Courses for Honours degree offered by the Department of Physics

	Advanced Materials Physics
S. No.	**Course Name**
1.	Advanced Condensed Matter Physics
2.	Advanced Statistical Mechanics
3.	Frontiers in Nanomaterials and Nanotechnology
4.	Advanced Characterization Techniques
5.	Advanced Physics lab

DETAILS OF THE COURSE

Course Type	Course Code	Course Title	Credits	Lecture	Tutorial	Practical	Studio
PE	26PHTXXX	Advanced Condensed Matter Physics	3	3	0	0	0

PREREQUISITE – Basics of Solid State Physics, Quantum Mechanics

COURSE OBJECTIVE(s)

Build on prior knowledge of solid state physics, introduce deeper physical concepts and modern topics, connect condensed matter physics with devices and emerging technologies, and develop ability to analyze real materials and systems.

COURSE ASSESSMENT

The Course Assessment (culminating to the final grade), will be made up of the following three components;

S. No.	Component	Weightage
a)	Internal assessment (based upon assignments, quizzes and attendance)	20%
b)	Mid-term examination	30%
c)	End Semester Examination	50%

COURSE CONTENTS

Unit I: Electronic Structure Beyond Basics

Quick recap: Bloch theorem, bands, Effective mass and band curvature, Density of states (2D, 3D systems), Fermi surface and its significance, Band engineering (direct vs indirect gap), Semiconductor physics (advanced view), Applications: diodes, transistors, optoelectronics

(No. of lectures- 07)

Unit II: Phonons & Electron-Phonon Physics

Phonons (brief recap + dispersion relations), Debye model (quick revision), Lattice thermal conductivity, Electron-phonon interaction, Phonon scattering and resistivity, Thermoelectric materials (Seebeck effect intro), Applications: thermal management, energy materials.

(No. of lectures- 07)

Unit III: Transport & Low-Dimensional Physics
Beyond Drude: limitations and corrections, Boltzmann transport equation (conceptual), Electrical and thermal transport, Hall effect (advanced interpretation), Magnetoresistance, Quantum transport basics, 2D electron gas and quantum confinement, Introduction to mesoscopic physics, Applications: nanoelectronics, sensors. **(No. of lectures- 09)**

Unit IV: Magnetism & Superconductivity
Microscopic origin of magnetism, Exchange interaction (qualitative + insight), Magnetic ordering and domains, Spin waves (intro), Superconductivity: phenomenology, Meissner effect and London equations, BCS theory (conceptual understanding), Ginzburg-Landau Theory, Applications: superconducting devices. **(No. of lectures- 08)**

Unit V: Modern Condensed Matter & Devices
Quantum confinement & nanomaterials, Graphene and 2D materials, Topological insulators (conceptual intro), Spintronics and magnetic devices, Strongly correlated systems (overview), Experimental techniques (XRD, STM, ARPES basics), Condensed matter in real devices, Future trends. **(No. of lectures- 08)**

TEXT/ REFERENCE BOOKS: -

1. Introduction to Solid State Physics, Charles Kittel, Wiley, 8th Edition, 2004, ISBN: 978-0471415268
2. Solid State Physics, Neil W. Ashcroft and N. David Mermin, Brooks/Cole, 1976, ISBN: 978-0030839931.
3. Condensed Matter Physics, Michael P. Marder, Wiley, 2nd Edition, 2010, ISBN: 978-0470949948
4. Magnetism in Condensed Matter, S Blundell (Oxford University press (2001)
5. Physics of Semiconductor Devices, Simon M. Sze and Kwok K. Ng, Wiley, 2006, ISBN: 978-0471143239
6. Electronic Transport in Mesoscopic Systems, Supriyo Datta, Cambridge University Press, 1997, ISBN: 978-0521599436
7. Introduction to Nanoscience, Stuart Lindsay, Oxford University Press, 2009, ISBN: 978-0199544219

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DETAILS OF THE COURSE

Course Type	Course Code	Course Title	Credits	Lecture	Tutorial	Practical	Studio
PE	26PHTXXX	Advanced Statistical Mechanics	3	3	0	0	0

PREREQUISITE – Thermodynamics, Mathematical Physics, Quantum Mechanics, Basic Statistical Mechanics

COURSE OBJECTIVE(s)

After completing this course, students should be able to:

1. Use statistical methods to connect microscopic models with macroscopic thermodynamic behavior.
2. Apply canonical, grand canonical, and microcanonical ensembles to physical systems.
3. Analyze interacting systems and phase transitions using model Hamiltonians.
4. Understand fluctuations, correlations, response functions, and transport at an introductory advanced level.
5. Use simple analytical and computational techniques for lattice and many-particle systems.
6. Appreciate applications in condensed matter, soft matter, and engineering physics.

COURSE ASSESSMENT

The Course Assessment (culminating to the final grade), will be made up of the following three components;

S. No.	Component	Weightage
a)	Internal assessment (based upon assignments, quizzes and attendance)	20%
b)	Mid-term examination	30%
c)	End Semester Examination	50%

COURSE CONTENTS

Unit I: Foundations of Advanced Statistical Mechanics: Review of probability theory, Random walks, multiplicity, entropy, Thermodynamic limit, Equal a priori probability, ergodic hypothesis, Microstates, macrostates, density of states **[No. of lectures - 3]**

Unit II: Ensembles: Microcanonical ensemble, Canonical ensemble and partition function, Grand canonical ensemble, Energy fluctuations and equivalence of ensembles, Maxwell-Boltzmann statistics **(No. of lectures – 6)**

Unit III: Quantum Statistical Mechanics: Indistinguishability and Gibbs paradox, Bose-Einstein and Fermi-Dirac statistics, Ideal quantum gases Degenerate Fermi gas, Bose-Einstein condensation, Blackbody radiation and phonons **(No. of lectures – 6)**

Unit IV: Interacting Systems and Phase Transitions: Ising model: physical motivation and 1D transfer matrix idea, Mean-field theory, Order parameter, symmetry breaking, Landau theory of continuous and first-order phase transitions, Critical temperature, susceptibility, heat capacity Critical exponents and universality: introductory treatment (**No. of lectures – 12)**

Unit V: Fluctuations, Correlations, and Response: Correlation function and correlation length, Gaussian fluctuations, Fluctuation-dissipation theorem: introductory treatment, Diffusion and random processes, Linear response ideas, Structure factor and pair correlations: qualitative introduction **(No. of lectures – 6)**

Unit VI: Selected Advanced Topics: XY model and BKT transition: concept only, Potts model: overview, Liquid crystals / polymers / colloids / superconductivity: one or two application modules, Optional computational introduction: Monte Carlo idea for Ising model **(No. of lectures – 6)**

Textbooks / References

1. R. K. Pathria and Paul Beale, *Statistical Mechanics*.
2. Kerson Huang, *Statistical Mechanics*.
3. F. Reif, *Fundamentals of Statistical and Thermal Physics*.
4. Mehran Kardar, *Statistical Physics of Particles* and *Statistical Physics of Fields*.
5. Nigel Goldenfeld, *Lectures on Phase Transitions and the Renormalization Group*.
6. Chaikin and Lubensky, *Principles of Condensed Matter Physics*.
7. Daniel Arovas, lecture notes on thermodynamics and statistical mechanics.

DETAILS OF THE COURSE

Course Type	Course Code	Course Title	Credits	Lecture	Tutorial	Practical	Studio
PE	26PHTX XX	Frontiers in Nanomaterials and Nanotechnology	3	3	0	0	0

PREREQUISITE: None

COURSE OBJECTIVE(s)

The course Frontiers in Nanotechnology and Nanoscience aims to provide a fundamental understanding of nanoscale science and nanotechnology, including their engineering applications. It covers fabrication techniques, cleanroom processes, and characterization methods for nanomaterials and devices. The course emphasizes the role of nanomaterials in electronic, energy, sensing, and optoelectronic applications while introducing emerging technologies and industrial challenges, preparing students for careers in advanced materials and semiconductor industries.

COURSE ASSESSMENT

The Course Assessment (culminating in the final grade) will be made up of the following three components;

S. No.	Component	Weightage
a)	Internal assessment (based upon assignments, quizzes and attendance)	20%
b)	Mid Term examination	30%
c)	End Term Examination	50%

COURSE CONTENTS

Unit I: Fundamentals and Nanoscale Physics in Devices

Science behind nanotechnology: concept and importance, History of nanoscience and key developments, Overview and Classification of nanomaterials: 0D, 1D, 2D, Quantum confinement, Density of states in low-dimensional systems, Size dependent properties of Nanomaterials, Applications of thin films in device fabrication, Role of surface and interface effects in nanotechnology, Defects in nanomaterials and their types, Effect of defects on device performance, Reliability issues in nanoscale devices. **(No. of lectures -8)**

Unit II: Fabrication of Nanomaterials

Basics of vacuum technology, Cleanroom basics and Wafer processing steps, top-down and bottom-up approaches, Lithography and Etching techniques, Thin film deposition: sputtering, CVD, ALD, E-beam evaporation, Doping and defect control, Heterostructure and multilayer fabrication, Process integration and device fabrication, Fabrication challenges in nanoscale devices (uniformity, defects, reproducibility). **(No. of lectures -12)**

Unit III: Characterization of Nanomaterials and Devices

Structural characterization: X-ray Diffraction (XRD), Morphological analysis: Scanning Electron Microscope (SEM), Transmission electron microscopy (TEM), Topographical characterization: Atomic Force Microscopy (AFM), Scanning Tunneling Microscope (STM), Spectroscopic techniques: Raman, UV–Visible spectroscopy, X-ray Photoelectron Spectroscopy (XPS), Electrical characterization: I–V, C–V, Optical characterization for device applications, Correlation of characterization results with material properties and device performance, Defect and interface analysis. **(No. of lectures -11)**

Unit IV: Nanomaterials in Devices and Emerging Applications

Nanomaterials in electronic devices: transistors, memory (RRAM), Optoelectronic devices: photodetectors, LEDs, solar cells, Energy applications: batteries, supercapacitors, Sensors: gas sensors, biosensors, Flexible and wearable electronics, Spintronics and quantum devices, "Role of nanomaterials and thin films in device performance, Neuromorphic devices and AI hardware, Nanotechnology for sustainability (water purification, green energy), Biomedical nanotechnology (drug delivery, diagnostics) Challenges in device integration and commercialization.

(No. of lectures -8)

TEXT BOOKS:-

1. Nanostructures and Nanomaterials Synthesis, Properties and Applications: G. Cao (Imperial College Press-2006).
2. Introduction to Nanoscience and Nanotechnology, K K Chattopadhyay & A N Banerjee (PHI, EEE, October 2012)

REFERENCE BOOKS:

1. Introduction to Nanotechnology: Charles P. Poole, Jr. and Frank J. Owens (Wiley).
2. Nanotechnology: Basic Science & Emerging Technology: M. Wilson, K. Kannangara, G. Smith, M. Simmons and B. Raguse (Overseas Press-2005).
3. Nanotechnology: Principles and Practices, Sulabha K. Kulkarni (Springer)
4. Fundamentals of Nanotechnology: G. L. Hornyak, H. F. Tibbals, J. Dutta, and J. J. Moore (CRC Press, 2008).
5. Semiconductor Device Fundamentals: R. F. Pierret (Pearson Education, 1996).

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DETAILS OF THE COURSE

Course Type	Course Code	Course Title	Credits	Lecture	Tutorial	Practical	Studio
PE	26PHTXXX	Advanced Characterization Techniques	**3**	**2**	**1**	**0**	**0**

PREREQUISITE – Basic Solid State Physics

COURSE OBJECTIVE(s)

The course aims to Impart fundamental knowledge of material characterization phenomena, develop capabilities to apply these concepts in structural, morphological, and compositional applications, and train students to solve analytical problems independently.

COURSE ASSESSMENT

The Course Assessment (culminating to the final grade), will be made up of the following three components;

S. No.	Component	Weightage
1	Internal assessment (based upon assignments, quizzes and attendance)	20%
2	Mid-term examination	30%
3	End Semester Examination	50%

COURSE CONTENTS

Module 1: Structural and Morphological Characterization

Surfaces, interfaces, bulk solid materials, X-ray Diffraction (XRD), Structure determination and indexing, Scanning electron microscopy (SEM), High-resolution transmission electron microscopy (HRTEM), Low-energy electron diffraction (LEED), Scanning tunnelling microscopy (STM), Atomic force microscopy (AFM), Morphology and grain size determination. **(no. of lectures- 13)**

Module II: Chemical Composition and Surface Analysis

Elemental composition, chemical states, depth profiles, Electron Probe Micro Analysis (EPMA), Energy Dispersive X-ray Analysis (EDAX), Wavelength Dispersive Analysis (WDS), X-ray Fluorescence (XRF), X-ray Photoelectron Spectroscopy (XPS), Surface oxidation states.

(no. of lectures- 8)

Module III: Mini Project

Processing and analysis of selected characterization techniques data using software.

(no. of lectures- 5)

TEXT/ REFERENCE BOOKS: -

1. Surface Analysis Methods in Materials Science: D. J. O. Conner (Springer Verlag).
2. Surface and Interfaces of Solids: H. Lueth (Springer).
3. Advanced Techniques for Materials Characterization: A. K. Tyagi, M. Roy, S. K. Kulshrestha, S. Banerjee (Materials Science Foundations-Trans Tech Publications).

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DETAILS OF THE COURSE

Course Type	Course Code	Course Title	Credits	Lecture	Tutorial	Practical	Studio
PC	26PHPXXX	Advance Physics Lab	3	0	0	6	0

COURSE CONTENTS

Fabrication of Materials

1. Preparation of 3-D bulk materials (superconductor, ferromagnetic, ferroelectric) using solid state reaction method.
2. Synthesis of metal oxide particles by hydrothermal method.
3. Preparation of material/polymer composites using wet chemical method.
4. Determination of band gap of optical materials by UV-visible spectroscopy.
5. Determination of resistivity of Al and Cu thin film using four probe method (Van der Pauw method).
6. Determination of different modes of a Raman active material.
7. Determination of electrochemical activity of energy materials by electrochemical techniques.
8. Measurement of pressure, strain and torque using strain gauge.
9. Measuring change in resistance of Light Dependent Resistor (LDR) with light.
10. Measurement of displacement using Linear Variable Differential Transformers (LVDT).
11. Measurement of force and pressure using load cells.
12. Measurement of displacement using inductive transducer and capacitive transducer.
13. Measurement of Temperature using Temperature Sensors/RTDTo study the performance characteristics of an analog PID controller
14. Measurement of magnetic field and current using Hall effect sensors.

TEXT BOOKS/ REFERENCE BOOKS: -

1. Nanotechnology: Principles and Practices; S. K. Kulkarni, 3rd edition, Springer, 2014.
2. Polymer Synthesis and Characterization: A Laboratory Manual; S. S. Sandler et al. 1998.
3. Essentials of Inorganic Materials Synthesis; CNR Rao, K. Biswas, John Wiley & Sons, 2015
4. Rangan C S, Sharma G R and Mani V S V, "Instrumentation Devices and Systems", 2nd Ed., Tata McGraw-Hill (2008)
5. Doebelin E O and Manik D N, "Measurement Systems", 5th Ed., Tata McGraw-Hill (2008)
6. Cooper W D and Helfrick A D, "Modern Electronic Instrumentation and Measurement Techniques", Pearson Education (2008).
7. Anand M M S, "Electronic Instruments and Instrumentation Technology", Pearson Education (2008).
8. Nakra B C and Chaudhry K K, "Instrumentation Measurements & Analysis" McGraw Hill (2002).
9. Sayer M and Mansingh A, "Measurement, Instrumentation & Experiment Design in Physics & Engineering", PHI (1999).