भारतीय प्रौद्योगिकी संस्थान जोधपुर
Indian Institute of Technology Jodhpur

Curriculum of M.Sc. in Physics

भौतिकी विभाग
Department of Physics

Introduction

The Department of Physics at the Indian Institute of Technology Jodhpur offers a postgraduate program, Master of Science (M.Sc.) in Physics. This program is designed on the principle that deep theoretical understanding, mathematical rigor, computational proficiency, experimental observation, and empirical inquiry together form the foundation of scientific knowledge. It bridges undergraduate foundations with applied physics towards research and innovation in emerging technologies of national and global importance.

Program Objectives:

To develop highly competent physics professionals with a deep understanding of fundamental physics and strong expertise across advanced and emerging areas of physics.

1. To equip students with advanced analytical, computational, and experimental skills to solve complex scientific problems.
2. To foster innovation and research aptitude in emerging domains such as quantum technologies, condensed matter physics, optics and photonics, high-energy physics, and astrophysics.
3. To prepare graduates to excel in diverse pathways including academia, research and R&D based industries.
4. To develop effective communication, interdisciplinary thinking, teamwork, and leadership skills with ethical practices for collaborative scientific and professional environments.

Graduate Attributes:

Demonstrate a thorough understanding of fundamental and advanced concepts in physics.

1. Utilize physics principles along with logical reasoning and quantitative methods to address real-world societal challenges.
2. Employ modern computational tools, including computational physics, AI/ML, and data analytics, for modeling and analysis of complex systems.
3. Design, conduct, and critically analyze experimental and computational data to draw meaningful conclusions using both basic and advanced techniques.
4. Communicate scientific ideas clearly and effectively through oral and written formats adhering to ethical practices.
5. Work effectively in a collaborative team and demonstrate leadership.

Learning Outcomes:

1. Demonstrate comprehensive knowledge and deep understanding of fundamental and applied physics.
2. Apply technical knowledge and advanced experimental skills to understand, analyze, and contribute to interdisciplinary research areas including advanced materials.
3. Utilize computational physics, AI/ML, and modern simulation tools for visualization, modeling, and design of complex systems.
4. To pursue higher studies, doctoral research, R&D, and specialized roles in industry across areas such as High Energy Physics, Astrophysics, Quantum Information and Technologies,

Nanotechnology, Plasma Technology, Semiconductors, Thin Films and Devices, Nonlinear Optics, and Fiber Optics.

5. Demonstrate the ability to integrate theoretical, experimental, and computational approaches for problem-solving in physics and related domains.
6. Exhibit awareness of societal needs and apply scientific knowledge with a commitment to sustainable development and ethical practices.

M.Sc. (Physics) - Program Structure and Curriculum

Core (PC)	Program Elective (PE)	Open Elective (OE)	Internship	Thesis (T)	Total
40	**15**	**3**	**2**	**12**	**72**

Program Structure

<table>
<tr><th>S. No.</th><th>Semester</th><th>Course Category</th><th colspan="2">Credits</th></tr>
<tr><td rowspan="2">1.</td><td rowspan="2">Semester I</td><td>Program Core (PC)</td><td>16</td><td rowspan="2">19</td></tr>
<tr><td>Laboratory (PC)</td><td>3</td></tr>
<tr><td rowspan="2">2.</td><td rowspan="2">Semester II</td><td>Program Core (PC)</td><td>18</td><td rowspan="2">21</td></tr>
<tr><td>Laboratory (PC)</td><td>3</td></tr>
<tr><td></td><td>Summer Semester</td><td>Internship</td><td>2</td><td>2</td></tr>
<tr><td rowspan="3">3.</td><td rowspan="3">Semester III</td><td>Program Elective (PE)</td><td>9</td><td rowspan="3">15</td></tr>
<tr><td>Open Elective (OE)</td><td>3</td></tr>
<tr><td>MSc Thesis (T)</td><td>3</td></tr>
<tr><td rowspan="2">4.</td><td rowspan="2">Semester IV</td><td>Program Elective (PE)</td><td>6</td><td rowspan="2">15</td></tr>
<tr><td>MSc Thesis (T)</td><td>9</td></tr>
<tr><td colspan="4">Total</td><td>72</td></tr>
</table>

https://iitj.ac.in/physics/en/postgraduate-program

Course Curriculum Structure: Semester-wise plan for M.Sc. (Physics)

Cat	*Course*	*LTP*	*CH*	*NC*	*GC*	*Cat*	*Course*	*LTP*	*CH*	*NC*	*GC*
	I Semester						**II Semester**				
PC	Mathematical Physics	3-0-0	3	-	3	PC	Electrodynamics	3-0-0	3	-	3
PC	Classical Mechanics	3-1-0	4	-	4	PC	Condensed Matter Physics	3-0-0	3	-	3
PC	Quantum Mechanics	3-0-0	3	-	3	PC	Atomic and Molecular Spectroscopy	3-0-0	3	-	3
PC	Statistical Physics	3-0-0	3	-	3	PC	Nuclear and Particle Physics	3-0-0	3	-	3
PC	Electronics	3-0-0	3	-	3	PC	Advanced Quantum Mechanics	3-0-0	3	-	3
						PC	Scientific Computing and Machine Learning	3-0-0	3	-	3
PC	Physics Lab 1	0-0-6	6	-	3	PC	Physics Lab 2	0-0-6	6	-	3
	Total			**19**			**Total**			**21**	
	Summer Semester										
	Industry-Academia Summer Internship / Academic Internship									2	
							Total			**2**	
	III Semester						**IV Semester**				
PE	Program Elective-1	3-0-0	3	-	3	PE	Program Elective-4	3-0-0	3	-	3
PE	Program Elective-2	3-0-0	3	-	3	PE	Program Elective-5	3-0-0	3	-	3
PE	Program Elective-3	3-0-0	3	-	3						
OE	Open Elective-1	3-0-0	3	-	3						
T	Thesis	0-0-3	-	-	3	T	Thesis	0-0-9	-	-	9
	Total			**15**			**Total**			**15**	
							Total Credits			**72**	

List of Proposed Courses:

S. No.	Course Code	Course Name	L-T-P
Program Core Courses			
1	PHL4xx0	Mathematical Physics	3-0-0
2	PHL4xx0	Classical Mechanics	3-1-0
3	PHL4xx0	Quantum Mechanics	3-0-0
4	PHL4xx0	Electronics	3-0-0
5	PHL4xx0	Statistical Physics	3-0-0
6	PHL4xx0	Electrodynamics	3-0-0
7	PHL4xx0	Condensed Matter Physics	3-0-0
8	PHL4xx0	Atomic and Molecular Spectroscopy	3-0-0
9	PHL4xx0	Nuclear and Particle Physics	3-0-0
10	PHL4xx0	Advanced Quantum Mechanics	3-0-0
11	PHL4xx0	Scientific Computing and Machine Learning	3-0-0
12	PHP4xx0	Physics Lab 1	0-0-6
13	PHP4xx0	Physics Lab 2	0-0-6
Program Elective Courses			
1	PHL7550	Advanced Condensed Matter Physics	3-0-0
2	PHL7xx0	Advanced Statistical Physics	3-0-0
3	PHL7370	Cold Plasma Technologies	3-0-0
4	PHL7510	Energy Harvesting	3-0-0
5	PHL7360	Introduction to Material Characterization	3-0-0
6	PHL6xx0	Quantum Materials and Devices	3-0-0
7	PHL7xx0	General Theory of Relativity	3-0-0
8	PHL7490	High Energy Physics	3-0-0
9	PHL6xx0	Particle Accelerators and Detectors	3-0-0
10	PHL6xx0	Quantum Field Theory	3-0-0
11	PHL7330	Laser Technologies and Ultrafast Optics	3-0-0
12	PHL6xx0	Nonlinear Optics	3-0-0
13	PHL7xx0	Fiber-Optic Communication	3-0-0
14	QCL7330	Device-independent Quantum Technologies	3-0-0
15	PHL7480	Open Quantum Systems	3-0-0
16	PHL6xx0	Quantum Optics and Engineering	3-0-0

Course Content of Program Core Courses

Title	**Mathematical Physics**	**Number**	**PHL4xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	MSc in Physics	Type	**Compulsory**
Prerequisite	None		

Objectives

- To gain the mathematical skills necessary to approach problems in fundamental and advanced physics courses.
- To understand Fourier and Laplace transforms and apply their applications in various fields of physics.

Learning Outcomes

The students are expected to have the ability to:

- Apply the mathematical skills in designing problems and solving them.
- Will enable students to apply different transforms to solve mathematical problems of interest in science and engineering

Contents

- **Complex variables**: Analyticity and Cauchy-Reimann Conditions, Cauchy's integral theorem and formula, Taylor's series and Laurent's series expansion, Branch Points and Cuts, Reimann Sheets and surfaces, Residues, Cauchy's Residue theorem, Jordan's Lemma to evaluate infinite integrals, Evaluation of definite integrals **[11 Lectures]**
- **Differential Equations and Special Functions**: Ordinary differential equations, second order homogeneous and inhomogeneous equations, Wronskian, General solutions, Series solution. Gauss hypergeometric and confluent hypergeometric equations, Sturm Liouville problem, Legendre, Hermite and the associated polynomials, Bessel functions, Integral representation of special functions, Applications to electrostatics and quantum mechanics. **[15 Lectures]**
- **Fourier and Laplace Transforms:** Fourier transform, Sine, Cosine and Complex transforms with examples, Definition, Properties and Representations of Dirac Delta Function, Properties of Fourier Transforms, Transforms of derivatives, Parseval's Theorem, Convolution Theorem,Momentum representation, Applications to Partial differential equations, Discrete Fourier transform, Fast Fourier transform, Laplace transform, Convolution theorem and its applications, Laplace transform method of solving differential equations, Applications to electrostatics. **[13 Lectures]**

Textbooks

1. Arfken George, B. and Weber Hans, J., *Mathematical Methods for Physicists*, Academic Press,
2. Boas Mary, L., *Mathematical Methods in the Physical Sciences*, John Wiley & Sons, 2005.

Self-Learning Materials

1. Selected topics in Mathematical Physics, NPTEL course,
2. https://nptel.ac.in/courses/115106086/ (by Professor V. Balakrishnan, Department of Physics IIT Madras

Preparatory Course Material

1. Mathematical physics online NPTEL course by Dr. Saurabh Basu, IIT Guwahati.

Title	**Classical Mechanics**	**Number**	**PHL4xx0**
Department	Physics	L-T-P [C]	**3-1-0 [4]**
Offered for	MSc in Physics	Type	**Compulsory**
Prerequisite	None		

Objectives

The Instructor will:

- Develop a deep conceptual and mathematical understanding of the fundamental principles governing classical mechanical systems.
- Provide concepts and problem solving approaches related to Lagrangian and Hamiltonian formulation in Mechanics.

Learning Outcomes

The students are expected to have the ability to:

- Apply the Variational principles to physical problems.
- Model mechanical systems using Lagrange and Hamilton equations of motion

Contents

- **Newtonian Framework of Single Particle System:** Overview of Newton's laws and their interpretation in describing physical systems. Definition of inertial reference frames, force, and mass. Galilean transformation. Non-inertial frames and fictitious forces. Central force and motion under the inverse square law of force, Kepler's laws, equation of orbit. **[7 Lectures]**
- **Many-Particle Systems:** System of particles, internal and external forces. Linear and angular momentum, torque, and conservation laws. Centre of mass motion and the two-body problem. **[5 Lectures]**
- **Rigid body dynamics:** Constraints defining the rigid body. Degrees of freedom of a rigid body. Moment of inertia tensor. Moments and products of inertia of some symmetrical bodies. Euler's equations of motion. Symmetric top. **[7 Lectures]**
- **Lagrangian Approach to Mechanics**: Constraints and their classification. Principle of least action. D'Alembert's principle. Generalized coordinates, Euler-Lagrange's equations of motion. Generalised force. Applications of the Lagrangian formulation: harmonic oscillators, simple pendulum, spherical pendulum.
[7 Lectures]
- **Hamiltonian formalism:** Canonical conjugate momenta. Legendre transformation. Hamilton's equations of motion. Cyclic coordinates and Noether's theorem. Applications of Hamilton's equations. **[7 Lectures]**
- **Canonical Transformation:** Generating functions. Canonical transformations. Poisson brackets and conservation theorems in the Poisson bracket formalism. Transition from Poisson brackets to quantum commutators. **[6 Lectures]**

Textbooks

1. Goldstein, H., Classical Mechanics, Pearson India Limited, New Delhi (2011).

Reference Books

1. Jose, J. V. and Saletan, E. J., Classical Dynamics: A Contemporary Approach, Cambridge University Press, (2002).
2. Landau, L.D. and Lifshitz, E.M., Mechanics, Pergamon Press, (1960)

Self-Learning Material

1. Banerjee D., Classical Mechanics, Indian Institute of Technology Kharagpur, Kharagpur, https://nptel.ac.in/courses/115105098.

Title	**Quantum Mechanics**	**Number**	**PHL4xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS in Engineering Physics, MSc in Physics	Type	**Compulsory**
Prerequisite	None		

Objectives

The Instructor will:

1. Address the limitations of classical mechanics and illustrate how quantum mechanics can overcome them
2. Illustrate the postulates, basic descriptions of quantum systems, and important applications of quantum mechanics

Learning Outcomes

Students will be able to

1. Understand the necessity and the domain of applications of the quantum mechanical approach
2. Solve Schrödinger's equation for model systems
3. Understand the operator algebra of quantum mechanical angular momentum

Contents

- **Need for Quantum Physics**:
  Failure of classical physics: The black body radiation, Photoelectric effect, Dual nature of light, Failure of Rutherford's atomic model, Bohr's theory and Franck-Hertz's experiment, Introduction to Sommerfeld quantization; harmonic oscillator, hydrogen atom and Space quantization, De Broglie hypothesis and Applications; State of a system and wavefunction, Fundamental Postulates, superposition of states, wave packets, the uncertainty principle. **[8 Lectures]**
- **Schrödinger's equation and its applications**:
  Schrödinger's equation, One-dimensional and extension to three-dimensional, time-independent and time-dependent, Operator for variables, special functions (Hermite, Legendre) in quantum mechanics, Particle in a box, Particle in an infinite and finite potential well, Potential barrier (tunneling), Linear Harmonic oscillator. **[11 Lectures]**
- **Mathematical Formalism**:
  Vector spaces and Hilbert space, Operators and eigenvalue problems, eigen vectors, Commutation relations, Expectation values and uncertainties, Dirac notation (bra-ket formalism), Matrix representation of operators. Representation of states, time evolution operator, Pictures: Schrodinger, Heisenberg, Interaction, Ehrenfest theorem, Ladder operators, Harmonic oscillator in operator formalism. **[10 Lectures]**
- **Theory of Angular Momentum**:
  Orbital Angular Momentum and Commutation relations, Spin angular momentum and Pauli Matrices, Addition of angular momentum - Clebsch-Gordan coefficients, selection rule, the hydrogen atom. **[10 Lectures]**

Textbooks

1. Shankar, R., Principles of Quantum Mechanics, Springer, 2nd edition, 2014.
2. Griffiths, D. J., and Schroeter, D. F., Introduction to Quantum Mechanics, Cambridge University Press, 3rd edition, 2018.

Reference Books

1. Feynman, R. P., Leighton, R. B., and Sands, M., The Feynman Lectures on Physics, Vol. 3: Quantum Mechanics (The New Millennium Edition), Pearson Education, 1st edition, 2012.
2. Merzbacher, E., Quantum Mechanics, Wiley, 3rd edition, 1998.
3. Zettili, N., Quantum Mechanics, Wiley India Pvt. Ltd., 2nd edition, year not specified.

Self-Learning Materials

1. NPTEL Course Material, Balakrishnan, V., Department of Physics, IIT Madras https://nptel.ac.in/courses/ 122106034/
2. NPTEL Course Material, A. Ghatak, https://nptel.ac.in/courses/115102023
3. Prof. H. C. Verma, IIT Kanpur, https://hcverma.in/QuantumMechanics

Title	Electronics	Number	PHL4xx0
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS in Engineering Physics, MSc in Physics	Type	**Compulsory**
Prerequisite	None		

Objectives

1. To provide an understanding of semiconductor devices and their application in analog electronic circuits.
2. To design and analyze circuits, filters, oscillators, timers and switchers.
3. To understand and implement analog signal conversion techniques, including current/voltage converters.
4. To introduce practical analog system components such as sample-and-hold circuits, comparators, and precision rectifiers.
5. To develop an understanding of digital electronics, including number systems, Boolean algebra, and logic circuit design.

Learning Outcomes

Upon successful completion of this course, students will be able to:

1. Explain the operation and characteristics of semiconductor devices and their role in analog circuits.
2. Design and evaluate filters, oscillators, timing circuits, and signal conversion circuits for practical applications.
3. Analyze and design digital circuits using Boolean algebra, combinational and sequential logic principles.

Contents

- **Semiconductor & Device Review**: Semiconductor basics (bands, carriers, doping), p-n junction, BJT overview (structure, operation), small signal models (hybrid-pi), transconductance, input/output resistance, BJT characteristics (input/output, regions: cutoff, active, saturation), Configurations: CE, CB, CC, Biasing techniques, load-line analysis, FET overview (structure, operation), BJT and FET as switch. **[8 Lectures]**
- **Feedback and Operational amplifier**: Feedback concepts: type of feedback, effect on gain, bandwidth and impedance Op-amp basics & characteristics (ideal vs real), inverting and noninverting amplifier, unity gain buffer, summer, Differential amplifier, integrator and differentiator, instrumentation amplifier.
  Signal conversion: Current mirror, voltage to current converters, current to voltage converter. **[7 Lectures]**
- **Op-amp Applications**: Precision diode, ac to dc converters using precision diodes, comparator, Schmitt trigger and Square wave oscillators
  Active Filter circuits: Classification of filters, their specifications and transfer functions, First order and second order filter transfer functions and their implementation using active filters (Sallen and Key structure), all pass filters.
  Oscillators: RC oscillators (phase shift, Wien bridge) and LC oscillators (Hartley, Colpitts), Voltage-controlled oscillators. **[8 Lectures]**

- **Timing Circuits**: 555 times and its applications, astable and monostable operation, sample and hold circuits, operation and applications, aperture error, droop rate **[3 Lectures]**
- **Sample and hold (S/H) circuits**: Introduction to S/H circuits and their applications, Basic circuits, Performance parameter of S/H circuit, Non-ideal behavior of S/H circuits, sampling theorem and aliasing, introduction to quantization. ADC (flash, SAR), **[4 Lectures]**
- **Digital**: DAC (binary weighted, R-2R ladder), quantization error and noise, Basic logic gates, canonical forms (SOP, POS), Karnaugh map, flip flops, registers and counters **[9 Lectures]**

Textbooks

1. Jacob Millman and Arvin Grabel, Microelectronics, 2nd Ed. Tata Macgraw Hill, New Delhi.
2. Operational Amplifiers & Linear Integrated Circuits: Theory and Application, by James M. Fiore, 3rd ed
3. *Digital Principles and Applications* by Leach, Malvino, Saha, 8th ed, McGraw Hill

Reference Books

1. Donald Neamen, Electronic Circuit Analysis, McGraw-Hill, 2001
2. R. Gayakwad, Op-Amps and Linear Integrated Circuits, 4th Edition, Pearson, **2001**
3. Taub and Shilling, “Digital Integrated Electronics”, McGraw Hill.

Self-Learning Material

1. A. Aggarwal, Circuits and Electronics, 2007, MIT OpenCourseWare : http://ocw.mit.edu/6-002S07

Title	**Statistical Physics**	**Number**	**PHL4xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS in Engineering Physics, MSc in Physics	Type	**Compulsory**
Prerequisite	None		

Objectives

The Instructor will:

1. Introduce various aspects of quantum statistics.
2. Build analytical skills for solving complex systems in fields like condensed matter, biophysics.

Learning Outcomes

The students are expected to have the ability to:

1. Apply the fundamental principles of statistical physics.
2. Ability to appreciate and apply concepts of statistical physics in real world problems.

Contents

- **Review of thermodynamics:** Thermodynamic potentials, Conditions for phase equilibrium and stability, Thermodynamics of Phase Transitions. **[6 Lectures]**
- **Statistical mechanics:** Ensembles, Non-interacting ideal systems, Energy fluctuations in canonical/grand canonical ensemble, Equipartition and Virial theorems, Partition function for various systems. **[14 Lectures]**
- **Quantum statistics:** Bose-Einstein and Fermi-Dirac distributions, Ideal Bose gas, Bose-Einstein condensation, Blackbody radiation, Ideal Fermi gas, Magnetism of ideal Fermi gas, Electron gas in metals. **[12 Lectures]**
- **Statistical Mechanics for interacting systems:** Introduction, Ising Model, Transfer matrix method, Mean field theory. **[7 Lectures]**

Textbooks

1. Huang, K., *Statistical Mechanics*, John Wiley and Sons, 1987.
2. Pathria, R. K. and Beale, P. D., *Statistical Mechanics*, Academic Press, 3rd Ed. 2011.

Reference Books

1. Chandler, D., *Introduction to Modern Statistical Mechanics*, Oxford University Press, 1987.
2. Landau, L. D. and Lifshitz, E. M., *Statistical Physics*, Part 1, Pergamon Press, 1980.
3. Blundell S.J. and Blundell K.M.. *Concept in Thermal Physics,* Oxford University Press, 2009

Self Learning Material

1. NPTEL course material, Balakrishnan, V., Department of Physics, IIT Madras https://nptel.ac.in/courses/122106027.

Title	Electrodynamics	Number	PHL4xx0
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	MSc in Physics	Type	**Compulsory**
Prerequisite	None		

Objectives

The Instructor will:

1. Provide the concepts regarding fields and forces in Electrodynamics and Magneto dynamics using basic scientific methods.
2. Basic understanding of relativistic electrodynamics and its applications in branches of Physical Sciences.

Learning Outcomes

The students are expected to have the ability to:

1. Explain and solve problems based on classical electrodynamics using Maxwell's equation.
2. To understand and proficiently carry out research by applying Classical relativistic electromagnetism using fundamental concepts of physical sciences.

Contents

- **Electrostatics, Magnetostatics and Electrodynamics:** Gauss's law, Boundary value problems, multipoles, dielectrics, Biot and Savart law, Ampere's law, Faraday's law, Displacement current, Maxwell's equations, Wave propagation in Conductors and Dielectrics **[5 Lectures]**
- **Plane Electromagnetic Waves and Wave Propagation:** Plane Waves in Non-conducting Medium Linear and Circular Polarization, Stokes Parameter, Reflection and Refraction of Electromagnetic Waves at a Plane Interface between Dielectrics, Fresnel Equation, Group Velocity Dispersion (GVD), Kramers-Kronig Relations **[9 Lectures]**
- **Waveguides and Resonant Cavities:** Fields at the surface of and within a Conductor; Cylindrical Wave Guides **[6 Lectures]**
- **Simple Radiating Systems and Diffraction:** Fields of Radiation of localized oscillating Source, Electric Dipole fields and radiation and its application to radio waves **[6 Lectures]**
- **Radiation by Moving Charges:** Lienard-Wiechertz Potentials and Fields for a Point Charge, Total power Radiated by an Accelerating charge, Larmor's formula **[5 Lectures]**
- **Special Theory of Relativity:** Minkowski Space and Four vectors, Concepts of Four-velocity, Four Acceleration and higher rank tensors, relativistic formation of electrodynamics, Action principle and Electromagnetic energy momentum Tensor **[8 Lectures]**

Textbooks

1. Jackson, J. D., Classical Electrodynamics, Wiley India Pvt. Ltd., 2007.
2. Griffiths D.J. Introduction to Electrodynamics, Cambridge University Press, 2017 (4th ed.)

Reference Books

1. Lorrain, P. and Corson, D., Electromagnetic Fields and Waves, CBS Publishers, 2003.

2. Panofsky W.K.H. and Philips M., Classical Electricity and Magnetism, Dover Publishers, 1990.

Self-Learning Materials

1. Dighe, A., Electrodynamics, Tata Institute of Fundamental Research, Mumbai, https://nptel.ac.in/syllabus/115101004/.
2. Gut, A., Lecture notes on Electromagnetism II, MIT open course ware https://ocw.mit.edu/courses/physics/8-07-electromagnetism-ii-fall-2012/lecture-notes/.

Title	**Condensed Matter Physics**	**Number**	**PHL4xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS in Engineering Physics, MSc in Physics	Type	**Compulsory**
Prerequisite	None		

Objectives

The instructor will:
1. Provide the student with an extended knowledge of the principles and techniques of solid-state physics.
2. Provide an understanding of structure, thermal, electrical and magnetic properties of matter.

Learning Outcomes

The students will be able to:
1. Formulate basic models for electrons and lattice vibrations for describing the physics of crystalline materials.
2. Develop an understanding of the relation between band structure and the electrical/optical properties of a material.

Contents

- **Bond Formation**: Review of crystallography, Reciprocal Lattice, Brillouin Zone, Various bonds in solids: ionic, covalent, Vander Waals, metallic and hydrogen **[7 Lectures]**
- **Lattice Vibrations**: Elastic waves, Enumeration of modes, Density of states of a continuous medium, Specific heat models of Einstein and Debye, Concept of phonon, Lattice waves, Lattice dynamics of crystals with up to two atoms per primitive basis, Density of states of a lattice, Thermal Conductivity, Scattering of X-rays, neutrons and light by phonons **[11 Lectures]**
- **Electronic Properties of Solids**: Overview of Drude theory, Free electron theory, density of states, Fermi surface, Electrons in periodic potential, Band Theory, modification in Fermi surface, Tight Binding, Cellular and Pseudo potential methods, Symmetry of energy bands **[10 Lectures]**
- **Magnetism & Superconductivity**: Introduction to types of magnetism, Curie-Weiss Law, Magnetic Domains & Hysteresis, Zero resistance, Meissner effect, Thermodynamics of the superconducting transition, Electrodynamics of superconductivity, BCS theory of superconductivity, Josephson effect **[11 Lectures]**

Textbooks

1. Kittel, C., Introduction to Solid State Physics, Wiley, 8th Edition, 2008.
2. Ashcroft, N., W. and Mermin, N., D., Solid State Physics, Cengage Learning, 1976.
3. Omar, M. A., Elementary Solid State Physics, Pearson, 2009.

Reference Book

1. Simon, H., S. (2013), The Oxford Solid State Basics, Oxford University Press.

Self-Learning Materials

1. Rangarajan, G., Condensed Matter Physics, NPTEL Course Material, Department of Physics, Indian Institute of Technology Madras, https://nptel.ac.in/courses/115106061/.
2. Wen, X-G., Physics of Solids I, MIT open course, https://ocw.mit.edu/courses/physics/8-231-physics-of-solids-i-fall-2006/

Title	**Atomic and Molecular Spectroscopy**	**Number**	**PHL4xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS in Engineering Physics, MSc in Physics	Type	**Compulsory**
Prerequisite	Quantum Mechanics		

Objectives

1. Understand atomic structure, spectra, and fine/hyperfine interactions.
2. Analyze atom–radiation interaction and transition mechanisms.
3. Explore multi-electron atoms and molecular spectroscopy fundamentals.

Learning Outcomes

1. The students will understand quantum behavior of atoms in external electric and magnetic fields.
2. Apply selection rules and evaluate transition probabilities and line broadening.
3. The students will also learn various types of spectroscopy techniques.

Contents

- **One electron atoms:** Spectra of hydrogen and hydrogen-like atoms. Fine structure and hyper fine structure: spin-orbit coupling and relativistic correction to the kinetic energy. Dirac equation in the non-relativistic limit, Lamb shift. Stark and Zeeman effects **[9 Lectures]**
- **Interaction of one electron atoms with electromagnetic radiation**: The dipole approximation, electric dipole, magnetic dipole and electric quadrupole transitions. Spontaneous and stimulated emissions and Einstein coefficients, Selection rules, Transition probabilities and intensity of spectral lines. Rabi flopping, Line broadening mechanisms. Quantization of the electromagnetic field. The spin-statistics theorem. **[10 Lectures]**
- **Two electron and Many electron atoms:** Electron configurations and spectroscopic notation, equivalent and non-equivalent electrons and Hund's rules. Hartree-Fock SCF method, proof of Koopmans theorem, Slater's approximation to exchange **[7 Lectures]**
- **Molecular Spectroscopy:** Total Hamiltonian of a molecule. Born -Oppenheimer approximation. Rotational and Vibrational Spectra of molecules, The Raman effect. Anharmonicity, Franck-Condon principle, Electronic. Infrared and Raman Spectra analysis. Molecular Orbital and Electronic configuration of Diatomic molecules: H_2, C_2, O_2, NO and CN; Vibrational structure and vibrational analysis, Dissociation Energy, Rotational Raman spectra and influence of nuclear spin. **[13 Lectures]**

Textbooks

1. Bransden, B.H. and Joachain, C.J., (2004), *Physics of Atoms and Molecules*, Prentice Hall, 2nd Edition, Pearson Education, Delhi
2. Colin N. Banwell and Elaine M. McCash, (1995), Fundamentals of Molecular Spectroscopy, McGraw-Hill

Reference Book

1. Condon, E. U. and Shortley, G. H., (1951), The Theory of Atomic spectra, Cambridge University Press

Self-Learning Material

1. NPTEL course material Prof. T. Kundu, IIT Mumbai https://nptel.ac.in/syllabus/115101003/

Title	**Nuclear and Particle Physics**	**Number**	**PHL4xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS in Engineering Physics, MSc in Physics	Type	**Compulsory**
Prerequisite	None		

Objectives

The instructor will:

1. Develop a conceptual foundation of the nuclear system and interactions.
2. Introduce the principles of nuclear processes and decays, and their applications
3. Provide an overview of elementary particles and fundamental interactions.

Learning Outcomes

Students will be able to:

1. Apply theoretical models to explain nuclear structure, properties, and stability.
2. Evaluate radioactive decay, nuclear reactions, and radiation detection techniques using experimental and analytical approaches.
3. Interpret the classification and interactions of elementary particles in the context of fundamental forces and current developments.

Contents

- **Nuclear Structure and Properties:** Nuclear properties,, Angular momentum, Spin and Parity, Binding energy, Magnetic dipole and Electric quadrupole moments, Isospin, Experimental determination of nuclear properties: Hofstadter's experiment, nuclear forces and their spin dependence, deuteron problem **[13 Lectures]**
- **Radioactivity, Nuclear Forces and Models:** Radioactivity and decay laws, α-decay with quantum tunneling, β-decay including Fermi theory and parity violation, γ-decay including multipole radiation and transition probabilities, nuclear forces and nucleon–nucleon interactions, mean-field description of nuclei, and nuclear models including Liquid Drop, Shell and Collective models. **[10 Lectures]**
- **Nuclear Reactions, Detectors, and Applications:** Nuclear reactions and mechanisms, Q-value, Compound nucleus, Nuclear fission and fusion, Stellar energy and nucleosynthesis, Interaction of radiation with matter and energy loss of charged particles, Basic principles of radiation detection, Detectors: Gas-based, Semiconductor, Scintillation, Cerenkov and Calorimeters. **[9 Lectures]**
- **Elementary Particles:** Discovery and classification of elementary particles, Fundamental interactions, Conservation laws and symmetry principles, Properties of Pion, Muon, strange mesons, hyperons and resonance particles **[7 Lectures]**

Textbooks

1. Krane, K. S., Introductory Nuclear Physics, Wiley, 1st edition, 1987.
2. Ghoshal, S. N., Nuclear Physics, S. Chand, edition not specified, 2011.
3. Griffiths, D., Introduction to Elementary Particles, Wiley-VCH, 2nd edition, 2008.

Reference Books

1. Cohen, B. L., Concepts of Nuclear Physics, McGraw-Hill, edition not specified, 2017.
2. Wong, S. S. M., Introductory Nuclear Physics, Prentice Hall, edition not specified, 1998.
3. Burcham, W. E., and Jobes, M., Nuclear and Particle Physics, John Wiley & Sons, 1st

edition, 1995.
4. Povh, B., Rith, K., Scholz, C., and Zetsche, F., Particles and Nuclei: An Introduction to Physical Concepts, Springer, 7th edition, 2015.
5. Perkins D.H., Introduction to High Energy Physics, Cambridge University Press, 4th edition

Self-Learning Materials
1. NPTEL – H. C. Verma, Nuclear Physics: Fundamentals and Applications https://nptel.ac.in/courses/115104043/ 2. MIT OpenCourseWare: https://ocw.mit.edu/courses/8-701-introduction-to-nuclear-and-particle-physics-fall-2020/?

Title	**Advanced Quantum Mechanics**	**Number**	**PHL4xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS in Engineering Physics, MSc in Physics	Type	**Compulsory**
Prerequisite	Quantum Mechanics and STR		

Objectives

The Instructor will:

1. To extend the principles of quantum mechanics to advanced topics
2. To develop a deeper understanding of relativistic quantum mechanics
3. To provide a conceptual foundation connecting quantum mechanics to modern frameworks, including particle physics and the need for quantum field theory

Learning Outcomes

The students are expected to have the ability to:

1. Analyze quantum systems using scattering theory and approximation techniques
2. Apply symmetry principles and conservation laws
3. Derive and interpret relativistic wave equations, and explain the emergence of antiparticles, chirality, and the motivation for quantum field theory.

Contents

- **Approximation methods:**
  Perturbation theory - Time independent and time dependent with examples: Fermi-Golden rules and its applications, WKB approximation: Modified potential box, Variational method: Helium Atom **[11 Lectures]**
- **Scattering**:
  Identical particles, Scattering experiment, Scattering amplitude, partial wave method, Born Approximation **[8 Lectures]**
- **Symmetry**:
  Symmetry and degeneracy, Continuous transformation - Space translation, Time translation, Space rotation, Discrete Transformation - Parity, Charge Conjugation, Time reversal **[7 Lectures]**
- **Relativistic Quantum Mechanics**:
  Limitations of non-relativistic quantum mechanics; Klein-Gordon Equation and limitations; Dirac Equation; Gamma matrices; Lorentz transformation of spinors; Bilinear covariants; Dirac hole theory, interaction with EM field and non-relativistic limit; chirality and helicity; projection operators; Weyl spinors; Klein Paradox **[13 Lectures]**

Textbooks

1. Sakurai, J. J. and Napolitano, J., Modern Quantum Mechanics, Cambridge University Press, 3rd edition, 2020.
2. Bjorken, J. D. and Drell, S. D., Relativistic Quantum Mechanics, McGraw-Hill, 1st edition, 1964.

Reference Books

1. Shankar, R., Principles of Quantum Mechanics, Springer, 2nd edition, 1994.
2. Zettili, N., Quantum Mechanics: Concepts and Applications, Wiley India, 2nd edition, 2009.
3. Greiner, W. and Bromley, D. A., Relativistic Quantum Mechanics: Wave Equations, Springer, 3rd edition, 2000

Self-Learning Materials

1. Stanford University (Advanced Quantum Mechanics lecture series) https://www.youtube.com/@stanford/search?query=advanced%20quantum%20mechanics
2. Advanced Quantum Mechanics with Applications by Prof. S. Basu, IIT Guwahati: https://nptel.ac.in/courses/115103104

https://iitj.ac.in/physics/en/postgraduate-program

3. Quantum Mechanics in the Relativistic Regime by Prof. Vempati, IISc Bangalore: https://nptel.ac.in/courses/115108791

Title	**Scientific Computing and Machine Learning**	**Number**	**PHL4xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS in Engineering Physics, MSc in Physics	Type	**Compulsory**
Prerequisite	None		

Objectives

The instructor will:
1. Introduce numerical methods, computational physics techniques.
2. Provide fundamental understanding of machine learning ideas

Learning Outcomes

The students are expected to have the ability to:
1. Solve complex mathematical and physics related problems by using numerical methods.
2. Apply computational and machine learning techniques to model and simulate physical phenomena

Contents

- **Advanced numerical methods** Solution of algebraic, transcendental and nonlinear equations: Iterative, bisection and Newton-Raphson methods, Newton's and Lagrange's Interpolations, Least square curve fitting, Numerical differentiation and integration, LU decomposition, Gauss elimination, Gauss-Jordon and Iterative methods for solving linear systems, Eigenvalue problems, Euler and Runge-Kutta methods for solving ODEs **[17 Lectures]**
- **Computational Physics and Simulation**: Monte Carlo integration, variance reduction, importance sampling, Markov Chain, Detailed balance condition, Metropolis algorithm, Random processes, Brownian motion, Diffusion equation **[13 Lectures]**
- **Machine Learning:** Linear models, Kernel methods and SVM, Probabilistic models: Gaussian mixture models, Dimensionality reduction: PCA, Introduction to manifold learning, Neural networks: Multilayer perceptrons, Backpropagation; and Machine learning in physics. **[9 Lectures]**

Textbooks

1. Chapra, S. C., and Canale, R. P. Numerical Methods for Engineers, 7th Edition, McGraw-Hill Education.
2. Newman, M., Computational Physics, CreateSpace Independent Publishing Platform, 2012.
3. Press, W. H., Teukolsky, S. A., Vetterling, W. T., and Flannery, B. P. Numerical Recipes: The Art of Scientific Computing, 3rd Edition, Cambridge University Press, 2007

Reference Books

1. Allen, M. P., and Tildesley, D. J., Computer Simulation of Liquids, Oxford University Press, 2nd ed. 2017.
2. Landau, D. P. and Binder, K., A Guide to Monte Carlo Simulations in Statistical Physics, 3rd Edition, Cambridge University Press, 2009.
3. Mackay, D., Information Theory, Inference, and Learning Algorithms, Cambridge University Press, 2005.

Self-Learning Material

1. MIT Open CourseWare, 3.320 "Atomistic Computer Modeling of Materials (SMA 5107)", by Ceder, G. and Marzari, N.; Spring 2005, https://ocw.mit.edu/courses/materials-scienceand-engineering/3-320-atomistic-computer-modeling-of-materials-sma-5107-spring-2005/

Title	**Physics Lab 1**	**Number**	**PHP4xx0**
Department	Physics	L-T-P [C]	**0-0-6 [3]**
Offered for	MSc in Physics	Type	**Compulsory**
Prerequisite	None		

Objectives

1. To understand and experimentally verify the fundamental principles of electronic devices, analog/digital circuits, and optical phenomena.
2. To design, analyze, and characterize electronic circuits and optical systems using appropriate experimental techniques.
3. To develop hands-on skills in measurement, data analysis, and interpretation of results in electronics and photonics experiments.

Learning Outcomes

1. Students will be able to analyze the behavior of semiconductor devices, amplifiers, digital circuits, and optical systems through experimental observations.
2. Students will be able to design and evaluate electronic circuits (analog/digital) and optical setups, and compare results with theoretical models.
3. Students will acquire proficiency in using laboratory instruments and interpreting data related to electronics, lasers, and optoelectronic systems.

Contents

- **Electronics**
  1. **PN Junction Diode:** To determine the ideality factor and reverse saturation current from the I–V characteristics of a PN junction diode.
  2. **Common Emitter Amplifier:** To measure the voltage gain and validate the small-signal model of a common emitter amplifier.
  3. **Frequency Response of Amplifier:** To determine the lower and upper cutoff frequencies and evaluate the bandwidth of an amplifier.
  4. **Differential Amplifier:** To measure the common-mode rejection ratio (CMRR) and input offset voltage of a differential amplifier.
  5. **Op-Amp Non-Idealities:** To study non-ideal parameters of an operational amplifier such as slew rate, input offset voltage, and bias current.
  6. **Active Filters:** To design a second-order active filter and estimate its quality factor (Q-factor).
  7. **Oscillators:** To analyze the operation of a Wien bridge oscillator and study its frequency stability.
  8. **K-Map Based Logic Optimization:** To simplify Boolean expressions using Karnaugh maps and implement the optimized logic circuit.
  9. **Code Converters (Binary ↔ Gray):** To design and implement binary to Gray code and Gray to binary code converters.
  10. **DAC using R–2R Ladder Network:** To design and study the performance of a digital-to-analog converter using an R–2R ladder network.
  11. **ADC Study:** To analyze sampling and quantization effects in an analog-to-digital conversion process.

- **Optics and Lasers**

12. **Michelson Interferometer:** To determine the wavelength of monochromatic light (or small displacement/refractive index changes) by analyzing interference fringes produced by path differences.
13. **Fabry–Perot Interferometer:** To measure very small wavelength differences or resolve spectral lines using multiple-beam interference between closely spaced parallel plates.
14. **Refractometer:** To determine the refractive index of a given material by measuring the deviation or critical angle of light passing through it.
15. **Brewster Angle Measurement:** To determine the refractive index of a material by measuring the angle at which reflected light becomes completely plane polarized (Brewster angle).
16. **Polarization by Wave Plates:** To study the transformation of polarization states of light using quarter-wave and half-wave plates.
17. **Single Slit Diffraction:** To determine the wavelength of light or slit width by analyzing the diffraction pattern produced by a single narrow slit.
18. **Pockels Effect:** To study the linear electro-optic effect and determine the change in refractive index of a crystal under an applied electric field.
19. **Characteristic Study of Diode Laser:** To study the output characteristics of a diode laser, including threshold current and power–current relationship.
20. **Holography Experiment:** To record and reconstruct a hologram using coherent light and study the principles of interference and diffraction in holography.
21. **Optical Fiber Characterization:** To determine key parameters of an optical fiber such as numerical aperture, attenuation, and propagation losses.
22. **Solar Cell:** To study the characteristics of a solar cell under different illumination conditions.
23. **LED and Photodiode:** To study the LED and photodiode characteristics for optical communication.

Textbooks

1. A.S. Sedra and K.C. Smith, Microelectronic Circuits
2. Experimental Electronics, Malvino
3. Ghatak, A., Optics, 2nd edition, Tata McGraw-Hill, 2000

Reference Books

1. Jacob Millman and Arvin Grabel, Microelectronics
2. M. Morris Mano, Digital Design
3. Saleh, B. E. A. and Teich, M. C., Fundamentals of Photonics, Wiley, 2018

Self-Learning Material

1. Manuals

Title	**Physics Lab 2**	**Number**	**PHP4xx0**
Department	Physics	L-T-P [C]	**0-0-6 [3]**
Offered for	MSc in Physics	Type	**Compulsory**
Prerequisite	None		

Objectives

The Instructor will:

1. Provide an experimental understanding of solid-state physics, quantum mechanics and nuclear physics to observable phenomena.
2. Train students in the operation and underlying principles of various diagnostic tools, including cryogenic systems, multi-spectrum spectrometers (Raman, ESR, UV-Vis), and high-energy particle detectors.
3. Describe methodologies used to probe the electrical, magnetic, thermal, and optical properties of materials

Learning Outcomes

The students are expected to have the ability to:

1. Understand the basics related to atomic, nuclear and condensed matter physics and the working principles of various measurement techniques.
2. Measure and analyze fundamental solid-state parameters, including dielectric phase transitions, magnetic hysteresis, transport properties, and lattice thermal dynamics.
3. Extract key quantum mechanical constants and physical parameters such as the Rydberg constant, by analyzing complex, multi-dimensional spectroscopic data

Contents

1. **Dielectrics and Magnetism:**
   a. Dielectric constant (2-Probe): Study of dielectric constant and curie temperature of ferroelectric ceramics.
   b. Hysteresis Loop Tracer (M-H curve): To measure and analyze the magnetic properties of different materials using the Hysteresis Loop Tracer.
2. **Semiconductor Physics and Transport**:
   a. Four Probe Method: To find the resistivity and band gap of a crystal using the four-probe method.
   b. Energy Band Gap (Junction Diode): To determine the Energy Band Gap in a semiconductor using a Junction Diode.
3. **Lattice and Thermal Properties:**
   a. Lattice Dynamics: To study the dispersion relation of the diatomic lattice and monoatomic lattice.
   b. Lee's Disc Experiment: To find the thermal conductivity of bad conductors using Lee's disc method.
4. **Spectroscopic Analysis:**
   a. UV-Visible Spectrometer: Determination of energy band gap of a sample using UV-Visible Spectroscopy.
   b. Electron Spin Resonance (ESR): Determination of Lande G-factor for the given sample using an ESR Spectrometer.
5. **Advanced Material Characterization**:
   a. Confocal Raman Spectrometer: To measure and analyze the Raman spectra of a given sample using a Confocal Raman Spectrometer.
   b. Plasma Experiment: Paschen Curve Experiment using a DC Discharge Unit.
6. **Characterization of Materials**:
   a. DSC/TGA measurement of bulk materials

   b. X-Ray Diffraction: X-ray Diffraction measurements for crystalline, polycrystalline, and amorphous materials.
7. **Cryogenic and Superconducting Properties using PQMS**:
   a. Critical Temperature (TC): Using the physical quantity measurement system (PQMS) to measure the critical temperature of a superconductor.
   b. Low-Temperature Magnetometry: To measure the magnetic properties at low temperatures using PQMS.
8. **Atomic Spectra in free space and in magnetic field:**
   a. Recording of Mercury Spectra
   b. Zeeman effect- Atom in a magnetic field
9. **Measurements of electron charge and charge to mass ratio**
   a. Charge of Electron- Millikan Oil drop method
   b. Measurement of charge to mass ratio of an electron (e/m ratio)
10. **Measurements of fundamental constants**
   a. Measurement of Planck's Constant
   b. Recording of Hydrogen Spectra - Rydberg Constant
11. **Resonances in atoms**
   a. Frank-Hertz Experiment
   b. ESR Spectroscopy- Solids
12. **Geiger–Müller (GM) Counter**:
   a. GM Tube characterization and study of the statistical nature of radioactive decay.
   b. Gamma-Ray absorption in the material (Aluminium and Copper).
13. **Gamma-Ray Spectroscopy and Dosimetry**:
   a. Energy Resolution of a Gamma-Ray Detector Using FWHM and Energy resolution of a gamma-ray spectrometer.
   b. Radiation Dosimeter Calibration Using Gamma Sources
14. **Nuclear Scattering and Alpha-Particle Properties**:
   a. To study Rutherford scattering and verify the angular dependence of alpha-particle scattering.
   b. To measure the energy spectrum of alpha particles using a semiconductor detector.
15. **Particle Physics Simulation**:
   a. Detector Simulation and Energy Deposition Study Using GEANT4
   b. Simulation of Proton–Proton Collisions Using PYTHIA

Computational Lab Components

1. Solution of algebraic and transcendental equations
2. Solution of simultaneous linear equations
3. Numerical Differentiation and Integration
4. Random Number Generators and Monte Carlo integration
5. Calculation of Pi, Importance Sampling, Metropolis algorithm
6. MC simulation of a random walk
7. Classification and performance evaluation
8. Clustering and dimensionality reduction

Textbooks

1. Melissinos Adrian C. and Napolitano J. Experiments in Modern Physics, Academic Press (2003).
2. Glenn F. Knoll, Radiation Detection and Measurement, John Wiley & Sons, 4th Edition, (2010).
3. Chapra, S. C., and Canale, R. P. Numerical Methods for Engineers, 7th Edition, McGraw-Hill Education.

4. Newman, M., Computational Physics, CreateSpace Independent Publishing Platform, (2012).
5. Géron, A., Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow, 3rd Edition, O'Reilly Media

Reference Books

1. Kittel, C., Introduction to Solid State Physics, Wiley, 8th Edition, (2008).
2. Walter F. Smith, Experimental Physics: Principles and Practice for the Laboratory, CRC Press (Taylor & Francis Group), 1st edition (2020).
3. Kaufmann, E. N., Characterization of Materials, Wiley, (2012).
4. Allen, M. P., and Tildesley, D. J., Computer Simulation of Liquids, Oxford University Press, 2nd Edition. (2017).
5. Landau, D. P. and Binder, K., A Guide to Monte Carlo Simulations in Statistical Physics, 3rd Edition, Cambridge University Press, (2009).
6. Mackay, D., Information Theory, Inference, and Learning Algorithms, Cambridge University Press, (2005).

Self-Learning Materials

1. Experimental Physics I, II and III: https://nptel.ac.in/courses/115105110, https://nptel.ac.in/courses/115105120, and https://nptel.ac.in/courses/115105121
2. https://nptel.ac.in/courses/115103101
3. Manuals of the Experiment.
4. MIT Open CourseWare, 3.320 "Atomistic Computer Modeling of Materials (SMA 5107)", by Ceder, G. and Marzari, N.; Spring 2005, https://ocw.mit.edu/courses/materials-scienceand-engineering/3-320-atomistic-computer-modeling-of-materials-sma-5107-spring-2005/

Course Content of
Program Elective Courses

Title	Advanced Condensed Matter Physics	Number	PHL7550
Department	Physics	L-T-P [C]	3-0-0 [3]
Offered for	MSc in Physics, PhD	Type	Elective
Prerequisite			

Objectives

1. Provide training and knowledge to condensed matter physics of complex systems
2. Help in understanding both fundamental as well as applied aspects of condensed matter physics .
3. Functional materials and their integration

Learning Outcomes

Upon successful completion of this course, students will be able to:
1. Understand magnetism, ferroelectricity, opto-electronic properties.
2. Understand basics of soft condensed matter physics.

Contents

- **Magnetism and Ferroelectricity**: Dia/para magnetism, ferro, ferri/anti-ferro magnetism, superpara/superferro magnetism, magnetic domains, domain dynamics, introduction to magnetic resonance.Dielectric constant and polarizability, phase transition, ferroelectric crystals classification, displacive transitions, Landau theory of phase transition, first and second order transition, antiferroelectricity, ferroelectric domains and imaging. **[10 Lectures]**
- **Optical properties and plasmons**: Electron gas, dielectric function of electron, dispersion relation, plasmon, electrostatic screening, polaritons, Electron-electron and electron-phonon interaction, Kramer-Kroning relation, excitons, Raman effect. **[10 Lectures]**
- **Defects and Interfaces**: Surface crystallography, Surface electronic structure, Heterostructures, point defects, dislocations, Burger vectors, dislocation, and crystal growth. **[9 Lectures]**
- **Soft Matter**: Time and length scales, Colloids, polymers, liquid crystals and ionic soft matter, phase transition in soft matter systems. **[10 Lectures]**

Textbooks

1. Kittel C, Solid State Physics, Wiley, 2004.
2. Ashcroft N. W., Mermin N. D., Solid State Physics, Saunders, 1976.
3. R. A. L. Jones, Soft Condensed Matter, Oxford University Press 2002

Reference Books

1. Sander M. Leonard, Advanced Condensed Matter Physics, Cambridge Univ. Press, 2009.
2. Snoke W. David, Solid State Physics: Essential Concepts, Pearson, 2009.
3. M. Doi, Soft Matter Physics, Oxford University Press, 2014.

Self-Learning Materials

1. Rangarajan, G., Condensed Matter Physics, NPTEL Course Material, Department of Physics, Indian Institute of Technology Madras, https://nptel.ac.in/courses/115106061/.
2. Wen, X. G., Physics of Solids I, MIT open course, https://ocw.mit.edu/courses/physics/8-231-physics-of-solids-i-fall-2006/

Title	Advanced Statistical Physics	Number	PHL7xx0
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	MSc in Physics, PhD	Type	**Elective**
Prerequisite	Statistical Physics		

Objectives

1. To provide exposure to advanced concepts in statistical physics, such as phase transitions in fluids, magnets, liquid crystals, etc.
2. To provide a fundamental and theoretical framework for systems driven away from equilibrium

Learning Outcomes

1. Ability to apply mean field theory and lattice models to different problems in physics.
2. Ability to appreciate and apply concepts of phase transitions and stochastic processes

Contents

- **Non-Ideal Systems:** Basic concepts in statistical physics, Partition function for a fluid, Cluster expansion, Virial expansion, Second virial coefficients for various potentials, Van der Waals equation **[10 Lectures]**
- **Phase Transitions:** Mean field theory of Magnets, Landau theory, Critical Exponents, Universality within the Mean Field Approximation, Ginzburg criterion, Scaling hypothesis **[14 Lectures]**
- **Nonequilibrium Processes:** Diffusion equation, Random walk, Brownian motion, Langevin equation, Fluctuation-dissipation relation, Stokes-Einstein relation, Anomalous diffusion, Persistent random walk, Self-propelled dynamics of active matter **[15 Lectures]**

Textbooks

1. Pathria, R. K. and Beale, P. D., Statistical Mechanics, Academic Press, 3rd Ed. (2011).
2. Kubo, R., Toda, M., and Hashitsume, N., Statistical Physics II: Nonequilibrium Statistical Mechanics, Springer-Verlag (2012).
3. Balakrishnan, V., Elements of Nonequilibrium Statistical Mechanics, Springer (2021).
4. Linda, E. R., A Modern Course in Statistical Physics, 4th Edition, Wiley, (2016).

Reference Books

1. Yeomans, J. M., Statistical Mechanics of Phase Transitions, Clarendon Press, Oxford (1992).
2. Chaikin, P. M. and Lubensky, T. C., Principles of Condensed Matter Physics, Cambridge University Press (1995).
3. Zwanzig, R., Nonequilibrium Statistical Mechanics, Oxford University Press (2001).

Self-Learning Material

1. NPTEL course by Prof. Santra, S. B., Department of Physics, IIT Guwahati; "Computational Chemistry and Classical Molecular Dynamics"; https://nptel.ac.in/syllabus/115103028/

Title	**Cold Plasma Technologies**	**Number**	**PHL7370**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	MSc in Physics, PhD	Type	**Elective**
Prerequisite	Electromagnetic theory and kinetic theory of gases		

Objectives

The instructor will:

1. provide an overview of the importance of cold plasma technologies
2. present an overview of commercially important plasma sources, including the fundamental principles of their operation, their diagnostics and associated vacuum technologies.

Learning Outcomes

The students are expected to have the ability to:

1. understand the operating principles of the most significant types of experimental plasma sources and will also be able develop an understanding of the concepts required for choosing plasma systems for different applications.
2. select appropriate plasma diagnostic and measurement tools for experimental studies.
3. work in different operating regimes of plasma discharges and acquire conceptual understanding of different vacuum pumps, vacuum sensors and vacuum systems design concepts that are integral parts of the laboratory plasma systems.

Contents

- **Electrical breakdown of gases-** Background ionization, Saturation regime, Townsend discharge and electrical breakdown condition of gases, Paschen Curve, Theory of low-pressure DC glow discharge, Cold plasma systems and their characteristics **[10 Lectures]**
- **RF-driven gas discharges-** Capacitive coupling, Inductive coupling, Microwave driven, Magnetically enhancement **[5 Lectures]**
- **High pressure gas discharges-** Plasma Arc discharge and Glow discharge concept, Cold atmospheric pressure discharge, Dielectric Barrier Discharges, Cold Plasma Jets, Microplasmas **[5 Lectures]**
- **Vacuum Pumps and Instrumentation-** Mechanical, diffusion, turbo molecular pumps (general working principles and operating regimes). Vacuum gauges, Gas regulators, Flow meters, Residual gas analysers, Leak detection **[5 Lectures]**
- **Plasma Diagnostics-** Overview of plasma diagnostics, Langmuir probe, Magnetic probe, Emissive probe, Measurement of circuit parameters including current, voltage and power, Fundamentals of emission of radiations by plasmas and their measurements **[8 Lectures]**
- **Laboratory Plasma Applications-** Plasma treatment of surfaces, Plasma deposition of the surfaces, Plasma Etching, Cold plasma applications in health, food and agriculture, Plasma Lightening devices, Nanoscale fabrications and plasma for biomedicines **[8 lectures]**

Textbooks

1. Yuri P. Raizer, Gas Discharge Physics, Springer-Verlag Berlin Heidelberg, 1991
2. J. Reece Roth, Industrial Plasma Engineering, Vol. 1 & 2, Institute of Physics Publishing, 2003
3. P.I John, Plasma Sciences and the Creation of Wealth, Tata McGraw-Hill Education Company Pvt. Ltd., New Delhi, 2005

Reference Books
1. I. H. Huchinson, Principles of plasma diagnostics, Cambridge University Press, 1987 2. Michael Lieberman and Allan J. Lichtenberg, Principles of Plasma Discharges and Materials Processing, John Wiley, 2005
Self-Learning Materials
1. https://nptel.ac.in/courses/115102020/

Title	**Energy Harvesting**	**Number**	**PHL7510**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS Engineering Physics, MSc, PhD	Type	**Elective**
Prerequisite			

Objectives

1. To provide the student with an extended knowledge of the basic principles and recent advances in Energy harvesting technologies for low-power applications including self-powered or autonomous systems.
2. To provide the students with the role of materials in energy harvesting technologies with a focus on miniaturized and microfabricated devices

Learning Outcomes

The students will:

1. Develop an understanding of basic principle, concept, working mechanism and applications of various energy harvesting devices.
2. Develop an understanding to design new energy harvesting systems.

Contents

- **Micro Photovoltaic Module Energy Harvesting:** *p-n* Junction and Crystalline Si Solar Cells, Amorphous Silicon Solar Cell, CIGS and CdTe Solar Cell Development , Polymer Solar Cell, Dye-Sensitized Solar Cells (DSSC), Perovskite Solar Cells, Monolithically Integration of Solar Cells with IC, Low-Power Micro Photovoltaic Systems, Maximum Power Point Tracking **[14 Lectures]**
- **Mechanical Energy Harvesting:** Energy Harvesting from Macro to Micro to Nano, Piezoelectric MEMS Energy Harvesters, Nano-Piezoelectric Generator, Piezoelectric Cantilever Generator, Piezoelectric Transducers. New-generation Triboelectric Nanogenerators **[12 Lectures]**
- **Thermal Energy Harvesting:** Overview of Nanoscale Heat Conduction and the Seebeck Effect, Thermoelectric energy harvesting and Power Generation, Thermoelectric figures of merit, Novel nanostructured Thermoelectric materials and devices, Thermal energy harvesting using pyroelectric materials, Thermodynamic cycles for Pyroelectric energy harvesting, Nanostructured and micro-scale materials and devices **[13 Lectures]**

Textbooks

1. J. Nelson, The Physics of Solar Cells, Imperial College Press, (2003)
2. Briand, D., Yeatman, E., Roundy, S., *Micro Energy Harvesting* Wiley, 2015.
3. Shashank, P., Inman, D. J., *Energy Harvesting Technologies*, Springer, 2009

Reference Books

1. Elvin, N., Erturk, A., *Advances in Energy Harvesting Methods*, Springer, 2013.
2. S., Fonash, (2010), *Solar Cell Device Physics*, Academic Press.

Self-Learning Materials

1. Pal, K., Selection of Nanomaterials for Energy harvesting and Energy Storage Applications, https://nptel.ac.in/courses/112107283/
2. Buonassisi, T., Fundamentals of Photovoltaics, 2011, MIT OpenCourseWare : http://ocw.mit.edu/2-627F11
3. Jaffe, R., and Taylor, W., Physics of Energy, MIT open course, https://ocw.mit.edu/courses/physics/8-21-the-physics-of-energy-fall-2009/

Title	**Introduction to Material Characterization**	**Number**	**PHL7360**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS Engineering Physics, MSc, PhD	Type	**Elective**
Prerequisite			

Objectives

1. To introduce the fundamental principles and importance of material characterization
2. To explain structural, optical and electrical characterization techniques for crystalline and amorphous materials.
3. To enable interpretation of experimental data and correlation with material properties

Learning Outcomes

Upon successful completion of this course, students will be able to:

1. Select appropriate characterization techniques for specific material properties and applications.
2. Analyze and interpret data obtained from structural, microscopic, and spectroscopic methods.
3. Correlate characterization results with structure-property relationships in materials

Contents

- **Material Characterization by Diffraction and Electron Microscopy:** Introduction and Necessity of Material Characterization: Structural and functional properties of materials, Diffraction based Characterization: Structure of crystalline and non-crystalline materials by x-ray diffraction, indexing of lattice planes and lattice parameter determination, electron and neutron diffraction, small angle scattering, Introduction to Electron Microscopy: Scanning Electron Microscopy (SEM) **[13 Lectures]**
- **Characterization of Materials by Microscopy and Spectroscopy:** Optical microscopy, Polarization Microscopy, Fluorescence Microscopy, Phase contrast Microscopy, Scanning Tunneling Microscopy (STM) and Atomic Force Microscopy (AFM), Spectroscopic based Characterization: UV-Vis-NIR, FTIR, Photoluminescence **[13 Lectures]**
- **Functional Properties of Materials: Electrical properties:** Resistivity (Four probe and Van der Pauw method), Magnetoresistance and Hall effect, Magnetic properties: Magnetization and magnetic moment, Measurement of Magnetization by force and by induction, Magnetic Hysteresis, Magnetic susceptibility, Principles of Electron Paramagnetic Resonance and Nuclear Magnetic Resonance (NMR) **[13 Lectures]**

Textbooks

1. Zhang, S., Li, L. and Kumar, A., Materials Characterization Techniques, CRC Press, 2008
2. Mertz, J., Introduction to Optical Microscopy, 2nd Edition, Cambridge University Press, 2019

Reference Books

1. Yang Leng “Materials Characterization: Introduction to Microscopic and Spectroscopic Methods”
2. Cullity, B. D., and S. R. Stock. Elements of X-Ray Diffraction. 3rd edition

Self-Learning Materials

1. Shankaran, S., Materials Characterization, NPTEL Course Material, Department of Metallurgical & Materials Engineering, Indian Institute of Technology Madras, http://nptel.ac.in/courses/113106034/.

Title	**Quantum Materials and Devices**	**Number**	**PHL6xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS Engineering Physics, MSc	Type	**Elective**
Prerequisite	Basic understanding of Condensed Matter Physics		

Objectives

The instructor will:

1. Provide an understanding about mathematical topological invariants and the tangible electronic and magnetic properties of modern quantum topological materials.
2. Explain the physical principles and operational advantages of next-generation quantum hardware, including topological qubits, spintronic memory, and high-precision quantum sensors.

Learning Outcomes

The students will be able to:

1. Understand the basics of geometric phases and different types of electronic and magnetic properties of quantum topological materials.
2. Analyze the experimental signatures of various quantum effects, modern magnetism, and apply them to certain applications.

Contents

- **Geometric Phases & Dirac Physics:** Review of quantum technologies, Aharonov-Bohm Effect: magnetic vector potential, phase shifts, and charge-flux composites; geometric phases: introduction of Berry phase, Berry connection, Berry curvature and its dipole; Bloch sphere geometry; Dirac equation in solids; Graphene and Kramer's degeneracy **[10 Lectures]**
- **Quantum Topological Materials:** The integer quantum Hall effect (IQHE): phenomenology of 2D electrons in high magnetic fields, Landau levels and the role of disorder; Chern number and TKNN invariant, time reversal symmetry and Z2 invariants; topological insulators (TIs): distinctions between 2D and 3D TIs; Weyl and Dirac semimetals; topological magnetic materials and vdW magnets; topological superconductors; ARPES (mapping of Brillouin zone): principles and data interpretation**. [10 Lectures]**
- **Quantum Transport & Hall Effects:** Ordinary, Anomalous, Spin, Topological, and Nonlinear Hall effects; symmetry restrictions in different Hall effects, driving force, materials, and key observables for each Hall effect; role of Berry curvature as an effective magnetic field in momentum space **[8 Lectures]**
- **Quantum Devices & Applications:** Sensing: NV centers & SQUIDs; spintronics: Dutta-Das transistor, MOSFET, SOT/STT-MRAM; computing: superconducting & topological qubits; quantum memory/batteries, quantum dots in various applications **[11 Lectures]**

Textbooks

1. David Vanderbilt, Berry Phases in Electronic Structure Theory: Electric Polarization, Orbital Magnetization and Topological Insulators, Cambridge University Press (2018).
2. Shun-Qing Shen, Topological Insulators (Dirac Equation in Condensed Matter), Springer, 2nd Edition (2017)
3. Sadamichi Maekawa, Sergio O. Valenzuela, Eiji Saitoh, and Takashi Kimura, Spin Current, Oxford University Press, 1st edition (2012).

Reference Books
1. Supriyo Datta, Quantum Transport: Atom to Transistor, Cambridge University Press (2005) 2. Gabriele Giuliani and Giovanni Vignale, Quantum Theory of the Electron Liquid, Cambridge University Press (2005) 3. M. Z. Hasan and C. L. Kane, Colloquium: Topological insulators, Rev. Mod. Phys. 82, 3045 (2010) DOI: 10.1103/RevModPhys.82.3045 4. B. Andrei Bernevig (with Taylor L. Hughes), Topological Insulators and Topological Superconductors Princeton University Press (2013).
Self-Learning Materials
1. https://onlinecourses.nptel.ac.in/noc25_ph29/preview 2. Ahn, E.C. 2D materials for spintronic devices. npj 2D Mater Appl 4, 17 (2020). https://doi.org/10.1038/s41699-020-0152-0 3. Maze et al., Nanoscale magnetic sensing with an individual electronic spin in diamond, Nature, 455, 644–647 (2008)

Title	General Theory of Relativity	Number	PHL7xx0
Department	Physics	L-T-P [C]	3-0-0 [3]
Offered for	BS Engineering Physics, MSc, PhD	Type	Elective
Prerequisite	Nuclear and Particle Physics, Relativistic Quantum Mechanics		

Objectives

The Instructor will:

1. Give the student a basic understanding of the General Theory of Relativity and its importance for modern physics.

Learning Outcomes

1. Will give detailed insight regarding theory and dynamics related to gravity.
2. The students will be able to apply the theory of general relativity in many fields of physics for example, in astrophysics and cosmology.

Contents

- **Preliminary discussions:**
  Review of special theory of relativity, vector and tensor, particle dynamics, electrodynamics, energy momentum tensor, relativistic hydrodynamics. Statement of the principle, gravitational forces, geodesic–affine connection, Newtonian limit **[8 Lectures]**
- **Tensor analysis:**
  Tensor algebra, tensor density, transformation of affine connection, covariant differentiation, gradient, divergence, curl, parallel transport **[11 Lectures]**
- **Curvature:**
  Curvature tensor, Bianchi identity, Ricci tensor, curvature scalar, Killing vectors, and symmetries.
  Einstein's field equation: Derivation of field equation, Schwarzschild solution, Birkhoff's theorem, geodesic equation in Schwarzschild space time, Precession of perihelion of mercury, bending of light rays, gravitational red shift **[12 Lectures]**
- **Stellar equilibrium and collapse:** Differential equation for stellar structure, White dwarfs, neutron stars, comoving coordinates, Schwarzschild blackholes, collapse to a blackhole **[8 Lectures]**

Textbooks

1. Weinberg, S., Gravitation and Cosmology: Principle and Applications of the General Theory of Relativity, 1st Ed., John Willey & Sons 1972.
2. Schutz, B., A first course in General relativity, 2nd Ed, Cambridge University Press 2009

Reference Book

1. Hartle, J. B., Gravity, 1st Ed. Pearson education 2011

Self-Learning Material

1. Einstein's General Theory of Relativity, Stanford University, Youtube https://youtu.be/hbmf0bB38h0?si=P6zmtSNPXPYLeQCD

Title	**High Energy Physics**	**Number**	**PHL7490**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS Engineering Physics, MSc, PhD	Type	**Elective**
Prerequisite	Nuclear and Particle Physics, Relativistic Quantum Mechanics		

Objectives

The instructor will:

1. Introduce fundamental particles, interactions, and underlying symmetry principles.
2. Develop conceptual and analytical understanding of particle interactions and gauge theories.
3. Provide a foundation for the Standard Model and exposure to current directions in high-energy physics

Learning Outcomes

Students will be able to:

1. Understand fundamental particles and their interactions, as well as the limitations of the Standard Model.
2. Develop a foundation for experimental and phenomenological research in high-energy physics with exposure to open problems.

Contents

- **Fundamentals of Particle Physics:** Fundamental particles and interactions, Symmetry principles and basic ideas of group theory, Conservation laws, Isospin and flavor symmetry, Color Quantum Number and Multiplet structure of hadrons **[7 Lectures]**
- **Quantum Electrodynamics:** Basic principles, Feynman diagrams, interaction vertices, QED scattering processes such as electron-electron, electron-positron annihilation, and electron-muon, U(1) gauge symmetry **[8 Lectures]**
- **Strong Interactions and Quantum Chromodynamics:** Introduction to Yang–Mills theory, Strong interaction, color charge, SU(3) symmetry, introduction to Quantum Chromodynamics, deep inelastic scattering, Bjorken scaling, parton model **[10 Lectures]**
- **Weak and Electroweak Interactions:** V–A structure, charged and neutral weak current processes, Cabibbo angle, GIM mechanism, CKM matrix and CP violation, SU(2) symmetry, electroweak unification, gauge bosons and fundamental fermions, spontaneous symmetry breaking and Higgs mechanism, limitations of the Standard Model: neutrino properties and oscillations **[14 Lectures]**

Textbooks

1. David J. Griffiths, Introduction to Elementary Particles, 2nd Edition, Wiley-VCH, 2008.
2. Francis Halzen and Alan D. Martin, Quarks and Leptons: An Introductory Course in Modern Particle Physics, Wiley, 1984.
3. Howard Georgi, Lie Algebras in Particle Physics: From Isospin to Unified Theories, 2nd Edition, Westview Press, 1999

Reference Books

1. T.-P. Cheng and L.-F. Li, Gauge Theory of Elementary Particle Physics, Oxford University Press.
2. An Introductory Course of Particle Physics by Palash B. Pal, CRC Press.

Additional References (Optional)

1. Donald H. Perkins, Introduction to High Energy Physics, 4th Edition, Cambridge University Press, 2000.

2. Michael E. Peskin and Daniel V. Schroeder, An Introduction to Quantum Field Theory, Westview Press, 1995.
3. Y. Grossman and Y. Nir, The Standard Model: From Fundamental Symmetries to Experimental Tests, Princeton University Press.

Self-Learning Materials

1. NPTEL Course on Nuclear and Particle Physics by Prof. Poulose Poulose, IIT Guwahati: https://nptel.ac.in/courses/115103101
2. NPTEL Course on Particle Physics and the Standard Model by Prof. Nirmal Raj, IISc Bangalore: https://nptel.ac.in/courses/115108642
3. MIT OpenCourseWare, Introduction to Nuclear and Particle Physics, https://ocw.mit.edu/courses/8-701-introduction-to-nuclear-and-particle-physics-fall-2020/

Title	**Particle Accelerators and Detectors**	**Number**	**PHL6xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS Engineering Physics, MSc in Physics	Type	**Elective**
Prerequisite			

Objectives

The instructor will:

1. To understand the fundamental principles of the interaction of radiation with matter and their role in signal formation for detection.
2. To learn the working principles and performance of major radiation detectors and accelerator systems.
3. To develop an understanding of modern experimental techniques, including data acquisition, signal processing, and applications in high-energy, nuclear, and medical physics.

Learning Outcomes

Students will be able to:

1. Explain the interaction of radiation with matter and the principles of radiation detection.
2. Describe the operation and applications of radiation detectors and particle accelerators.
3. Relate detection and accelerator techniques to modern experimental and research systems

Contents

- **Interaction of Radiation with Matter and Detection:** Energy loss mechanisms of charged particles, linear energy transfer, range and Bragg curve, interactions of charged particles and photons with matter, attenuation of radiation
  [6 Lectures]
- **Particle Accelerators:** Motion of charged particles in electromagnetic fields, principles of linear accelerators (LINACs), cyclotrons and synchrotrons, synchrotron radiation, basic ideas of beam control and RF cavities, and an illustrative example of the Large Hadron Collider and SuperKEKB. **[9 Lectures]**
- **Particle Detectors, Systems, and Readout:** General detector requirements and resolution of energy, position, and time; Various types of Detectors, overview of tracking and calorimetric detectors, Modern semiconductor detectors for fast timing and radiation-hard applications, basic detector electronics, principles of trigger systems, and overview of the data acquisition.
  [15 Lectures]
- **Applications at Modern High Energy Physics Experiments:** Overview of fixed-target and collider experiments, basic concepts of luminosity, cross-section, and event rate. Introduction to event generators, basic detector simulation using GEANT4, event reconstruction, and collider observables. **[9 Lectures]**

Textbooks

1. Leo, W. R. (1994). Techniques for Nuclear and Particle Physics Experiments: A How-to Approach. Springer.
2. Claus Grupen & Boris Shwartz (2008), Detectors in Particle Physics: A Modern Introduction, Springer
3. Edwin J. Wilson (2001), An Introduction to Particle Accelerators, Oxford University Press

Reference Books

1. Knoll, G. F. (2010). Radiation Detection and Measurement (4th ed.). Wiley.
2. Schwartz, M. D. (2014). TASI Lectures on Collider Physics. World Scientific.

3. Introduction to Experimental Particle Physics by Richard Clinton Fernow, Cambridge University Press
Self-Learning Materials
1. NPTEL: NOC: Accelerator Physics, https://nptel.ac.in/courses/115101132 2. MIT OpenCourseWare: Introduction to Nuclear and Particle Physics, https://ocw.mit.edu/courses/8-701-introduction-to-nuclear-and-particle-physics-fall-2020/pages/video-lectures/chapter-10--instrumentation/

Title	**Quantum Field Theory**	**Number**	**PHL6xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	MSc in Physics	Type	**Elective**
Prerequisite			

Objectives

This course aims to:

1. Provide the necessary theoretical foundation to understand the fundamental principles of quantum field theory, including the quantization of scalar, spinor, and gauge fields.
2. Develop the ability to apply canonical and field quantization methods to relativistic systems.
3. Introduce students to the role of symmetries and conservation laws in field theory.
4. Prepare students for advanced topics such as particle interactions and perturbation theory.

Learning Outcomes

Students will be able to

1. Understand interrelations between quantum fields, symmetry, and conservation laws.
2. Apply the techniques of Feynman rules and diagrams to various elementary scattering

Contents

- **Preliminary:**Lagrangian Formulation of Continuous System, Energy-Momentum Tensor, Generators, Functional Variable, Noether's Theorem, Example. **[4 Lectures]**
- **Scalar and Dirac field:**Equation of motion, Real field, Conserved quantities, Complex field, Gauge symmetry, charge, Canonical quantization, commutation relation, normal ordering, Propagator, Yukawa interaction and corresponding Feynman rules, decay rate of a scalar into a fermion/anti-fermion pair. **[10 Lectures]**
- **Electromagnetic Field:**Invariance under local gauge transformation of Dirac field, gauge charges, electromagnetic field, Lagrangian of electromagnetic field, equation of motion, problem with quantization, Modifying the classical Lagrangian, Quantization, Physical states, Propagator, Feynman rules for photons. **[10 Lectures]**
- **S-Matrix Theory and Feynman Diagram Techniques:**Example of interaction, Evolution operator, S-matrix, Wick's theorem. Matrix element, Feynman amplitude, Feynman rules, Virtual particle, example of scattering, Example of decay rate calculation, Scattering cross section. **[15 Lectures]**

Textbooks

1. Lahiri & Pal, A first book of quantum field theory, Narosa, 2007
2. Schwartz, M. D., Quantum Field Theory and the Standard Model, Cambridge University Press, 2013.
3. Weinberg, S., The Quantum Theory of Fields, Vol. I, Cambridge University Press, 2008.

Reference Book

1. Peskin, M. E., and Schroeder, D. V., An Introduction to Quantum Field Theory, Frontiers in Physics, 1995.
2. Lewis H. Ryder, Quantum Field Theory, Cambridge University Press, 2nd Edition, 1996.
3. Das, A., Lectures on Quantum Field Theory, World Scientific Publishing Co. Inc., 2009.

Self-Learning Materials

1. Tripathy, P. K., Quantum Field Theory, IIT Madras, https://nptel.ac.in/courses/115106065/
2. Tong D., Lectures on Quantum Field Theory, University of Cambridge, http://www.damtp.cam.ac.uk/user/tong/qft.html

Title	**Laser Technologies and Ultrafast Optics**	**Number**	**PHL7330**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS Engineering Physics, MSc, PhD	Type	**Elective**
Prerequisite			

Objectives

1. Understand laser fundamentals, rate equations, and resonator dynamics.
2. Analyze laser operation, coherence, modes, and pulse generation techniques.
3. Explore ultrafast optics, pulse shaping, and advanced laser systems.

Learning Outcomes

1. Explain laser principles, threshold conditions, and line broadening mechanisms.
2. Apply concepts of mode locking, Q-switching, and beam propagation.
3. Analyze ultrashort pulse generation, measurement, and modern laser applications.

Contents

- **Fundamentals of Lasers:** Spontaneous and stimulated processes, pumping, and relaxation, Einstein coefficients, Laser oscillator, Laser characteristics, Light amplification, The Threshold Condition, Laser rate equations, Line broadening mechanisms, modes and mode selection, Laser Line width and broadening, Q-Switching, Stability condition for resonator, Quality factor, Mode locking, Gaussian Beams and optical resonators. **[14 Lectures]**
- **Types of Lasers and Applications:** Basics and technologies of gas lasers, liquid lasers, solid-state lasers, Fiber lasers, semiconductor lasers with examples. Two-beam interference, Temporal coherence and line-width, Michelson interferometer (LIGO), Sagnac interferometer**. [8 Lectures]**
- **Ultrashort pulses: Mode locking:** Active mode locking, Passive mode locking, Ultrashort pulse (nanosecond, picosecond, femtosecond and attosecond) generation and propagation, Chirping and Pulse compression, laser amplifiers, interferometric autocorrelation for pulse measurement, collinear and non-collinear methods, YAG Lasers, State-of-art-lasers (Ti: Sapphire Lasers and Fiber Lasers). Terahertz generation (Optical rectification in a nonlinear medium), Transient absorption/reflection spectrometer **[17 Lectures]**

Textbooks

1. Sigman, A., Lasers, Mill Valley, Calif. University Science Books, 1986
2. Rulliere, C., Femtosecond Laser Pulses, Springer, 2003.
3. Yariv A & Pochi, Y., Photonics, Oxford University Press, 2006.
4. Optical Electronics; Ajoy Ghatak and K. Tyagrajan, Cambridge University Press, Cambridge, 1989.

Reference Books

1. Shen. Y. R., The Principles of Nonlinear Optics, Wiley-Interscience, 2002.
2. Dexheimer. S. L., Terahertz Spectroscopy, CRC Press, 2008.

Self-Learning Materials

1. Unique properties of lasers and their applications, Manabendra Chandra, https://nptel.ac.in/courses/104104085/.
2. Lectures of Rick Trebino https://frog.gatech.edu/talks.html

Preparatory Course Material

1. Understanding Lasers and Fiber Optics, Prof. Shaoul Ezekiel https://ocw.mit.edu/resources/res-6-005-understanding-lasers-and-fiberoptics-spring2008.

Title	**Nonlinear Optics**	**Number**	**PHL6xx0**
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS Engineering Physics, MSc in Physics	Type	**Elective**
Prerequisite	Basic Optics Foundation		

Objectives

1. Understand fundamentals of nonlinear optical response and susceptibilities.
2. Analyze second- and third-order processes with phase matching.
3. Explore nonlinear wave propagation and photonic applications.

Learning Outcomes

1. Explain and derive key nonlinear optics concepts and equations.
2. Evaluate SHG, THG, SPM, and FWM.
3. Apply concepts to modulators, solitons, and supercontinuum generation.

Contents

- **Fundamentals of Nonlinear Optics:** Linear vs nonlinear optical response, microscopic origin of nonlinearity, Nonlinear polarization expansion and susceptibilities, Kramers-Konig relations, Wave equation in anisotropic and nonlinear media. **[10 Lectures]**
- **Second-Order Nonlinear Optics:** Second-order susceptibility and symmetry, Sum and Difference Frequency Generation (SFG/DFG), Second Harmonic Generation (SHG), Electro-optic effect, Phase matching and coherence length, Birefringent and quasi-phase matching, Optical parametric amplification and oscillation (OPA/OPO). **[11 Lectures]**
- **Third-Order Nonlinear Optics:** Optical Kerr effect and nonlinear refraction, Third Harmonic Generation (THG), Self-phase modulation (SPM), Four-wave mixing (FWM), Self-focusing and beam propagation effects. **[10 Lectures]**
- **Nonlinear Wave Propagation:** Optical solitons, Supercontinuum generation, Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering (SBS), Multiphoton absorption **[8 Lectures]**

Textbooks

1. Robert. W. Boyd, Nonlinear Optics, Academic Press, Elsevier, 2023
2. Yariv, Optical electronics in modern communications, Oxford University Press, 1997
3. A. K. Ghatak and K. Thyagarajan, Optical electronics, Cambridge University Press, 1991

Reference Books

1. Y.R. Shen, Principles of Nonlinear Optics, Wiley Classics Library, 2002
2. Saleh, B. E. A. and Teich, M. C., Fundamentals of Photonics, Wiley, 2018
3. G. S. He and S. H. Liu, Physics of Nonlinear Optics, World Scientific 2000
4. P. N. Butcher and D. Cotter, The elements of Nonlinear Optics, Cambridge University Press, 1990.

Self-Learning Materials

1. NPTEL course by Prof. K.C. Rustagi, Prof. B.P. Singh, IIT Bombay," Nonlinear Optics" https://nptel.ac.in/courses/115101008
2. NPTEL course by Prof. K. Thyagarajan, IIT Delhi, "Quantum Electronics" https://nptel.ac.in/courses/115102022

Title	Fiber-Optic Communication	Number	PHL7xx0
Department	Physics	L-T-P [C]	3-0-0 [3]
Offered for	BS in Engineering Physics, MSc, PhD	Type	Elective
Prerequisite	Basic Optics Foundation	Antirequisite: Optical fiber communication and Optical communication systems	

Objectives

1. Understand optical communication principles, modulation, and multiplexing techniques.
2. Analyze light propagation in optical fibers and related losses/dispersion.
3. Explore fiber devices, system performance, and coherent communication

Learning Outcomes

1. Explain fiber modes, dispersion, and nonlinear effects in communication systems.
2. Evaluate performance metrics like BER, power budget, and receiver sensitivity.
3. Apply concepts to optical transmitters, amplifiers, and modulation schemes.

.

Contents

- **Introduction of basic communication theory:** Intensity Modulation, Phase modulation, Pulse Modulation, Wavelength Division Multiplexing light-wave systems and components, Time Division Multiplexing. **[5 Lectures]**
- **Ray and Modal analysis of step and graded index multimode fibers,** Weakly guiding approximation, Single mode fibers, Power confinement and Mode cutoff. Fabrication of Optical fiber, Loss mechanism in optical fiber. **[8 Lectures]**
- **Pulse dispersion and chirping in single-mode fibers,** Dispersion compensation mechanisms, Nonlinear effects in optical fibers, Solitons in Optical fiber. **[10 Lectures]**
- **Fiber based devices:** Er-doped fiber amplifiers, Fiber Bragg gratings, Fiber Lasers, Optical Fiber sensors. **[7 Lectures]**
- **Noise and receiver sensitivity,** Bit Error Rate, Power budget, Rise-time budget, Power penalty. Coherent light-wave systems: Amplitude-Shift-Keying, Frequency-Shift-Keying, Phase-Shift-Keying. **[9 Lectures]**

Textbooks

1. H. Taub and D. L. Schilling, G. Saha, Principles of Communication Systems, McGraw-Hill, (2007).
2. G. P. Agarwal, Fiber Optic Communication Systems, John Wiley Sons (1997).
3. J. M. Senior, Optical Fiber Communication, Prentice Hall (1999).
4. A. K. Ghatak & K. Thyagarajan, Introduction to Fiber Optics, Cambridge University Press (1998).

Reference Books

1. I. P. Kaminov & T. L. Koch, Optical Fiber Telecommunications III A & IV A, Academic Press, (1997).
2. F. Allard, Fiber Optics Handbook for Engineers and Scientists, McGraw-Hill, New York, (1990).
3. G. Keiser, Optical Fiber Communications, McGraw Hill (2000).

Self-Learning Material

1. NPTEL course by Prof. Deepa Venkitesh, IIT Madras, “Fiber Optic Communication Technology” nptel.ac.in/courses/108106167

Title	Device Independent Quantum Technologies	Number	QCL7330
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	MSc in Physics, PhD	Type	**Elective**
Prerequisite			

Objectives

The Instructor will:

1. Impart the foundational mathematical framework for designing device-independent quantum technologies.
2. Discuss the state-of-the-art device independent technologies that leverage Bell nonlocality.

Learning Outcomes

The students are expected to have the ability to:

1. Understand how the fundamental laws of nature (here Bell's theorem) empower cutting-edge quantum technologies.
2. Be able to apply Bell's theorem to design device independent quantum technologies.

Contents

- **Introduction:**
  Recap of linear algebra, Postulates of quantum mechanics, EPR paradox **[4 Lectures]**
- **Review of Prerequisites for Device Independent (DI) Technologies:**
  Bell Nonlocality: Quantum formalism for qubit, Qubit deterministic model (Bell model), Bell's theorem and its implication, Quantum violation of Bell inequality - Refutation of Local Hidden Variable Theory, Nonlocality of PR correlation and its comparison with quantum nonlocality, Applications of Bell nonlocality: Device Independent Technology – motivation and definition. **[7 Lectures]**
- **Device Independent (DI) Technologies:**
  Certification of Entanglement: Entanglement witness, DI entanglement witness. **[4 Lectures]**
  Certification of Randomness: Importance of randomness, Pseudo-random numbers, DI randomness certification. **[5 Lectures]**
- **Witnessing System Dimension:** CGLMP inequality, Hardy's nonlocality paradox, DI certification of system dimension. **[6 Lectures]**
  Self-testing of quantum states and measurements. **[4 Lectures]**
  Cryptography: BBM92 protocol and its device dependency, Device independent secret key generation by PR correlation and possibility of extending it to quantum regime, DI Quantum Key Distribution. **[7 Lectures]**
- **Other Real-world Applications of Bell Nonlocality:**
  Quantum advantage in solving Bayesian game theoretic problems. **[2 Lectures]**

Textbooks

1. Nielsen, M. A. and Chuang, I. L., Quantum Computation and Quantum Information, 10th edition, Cambridge University Press (2000).
2. Asher Peres, Quantum Theory: Concepts and Methods (Fundamental Theories of Physics), Springer Science & Business Media (1995)

3. Jean-Daniel Bancal, On the Device-Independent Approach to Quantum Physics: Advances in Quantum Nonlocality and Multipartite Entanglement Detection, Springer International Publishing (2013)
Reference Books
1. Bell nonlocality; Nicolas Brunner, Daniel Cavalcanti, Stefano Pironio, Valerio Scarani, and Stephanie Wehner; Rev. Mod. Phys. 86, 419 (2014). 2. N. David Mermin, Hidden variables and the two theorems of John Bell; Rev. Mod. Phys. 65, 803 (1993). 3. Valerio Scarani, The device-independent outlook on quantum physics (lecture notes on the power of Bell's theorem), Acta Physica Slovaca 62, 347 (2012); arXiv:1303.3081

Title	Open Quantum Systems	Number	PHL7480
Department	Physics	L-T-P [C]	3-0-0 [3]
Offered for	MSc in Physics, PhD	Type	Elective
Prerequisite	Knowledge of basic Quantum and Statistical Mechanics		

Objectives

The Instructor will:
1. Help in understanding the basic ideas of open quantum systems.
2. Help in grasping the basic models of dissipative quantum statistical mechanics.

Learning Outcomes

The students are expected to have the ability to:
1. Grasp the concepts of open quantum systems in various regimes.
2. Make contact of theoretical developments with experimental advances

Contents

- **Introduction to quantum statistical mechanics:** Density matrices; BCH Theorem; harmonic oscillator. **[6 Lectures]**
- **Introduction to path integrals:** Partition function as a path integral; density matrix evolution as a path integral. **[6 Lectures]**
- **Master Equations:** Liouville equation; Langevin equation; Fokker-Planck equation; Boltzmann equation; quantum dynamical semigroups and Lindblad equations; projection operator techniques. **[7 Lectures]**
- **Dissipative Harmonic Oscillator:** Lindblad approach; quantum Brownian motion. **[6 Lectures]**
- **Dissipative Two-State System:** Spin-Boson Model. **[4 Lectures]**
- **Quantum Thermodynamics and Heat Engines:** Interface of quantum mechanics with thermodynamics; impact of quantum mechanics on heat engines. **[4 Lectures]**
- **Interface with Quantum Information:** Role of open systems in quantum information; geometric phase; quantum cryptography. **[6 Lectures]**

Textbooks

1. Banerjee, S, (2018), Open Quantum Systems: Dynamics of Nonclassical Evolution, Springer, 2018
2. Breuer, H., -P., (2007), The Theory of Open Quantum Systems, Oxford University Press, 2007

Reference Book

1. Weiss, U., (2012), Quantum Dissipative Systems, World Scientific, 2012.

Self-Learning Material

1. Fraas, M., Theory of Open Quantum Systems, ITP Lecture Archive.

Title	Quantum Optics and Engineering	Number	PHL6xx0
Department	Physics	L-T-P [C]	**3-0-0 [3]**
Offered for	BS in Engineering Physics, MSc in Physics	Type	**Elective**
Prerequisite			

Objectives

The Instructor will:

1. Provide various aspects of nonclassical/quantum light and its manifestation.
2. Basic understanding of novel applications of light matter interaction.
3. Introduce various aspects of Photon distribution and its relevance to applications in quantum optics and engineering

Learning Outcomes

The students are expected to have the ability to:

1. Understanding the fundamental principles of quantum optics.
2. The students will become familiar with concepts such as squeezing, lasing and atom optics
3. Appreciate and apply quantum optics in newer frontiers of physics.

Contents

- **Introduction to Lasers [3 Lectures]**
- **Quantum theory of radiation:** Quantum theory of the free electromagnetic field **[5 Lectures]**
- **Coherent and squeezed states of radiation:** Radiation from a classical current; coherent states; squeezed state and its detection. **[6 Lectures]**
- **Generation of Entangled Photons and Photon Statistics:** Spontaneous Parametric Down-Conversion (SPDC) process, Entangled photon detection, HOM and Franson Interferometer, Hanbury-Twiss Interferometer **[7 Lectures]**
- **Quantum distribution theory:** Q, P and W distributions **[5 Lectures]**
- **Photon-photon interferometry:** Photon detection and quantum coherence functions **[5 Lectures]**
- **Atom-field interaction:** Atom-field interaction Hamiltonian; density matrix of two-level atom with a single mode field, Lasing without inversion, coherent trapping, electromagnetically induced transparency: Basic concepts of these quantum interference phenomena. **[8 Lectures]**

Textbooks

1. Mandel, L. and Wolf, E., (1995), Optical Coherence and Quantum Optics, Cambridge University Press, 1995.
2. Scully, M. O. and Zubairy, M. S., (2000), Quantum Optics, Cambridge University Press, 1997.
3. Loudon, R., (2000), The Quantum Theory of Light, Oxford University Press, 2000.

Reference Book

1. Agarwal, G. S., (2012), Quantum Optics, Cambridge University Press, 2012.

Self-Learning Material
1. Satyanarayana, M. V., Quantum Optics, NPTEL Course Material, Department of Physics, IIT Madras, Link https://nptel.ac.in/syllabus/115106067/