFock method.	8
4	**Quantum Field Theory:** Preliminaries: why QFT? Classical Field Theory; Lagrangian formulation; Action for a scalar field; Symmetries and conservation	12

	laws, Noether's theorem; Quantum equation for field, Canonical quantization of scalar field; Dirac Field; Fock space and particle number representation.	
Total		**39**

Text Books:

1. Relativistic Quantum Mechanics: Wave Equations, 3/Ed; W. Greiner; Springer Int.; 2006.
2. Modern Quantum Mechanics; J. J. Sakurai; Pearson; 1994.
3. Relativistic Quantum Mechanics and Quantum Fields; Katiyar; Campus Books Int.; 2009.
4. A First Book on Quantum Field Theory: Lahiri; Narosa Book Distributors Pvt Ltd; 2005.

Reference Books:

1. Relativistic Quantum Mechanics: Bjorken and Drell; McGraw-Hill; 1998.
2. Quantum Field Theory, Rev.Ed.; Mandland Shaw; Wiley; 1993.
3. Principles of Quantum Mechanics; Shankar; Springer; 2006.
4. Quantum Computation and Quantum Information: M. A. Nielsen and I. L. Chuang, Cambridge University Press.
5. An Introduction to Quantum Field Theory; Peskinand Schroeder; Westview Press; 1995.

PHD509	**ADVANCED CONDENSED MATTER PHYSICS**	**(300)**
Course Philosophy	To introduce the basic theoretical background of condensed matter physics.	
Learning Outcome	A student will be acquainted with the basic theoretical knowledge that explains various phenomena of condensed matter such as superconductivity, fractional Hall effect etc.	
Unit No.	**Topics**	**No. of lectures**
1	**Many electron theory:** Introduction to many-electron wave function, Hartree-Fock theory, Second quantization formalism; Interactions of Electrons and Phonons with Photons, Excitons and Polaritons.	8
2	**Localization in Disordered Systems:** Electron Localization, Anderson localization, Mott's Localization, Hopping Conductivity.	5
3	**Correlated Systems:** Hubbard Model, Mott insulator, Kondo effect.	5
4	**Theory of Superconductivity:** Flux quantization, Macroscopic Quantum interference, Cooper Pairing, Energy gap, BCS theory; Ginzburg-Landau theory; Introduction to high temperature superconductors.	11
5	**Quantum Hall Effect:** Integer quantum Hall effect, Introduction to fractional QHE.	4
6	**Introduction to Soft Matter:** What is Soft Condensed Matter: Qualitative discussion of Colloids, Polymers, Gels, Liquid crystals.	6
Total		**39**

Text Books:

1. Quantum approach to condensed matter physics, Taylor and Heinonen, Cambridge.
2. Many-Particle Physics; G.D. Mahan, Springer; 3rd ed., 2000
3. Introduction to Condensed Matter Physics, F. Duan, J. Guojun, World Scientific.
4. Soft Condensed Matter: Jones; Oxford University Press; 2002

Reference Books:

1. Advanced Condensed Matter Physics, L. M. Sander, Cambridge.
2. Basic notions of Condensed Matter Physics, P.W. Anderson, Perseus Books
3. Physics of Condensed Matter, P. K. Mishra, Academic Press, 2012.
4. Condensed matter field theory, Altland and Simmons , Cambridge
5. Quantum field theory and condensed Matter, R. Shankar, Cambridge