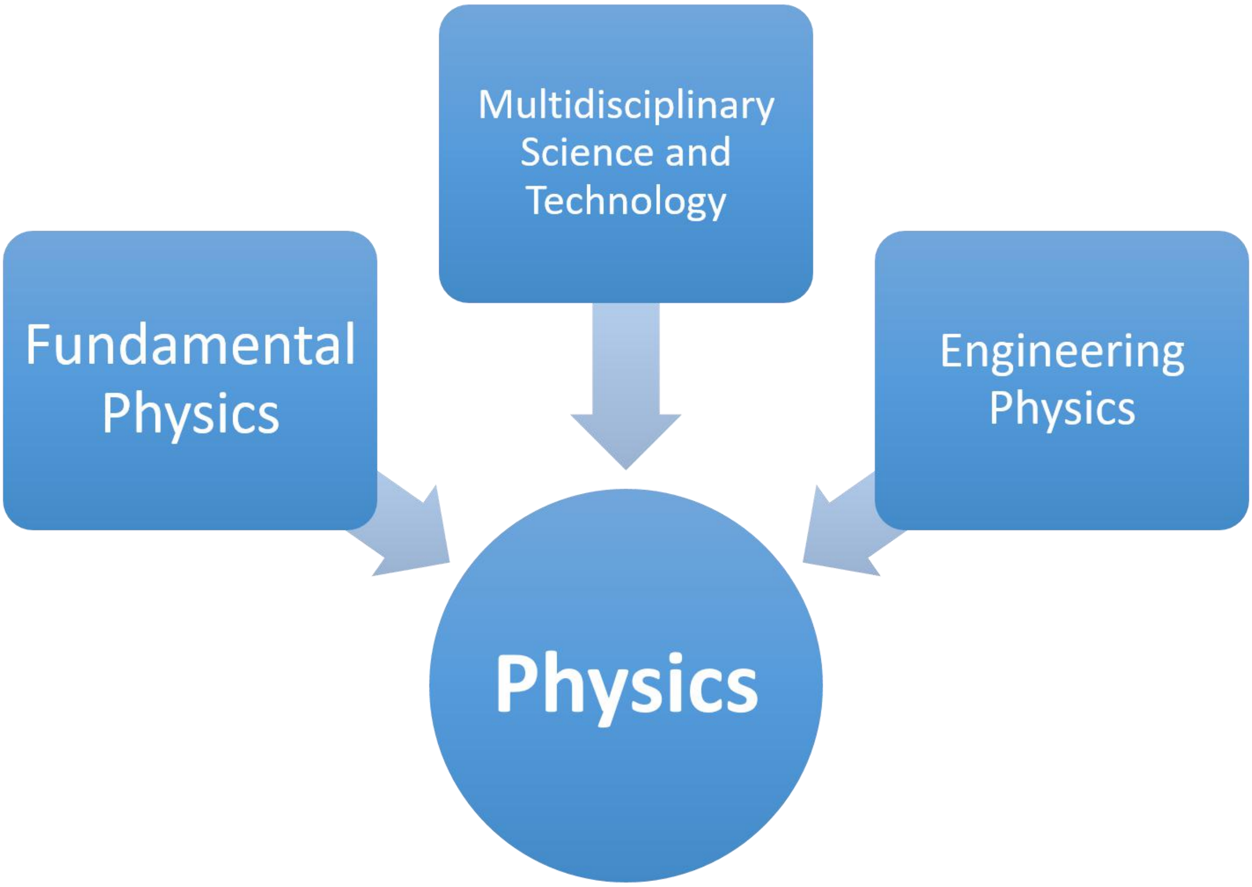
Department of Physics
Indian Institute of Technology Jodhpur

PhD Program

Elective Courses

July 2019

Topic Cloud


Multidisciplinary Science and Technology
Fundamental Physics
Engineering Physics
Physics

Title	**Computational Physics**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

1. To incorporate modern computational skills into the scientific problem solving paradigm.

Learning Outcomes

1. The successful students will become familiar with commonly used numerical techniques to solve problems in physics.

Contents

(Fractal 1) PHL7XX1 Numerical Methods-I [1-0-0] Solution of algebraic and transcendental equations: Iterative, bisection and Newton Raphson methods, Solution of simultaneous linear equations: Matrix inversion method (14 lectures)

(Fractal 2) PHL7XX2 Numerical Methods-II [1-0-0] Interpolation: Newton and Lagrange formulas, Numerical differentiation, Numerical Integration, Trapezoidal, Simpson and Gaussian quadrature methods, Least-square curve fitting, straight line and polynomial fits. (8 lectures)

Numerical solution of ordinary differential equations: Euler and Runge-Kutta methods. (6 lectures)

(Fractal 3) PHL7XX3 Simulations: Numerical Methods [1-0-0] Generation of uniformly distributed random integers, Statistical tests of randomness, Monte-Carlo evaluation of integrals and error analysis, Non-uniform probability distributions, Importance sampling, Rejection method, Metropolis algorithm, Molecular diffusion and Brownian motion as random walk problems and their Monte Carlo simulation. (8 lectures)

Quantum Simulations: Time-independent Schrodinger equation in one dimension (radial or linear equations), Scattering from a spherical potential, Born Approximation, Bound State solutions. (6 lectures)

The students will be assigned computer laboratory work based on the above syllabus.

Textbook

1. Koonin, S. E. and Meredith, D. C., Computational Physics, Addison-Wesley, 1990.
2. Tao Pang, An Introduction to Computational Physics, Cambridge Univ. Press, 1997.

Self-Learning Material

1. https://nptel.ac.in/courses/115104095/
2. https://nptel.ac.in/syllabus/115106060/

Reference Course Material

1. Landau, R. H. and Mejia, M. J. P., Computational Physics, John Wiley, 1997.
2. Thijssen, J. M., Computational Physics, Cambridge Univ. Press, 1999.

Title	**High Energy Physics**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3-0-0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide background to understand the concepts of particle physics.
2. Acquaint with techniques used in recent neutrino telescopes.

Learning Outcomes

The students are expected to have the ability to:

1. Understand concepts of Feynman calculus, details of QED and weak interactions.
2. Learn results and future prospects associated with recent neutrino observatories.

Contents

Quantum field theory (QFT): Classical field theory: Lagrangian and Hamiltonian formalisms; Noether's theorem. This introduces the concept of symmetries in a consistent fashion. Need for quantum field theory: particles and fields, Charge conjugation and C Parity, Interaction of a spin-0 particle with an electromagnetic field. (5 Lectures)

Klein Gordon Equation: KG equation, The non-relativistic limit, Free spin-0 particles, The charged KG field, Lagrange density and energy-momentum tensor of the KG-field, Lorentz Invariance of the KG equation. (6 Lectures)

Gauge invariance of the couplings, Lagrange density and energy-momentum tensor for a KG particle in an electromagnetic field, Negative Energy Solutions, Antiparticles, Gamma-matrices and their properties, Covariance of Dirac equation, Charge conjugation, Parity & Time reversal invariance, Plane wave solution, Two component theory of neutrino, Spin and Helicity. (6 Lectures)

Quantum Electrodynamics (QED): Feynman rules for QED, Electron-Muon scattering, Electron-Electron scattering, Compton scattering, Casimir's trick, Mott and Rutherford scattering, Pair annihilation. (9 Lectures)

Weak Interactions: Parity violation and the V-A form of the weak interaction, interpretation of the coupling G, Nuclear β-decay, Muon and pion decay, Charged current neutrino-electron scattering, neutrino quark scattering, Observation of weak neutral current, Neutral current neutrino-quark scattering, Cabibbo angle. (10 Lectures)

Neutrino Telescope: Interaction of Ultra-High Energy (UHE) neutrinos with cosmic microwave background, Askaryan effect, Relic neutrinos, Cherenkov based neutrino detectors, Antarctic Impulsive Transient Antenna (ANITA) experiment, Antarctic Muon and Neutrino Detector Array (AMANDA) and Ice Cube experiments, ANTARES telescope, Next generation neutrino telescopes. (6 Lectures)

Text Books

1. Griffiths, D., *Introduction to Elementary Particles*, Wiley-Vch 2010.
2. Giunti, C. and Kim, C.W., *Fundamentals of neutrino physics and Astrophysics*, Oxford University Press; 1st edition 2007.

Self-Learning Material

1. Guth A., Lecture Notes MIT Course No. 8.323, *Relativistic Quantum Field Theory I*, Spring Sem., 2008.

Preparatory Course Material

1. Sakurai,J.J., *Advanced Quantum Mechanics*, Addison-Wesley 1967.

Title	**Introduction to Space Science**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3-0-0 [2]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide introduction to space science.
2. Provide introduction of cosmology

Learning Outcomes

The students are expected to have the ability to:

1. Grasp different physical aspects of space science.

Contents ((i) Introduction to Astronomy, (ii) General theory of relativity and Cosmology)

PHL7XX1 (Introduction to Astronomy) [1-0-0]

Basic *observation* of space: Celestial coordinates, brightness, absolute and relative *magnitude, sources of astronomical information, astronomy in different bands of electromagnetic radiation. (4 Lectures)*

X-ray Astronomy: X-ray emissions- Thermal, non-thermal: Bremsstrahlung, Synchrotron, X-ray satellite detectors. Properties of stars: Colour and surface temperature, stellar spectra, the Hertzsprung-Russel diagram, size, mass and temperature of stars. Celestial objects: The Sun, Neutron stars, classification of Galaxies, Exotic matter in space: dark matter. (10 Lectures)

PHL7XX2 (General Theory of Relativity and Cosmology) [2-0-0]

General theory of relativity: Principle of equivalence–gravitational forces–geodesic–Tensor algebra–tensor density–Killing vectors and symmetries Einstein's field equation. (8 lectures)

Schwarzschild solution–Birkhoff's theorem - geodesic equation in Schwarzschild space time–Precession of perihelion of mercury - gravitational frequency shift - Shapiro delay. (4 lectures)

Cosmology: Olber's paradox: Why is the sky dark at night? Expanding universe and Hubble's law, Finiteness and infiniteness of the universe. Evolutionary view of the Universe: The paradox of thermal death, Thermodynamics of the expanding universe (Radiation under adiabatic expansion, Particles under adiabatic expansion), the negative thermal capacity of the solar system, structure formation. (10 Lectures)

Thermal history of the universe: Cosmic microwave background. Cosmological Models: Friedmann-Robertson Walker equation, Open, flat and closed universe, dark energy. (6 Lectures)

Text Books

1. Narlikar, J. V., *An introduction to cosmology*, Cambridge University Press 2002.
2. Carroll, S. M., *Spacetime and Geometry*, Pearson India Education Services 2018.
3. M.Longair, High Energy Astrophysics vol 1, Cambridge University Press.

Self-Learning Material

1. Bertschinger E. & Taylor E. F., Lecture Notes MIT Course No. 8.224, *General Relativity and Astrophysics*, Spring Sem., 2003.
2. Rappaport, S. A., and Elliot, J., *Introduction to Astronomy*, https://dspace.mit.edu/handle/1721.1/34941

Preparatory Course Material

1. https://nptel.ac.in/courses/115105046/.

Title	**Nanoscience and Nanotechnology**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Introduce physics of low dimensional objects and discuss changes in mechanical, electronic, magnetic and optical properties at reduced dimensions.

Learning Outcomes

The students are expected to have the ability to:

1. Obtain a flavor of nanoscience and nanotechnology and develop insight into the physical concepts behind nano-scale phenomena.
2. Understand few nano-structures for practical device applications will also be discussed.

Contents

PHL7XX1 (Basics of Nanomaterials, Nanoparticles and Clusters) [1-0-0]

(a) Quantum Confinement and definition of Nano: Electron states, energy bands and density of states for quantum Systems; Heterojunctions, Type I and Type II Heterostructures, Quantum wells, Quantum wires and Quantum dots, Effective Mass. (5 lectures)

(b) Nanoparticles and Clusters: Metal nanoclusters, Magic numbers, Geometric structures, Electronic structures, Magnetic and semiconducting clusters and nanoparticles, Rare gas and molecular clusters, Carbon nanostructures, 2-D materials. (9 lectures)

PHL7XX2 (Nanotechnology for Energy) [1-0-0]

(a) Energy generation/storage: Dye sensitized solar cells, Quantum Dot sensitized solar cell, electrode materials for rechargeable batteries, supercapacitors, fuel cells, Hydrogen storage in carbon nanomaterials, nanocatalyst. (10 lectures)

(b) Nanotechnology in data storage: Magnetic hard disk drive, Magnetic read and write head, Flash memory, Solid state drive, Future of data storage. (4 lectures)

PHL7XX3 (Nanotechnology for Water and Healthcare) [1-0-0]

(a) Nanotechnology in Water/Air purification: Nanomaterials for water and air purification, Water desalination using carbon nanomaterials. (8 lectures)

(b) Nanotechnology in healthcare: Diagnostics using nanomaterials, i.e., biosensors, drug delivery using magnetic nanoparticles, magnetic hyperthermia for cancer treatment. (6 lectures)

Textbook

1. Poole C.P. Jr. and Owens F.J., *Introduction to nanotechnology*, Wiley-Interscience, 2003
2. Shong C.W., Haur S.C. and Wee A. T. S., *Science at the nanoscale*, CRC Press, 2009
3. Davis J.H., *The physics of low-dimensional semiconductors*, Cambridge Uni Press, 2012

Self-Learning Material

1. Quereshi, M., Department of Chemistry, IIT Guwahati, https://nptel.ac.in/syllabus/104103019/.
2. Online review papers in various journals.

Preparatory Course Material

1. Balani, K. and Subramaniam, A., Department of Material Science and Engineering, IIT Kanpur, NPTEL Course: https://nptel.ac.in/syllabus/118104008/.

Title	**Advanced Condensed Matter Physics**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide training and knowledge to condensed matter physics of complex systems including both fundamental as well as applied aspects.

Learning Outcomes

1. The students are expected to have the ability to understand magnetism, ferroelectricity, opto-electronic properties and 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. (11 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, magnetoresistance, Heterostructures, point defects, dislocations, Burger vectors, dislocation and crystal growth. (10 lectures)

Soft Matter: Time and length scales, Colloids, polymers, liquid crystals and ionic soft matter, phase transition in soft matter systems. (11 lectures)

Textbook

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.

Online Course Material

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	**Introduction to Material Characterization**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide an introduction to various characterization techniques for materials and devices

Learning Outcomes

The students are expected to have the ability to:

1. Obtain basic idea of various techniques used to determine structural, compositional, and functional properties such as electrical, magnetic and optical properties of materials
2. Appreciate the distinction between diffraction, imaging and spectroscopic based techniques for material characterization

Contents

PHL7XX1 *(Material Characterization by Diffraction and Electron Microscopy) [1-0-0]*

(a) Introduction and Necessity of Material Characterization: Structural and functional properties of materials (2 lectures)

(b) 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 (9 lectures)

(c) Introduction to Electron Microscopy: Scanning Electron Microscopy (SEM). (3 lectures)

PHL7XX2 *(Characterization of Materials by Microscopy and Spectroscopy) [1-0-0]*

(a) Optical microscopy, Polarization Microscopy, Fluorescence Microscopy, Phase contrast Microscopy, Scanning Tunneling Microscopy (STM) and Atomic Force Microscopy (AFM)

(b) Spectroscopic based Characterization: UV-Vis-NIR, FTIR, Photoluminescence (14 lectures)

PHL7XX3 *(Functional Properties of Materials) [1-0-0]*

(a) Electrical properties: Resistivity (Four probe and Van der Pauw method), Magnetoresistance

and Hall effect. (5 lectures)

(b) 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). (9 lectures)

Textbook

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

Self-Learning Material

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	**Magnetism and Superconductivity**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Introduce magnetism and superconductivity principles and their applications
2. Impart advanced concepts of magnetic materials in modern research

Learning Outcomes

The students are expected to have the ability to:

1. Understand atomic origin of spin and magnetism and get insight into manifestation of quantum mechanics at macro level.
2. Grasp in-depth knowledge of magnetism and its modern application

Contents

Brief introduction: Magnetic moment, magnetic dipole, Magnetization and angular momentum (2 lectures)

Isolated magnetic moment: Atom in a magnetic field, Susceptibility, Diamagnetism, Paramagnetism, Semiclassical treatment of paramagnetism, Langevin and Brillouin Theory Ground state of ion and Hund's rule, spin-orbit coupling L-S and j-j coupling, Adiabatic Demagnetization (8 lectures)

Magnetic interactions: Dipole-dipole, Exchange, Origin of exchange, direct, indirect and anisotropic exchange (4 lectures)

Magnetic Order: Ferromagnetism, Weiss model, Antiferromagnetism, Weiss model of antiferromagnetism, Ferrimagnetism, Helical order, Spin glass (5 lectures)

Concept of broken order and symmetry, Landau theory of ferromagnetism, Phase transition, Magnons, Spin waves (4 lectures)

Magnetic domains, domain walls, Anisotropy, Domain observation and Hysteresis (5 lectures)

Band Magnetism: Free electron model, Pauli paramagnetism, Stoner criterion, Landau levels, Landau diamagnetism (5 lectures)

Device applications: Magnetic data storage, magneto-optic effect, magnetic semiconductors, Giant Magneto Resistance, Spintronics devices (4 lectures)

Superconductivity and related effects, superconducting materials and their applications, Josephson junction and SQUID (5 lectures)

Textbook

1. Culity B. D. and Graham, C. D., *Introduction to magnetic materials,* Addison-Wesley, 1972
2. Blundell, S., *Magnetism in Condensed Matter,* Oxford University Press, 2001
3. Annett, J. F., *Superconductivity, Superfluids and Condensates*, Oxford University Press, 2004

Self-Learning Material

1. O'Handley, R., *Magnetic Materials*, MIT Open Course-Materials Science and Engineering, https://ocw.mit.edu/courses/materials-science-and-engineering/3-45-magnetic-materials-spring-2004/index.htm

Title	**Electronic Transport in Mesoscopic Systems**	Number	PH7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

To understand the electronic transport mechanism in mesoscopic systems.

Learning Outcomes

Nanodevice fabrication will be much easier than before.

Contents

An atomistic view of electrical resistance: Energy level diagram, what makes electrons flow, the quantum of conductance, potential profile, Coulomb blockade, towards Ohm's law. (8 lectures)

Schrodinger equation and Self-consistent field: Hydrogen atom, Method of finite differences, the self-consistent field procedure, relation to the multi-electron picture, bonding, multi-electron picture, basis functions as a computational tool, basis function as a conceptual tool, equilibrium density matrix. (10 lectures)

Band Structure: Examples of 1D and 2D solids, common semiconductors, effect of spin-orbit coupling, Quantum wells, wires, dots, and nanotubes, density of states, minimum resistance of a wire, velocity of a sub-band electron. (10 lectures)

Capacitance and Level broadening: Model Hamiltonian, electron density/density matrix, quantum vs electrostatic capacitance, open systems, local density of states, lifetime, what constitutes a contact? (5 lectures)

Coherent and Non-coherent transport: Density matrix, inflow/outflow, transmission, overview of non-coherent transport, why does an atom emit light? Inflow/outflow, some ideas on phonons, atoms to transistor, quantum transport equations, physics of Ohm's law, where is the heat dissipated? Where is the voltage drop? (9 lectures)

Textbook

1. Datta, S., *Quantum transport: atoms to transistor*, 2011, 2nd ed. Cambridge University

Reference Books

1. Zwanzig, R., *Non-equilibrium statistical mechanics*, Oxford University Press

Online Course Material

1. Datta, S., *Fundamentals to Nanoelectronics*: https://nanohub.org/courses/fon1

Title	**Physics of Solar Cells**	Number	PH7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Make the students understand the physical principle behind different types of solar cells.
2. Make the students understand the role of quality of light, types of materials, and device fabrication techniques.
3. Make the students understand the inexpensive ways to fabricate the solar cells.

Learning Outcomes

The students are expected to have the ability to:

1. Fabricate unconventional solar cells.
2. Increase the efficiency of the solar cells by applying the theoretical knowledge.

Contents

Basic Concepts of Solar Cell: PV cells and modules, photocurrent and quantum efficiency, open circuit voltage, short circuit current, parasitic resistance (3 lectures)

Role of light: Solar resources, Equilibrium condition under illumination, available work, photocurrent, dark current. (4 lectures)

Properties of semiconductor: bands in crystals, density of states, electron distribution function, electron and hole densities, impurities and doping, drift current, diffusion current. (8 lectures)

Generation and Recombination: semiconductor transport equations, generation and recombination, photogeneration, types of recombination. (5 lectures)

Junction: Origin of photovoltaic action, metal semiconductor junction, ohmic contacts, p-n junction, p-i-n junction, p-n heterojunction, junctions in organic materials. (6 lectures)

Analysis of p-n junction: formation of p-n junction, calculation of depletion width, calculation of carrier and current densities, p-n junction in dark, p-n junction under illumination, p-n junction as a photovoltaic cell. (8 lectures)

Monocrystalline Solar Cells: Materials and Design, silicon material properties, band structure and optical absorption, doping, recombination and carrier transport. (3 lectures)

Thin film solar cells: Materials, amorphous silicon, defects in amorphous material, absorption, doping, stability, design of the solar cell. (3 lectures)

Strategies for high efficiency: multiple band gap, tandem cells, principles of cooling and hot carrier solar cell, impact ionization solar cells. (2 lectures)

Textbook

1. J., Nelson, *The Physics of Solar Cells*, Imperial College Press, (2003).

Reference Books

1. P.,Wurfel, U., Wurfel, (2016), *Physics of Solar Cell,* Willey VCH.
2. S.,Fonash, (2010), *Solar Cell Device Physics*, Academic Press.

Online Course Material

1. Buonassisi, T., *Fundamentals of Photovoltaics*, 2011, MIT OpenCourseWare : http://ocw.mit.edu/2-627F11

Title	**Fundamentals of Plasma and Fusion Science**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. present the fundamental principles of basic plasma and plasma behavior by pointing out specific plasma properties useful in technological applications.
2. Also, provide an overview of fusion plasma science and its consequences in the 21st century for the benefit of mankind.

Learning Outcomes

The students are expected to have the ability to:

1. Understand the important scientific and technical terms of plasma.
2. Use mathematical knowledge in the solution of plasma physics problems.
3. Recognize the importance of plasma based controlled thermonuclear fusion.

Course Content

Introduction of plasma- Plasmas in nature and applications, Relevant concepts from gas (kinetic) theory, Debye Shielding, Definition of plasma and relevant characteristic parameters, Collision rates and mean-free paths. (6 Lectures)

Single particle motions- Charged particle motion in uniform electromagnetic field, Charged particle motion in non-uniform magnetostatic field, Charged particle motion in time varying electromagnetic fields, Adiabatic invariants. (4 Lectures)

Plasma fluid theory- Continuity equations, Convective derivative, Equations of state, Single fluid approximation, MHD, MHD equilibria, Generalised Ohm's Law. (8 Lectures)

Waves and instabilities in plasmas- Cold plasma waves, Thermal effects on plasma waves, Electron plasma waves, Electromagnetic waves in plasma, Equilibrium and stability, Two-stream instability. (8 Lectures)

Plasma generation and properties- Concepts of plasma generation in laboratory, Plasma sheath, Particle and energy balance, Scaling laws. (8 Lectures)

Concept of Fusion Plasma Science- Thermonuclear fusion burn basics, Fusion Reaction, Thermonuclear fusion, Power balance, Ignition, Tokamaks, Fuel resources, Tokamak economics. (8 Lectures)

Text Books

1. F.F. Chen, *Introduction to Plasma Physics and Controlled Fusion, Volume 1: Plasma Physics,* NY, Plenum Press, 1984.
2. John Wesson*, Tokamaks,* Clarendon Press- Oxford, 2004.

Reference Books

1. R.J Goldston and Paul H. Rutherford*, Introduction to Plasma Physics,* Institute of Physics Publishing, Bristol 1995.
2. R. Dendy, *Plasma Physics: An Introductory Course*, Cambridge, Cambridge University Press, 1993.

Online course material

1. Tripathi, V.K.,Plasma Physics: Fundamentals and Applications , NPTEL Course Material, Department of Physics, Indian Institute of Technology Delhi, https://nptel.ac.in/courses/115102020/.

Title	**Introduction to Quantum Technologies**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide various facets of frontiers of quantum technological domains and its understanding from the beginner's perspective.

Learning Outcomes

The students are expected to have the ability to:

1. In understanding fundamental principles of quantum state engineering.
2. Apply modern quantum state engineered tools in advanced domain of physics

Contents

Non-classical States Generation: Generation of Single Photon, Heralded Photon and Photon added/subtracted states, NOON State. (6 Lectures)

Random Number Generation (RNG): True RNG Generation, Validation and relevant experimental details. (6 Lecture)

Photon Statistics: Detailed analysis of Photon Statistics and higher-order moments for non-classical states and quantum Metrology. (6 Lecture)

Quantum State Engineering and tomography: Methods to generate engineered quantum states and its applications, Quantum State Tomography (QST). (6 Lectures)

Quantum Cryptography: Introduction to Quantum Cryptography. (6 Lectures)

Quantum Computation: Physical realization of quantum computers, and algorithms, qubits using photons and superconducting quits, modern quantum algorithms. (6 Lectures)

Open Quantum Systems: Introduction to Open quantum system and its Technological Implementation. (6 Lecture)

Textbooks

1. Agarwal, G. S., Quantum Optics, Cambridge University Press, 2012.
2. Banerjee, S., Open Quantum Systems: Dynamics of Nonclassical Evolution, Springer and Hindustan Book Agency, 2018.

Reference Books

1. Evans, M. W., Luks, A., Perina, Jan., Phase in Optics, World Scientific Publishing Company, 1997.

Self-Learning Material

1. Prof Dipan Ghosh, Quantum Information and Computing Indian Institute of Technology Bombay, https://nptel.ac.in/syllabus/115101092/.

Title	**Laser Technologies**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

1. This course aims to provide the student with a basic understanding of Lasers and an extended knowledge of the Laser-based technologies.

Learning Outcomes

2. The course provides students with knowledge of laser physics and introduces them to nonlinear optics, laser interferometer, and spectroscopy applications. Also, it provides a good understanding of the critical laser parameters important for their use in various real-world applications such as: quantum optics, quantum technologies, telecommunications, industrial material processing, sensing, bio-medicine, imaging, ranging and automobile industry.

Course Contents

Fundamentals of Lasers: Absorption, Spontaneous emission and Stimulated emission, Einstein coefficients and their significance, Lasing mechanisms, Laser oscillator, Laser characteristics, Principles for operation of Lasers, modes and mode selection, Temporal & Spatial Coherence, comparison of laser with conventional sources of light, Laser Line width and Line broadening mechanisms, Gaussian Beams and optical resonators. (7 lectures)

Types of Lasers: rate equations, CW lasers, and Pulsed Lasers, Gas lasers, solid state lasers, semiconductor lasers, Dye Lasers and Fiber lasers, Spectral coverage with current Laser technologies. (7 lectures)

Generation of short and Ultrashort pulses: Q-Switching, Mode locking, Chirping and Pulse compression, YAG Lasers, State-of–art-lasers (Ti: Sapphire Lasers and Fiber Lasers). (7 lectures)

Nonlinear Optics: Second and Third order nonlinear susceptibilities and nonlinear optical phenomena, Self-phase modulation in fibers, broadband and supercontinuum sources. (6 lectures)

Laser Interferometry: Michelson & Mach-Zehnder Interferometer, Sagnac Interferometer, HOM interferometer, Shearing Interferometer, and its connection to spatial Coherence, Fabry-Perot interferometer, LIGO, applications. (7 lectures)

Laser Spectroscopy: Four-wave mixing, Terahertz generation (Optical rectification in a nonlinear medium), Transient absorption/reflection spectrometer. (8 lectures)

Text Books

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.

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 course material

1. Unique properties of lasers and their applications, Manabendra Chandra, https://nptel.ac.in/courses/104104085/.

Preparatory course material

1. Understanding Lasers and Fiber Optics, Prof. Shaoul Ezekiel https://ocw.mit.edu/resources/res-6-005-understanding-lasers-and-fiberoptics-spring-2008/.

Title	**Computational Materials Science**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Help in understanding the physical properties of materials.
2. Help in implementing the theoretical concepts to compute materials properties.

Learning Outcomes

The students are expected to have the ability to:

1. Learn theoretical concepts of different computational techniques in materials science.
2. Simulate and compute material properties using density functional theory, molecular dynamics and Monte Carlo methods.

Contents

(Fractal 1) PHL7XX1 ***Basic concepts in Density Functional Theory (DFT) (1-0-0)***

Uniform electron gas, Thomas-Fermi model, The Hohenberg-Kohn theorems, formulation of DFT, Kohn-Sham variational principle, Local/spin density approximation (LDA/LSDA), Generalized-gradient approximations (GGAs), Orbital dependent functional, Hybrid functionals, Introduction to Quantum Espresso. (14 lectures)

(Fractal 2) ***PHL7XX2 Molecular dynamics Simulations (1-0-0)***

Equations of motion, integrators, Interaction potential models, Force calculations, Long-range corrections, Molecular dynamics in various ensembles, Advanced MD techniques, Linear response theory and Introduction to LAMMPS & GROMACS. (14 lectures)

(Fractal 3) PHL7XX3 ***Monte Carlo Simulations (1-0-0)***

Monte Carlo integration, Importance sampling, Metropolis algorithm, Detailed balance, Free energy calculations, Widom insertion and Grand canonical Monte Carlo. (14 lectures)

Textbook

1. Sholl, D, and Steckel, J. A., *Density Functional Theory: A Practical Introduction*, Wiley-Interscience 2009.
2. Frenkel, D, and Smit, B., *Understanding Molecular Simulation: From algorithms to applications*, Academic Press 2001.
3. Landau, D. P. and Binder, K., *A Guide to Monte Carlo Simulations in Statistical Physics*, 3rd Edition, Cambridge University Press 2009.

Reference Books

1. Martin, R. M., *Electronic Structure Basic Theory and Practical Methods*, Cambridge University Press 2004.
2. Allen, M. P., and Tildesley, D. J., *Computer Simulation of Liquids*, Oxford University Press, 2nd ed. 2017.

Online Course Material

1. MIT Open Course Ware, 3.320 "*Atomistic Computer Modeling of Materials (SMA 5107)*", by Ceder, G. and Marzari, N.; Spring 2005, https://ocw.mit.edu/courses/materials-science-and-engineering/3-320-atomistic-computer-modeling-of-materials-sma-5107-spring-2005/
2. NPTEL course by Prof. Tembe, B. L., Department of Chemistry, IIT Bombay; "Computational Chemistry and Class Molecular Dynamics"; https://nptel.ac.in/courses/104101095/.
3. LAMMPS MD simulation package https://lammps.sandia.gov/index.html.

Title	**Soft Matter Physics**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

understand theoretical concepts in soft matter physics.
understand the structural and thermodynamic properties of soft matter materials.

Learning Outcomes

1. Ability to apply statistical physics concepts to soft matter.
2. Ability to appreciate the role of self-assembly, liquid crystals, macromolecular solutions in technological applications.

Contents

(Fractal 1) ***PHL7XX1*** *Fundamentals of Soft Matter Physics [1-0-0]*
What is soft matter?; time, length and energy scales; intermolecular forces; macromolecules; biopolymers; colloids, liquid crystals, membranes and self-assembly; (14 lectures)

(Fractal 2) ***PHL7XX2*** *Theory of Simple Liquids [1-0-0]*
Densities and distribution functions; energy, pressure and compressibility, YBG hierarchy, virial expansion, hard-sphere equation of state and numerical calculation of Lennard-Jones systems (14 lectures)

(Fractal 3) ***PHL7XX3*** *Polymer Physics [1-0-0]*
Random walks, model systems, distribution functions, chain statistics, coil-globule transition, polymer solutions, flexibility and semi-flexibility, self-avoidance, entanglement, viscoelasticity, reptation and Rouse models. (14 lectures)

Textbook

1. Doi, M., *Soft Matter Physics,* Oxford University Press 2014.
2. Jones, R. A. L., *Soft Condensed Matter*, Oxford University Press 2002.

Reference Books

1. Chaikin, P. M., and Lubensky, T. C., *Principles of Condensed Matter Physics*, Cambridge University Press

Online Course Material

1. NPTEL course by Profs. Sunil Kumar, P. B., and Menon, G. I.,; "*Physics of Soft Condensed Matter*"; https://nptel.ac.in/syllabus/115106063/

Title	**Statistical Methods for Data Analysis**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives:

The Instructor will:

1. Provide knowledge on commonly used statistical methods in analyzing physics data.

Learning Outcomes

The students are expected to have the ability to,

1. Understand statistical methods in analyzing physical data.

Contents

Basic Statistics and Common Probability Distributions: Probability, Random variables, discrete and continuous probability distributions, cumulative distributions. Mean, variance and covariance. Central Limit Theorem. Method of moments. Monte Carlo Methods: transformation of PDFs, acceptance-rejection technique. (8 Lectures)

Bayesian Statistics: Likelihoods, priors and posteriors. Nuisance parameters, systematics uncertainties, and marginatization. (8 Lectures)

Random and Systematic Uncertainties: Error bars and error propagation. Correlation and 'error matrix'. Non-Gaussian uncertainties. Techniques for managing systematic uncertainties.

(8 Lectures)

Parameter Estimation: Least square regression. Minimization techniques. "Robust" alternatives to the least square method. (8 Lectures)

Statistical Tests: Hypotheses, test statistics, significance level, power, Neyman-Pearson test, statistical trials, likelihood ratio tests, Goodness-of-fit tests. Bayesian approach: posterior odds, the Bayes Factor, the Ockham Factor. Method of maximum likelihood. Statistical errors, confidence intervals and limits. (10 Lectures)

The students will be assigned computer laboratory work based on the above syllabus.

Textbooks

1. Louis, L., *Statistics for nuclear and particle physics*, Addison-Wesley, 1990.
2. Cowan, G., *Statistical Data Analysis*, Oxford University Press, 1998.

Self-Learning Material:

1. Sivia, D. S. and Skilling J., *Data Analysis A Bayesian Tutorial*, Oxford University Press, 2nd edition, 2006.
2. Martin, B. R., *Statistics for Physical Science: An Introduction*, Academic Press, 1st edition, 2012.

Preparatory Course Material:

1. http://www-library.desy.de/preparch/books/vstatmp_engl.pdf

Title	**Optical Fiber Technology**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

1. To understand and gather knowledge on guided wave optics namely fiber optics and its applications.

Learning Outcomes

1. The students will become familiar with the concepts of modes, propagations of optical pulses, and nonlinear aspect of light matter interaction inside fibers.
2. Students will become familiar with fiber characterization/measurement techniques and state-of-the-art applications.

Contents

(Fractal 1) ***PHL7XX1*** *Introduction to Optical Fiber [1-0-0] Vector Nature of Light, Optical Fiber – Single and Multimode, Step index and Graded Index Fibers, Ray and Wave picture of propagation, Cut-off, mode field diameter, group delay, Gaussian field approximation. (8 Lectures)*

Transmission Characteristics: The consequences of attenuation and dispersion in Optical Fibers: Material, Waveguide, Polarization, Intermodal and Intramodal Dispersion, Group velocity Dispersion, Dispersion modified single mode fibers. Fiber Fabrication Methods. (6 Lectures)

(Fractal 2) ***PHL7XX2*** *Optical Fibers and Communication [1-0-0] Attenuation, dispersion and pulse band width, refractive index profile, bend loss, other parameters. (5 lectures)*

Erbium doped fiber amplifiers: Optical amplification, gain spectrum and bandwidth, noise in EDFA, WDM. (4 lectures)

Fiber optic communications- Dispersion management and WDM systems, bit-error rate, signal-to-noise ratio, Optical communications. (5 lectures)

(Fractal 3) ***PHL7XX3*** *Nonliear Fiber Optics [1-0-0] Photonic crystal fibers*: Index and photonic bandgap guiding mechanism, endless single-mode guidance, fiber optic sensors. (7 lectures)

Nonlinear phenomena in optical fibers: Nonlinear refraction, nonlinear pulse propagation, self-phase modulation, changes in pulse spectra, optical wave breaking, optical solitons, cross-phase modulation. (7 lectures)

Textbook

1. Ghatak, A. K., and Thyagarajan, K., *Introduction to Fiber Optics*, Cambridge University Press 1998.
2. Agrawal, G. P., *Nonlinear Fiber Optics*, Academic press, 4th edition, 2007.

Self-Learning Material

1. Rastogi, V., *Fiber Optics*, Indian Institute of Technology Roorkee, https://nptel.ac.in/courses/115107095/.

Reference Course Material

1. Crisp, J. and Elliot, B., *Introduction to Fiber Optics*, 3rd edition, Newnes, 2005.

Title	**Energy Harvesting Technologies**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Make the students understand different energy harvesting technologies from unconventional resources and waste energy management.

Learning Outcomes

The students are expected to have the ability to:

1. Understand the energy harvesting technologies and their applications in different domains.

Contents

Energy sources: Non-renewable and renewable energy sources, Energy demand and crisis nexus, waste energies and their harvesting (5 lectures)

Harvesting Waste Mechanical Energy: Principle of piezoelectricity, piezoelectric materials, their characterizations, common piezoelectric materials e.g. PZT, ZnO. Recent trends on new materials ceramics and polymer composites; Principles of energy harvesting using piezoelectric effect, Electrical equivalent modelling, examples of energy harvesting systems e.g. Human body motion based, human shoe based and human joint based energy harvesters, Energy from natural sources: wind and water flow, Energy from transportation etc (15 lectures)

Nanopiezoelectric materials and devices: Nanopiezoelectric effect, materials for nanogenerators, principles of nanogenerators, devices, characterization, current trends in materials. (7 lectures)

Thermal Waste Energy harvesting: Thermoelectric effect and related principles, such as Seebeck and Peltier effect, Thomson effect, Thermoelectric device materials and characterization, Strategies for improving thermoelectric performance, Nanostructured thermoelectric materials; principle of pyroelectric effect, pyroelectric and electrocaloric coefficients, pyroelectric figure of merit, pyroelectric materials, Thermal phase change materials for waste energy harvesting, principles and materials. (10+05 lectures)

Textbook

1. Priya, S., Inman, D. J., *Energy Harvesting Technologies*, Springer (2009).
2. Mescia, L., Losito, O., Prudenzano, F., Innovative *Materials and Systems for Energy Harvesting Applications*, IGI Global (2015)

Reference Books

1. Kazmierski, T. J., Beeby, S., *Energy Harvesting Systems*, Springer (2011).
2. Yang, B., Liu, H., Liu, J., Lee, C., *Micro and Nano Energy Harvesting Technologies*, Artech House (2015)

Online Course Material

1. W. Tester, Jefferson, Kazimi, Mujid S., Shao-Horn, Yang, Ghoniem, Ahmed F. *Fundamentals of Advanced Energy Conversion,* https://ocw.mit.edu/courses/mechanical-engineering/2-60-fundamentals-of-advanced-energy-conversion-spring-2004/#

Title	**Solar Energy Technologies**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Make the students understand energy technologies such as solar photovoltaics, solar thermal together with solar radiation.

Learning Outcomes

The students are expected to have the ability to:

1. Understand the solar technologies and their applications.

Contents

Basic Concepts of Solar Radiation: Radiation fundamentals, types of radiation, measurements, and its usages. (10 lectures)

Solar photovoltaics: Principles of solar cells, their types and working mechanisms, generation and recombination of carriers, types of recombination, Details about p-n homo and hetero junctions, inorganic and organic junction-based PV devices, analysis and characterization. Effect of temperature on device performance. (10 lectures)

Solar thermal: Solar thermal technologies (concentrating and non-concentrating) and their operating principles, classification based on temperature ranges and their applications, Component analysis, Introduction to solar thermal plants and energy generation. (10 lectures)

Energy storage: Electrical energy storage using batteries and supercapacitors, principles, issues and challenges, current state of the art; Thermal energy storage using phase change and thermochemical means, principles, materials, issues and challenges. (10 lectures)

Textbook

1. Nelson, J., (2003), *The Physics of Solar Cells*, Imperial College Press.
2. Sukhatme, S. P., Naik, J. K., *Solar Energy: Principles of thermal collection and storage*; TMH, 2017.

Reference Books

1. Wurfel, P., Wurfel, U., (2016), *Physics of Solar Cell*, Willey VCH.
2. Duffie, J. A., Beckman, W. A., *Solar Engineering of Thermal Processes*, John Wiley & Sons 4th Ed, 2013.

Online Course Material

1. Buonassisi, T., Fundamentals of Photovoltaics, 2011, MIT OpenCourseWare : http://ocw.mit.edu/2-627F11.

Title	**Quantum Optics and Engineering**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		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 (3 Lectures)
Coherent and squeezed states of radiation: Radiation from a classical current; coherent states; squeezed state physics 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. (7 Lectures)
Lasing without inversion, coherent trapping, electromagnetically induced transparency: Basic concepts of these quantum interference phenomena. (6 Lectures)

Textbook:

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

Reference Book:

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

Self-Learning Material:

1. Satyanarayana, M. V., Department of Physics, IIT Madras, Quantum Optics, https://nptel.ac.in/syllabus/115106067/

Title	**Cold Plasma Technologies**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

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 and diagnostics.

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.
2. acquire conceptual understanding of plasma measurement tools, different vacuum pumps and plasma systems design concepts.

Content

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. (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. Vacuum gauges, Gas regulators, 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 Lighting devices, Nanoscale fabrications and plasma for biomedicines. (8 lectures)

Text Books

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.

Online course material

1. Tripathi, V.K., *Plasma Physics: Fundamentals and Applications*, NPTEL Course Material, Department of Physics, Indian Institute of Technology Delhi, https://nptel.ac.in/courses/115102020/.

Title	**Critical Phenomena and Renormalization Group**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Help in understanding the basic concepts of critical phenomena.
2. Help in grasping the concepts of the renormalization group

Learning Outcomes

The students are expected to have the ability to:

1. Grasp the concept of universality in phase transitions, crucial for understanding critical phenomena.
2. Understand scaling and renormalization group ideas.

Contents

Introduction to critical phenomena: Phase Transitions and Transfer Matrix, Order Parameter and Cluster Properties, Stochastic Processes and Phase Transitions, The Ising model, the mean field, correlation functions. (10 Lectures)

Landau theory: The Landau theory of phase transitions, Universality within the Mean Field Approximation, Critique of the Landau approximation, and the Ginzburg criterion, Power Counting and the Role of Dimension Four. (10 Lectures)

Real-space Renormalization Group: Renormalization Group (RG) transformation of the Hamiltonian and its fixed points, Relations between critical exponents from RG, some applications of the linearized RG transformations. (6 Lectures)

Momentum-space Renormalization Group: RG transformation in wave number space, Scaling dimension: anomalous and normal, Partition function and fixed points for the Gaussian model. (10 Lectures)

Two-dimensional models: The X Y model, Nonlinear sigma-models. (6 Lectures)

Textbook

1. Ma, S. K., (1976), *Modern theory of critical phenomena*. Benjamin, Philadelphia.
2. Bellac, M. L., (1991), *Quantum and Statistical Field Theory*, Clarendon Press, Oxford.

Reference Books

1. Zinn-Justin., J., (1989), *Quantum field theory and critical phenomena*, Oxford University Press, Oxford.

Online Course Material

1. Santra, S. B., *Advanced Statistical Mechanics*, NPTEL Course Material, Department of Physics, Indian Institute of Technology Guwahati, http://nptel.ac.in/courses/115103028/.
2. Kardar, M., 8.334 Statistical Mechanics II, Spring 2014, MIT OpenCourseWare Massachusetts Institute of Technology, https://ocw.mit.edu

Title	**Non-perturbative aspects of Quantum Field Theory**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Help in understanding the basic ideas of non-perturbative phenomena.
2. Help in grasping the basic models of non-perturbative quantum field theory (QFT).

Learning Outcomes

The students are expected to have the ability to:

1. Grasp the concepts of QFT beyond the perturbation regimes.
2. Understand some of the important tools needed for non-perturbative QFT.

Contents

Introduction to general properties of QFT: Relativistic covariance, microcausality and ultraviolet singularities, Wightman functions and their properties; Euclidean QFT, Osterwalder-Schrader condition, local structure of QFT, Haag theorem; Schwinger model, Thirring model. (6 Lectures)

Kinks and Domain Walls: Humps of energy with a topological basis. Formation of kinks and domain walls during a phase transition, Kibble and Kibble-Zurek mechanisms. Action of kink and domain walls. (8 Lectures)

Solitons and Instantons: Relativistic quantum field theories starting from classical solutions of the corresponding non- nonlinear field equations. Classical field equations belong to either the Minkowskian metric or to Euclidean equations. The Minkowskian solutions will have finite energy with a localised, non-dispersive energy density; referred to as solitons. Correspondence between classical soliton solutions of any given field theory and extended-particle states of the quantised version of that theory will be discussed. Instantons are localised finite-action classical solutions of the Euclidean version of the field equations of any given model. They lead to tunnelling effects that can significantly affect the structure of the vacuum state. It will be discussed how the existence of a non-zero topological index, in the instantons, leads to the generation of a family of vacuum states, characterized by a vacuum angle theta. (20 Lectures)

Non-Linear Sigma Model: Models possessing global symmetries non-linearly realized on the fields. This model has an 0(N) symmetry, the field being a N-vector of fixed length. In this context, the 1/N expansion will be discussed. Also, discussed will be the connection of the O(2) model to the sine-Gordan and massive Thirring models. (8 Lectures)

Textbook

1. Rajaraman, R., (1989), *Solitons and Instantons,* North-Holland.
2. Abdalla, E., Abdalla, M. C. B., and Rothe, K. D., (2001), *Non-perturbative methods in 2 Dimensional QFT*, World Scientific, Singapore.

Reference Books

1. Zinn-Justin., J., (1989), *Quantum field theory and critical phenomena*, Oxford University Press, Oxford.

Online Course Material

1. Govindarajan, S., *Classical Field Theory*, NPTEL Course Material, Department of Physics, Indian Institute of Technology Madras, http://nptel.ac.in/courses/115106058/.
2. Hanany, A., 8.871 Selected Topics in Theoretical Particle Physics: Branes and Gauge Theory Dynamics, MIT OpenCourseWare Massachusetts Institute of Technology, https://ocw.mit.edu

Title	**Nuclear Engineering**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide various aspects of Nuclear Engineering from perspective nuclear power plant and its safety.

Learning Outcomes

The students are expected to have the ability to:

1. In understanding fundamental principles of nuclear engineering.

Contents

***PHL7XX1 Nuclear** Reactor and Safety [2-0-0]*

Introduction to Nuclear Physics: (2 Lecture).

Nuclear Decay Series: U, Th, Pu and Other radioactive sources and their decay series; basic understanding of differential cross-section and half-life. (6 Lecture)

Nuclear Reactors: Reactor Physics and Pressurized Water Reactor, Boiling Water Reactor, Fast-Breeder Reactor (FBR), Reactor Design (Heavy Water, Liquid Metal and Gas). (12 Lecture)

Nuclear Safety: Reactor Safety, Structural Mechanics, Accidents and Contamination. (8 Lecture)

***PHL7XX1 Fluid** Flow and Power cycles [1-0-0]*

Fluid Flow and Power Cycles: Single-Phase Flow & Two-Phase Flow, Heat-Exchangers Design and Different Power Cycles. (14 Lectures)

Textbooks:

1. Glasstone, S. and Sesonske, A., *Nuclear Reactor Engineering*, D. Van Nostrand Company, 1967.
2. Knief, R. A. *Nuclear Engineering: Theory and Technology of Commercial Nuclear Power*. 2nd ed. La Grange Park, 2008.

Reference books:

1. Oka, Y., (Eds.), *Nuclear Reactor Design*, Springer-Verlag, Tokyo, 2010.

Self-Learning Material:

1. Kannan, I., Department of Mechanical Engineering, IIT Bombay, Nuclear Engineering, https://nptel.ac.in/courses/112101007/.

Title	**General Theory of Relativity**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

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

The students are expected to have the ability to:

1. have detailed insight regarding theory and dynamics related to gravity.
2. 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.

Principle of equivalence: 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. (8 Lectures)

Curvature: curvature tensor, Bianchi identity, Ricci tensor, curvature scalar, Killing vectors and symmetries. (5 Lectures)

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. (8 Lectures)

Stellar equilibrium and collapse: Differential equation for stellar structure, White dwarfs, neutron stars, comoving coordinates, Schwarzschild blackholes, collapse to a blackholes.

Gravitational radiation: (10 Lectures)

Universe: Friedmann-Robertson-Walker solution, our Universe. (3 Lectures)

Textbook

1. Weinberg, S., *Gravitation and Cosmology: Principle and Applications of the General Theory of Relativity*, 1st Ed., John Willey & Sons 1972.
2. Hartle, J. B., *Gravity*, 1st Ed. , Pearson education 2011.
3. Misner, C.W., Thorne, K. S. and Wheeler, J. A., *Gravitation,* Princeton University Press 2017

Self-Learning Material

1. Schutz, B., *General Relativity*, Cambridge University Press 2011
2. https://www.youtube.com/watch?v=hbmf0bB38h0&list=PLGI_2C39f-V1AACba_7pZP8A9M7PmQJqx
3. Bertschinger, E. W., *General Relativity*, http://hdl.handle.net/1721.1/36859.

Title	**Particle Physics**	Number	PHL7XX0
Department	Physics	L-T-P-Th [C]	3–0–0-0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide background to understand the concepts of modern particle physics.

Learning Outcomes

The students are expected to have the ability to:

1. Understand details of Quantum Electrodynamics, Quantum Chromodynamics and Weak interactions.
2. Grasp concepts of Standard Model of particle physics and its limitations.

Contents

A preview of Particle Physics: Elementary particle dynamics, Quark structure of Hadrons, Decay rates and cross sections (4 Lectures).

Quantum Electrodynamics (QED): Elementary QED processes, Anomalous magnetic moment, Extracting the moment and evaluating the graphs, Electron self-energy, Pole mass, Minimal Subtraction, Counter terms, Two- and three-point functions, Infrared divergences, Jets, Renormalizability of QED. (12 Lectures)

Quantum Chromodynamics (QCD): Feynman rules for QCD, Elastic and inelastic electron-proton *scattering*, The Rosenbluth formula, Parton distribution functions, Callan-Gross relation, Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) splitting function, Factorization and the parton model, The operator product expansion (14 Lectures)

Weak and Electroweak Interactions: The weak charged current interactions, V-A and chiral structure of weak interaction, Lepton universality, Charged and neutral current neutrino scattering, Electroweak Unification, The Higgs mechanism, Discovery of Higgs Boson, Need for physics beyond the standard model. (12 Lectures)

Textbook

1. Schwartz, M. D., *Quantum Field Theory and the Standard Model*, Cambridge University Press, 2014.
2. Thomson, M., *Modern Particle Physics*, Cambridge University Press, 2016.

Self-Learning Material

1. Susskind, L., *New Revolutions in Particle Physics: Basic Concepts,* *https://www.youtube.com/watch?v=2eFvVzNF24g&list=PL768E1383EA79C603*

Title	**Quantum Field Theory**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide background to understand basic concepts of quantization of scalar, spinor and gauge fields.

Learning Outcomes

The students are expected to have the ability to:

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

Contents

Classical field theory: Lagrangian and Hamiltonian formalisms; Occupation number representation, Noether's theorem, Continuous and discrete symmetries (4 lectures).

Canonical Quantization: General Formulation, Normal ordering, Mode expansion, Quantization of real and complex scalar fields, Commutation relations, Quantization of Dirac fields, Anti-Commutators, Quantization of massless gauge fields in radiation and Lorentz gauge, Quantization of massive vector fields (14 lectures).

Interacting field theory: Propagators and Green's functions, The S-matrix, Perturbation expansion of the S-matrix, Wick's Theorem, Feynman Rules and Feynman diagrams for interacting scalar field theory and spinor electrodynamics, Lowest Order Cross-Section for Rutherford and Mott scattering (16 lectures).

Radiative Corrections and Renormalization: Casimir effect, Vacuum polarization, Electron magnetic moment, Lamb's shift, Mass renormalization (8 lectures)

Textbook

1. Peskin, M. E. and Schroeder, D. V., An *Introduction to Quantum Field Theory*, Frontiers in Physics, 1995.
2. Weinberg, S., *The Quantum Theory of Fields I*, Cambridge University Press, 2008.

Self-Learning Material

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	**Astrophysics**	Number	PHL7XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Familiarize the basic ideas needed to understand astrophysical phenomena.
2. Elucidate the nature and properties of compact astrophysical objects.

Learning Outcomes

The students are expected to have the ability to:

1. have idea how astrophysical observations, measurements can be carried out and how the observational data can be interpreted.
2. be acquainted with the physics of compact objects.

Contents

Properties of Sun: Estimate of surface temperature, luminosity, radius, mass, sun's spectrum, composition of sun. (2 Lectures)

Fundamental of radiative transfer: Radiative flux, the specific intensity, radiative transfer, optical depth, plane parallel atmosphere, the grey atmosphere problem, formation of spectral line, opacity, calculation of opacity. (8 Lectures)

Properties of stars: Colour and surface temperature, stellar spectra, spectroscopy parallax. the Hertzsprung-Russel diagram, size, mass and temperature of stars. (6 Lectures)

Stellar formation and evolution: Hydrostatic equilibrium, virial theorem, Jeans' crieria for star formation, brown dwarf, stellar structure equations. (7 Lectures)

Nucleosynthesis inside stars: Possibility of nuclear reactions in stars, Nuclear reaction rates, important nuclear reactions in stars, evolution of stars with different masses. (4 Lectures)

White dwarfs: - equation of state for degenerate gas, polytropic EoS, Lane-Emden equation, Chandrasekhar mass limit. (6 Lectures)

Neutron stars: Supernova, neutron star, neutron drip, TOV equation, pulsars, magnetic dipole model of pulsars, nonvacuum pulsar model, glitch, cooling of neutron stars, neutron stars in binary. (6 Lectures)

Galaxies: Stellar dynamics, Interstellar medium. (3 Lectures)

Textbook

1. Rai Choudhari A., *Astrophysics for physicists*, 1st Ed., Cambridge University Press 2010.
2. Morison I., *Introduction to astronomy and cosmology*, 1st Ed., Willey and Sons ltd 2008.
3. Shapiro, S. L., Teukolsky, S. A., *Black Holes, White Dwarfs, and Neutron Stars*, 1st ed., WILLEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004.

Self-Learning Material

1. https://www.youtube.com/watch?v=dpRqK_awV9Y&list=PLy5Ast_vPItFNkraErbQ8AmWEaQMt34Rx
2. https://www.edx.org/course/introduction-astrophysics-epflx-phys-209-enx
3. https://www.youtube.com/watch?v=nzmFc2gjUo4&list=PLE17CC91B39224675

Title	**Vacuum Systems and Thin Film Technology**	Number	PHL8XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite	Introduction to Characterization & Advanced Condensed Matter Physics		

Objectives

The Instructor will:

1. Introduce basic concept of vacuum science and thin film depositions & characterizations

Learning Outcomes

The students are expected to have the ability to:

1. Understand the physical concepts behind the thin film depositions by CVD and PVD systems
2. Knowledge about vacuum pumps and gauges
3. Design protocols for thin film deposition and characterization

Contents

Vacuum technology: Production of Vacuum - Mechanical pumps, Diffusion pump, Getter and Ion pumps, Cryopumps, Pressure Measurements Gauges, Leak Detection. (5 lectures)

Physical Vapor Deposition: Hertz Knudsen equation; mass evaporation rate; Knudsen cell, Directional distribution of evaporating species, Evaporation of elements, compounds, alloys, Raoult's law; e-beam, pulsed laser and ion beam evaporation, Glow Discharge and Plasma, Sputtering–mechanisms and yield, DC and RF sputtering, Bias sputtering, magnetically enhanced sputtering systems, reactive sputtering, Hybrid and Modified PVD- Ion plating, reactive evaporation, ion beam assisted sputtering. (11 lectures)

Chemical Vapor Deposition: reaction chemistry and thermodynamics of CVD; Thermal CVD, laser & plasma enhanced CVD, Chemical Techniques - Spray Pyrolysis, Electro-deposition, Sol- Gel and LB Techniques (8 lectures)

Nucleation & Growth: capillarity theory, atomistic and kinetic models of nucleation, basic modes of thin film growth, stages of film growth & mechanisms, amorphous thin films, Epitaxy–homo, hetero and coherent epitaxial layers, lattice misfit and imperfections, epitaxy of compound semiconductors. (8 lectures)

Film Formation and Structure: Capillarity Theory, Atomistic Nucleation Processes, Cluster Coalescence and Depletion, Experimental Studies of Nucleation and Growth, Grain Structure of Films and Coatings (5 lectures)

Methods for characterization of film properties: chemical composition, microstructure, optical, mechanical and electrical properties (5 lectures)

Textbook

1. Ohring, M., *The materials science of Thin films*, Academic Press Ltd, 2nd Edition, 2002
2. Chopra, K. L., *Thin Film Phenomena,* McGraw-Hill Book Company, 1969
3. Smith D. L., *Thin Film Deposition: Principles and Practice*, McGraw Hill 1995

Self-Learning Material

1. Shekhar, S. and Gaur, A., *Fundamentals of Material Processing Part 2 (Module 2)*, IIT Kanpur, https://nptel.ac.in/courses/113104075/

Title	**Plasma Diagnostics**	Number	PHL8XX0
Department	Physics	L-P-T (C)	3-0-0 [3]
Offered for	PhD		
Prerequisite	Cold Plasma Technologies		

Objectives

The instructor will:

1. provide an overview of the important plasma diagnostic and data analysis tools, which are used in process development and plasma reactor monitoring.
2. provide students a critical appreciation of where and when specific techniques are applicable.

Learning Outcomes

The students are expected to have the ability to:

1. understand the fundamental principles of electrical, optical and particle measurement techniques.
2. understand quantitatively the validity of plasma measurements.
3. distinguish process control issues and chalk out strategies for specific plasma process

Course Content

Plasma Parameters- Electron and Ion plasma densities, temperature, and particle distribution functions. Wall fluxes of charged and neutral species, energy distribution functions. Plasma emission. Plasma operating regimes. (7 Lectures)

Electrical Measurements- Electrical Probes (Langmuir single, double probes, emissive proves), Current transformers, Rogowski coil, dielectric charging and laser heated techniques. (8 Lectures)

Optical and Spectroscopic Techniques- Fundamentals of emission of radiation by plasmas. Corona equilibrium, Local-thermodynamic equilibrium (LTE), Collinsonal-radiative (CR) processes. Line shapes and broadening, i.e., Natural Broadening, Doppler Broadening, Stark Broadening, line shifts. Absorption spectroscopy and active techniques including LIF (Laser Induced Fluorescence) technique. (12 Lectures)

Particle Measurements and Process Control- Energy analysers (Ion-energy analyzers, Faraday Cup), ion mass spectrometry, process gas analysis in plasmas, process control strategies. statistical process analysis, end point detection. (8 lectures)

Data analysis software and tools- Data analysis introduction and overview of COMSOL, Vsim, Oopic-pro, Atomic Data and Analysis Structure, Interactive Data Language, Matlab and Origin. (7 lectures)

Text Books

1. I. H. Huchinson, *Principles of plasma diagnostics,* Cambridge University Press, 1987.
2. P.I John, *Plasma Sciences and the Creation of Wealth,* Tata McGraw-Hill Education Company Pvt. Ltd., New Delhi, *2005*

Reference Books

1. Lochte-Holtgreven, *Plasma Diagnostics,* AIP Press American Institute of Physics, New York (1995)
2. P.C. Stangeby, *Plasma Diagnostics,* Vol. 2, Surface analysis and interactions, Academic Press, Boston (1989)

Preparatory Course Material

1. Ram Prakash, Book Chapter *"Recent Trends in Plasma Chemistry and Spectroscopy Diagnostics"* Research Methodology in Chemical Sciences: Experimental and Theoretical Approach, Applied Academic Press, USA (2016).

Title	**Materials and device characterization**	Number	PHL8XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite	**Introduction to Material Characterization**		

Objectives

The Instructor will:

1. Introduce the advanced characterization tools for materials and devices

Learning Outcomes

The students are expected to have the ability to:

1. Understand the concepts and theory underlying the modern techniques employed to determine semiconductor material and device parameters.

Contents

Introduction to materials characterization and their necessity including physical, chemical and electrical characterization. (2 lectures)

Structural and crystallographic Characterization: X-ray, neutron and electron diffraction, LEED, RHEED, characterization of crystalline and non-crystalline materials. (6 lectures)

Microscopy techniques: Geometrical optics and optical microscopy, Scanning electron and Transmission electron microscopy. (10 lectures)

Optical spectroscopy: UV-Vis and FTIR spectroscopy, Raman spectroscopy with introduction vibrational spectroscopic concepts. (4 lectures)

Magnetic measurement techniques: SQUID magnetometer, temperature and field dependent magnetic measurements using PPMS and SQUID, introduction magnetic imaging techniques such as MRI and NMRI. (6 lectures)

Electrical measurement:Drude model introduction, Four probe resistivity measurements, Van der Pauw method, Hall measurement, PN junction measurements, Schottky barriers, Thermally stimulated current spectroscopy. (6 lectures)

Low temperature measurements: Introduction to cryogens, Dewars, He-4/3 cryostat, Dilution cryostat, Adiabatic demagnetization, Resistance thermometry. (4 lectures)

Mossbauer spectroscopy techniques: Principle, method, experiments for material characterization, X-ray photoelectron/Auger spectroscopy measurements. (4 lectures)

Textbook

1. Schroder, D. K., *Semiconductor material and device characterization*, Wiley 3rd Edition, 2015
2. Zhang, S., Li, L. and Kumar, A., *Materials characterization techniques,* CRC press, 2008
3. Egerton, R. F., *Physical principles of electron microscopy: An introduction to TEM, SEM and AEM,* Springer, 2005

Self-Learning Material

1. Biswas, K., *NPTEL course: Advanced Characterization Techniques*, IIT Kanpur, https://nptel.ac.in/syllabus/113104004/

Title	**Computational Condensed Matter Physics**	Number	PHL8XX0
Department	Physics	L-T-P [C]	3–0–1 [4]
Offered for		Type	Elective
Prerequisite	Computational Materials Science		

Objectives

The Instructor will:

1. Help in understanding the condensed matter physics concept and their correlation in materials properties.
2. help students to implement the concept to apply for computing materials properties.
3. Encourage students to apply the computational condensed matter physics knowledge in their research if interested.

Learning Outcomes

The students are expected to have the ability to:

1. Learn the concept of condensed matter and computational aspects for real implementation
2. Design application driven materials need

Contents

Basic Concepts in Electronic Structure: Interacting electron & nuclei systems, Forces & stress theorems, a bit of statistical mechanics and density matrix. Independent electron approximation, Exchange & correlation. Periodic solids and electron bands. Uniform electron gas model. (5 lectures)

Hartee-Fock approximation: Non-interacting systems (2 lectures)

Density Functional Theory (DFT): Thomas-Fermi model, The Hohenberg-Kohn theorems, Extension of Hohenberg-Khon theorems, formulation of DFT. The Kohn-Sham vibrational principle. (8 lectures)

Functionals for exchange correlation: Local/ spin density approximation (LDA/LSDA), Generalized-gradient approximations (GGAs), Orbital dependent functional, Hybrid functionals.

Electronic structure of atom and pseudopotential: scattering amplitude and pseudopotentials, orthogonalized plane wave (OPWs) and pseudopotentials, Nrom-conserving pseudopotentials, unscreening and core correction, Ultrasoft pseudopotentials, Projector augumented waves (PAWs) (16 lectures)

Computation of electronic band structure: Self-consistent solution of coupled Kohn-Sham equations, Total energy functionals, Force & stress (5 lectures)

Practical applications: Introduction to supercells, surfaces, interfaces, phonons and defects, other material properties such as magnetic, ferroelectric and piezoelectric properties. Thermal properties using phonon dispersion. (6 lectures)

Textbook

1. Marder, M. P., *Condensed Matter Physics*, Wiley, 2000
2. Sholl, D., and Steckel, J. A., *Density Functional Theory: A Practical Introduction*, Wiley-Interscience, 2009

Reference Books

1. Martin, R. M., *Electronic Structure Basic Theory and Practical Methods*, Cambridge University Press, 2004
2. Kittel C. C., *Quantum Theory of Solids*, John Wiley & Sons Inc, 1987
3. Journal articles for relevant sections

Self-Learning Material

1. Online resources: http://www.quantum-espresso.org/ (For computational purpose and online lectures and reading materials)

Title	**Semiconductor Device Technology**	Number	PHL8XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite	Advanced Condensed Matter Physics		

Objectives

The Instructor will:

1. Introduce basic properties of semiconductors, physical principles and operational characteristics of semiconductor devices
2. Put forth advanced device issues relevant to state-of-the-art integrated-circuit technologies.

Learning Outcomes

The students are expected to have the ability to:

1. Familiarize with the physical concepts behind the solid state electronics devices

Contents

Physics and Properties of Semiconductors: crystal structure, energy bands, statistics, Fermi level, carrier concentration at thermal equilibrium, carrier transport phenomena, Hall effect, recombination, optical and thermal properties, basic properties for semiconductor operation. (5 lectures)

Device Processing Technology: oxidation, diffusion, ion-implantation, deposition, lithography, etching and interconnect. (8 lectures)

p-n Junction: depletion region, diffusion, generation-recombination, current-voltage characteristics, junction breakdown, charge storage and transient behavior. (4 lectures)

Bipolar transistor: transistor action and dependence on device structure, charge control switching model, Ebers-Moll Model, current-voltage characteristics, non-ideal and limiting effects at extremes of bias. (6 lectures)

State-of-the-Art Bipolar Transistor Technology: poly-si emitters, narrow base, structural tradeoffs in optimizing performance. (3 lectures)

Metal-Semiconductor Contacts: equilibrium, idealized metal semiconductor junctions, nonrectifying (ohmic) contacts, Schottky diodes, tunneling. (4 lectures)

Metal-Oxide-Silicon System: MOS structure, capacitance, oxide and interface charge (charging of traps, tunneling through oxide). (4 lectures)

MOS Field-Effect Transistor: threshold voltage, derivation of current-voltage characteristics, dependence on device structure. (3 lectures)

State-of-the-Art MOS Technology: small-geometry effects, mobility degradation due to channel and oxide fields, velocity saturation, hot-electron effects. (3 lectures)

Modern CMOS Technologies: CMOS Process flow starting from Substrate selection to multilevel metal formation, comparison between bulk and SOI CMOS technologies. (2 lectures)

Textbook

1. Donald , A. N., *Semiconductor Physics and Devices*, Tata McGraw-Hill, 2007.
2. Sze, S.M., *Physics of Semiconductor Devices*, John Wiley & Sons, 2001.
3. James,P., Deal, M. and Griffin P., *Silicon VLSI Technology*, Prentice Hall, Electronics and VLSI series, 2000

Self-Learning Material

1. Fonstad, C., Jr, *MIT Open course: Microelectronic Devices and Circuits*, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-012-microelectronic-devices-and-circuits-fall-2009/index.htm

Title	**Understanding Scanning Tunneling Microscope**	Number	PHL8XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite	Advanced Condensed Matter Physics		

Objectives

1. To understand the principles behind scanning tunneling microscope.

Learning Outcomes

1. One can get acquainted and operate scanning tunneling microscope.

Content

Overview: Tunneling an elementary model, probing electronic structure in atomic scale, spatially resolved scanning spectroscopy, lateral resolution, origin of atomic resolution in STM, tip-sample interaction effects. (6 lectures)

Imaging Mechanism: atom-scale tunneling, perturbation approach, image force, the square-barrier problem, modified Bardeen approach, effect of image force on tunneling, tunneling matrix elements, tip wavefunctions, Green's function and tip wavefunctions, wavefunctions at surfaces, related model, concept of surface states, field emission spectroscopy, atom-beam diffraction, first principles theoretical studies. (10 lectures)

Imaging crystalline surfaces: types of STM images, surfaces with one-dimensional corrugation, surface with *tetragonal*, hexagonal or trigonal symmetry, corrugation inversion, the S-wave-tip model. (5 lectures)

Imaging atomic states and the role of atomic force in tunneling: Slater atomic wavefunctions, profiles of atomic states as seen by STM, Na-atom tip model, images of surfaces: Independent orbital approximation, effect of atomic force in STM, attractive atomic force as a tunneling phenomenon, attractive atomic force and tunneling conductance. (11 lectures)

Tip-sample Interactions and scanning tunneling spectroscopy: Local modification of sample wavefunction, deformation of tip and sample surface, electronics for spectroscopy, nature of the spectra, tip-treatment for spectroscopy studies, The Fenestra parameter, ex situ and in situ determination of tip DOS. (10 lectures)

Textbook

1. Chen, C. J., *Introduction to Scanning Tunneling Microscopy*, Oxford University, 2012

Reference Books

1. Weisendanger, R., *Scanning Probe Spectroscopy and Microscopy*, Cambridge Uni.

Online Course Material

Review of Quantum Tunneling/Introduction to STM: http://nanohub.org/resources/9600

Title	**Physics of neutrinos**	Number	PHL8XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide background to understand the role of neutrinos in probing fundamental interactions of nature.

Learning Outcomes

The students are expected to have the ability to:

1. Grasp the theoretical concepts of neutrino oscillations and various neutrino mass models.
2. Understand details of various currently running and upcoming experimental facilities.
3. Understand the role of neutrinos in the early universe.

Contents

Neutrino oscillations: Solar and atmospheric neutrino puzzles, Neutrino oscillations in vacuum, plane wave & wave packet treatment, Neutrino oscillations in constant matter density, MSW resonance, Neutrinos through varying matter density, Terrestrial neutrino oscillation experiments, Supernova neutrinos. Synchronized & Bipolar oscillations, Spectral split. (10 Lectures)

Sterile Neutrinos: LSND anomaly, More neutrino species, MiniBoone experiment, New anomalies - Reactor neutrino anomaly and Gallium experiments calibration anomaly, Proposed future experiments, Sterile neutrinos in astrophysics and cosmology. (10 Lectures)

Neutrino Nature and Mass: Absolute mass experiments, Dirac and Majorana masses for neutrinos, Neutrinoless double beta decay, Neutrino mass models, Seesaw mechanism, Type I, II and III Seesaw models, Zee model, Left-right symmetric model, GUT-based models, Supersymmetric models. (10 Lectures)

Neutrino Cosmology: Robertson–Walker metric, Dynamics of expansion, The cosmic neutrino background, Neutrino temperature, Energy density of light massive neutrinos, Energy density of heavy neutrinos, Neutrinos as dark matter. (8 Lectures)

Ultra-high energy Neutrinos: Neutrinos from Astrophysical objects: AGNs, GRBs, GZK neutrinos, Neutrino Astronomy. (4 Lectures)

Textbook

2. Giunti, C., & Kim, C. W., *Fundamentals of Neutrino Physics and Astrophysics*, Oxford University Press 2007.
3. Kim, C. W., & Pevsner, A., *Neutrinos in physics and astrophysics*, Harwood Academic 1993.

Reference Books

1. Fukugita, M., & Yanagida, T., *Physics of Neutrinos*, Springer Verlag 2003
2. Boehm, F., & Vogel, P., *Physics of Massive Neutrinos*, Cambridge University Press 1992.

Self-Learning Material

1. Dighe, A., *Neutrino Physics,* Tata Institute of Fundamental Research Mumbai, https://www.youtube.com/playlist?list=PL28B95E11276C75F6

Title	**Gauge theory of weak interactions**	Number	PHL8XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide background to understand basic concepts of non-abelian global and local gauge symmetries.

Learning Outcomes

The students are expected to have the ability to:

1. Grasp the theoretical concepts of spontaneously broken symmetry, both global and local.
2. Understand details of Glashow-Salam-Weinberg gauge theory of electroweak interactions.

Contents

Global non-Ablelian symmetries: Flavor symmetries $SU(2)_f$ *and* $SU(3)_f$*, Non-Abelian global symmetries in Lagrangian quantum field theories, chiral symmetry. (4 Lectures)*

Local non-Ablelian symmetries: Local SU(2) symmetry: the covariant derivative, Geometrical curvature and the gauge field strength tensor, Local SU(3) symmetry, Local SU(2) and SU(3) Lagrangians, Quantizing non-Abelian gauge fields: Interaction of non-Abelian gauge bosons, The Faddeev-Popov Lagrangian, Ghosts and Unitarity, Becchi-Rouet-Stora-Tyutin (BRST) symmetry, One loop divergences of non-Abelian gauge theory, β *function. (8 Lectures)*

Spontaneous symmetry breaking: The Fabri-Picasso theorem, Spontaneously broken symmetry in condensed matter physics: The ferromagnet and The Bogoliubov superfluid, Goldstone's theorem, Spontaneously broken global U(1) symmetry: the Goldstone model, Spontaneously broken global non-Abelian symmetry, Chiral Symmetry Breaking: The Nambu analogy, Two flavour QCD and $SU(2)_{fL}$ *X* $SU(2)_{fR}$*, Pion decay and the Goldberger-Treiman relation, The linear and nonliear σ -models, Chiral anomalies; Massive and massless vector particles, The generation of 'photon mass' in a superconductor, Spontaneously broken local U(1) symmetry: the Abelian Higgs model, 't Hooft's gauges, Spontaneously broken local SU(2) X U(1) symmetry. (15 Lectures)*

Electroweak Unification: Violation of unitarity in the current–current model, The Intermediate vector Boson (IVB) model, Violation of unitarity bounds in the IVB model, The problem of non-renormalizability in weak interactions, Glashow-Salam-Weinberg theory of Electroweak Interactions: Weak isospin and hypercharge, The SU(2) X U(1) group of the electroweak interactions, quantum number assignments and W and Z masses, The leptonic currents and massless neutrinos, The quark currents, simple tree-level predictions, Anomaly cancellations, The discovery of the $W^{\pm}$ *and* Z^0 *at the CERN* $p\underline{p}$ *collider, The fermion mass problem, Quark and neutrino flavour mixing, Higher-order corrections, The top quark, The Higgs sector, Theoretical considerations concerning Higgs mass, Higgs phenomenology, Discovery of Higgs Bosons. (15 Lectures)*

Textbook

1. Aitchison, I. J. R. & Hey, A. J. G., *Gauge Theories in Particle Physics, Volume II: A Practical Introduction: Non-Abelian Gauge Theories: QCD and the Electoweak Theory*, Taylor & Francis, 2003.
2. Cheng, T. P. & Li, L. F., *Gauge theory of elementary particle physics*, Oxford University Press, 2000.

Self-Learning Material

1. Langacker, P., The Standard Model, Institute of Advanced Study Princeton, https://www.youtube.com/playlist?list=PLNhSjK9aGXjq22HAdhjMdJM3Ig4KdLayP

Preparatory Course Material

1. Peskin, M. E. & Schroeder, D. V., *An Introduction to Quantum Field Theory*, Addison-Wesley Pub. Co, 1995.

Title	**Dark Energy**	Number	PHL8XX0
Department	Physics	L-T-P [C]	3–0–0 [3]
Offered for		Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide background to understand concepts related to Dark Energy which is thought to comprise 68% of the known universe.
2. Provide background to develop insight of theoretical models of Dark Energy.

Learning Outcomes

The students are expected to have the ability to:

1. Grasp concepts of various matter and gravity modified models of Dark Energy.
2. Understand details of a number of experimental methods to probe Dark Energy.

Contents

Theoretical Framework: Friedmann equations, equation of state of dark energy, Correlation function and power spectrum, Cosmological perturbation theory, The Newtonian gauge, Single-fluid model, Scales larger than the horizon, Scales smaller than the Hubble radius, Two-fluid solutions, The matter power spectrum, Perturbed photon propagation. (10 Lectures)

Cosmological Constant: The fine-tuning problem, The coincidence problem, Supersymmetric models, Cosmological constant and the anthropic principle, The decoupling of the cosmological constant from gravity. (4 Lectures)

Modified Matter Models of Dark Energy: Quintessence, Quintessence potentials in particle physics, Reconstruction of quintessence from observations, k-essence, Phantoms, Coupled dark energy, Chameleon scalar fields, Dark energy models with scaling solutions, Unified models of dark energy and dark matter. (8 Lectures)

Modified gravity Models of Dark Energy: f (R) gravity, Gauss–Bonnet dark energy models, Scalar-tensor theories, Dvali, Gabadadze and Porrati (DGP) braneworld model. (4 Lectures)

Cosmic Acceleration without Dark Energy: Lemaître–Tolman–Bondi (LTB) models, Backreaction of Cosmological Perturbations. (4 Lectures)

Observational Methods: Type Ia Supernovae as Dark Energy Probe, Baryon Acoustic Oscillations (BAO) as Standard Ruler, The Alcock–Paczynski Test, Weak Gravitational Lensing, Weak Lensing Observational Results, Cluster Abundance as a Dark Energy Probe, X-Ray Gas Mass Fraction as a Dark Energy Probe, Gamma Ray Bursts and Radio Galaxies as Cosmological Probe. (12 Lectures)

Textbook

1. Amendola, L. & Tsujikawa, S., (2010), *Dark Energy: Theory and Observations*, Cambridge University Press.
2. Wang, Y., (2010), *Dark Energy*, Wiley-VCH.
3. Dodelson, (2000), *Modern Cosmology*, Elsevier.

Self-Learning Material

1. Turner, M., The Dark Side of the Universe: Dark Matter and Dark Energy, Department of Astronomy and Astrophysics, University of Chicago. http://videolectures.net/cernacademictraining2010_turner_dark/