Centre for Physical Sciences
Scheme of Programme: Ph.D. in Physics (2017-18)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Paper Code</th>
<th>Course Title</th>
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Choose any one of the following#

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<td>Condensed Matter Physics</td>
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<td>Thin Film and Vacuum Technology</td>
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* 2 practical hours are equivalent to 1 credit hour.
# Elective course will be decided by the guide/supervisor of the student

Course Title: Research Methodology
Paper Code: PHY.701
Total Lectures: 60

Course Objective: The course Research Methodology has been framed to introduce basic concepts of Research Methods. The course covers preparation of research plan, reading and understanding of scientific papers, scientific writing, research proposal writing, ethics, plagiarism, laboratory safety issues etc. The course also covers important experimental techniques in order to teach the same that will help to doctoral students in carrying out experiments.

Unit I (18)

Introduction: Meaning and importance of research, Different types and styles of research, role of serendipity, Critical thinking, Creativity and innovation, Hypothesis formulation and development of research plan, Art of reading and
understanding scientific papers, Literature survey, Interpretation of results and discussion. **Library:** Classification systems, e-Library, Reference management, Web-based literature search engines, Intellectual property rights (IPRs).

**Unit II**

**Scientific and Technical Writing:** Role and importance of communication, Effective oral and written communication, Scientific writing, Research paper writing, Technical report writing, Making R&D proposals, Dissertation/Thesis writing, Letter writing and official correspondence, Oral and poster presentation in meetings, seminars, group discussions, Use of modern aids; Making technical presentations. **Research and academic integrity:** Plagiarism, copyright issues, ethics in research, and case studies. **Laboratory safety issues:** lab, workshop, electrical, health & fire safety, safe disposal of hazardous materials.

**Unit III**

**Microscopic and Imaging Techniques:** Basics of electron and light microscopy, Polarizing optical microscopy (POM), Fluorescent microscopy, Scanning electron microscopy (SEM), Transmission electron microscopy (TEM), Bright and dark field imaging, Scanning-probe microscopy (SPM), Atomic force microscopy (AFM), Raman spectroscopy, Ion Beam Techniques in Materials Science.

**Unit IV**

**Spectroscopic Techniques:** UV-Visible Spectroscopy, Infra red spectroscopy, photoluminescence spectroscopy, Impedance/dielectric spectroscopy.

**Recommended Books:**


<table>
<thead>
<tr>
<th>Course Title: Statistics and Computer Applications</th>
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<th>Credits</th>
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Total Lab Hours: 30

Course Objective: The course *Statistics and Computer Applications* has been designed to introduce basic concepts of data analysis. The course covers errors and uncertainty, various types of distributions, least square fitting etc. The course also contains the basics of MATLAB language to solve the numerical problems.

Unit I

**Introduction:** Measuring errors, Uncertainties, Parent and sample distributions, Mean and standard deviation of distribution.

Unit II

**Probability Distributions:** Binomial distribution, Poission distribution, Gaussian distribution and Lorentzian distribution. **Error Analysis:** Different types of errors: Instrumental, Statistical errors, Propagation of errors, Error formulae, Application of error equation.

Unit III

**Least Square Fitting:** Least-square fitting to a straight line by minimizing $\chi^2$, Error estimation, Least-square fit to a polynomial, Matrix solution, Least-square fit to an arbitrary function, Nonlinear fitting, Grid search method, Gradient search method, Expansion method and Marquardt method. **Testing the Fit:** $\chi^2$ test for goodness of fit, Linear-correlation coefficient, Multivariable correlations, Confidence intervals, Monte Carlo tests.

Unit IV

**Introduction to MATLAB:** Standard Matlab windows, Operations with variables: Arrays: Columns and rows: creation and indexing, Size and length, Multiplication, Division, Power, Writing script files: Logical variables and operators, Loop operators; Writing functions: Input/output arguments, Simple graphics: 2D plots, Figures and subplots; Data types: Matrix, string, cell and structure, File input-output, Polynomial fit: 1D and 2D fits; Arbitrary function fit: Error function, Goodness of fit: criteria, Error in parameters; Graphics objects, Differentiation and integration through MATLAB, Solution of system of linear equations using MATLAB.

Recommended Books:
Course Title: Review Writing and Seminar Presentation  
Paper Code: PHY.703  
Total Lectures: 120

Objective: The objective of this course would be to ensure that the student learns the aspects of the Review writing and seminar presentation. Herein the student shall have to write a 5000 words review of existing scientific literature with simultaneous identification of knowledge gaps that can be addressed through future work.

The evaluation criteria for “Review Writing and Presentation” shall be as follows:

Maximum Marks: 200

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<th>Criteria</th>
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<tr>
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<td>Identification of gaps in knowledge</td>
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<td>Content of presentation</td>
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<td>Presentation Skills</td>
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<td>6.</td>
<td>Handling of queries</td>
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Total 100

Course Title: Condensed Matter Physics  
Paper Code: PHY.704  
Total Lectures: 60

Course Objective: The purpose of this course is to introduce students to the fundamental and advanced concepts of solid materials. The topics include Band gap in semiconductor, Plasmons, Dielectric, optical, ferroelectric properties, Alloys, Magnetism, Magnetic materials and Magnetic resonances.

Unit I (15)

Semiconductor Crystals: Band gap, Equation of motion, Effective mass, Intrinsic carrier concentration, Impurity conductivity, Thermoelectric effects.

Fermi Surfaces and Metals: Construction of Fermi surfaces, Electron orbits, Hole orbits and open orbits, Calculation of energy bands, Experimental methods in Fermi surface studies.
Unit II  


Optical Properties, Color Centers and Excitons: Optical reflectance, Optical properties of metals, Luminescence, Types of luminescent systems, Electroluminescence, Color centers, Production and properties, Types of color centers, Excitons (Frenkel, Mott-Wannier), Experimental studies (alkali halide and molecular crystals), Raman effect in crystals, Energy loss of fast particles in a solid.

Unit III  

Dielectrics and Ferroelectrics: Polarization, Macroscopic and local electric field, Dielectric constant and polarizability, Pyroelectric and ferroelectric crystals and classification, Polarization catastrophe, Soft modes, Phase transitions, Landau theory of phase transition, Antiferroelectricity, Piezoelectric crystals, Applications.


Unit IV  

Magnetism, and Magnetic Resonance: Types and properties of magnetism, Spin waves, Magnons, Magnon dispersion relations, Bloch $T^{3/2}$ Law, Electron spin resonance (ESR), Nuclear magnetic resonance (NMR), Spin relaxation (spin-lattice, spin-spin), Applications of ESR and NMR.


Recommended books:

Course Title: Thin Film and Vacuum Technology  

Paper Code: PHY.705  

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Total Lectures: 60

Course Objective: To introduce thin film deposition techniques and study of its optical, electrical, magnetic and mechanical properties and applications of thin films. It also aims to introduce basics of vacuum techniques, vacuum measurement systems and leak detection techniques.

Unit I (15)

**Thin Films:** Classification of thin films, Preparation methods: Electrolytic deposition, Thermal evaporation, Spray pyrolysis, Sputtering Pulse laser deposition, LB, Spin coating, Dip coating solution cast, Tape casting, Sol gel Sputtering, Chemical vapour deposition, Molecular beam epitaxy, Cluster beam evaporation, Ion beam deposition, Chemical bath deposition with capping techniques, Thickness measurement and monitoring, Electrical, Mechanical, Optical interference.

Unit II (15)

**Properties and Applications of Films:** Elastic and plastic behavior, Optical properties, Reflectance and transmittance spectra, Anisotropic and gyrotropic films, Electric properties of films: Conductivity in metal, semiconductor and insulating films, Dielectric properties, Micro and optoelectronic devices, data storage, Optical applications, Electric contacts, resistors, Capacitors and inductors, Active electronic elements, Integrated circuits.

Unit III (15)

**Vacuum Techniques Basics:** Basic elements of vacuum science, Viscous and molecular flow, Conductance, Performance measure: Pumping speed, Throughput, Uses of vacuum pumps, Operating pressure range.

**Positive Displacement Pumps:** Rotary pump, Scroll pump, Momentum transfer or molecular pumps, Diffusion and turbo molecular pump.

**Entrapment Pumps:** Ion pumps, Sputter pumps, Cryo pumps, Sorption pumps, Design of ultra high vacuum systems.

Unit IV (15)

**Vacuum Measurement Systems:** Vacuum measurement gauges, Hydrostatic gauges, Mechanical or elastic gauges, Thermal conductivity gauges, Ion gauges, Control and interlock systems.

**Leak detection techniques:** Types of leaks, Bubble test, Pressure decay test, Tracer gas leak testing using helium gas.

Recommended Books:


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**Course Title: Nanostructured Materials**

**Paper Code: PHY.706**

**Total Lectures: 60**

**Unit I**

**Synthesis:** Introduction to nanotechnology and nanomaterials, Top down and bottom up approaches, Sol-gel, Spin and dip coating, Pulsed Laser Diposition (PLD), Molecular beam epitaxy, Spray pyrolysis, Sputtering, Electron beam lithography, Ion beam lithography, Ball milling, Laser ablation, Thermal and ultrasonic decomposition, Reduction methods, Self-assembly, Focused ion beams, Nanoimprinting, Nanostructuring and modification by swift heavy ions (SHI).

**Unit II**

**Nanomaterials:** Carbon fullerenes and CNTs, Metal and metal oxides, Self-assembly of nanostructures, Core-shell nanostructures, Nanocomposites, Quantum wires, Quantum dots.

**Unit III**

**Characterization:** Characterization of nanomaterials for the structure, High resolution X-Ray diffractogram, High resolution transmission electron Microscopy (HRTEM), Fluorescent microscopy, Scanning electron microscopy (SEM), Scanning tunneling microscopy (STM), Bright and dark field imaging, Scanning-probe microscopy (SPM), Field emission scanning electron microscopy (FESEM), Atomic force microscopy (AFM), Impedance spectroscopy, Dielectric spectroscopy, Fourier transform infrared spectroscopy (FT-IR), Raman Spectroscopy, Thermogravimetric Analysis (TGA), Differential scanning calorimetry (DSC), Dynamic mechanical analysis, Universal tensile testing, Transport number, Electron spin resonance, UV spectrophotometer.

**Unit IV**

**Physical Properties of Nanomaterials:** Dielectric, Magnetic, Optical, Mechanical and photocatalytic properties.

**Applications:** Electronic devices based on nanostructures, High electron mobility transistors, Nanomagnetism, Surface/interface magnetism, Nanophotonics, Solar cell, Memory devices, Supercapacitors, Lithium ion
batteries, Fuel cells, Organic semiconductors, Ferro-fluids.

**Recommended Books:**

**Course Title:** Density Functional Theory and Applications  
**Paper Code:** PHY.707  
**Total Lecture:** 60

**Course Objective:** The objectives of this course are to understand the basics of Density Functional Theory (DFT). With the increasing power of computers, DFT-based calculations are emerging as an useful tool to characterize the materials properties. This course will review the various theories/approximations necessary to understand most popular framework of modern DFT.

**Unit-I**  

**Unit-II**  
**From Wave Functions to Density Functional:** Idea of functional, Functional derivatives, Electron density, Thomos Fermi model, Hohenberg-Kohn theorems, Approximations for exchange-correlation: Local density approximation (LDA) and local spin density approximation (LSDA), Gradient expansion and generalized gradient approximation (GGA), Hybrid functionals and meta-GGA approaches. Self-interaction corrections (SIC).

**Unit-III**  
**Practical Implementation of Density Functional Theory (DFT):** Kohn-Sham formulation: Plane waves and pseudopotentials, Janak’s theorem, Ionization potential theorem, Self consistent field (SCF) methods,
Understanding why LDA works, Consequence of discontinuous change in chemical potential for exchange-correlation, Strengths and weaknesses of DFT.

Unit-IV (14)

**Electronic Structure with DFT:** Free electron theory, Band theory of solids, Tight-binding method, Semiconductors, Band structure, Density of states. Interpretation of Kohn-Sham eigenvalues in relation with ionization potential, Fermi surface and band gap. Electronic structure of Graphene

**Recommended Books:**

5. C. Kittel, *Introduction to Solid State Physics* (Wiley India (P) Ltd., New Delhi, India) 2007

**Course Title:** 1D Nanomaterials Synthesis and Characterization

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**Paper Code:** PHY.708

**Total Lectures:** 60

**Course Objective:** This course aims to introduce the variety of one-dimensional (1D) nanomaterials, manipulate the processes to create 1D nanostructure, analyze those structures with various techniques, and understand their structure-properties relationship for utilization in the variety of applications.

**Unit 1:** (14)

**Nanomaterials and Nanostructures:** Introduction to nanotechnology and nanomaterials, Going Public: Risk, Trust and Public Understanding, Types of nanomaterials (i.e. Zero (0), One (1), Two (2), and Three (3) dimensional), Science (Physics and Chemistry) of 1D nanomaterials, unique electrical, optical, mechanical, chemical, and magnetic properties at 1D nanoscale, Growth mechanisms 1D nanostructures, Vapor-Liquid-Solid (VLS) growth, Solution-Liquid-Solid (SLS) growth, Vapor-Solid growth, advantages of 1D nanostructures, Challenges and Future of 1D nanostructures, possible applications.

**Unit 2:** (16)

**Synthesis of 1D nanomaterials:** Processing of 1D nanomaterials, top-down and bottom-up approaches, various physical and chemical techniques of synthesis (e.g. physical vapor deposition, chemical vapor deposition, hot-filament vapor deposition, Pulsed Laser Deposition, confinement growth, glancing angle, sol-gel technique,
hydrothermal synthesis etc.) Importance of materials from applications view point (case studies).

**Unit 3:**


**Unit 4:**

**Applications:** Dye Sensitized Solar Cells (1D nanomaterials and concepts involved in the fabrication, property measurements) Supercapacitor and Electrochromic smart displays devices (1D nanostructures and various electrolytes utilized, device fabrication, property measurements and other related concepts), Field Emitters (basic concepts of using 1D nanostructures, device fabrication etc) Nanogenerators (working principles, fabrication and utilization), Nanoelectronics (advantages, disadvantages and other related concepts of utilizing 1D nanomaterials, fabrication of various electronic components e.g. diodes, transistors etc) Hydrogen production (Photovoltaic and photoelectrochromic), gas sensors, Resistive switching devices, and LED etc.

**Books**


**Course Tile:** Energetic materials and storage devices

**Paper Code:** 709

**Total Lectures:** 60

**Course Objective:** This course aims to introduce different materials use in development of solar cell starting from importance of material, band engineering in device assembly and its device characterizations.

**Unit:** 1
Materials for energy conversion and storage devices: Nanomaterials, Mesoporous materials, Biomaterials, Carbon based materials, Best absorbing materials, electron transport materials, hole transport materials, Perovskites and oxides

Unit: 2

Material synthesis: Physicochemical method, Electrochemical method, Spin coating, Dip coating, Sol-gel, Spray pyrolysis, Doctor blade, Hydrothermal, Chemical bath deposition, Chemical vapor deposition, Physical vapor deposition (DC/RF Magnetron sputtering, Electron beam evaporation, LASER ablation etc).

Unit: 3

Band engineering: Electron in a crystal, Intrinsic semiconductor, Extrinsic semiconductor, Alignment of Fermi levels, Drift of electrons in an electric field, Mobility, Drift current, Diffusion current, Generation/Recombination Phenomena, Origin of bands, Band theory, Models of band engineering, Schottky diode, Ohmic contact

Unit: 4

Energy Conversion Devices: Solid state devices, Solid state mesoscopic solar cells, Silicon based solar cells, Dye sensitized solar cells, Organic solar cells, Dark current measurement, Calculation of efficiency, Supercapacitors, Batteries.

References:


Course Title: Accelerator and Plasma

Paper Code: PHY.710

Total Lectures: 60

Course Objective: The objective of the course on Nuclear and Particle Physics is to teach the students the basic of nuclear properties, nuclear interactions, nuclear decay, nuclear models, detectors, nuclear reactions and elementary particles.

Unit: 1
**Accelerators:** Motion of charged particles in electric and magnetic fields, axial and radial magnetic field distributions in dipole, quadrupole and hexapole arrangement, Equipotential lines in different electrodes arrangement, Particle trajectory in electric and magnetic field, Electron sources, ion sources, Van de Graaf generator, DC linear accelerator, RF linear accelerator, Cyclotron, Microtone, introduction to advance accelerator (LHC)

**Unit: 2**

**Detectors:** Relation detectors Gaseous ionization, ionization and transport phenomena in gases, proportional counters, organic and inorganic scintillators, detection efficiency for various types of radiation, photomultiplier gain, semiconductor detectors, surface barrier detector, Si(Li), Gel(Li) and HPGe detectors.

**Unit: 3**

**Plasma:** Introduction to Plasma, Properties of low and high temperature plasma, plasma parameters (electron density, ion density, electron temperature, ion temperature, ion velocity, Debye length etc), Types of Plasma, Radio-frequency (RF) discharges: Capacitive RF discharge, Inductive RF discharge, Electron-cyclotron resonance (ECR) discharge, Dielectric barrier discharges, Atmospheric pressure plasmas, Magnetron discharge, Matching circuits and Applications.

**Unit: 4**

**Electron/Laser Beam Interaction with Plasma:** Plasma wake field acceleration, Drive beam, Tailor Beam, Plasma density, Plasma length, Plasma frequency, linear regime, blowout regime, Laser wake field acceleration.

**Recommended books**