M.Sc. Physics Syllabus

(Revised and operational from the Academic Year 2018-19)

Updated version: Jan. 2020

2-year Post-Graduate Programme:
Master of Science in Physics

Choice Based Credit System (CBCS)

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I. Programme Objectives

The Department of Physics, Gauhati University since its establishment in 1954 has been rendering service to society through Physics education and research and is known for its premier efforts in the North-East India. The Master of Science in Physics is the flagship programme of the department where students are trained to be competent to carry forward learning objectives of this natural science. The students will be able to understand the Core, Elective, and Open Elective Courses under the Choice Based Credit System (CBCS). The department has seven sections – Astronomy & Astrophysics, Condensed Matter Physics, Electronics, High Energy Physics, Nanophysics, Nuclear Physics, and Spectroscopy, and offers a range of elective courses to facilitate students to choose courses based on their interest.

Programme specific outcome: On completion of the course, a student acquires good theoretical and experimental knowledge of Physics. The students will get an exposure to a research field through project/dissertation. They could readily join a research programme in Universities/Institutes/Research Labs, or take up a teaching position.

II. Programme Structure

The M.Sc. programme in Physics is a 2-year course planned in four semesters. A student needs to complete the core courses, which are mandatory and common to all students, admitted to this programme. In addition, a student is required to opt for elective papers in Semester-III and Semester-IV. The students can choose project/dissertation under open elective category in order to undertake basic level research training in broad areas of Physics. The department offers a few open electives for students from other disciplines as well as for Physics students. A student from the parent department may also opt for an open elective offered by other departments.

a) Credit distribution for various courses in all four semesters:

Semester	Core			Elective			Open Elective			Total credits
	No. of papers	credits (L+T+P)	Total credits	No. of papers	Credits (L+T+P)	Total credits	No. of papers	Credits (L+T+P)	Total credits	
Sem-I	5	16+4+6	26	0	0	0	0	0	0	26
Sem-II	5	16+4+6	26	0	0	0	0	0	0	26
Sem-III	1	2+1+2	5	4	8+2+10 OR 12+3+5	20	0	0	0	25
Sem-IV	2	8+2+0	10	2	6+2+0	8	1	5+1+0 OR 3+1+2 OR 6	6	24
Total credits for Core courses										67
Total credit for Elective courses										28
Total credit for Open Elective courses										6
Grand total credits										101

*L– lecture, T– tutorial & assignments, P– practical

b) Semester wise break-up of courses, credits and marks

<table>
<tr><th>Semester</th><th colspan="4">Nature of courses</th><th>Total credits</th><th>Total marks</th></tr>
<tr><td>I</td><td colspan="4">Core 1, Core 2, Core 3, Core 4, Core 5 (Gen. Lab-I)</td><td>5+5+5+5+6=26</td><td>5×100=500</td></tr>
<tr><td>II</td><td colspan="4">Core 6, Core 7, Core 8, Core 9, Core 10 (Gen. Lab-II)</td><td>5+5+5+5+6=26</td><td>5×100=500</td></tr>
<tr><td>III</td><td>Core 11</td><td>E1+E2 (from any of Gr. A1/A2/A3/A4)</td><td colspan="2">E3+E4 (from any of Gr. B1/B2/B3)</td><td>5+5+5+5+5=25</td><td>5×100=500</td></tr>
<tr><td>IV</td><td>Core 12, Core 13</td><td>E5 (from any of Gr. A5/A6/A7/A8)</td><td>E6 (from any of Gr. B4/B5/B6)</td><td>Open Elective</td><td>5+5+4+4+6=24</td><td>5×100=500</td></tr>
<tr><td colspan="7">Total Core courses: 13</td></tr>
<tr><td colspan="7">Total Elective courses: 6</td></tr>
<tr><td colspan="7">Total Open Elective courses: 1</td></tr>
<tr><td colspan="7">Total credits: 101</td></tr>
<tr><td colspan="7">Total marks: 2000</td></tr>
</table>

c) Course structure in Semester-I

Semester-I						
Total number of Core courses: 5 *(No elective or open elective course is offered in this semester)*	Marks		Credits in Core courses			
	Sessional+ End Semester	Total	Lecture (L)	Tutorial & assignments (T)	Practical (P)	Total credits
PHY1015: Mathematical Physics	20+80	100	4	1	0	5
PHY1025: Classical Mechanics	20+80	100	4	1	0	5
PHY1035: Quantum Mechanics-I	20+80	100	4	1	0	5
PHY1045: Electrodynamics	20+80	100	4	1	0	5
PHY1056: General Lab-I	20+80	100	0	0	6	6
Total credit in Semester-I						26

d) Course structure in Semester-II

Semester-II						
Total number of Core courses: 5 *(No elective or open elective course is offered in this semester)*	Marks		Credits in Core courses			
	Sessional+ End Semester	Total	Lecture (L)	Tutorial & assignments (T)	Practical (P)	Total credits
PHY2015: Atomic, Molecular & Laser Physics	20+80	100	4	1	0	5
PHY2025: Nuclear Physics	20+80	100	4	1	0	5
PHY2035: Condensed Matter Physics	20+80	100	4	1	0	5
PHY2045: Electronics	20+80	100	4	1	0	5
PHY2056: General Lab-II	20+80	100	0	0	6	6
Total credit in Semester-II						26

e) Course structure in Semester-III

Semester-III		Marks		Credits			
Total number of Core course: 1 Total number of Elective courses: 4 *(No open elective course is offered in this semester)*		Sessional + End Semester	Total	L	T	P	Total credits
Core Course PHY3015: Computational Physics		20+80	100	2	1	2	5
Elective Courses (Group A): Elective-I: *Any one combination with total 10 credits to be chosen from **Group A1 to Group A4***							
Group A1	PHY3025: Advanced Nuclear Physics-I	20+80	100	4	1	0	5
	PHY3035: Advanced Nuclear Physics Lab	20+80	100	0	0	5	5
Group A2	PHY3045: Advanced Condensed Matter Physics-I	20+80	100	4	1	0	5
	PHY3055: Advanced Condensed Matter Physics Lab	20+80	100	0	0	5	5
Group A3	PHY3065: Astronomy & Astrophysics-I	20+80	100	4	1	0	5
	PHY3075: Astro Lab	20+80	100	0	0	5	5
	PHY3085: Advanced Mathematical Physics	20+80	100	4	1	0	5
	Note: *Either PHY3075 or PHY3085 may be opted with PHY3065.*						
Group A4	PHY3095: Nanophysics-I	20+80	100	4	1	0	5
	PHY3105: Nanophysics Lab	20+80	100	0	0	5	5
Elective Courses (Group B): Elective-II: *Any one combination with total 10 credits to be chosen from **Group B1 to Group B3***							
Group B1	PHY3115: Advanced Electronics-I	20+80	100	4	1	0	5
	PHY3125: Advanced Electronics Lab	20+80	100	0	0	5	5
Group B2	PHY3135: High Energy Physics-I	20+80	100	4	1	0	5
	PHY3085: Advanced Mathematical Physics	20+80	100	4	1	0	5
	Note: *For combinations of Group B2 with Group A3, PHY3075 should be opted with PHY3065*						
Group B3	PHY3145: Lasers & Spectroscopy-I	20+80	100	4	1	0	5
	PHY3155: Lasers & Spectroscopy Lab	20+80	100	0	0	5	5
Total credit in Semester-III							25

*L– lecture, T– tutorial & assignments, P– practical.

f) Course structure in Semester-IV

Semester-IV							
Total number of Core courses: 2 Total number of Elective courses: 2 Total number of Open Elective course: 1		Marks		Credits			
		Sessional + End Semester	Total	L	T	P	Total credits
Core Courses							
PHY4015: Statistical Mechanics		20+80	100	4	1	0	5
PHY4025: Quantum Mechanics-II		20+80	100	4	1	0	5
Elective Courses (Group A): Elective-III: *One course of 4 credits* ***in line with Group A1 to Group A4*** *of Semester-III to be chosen*							
Group A5	PHY4034: Advanced Nuclear Physics-II	20+80	100	3	1	0	4
Group A6	PHY4044: Advanced Condensed Matter Physics-II	20+80	100	3	1	0	4
Group A7	PHY4054: Astronomy & Astrophysics-II	20+80	100	3	1	0	4
Group A8	PHY4064: Nanophysics-II	20+80	100	3	1	0	4
Elective Courses (Group B): Elective-IV: *One course of 4 credits* ***in line with Group B1 to Group B3*** *of Semester-III to be chosen*							
Group B4	PHY4074: Advanced Electronics-II	20+80	100	3	1	0	4
Group B5	PHY4084: High Energy Physics-II	20+80	100	3	1	0	4
Group B6	PHY4094: Lasers & Spectroscopy-II	20+80	100	3	1	0	4
Open Elective Course Elective-V: *One course of 6 credits needs to be chosen. The students may also opt an open elective course from other departments/institutes as per the guidelines of P.G. CBCS of Gauhati University. These courses are open to students from other departments/institutes as well subject to availability of seats and fulfillment of prerequisites as notified by the department and CBCS, Gauhati University.*							
PHY4106: Atmospheric Physics		20+80	100	5	1	0	6
PHY4116: Nano Fabrication		20+80	100	3	1	2	6
PHY4126: Plasma Physics		20+80	100	3	1	2	6
PHY4136: Project/Dissertation		20+80	100	Experiment/ Theory			6
PHY4146: Fundamentals of Lasers & Photonics		20+80	100	5	1	0	6
Note: *PHY4146 is exclusively for the students from other departments/institutes*							
Total credit in Semester-IV							24

*L– lecture, T– tutorial & assignments, P– practical

III. Course Wise Syllabi with Course Objectives

Semester-I

Course Code: PHY1015

Course Name: Mathematical Physics

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *The students will be able to learn the relevance of different tools of pure mathematics in the context of the laws of physics and hence will be able to apply the same to deal with the different concrete problems of natural phenomena.*

Contents

Unit-I: Linear Vector Spaces

N-dimensional linear vector space, orthonormal basis, Inner product, Hilbert space, Gram-Schmidt orthonormalisation, Outer product. Linear operators and their algebra, Matrix representation of operators, Similarity transformation, Diagonalisation of Hermitian, Symmetric, Complex and Complex symmetric matrices, Cayley-Hamilton theorem.

Unit-II : Tensor Calculus

Manifolds and coordinate systems. Transformation of coordinates: Galilean and Lorentz transformations. Tangent vectors and gradients. Metric tensor in different curved spaces. Four vectors and physical examples from special relativity and electrodynamics. Covariant derivatives and parallel transport. Geodesics. Idea of curvature. Calculation of Laplacian in curved spaces.

Unit-III: Special Function and Partial Differential Equations

Associated Legendre polynomials and spherical harmonics - physical applications. Applications of Hermite's Polynomials, Bessel function and Spherical Bessel function, Hypergeometric equations (solutions only). Gamma, Beta functions, Dirac-□ function. One-dimensional wave equation, one-dimensional heat flow equation (finite and infinite rod). Laplace's equation and its solution. Green's function.

Unit-IV: Integral Equations

Integral equations and their classifications - Fredholm and Volterra types. Method of substitution.

Unit-V: Integral Transformations

Laplace transform and inverse Laplace transform. Fourier transform. Shifting theorem and convolution. Solution of differential equations with the help of Laplace and Fourier transform.

Unit-VI: Group Theory

Group axioms, permutation groups (S_2 and S_3) and symmetry operations of equilateral triangle, multiplication table, subgroup, classes, finite groups (Z_n), direct and semi-direct products, block diagonalisation - reducible and irreducible representation. Infinite group, generators and their algebra, spin/Isospin invariance and SU(2) group, SO(3) group and its generators, Isomorphism.

Suggested Books

1. *Mathematical methods for physicists*, Arfken and Weber
2. *Mathematical Physics* , P K Chattopadhyay
3. *Mathematical Physics*, B S Rajput
4. *Matrices and tensors in Physics*, A W Joshi
5. *Mathematical methods in the Physical Sciences*, Mary L Boas
6. *Mathematics for physicists*, P Dennery and A Krzywick
7. *Partial differential equations of Mathematical Physics* , A G Webster
8. *Differential equations and their applications*, Zafar Ahsan
9. *Mathematical Physics*, A G Ghatak, I C Goyal and S J Chua

Semester-I

Course Code: PHY1025

Course Name: Classical Mechanics

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *This course aims at introducing the foundation of physics – the theory of classical mechanics.The students will be able to describe a wide variety of physical phenomena by the Lagrangian and the Hamiltonian formalisms. They will be able to generalise the laws of physics in higher dimensions, and will be able to apply the formalism of classical mechanics to more advanced frameworks.*

Contents

Unit-I: Formalism of Classical Mechanics

Lagrangian and Hamiltonian formalisms and equations of motion - their applications to physical problems. Cyclic coordinates, Variational principle and Noether's theorem, symmetry & conservation laws; Special theory of relativity, addition of velocities, Lorentz transformations and the light cone, relativistic form of Lagrangian and Hamiltonian relativistic kinematics and mass–energy equivalence, Covariant form of electromagnetic equations and their Lorentz invariance.

Unit-II: Central Force Problems

Central-force motion - two-body collisions, Kepler problem, Effective potential, Scattering in laboratory and centre-of-mass frames.

Unit-III: Rigid Body Dynamics

Rigid body dynamics, moment of inertia tensor, non-inertial frames and pseudo forces. Principal axes and principal moments of inertia. Euler's equation of motion. Symmetric top motion and Foucault's pendulum.

Unit-IV: Theory of Canonical Transformation

Poisson brackets and their properties; Canonical transformations and generating function. Hamilton's equation in terms of Poisson bracket, Jacobi identity.

Unit-V: Hamilton-Jacobi & Action Angle Formalism

Hamilton's Jacobi theory and its application to solve central force problem. Action–angle variables, application to simple harmonic oscillator, planetary motion, adiabatic invariants.

Unit-VI: Theory of Small Oscillations

Equilibrium and small oscillations, normal coordinates, normal modes, coupled oscillations, diatomic and triatomic molecules.

Unit-VII: Fluid Dynamics

Fluid variables; Equation of continuity; Perfect fluid motion, Euler's and Bernoulli's equations, vorticity, Navier-Stoke's equation.

Unit-VIII: Nonlinear Dynamics

Introduction to nonlinear systems, concept of catastrophe, bifurcation, chaos and strange attractors, fractals, physical examples.

Suggested Books

1. *Classical Mechanics*, H. Goldstein
2. *Classical Mechanics*, Rana and Joag
3. *Mechanics*, Landau and Lifshitz
4. *Classical Mechanics*, V. B. Bhatia
5. *Classical Mechanics*, A. K. Raychaudhury
6. *Classical Mechanics of Particles and Rigid Bodies*, K. C. Gupta
7. *Introduction to Mathematical Physics - Methods and Concepts*, C. W. Wong
8. *Chaos and Nonlinear Dynamics*, S Strogatz

<u>**Semester-I**</u>

Course Code: PHY1035

Course Name: Quantum Mechanics-I

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *The objective of this course is to introduce students to the laws of Physics in the context of the micro world. The students will be able to understand the underlying mechanics of atomic and sub-atomic phenomena. This course delivers the essence of wave mechanics and matrix formulations of quantum mechanics, concept of identical particles, symmetry, and approximation methods.*

<u>**Contents**</u>

Unit-I: Basic Principles of Quantum Mechanics

Essence of wave mechanics, physical interpretation of wave function, central potential, spherical harmonics and complete wave function (H-atom), orbital angular momentum. Particles at potential steps and potential barriers. Quantum wells and bound states. Matrix formulation of quantum mechanics, Bra and Ket vectors and applications, orthonormal and completeness conditions, simultaneous eigen states, expectation values, linear harmonic oscillator in operator method. Heisenberg's uncertainty principle in matrix mechanics. Heisenberg's equation of motion and physical equivalence of Schrödinger & Heisenberg picture.

Unit-II: Identical Particles

Indistinguishability, combinations of wave functions for a system of particles, symmetric and antisymmetric wave functions, spin-statistics connection, evolution of quantum statistics, exchange symmetry and exchange degeneracy.

Unit-III: Symmetry, Invariance Principle, and Conservation

Space and time translations, rotational invariance under infinitesimal and finite rotations. Angular momentum operators, ladder operators, addition of angular momenta - Clebsch-Gordan coefficients.

Unit-IV: Approximation Methods in Quantum Mechanics

Time independent perturbation theory, Stark and Zeeman effects, variational method and its applications, WKB approximation, time dependent perturbation theory, transition to continuum states, Fermi's Golden rule, adiabatic and sudden approximation.

Suggested Books

1. *Quantum Mechanics*, L I Schiff
2. *Quantum Mechanics*, S N Biswas
3. *Quantum Mechanics*, A K Ghatak and S Lokanathan
4. *Introductory Quantum Mechanics*, R L Liboff
5. *Principles of Quantum Mechanics*, R Shankar
6. *Quantum Mechanics: concepts and applications*, N Zettili

Semester-I

Course Code: PHY1045

Course Name: Electrodynamics

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *The students will acquire advanced knowledge of electromagnetic fields, propagation and scattering of electromagnetic waves. They will be able to investigate the collective behaviour of charged particles and their dynamics, which provides the basic working model of plasma.*

Contents

Unit-I: Boundary-value Problems in Electrostatics

Electrostatic boundary value problems, solution of problems involving Laplace's and Poisson's equations in spherical, cylindrical and Cartesian coordinates, use of Green's function approximation.

Unit-II: Gauge Transformations

Review of Maxwell's equations, electromagnetic potentials, gauge transformation, Lorentz and Coulomb gauge, gauge invariance.

Unit-III: Propagation of Electromagnetic Waves

Propagation of electromagnetic waves in free space, non-conducting and conducting media, reflection and transmission at the boundary of two non-conducting media, reflection from a metal surface, propagation of electromagnetic waves in bounded media, wave guides.

Unit-IV: Scattering of Electromagnetic Waves

Scattering of electromagnetic waves due to free electrons, Thomson scattering, scattering from bound electrons, Rayleigh scattering and resonance fluorescence, dispersion – normal and anomalous.

Unit-V: Motion of Charged Particles

Non-relativistic motion of a charged particle in uniform constant fields and slowly varying field; gradient drift, magnetic mirror.

Unit-VI: Radiation Fields

Retarded potential, radiation from oscillatory dipole, radiation fields, radiation from a point charge in motion, Lienard-Wiechart potential, fields of a point charge in motion, power radiated by a point charge, Larmor formula, Bremsstrahlung.

Unit-VII: Covariant Form of Maxwell's Equations

Four dimensional Lorentz transformation, covariance of Maxwell's equations, electromagnetic field tensor.

Unit-VIII: Basics of Plasma

Propagation of plane electromagnetic waves in low pressure ionised gases, conductivity of ionised gas, plasma frequency, Debye screening length, propagation of transverse waves in a perfectly conducting fluid embedded in a magnetic field (frozen-in field), and MHD, Alfvén waves, basic idea of plasma confinement.

Suggested Books

1. *Introduction to Electrodynamics*, D J Griffiths
2. *Foundation of Electromagnetic Theory*, J R Reitz, F J Milford and R W Christy
3. *Electricity and Magnetism*, M H Nayfeh and M K Brussel,
4. *Classical Electrodynamics*, J D Jackson
5. *The Feynman Lectures on Physics (Vol II)*, R P Feynman
6. *Introduction to Plasma Physics*, F F Chen
7. *Plasma Physics*, R J Goldstone and P H Rutherford.

Semester-I
Course Code: PHY1056
Course Name: General Lab-I

Marks: 100 (20+80) **Credit:** 6 (0L+0T+6P)

Course Outcome: *This course aims at performing basic physics experiments by the students. The students will be able to bring out responses in the concerned equipments for general physics experiments. They will be able to justify some of the theoretical understanding of Physics.*

Contents

The students need to complete at least eight experiments from the given set of practicals and the tentative list of experiments is enumerated below.

A1. *Study OPAMP as amplifier and RC phase shift oscillator. Draw the transfer characteristics of the amplifier in different feedback configurations. Estimate the practical and theoretical frequency of oscillation.*

A2. *Design an integrator and differentiator circuit using 741 IC. Draw the frequency response and observe the output for different inputs.*

A3. *Determine the track spacing and pattern of the tracks of a CD.*

A4. *Determine the Young's modulus of the material of a rod by Newton's ring method.*

A5. *Determine the Stefan's constant using ballistic galvanometer.*

A6. *Measure the resistivity and hence the band gap of a semiconductor using four-probe method.*

A7. *Determine the plateau of the given GM counter and its percentage slope. Hence, study the statistical fluctuation (with beta source).*

A8. *Study the absorption of beta rays passing through different thickness of Al and determine the linear absorption coefficient.*

B1. *Study OPAMP as amplifier and RC phase shift oscillator. Draw the transfer characteristics of the amplifier in different feedback configurations. Estimate the practical and theoretical frequency of oscillation.*

B2. *Design an integrator and differentiator circuit using 741 IC. Draw the frequency response and observe the output for different inputs.*

B3. *Determine the velocity of ultrasound in given liquids.*

B4. *Verify the Heisenberg's uncertainty principle using He-Ne laser.*

B5. *Measure the resistivity and hence the band gap of a semiconductor using four-probe method.*

B6. Find the constant of ballistic galvanometer using *i-H* and *d-H* curves.

B7. *Determine the plateau of the given GM counter and its percentage slope. Hence, study the statistical fluctuation (with beta source).*

B8. *Study the absorption of beta rays passing through different thickness of Al and determine the linear absorption coefficient.*

N.B.: The students are distributed in two groups – **Group A** and **Group B**. Accordingly, the set of experiments, either **A1–A8** or **B1–B8** should be completed for this course.

Suggested Reference

1. *Laboratory Manual,* General Lab-I

<u>Semester-II</u>
Course Code: PHY2015

Course Name: Atomic, Molecular & Laser Physics

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *The students will be able to determine certain parameters associated with length, mass, time and energy from atomic and molecular spectra. They will be able to explain the working of a few laser systems.*

<u>Contents</u>

Unit-I: Atomic Physics

Pauli exclusion principle: spectral terms from two equivalent electrons, Vector model for three or more valence electrons and spectral terms, branching rule, Landé interval rule, LS and j-j coupling schemes, energy levels, selection rules, spectra of oxygen, nitrogen and manganese atoms; Zeeman effect, Paschen-Back effect, Stark effect in hydrogen, hyperfine structure, determination of nuclear spin and nuclear g-factors, Breadth of spectrum lines: natural broadening, Doppler broadening, collision broadening, and Stark broadening.

Unit-II: Molecular Physics

IR spectra - rotation, vibration and rotation-vibration spectra of diatomic molecules, selection rules, determination of rotational constants. Electronic spectra: Born-Oppenheimer approximation, vibrational structure of electronic transition, progressions and sequences of vibrational bands, Intensity distribution, Franck Condon principle. Raman spectra: Classical theory of Raman effect, Vibrational Raman spectrum, selection rules, Stokes and anti-Stokes lines, Rotational Raman spectrum, selection rule.

Unit-III: Lasers

Basic elements of a laser, properties of laser light; spontaneous and stimulated emission: Einstein coefficients, light amplification, population inversion and threshold condition for laser oscillations, optical resonator modes of a rectangular cavity, rate equations: two-level, three-level and four-level systems; ammonia maser, ruby laser, He-Ne laser, CO_2 lasers, laser applications: holography and optical communication.

Suggested Books

1. *Introduction to Atomic Spectra*, H E White.
2. *Physics of Atoms and Molecules*, B H Bransden and C J Joachain
3. *Fundamentals of Molecular Spectroscopy*, C N Banwell and E M McCash.
4. *Spectra of Diatomic Molecules (Vol. 1)*, G Herzberg.
5. *Lasers and Nonlinear Optics*, B B Laud.
6. *Lasers : Theory and Applications*, K Thyagarajan and A K Ghatak.

Semester-II

Course Code: PHY2025

Course Name: Nuclear Physics

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *The students will be able to give an in-depth description of the nucleus and its various properties. They will be able to describe the structure of the nucleus and the nature of the interaction that keeps the nucleus bound.*

Contents

Unit-I: General Properties of Nuclei

Basic Nuclear Properties: size, shape and charge distribution, spin, parity and isospin of nucleon and nuclei.

Unit-II: Models of Nuclei

Liquid drop Model: Semi empirical mass formula and its applications in - (i) Estimation of energy released in fission reactions, (ii) predicting the most stable member of an isobaric family, (iii) predicting the condition for spontaneous fission. Failure of Liquid drop Model. Shell Model: Magic numbers and experimental evidences of shell models, Single particle shell model and its application in predicting the spin and parity of even A and odd A nuclei, Failures of extreme single particle shell model. Concepts of collective model of nuclei.

Unit-III: Nuclear Reaction

Concept of two body nuclear reaction for fixed target experiments - concept of flux, fluence, pnA, solid angle, cross-section, Classifications of nuclear reactions, Kinematics of two body nuclear reaction - Lab and CMS co-ordinate systems, Rutherford alpha particle scattering experiment - corrections for extended object, quantum mechanical and relativistic effects. Concept of nuclear reaction - Bohr compound nucleus hypothesis and Ghosal experiment.

Unit-IV: Forces between Nucleons

Two nucleon system - bound state problem, Characteristics of nucleon-nucleon interactions, Deuteron as the simplest two body bound system - its ground state spin, parity, magnetic dipole and electric quadruple moments, experimental values, concept of non-central nuclear force, Deuteron ground state with square-well potential.

Unit-V: Nuclear Instrumentation

Part A: Radiation Detectors

Interaction of charged particles and radiation with matter, detector response, efficiency and resolution of a detector. Gas filled detector: current vs applied voltage curve, Ionisation region, Proportional region, GM region and spark region. Construction and working principle of GM counting system, its advantages and limitations.

Part B: Charge Particle Accelerators

Linear accelerator (LINAC) - Pelletron-construction and principle of operation, its advantages and limitations.

Part C: Cyclic Accelerators

Cyclotron - Construction and principle of operation, its advantages and limitations, Concept of synchro-cyclotron.

Unit-VI: Nuclear Decay

Essential condition of beta decays, beta ray spectrum, apparent violation of energy-momentum conservation rules in beta decay, Pauli's neutrino hypothesis, experimental discovery of neutrino - Cowan's experiment, Fermi's theory of beta decay, Kurie plot and concept of massive neutrino, 2□ and 0□ double beta decays.

Unit-VII: Elementary Particles

Classifications of elementary particles and their interactions, conservation laws, symmetry principles and quantum numbers, strangeness and isospin, Gellman-Nishijima scheme, Quark model.

Suggested Books

1. *Introductory Nuclear Physics*, Kenneth S Krane
2. *Introductory Nuclear Physics*, Samuel S M Wong
3. *Atomic and Nuclear Physics (Vol. 2)*, S N Ghoshal
4. *Concepts of Modern Physics*, Arthur Beiser
5. *Techniques for Nuclear and Particle Physics Experiments*, W R Leo
6. *Nuclear reactions and structure studies*, P E Hodeson
7. *Techniques of radiation Measurements*, G F Knoll

Semester-II

Course Code: PHY2035

Course Name: Condensed Matter Physics

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *This course aims at acquiring the knowledge of matter in the condensed phase, their structural, electrical, and magnetic properties. The students will be able to compute parameters related to extent and nature of crystallinity, conductivity, defects etc and the way these affect some basic properties.*

Contents

Unit-I: Crystalline Solids
Fundamentals of crystal structure, symmetry operations, point groups and space groups, X-ray diffraction, reciprocal lattice, atomic scattering factor, geometrical structure factor, Quasicrystals, Imperfection in solids, Fick's law.

Unit-II: Lattice Dynamics
Dispersion relations in monoatomic and diatomic linear lattices, normal modes, phonons.

Unit-III: Dielectric and Ferroelectric Properties
Complex dc dielectric constant and dielectric loss, dielectric relaxation, Debye equations, dipole theory of ferroelectric domains, anti-ferroelectricity.

Unit-IV: Energy Bands in Solids
Bloch function, Kronig-Penney model, Brillouin zones, effective mass of charge carriers. Tight binding and Wigner Seitz method. Very brief idea about Thin Film Physics, Nanophysics, and Soft Condensed Matter Physics.

Unit-V: Semiconductors
Intrinsic and extrinsic semiconductor, number density of carriers in intrinsic and extrinsic semiconductors, expression for Fermi levels, recombination processes, photoconductivity, Hall effect in metals and semiconductors, QHE.

Unit-VI: Magnetic Properties
Fundamental concepts, quantum theory of diamagnetism and paramagnetism, diamagnetic and paramagnetic susceptibilities of free electrons, molecular field theory of ferromagnetism, anti-ferromagnetism and ferrimagnetism, anisotropic energy, electron paramagnetic resonance and nuclear magnetic resonance.

Unit-VII: Superconductivity
Thermodynamics of superconducting state, London equations, coherence length, idea of BCS theory, flux quantization, Josephson effect.

Suggested Books

1. *Introduction to Solid State Physics*, C Kittel
2. *Lattice Dynamics*, A K Ghatak and L S Kothari
3. *Solid State Physics*, A J Dekker.
4. *Introductory Solid State Physics*, H P Myers.
5. *Solid State Physics*, N W Ashcroft and N D Mermin
6. *Magnetism in solids*, D H Martin
7. *Physics of Magnetism*, S Chikazumi.

Semester-II

Course Code: PHY2045

Course Name: Electronics

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *The students will become acquainted with important electronic devices, circuits and microprocessors.*

Contents

Unit-I: Electronic Devices and Nanoelectronics

Part A: Electronic Devices
Carrier concentrations in semiconductors; direct and indirect band gap semiconductors, Band structure of p-n junction; Homo and hetero-junction devices; Thyristor devices: SCR, UJT, Triac; FET Devices: JFET, MOSFET, MESFET, CMOS; Opto Electronic Devices: Optical absorption, Beer-Lambert law, Solar Cell, Photodetectors, LED, Laser Diodes; Microwave devices: Basic principle of operation of a Klystron and Cavity Magnetron, quantum mechanical phenomenon and tunnel diode, transferred electron effect and Gunn Diode, IMPATT/AVALANCHE diode; Fabrication of semiconductor devices, Noise in electronic devices.

Part B: Nanoelectronics
Introduction to quantum view of bulk solids: key ideas in electronic properties. Review of basic semiconductor device physics with a broad survey of modern device technology. Introduction to nanomaterials and their special features in electronics. Overview of nanoelectronics devices and materials requirement.

Unit-II: Operational Amplifier and Linear Integrated Circuits

Differential Amplifier, OPAM circuits, comparators, logarithmic amplifiers, Analog Computation, Active filters, digital to analog converter: Binary Weighted R-2R ladder network, 555 timer, voltage regulators, voltage-controlled oscillator, phase locked loop, waveform generators.

Unit-III: Digital Circuits

Logic families; Signal levels and noise margin; Boolean algebra; Combinational logic: adders, subtractors; Encoders; Decoder; Multiplexer; Demultiplexer; Comparator; parity generator and checker; Sequential logic: flip-flop; Register; Counters; Memory Concepts; Analog to Digital Converter, Basics of microprocessor.

Suggested Books

1. *Electronic Devices and Circuit Theory*, R L Boylestad
2. *OPAMPS and Linear Integrated Circuits*, Ramakant A Gayakwad.
3. *Operational Amplifier and Linear Integrated Circuits*, R F Coughlin and F F Driscoll.
4. *Modern Digital and Analog Communication Systems*, B P Lathi.
5. *Electronic Communication System*, George Kennedy.
6. *Communication Systems*, Simon Haykin.

Semester-II

Course Code: PHY2056

Course Name: General Lab-II

Marks: 100 (20+80) **Credit:** 6 (0L+0T+6P)

Course Outcome: *This course aims at performing basic physics experiments by the students. The students will be able to determine some physical parameters and design circuits to understand important principles of Physics.*

Contents

The students need to complete at least eight experiments from the given set of practicals and the tentative list of experiments is mentioned below.

A1. *To determine the thickness of a given mica sheet by using Jamin's interferometer*

A2. *To find out the separation between the sodium D-lines using a grating and hence to determine the minimum number of lines required in the given grating to resolve sodium D-lines in the first and second order.*

A3. *Perform the Hall Effect experiment by recording the Hall voltage at different sample currents under different magnetic field strengths. Plot suitable graph and hence determine Hall coefficients. Identify conductivity type of the semiconductor.*

A4. *To study the dispersion relation for the monoatomic and diatomic lattice*

A5. *To determine the beta particle range and maximum energy by half thickness method*

A6. *To verify inverse square law for gamma rays using GM tube*

A7. *Using a 741 IC (a) design 1st and 2nd order Low pass filter, high pass filter,(b) draw the frequency response ,(c) find the roll off rate ,(d) determine the gain and theoretical & practical cutoff frequencies.*

A8. *Design an astable multivibrator using 555 IC to produce square wave pulse and to find out the frequency.*

B1. *Determine wavelength of a given light source using the Michelson interferometer*

B2. *Determination of the grating element of the double slit by observing interference and using lamp and scale method*

B3. *Perform the Hall Effect experiment by recording the Hall voltage at different sample currents under different magnetic field strengths. Plot suitable graph and hence determine Hall coefficients. Identify the conductivity type of the semiconductor.*

B4. *Determine the coercivity, retentivity, and saturation magnetization of a given ferromagnetic specimen using B–H loop curve.*

B5. *Determine the beta particle range and maximum energy by half thickness method*

B6. *Verify inverse square law for gamma rays using a GM tube.*

B7. *Using a 741 IC (a) design 1st and 2nd order Low pass filter, high pass filter,(b) draw the frequency response ,(c) find the roll off rate ,(d) determine the gain and cutoff theoretically and practically*

B8. *Design a FM modulator using a 555 IC. Estimate the modulation index, bandwidth and spectra for different amplitude of the modulating signal. Draw the FM spectra.*

N.B.: The students are distributed in two groups – **Group A** and **Group B**. Accordingly, the set of experiments, either **A1–A8** or **B1–B8** should be completed for this course.

Suggested Reference

1. *Laboratory Manual,* General Lab-II

Semester-III

Course Code: PHY3015

Course Name: Computational Physics

Marks: 100 (20+80) **Credit:** 5 (2L+1T+2P)

Course Outcome: *This course aims to acquaint students with computer programming and numerical analysis. Through this course, students will be able to learn the useful computational techniques to find out solutions to those complicated physical problems where analytic solutions are not obtainable.*

Contents:

This paper has a theory and practical part combined together.

***Unit-I**: Computer Programming*

Part A: Introduction to programming, basics of computer programming, concepts of file structure, directories, compilers and debuggers in relation to GNU Linux O/S. Basic commands in GNU Linux. Plotting with GNUPLOT.

Part B: Introducing FORTRAN 90, FORTRAN 90 as a structured programming language for solving scientific problems. Basic structure of FORTRAN 90- concept of variables, operators, and precedence of operations. Difference between a mathematical statement and a FORTRAN statement - incrementing a variable. Global and local variables - concept of modules and indexed variables (arrays). Types of variables- integer, floating point, and character variables. Concept of logical statements- if-then-else, do-while statements. Structured programming - function and subroutine. I/O statements and formatting.

***Unit-II**: Numerical Analysis*

Part A: Introduction to numerical analysis. The need for numerical analysis and its limitations. Concept of errors with examples.

Part B: Solution of transcendental equations. Solving an equation with Newton-Raphson method and bisection, comparison of their limitations, propagation of errors.

Part C: Solution of ordinary differential equations (ODEs). Concept of finite differencing. Solution of a first order ODE with Euler's method and its limitations. Need for a higher-order method - solution of a first order ODE with Runge-Kutta method. Solving higher order ODE- coupled ODEs.

Part D: Numerical integration. The concept of numerical integration - quadrature. Trapezoidal and Simpson's rules and their relation to interpolation.

Part E: Partial differential equations (PDEs). The concept of initial and boundary value problems- solving the Poisson equation by Gauss-Siedel iteration. Concept of numerical stability-von Neumann stability analysis with examples and importance Courant-Friedrichs-Lewy (CFL) condition. Implicit and explicit schemes.

Part F: Manipulation of matrix. Solution of linear equations - Gauss-Jordan elimination. Concept of pivoting.

Part G: Random numbers in numerical analysis. The concept of random numbers - pseudo random numbers and their generators. Application - Monte-Carlo integration. Examples from Physics to be given.

Suggested Books

1. *Numerical Recipes*, W H Press, S A Teukolsky, W T Vetterling, B P Flannery
2. *Fortran 90 Handbook,* J C Adams, W S Brainerd, J T Martin, B T Smith, J L Wagener
3. *Computer Oriented Numerical Methods,* V Rajaraman

<u>Semester-III</u>

Course Code: PHY3025

Course Name: Advanced Nuclear Physics-I

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *This course is an advanced course in Nuclear Physics developed in continuation with the Semester-II. After completion of this course, the students will have advanced knowledge on Nuclear Structure – shell and collective models, their success and failures; Nuclear Reactions nucleon-nucleon scattering, reactions of nucleons and nuclei with heavy ions at low energies (MeV), about Nuclear Multipole Radiations - properties of electric and magnetic multipole transitions, and Nuclear Radiation Detector - construction and working principles of various photon and charged particle detectors. The course also covers an introduction to neutron physics - production, detection and slowing down of neutrons as well as construction and working principles of various nuclear detectors – both photon and charge particle detectors.*

<u>Contents:</u>

Unit-I: Nuclear Models

(i) Applications of SPSM: Magnetic dipole moments of nucleon and nuclei in the light of SPSM - C-N Catastrophe, Schmidt's one nucleon model of total angular momentum and total magnetic moment. Electric quadrupole moments of various nuclei with single particle and many particles outside the closed shell.

(ii) Collective Models : Failure of shell model in understanding the excited states of odd A and even-even nuclei, Evidences in favour of collective motion of nucleons, dynamics of collective motion, vibrational modes-volume and shape vibrations, EOS of a vibrating nuclei, states of vibrational model. Rotational model and rotational energy states of a deformed nucleus. Shell model with asymmetric potential-Nilsson model - labeling of energy levels of Nilsson Model (first few levels only).

Unit-II: Electromagnetic Interaction with Nuclei

Multipole expansion of Radiation field, multipolarity, gamma-ray transition probability, Angular momentum and Parity selection rules. Comparison with experiments, Nuclear Isomerism, Internal Conversion of gamma-rays, Angular distribution of gamma-rays, Angular correlation in gamma-gamma-cascade.

Unit-III: Nuclear Reactions

(i) Optical Model of Nuclear Reaction: General concept of optical model (OM) for elastic scattering, Optical potential for N-N scattering, OM parameters, imaginary part of OM and absorption - interpretation in scattering experiment results.

(ii) Compound Nuclear Model: Difference between a direct reaction and compound nucleus (CN) formation process. Compound nucleus processes - a) cross section for discrete levels of CN , b) cross section for overlapping CN levels. Statistical theory of CN, Dependence of nuclear entropy and energy on nuclear temperature and Evaporation theory of nuclear reaction.

(iii) Transfer and inelastic scattering: Definitions of transfer and inelastic scattering with examples, Born amplitute and Distorted Wave Born approximation (DWBA) for rearrangement reaction.

(iv) Compound Nucleus Resonance: Concept of cross section in terms of scattering and reaction. Nuclear cross sections in terms of phase shift (or nuclear radius), Breit-Wigner formula in the neighborhood of a single isolated resonance level i.e. l=0 (s-wave) and all values of l.

Unit-IV: Nuclear Radiation Detector

Photon Detectors: Interaction of gamma radiation with matter – photo-electric effect, Compton effect and pair production; Scintillation detector – NaI(Tl) scintillation detector and PMT- construction and working principle. Ge (Li) detector – an introduction.

Charged particle detectors: Silicon surface barrier (SSB) detector – construction and working principle. Solid State Nuclear Track Detector (SSND)- formation of tracks in solids, track visualization, applications of SSNTDs.

Nuclear Electronics: Pulse Signals in Nuclear Electronics, The Frequency Domain, Bandwidth, Pre-amplifiers, Main Amplifiers, Discriminators, Single-Channel Analyzer, ADC, TDC, MCA, Coincidence Units.

Unit-V: Neutron Physics

Neutron Physics: Classification of neutrons based on their kinetic energy. Sources of neutron - radioactive and other sources. Detection of neutrons - fast and slow neutrons detectors - BF_3 proportional counter and scintillation neutron detectors. Slowing down of neutrons - fractional energy loss, logarithmic decrement. Fermi age equation.

Suggested Books

1. *Introductory Nuclear Physics*, Kenneth S Krane
2. *Nuclear Physics: Theory and Experiment*, Roy and Nigam
3. *Introduction to Nuclear Reactions*, G R Satchle
4. *Nuclear & Particle Physics*, W E Burcham, M Jobes
5. *Nuclear Physics - Principles & Applications*, John Lilley
6. *Radiation Detection and Measurement*, G F Knoll
7. Concept of Nuclear Physics - B L Cohen
8. *Techniques for Nuclear and Particle Physics Experiments*, W R Leo
9. *Nuclear Radiation Detector*, S S Kapoor and V S Ramamurthy
10. *Introduction to Nuclear & Particle Physics,* A Das & T Ferbel.

<u>Semester-III</u>

Course Code: PHY3035

Course Name: Advanced Nuclear Physics Lab

Marks: 100 (20+80) **Credit:** 5 (0L+0T+5P)

Course Outcome: *This course is designed for advanced students to provide an hand-on experience on various nuclear detectors such as GM Counters, Scintillation detector, Si Surface Barrier detector, Nuclear emulsion and Solid State Nuclear Track Detector (SSNTD). Besides these, the students will have practical experience of working with thermal neutron source, alpha, beta and gamma sources. Students will also learn handling various components such as HVPS, Pre-Amp, Main Amp, Oscilloscope, SCA/MCA, Signal generator of data acquisition system. They will learn how to create and measure low pressure using rotary pump and Pirani gauge.*

List of Experiments *(All experiments are compulsory)*

Expt 1: *To produce an artificial beta radioactive In^{116*} source using thermal neutrons from a neutron howtizer and determine the halflife of the produced source.*

Expt 2: *To draw the energy spectrum of alpha particles emitted from the radioactive Am^{241} α- source using a Silicon Surface Barrier (SSB) detector and a Multi Channel Analyser (MCA) and hence to find the energy resolution of the SSB detector.*

Expt 3: *(i) To scan a given nuclear emulsion plate to determine the mean number (N) of heavily ionizing charged particles emitted in h-Em interactions. Hence draw the Nh distribution curve for the scanned interactions and calculate the excitation energy of the interaction.*
(ii) To determine the scattering cross-section for the studied interactions.

Expt 4: *(i) To study the complete spectrum of different gamma sources and to locate the corresponding photo peak, compton edge etc. using NaI(Tl) scintillation detector and single channel analyser (SCA) and draw calibration curve.*
(ii)To find the resolution R for different energies and hence to draw logR vs. logE curve

Expt 5: *To determine the average diameter of α-particle tracks in SSNTD.*

Expt 6: *To study the absorption of beta rays emitted from different radioactive sources in Al to study the range-energy relation for beta particles by Feather's method and hence to find the energy of the given unknown beta source and identify it.*

Suggested References

1. *Radiation Detection and Measurement*, G Knoll
2. *Techniques for Nuclear and Particle Physics Experiments*, W R Leo
3. *Nuclear Radiation Detector*, S S Kapoor and V S Ramamurthy
4. *Nuclear Tracks in Solids: Principle and Applications*, R L Fleischer, P B Price and R M Walker
5. *The Study of Elementary Particles by the Photographic Method*, C F Powel, P H Fowler and D H Perkins

<u>Semester-III</u>

Course Code: PHY3045

Course Name: Advanced Condensed Matter Physics-I

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *Students will acquire advanced theoretical knowledge of lattice vibration, optical, magnetic, semiconducting and superconducting properties of matter. Assimilating these properties, they will be able to compute parameters for some specific problems, generate ideas for some device fabrication and utilize in research application.*

<u>Contents:</u>

Unit-I: Phonon Spectrum
Phonon creation and annihilation operators, elastic scattering of electrons by phonon, inelastic scattering of photons by phonons, inelastic scattering of neutrons by phonons including experimental details, inelastic phonon- phonon scattering, normal and umklapp processes.

Unit-II: Optical Properties of Solids
Optical constants, dispersion relation of optical constants from Maxwell's equations, Kramers-Kronig relations, optical absorption and emission in semiconductors, exciton absorption, impurity and interband transitions, luminescence, activators, Frank-Condon principle, photoluminescence and thermoluminescence.

Unit-III: Superconductivity
Isotope effect, Frohlich interaction, electron-phonon interaction and BCS theory of superconductivity (extensive), superconducting quantum interference device (SQUID), Ginsburg-Landau theory of the type II superconductivity, high temperature superconductivity and superconducting magnets.

Unit-IV: Semiconductor Devices
Metal-semiconductor junctions, Semiconductor homo and heterojunctios, I-V characteristics of junctions, some optoelectronic devices, photogeneration at p-n junction, photovoltaic effect.

Unit-V: Magnetic Phenomena in Solids
Magnetoconductivity, cyclotron resonance, Landau levels and Landau cylinders, de Haas-van Alphen effect, Fermi surface studies. Exchange interaction and exchange integral for two-electron system, Heisenberg Hamiltonian for exchange interaction, relationship between exchange energy and molecular field, ferromagnetic spin waves and antiferromagnetic spin waves and their dispersion relations, magnons, and antiferromagnetic ordering.

Suggested Books

1. *Lattice Dynamics*, A K Ghatak and L S Kothari
2. *Theory of Superconductivity*, J R Schriffer
3. *Solid State Physics*, A J Dekker
4. *Fundamentals of Solid State Physics*, J R Christman
5. *Introduction to Solid State Physic,* C Kittel
6. *Solid State Theory*, W. Harrison
7. *Intermediate Quantum Theory of Crystalline Solids*, A O E Animalu

Semester-III

Course Code: PHY3055

Course Name: Advanced Condensed Matter Physics Lab

Marks: 100 (20+80) **Credit:** 5 (0L+0T+5P)

Course Outcome: *The hands on laboratory training in Advanced Condensed Matter Physics allows the students handling advanced equipment in the field of electrical and optical transport, transport in magnetic field, dielectric phenomena and spin resonance which they are taught in the Advanced Condensed Matter Physics theory paper (PHY3116), so that they can have a real feel for the topics. They will develop the skill to solve the experimental problems, interpret and analyse the experimental data related to these topics.*

List of Experiments *(All experiments are compulsory)*

Expt 1: *Measurement of magnetoresistance of the supplied material*

Expt 2: *Study of temperature dependent Hall effect of the supplied semiconductor*

Expt 3: *Determination of Landé g factor using the ESR set-up*

E**xpt 4**: *Study of photoconductivity of the CdS sample*

Expt 5: *Determination of transition temperature of the supplied ferroelectric sample*

Expt 6: *Determination of solar cell characteristics using the supplied set up*

Suggested References

1. *Lab Manual*, Advanced Condensed Matter Physics Lab

Semester-III

Course Code: PHY3065

Course Name: Astronomy &Astrophysics-I

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *This course contains introduction to observational techniques in astronomy, stellar astrophysics and galaxies. This is a foundational course, which will help students in understanding basic physical principles of stars and galaxies and their evolution. At the end of the course, students will be aware of several observational techniques used in astronomy. They will be able to apply the physical principles in pursuing the studies of stellar structure and evolution.*

Contents

Unit-I: Basic Astronomy and Coordinate System

Stellar magnitudes, Astronomical filters, Colour-index of stars, stellar binaries - variable stars and types, Spectral classification of stars, Luminosity classification of stars, HR diagram, Star clusters, Astronomical co-ordinate systems, measurement of distances to the nearby Stars, Stellar positions and motions.

Unit-II: Observational Techniques (Optical & Infra-red)

Details about the telescopes and their different properties, Telescope Mount, Adaptive/Active Optics, Detectors and their characteristics (Photodiode, PMT and CCD), spectrograph, concept of photometry, spectroscopy and polarimetry, standard photometric system, atmospheric extinction and transformation equations for standardization.

Unit-III: Star Formation and Radiation Theory

Interstellar medium(ISM), Interstellar Dust, Jeans theory of star formation, Theory of radiative transport, stellar opacity, Saha's ionisation equation and formation of stellar spectra.

Unit-IV: Stellar Structure

Relation between mass, radius and luminosity; Hydrostatic equilibrium, Virial theorem, Stellar structure equations and stability conditions, Integral theorems, Gaseous and radiative stars; Polytropes: Lane Emden equation and its solutions, stability; Eddington's standard model of stars, Mass-radius and pressure density relations.

Unit-V: Stellar Evolution

The HR diagram; Evolution of low and high mass stars. Synthesis of Carbon and heavy elements (r and s processes), Supernovae (SNe) and their types, light curves of SNe. Introduction to Gamma Ray Burst (GRB).

Unit-VI: Compact Objects

White dwarf and Chandrasekhar mass limit, Mass radius relation, Neutron stars, Oppenheimer-Volkov equation, Maximum mass, X Ray binaries.

Unit-VI: Galactic Structure

Local and large scale distribution of stars and interstellar matter. The Milky Way and its Center. Classification of galaxies (morphology and surface brightness)

Suggested Books & References

1. *An Introduction to the Study of Stellar Structure*, S Chandrasekhar.
2. *Astrophysics for Physicists*, A Ray Chowdhury.
3. *Stellar Atmospheres, Interiors and Evolution*, E Bohm-Vitense.
4. *The Physics of Stars*, A C Phillips.
5. *A Text Book of Astronomy and Astrophysics with Elements of Cosmology*, V B Bhatia.
6. *Astronomy Method*, Hale Bradt.
7. *Handbook of CCD Astronomy*, S B Howell.
8. *An Introduction to the Theory of Stellar Structure and Evolution*, Dina Prialnik.
9. *Stellar structure and Evolution*, R Kippenhahn and A Weigert.
10. *Physical Universe*, F Shu.
11. *Astrophysical Techniques*, C R Kitchin
12. *Telescopes and Techniques*, C R Kitchin
13. *Astronomical Polarimetry*, Jaap Tinbergen
14. *Spherical Astronomy*, W M Smart
15. *Observational Astrophysics*, Pierre Lena
16. *Physical Processes in the Interstellar Medium,* Lyman Spitzer Jr.
17. *Dust in the Galactic Environment,* Doug C. B. Whittet

Semester-III

Course Code: PHY3075

Course Name: Astro Lab

Marks: 100 (20+80) **Credit:** 5 (0L+0T+5P)

Course outcome: *The aim of this course is to train students in performing astronomical observations by using telescopes and carry out data analysis by using real astronomical data. At the end of the course, students are expected to get idea of how to draw inference of physical importance after observing the celestial objects and analysing their data. The hands on practices through use of computer software will enable them in visualising the theoretical concepts developed in theory classes.*

Note: The course contains laboratory exercises in astrophysics and analysis of astrophysical phenomena by using available databases and tools. Tools to be used are data reduction software like IRAF, databases like SDSS, Skyview, SIMBAD, VizieR, Aladin and .NED, AAVSO, and the available telescopes and back-end instruments at Gauhati University Observatory (GUO). Any 5 of the following lab exercises in PART A and any 3 from PART B have to be completed with report writing in laboratory notebooks.

Content

Part A

A1: *(i) To generate HR diagram of variable stars by using CHANDRA and AAVSO educational materials.*

(ii) To draw light curve of variable stars and estimate period by using archived data and applying differential photometric technique.

A2: *To measure the Hubble parameter from the spectra of galaxies in SDSS DR14*

A3: *To estimate the percentage of early and late galaxies through colour-colour diagram of galaxies in Abell 2255 using SDSS DR14.*

A4: *Comparative analysis of H-R diagrams of open clusters to determine distances and ages using archived data.*

A5: *Photometric standardization using archived data.*

A6 (i) Virtual Observatory (VO) Tools–I**:** *Getting started – Introduction: Functionality. Search for Images and Information: Aladin, SkyView, WEBDA, SIMBAD, SDSS, VizieR, AAVSO, NED. Search for Spectra: Aladin, CASSIS, SPLAT, Specview, VOSpec, SDSS. Search for Catalogues: Aladin, VizieR, VODesktop.*

(ii) Virtual Observatory (VO) Tools–II: *Image visualisation: Aladin, SkyView, DS9. Spectra visualisation: IRAF, DS9, SPLAT, Specview. Catalogues visualisation: Aladin, VizieR. Cross-correlation: Aladin, X-match. Plots and histograms: VOPlot, DS9, IRAF*

A7: *Surface photometry of some Galaxy using IRAF*

A8: *To study artificial stars using U B V photometry.*

Part B

Any two of the following lab works have to be completed in Gauhati University Observatory (GUO). If weather does not permit these two will be replaced by data exercises of part A. The following lab-works will be based on the observations at GUO, depending on the sky condition throughout the semester.

B1: *Determination of plate scale of a telescope using some nearby terrestrial objects*

B2: *Determination of heights of lunar mountains and size of lunar craters*

B3: *To obtain the period of the moons of Jupiter from imaging*

B4: *To measure the width of the Saturn's ring from imaging*

B5: *To find diameter of the Moon from its angular size on detector and distance*

B6: *To measure the rotation period of the Sun from sunspot measurements*

Suggested Reference

1. *Lab Manual*, Astro Lab

Semester-III

Course Code: PHY 3085
Course Name: Advanced Mathematical Physics

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *The students taking Astronomy & Astrophysics and High Energy Physics as Elective Courses in Semester-III will study this course. This is an excellent opportunity for them to prepare for much advanced courses in Astrophysics, General Relativity, and High Energy Physics. Students will be equipped with mathematical techniques to solve physical problems is Astrophysics and Particle Physics. They will be capable of applying these techniques to pursue advanced projects in the related disciplines.*

Contents

Unit-I: Spacetime

Events; Light Cone structure of spacetime, causality. Differentiable manifold and structures – coordinates and the metric. Gravitation and Curvature, geodesics; tangent spaces, parallel transport and the Riemann tensor. Hilbert action- Einstein equations. Stress–energy tensor, Black hole spacetime (Schwarzschild and Kerr metric), black hole theorems; horizon structure and singularities. Idea of quantum gravity (introductory ideas only)

Unit-II: Integral Equations in Physics

Classification of integral equations. Methods of solution of integral equations. Applications to radiative transport in stars and quantum mechanical scattering problems.

Unit-III: Path Integral Approach

Action as Functional, Functional Derivative: Euler-Lagrange's equation; First principles of quantum mechanics, Path integration: Dirac's formulation, Propagator; Derivation of the Schrodinger's equation.
Path integral foundation of Quantum Field Theory: Vacuum, Force, Feynman Diagrams.

Unit-IV: Applications of Group Theory

Lorentz group, Lie algebra, Representation theory, Schur's Lemma, Orthogonality theorem and other useful theorems, Character table, Direct product representations, Irreducible representations, Young tableaux, Connection between special unitary groups and permutation groups, Application to the simple quark model.

Suggested Books

1. *Spacetime*, S M Carroll
2. *Gravity*, J B Hartle
3. *Lecture Notes on General Relativity*, S M Carroll
4. *Gravitation*, C W Misner, K S Thorne and J A Wheeler
5. *Feynman's Thesis: A New Approach to Quantum Theory*, R P Feynman and L M Brown
6. *Quantum Field Theory in a Nutshell*, A Zee
7. *Group Theory and its Application to Physical Problems*, M Hamermesh
8. *Unitary Symmetry and Elementary Particles*, D B Lightenberg
9. *Quantum Mechanics: Symmetries*, W Greiner and B Muller

<u>Semester-III</u>

Course Code: PHY3095

Course Name: Nanophysics-I

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *The objective of this course is to facilitate learning of nanoscale phenomena. Upon completion of the course, the students will be able to gain insight of the nucleation and growth processes, synthesis and characterization of nanostructured materials. Through this course, the students will be able to understand fascinating properties of low dimensional materials leading to novel applications of nanomaterials.*

<u>Contents</u>

Unit-I: Nucleation and Growth

Classical nucleation theory, critical nuclei size, homogeneous and heterogeneous nucleation, growth of nanocrystals in solution, Ostwald ripening, LaMer's mechanism of nucleation, supersaturation and monodispersity, LSW theory, limited Ostwald ripening.

Unit-II: Nanostructure Synthesis and Characterization

Top-down and bottom-up approaches, natural occurrence, chemical methods, chemical vapour deposition, physical vapour deposition, magnetron sputtering, pulsed laser deposition, molecular beam epitaxy, lithography, mechanical alloying, biosynthesis, nanomanipulation. X-ray diffraction, crystallite size and strain, X-ray line profile analysis - size and strain broadening, electron microscopy, atomic probe microscopy, magnetometry, absorption and luminescence spectroscopy, X-ray photoelectron spectroscopy.

Unit-III: Surface Effects

Increased surface-area-to-volume ratio, melting point suppression, increased reactivity, catalysis, superhydrophobicity

Unit-IV: Quantum Effects in Nanosized Semiconductors-I

Low dimensional structures (2D, 1D, 0D) and density of states, □–k diagram, band gap engineering, compositional variation and quantum confined structure, quantum well and superlattice.

Unit-V: Carbon Nanostructures and 2D Semiconductors

Small carbon clusters, structure and properties of C_{60}, synthesis and properties of carbon nanotubes, electronic properties of graphene, 2D transition metal dichalcogenides (TMDC): electronic and optical properties

Suggested Books

1. *Kinetic Processes*, K A Jackson
2. *Nanophysics and Nanotechnology*, E L Wolf
3. *Elements of X-ray Diffraction*, B. D. Cullity, S. R. Stock
4. *Nano: The Essentials, Understanding Nanoscience and Nanotechnology,* T. Pradeep
5. *Nanotechnology: Principles and Fundamentals*, G. Schmid
6. *Springer Handbook of Nanotechnology*, B. Bhushan (Ed.)
7. *Introduction to Nanotechnology*, C. P. Poole, J. F. J. Owens
8. *Introduction to Nanoscience and Nanotechnology*, K. K. Chattopadhyay, A. N. Banerjee

Semester-III

Course Code: PHY3105

Course Name: Nanophysics Lab

Marks: 100 (20+80) **Credit:** 5 (0L+0T+5P)

Course Outcome: *This course aims at performing experiments by the students to visualize and realize the growth of nanostructured materials and to study their structural, electronic, and optical properties using advanced level experimentation. The students will be able to grow nanomaterials by both top-down and bottom-up approaches and to observe variations of a few physical properties with size and shape as well as with bulk materials.*

Contents

List of Experiments *(All experiments including demo are compulsory)*

Exp 1: *Familiarization with ORIGIN Graphing and Analysis Software for analysis of absorption & photoluminescence spectra and X-ray diffraction patterns (Demo)*

Exp 2: *Production and measurement of low pressure using high vacuum pumping system (Demo)*

Exp 3: *Synthesize CdS nanostructures by the chemical co-precipitation method and record UV-Vis absorption spectra. Examine possible quantum confinement effect.*

Exp 4: *Obtain the powder diffraction pattern of a polycrystalline material using the Debye-Scherrer method. Analyze the results to determine the crystal structure.*

Exp 5: *Deposit Ag nanoparticles on glass substrate by magnetron sputtering. Record the absorption spectra and study surface plasmon resonance.*

Exp 6: *Prepare undoped ZnS and Mn-doped ZnS nanocrystals by chemical co-precipitation method. Record photoluminescence spectra and analyze your results.*

Exp 7: *Using the ball milling method, prepare nanocrystalline ZnO powder. Record X-ray diffraction patterns of milled and unmilled powders. Index diffraction patterns and determine the crystallite size.*

Suggested References

1. *Lab Manual,* Nanophysics Lab
2. *Instruments operation manual*

Semester-III

Course Code: PHY3115

Course Name: Advanced Electronics-I

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *The course is intended to introduce to the students the different areas of electronics like communication systems, use of OPAM, microcontrollers and nanoelectronics. The students will be able to apply their knowledge of electronics to the various aspects of system design using the electronic circuits and to other branches of physics.*

Contents

Unit-I: Communication

Analog and digital Communication: Review of analog communication, Necessity of digital communication; Coherent and Non-coherent ASK, FSK, PSK, Differential PSK, MSK;QPSK; M-arysignaling; Error Control Code' Spread Spectrum modulation; Multiplexing: PCM;Differential PCM, Delta Modulation; Information theory: Information, channel and fundamental limits on performance, Random signal, uncertainty , entropy Source encoding theorem, Shanon's encoding theorem , Shanon-Hartley theorem and Channel capacity, Shannons Limit.

Fibre Optic Communication: Propagation of optical signal through fibre, single mode, step index, graded fibre, Optical fibre performance; Optoelectronic communication circuits.

Satellite communications: Orbital and Geostationary satellites, orbital patterns, GPS. Radar, Radar block diagram, Radar performance: range equation, noise; radar frequencies, Pulse system, antenna and scanning, display.

Antenna: Parabolic antenna; Horn Antenna; lens antenna: single surface dielectric, stepped lenses and metal plate lens antenna, aperture and field, Microstrip antenna: cavity model, impedance, radiation pattern, smart antenna: switched beam, adaptive array, SDMA; Overview of mobile adhoc network.

Transmission Line: Types of transmission lines, Cable parameters, Open and Short circuited transmission lines, Half wave and Full wave transmission line, Smith Chart.

Unit-II: OPAMP

Butterworth Filters, Chebyshev Filters, Bessel filters, Frequency, transformation, instrumentation amplifiers.

Unit-III: Microprocessor and Microcontrollers-I

Microprocessor as a CPU, Organization of a Microprocessor based system, 8085 Architecture, operations and pin diagram, 8085 programming model: Registers, Accumulator, Flags, Program counter and Stack pointer, Bus organization, Microprocessor communication and Bus Timing, 8085 programming: Instruction Set, Addressing Modes, Stack and Subroutine, Introduction to 8051 Microcontroller.

Unit-IV: Nanoelectronics-I

Fabrication techniques for nanostructures, Nanolithography, etching and other means for fabrication of nanostructures and nanodevices, Fabrication of nanoelectromechanical systems (NEMS).

Suggested Books

1. *Communication Systems*, Simon Haykin
2. *Modern Analog and Digital Communication,* B P Lathi
3. *Microprocesors, Architecture, Programming and Applications with the 8085*, Ramesh Gaonkar
4. *Electronic Communication Systems*, George Kennedy
5. *Introduction to Nanoelectronics*, V. Mitin, V. Kochelap, M. Stroscio
6. *Fundamentals of Nanoelectronics*, George W. Hanson.

Semester-III

Course Code: PHY3125
Course Name: Advanced Electronics Lab

Marks: 100 (20+80) **Credit:** 5 (0L+0T+5P)

Course Outcome: *In this course, the students will be able to handle measuring devices like the Mixed Signal Oscilloscope (MSO), lock in amplifier and Vector Network analyzers. They will also have hands on practice on the use of VHDL in simple digital circuits design. The students will be equipped with the basics of signal processing in virtual instrumentation platform. They will familiarize themselves with Communication techniques like fm modulation, optical fibre communication and sampling/reconstruction of analog signals. The system design using programmable systems on chip will be introduced. Introduction to microprocessors in board and in SoC will also be done.*

Contents

List of Experiments (*Any five experiments should be completed*)

Exp 1: *Design a Frequency modulation circuit using IC 555. Observe the components of the FM modulated spectrum for different modulation index. Compare the same with the theoretical value. Estimate the bandwidth required for the FM modulated signal.*

Exp 2: *Design a FM demodulation circuit using PLL. Estimate the free running signal and the lock range. Use the circuit for demodulating a FM modulation system.*

Exp 3: *Use the 8085 microprocessor for performing simple computation like addition, subtraction, division, multiplication, AND, OR, XOR etc. Also implement the system in a simulator.*

Exp 4: *Use an Optical Fibre for the following: (i) IV Characteristics (ii) analog transmission (iii) digital transmission, (iv) estimate the numerical aperture.*

Exp 5: *Study and analysis the sampling theorem and reconstruction of analog signal*

Exp 6: *Implementation of simple circuits and systems in Programmable Logic and SoC*

Exp 7: *Use of hands on test and measurement equipments: VNA and MSO, lock in amplifier*

Exp 8: *Use of virtual instrumentation for signal acquisition and analysis (Labview and DAQ)*

Suggested Reference

1. *Lab Manual*, Electronics Lab

<u>Semester-III</u>
Course Code: PHY3135
Course Name: High Energy Physics-I

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *The aim of the course is to make the students understand the quantum reality of the physical universe in a more rigorous way. The course focuses on how the fundamental particles and their interactions can be realized through the principles based on the special theory of relativity, quantum mechanics, group theory and symmetry principles. Through this course, the students would learn that the particle and the wave nature are nothing but the different manifestations of a single entity called quantum field. After completion of this course, the students will be equipped with the knowledge and techniques to go for the advanced courses as well as to opt for research career in this field.*

<u>Contents</u>

Unit-I: Preliminaries
Klein-Gordon, Dirac equations and plane wave solutions (brief introduction), Dirac's Gamma matrices (useful theorems), Bilinears. Quantum theory of electromagnetic field (concept of photon).

Unit-II: Introduction to Quantum Field Theory
Classical fields as generalized coordinates, Euler-Lagrange equation, Canonical quantization of a one dimensional classical system, Fock space, the method of second quantization, canonical quantization of free fields (Hermitian and non Hermitian scalar fields, electromagnetic field, Dirac field), conservation of energy, momentum and charge of the field, the vacuum in field theory, C, P, T transformation of scalar and e.m. fields.

Unit-III: Quantum Electrodynamics
Covariant perturbation theory, Feynman rules in momentum space, reduction of time-ordered products, calculation of second order process, Casimir's trick, Useful trace theorems, Compton scattering, Klein-Nishima formula, Mott scattering, elements of renormalization of charge and mass.

Unit-IV: Gauge Symmetries
The Aharonov–Bohm effect, Different gauges and vector boson fields (Both massless and massive) Global gauge transformation and Noether's theorem, Lie algebra and Charge algebra, Local Gauge transformation, Gauge fields and their transformation, Abelian and Nonabelian models based on O(2), U(1) (QED), SU(2) groups(Yang-Mills Theory).

Unit-V: Symmetry Breaking
Spontaneous symmetry breaking, Mexican hat potential, Goldstone's theorem, Mass matrix and choice of ground states, Useful parametrization of U(1) and SU(2) models, Unitary gauge and Higgs mechanism (in the context of SU(2)), Conservation of degrees of freedom, Mass generation of matter and gauge fields, Yukawa term.

Suggested Books

1. *An Introduction To Quantum Field Theory*, M E Peskin and D V Schroeder
2. *The Quantum Theory of Fields*, Steven Weinberg
3. *Quantum Field Theory*, F Mandal and G Shaw
4. *Field Quantization*, W Greiner and J Reinhardt
5. *Gauge Theory of Elementary Particle Physics*, T P Cheng and L F Li
6. *Quantum Electrodynamics*, W Greiner and J Reinhardt
7. *The Physics of Standard Model and Beyond,* T Morii, C S Lim and S N Mukherjee

<u>Semester-III</u>
Course Code: PHY3145
Course Name: Lasers & Spectroscopy-I

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *The students will be able to analyse complex spectra and determine different atomic and molecular parameters. They will be able to explain the generation of modes and short-intense pulses, and determine the condition for stability of a laser cavity and achieving laser action.*

<u>Contents</u>

Unit-I: Atomic, Molecular and Fluorescence Spectra
Part A: Atomic Spectra – Intensity relations, Relative intensities of multiplet lines; Zeeman and Paschen-Back effects in complex spectra; Zeeman effect and Goudsmit effect in hfs; X-ray spectra: X-ray emission and absorption spectra, X-ray doublet laws; Isoelectronic sequences.

Part B: Electronic spectra of diatomic molecules – Fine structure of electronic transitions: rotational analysis, combination relations with and without Q branches, determination of rotational constants, internuclear distance and moment of inertia, determination of band origins; Wave mechanical formulation of Franck Condon principle: overlap integral, band intensities in emission and absorption, vibrational sum rule and vibrational temperature. Intensity distribution in rotational structure: rotational temperature, intensity distribution in homonuclear molecules. NMR & ESR spectra: Magnetic properties of nuclei, nuclear resonance, Spin-spin & spin-lattice interaction, chemical shift, nuclear coupling.

Part C: Fluorescence spectra – Luminescence: fluorescence and phosphorescence, Jablonski diagram, Characteristics of fluorescence emission, Fluorescence lifetimes and Quantum Yields, Fluorescence anisotropy, Resonance energy transfer, Steady state and Time-resolved fluorescence, Molecular information from fluorescence.

Unit-II: Lasers Fundamentals and Applications
Resonators – Modes of a resonant cavity: longitudinal & transverse laser modes; stability condition; properties of Gaussian beams; single and multimode oscillations; Q switching; mode locking.

Types of lasers – Nd:YAG laser, Semiconductor laser, Dye laser, Titanium sapphire laser, He : Cd laser, and Excimer laser.

Selected applications of lasers **–** Laser-induced fluorescence of vegetation and other biological materials.

Suggested Books

1. *Laser Fundamentals*, W T Silfvast
2. *Principles of Fluorescence Spectroscopy*, J R Lakowicz
3. *Essentials of Laser and Nonlinear Optics*, G D Baruah
4. *Molecular Spectra and Molecular Structure (Vol. 2),* G Herzberg

<u>Semester-III</u>

Course Code: PHY3155

Course Name: Lasers & Spectroscopy Lab

Marks: 100 (20+80) **Credit:** 5 (0L+0T+5P)

Course Outcome: *The students will be able to handle sophisticated equipments and carry out advanced level experiments. The students will be able to determine some physical parameters, that is, obtain numerical values of certain physical quantities, experiments based on theories in paper PHY3226.*

<u>Contents</u>

List of Experiments

Exp 1: *Determine the vibrational frequency and anharmonicity constant of Aluminium oxide molecule by taking the emission spectrum of aluminium arc, using a high-resolution spectrometer.*

Exp 2: *Determine the variation of length of a material with magnetic field using Michelson Interferometer.*

Exp 3: *Determine the Bohr Magneton using Zeeman effect*

Exp 4: *Study the frequency response of a defocussed optical imaging system*

Exp 5: *Determine the heat of dissociation of iodine molecule in the ground state, taking absorption spectra.*

Exp 6: *Study the quantum defect in a sodium source*

Suggested Reference

1. *Lab Manual*, Lasers & Spectroscopy Lab

Semester-IV

Course Code: PHY4015
Course Name: Statistical Mechanics

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *This course is intended to understand the microscopic details of thermodynamic systems through the constructions and applications of ensemble theory. In this course, the students will experience the rigorous approach of Statistical Mechanics to explore curious phenomenon like Bose-Einstein Condensation. Upon completion of the course, students will be able to apply statistical mechanics in classical and quantum systems for the detailed understanding of various physical, chemical, and biological phenomena.*

Contents

Unit-I: Classical Statistical Mechanics

Statistical basis of thermodynamics, probability concepts, microstate and macrostate, link between statistics and thermodynamics, classical ideal gas, Gibbs paradox.

Theory of ensembles, phase space and Liouville's theorem, microcanonical ensemble, postulate of equal a priori probability.

Canonical ensemble, system in canonical ensemble, partition function, classical systems, energy fluctuations in canonical ensemble, harmonic oscillators, paramagnetism, thermodynamics of magnetic systems, negative temperatures.

Grand canonical ensemble, system in grand canonical ensemble, grand partition function, fluctuations in grand canonical ensemble, equivalence to other ensembles.

Unit-II: Quantum Statistical Mechanics

Framework of quantum statistics, inadequacy of classical theory, density matrix, quantum mechanical ensembles, microcanonical, canonical, and grand canonical ensembles, postulates of quantum statistical mechanics.

Theory of gases, Maxwell–Boltzmann, Bose–Einstein and Fermi–Dirac statistics, partition and grand partition functions, statistics of occupation numbers, distinction between classical and quantum statistics, fluctuations.

Ideal Bose gas, equations of state, properties of ideal Bose gas, Bose-Einstein condensation (BEC) and experimental evidences, thermodynamics of black body radiation, photon counting.

Ideal Fermi gas, thermodynamic behaviour and properties of ideal Fermi gas, degenerate and non-degenerate Fermi gas, electrons in metals, thermodynamic equilibrium of white dwarf stars.

Unit-III: Fluctuations

Brownian motion, Einstein–Smoluchowski theory, Langevin theory, approach to equilibrium: Fokker–Planck equation.

Unit-IV: Phase Transitions

Phase transitions, Ising model, lattice gas and binary alloy, theory of Lee and Yang.

Unit-V: Liquid Helium

Two fluid hydrodynamics, Tisza's two fluid model, Landau criterion, Theory of Feynman.

Suggested Books

1. *Statistical Mechanics*, R K Pathria and P D Beale
2. *Statistical Mechanics*, K Huang
3. *Introduction to Statistical Physics*, S R A Salinas
4. *Thermodynamics and Statistical Mechanics*, W. Greiner, L Neise, H Stöcker
5. *Statistical Physics*, L D Landau and E M Lifshitz

<u>Semester-IV</u>

Course Code: PHY4025
Course Name: Quantum Mechanics-II

Marks: 100 (20+80) **Credit:** 5 (4L+1T+0P)

Course Outcome: *This course introduces the method of applying rules of quantum mechanics to understand the quantum properties of particles, radiations, atoms and their interaction. Students will be able to apply the mathematical theories of quantum mechanics to real problems in particle physics and atomic & nuclear physics.*

<u>Contents</u>

Unit-I: Relativistic Quantum Mechanics
Concept of four vectors, natural units, Minkowski space, Klein Gordon (KG) equation, Problem with KG equation, Feynman-St□ckelberg interpretation and Antiparticle, Dirac equation and evaluation of the Dirac matrices, Plane wave solution of Dirac equation, concept of negative energy and vacuum, Non-relativistic limit of Dirac equation, prediction of spin of electron. Covariant formulation of Dirac equation, Transformation of spinor, Dirac bilinear, Dirac gamma matrices, Helicity and Chirality.

Unit-II: Scattering Theory
Introduction to scattering cross section and differential cross section. Scattering by a potential, partial wave analysis, optical theorem, Lippman Schwinger equation, Green function solution, transition matrix. Born series and Born approximation, scattering cross section for Yukawa, Coulomb and square well potential. Resonance scattering, Breit–Weigner formula.

Unit-III: Interaction of Radiation with Matter
Electromagnetic field and its interaction with single electron atom, harmonic perturbation and transition rates, spontaneous and stimulated emission, absorption, Einstein A and B coefficients. Selection rules.

Unit- IV: Path Integral Approach to Quantum Mechanics
Distinguishable and Indistinguishable paths, Feynman's Path Integral method, equivalence of Feynman and Schrödinger equations.

Unit-V: Measurement Problem
EPR paradox, Bell's inequality, The No-Clone theorem, Schrödinger's cat.

Suggested Books

1. *Relativistic Quantum Mechanics*, J D Bjorken and S D Drell
2. *Quantum Mechanics*, B H Bransden and C J Joachain
3. *Advanced Quantum Mechanics*, J J Sakurai
4. *Quantum Mechanics*, Eugene Merzbacher
5. *Quantum Mechanics*, L I Schiff and J Bandhyopadhyay
6. *Quantum Mechanics,* A Ghatak
7. *Principles of Quantum Mechanics*, R Shankar
8. *Feynman's Thesis: A New Approach to Quantum Theory*, R P Feynman and L M Brown
9. *Introduction to Quantum Mechanics,* D Griffiths

Semester-IV

Course Code: PHY4034
Course Name: Advanced Nuclear Physics-II

Marks: 100 (20+80) **Credit:** 4 (3L+1T+0P)

Course Outcome: *This course is designed to introduce the students with few topics on applications of nuclear physics such as - fission physics and nuclear reactor, fusion reactions and production of energy in stars and laboratory, biological effects of radiation, radiation dosimetry etc. A portion of the syllabus also contains a few advanced topics on elementary particles, which were not included in the core course in Semester- II. After completion of the course, the students are expected to learn the physics of nuclear fission and nuclear reactor, nuclear fusion and tokomak, nuclear radiation hazard and radiation dosimetry. Students will also get some advanced knowledge on elementary particle physics.*

Contents

Unit-I: Nuclear Fission and Reactor Physics

Spontaneous and induced fission, Q-value of fission, fission barrier, activation energy, condition for spontaneous fission. Characteristics of fission- energy distribution of fission product, mass distribution, no. of neutrons emitted in fission, fast and delayed neutrons, fission cross-section. Bohr-Wheeler theory of fission reaction. Fissionable materials, enriched uranium, Fission chain reaction – critical, sub-critical and super critical reactions. Neutron balance in a nuclear reactor – four factor formula and dimension of a reactor, Production reactor, India's peaceful nuclear programme.

Unit-II: Nuclear fusion in Steller and Laboratory Environments

(i) Nuclear fusion and Nucleosynthesis: Basic fusion process, characteristics of fusion , Stages of evolution of universe – nuclear reaction era, thermonuclear fusion & Nucleosynthesis - pp chain reactions & CNO cycle. Production of elements with mass $A > 56$ - s & r processes.

(ii) Controlled fusion reaction: plasma, Debye length, Confinement of plasma - magnetic confinement and Torodial confinement, Lawson criterion – Tokamak.

Unit-III: Radioactivity & Biological Effects of Nuclear Radiations

Laws of successive transformation, Natural Radioactive series, Radioactive equilibrium. Units of radioactivity – Becqueral, Curie, Rutherford, Radiation doses and its unit – quality or weighting factor - equivalent dose, effective dose, committed effective dose, collective effective dose, Biological effect of radiation - Acute and chronic exposure, Effects and symptoms of exposure. Exposure limits. Exposure protection. Commonly used radio-active sources in medical treatment, Source of radionuclides and their characteristics.

Dosimetry Instrument: Quartz Fibre Electroscope, Film Badge dosimeter, Thermoluminescent dosimeter (TLD), Optically stimulated thermoluminescent dosimeter (OSLD), Track detector dosimeter

Unit-IV: Elementary Particles

Resonance states of Hadrons, Spin and Parity determination of pions and strange particles, Properties of quarks and their classification. Colored quarks and gluons.

Elementary ideas of SU(2) and SU(3) symmetry groups. Introduction to Standard Model. Weak isospin and color symmetry – Gauge bosons. Grand unified theories.

Suggested Books

1. *Introduction to Atomic and Nuclear Physics*, H Semat
2. *Introduction to Nuclear Physics*, H S Krane
3. *Atomic and Nuclear Physics, Part–II*, S N Ghosal
4. *Introductory Nuclear Physics*, Samuel S M Wong
5. *Nuclear and Particle Physics*, W E Burcham and M Jobes
6. *Introduction to Elementary Particles*, David Griffiths

Semester-IV

Course Code: PHY4044

Course Name: Advanced Condensed Matter Physics-II

Marks: 100 (20+80) **Credit:** 4 (3L+1T+0P)

Course Outcome: *Gathering knowledge of the properties of matter at microscopic level with reduction in size (thin films and nanomaterials) and dealing with some unconventional condensed matter (soft matter), the students will be able to develop an understanding of the correlation between the size and the properties of matter and get acquainted with some unusual phenomena in soft matter. The students can apply these concepts for device fabrication and can go for research in the field of condensed matter physics and material science.*

Contents

Unit-I: Physics of Thin Films

Definition of a thin film, different methods of film preparation: thermal evaporation, sputtering.

Film thickness measurement: optical interference methods and other methods, Analytical techniques for chemical, structural and surface studies.

Nature of thin films: Theories of nucleation: the capillarity and the atomistic model, growth processes, epitaxial films and their growth.

Mechanical properties of thin films: Internal stress, stress and adhesion.

Electrical conduction in discontinuous and continuous metal and semiconducting films, theories of size effect, galvanomagnetic size effect.

Magnetism in thin metal films, ferromagnetic and antiferromagnetic properties of thin films, surfaces and interfaces of ferromagnetic metals, spin dependent current. QHE and GMR, some thin film devices.

Unit-II: Physics of Nanomaterials

Definition of nanomaterials, Types of nanomaterials: Metal, semiconductor (elemental and compound), methods of preparation. Quantum confinement: One, Two and Three-dimensional. Electrical, Optical and magnetic properties of nanomaterials. Nanomaterial based devices: Electronic, photonic, spintronics.

Unit-III: Soft Condensed Matter Physics

Definition of soft matter, Different types of soft matter: Liquid Crystals, Polymers: high polymers and conducting polymers, Surfactants, Biological materials, Correlated and uncorrelated systems, Nonlinear dynamics in soft matter, Recent studies on soft condensed matter.

Suggested Books

1. *Materials Science of Thin Films*, M Ohring
2. *Handbook of Thin Films*, Maissel and Glang
3. *Thin Film Phenomena*, K L Chopra
4. *Thin Film*, Ashok Goswami
5. *Introduction to Nanotechnology*, C P Poole and F J Owens
6. *Soft Condensed Matter,* R A L Jones

<u>Semester-IV</u>

Course Code: PHY4054
Course Name: Astronomy and Astrophysics-II

Marks: 100 (20+80) **Credit:** 4 (3L+1T+0P)

Course Outcome: *This course surveys gravitation and cosmology from both theoretical and observational perspectives. Applications of general relativity to astrophysical phenomena and large scale structure of the universe are introduced. The basic ideas of radio, x-ray and gamma ray observational techniques used in extragalactic astronomy and cosmology will also be introduced. At the end of the course, students are expected to be aware of applications of the methods of general relativity and cosmology being used in current trends of research in these fields. They will be well acquainted with observational techniques used to address fundamental questions in astronomy. Particularly they will be aware of the problems of multi-messenger astronomy.*

<u>Contents</u>

Unit-I: General Relativity (GR)
Principle of Equivalence (WEK, EEP and SEP) - Gravity and geometry- differentiable manifolds and curved spaces - Einstein's equations - Schwarzschild and Kerr solutions, orbits, Linearisation of Einstein equations and Schwarzschild solution. Gravitational Waves and binaries (introduction). Black holes and singularities.

Unit-II: Astronomical Tests of GR
Post-Newtonian and PPN formalism, solar system tests; Galactic Centre black hole.

Unit-III: Observational Techniques (Radio, X-ray and Gamma Ray)
Radio signals and their emission mechanisms, Radio Telescope, Single dish aperture, interferometry, Radio observation's highlights, HI 21 cm-line, molecular lines, radio galaxies. Mechanism of production of X-ray and Gamma- ray in astrophysics, X-ray and Gamma-ray Telescopes, X ray and Gamma ray sources in the sky, Space based X-ray and Gamma-ray Astronomy.

Unit-IV: Extragalactic Astronomy
Extragalactic astronomy, Distance measurements: Cepheids, RR Lyrae, Type Ia supernovae, Tully-Fisher relation, Shapley- Curtis debate, Hubble's observations and implications. Active Galactic Nuclei and quasars. Intergalactic medium (IGM). Black hole-galaxy co-evolution.

Unit-V: Basic Cosmology
Large scale structure of the universe: galaxy surveys, Galaxy clustering: 2-point correlation function and matter power spectrum. Cosmological principle, FLRW metric, H_0, q_0; luminosity distance and magnitude-redshift relation. Friedmann models (matter, radiation, curvature and the Lambda term). Cosmological parameters. The Hot Big Bang model- thermodynamics and Big Bang Nucleosynthesis (He-synthesis), recombination, Cosmic Microwave Background (CMB) and anisotropies. Formation of large scale structures (introduction)

Unit-VI: The Dark Universe
Mass-to-light ratio of galaxies, clusters and dark matter, Galaxy rotation curves, Clusters of galaxies and Sunyaev–Zeldovich effect. Cold Dark Matter (CDM) versus Hot Dark Matter (HDM) (neutrinos), Accelerating universe, □CDM model and dark energy.

Suggested Books & References

1. *Gravity*, J B Hartle
2. *Gravitation*, Misner, Thorne and Wheeler
3. *Introduction to Cosmology,* J V Narlikar
4. *An Introduction to Modern Cosmology*, A Liddle
5. *Astronomy Method*, Hale Bradt
6. *X-ray Detectors in Astronomy*, G W Fraser
7. *Galactic Dynamics*, J Binney and S Tremaine
8. *Galactic Astronomy*, Binney and Merrifeld
9. *The case for the relativistic hot Big Bang cosmology*, P J E Peebles, D N Schramm, E L Turner & R G Kron, Nature 352 (1991) 769–776.
10. *An Introduction to Cosmology*, B Ryden
11. *Physical Universe*, F Shu
12. *Observational Cosmology,* Stephan Serjeant
13. *X-ray Astronomy*, R Giacconi
14. *Frontiers of X-ray Astronomy*, A C Fabian *et al.* (Eds.)

<u>Semester-IV</u>

Course Code: PHY4064
Course Name: Nanophysics-II

Marks: 100 (20+80) **Credit:** 4 (3L+1T+0P)

Course Outcome: *This course is an advanced one for the students who have completed the course PHY3136 in Semester-III for greater understanding of nanoscale physics. The students will be able to find deeper view of the quantum effects in nanosized semiconductors and devices. Through this course, the students will be able to explore fundamentals of plasmonics, origin of nanoscale magnetism, transport properties at nanoscale, and nanocomposites for various applications.*

<u>Contents</u>

Unit-I: Quantum Effects in Nanosized Semiconductors-II
Quantum island, shrinking to quantum dot (QD), energy gap of semiconductor quantum dot, shape effect, exciton Bohr radius and exciton binding energy, strong and weak confinement, core-shell QD and light emitting device, sub-nm QD and challenges.

Unit-II: Plasmonics
Dielectric function of free electrons, Lorentz oscillator model and Drude theory, bulk plasmons, surface plasmon polaritons (SPPs) at plane interfaces, excitation of SPPs, localized surface plasmons (LSPs) in metal particles, scattering and absorption cross-sections, scattering and emission enhancements, plasmonic effect in metal-semiconductor nanostructures.

Unit-III: Nanoscale Magnetism
Review of basic magnetism: exchange interaction, magnetocrystalline anisotropy, magnetic domains, particle size and surface effects on magnetic behaviour, superparamagnetism, ultrasoftmagnetism, magnetism in multilayers, dilute magnetic semiconductors, spintronics, ferrofluids, magnetic recording.

Unit-IV: Transport Properties
Coulomb blockade transport: Coulomb blockade in a nanocapacitor and a quantum dot circuit, single electron transistors; Ballistic transport: review of classical theory of transport, ballistic transport model, quantum resistance; nanoscale thermal transport, magnetotransport.

Unit-V: Nanocomposites
Natural nanocomposites, biomimetic and bioinspired nanocomposites, metal/ceramic nanocomposites, polymer based nanocomposites, dispersion of nanophase, mechanical properties of CNT/polymer composites, nanocomposites for opto-electronic applications.

Suggested Books

1. *Nanotechnology: Principles and Fundamentals*, G Schmid
2. *Plasmonics: Fundamentals and Applications*, S A Maier
3. *Principles of Nanomagnetism*, A P Guimaraes
4. *Fundamental of Nanoelectronics*, G W Hanson
5. *Experimental Micro/Nanoscale Thermal Transport*, X Wang
6. *Nanocomposite Science and Technology*, P M Ajayan, L S Schadler, P V Braun

<u>Semester-IV</u>

Course Code: PHY4074
Course Name: Advanced Electronics-II

Marks: 100 (20+80) **Credit:** 4 (3L+1T+0P)

Course Outcome: *The course is intended to introduce the students digital signal processing, microcontrollers, control systems, network analysis and waveguides. The knowledge of the students will be enhanced in digital circuits and nanoelectronics. After completion of the course, the students will be equipped with required knowledge in electronics that can be applied to design of a system using discrete components, programmable logic or embedded systems. The students will also get the key know-how of analysis of signals digitally in any application. Use of waveguides will enlighten the students in high frequency signal transfer. The incorporation of physics and application areas of electronics will give the students an overall idea of the current development status of electronics.*

<u>Contents</u>

Unit-I: Digital Circuits (Continued)
Simplification of boolean functions: Mapping and function minimization (SOP and POS) Sequential logic: RS, JK, D and T flip flop; shift register; synchronous and asynchronous counters; Memory Concepts. Fault detection in digital circuits. Synthesis and design of sequential circuits: Analysis and synthesis of synchronous and asynchronous circuits, hazard free asynchronous circuits, sequential machine.Flash Converter; Successive Approximation ADCs; Counting and Integrating ADC Architectures. Implementation of digital circuits in VHDL and FPGA.

Unit-II: Digital Signal Processing
Signals and systems, Impulse Response and Convolution sum , difference equation ,FIR and IIR systems , Stable and Unstable systems. z transform , delay operator, System function, Stability Criterion , Frequency response of a system , Design of Digital Filters, discrete fourier transform, fast fourier transform, digital signal processor

Unit-III: Microprocessor and Microcontrollers-II
8051 microcontroller Architecture, on chip peripherals, Instruction Set, SFR, Introduction to Arduino programming.

Unit-IV: Control Systems
Open and close loop system, Mathematical Modeling of Physical Systems. First and Second order system with derivative & integral control, Servo motor and its simple control circuits.

Unit-V: Network Analysis
Network functions; poles and zeros, zero input and zero state response; effect of position of poles and zeros on system response, Routh Array; frequency response analysis, Bode plot, Nyquist Criterion for stability, Nyquist path, Nyquist Path, Gain ,Margin, Phase Margin.

Unit-VI: Nanoelectronics-II
Graphene, Carbon nanotubes, Single Electron Transistor, Carbon nanotube transistor, Graphene transistor, Semiconductor Nanowire transistor, Quantum dot transistor.

Unit-VII: Waveguides
Fundamental concepts of signal transmission through wave guide, relation between cut off frequency and waveguide dimension of rectangular waveguide.

Suggested Books

1. *Electronic Communication*, George Kennedy
2. *Digital Signal Processing*, J G Proakis and D Malonakis
3. *Network Analysis*, M V Valkenburg
4. *The 8051 Microcontroller and Embedded Systems*, Mazidi
5. *Introduction to Nanoelectronics*, V Mitin, V Kochelap, M Stroscio
6. *Fundamentals of Nanoelectronics,* G W Hanson

Semester-IV
Course Code: PHY4084
Course Name: High Energy Physics-II

Marks: 100 (20+80) **Credit:** 4 (3L+1T+0P)

Course Outcome: *The present course focuses on the application of the quantum field theory to understand the fundamental particles and their interactions. The course gives a detailed visualization of how the Standard model of particle physics is developed and what are the other possible ways to go beyond the standard model to address certain unsolved problems of nature. This course will provide a concrete platform to the students to undertake their research career in the field of both theoretical and experimental High Energy Physics.*

Contents

Unit-I: Elementary Particles and Fundamental Interactions
Brief introduction to the elementary particles and their properties, Strangeness, Charm and Bottom, Parity of lepton-antilepton pair, photon and pion, C Parity, T Reversal and principle of detailed balance, CPT Theorem, G Parity. Fundamental forces and Conservation laws, Electro-magnetic and Weak processes. Basic vertices, quark-lepton symmetry, quark mixing, charged and neutral currents.

Unit-II: Quark Model
Meson and Baryon Isospin states under SU(2), Extension to SU(3), Shift operators, Weight Diagrams and Eight-fold way, Colour, Hadron Wave functions, Hadron masses, Exotic Hadrons.

Unit-III: Standard Model of Particle Physics
Weak interaction Phenomenology, Weak isospin charges and their algebra, SU(2)L ⊗ U(1)Y model and Electroweak unification, Higgs mechanism, masses of the gauge bosons and other fermions (Quantitative study), GIM Mechanism.

Unit-IV: Quantum Chromodynamics
QCD Lagrangian, Running Coupling constant, Form factors and structure functions, scaling, jet production.

Unit-V: Beyond Standard Model
Introduction to Grand Unified Theories (GUTs)-SU(5) and SO(10) and proton decay predictions, Minimal Supersymmetric Standard Model (MSSM) and its extension and predictions, Introduction to String Theories and Planck scale physics.

Unit-VI: Neutrino Physics
Solar and atmospheric neutrino puzzles, theory of neutrino oscillations in vacuum and medium (MSW mechanism), neutrino masses and leptonic mixings, survey of various neutrino oscillation experiments, seesaw mechanism for small neutrino masses.

Suggested Books

1. *Quarks and Leptons: An Introductory Course in Modern Particle Physics*, F Halzen and A.D Martin
2. *Particle Physics*, B R Martin and G Shaw
3. *Introduction to Elementary Particles,* D Griffiths
4. *Gauge Theory of Elementary Particle Physics,* T P Cheng and L F Li
5. *The Physics of Standard Model and Beyond,* T Morii, C S Lim and S N Mukherjee
6. *Particle Physics in the LHC Era*, G Barr, R Devenish, R Walczak and T Weidberg
7. *Quantum Mechanics: Symmetries*, W Greiner and B M¨uller
8. *Unification and Supersymmetry*, R N Mohapatra
9. *Fundamentals of Neutrino Physics and Astrophysics*, C Giunti and C W Kim

Semester-IV

Course Code: PHY4094

Course Name: Lasers & Spectroscopy-II

Marks: 100 (20+80) **Credit:** 4 (3L+1T+0P)

Course Outcome: *The students will be able to interpret different types of molecular spectra. They could, in future, apply lasers in studies falling in areas of photophysics, photochemistry and photobiology.*

Contents

Unit-I: Spectroscopy

Part A: Spectra of diatomic molecules

Hund's coupling cases, symmetry properties of electronic states and rotational levels, selection rules, types of electronic transitions: $^1\Sigma - {}^1\Sigma$, $^2\Sigma - {}^2\Sigma$, $^1\Pi - {}^1\Sigma$, $^2\Pi - {}^2\Sigma$, Continuous and diffuse spectra: pre-dissociation, Auger effect, Heats of dissociation: determination of dissociation limits, band convergence, Birge-Sponer extrapolation.

Part B: Molecular orbital approximation

United and separated atom constructs, correlation of molecular orbitals, LCAO/MO theory, determination of terms and multiplicities from molecular orbitals.

Part C: Spectra of polyatomic molecules

Symmetry elements and symmetry operations of point group, Matrix representations of symmetry elements of a point group, Reducible and irreducible representations, Character Tables for C_{2v} and C_{3v} point groups. Normal modes of vibration and their distribution into symmetry species of the molecule, Infrared and Raman Selection rules.

Part D: Applications of molecular spectroscopy

In nuclear physics: spin & statistics, In astrophysics: absorption and emission in earth's atmospheres, terrestrial Fraunhofer lines, planetary atmospheres, comets, stellar atmospheres and interstellar space.

Unit-II: Lasers

Part A: Nonlinear optics

Nonlinear susceptibility, second harmonic generation, phase matching, parametric oscillation, intensity-dependent refractive index: self-focusing, phase conjugation: four wave mixing.

Part B: Laser spectroscopy

Preliminary ideas only: Laser Raman spectroscopy: experimental techniques, resonance Raman, stimulated Raman, hyper Raman and coherent anti Stokes Raman spectroscopy; Doppler limited spectroscopy: photo-acoustic spectroscopy and laser-induced fluorescence; Time-resolved spectroscopy: phase shift method, pulse excitation and quantum beat spectroscopy.

Part C: Selected applications of lasers in science and technology

Isotope separation, laser-induced fusion, Laser cooling of atoms, Applications in physical, chemical and biological systems: optical tweezers and chirped pulse amplification.

Suggested Books:

1. *Chemical Applications of Group Theory*, F A Cotton
2. *Introduction to Molecular Spectroscopy*, G M Barrow
3. *Modern Spectroscopy*, J M Hollas
4. *Laser Age in Optics*, V Tarasov
5. *The Principles of NonlinearOptics*, Y R Shen
6. *Laser Spectroscopy: Basic Concepts and Instrumentation*, W Demtröder

Semester-IV
Course Code: PHY4106
Course Name: Atmospheric Physics

Marks: 100 (20+80) **Credit:** 6 (5L+1T+0P)

Course Outcome: *The objective of this open elective course is to facilitate students to learn the different physical processes and the fundamental laws controlling the Earth-atmosphere system through a balance of theory and applications. This course will act as a starting point for the students to study climate change and associated physics.*

Content

Unit-I: Earth's Atmosphere
Thermal and dynamical structure of the atmosphere, composition and constituents of the atmosphere, atmospheric boundary layer, radiative equilibrium of the earth, global energy budget, atmospheric thermodynamic processes, hydrostatic equilibrium, static stability, Eddy transport of heat, moisture and momentum, green house effect, weather and climate, global wind pattern, precipitation, fog, fronts, low pressure systems, thunderstorms, monsoon.

Unit- II Atmospheric Dynamics
Atmospheric motions, Reynolds transport theorem, conservation of mass, energy and momentum, momentum equation in a rotating frame, Circulations and vorticity, turbulent diffusion, atmospheric oscillations, Quasi biennial oscillation, annual and semi- annual oscillations, mesoscale circulations, the general circulations, wave propagation.

Unit-III: Aerosol and Cloud
Classification of atmospheric aerosol, Production and removal mechanisms, Concentrations and size distribution, Absorption and scattering of solar radiation, Rayleigh scattering and Mie scattering, Bouguert-Lambert law.
Micro and Macrophysical characteristics of cloud: droplet growth and cloud dissipation mechanism, radiative transfer in cloudy atmosphere. Role of aerosol and cloud in climate.

Unit-IV: Atmospheric Circulation
Moist static energy, total potential energy, available potential energy, thermal properties of earth's surface, surface pressure and wind systems, Vorticity and divergence equations, Scale Analysis, Tropical circulations, wind and buoyancy driven circulation.

Unit-V: Atmospheric Observations
General principles of meteorological measurements and observational procedures. Conventional and self recording measurements of atmospheric variables. Upper air measurements: pilot balloons, radiosonde, dropsonde, ozonesonde, radiometersondes, GPS sonde.
Surface based Remote Sensing: Working principle and applications of LIDARS, SODARS, Weather RADARS, Wind Profiler, radio-acoustic sounding systems (RASS), microwave radiometer. Meteorological satellites, multi-scanner radiometers and their applications in the observation of weather parameters.

Suggested Books

1. *Physics of the Atmosphere and Climate*, Murry L Salby
2. *An Introduction to Dynamic Meteorology*, *Vol.1*, James R Holton
3. *Atmospheric Aerosols: Properties and Climate Impacts*, Olivier Boucher
4. *An Introduction to the Global Circulation of the Atmosphere*, David Randall
5. *The Weather Observers Handbook*, Stephen Burt
6. *Remote Sensing of Aerosols, Clouds, and Precipitation*, T Islam, Y Hu, A A Kokhanovsky, J Wang (Eds.)

<u>Semester-IV</u>

Course Code: PHY4116

Course Name: Nano Fabrication

Marks: 100 (20+80) **Credit:** 6 (3L+1T+2P)

Course Outcome: *The objective of this course is to make the students aware with the state of art technology related to device fabrication in the micro and nano scale, and to provide the students a foretaste of the semiconductor industry, which is the foundation of electronics. In this course the students will be exposed to the acute details and meticulousness related to the future of the semiconductor industry and nanotechnology and its challenges/opportunities in various fields.*

<u>Contents</u>

Unit-I: Introduction

Nanofabrication, necessity for a clean room, different types of clean rooms, construction and maintenance of a clean room, basic steps in IC fabrication, Lithography, Printing, semiconductor substrates, wafer preparation, Electronic grade silicon.

Unit-II: Crystal Growth

Chemical Vapor Deposition (CVD), Liquid phase epitaxy, Molecular beam epitaxy (MBE), Growth mechanism and kinetics, Thin oxides, Oxidation techniques, Oxide properties.

Unit-III: Lithography Techniques

Optical lithography: Light sources, Photo mask and alignment, Positive and negative photo resists, Limitations in Optical Lithography, Ultraviolet lithography.

X-Ray and electron lithography: Interaction of high energy beams with matter, X ray masks, X-ray sources, X ray projection, X ray resists, Scanning Electron beam lithography (EBL), mask less EBL.

Ion beam lithography: Focused ion beam, point sources of Ion, Ion column, Beam writing, Focusing ion beam lithography.

Additional Techniques: Atomic force Microscope (AFM) lithography.

Unit-IV: Etching Techniques

Wet etching, feature size control, thin membrane fabrication, Etching in gas environment, dry etching processes for specific materials, Reactive ion etching, Lift off Techniques.

Unit-V: Nanopatterning and Processing

Nanoimprint lithography (NIL), Soft Lithography for patterning, Self-Assembling systems - A novel route to functional architectures for organic electronic devices, functionalization and assembling, photolithographic patterning of organic electronic materials.

Unit -VI: Applications

Solar Cell, Molecular electronics and printed electronics, Liquid crystalline systems, Applications in displays and other devices, Nano materials for data storage, Photonics, Plasmonics, Chemical and biosensors.

Unit-VII: Laboratory Work

Investigating the dimension and defects in the micro/nano devices using different microscopic techniques. Surface wettability of the devices and measuring important parameters, Measuring key transport properties of 2-probe and FET devices, Design and device packaging using a 3D printer.

Suggested Books

1. *Nano Lithography*, Stefan Landis
2. *Nanolithography and Patterning Techniques in Microelectronics*, David G Bucknall
3. *Fabrication Engineering at the Micro- and Nanoscale,* Stephen Campbell
4. *Nanofabrication- Fundamentals and Applications*, Ampere A Tseng

Semester-IV

Course Code: PHY4126

Course Name: Plasma Physics

Marks: 100 (20+80) **Credit:** 6 (3L+1T+2P)

Course Outcome: *The course provides a comprehensive description on the physics of plasmas with an introduction to more advanced topics such as dusty plasmas and fusion plasmas. This enables the students to have a mature understanding of the applied electrodynamics and upon completion of the course, the students are fully ready to take up Plasma Physics as a research career. Given the growth of Plasma Physics research in the country (especially in the North East India), this course provides a major fillip to the overall physics knowledge of the student.*

Note: This course is conducted in credit sharing basis with the Institute of Advanced Study in Science and Technology (IASST), Guwahati.

Contents:

Unit-I: Review of Preliminary Ideas

Review of basic concepts of plasma physics: Concept of Plasma Temperature and Debye Shielding, Guiding centre motion and drifts, Adiabatic Invariants.

Unit-II: Development of Linear Theory of Plasma Waves and Instability with MHD

Development of Ideal MHD theory. Plasma as a Fluid. Linear theory of Plasma Waves with MHD description - Electron and Ion Waves. Concept of Plasma Resistivity. Single Fluid MHD equations and MHDWaves. Two-stream Instability.

Unit-III: Kinetic Theory of Plasma and its Application

Need for kinetic theory and MHD as approximation of kinetic theory. Application of Kinetic Theory to Electron Plasma Waves and Landau Damping.

Unit-IV: Introduction to Nonlinear Theory of Plasma Waves

Development of Nonlinear Theory of Plasma Waves. Introduction to Reductive Perturbation Method of Nonlinear Plasma Wave. Concept of Pseudo Potential (Sagdeev Potential). Theory of Plasma Sheath and its relation to Nonlinear Waves (Soliton).

Unit-V: Laboratory Work at IASST (30 marks)

Production of plasma in laboratory by DC/RF discharge. Measurement of plasma parameters by Electrostatic Probes. Observation of instability in plasma.

Suggested Books

1. *Plasma Physics*, R J Goldstone and P H Rutherford
2. *Introduction to Plasma Physics and Controlled Fusion*, F F Chen
3. *Fundamentals of Plasma Physics* J A Bittencourt

<u>**Semester-IV**</u>

Course Code: PHY4136

Course Name: Project / Dissertation

Marks: 100 (20+80) **Credit:** 6

Course Outcome: *The project or dissertation course is offered to motivate a student to take a research problem and pursue theoretical or experimental work under the mentorship of a faculty member. This is an optional course where a student will get a chance to explore new ideas while trying to solve a research problem. This course is an open invitation to a student for out of box thinking to provide a solution to a physics problem.*

<u>Note</u>: The faculty members of the department are usually the supervisors. The faculty members from the associated departments/institutes also supervise some of the projects/dissertations. The department will notify regarding the selection process and the probable vacancies.

Semester-IV

Course Code: PHY4146

Course Name: Fundamentals of Lasers & Photonics

Marks: 100 (20+80) **Credit:** 6 (5L+1T+0P)

Course Outcome: *The students will have foundations in lasers and of advanced topics in optics and some of optical phenomena, and their applications in science and engineering.*

Contents:

Unit-I: Lasers

Properties of laser light, spontaneous and stimulated emission - Einstein coefficients, light amplification, population inversion and threshold condition for laser oscillations, modes of a laser cavity.

Gaussian beam, ABCD matrix formulation, propagation of Gaussian beam through optical components, cavity stability criterion.

Techniques of intense and short pulse generation: Q-switching and mode-locking.

Two-, three- and four-level laser systems: rate equations.

Ammonia maser, ruby laser; He-Ne laser; semiconductor laser; CO_2 laser and dye laser.

Selected applications: optical communication, isotope separation, laser-induced fusion, laser-induced fluorescence of vegetation and other biological materials, optical cooling.

Unit-II: Photonics

Propagation of light in free space, optical Fourier transform, diffraction of light, propagation of light through a lens and conditions for Fourier transformation and imaging, holography.

Electromagnetic theory of light, monochromatic electromagnetic waves and their propagation in a dielectric medium, Fresnel reflection and transmission coefficients.

Nonlinear optical media, second-order nonlinear optics, third-order nonlinear optics, three-wave mixing, four-wave mixing, optical solitons.

Electro-optic effects, intensity modulators, phase modulators, travelling wave modulators; Magneto-optic devices: magneto-optic effects, Faraday effect, magneto-optic Kerr effect.

Principles of electro-optics, electro-optics of anisotropic media, electro-optics of liquid crystals, photorefraction, electro-optic devices.

Interaction of light and sound in matter, acousto-optic devices, acousto-optics of anisotropic media.

Photovoltaic devices: Photovoltaic device principles, equivalent circuit of solar cell, temperature effects, solar cell materials, devices and efficiencies.

Photonic switches, photodetectors, optical memory devices, optical communication devices.

Suggested Books

1. *Lasers : Theory and Applications*, K Thyagarajan and A K Ghatak
2. *Laser Fundamentals*, W T Silfvast
3. *Laser Age in Optics*, V Tarasov
4. *Introduction to Fourier Optics*, J W Goodman
5. *Optics*, E Hecht
6. *Fundamentals of Photonics*, B E A Saleh and M C Teich
7. *Photonics –An Introduction*, G A Reider

IV. Summary

The department offers the M.Sc. programme under the CBCS of Gauhati University. The department has good infrastructure and faculty strengths with expertise in diverse fields that create a vibrant environment for physics teaching & learning. The department through this programme facilitates the students to have sound understanding of the subject, through 13 core courses, 6 elective courses, and 1 open elective course. Altogether, the department presents as many as 38 courses, providing options to choose 6 elective courses from 21 elective courses, and 1 open elective course either from 4 open electives offered by the department or from any associated departments.

For the detailed information on CBCS regulations, please visit –
http://web.gauhati.ac.in/courses/cbcs/cbcs-regulations

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