UNIVERSITY OF DELHI

MASTER OF SCIENCE in PHYSICS

M. Sc. (Physics)

(*Effective from Academic Year 2018-19*)

PROGRAMME BROCHURE

M.Sc. (Physics)Revised Syllabus as approved by Academic Council on XXXX, 2018
and Executive Council on YYYY, 2018

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I About the Department

The Department of Physics & Astrophysics is possibly the largest science department in any Indian university. The "Old Block" of the Department is located in the picturesque Viceroy's complex, and shares space in an elegant pillared building with the Department of Chemistry. Established in 1922, the Department, in its early years was influenced by M. N. Saha and subsequently, by his illustrious student, Padma Bhushan (1964) and Padma Vibhushan (1973) Daulat Singh Kothari, who joined the Department in 1934.

The Masters' programme in the Department was started in 1942. Faculty members in the early days of the Department included eminent theorists A.N. Mitra, R. C. Majumdar, F. C. Auluck, N. K. Saha and P. K. Kichlu. Subsequently experimental groups in Optics, Nuclear Physics, Condensed Matter, and High Energy Physics were gradually added. When the UGC started the scheme of Centres of Advanced Study in 1963, the Physics Department was one of the first to be accorded the status, for its work in Theoretical Physics as well as experimental work in Low-Temperature Physics. For working at extremely low temperatures, the Department acquired a Helium Plant, which was unusual in Universities then. A telescope tower for a solar observatory, housed in the Department, continues to be an iconic landmark in the neighborhood.

The faculty members of the Department have won many honours and awards over the years. The national role of D.S. Kothari, both as Chairman UGC and through the Education Commission, is too well-known to require elaboration. The department boasts of several illustrious alumni and faculty, with the list reading like a virtual who's who of Indian physics. It includes Padma Vibhushan J.C. Pati, the prestigious S. S. Bhatnagar awardees A N Mitra, Kasturi Lal Chopra, Ajoy Kumar Ghatak, Shasanka Mohan Roy, R. Rajaraman, Deepak Kumar, Karmeshu, and Amitava Raychaudhuri. Many alumni have gone on to head national institutions. These include R. Ramachandran, H. S. Mani, Amitava Raychaudhari, Sabyasachi Bhattacharya, Amit Roy, and Praveen Chaddah. The Department hosted the National Physical Laboratory in its initial years and P.K. Kichlu and A.R.Verma went on to become its directors. Several members of the faculty during the 1970s and 1980s were Fellows of the National Science Academies, a tradition that has continued. Of the current faculty members, three are Fellows of the Indian Academy of Sciences, two of Indian National Science Academy and two of the National Academy of Sciences. Alumni have also made their mark in various other fields both within the country and abroad, branching out into other fields such as economics, molecular biology and education as well as many holding key administrative positions in the government.

The Department offers a two-year (4-semester) Master's program, with an annual intake of approximately 300 students. It continuously reinvents its teaching orientation and syllabi contents, taking into account contemporary requirements to introduce courses, particularly in applied and interdisciplinary areas. Advanced papers have been designed to acquaint students and provide them with a broader perspective. The Department, under a vibrant Ph.D. program, offers a plethora of cutting-edge research topics. Some of these include Astronomy, Astrophysics, Atomic Physics, Condensed Matter Physics, Cosmology, High Energy Physics, Molecular Physics, Nanoscience & Material Science, Nuclear Physics, Plasma Physics, and Theoretical Physics.

Aware of the wide-ranging needs of the diverse student groups, the Department offers intensive tutorials and interactions therein that are meant for the spectrum of learners to identify their academic level. The advanced learners are encouraged to take up informal projects/dissertations to enhance their learning. Emphasis is also placed on curriculum enrichment through informal means.

The quest for excellence in teaching and research is naturally the overriding motto. As a result, the department has, in successive years, found a place in the QS rankings, consistently featuring within the top 10 among the national institutes. It takes pride in being the highest ranked university physics department in the country. This focus is also reflected in both the number and the quality of publications. The department is an active participant in several national and international collaborations. Notable among these is the contribution of the groups of High Energy Physics, Nuclear Physics, Plasma Physics, and Astrophysics. The research atmosphere thrives through many successful sponsored projects and grants funded by various national and international agencies.

The Department undertakes several outreach activities and initiatives including organizing summer schools, student projects, visits of school students, and many such activities to address the career aspirations of young students.

II Introduction to CBCS (Choice Based Credit System)

II.1 Scope

The CBCS provides an opportunity for the students to choose courses from the prescribed courses comprising core, elective/minor or skill-based courses. The courses can be evaluated following the grading system, which is considered to be better than the conventional marks system. Grading system provides uniformity in the evaluation and computation of the Cumulative Grade Point Average (CGPA) based on student's performance in examinations which enables the student to move across institutions of higher learning. The uniformity in evaluation system also enable the potential employers in assessing the performance of the candidates.

II.2 Definitions

(i) 'Academic Programme' means an entire course of study comprising its programme structure, course details, evaluation schemes etc. designed to be taught and evaluated in a teaching Department/Centre or jointly under more than one such Department/ Centre

(ii) 'Course' means a segment of a subject that is part of an Academic Programme

(iii) 'Programme Structure' means a list of courses (Core, Elective, Open Elective) that makes up an Academic Programme, specifying the syllabus, Credits, hours of teaching, evaluation and examination schemes, minimum number of credits required for successful completion of the programme etc. prepared in conformity to University Rules, eligibility criteria for admission

(iv) 'Core Course' means a course that a student admitted to a particular programme must successfully complete to receive the degree and which cannot be substituted by any other course

(v) 'Elective Course' means an optional course to be selected by a student out of such courses offered in the same or any other Department/Centre

(vi) 'Open Elective' means an elective course which is available for students of all programmes, including students of same department. Students of other Department will opt these courses subject to fulfilling of eligibility of criteria as laid down by the Department offering the course.

(vii) 'Credit' means the value assigned to a course which indicates the level of instruction; One-hour lecture per week equals 1 Credit, 2 hours practical class per week equals 1 credit. Credit for a practical could be proposed as part of a course or as a separate practical course

(viii) 'SGPA' means Semester Grade Point Average calculated for individual semester.

(ix) 'CGPA' is Cumulative Grade Points Average calculated for all courses completed by the students at any point of time. CGPA is calculated each year for both the semesters clubbed together.

(x) 'Grand CGPA' is calculated in the last year of the course by clubbing together of CGPA of two years, i.e., four semesters. Grand CGPA is being given in Transcript form. To benefit the student a formula for conversation of Grand CGPA into %age marks is given in the Transcript.

III M. Sc. Programme Details

III.1 Programme Objectives (POs)

The objectives of the M.Sc. Physics programme are manifold and start with imparting students with an in-depth knowledge and understanding through the core courses which form the basis of Physics namely, Classical Mechanics, Quantum Mechanics, Mathematical Physics, Statistical Physics, Electromagnetic Theory, Solid State Physics, Electronics, Nuclear and Particle Physics along with Atomic and Molecular Physics. Creative thinking and problem-solving capabilities are also aimed to be encouraged through tutorials. The elective and open elective courses are designed for more specialized and/or interdisciplinary content to equip students with a broader knowledge base. The core and elective labs are designed to develop an appreciation for the fundamental concepts and working of devices used in everyday life employing scientific methods/tools of physics. Computational physics course is aimed to equip the students to use computers as a tool for scientific investigations/understanding. The dissertation(s) in both theory and experimental stream are expected to give a flavor of how research leads to new findings. In addition, the M.Sc. course is to lay a solid foundation for a doctorate in Physics/allied subjects later.

III.2 Programme Specific Outcomes (PSOs)

- Understanding the basic concepts of physics particularly concepts in classical mechanics, quantum mechanics, statistical mechanics and electricity and magnetism to appreciate how diverse phenomena observed in nature follow from a small set of fundamental laws through logical and mathematical reasoning.
- Learn to carry out experiments in basic as well as certain advanced areas of physics such as nuclear physics, condensed matter physics, nanoscience, lasers, and electronics.
- Understand the basic concepts of certain sub fields such as nuclear and high energy physics, atomic and molecular physics, solid state physics, and plasma physics, and astrophysics, general theory of relativity, nonlinear dynamics and complex system.
- Gain hands-on experience to work in applied fields.
- Gain a through grounding in the subject to be able to teach it at college and school levels.
- Viewing physics as a training ground for the mind developing a critical attitude and a faculty of logical reasoning that can be applied to diverse fields.

III.3 Programme Structure

The M. Sc. programme is a two-year course divided into four-semesters. A student is required to complete 72 credits for the completion of the course and the award of degree. The M.Sc. Physics Programme would make the students competent in a natural science, viz., Physics, and help them understand its role in modern day technology. Overall, the course would enable the students to understand the fundamental concepts and experimental methods of physics which would help them to innovate/apply/generate new devices/applications/insights/knowledge. Knowledge gained through the open electives would be an asset in branching out in fields other than physics.

		Semester	**Semester**
Part – I	First Year	Semester I	Semester II
Part – II	Second Year	Semester III	Semester IV

Course Credit Scheme

L= Lecture, T = Tutorial, P = Practical

Semester	Core Courses			Elective Course			Open Elective Course			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	
I	**05**	**12+4+4**	**20**	**0**	**0**	**0**	**0**	**0**	**0**	**20**
II	**05**	**12+4+4**	**20**	**0**	**0**	**0**	**0**	**0**	**0**	**20**
III	**02**	**3+1+4**	**08**	**3/2**	**3+1+0**	**12/8**	**0/1**	**3+1+0**	**0/4**	**20**
					0+0+4					
IV	**01**	**3+1+0**	**04**	**4/3**	**3+1+0**	**12/8**	**0/1**	**3+1+0**	**0/4**	**20**
					0+0+4					
Total Credits for the Course			**52**			**28/20**			**0/8**	**80**

- For each Core and Elective Course there will be 4 lecture hours of teaching per week.
- Open Electives to the maximum total of 8 credits.
- Each paper will be of 100 marks out of which 70 marks shall be allocated for the end-semester examination and 30 marks for internal assessment.
- Duration of the end-semester examination of each paper shall be for 3 hours.

III.4 Eligibility for Admissions

As per university rules.

III.5 Assessment of Students' Performance and Scheme of Examination

As per university rules.

III.6 Pass Percentage & Promotion Criteria

The passing percentage in any course shall be 40%. A student passing in at least 50% of courses in Semesters I and II combined shall be promoted to the second year of the Programme. A student who has at least 40% marks in the aggregate of all the required courses in the four semesters and has passed individually in courses accounting for at least 72 credits shall qualify for the award of the M.Sc. degree

III.7 Semester to Semester Progression

As per university rules.

III.8 Conversion of Marks into Grades

As per university rules.

III.9 Grade Points

As per university rules.

III.10 CGPA Calculation

As per university rules.

III.11 Division of Degree into Classes

As per university rules.

III.12 Attendance Requirement

As per university rules.

III.13 Span Period

As per university rules.

III.14 Guidelines for the Award of Internal Assessment Marks

III.15 M. Sc. Programme (Semester Wise)

Semester I				
Number of Core courses: 5	**Credits in each core course**			
CORE COURSES:	**Theory**	**Practical**	**Tutorial**	**Credits**
PH-CT401: Classical Mechanics	3	0	1	**4**
PH-CT402: Quantum Mechanics I	3	0	1	**4**
PH-CT403: Electronics	3	0	1	**4**
PH-CT404: Mathematical Physics	3	0	1	**4**
PH-CT405: General Lab I/II	0	4	0	**4**
Total credits in Core courses: 20	12	4	4	**20**
Number of Elective courses: Nil				
Total number of credits in Semester I: 20				

Semester II				
Number of Core courses: 5	**Credits in each core course**			
CORE COURSES:	**Theory**	**Practical**	**Tutorial**	**Credits**
PH-CT406: Quantum Mechanics II	3	0	1	**4**
PH-CT407: Statistical Physics	3	0	1	**4**
PH-CT408: Electromagnetic theory and Electrodynamics	3	0	1	**4**
PH-CT409: Solid State Physics	3	0	1	**4**
PH-CT410: General Lab I/II	0	4	0	**4**
Total credits in Core courses: 20	12	4	4	**20**
Number of Elective courses: Nil				
Total number of credits in Semester II: 20				

Semester III

Number of core courses: 2	Credits in each core course			
CORE COURSE:	**Theory**	**Practical**	**Tutorial**	**Credits**
PH-CT501: Nuclear and Particle Physics	3	0	1	**4**
PH-CT501: Computational Physics (Lab)	0	4	0	**4**
Total credits in Core courses: 8	3	4	1	**8**
Number of Elective/Open Elective courses: 3	**Credits in each elective course**			
ELECTIVE COURSES:	**Theory**	**Practical**	**Tutorial**	**Credits**
Experimental Modules:				
Module A-I:				
PH-ET511: Physics at the Nanoscale – I (Theory)	3	0	1	**4**
PH-EL512: Nanomaterials Lab – I (Lab)	0	4	0	**4**
Module B-I:				
PH-ET513: Advanced Electronics - I (Theory)	3	0	1	**4**
PH-EL514: Advanced Electronics - I (Lab)	0	4	0	**4**
Module C-I:				
PH-ET515: Advanced Nuclear Physics – I (Theory)	3	0	1	**4**
PH-EL516: Advanced Nuclear Physics - I (Lab)	0	4	0	**4**
Module D-I:				
PH-ET517: Lasers and Spectroscopy – I (Theory)	3	0	1	**4**
PH-EL518: Lasers and Spectroscopy - I (Lab)	0	4	0	**4**

Module E-I:				
PH-ET519: Advanced Solid State Physics –I (Theory)	3	0	1	**4**
PH-EL520: Advanced Solid State Physics – I (Lab)	0	4	0	**4**
Theory courses:				
PH-ET531: General Theory of Relativity and Cosmology I	3	0	1	**4**
PH-ET532: Astrophysics I	3	0	1	**4**
PH-ET533: Condensed Matter Physics I	3	0	1	**4**
PH-ET534: Plasma Physics I	3	0	1	**4**
PH-ET535: Particle Physics I	3	0	1	**4**
PH-ET536: Quantum Field Theory I	3	0	1	**4**
PH-ET537: Advanced Mathematical Physics	3	0	1	**4**
PH-ED540: Dissertation I	**-**	**-**	**-**	**4**
Open Elective Courses				
PH-OT541: Radiation Safety	3	0	1	**4**
PH-OT542: Introductory Astronomy	3	0	1	**4**
PH-OT543: Complex Systems & Networks	3	0	1	**4**
Total credits in Electives/Open Electives: 12				
Total credits in Semester III: 20				

Semester IV				
Number of core courses: 1	**Credits in each core course**			
CORE COURSE:	**Theory**	**Practical**	**Tutorial**	**Credits**
PH-CT503: Atomic and Molecular Physics	3	0	1	4
Total credits in Core courses: 4	3	0	1	**4**
Number of Elective/Open Elective courses: 4	**Credits in each elective course**			
ELECTIVE COURSES:	**Theory**	**Practical**	**Tutorial**	**Credits**
Experimental Modules:				
Module A-II:				
PH-ET551: Physics at the Nanoscale – II (Theory)	3	0	1	**4**
PH-EL552: Nanomaterials – II (Lab)	0	4	0	**4**
Module B-II:				
PH-ET553: Advanced Electronics - II (Theory)	3	0	1	**4**
PH-EL554: Advanced Electronics- II (Lab)	0	4	0	**4**
Module C-II:				
PH-ET555: Advanced Nuclear Physics – II (Theory)	3	0	1	**4**
PH-EL556: Advanced Nuclear Physics - II (Lab)	0	4	0	**4**
Module D-II:				
PH-ET557: Lasers and Spectroscopy – II (Theory)	3	0	1	**4**

PH-EL558: Lasers and Spectroscopy - II (Lab)	0	4	0	**4**
Module E-II:				
PH-ET559: Advanced Solid State Physics – II(Theory)	3	0	1	**4**
PH-EL560: Advanced Solid State Physics – II (Lab)	0	4	0	**4**
Module F:				
PH-ET561: Advanced Numerical Techniques (Theory)	3	0	1	**4**
PH-EL562: Advanced Numerical Techniques (Lab)	0	4	0	**4**
Module G:				
PH-EL564: Observational Astronomy Lab	0	4	0	**4**
Theory courses:				
PH-ET571: General Theory of Relativity and Cosmology II	3	0	1	**4**
PH-ET572: Astrophysics II	3	0	1	**4**
PH-ET573: Condensed Matter Physics II	3	0	1	**4**
PH-ET574: Plasma Physics II	3	0	1	**4**
PH-ET575: Particle Physics II	3	0	1	**4**
PH-ET576: Quantum Field Theory II	3	0	1	**4**
PH-ED580: Dissertation II	-	-	-	**4**
Special Theory courses:				

PH-ET581: Nonlinear Dynamics	3	0	1	**4**
PH-ET582: String Theory	3	0	1	**4**
PH-ET583: Superconductivity, Superfluidity & Critical Phenomena	3	0	1	**4**
PH-ET584: Soft Matter Physics	3	0	1	**4**
PH-ET585: Fluid Dynamics	3	0	1	**4**
PH-ET586: Nuclear Astrophysics	3	0	1	**4**
PH-ET587: Nuclear Safety & Security	3	0	1	**4**
PH-ET588: Applied Physics	3	0	1	**4**
OPEN ELECTIVE COURSES:	**Credits in each Open Elective**			
PH-OT591: Biological Physics	3	0	1	**4**
PH-OT592: Physics Education	3	0	1	**4**
Total credits in Electives/Open Electives: 16				
Total credits in Semester IV: 20				

- **Certain Elective Courses may have pre-requisites. Students should keep this in mind while opting for Elective courses.**
- **Elective courses offered by the Department fall under the following categories: Experimental Modules, Theory courses, Dissertation, Special Theory courses and Open electives.**
- **The list of Elective Courses offered, including open electives, may change from year to year depending upon the availability of faculty.**

SELECTION OF ELECTIVE/OPEN ELECTIVE COURSES:

SEMESTER III: THREE Elective/Open Elective courses are to be selected adding up to 12 credits.

SEMESTER IV: FOUR Elective/Open Elective/special theory courses/ Dissertation are to be selected adding up to 16 credits.

Restrictions:

- A maximum of one course each from the Open Electives is allowed in each of Semesters III and IV. Total number of credits in Open Electives cannot be more than 8.
- A maximum of 8 extra credits can be taken during the entire MSc duration.
- Further restrictions may be imposed for a particular term on a case-by-case basis depending on different constraints.
- Introductory Astronomy in Open Elective is not open to students who have opted for Astrophysics and Astronomy – I.

IV Course Wise Content Details for M. Sc. Physics Programme

MASTER of SCIENCE in PHYSICS

Semester I

Course Code: PH-CT401

Course Name: Classical Mechanics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The primary objective is to teach the students Classical Mechanics at a level more advanced than what they have learnt in B.Sc. This is a course which forms the basis of Physics of many areas of Physics.

Contents:

Unit I **(15 lectures)**

Newton's laws and symmetries. Generalized coordinates and constraints on dynamical systems. Variational calculus. Action and Euler-Lagrange equations. Cyclic coordinates and conserved quantities, Louville's theorem, Scaling laws, potential reconstruction. Examples. Hamiltonians and Hamiltonian equations. Phase space trajectories. Canonical variables and Poisson bracket. Examples.

Unit II **(10 lectures)**

Kepler problem. Perturbation and precessing orbits. The classical scattering problem. Small oscillations (non-diagonal kinetic and potential terms).

Unit III **(8 lectures)**

Canonical transformations, Generators of infinitesimal canonical transformations. Hamilton-Jacobi equation, Action and angle variables, Adiabatic invariants.

Unit IV **(6 lectures)**

Rigid Body, Euler angles, the symmetrical top.

Unit V **(6 lectures)**

System with infinite degrees of freedom Classical fields : Lagrangian and Hamiltonian formulations Equations of motion. Symmetries and invariance principles, Noether's theorem.

Course Learning Outcomes

Students will be equipped for advanced and specialized courses.The student learns to deal with particle mechanics at an advanced level and to learn the foundations of the classical theory of fields.

Suggested Readings

1. *Mechanics*, L. D. Landau and E. M. Lifshitz (3rd Ed., Pergamon, 1976).
2. *Classical Mechanics*, H. Goldstein (Pearson Education, 2014).
3. *Classical Mechanics*, N. C. Rana and P. S. Jaog (McGraw-Hill, 1991).

MASTER of SCIENCE in PHYSICS

Semester I

Course Code: PH-CT402

Course Name: Quantum Mechanics - I

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The primary objective is to teach the students the physical and mathematical basis of quantum mechanics for non-relativistic systems

Contents:

Unit I (**17 lectures**)

Abstract formulation of Quantum Mechanics: Mathematical properties of linear vector spaces. Dirac's bra and ket notation. Hermitian operators, eigenvalues and eigenvectors. Orthonormality, completeness, closure. Postulates of quantum mechanics. Matrix representation of operators. Position and momentum representations – connection with wave mechanics. Commuting operators. Generalised uncertainty principle. Change of basis and unitary transformation. Expectation values. Ehrenfest theorem.

Unit II (**17 lectures**)

Quantum Dynamics: Schrodinger picture,. Heisenberg picture, Heisenberg equation of motion, classical limit, Solution of simple harmonic oscillator problem by the operator method, general view of symmetries and conservation laws, Symmetries in Quantum Mechanics : hydrogen-like atoms and spherical harmonics. Spatial translation – continuous and discrete, time translation. parity, time reversal, Density matrices - properties, pure and mixed density matrices, expectation value of an observable, time-evolution, reduced density matrix

Unit III (**11 lectures**)

Angular Momentum: Commutation relations of angular momentum operators. Eigenvalues, eigenvectors. Ladder operators and their matrix representations. Spin angular momentum and Pauli matrices. Identical particles: Many-particle systems, Exchange degeneracy, symmetric and anti-symmetric wavefuncttions. Pauli exclusion principle. Addition of angular momenta. Clebsch-Gordan coefficients. Wigner - Eckart theorem.

Course Learning Outcomes

Students will learn the mathematical formalism of Hilbert space, hermitian operators, eigen values, eigen states and unitary operators, which form the fundamental basis of quantum theory. Application to simple harmonic oscillators, hydrogen-like atoms and angular momentum operators will teach the students how to obtain eigen values and eigen states for such systems elegantly. The topic of density matrices that plays significant roles in quantum information theory and statistical mechanics will also help the students considerably.

Suggested Readings

1. *Quantum Mechanics,* B. H. Bransden & C. J. Joachain (Pearson Education, 2000)
2. *Principles of Quantum Mechanics,* R. Shankar (3rd Ed., Springer, 2008)

3. *Quantum Mechanics (Vol. I),*Claude Cohen-Tannoudji, Bernard and Frank Laloe (Wiley, 1977)
4. *Modern Quantum Mechanics,* J. J. Sakurai (Addison-Wesley, 1993)
5. *Advanced Quantum Mechanics,* F. Schwabl (Springer, 2000)
6. *Quantum Mechanics,* A. S. Davydov (2nd Ed., Pergamon, 1991)
7. *Quantum Mechanics,* Eugen Merzbacher (3rd Ed., Wiley, 1997)
8. *Quantum Mechanics: Concepts and Applications,* Nouredine Zettili (Wiley 2nd edition 2009)

MASTER of SCIENCE in PHYSICS

Semester I

Course Code: PH-CT403

Course Name: Electronics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

To buildup on the basic knowledge of electronics with the introduction of advanced topics like circuit analysis and applications of semiconductor devices in analog and digital circuits.

Contents:

Unit I (**10 lectures**)

Circuit Analysis: Admittance, impedance, scattering and hybrid matrices for two and three-port networks and their cascade and parallel combinations. Review of Laplace Transforms. Response functions, location of poles and zeros of response functions of active and passive systems (Nodal and Modified Nodal Analysis).

Unit II (**12 lectures**)

Physics of Semiconductor Devices: p-n junction, BJT, JFET, equivalent circuits and high frequency effects, UJT, 4 layer pnpn device (SCR),. MOS diode, accumulation, depletion and inversion, MOSFET: I-V, C-V characteristics. Enhancement and depletion mode MOSFET.

Metal-semiconductor junctions; Ohmic and rectifying contacts, Schottky diode, I-V, C-V relations.

Unit III (**5 lectures**)

Analog circuits: Active filters and equalizers with feedback, Phase shift and delay.

Unit IV (**8lectures**)

Digital Circuits: Introduction to digital IC parameters (switching time, propagation delay, fan out, fan in etc.). TTL, MOS and CMOS gates, Emitter-coupled logic, MOSFET as transmission gate. A/D and D/A converters. Basics of micro-processor and micro-controller.

Unit V (**10 lectures**)

Communication Systems: Amplitude, Angle and Pulse-analog modulation: Generation and detection. Model of communication system, classification of signals, representation of signals.

Course Learning Outcomes

A student of this course is expected to be able to understand the design and functional performance of electronic circuits using various semiconductor devices. In addition, the student will understand the functional properties and characteristics of semiconductor devices in analog & digital circuits using analog and digital signals.

Suggested Readings

1. *Network Analysis and Synthesis*, F.F. Kuo (2nd Ed., Wiley, 2010)
2. *Network Analysis with Applications*, W.D. Stanley (4th Ed., Pearson, 2003)

3. *Electronic Devices and Circuits*, J. Millman and C. C. Halkias and S. Jit (4th Ed., McGraw-Hill, 2015)
4. *Integrated Electronics,* J. Millman, C. C. Halkias and C. D. Parikh (2nd Ed., McGraw-Hill, 2011)
5. *Communication Systems*, Simon Haykins (5th Ed., Wiley, 2009)
6. *Digital Signal Processing*, J. G. Proakis and D. G. Manolakis (4th Ed., Pearson, 2007)
7. *Solid State Electronic Devices*, B.G. Streetman (7th Ed., Pearson, 2015)
8. *Introduction to Semiconductor Materials and Devices*, M. S. Tyagi (1st Ed., Wiley, 2012)
9. *Digital Design,* M. Mano (5th Ed., Pearson, 2013)
10. *Digital principles and Applications*, A.P. Malvino and D.P.Leach (8th Ed., McGraw-Hill, 2014)

MASTER of SCIENCE in PHYSICS

Semester I

Course Code: PH-CT404

Course Name: Mathematical Physics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The primary objective is to teach the students basic mathematical methods that will be used in many of the other courses in the M.Sc. Syllabus.

Contents:

Unit I (**12 lectures**)

Linear Vector Space: A brief review of linear vector spaces, Inner product, norm, Schwarz inequality, linear operators, eigenvalue and eigenvector, adjoint of a linear operator, Hermitian or self-adjoint operators and their properties, unitary operators, ortho-normal basis –discrete and continuous.

Unit II (**9 lectures**)

Theory of Probability and Statistics: Random Variables, Binomial, Poisson and Normal Distributions. Central Limit Theorem, Hypothesis Testing and Data Analysis in Statistics.

Unit III (**9 lectures**)

Complex Analysis: Complex Analysis including use of residue theorem. Integral Transforms Green's functions.

Unit IV (**15 lectures**)

Group Theory: Abstract groups: subgroups, classes, cosets, factor groups, normal subgroups, direct product of groups; Examples, Homomorphism &isomorphism.
Representations: reducible and irreducible, unitary representations, Schur's lemma and orthogonality theorems, characters of representation, direct product of representations.
Introduction to continuous groups: Lie groups, rotation and unitary groups.
Representation of SO(3), SU(2), SU(3) and SO(3,1), Tensors.

Course Learning Outcomes

Students will learn the required Mathematics techniques that may have not been covered in the courses in B.Sc. CBCS program and which will be useful in many other courses in MSc.

Suggested Readings

1. *Mathematical Physics*, V. Balakrishnan (1st Ed., Ane Books, 2018)
2. *Mathematical Methods for Physicists*, G. Arfken (7th Ed., Elsevier, 2012)
3. *Advanced Engineering Mathematics*, E. Kreyzig (2nd Ed., Pearson, 2002)

MASTER of SCIENCE in PHYSICS

Semester I

Course Code: PH-CL405/ PH-CL410

Course Name: General Lab – I/II

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

The major objective of this course is to revise the basic concepts of electronics/nuclear physics through standard set of experiments. In addition, the continuous evaluation process allows each and every student to not only understand and perform the experiment but also suitably correlate them with the corresponding theory.

Contents:

Electronics

Unit I - Device Characteristics and Application

1. p-n junction diodes-clipping and clamping circuits.
2. FET – characteristics, biasing and its applications as an amplifier.
3. MOSFET – characteristics, biasing and its applications as an amplifier.
4. UJT – characteristics, and its application as a relaxation oscillator.
5. SCR – Characteristics and its application as a switching device.

Unit II - Linear Circuits

1. Resonant circuits.
2. Filters-passive and active, all pass (phase shifters).
3. Power supply-regulation and stabilization.
4. Oscillator-design and study.
5. Multi stage and tuned amplifiers.
6. Multivibrators-astable, monostable and bistable with applications.
7. Design and study of a triangular wave generator.
8. Design and study of sample and hold circuits.

Unit III - Digital Circuits and Microprocessors

1. Combinational.
2. Sequential.
3. A/D and D/A converters.
4. Digital Modulation.
5. Microprocessor application.

Nuclear Physics

Unit I - Detectors

1. G.M. Counters – characteristics, deadtime and counting statistics
2. Spark counter-characteristics and range of x-particles in air
3. Scintillation detector-energy calibration, resolution and determination of gamma ray energy
4. Solid State detector – surface barrier detector, its characteristics and applications.

Unit II - Applications

1. Gamma ray absorption-half thickness in lead for 60Co gamma-rays.
2. Beta ray absorption – end point energy of betaparticles.
3. Lifetime of a short lived radioactive source..

Unit III - High Energy Physics

1. Study of pi-mu-e decay in nuclear emulsions.
2. Study of high energy interactions in nuclear emulsions.

Course Learning Outcomes

At the end of this laboratory course, each and every student is expected to understand the basic concepts of electronics/nuclear physics through experiments, which would immensely help them in acquiring knowledge to tackle various competitive exam questions.

Suggested Readings

Electronics:

1. *Electronic Instrumentation and Measurement Techniques*, W. D. Cooper and A. D. Helfrick (2nd Ed., Phi Learning, 2008)
2. *Electronic Devices and Circuits*, J. Millman and C. C. Halkias and S. Jit (4th Ed., McGraw-Hill, 2015)
3. *Measurement, Instrumentation and Experimental Design in Physics and Engineering*, M. Sayer and A. Mansingh (Prentice Hall India, 2010)

Nuclear Physics:

4. *Radiation Detection and Measurement,* G. F. Knoll (John Wiley & Sons, Inc. 3rd Ed.,2000)
5. *Physics & Engineering of Radiation Detection,* S. N. Ahmed (Academic Press 2007)
6. *Techniques for Nuclear and Particle Physics Experiments,* W.R. Leo (Springer-Verlag 1987)

MASTER of SCIENCE in PHYSICS

Semester II

Course Code: PH-CT406

Course Name: Quantum Mechanics-II

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The primary objective is to teach the students various approximation methods in quantum mechanics. The important topic of quantum scattering is also dealt with. Relativistic quantum theory like Klein-Gordon equation and Dirac equation is also covered.

Contents:

Unit I (**13 lectures**)

Approximation Methods for Stationary Systems: Time-independent perturbation theory - (a) non- degenerate and (b) degenerate, variational method and its applications. WKB method and its applications.

Unit II (**13 lectures**)

Approximation Methods for time-dependent perturbations: Interaction picture. Time-dependent perturbation theory. Transition to a continuum of final states – Fermi's Golden Rule. Application to constant and harmonic perturbations. Sudden and adiabatic approximations.

Unit III (**12 lectures**)

Scattering: Wave packet description of scattering. Lippmann-Schwinger Equations, Formal treatment of scattering by Green's function method. Born approximation and applications. Definition and properties of S-Matrix Partial wave analysis. Optical theorem.

Unit IV (**7 lectures**)

Relativistic Quantum Mechanics: Klein-Gordon and Dirac equations. Properties of Dirac matrices. Plane wave solutions of Dirac equation. Spin and magnetic moment of the electron, non-relativistic reduction of the Dirac equation.

Course Learning Outcomes

Students will learn how to use perturbation theory to obtain corrections to energy eigen-states and eigen-values when an external electric or magnetic field is applied to a system. Scattering theory will teach them how to use projectiles to infer details about target quantum system. Relativistic quantum mechanics will provide an exposure to how special relativity in quantum theory leads to intrinsic spin angular momentum as well as anti-particles

Suggested Readings

1. *Quantum Mechanics* by B.H. Bransden & C.J. Joachain (Pearson Education, 2000)
2. *Principles of Quantum Mechanics* by R. Shankar (Springer, 3rd Edition, 2008)
3. *Modern Quantum Mechanics* by J.J. Sakurai (Addison-Wessley, 1993)

4. *Advanced Quantum Mechanics* by Schwabl F. (Sringer, 2000)
5. *Quantum Mechanics* by A.S. Davydov (2nd Ed., Pergamon, 1991)
6. *Quantum Mechanics* by Eugen Merzbacher (3rd Ed., Wiley, 1997)
7. *Introduction To Quantum Mechanics*: Schrodinger equation and Path Integral by H. J.W. Muller-Kirsten, (World Scientific, 2006)
8. *Quantum Mechanics*, volumes I and II by Cohen Tanaudji et al,
9. *Advanced Quantum Mechanics*, J. J. Sakurai (1st Ed. Pearson, 2002)
10. *Introduction to Quantum Mechanics*, D.J. Griffiths (2st Ed., Pearson, 2005)
11. *Quantum Mechanics: Concepts and Applications,* Nouredine Zettili (Wiley 2nd edition 2009)
12. *Quantum Field Theory*, Lewis H. Ryder (2nd Ed., Cambridge University .Press, 1996).
13. *Relativistic Quantum Fields, Vol.II*, J.D. Bjorken and S.D. Drell (McGraw-Hill, 1978)
14. *Relativistic Quantum Fields, Vol.I*, J.D. Bjorken and S.D. Drell (McGraw-Hill, 1964)

MASTER of SCIENCE in PHYSICS

Semester II

Course Code: PH-CT407

Course Name: Statistical Physics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This course introduces students to statistical mechanics, which is part of the foundation of several branches of physics and has many applications beyond physics. The course demonstrates the profound consequences of an economical set of assumptions about nature known as the postulates of statistical mechanics. In particular, it shows how the postulates explain the general laws of thermodynamics as well as properties of classical and quantum gases, other condensed matter systems in equilibrium, and phase transitions.

Contents:

Unit I (**5 lectures**)

Review of thermodynamics and topics in probability theory: Quasistatic and non-quasistatic processes, laws of thermodynamics, entropy of a probability distribution, random walks.

Unit II (**20 lectures**)

Classical ensemble theory: Phase space, microstates and macrostates; Liouville's equation, Postulates of statistical mechanics, Microcanonical ensemble, Boltzmann relation for entropy, Definition of temperature, derivation of the laws of thermodynamics for macroscopic systems, Sackur-Tetrode equation, Canonical ensemble; partition function; Helmholtz free energy, Grand-canonical ensemble, Equivalence of the various ensembles, Application to various classical systems.

Unit III (**10 lectures**)

Quantum statistical mechanics: Indistinguishable particles in quantum mechanics. Bosons and Fermions. Bose-Einstein statistics, ideal Bose gas, photons, Bose-Einstein condensation. Fermi-Dirac statistics, Fermi energy, ideal Fermi gas. Density operator, Quantum Liouville equation. Pure and mixed states.

Unit IV (**10 lectures**)

Interacting systems and phase transitions: Interacting spin systems. The Ising model. Exact solution of Ising model in 1-dimension, mean-field solution in higher dimensions. Paramagnetic and ferromagnetic phases. Critical exponents. Order parameter, Landau theory, Universality.

Course Learning Outcomes

Understand how a probabilistic description of nature at the microscopic level gives rise to deterministic laws at the macroscopic level. Relate the concepts of entropy and temperature as defined in statistical mechanics to their more familiar versions in thermodynamics. Solve for the thermal properties of classical and quantum gases and other condensed systems from a knowledge of their microscopic Hamiltonians. Appreciate that interactions between particles can explain the various phases of matter observed in nature, as well as the universality of critical exponents characterizing phase transitions.

Suggested Readings

1. *Statistical Physics of Particles*, Mehran Kardar (Cambridge University Press, 2007).
2. *Statistical Mechanics*, Kerson Huang (2ndEdition, Wiley-India, 2008).
3. *Statistical Mechanics*, R.K. Pathria (Butterworth-Heinemann, 1996).
4. *Statistical Mechanics*:*An Advanced course with problems and solutions*, Ryogo Kubo (North- Holland, 1965).

MASTER of SCIENCE in PHYSICS

Semester II

Course Code: PH-CT408

Course Name: Electromagnetic Theory & Electrodynamics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This course aims to introduce the student to topics in Electromagnetic Theory, Relativity and the Relativistic formulation of electromagnetism. The course reviews and builds on the students' knowledge of Relativity and introduces the formulation of relativity in 4-vector notation. It also builds up a covariant formulation of electrodynamics and includes a study of motion of charges in fields as well as radiation from moving charges as well as antennae.

Contents:

Unit I (**18 lectures**)

Review of Maxwell's Equations: Fundamental problem of electromagnetic theory. Scalar and vector potentials. Gauge transformations. Coulomb and Lorentz gauges. Review of Special Theory of Relativity (STR) and its application to electromagnetic theory: Conceptual basis of STR. Thought experiments. Concepts of invariant interval, light cone, event and world line. Four-vectors, Tensors. Lorentz transformation as 4-vector transformations. Transformation properties of electric and magnetic fields. E.M. field tensor. Covariance of Maxwell's equations (from tensorial arguments).

Unit II (**6 lectures**)

Relativistic Charged Particle Dynamics in Electromagnetic Fields: Motion in uniform static magnetic field, uniform static electric field and crossed electric and magnetic fields. Particle drifts (velocity and curvature) in non-uniform static magnetic fields. Adiabatic invariance of magnetic moment of a charged particle and torus principle of magnetic mirror.

Unit III (**15 lectures**)

Radiation: Green function for relativistic wave equation. Radiation from localized oscillating charges. Near and far zone fields. Multipole expansion. Dipole and quadrupole radiation. Centre- fed linear antenna. Radiation from an accelerated point charge. Lienard-Wiechert potentials. Power radiated by a point charge : Lienard's formula and its nonrelativistic limit (Larmor's formula). Angular distribution of radiated power for linearly and circularly accelerated charges.

Unit IV (**6 lectures**)

Lagrangian Formulation of Electrodynamics: Lagrangian for a free relativistic particle, for a charged particle in an E.M. field, for free electromagnetic field, for interacting charged particles and fields. Energy-momentum tensor and related conservation laws.

Course Learning Outcomes

A student having taken this course is expected to have a fair degree of familiarity with tensors and tensorial formulation of relativity and electrodynamics. In addition, s/he is expected to be able to solve problems of motion of charged particles in various field formations as well as find the radiation patterns from different time varying charge and current densities.

Suggested Readings

1. *Classical Electrodynamics*, John David Jackson (3^{rd} Ed..,Wiley,1998)
2. *Introduction to Electrodynamics*, David Griffiths (3rd Ed., Benjamin Cummings, 1999)
3. *Principles of Electrodynamics*, Melvin Schwartz (Dover Publications, 1987)
4. *Classical Electrodynamics*, J. Schwinger, L.L. Deraad Jr, K.A. Milton, W-Y. Tsai and J. Norton (Westview Press, 1998)
5. *Modern Problems in Classical Electrodynamics*, Charles A. Brau (Oxford Univ. Press, 2003)
6. *Electrodynamics of Continuous Media*, L. D. Landau and E. M. Lifshitz & L. P. Pitaevskii (Oxford, 2005)

MASTER of SCIENCE in PHYSICS

Semester II

Course Code: PH-CT409

Course Name: Solid State Physics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This course intends to provide knowledge of conceptual solid-state physics. In addition, this course aims to provide a general introduction to theoretical and experimental topics in solid state physics.

Contents:

Unit I (**6 lectures**)

Metals: Drude theory, DC conductivity, magneto-resistance, thermal conductivity, thermo-electric effects, Fermi-Dirac distribution, thermal properties of an electron gas, Wiedemann-Franz law, critique of free-electron model.

Unit II (**10 lectures**)

Crystal Lattices: Diffraction of electromagnetic waves by crystals: X-rays, Electrons and Neutrons, Symmetry operations and classification of Bravais lattices, common crystal structures, reciprocal lattice, Brillouin zone, X-ray diffraction, Bragg's law, Von Laue's formulation, diffraction from non-crystalline systems. Geometrical factors of SC, FCC, BCC and diamond lattices; Basis of quasi crystals.

Unit III (**4 lectures**)

Crystal Binding: Bond classifications – types of crystal binding, covalent, molecular and ionic crystals, London theory of van der Waals, hydrogen bonding, cohesive and Madelung energy.

Unit IV (**4lectures**)

Defects and Diffusion in Solids: Point defects: Frenkel defects, Schottky defects, examples of colour centres, line defects and dislocations.

Unit V (**6lectures**)

Lattice Dynamics: Failure of the static lattice model, adiabatic and harmonic approximation, vibrations of linear monoatomic lattice, one-dimensional lattice with basis, models of three-dimensional lattices, quantization of lattice vibrations, Einstein and Debye theories of specific heat, phonon density of states, neutron scattering.

Unit VI (**6lectures**)

Band theory of Solids: Periodic potential and Bloch's theorem, weak potential approximation, density of states in different dimensions, energy gaps, Fermi surface and Brillouin zones. Origin of energy bands and band gaps, effective mass, tight-binding approximation and calculation of simple band-structures. Motion of electrons in lattices, Wave packets of Bloch electrons, semi-classical equations of motion, motion in static electric and magnetic fields, theory of holes, cyclotron resonance.

Unit VII (**4 lectures**)

Semiconductors: General properties and band structure, carrier statistics, impurities, intrinsic and extrinsic semiconductors, drift and diffusion currents, mobility, Hall effect.

Unit VIII (**5 lectures**)

Superconductors: Phenomenology, review of basic properties, thermodynamics of superconductors, London's equation and Meissner effect, Type-I and Type-II superconductors, BCS theory of superconductors.

Course Learning Outcomes

The students should be able to elucidate the important features of solid state physics by covering crystal lattices and binding, lattice dynamics, band theory of solids and semiconductors.

Suggested Readings

1. *Introduction to Solid State Physics,* C. Kittel (8th Ed., Wiley, 2012)
2. *Solid State Physics,*N. W. Ashcroft and N. D. Mermin (Ist Ed., Cengage Learning, 2003)
3. *Principles of the Theory of Solids*, J. M. Ziman (2nd Ed., Cambridge University Press, 1972)
4. *Solid State Physics,* A. J. Dekker (1st Ed., Macmillan India, 2000)
5. *Solid State Physics,* G. Burns (1st Ed., Academic Press, 1985)
6. *Condensed Matter Physics*, M. P. Marder (Wiley, 2010)

MASTER of SCIENCE in PHYSICS

Semester II

Course Code: PH-CL405/ PH-CL410

Course Name: General Lab – I/II

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

The major objective of this course is to revise the basic concepts of electronics/nuclear physics through standard set of experiments. In addition, the continuous evaluation process allows each and every student to not only understand and perform the experiment but also suitably correlate them with the corresponding theory.

Contents:

Solid State Physics

Unit I - Experimental Techniques

1. Production and measurement of low pressures.
2. Production and measurement of high pressures.
3. Measurement and control of low temperatures.
4. Production and characterization of plasma.
5. Electron Spin Resonance.
6. Nuclear Magnetic Resonance.

Unit II -Electrical Transport Properties

1. Measurement of resistivity – Four probe and van der Paw techniques; determination of band gap.
2. Measurement of Hall coefficient – determination of carrier concentration.
3. Measurement of magneto resistance.
4. Measurement of thermoelectric power.
5. Measurement of minority carrier lifetime in semiconductors Hyne Shockley experiment.

Unit III -Phase Transitions and Crystal Structure

1. Determination of transition temperature in ferrites.
2. Determination of transition temperature in ferroelectrics.
3. Determination of transition temperature in high Tc superconductors.
4. Determination of transition temperature in liquid crystalline materials.
5. Crystal structure determination by x-ray diffraction powder photograph method.

Waves and Optics

Unit I -Waves

1. Velocity of sound in air by CRO method.
2. Velocity of sound in liquids – Ultrasonic Interferometer method.
3. Velocity of sound in solids – pulse echo method.
4. Propagation of EM waves in a transmission line – Lecher wire.
5. Determination of Planck’s constant.
6. Jamin’s interferometer – refractive index of air.

7. Study of elliptically polarized light.

Unit II -Optical Spectroscopy

1. Constant deviation spectrometer-fine structure of Hg spectral lines.
2. e/m or hyperfine structure using Febry Perot's interferometer.
3. Band spectrum in liquids.
4. Raman scattering using a laser source.
5. Luminescence.

Unit III -Laser Based Experiments

1. Optical interference and diffraction.
2. Holography.
3. Electro-optic modulation.
4. Magneto-optic modulation.
5. Acousto-optic modulation.
6. Sound modulation of carrier waves.

Course Learning Outcomes

At the end of this laboratory course, each and every student is expected to understand the basic concepts of electronics/nuclear physics through experiments, which would immensely help them in acquiring knowledge to tackle various competitive exam questions.

Suggested Readings

Solid State Physics:

1.

Waves and Optics:

1. *Lasers: Fundamental and Applications, Graduate Text in Physics, 2nd edition*, K. Thyagarajan, Ajoy ghatak (Springer, 2002)
2. *Polarization of light*, by Ajoy Ghatak and Arun Kumar (Mc GrawHill Education, 2012)
3. *Introduction to Fibre Optics*, Ajoy Ghatak and K. Thyagarajan, (Cambridge University Press, 2000)
4. *Teaching laser physics by experiments*, Am. J. Phys., (2011), http://doi.org/1-3488984

NOTE:

The list of experiments given above should be considered as suggestive of the standard and available equipment. The teachers are authorized to add or delete from this list whenever considered necessary.

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-CT501

Course Name: Nuclear & Particle Physics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The primary objective is to introduce the basic concept of Nuclear & Particle Physics and impart of knowledge for particle and radiations detectors.

Contents:

Unit I **(5 lectures)**

Static properties of Nuclei: Nuclear Mass & size determination, Mott scattering, nuclear form- factors. Angular momentum, spin, parity, iso-spin and moments of nuclei (Electric and Magnetic).

Unit II **(10 lectures)**

Two Nucleon Systems & Nuclear Forces: Dipole and quadrupole moments of the deuteron, Central and tensor forces, Evidence for saturation property, Neutron-proton scattering, exchange character, spin dependence (ortho and para-hydrogen), charge independence and charge symmetry. S-wave effective range theory. Proton- proton scattering (qualitative idea only). Evidence for hardcore potential. Meson theory.

Unit III **(8 lectures)**

Nuclear Models:Concept of Liquid drop model, Magic nuclei, nucleon separation energy, Single particle shell model (including Mean filed approach, spin orbit coupling), Physical concepts of the unified model (Collective Model)

Unit IV **(7lectures)**

Nuclear Decays and Reactions: Electromagnetic decays: selection rules, Fermi theory of beta decay. Kurie plot. Fermi and Gamow-Teller transitions. Logeft value, Parity violation in beta-decay. Gamma decay, selection rules, Introduction to Nuclear Reactions (Conservation Laws, kinematics of reactions, Q-value, reaction rate, reaction cross section), Concept of Direct and compound nuclear reaction

Unit V **(10 lectures)**

Elementary Particles: Relativistic kinematics, Various Interactions, Parity, Charge Conjugation and Time Reversal, Classification: spin and parity determination of pions and strange particles. Gell-Mann Nishijima scheme. Properties of quarks and their classification. Elementary ideas of SU(2) and SU(3) symmetry groups and hadron classification. Introduction to the standard model. Electroweak interaction-W & Z Bosons.

Unit VI **(5 lectures)**

Nuclear Detectors: Interaction of radiation with matter (qualitative idea), Basics of Solid state detectors, Scintillation and gas detectors for particle and electromagnetic radiation detection, Idea of Calorimeter, Hybrid detectors and arrays.

Course Learning Outcomes

Students will extend the understanding of fundamental forces by studying nuclear and weak forces. Understanding of nuclear structure and reaction dynamics will provides knowledge of nuclear-nucleon interaction. Students will also understand particle physics through this Course. Knowledge of uclear detectors and the interaction of radiation with matter will also be imparted to the students.

Suggested Readings

1. *Introducing Nuclear Physics*, K. S. Krane (Wiley India., 2008).
2. *Nuclear Physics – Theory & Experiments,* R.R. Roy & B.P. Nigam (New Age International, 2005)
3. *Nuclear Physics in A Nutshell*, C. A. Bertulani (1st Ed., Princeton University Press, 2007)
4. *Concept of Nuclear Physics*, B. L. Cohen (McGraw – Hill, 2003)
5. *Nuclear Physics*, S. N. Ghoshal (First edition, S. Chand Publication)
6. *Nuclear & Particle Physics : An Introduction*, B. Martin (Willey, 2006)
7. *Introduction to Elementary Particles*, D. Griffiths (Academic Press, 2nd Ed. 2008)
8. *Physics and Engineering of Radiation Detection* by Syed Naeem Ahmed(Academic Press 2007)
9. *Radiation detection and measurement*, G.F. Knoll (John Wiley & Sons, Inc. 3^{rd}Ed.,2000)

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-CL502

Course Name: Computational Physics (Lab)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This course is intended to be an Introduction to a programming Language (C/C++) as well as application for Numerical Analysis. The course would impart training in the structure of the programming language as well as train the students in using programs to numerically solve problems in various areas. In addition, it will also familiarize the students to the Unix environment.

Contents:

- Introduction to Linux and Computer Programming Language (C/C++).
- Introduction to Graphics (Gnuplot etc.)
- Finite & Infinite Series
- Root Finding (Bisection, Secant and Newton-Raphson Methods)
- Solving First & Second Order differential Equations including Simultaneous Equations (Euler & Runge Kutta)
- Numerical Integration (Trapezoidal, Simpson and Quadrature methods)
- Schroedinger Equation- Finding the Eigenvalues & Eigenfunctions.
- Matrices- Arrays of variable Size, Matrix Operations, Eigenvalues & Eigenvectors, Matrix Inversion, Solving Systems of Linear Equations.

Course Learning Outcomes

A student having taken the course would be expected to be proficient in programming in the language (C/C++). In addition, it is also expected that the student would be able to write programs for solving various problems in Physics using techniques like Summing up of infinite series, solving differential equations and using numerical integration.

Suggested Readings

1. *Numerical Recipes in C++: The Art of Scientific Computing*, William H. Press , Saul A. Teukolsky, William T. Vetterling, Brian P. Flannery (2nd Ed., Cambridge University Press, 2002)
2. *Numerical Recipes in C: The Art of Scientific Computing*, William H. Press , Brian P. Flannery, Saul A. Teukolsky, William T. Vetterling (2nd Ed., Cambridge University Press, 2002)
3. *Mathematical Methods for Physicists*, George Arfken, Hans Weber, Frank E. Harris (7th Ed., Elsevier, 2012)
4. *Lab. Manual for Computer Programming & Numerical Methods*, Dept. of Physics & Astrophysics, University of Delhi, 2017.

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET511

Course Name:Physics at the Nanoscale – I (Theory)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

To introduce knowledge on basics of nanoscience and the fundamental concepts behind size reduction in various physical properties. More specifically, the student will be able to understand the different properties of materials in reduced scales.

Contents:

Unit I **(10 lectures)**

Quantum confined systems: Quantum confinement and its consequences, quantum wells, quantum wires and quantum dots and artificial atoms. Electronic structure from bulk to quantum dot. Electron states in direct and indirect gap semiconductors nanocrystals. Confinement in disordered and amorphous systems.

Unit II **(14 lectures)**

Dielectric properties: Coulomb interaction in nanostructures. Concept of dielectric constant for nanostructures and charging of nanostructure. Quasi-particles and excitons: Excitons in direct and indirect band gap semiconductor nanocrystals. Quantitative treatment of quasi-particles and excitons. Charging effects.

Unit III **(11 lectures)**

Optical properties: Optical properties and radiative processes: General formulation-absorption, emission and luminescence; Optical properties of heterostructures and nanostructures. Carrier transport in nanostructures: Coulomb blockade effect, scattering and tunneling of 1D particle; applications of tunneling, single electron transistors. Defects and impurities: Deep level and surface defects.

Unit IV **(10 lectures)**

Characterization basics: Direct imaging by scanning electron microscope, transmission electron microscope, and scanning probe techniques.

Course Learning Outcomes

The learner will be able to comprehend the significance of nanoscience and nanotechnology and its applications in various fields. The students will have in-depth knowledge on the behavior of various class of materials in reduced dimensions.

Suggested Readings

1. *Nanostructures-Theory & Modelling*, C. Delerue and M. Lannoo (Springer, 2004)

2. *Nanostructure,* V. A. Shchukin, N. N. Ledentsov and D. Bimberg (Springer, 2004)
3. *Characterization of Nanophase Materials*, Z. L. Wang (Ed.) (Wiley-VCH, 2000)
4. *Semiconductor Nanocrystal Quantum Dots*, A. L. Rogach (Ed.) (Springer Wien NY, 2008)
5. *Introduction to Nanotechnology*, C. P. Poole Jr. & F. J. Owens (Wiley-Interscience, 2003)

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET512

Course Name: Nanomaterials – I (Lab.)

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

The main goal of this subject is to synthesis of different class of materials by various methods. As synthesised nano materials will be characterized by different analytical techniques and analysed with respect to size reduction in the respective physical properties.

Contents:

LIST OF EXPERIMENTS

1. Growth of nanoparticles by chemical routes.
2. Growth of nanophase by sputtering.
3. Growth of quantum dots by thermal evaporation.
4. Growth of nanoparticles by mechanical milling/attrition.
5. Growth of nanomaterials by nanopores-template method.
6. Growth of semiconductor quantum dots in matrices (glass/polymer etc).
7. Structural characterization of nanomaterials by XRD- determination of average grain size, lattice parameters, strains etc.
8. Structural characterization of nanomaterials by TEM - determination of grain size and its distribution.
9. Surface morphological characterization of nanomaterials by AFM.
10. Surface morphological characterization of nanomaterials by SEM.
11. Surface morphological characterization of nanomaterials by TEM.
12. Determination of pores size of nanomaterials.
13. Measurement and analyses of UV/vis Absorption spectrum of nanomaterials.
14. Measurement and analysis of Photoluminescence spectrum of nanomaterials.
15. Measurement and analysis of Raman spectrum of nanomaterials.
16. Measurement and analysis of photoluminescence/Absorption spectrum of nanomaterials at low temperatures.
17. Determination of optical constants of nanomaterials by ellipsometry.
18. Measurement of sensor property of nanomaterials.
19. Determination of stoichiometry of nanomaterials by XPS/EDAX/ESCA.
20. Measurement and analysis of ferroelectric properties of nanomaterials.
21. Thermal characterization of polymers by DSC technique.

Course Learning Outcomes

The students will get a better understanding of the concepts studied by them in the theory course and correlate with experimental observations. In addition, the students are exposed with thermal, microscopic, electrical and spectroscopic methods of characterization of nanomaterials.

Suggested Readings

1. *Nanotechnology*,G.Timp (AIP press, Springer-Verlag, New York, 1999)

2. *Nanostructured materials and nanotechnology,* Hari Singh Nalwa. (Academic Press, USA, 2002)
3. *Hand book of Nanostructured Materials and Technology. Vol.1-5,* Hari Singh Nalwa. (Academic Press, USA, 2000)
4. *Handbook of Nanoscience, Engineering and Technology,* W.Gaddand, D.Brenner, S.Lysherski and G.J.Infrate. *(Electrical Engineering Handbook)* (CRC Press, 2012)
5. *Sol-Gel Science*,C.J. Brinker and G.W. Scherrer(Academic Press, Boston, 1994)
6. *Nanoscale Characterization of Surfaces & Interfaces,* N John Dinardo,(Weinheim Cambridge: Wiley-VCH, 2000)
7. *Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM*, Ray F. Egerton (Springer, 2005)
8. *Scanning Probe Microscopy: Analytical Methods* (NanoScience and Technology), Roland Wiesendanger (Springer, 1968)
9. *Chemistry of nanomaterials: Synthesis, properties and applications*, CNR Rao et.al. (Wiley-VCH, 2004)

1.

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET513

Course Name: Advanced Electronics – I (Theory)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

To enhance the understanding of basic design principles and constructional details of specialized semiconductor devices used for high frequency applications in modern communication networks and systems. To understand the use of semiconducting devices for diverse applications acting as signal/light sources, detection of signals and transduction of analog signals used in day to day electronics.

Contents:

Unit I (**12 lectures**)

Microwave Devices: Vacuum tube devices: Reflex klystron and magnetron. Transfer electron devices: Tunnel and Gunn diode, Avalanche Transit time devices (Read, IMPATT diodes, parametric devices).

Unit II (**14 lectures**)

Photonic Devices: Radiative transition and optical absorption, LED, semiconductor lasers, heterostructure and quantum well devices, charge coupled devices, photodetector, Schottky barrier and p-i-n photodiode, avalanche photodiode, photomultiplier tubes, Solar cells.

Unit III (**6 lectures**)

Memory Devices: MOSFET (n-MOS, p-MOS) and CMOS. Static and dynamic RAM, non-volatile memories. Optical and magnetic memories.

Unit IV (**8 lectures**)

Other Devices: Piezoelectric sensors and actuators, Transducers (temperature, pressure, vacuum, magnetic field, vibration, particle detector). OLED, solid state battery and LCD.

Unit V (**5 lectures**)

IC fabrication technology: MOSFET fabrication process. Substrate, dielectric, conducting and resistive layers. Lithography. Diffusion of impurities and deposition techniques.

Course Learning Outcomes

A student of this course is expected to have enhanced awareness of the constant evolution in the physics of semiconductor devices and materials, the basic device design along-with the standard technological procedures adapted in the semiconductor industry for IC manufacturing and mass production of semiconductor devices.

Suggested Readings

1. *Physics of Semiconductor Devices*, S. M. Sze and K. K. Ng (3rd Ed., Wiley, 2008)
2. *Semiconductor devices Physics and Technology*, S. M. Sze (2nd Ed., Wiley, 2008)
3. *Microwave Devices and Circuits*, S. Y. Liao (3rd Ed., Pearson, 2003)
4. *Electronic Instrumentation and Measurement Techniques*, W. D. Cooper and A. D.Helfrick (2nd Ed., Phi Learning, 2008)

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET514

Course Name: Advanced Electronic – I (Lab.)

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

Contents:

Group A : **Three experiments**

Design of operational circuits (linear and digital) using discrete and I.C. components.

Phase sensitive detector, filters, multistage amplifiers, oscillators, wave shaping circuits.

Group B : **Two experiments**

Microprocessor/computer interfacing using standard self wave and interfacing circuits for physics experiments. (I.V. characteristics, temperature controller etc.)

Course Learning Outcomes

The student will gain practical knowledge of designing, assembling, and testing electronic circuits as well as understanding troubleshooting.

Suggested Readings

1. *Electronic Instrumentation and Measurement Techniques,* W. D. Cooper and A. D. Helfrick (2^{nd} Ed., Phi Learning, 2008)
2. *Electronic Devices and Circuits*, J. Millman and C. C. Halkias and S. Jit (4^{th} Ed., McGraw-Hill, 2015)
3. *Measurement, Instrumentation and Experimental Design in Physics and Engineering,* M. Sayer and A. Mansingh (Prentice Hall India, 2010)

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET515

Course Name: Advanced Nuclear Physics-I (Theory)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The course has been design to impart knowledge about the theory behind nuclear technologies to identify particles and radiation required to design and performed an experiment with the accelerator facilities and the its applications in various fields

Contents:

Unit I **(7 lectures)**

Accelerators: Type of accelerators (Tandem, Cyclotron, linear accelerator , synchrotron etc.) and their basic principle, accelerator facilities in world, Beam optics (brief overview only), Vacuum Techniques, Target and thin film preparation.

Unit II **(15 lectures)**

Radiation Detectors: Interaction of radiation (light and heavy charge particle, neutron and photon)with matters; Type of detectors: Gas detector; Ionization chambers, Proportional counter, Multi-Wire proportional Counters (MWPC); Scintillation Detectors: Inorganic (NaI(Tl), CsI(Tl), BGO, BaF_2, La_2Br_3) and Organic (Anthracene & Plastic) Scintillators. Solid states Detectors: Si(Li), HPGe, Clover and segmented HPGe Detectors, Surface Barrier Detectors, Passivated Detectors, Neutron Detectors; Basic principle and working of a neutron detectors (Liquid and solid based detectors)

Unit III **(8 lectures)**

Nuclear electronics and Signal processing: Basics of signal processing, NIM, ECL and TTL standard, types of noise, Front-end linear and logical units for slow and fast signal processing. Coincidence technique (slow and fast), Data acquisition systems - CAMMAC and VME, Digital pulse processing (introduction only).

Unit IV **(15 lectures)**

Nuclear Techniques & their Application: Methods for charge and mass identification: □E-E energy loss, Time of Flight (TOF), mass spectrometer, Neutron: TOF and n- □ discrimination, Detector array (Gamma-rays, neutrons, charge particles), Multiplicity, Charge particle, neutron and gamma-ray spectroscopy, Angular distribution and correlation, Brief ideas of multipolarity and transition probabilities, Wisskoff-estimate, Internal conversion coefficient and their ratios, Polarization and its measurement, Doppler shift and Doppler broadening, Methods for life time measurements: Delay coincidence, pulse beam (slope and centroid shift), recoil distance and Doppler shift attenuation method, measurement of magnetic and quadrupole moment (g -factor, Hyperfine interaction).

Application of nuclear techniques in other areas (Medical, Archeology, Material research, Agriculture etc).

Course Learning Outcomes

Students will gain the basic understanding of the theory behind nuclear experimental technologies to identify particles and radiation, principles of accelerators, beam optics, vacuum technology, nuclear electronics, digital pulse processing, data acquisition and detector technology.

After completing this course students will be equipped with advanced skill and understanding required to perform nuclear and particle physics experiment with accelerator facilities exists in the world. It will further provide knowledge of nuclear techniques applied in different field for societal needs.

Suggested Readings

1. *Radiation Detection and Measurement*, G. F. Knoll (John Wiley & Sons, Inc. 3rd Ed.,2000)
2. *Physics & Engineering of Radiation Detection*, S. N. Ahmed (Academic Press 2007)
3. *Techniques for Nuclear and Particle Physics Experiments*, W.R. Leo (Springer-Verlag 1987)
4. *Nuclear Physics: Principles and Applications*, J.S. Lilly (John Wiley & Sons, Inc. 2002)

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET516

Course Name: Advanced Nuclear Physics-I (Lab.)

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

It will impart the skill on the experimental technique and will provide a hand on experience about different nuclear detector, Nuclear electronics and data acquisition system.

Contents:

LIST OF EXPERIMENTS

1. Study of radioactive isotopes by thermal neutron activation analysis (Neutron flux, growth of activity and half-life measurements).
2. Determination of the absolute disintegration rate of natural ^{40}K source using UX2 source as a standard. Deduction of the partial beta-decay half life of ^{40}K.
3. Absorption of gamma-rays in material media at different energies.
4. Investigation of energy response and calibration of a Nal (TI) scintillation spectrometer based on Gamma-rays spectroscopy.
5. Detection of gamma ray in different scintillation based detectors and their Comprising. (Energy response, energy resolution).
6. Determination of detection efficiency of a Nal (TI) scintillation spectrometer.
7. Gamma-rays spectroscopy using a single crystal HPGe detector : a) energy response, b) energy resolution and c) detection efficiency determination.
8. Beta-ray spectroscopy using an anthracene scintillation spectrometer (energy calibration and end-point energy measurement by Kurie-plot).
9. Study of angular distribution of Compton scattered gamma rays using a scintillation spectrometer and the deduction of total scattering cross-section.
10. Resolving time of a fast and slow coincidence circuit by the method of random coincidence using scintillation detectors and measurement of absolute source strength.
11. Study of fast-slow delayed coincidence system (resolving time as a function of clipping length, true-to-chance-ratio and coincidence efficiency).
12. Directional correlation measurements of cascading gamma rays and the determination of the cascade anisotropy using ^{60}Co source.
13. Proportional counter, its energy response and low energy X-ray measurements.
14. Determination of gas pressure in a vacuum chamber with different pumps and vacuum pressure gauges.
15. Alpha spectroscopy using a Si surface-barrier detector: Energy response & Energy resolution measurements.
16. Measurement of stopping power of an alpha particle using Si surface-barrier detector.
17. Energy determination of alpha particles emitted in the thorium decay using nuclear emulsion plates.

NOTE

This list is tentative; changes in the list of experiments may be made, depending on the availability of the equipment and other relevant considerations. Interested students may be allowed to do project work.

Course Learning Outcomes

The student will gain practical knowledge of radiation sources and ability to identify various types of particles and radiations using different detectors. Experimental skill development by performing basic practical on γ,β radiation and they will gain a hands on experience with nuclear electronics including data acquisition and data processing

Suggested Readings

1. *Radiation Detection and Measurement*, G. F. Knoll (John Wiley & Sons, Inc. 3rd Ed.,2000)
2. *Physics & Engineering of Radiation Detection,* S. N. Ahmed (Academic Press 2007)
3. *Techniques for Nuclear and Particle Physics Experiments*, W.R. Leo (Springer-Verlag 1987)
4. *Nuclear Physics, Principles and Applications*, J.S. Lilly (John Wiley & Sons, Inc. 2002)

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET517

Course Name: Lasers & Spectroscopy-I (Theory)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

To teach the students the nature of molecular spectra (rotational, vibrational, electronic and Raman) of polyatomic molecules (including diatomic) classified on the basis of their topological symmetry using group theoretical approach. The fundamentals and properties of laser as a spectroscopic light source will also be taught.

Contents:

Unit I **(13 lectures)**

Molecular symmetry and group theory:Symmetry operations and point groups for molecules, the representation of a point group, matrices and basis sets, reducible and irreducible representations, application to vibrational spectroscopy.

Unit II **(20 lectures)**

Theory: Microwave, Infrared, Raman, far infrared and UV-VIS spectra of diatomic and polyatomic molecules, Quantum theory of Raman effect, rotational, vibrational and rotation-vibration Raman spectra of diatomic and polyatomic molecules, correlation of infrared and Raman spectra, far infrared and UV-VIS spectra of gases, liquids and solids, determination of force constants and force field from isotropic molecules and spectroscopic data, thermodynamic functions from spectroscopic data, determination of partition function, electronic contribution to thermodynamic properties, enthalpy and specific heats from spectroscopic data, spectroscopic instrumentation.

Unit III **(8 lectures)**

Laser fundamentals: Rate equations, lasing action, coherence, polarization, width and profile of spectral lines, lasers as spectroscopic sources, spectral characteristics of laser emission, single and multi-mode lasers, laser tenability.

Unit IV **(4 lectures)**

Spectroscopy: Fluorescence and Raman spectroscopy with lasers

Course Learning Outcomes

Students learn to assign the point groups to polyatomic molecules (including diatomic) and to predict the nature of their vibrational spectra depending on their symmetry using group theoretical treatment. The complete picture of rotational, vibrational and electronic spectra of polyatomic molecules will be comprehended. This kind of specialization is expected to provide a larger scope for research in the various related and interdisciplinary areas. The basics of the laser and some spectroscopic techniques using laser taught in this course will be an added asset.

Suggested Readings

1. *Molecular Symmetry*, D. J. Willock (John Wiley & Sons, 2009)
2. *Molecular Spectra and Molecular Structure*, G. Herzberg (Van Nostrand, 1950)
3. *Group Theory and Physics*, S. Sternberg (Cambridge Univ. Press, 1995)
4. *Modern Spectroscopy*, J. M. Hollas(4^{th} Ed., John Wiley, 2004)
5. *Molecular Quantum Mechanics*, P Atkins & R. Friedman (Oxford Univ. Press, 2005)
6. *Molecular Physics*, W. Demtroder (Wiley-VCH, 2005)
7. *Laser Spectroscopy*, W. Demtroder (3^{rd} Ed., Springer, 2003)

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MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET518

Course Name: Lasers and Spectroscopy– I (Lab.)

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

Provide an exposure to instrumentation such as light sources, spectrometers, optical detectors, optical and opto-mechanical components, gain experience in spectroscopic techniques for measurement, analyses of various kinds of spectra

Contents:

LIST OF EXPERIMENTS

1. White light reflection holography.
2. Transmission holography.
3. Birefringence and photoelasticity.
4. Kerr effect.
5. Pockels effect.
6. Measurement of radiant flux density and luminous intensity of an emission source.
7. Prism spectrometer.
8. Grating spectrometer.
9. Interferometric method for film thickness measurement.
10. Interferometric method for residual strain measurement in the film.
11. Measurement and analyses of atomic spectra.
12. Measurement and analyses of electronic spectra of molecules and liquids.
13. Measurement and analyses of vibrational spectra of molecules and liquids.
14. Measurement and analyses of rotational spectra of molecules and liquids.
15. Measurement and analyses of absorption/transmission spectra of solids.
16. Measurement and analyses of reflection spectra of solids.
17. Determination of optical constants of thin films by ellipsometry.
18. Measurement and analyses of Raman spectra of liquids/solids.
19. Measurement and analyses of fluorescence spectra of liquids/solids.
20. Measurement of absorption/transmission/reflection spectra at low temperatures.
21. Measurement and analyses of photoluminescence spectra of nanomaterials.
22. Measurement and analyses of XPS of nanomaterials/thin films/bulk samples.

NOTE

This list is tentative; changes in the list of experiments may be made, depending on the availability of the equipment and other relevant considerations. Interested students may be allowed to do project work.

Course Learning Outcomes

The student would be equipped with an in-depth knowledge of laser-based metrologies; spectroscopic techniques that can be applied in wide-ranging fields spanning semiconductors, pharmaceutical, chemical, food-processing industries, to name a few.

Suggested Readings

5. *Lasers: Fundamental and Applications, Graduate Text in Physics, 2nd edition*, K. Thyagarajan, Ajoy ghatak (Springer, 2002)
6. *Polarization of light*, by Ajoy Ghatak and Arun Kumar (Mc GrawHill Education, 2012)
7. *Introduction to Fibre Optics*, Ajoy Ghatak and K. Thyagarajan, (Cambridge University Press, 2000)
8. *Teaching laser physics by experiments*, Am. J. Phys., (2011), http://doi.org/1-3488984
9. *Infrared Spectroscopy, Fundamentals and Applications*, Barbara Stuart, (Wiley & Sons, 2004)
10. *Modern Raman Spectroscopy-a practical approach*, E. Smith and G. Dent (John Wiley & Sons, 2004)
11. *Spectroscopic Ellipsometry: Principles and Applications*, H. Fujiwara(Wiley& Sons, 2007)
12. *Introduction to Holography*, Vincent Toal, (CRC Press, 2012)

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MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET519

Course Name: Advanced Solid State Physics-I(Theory)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This courseintends to provide knowledge of conceptual advanced level solid-state physics. In addition, this course aims to provide a general introduction to theoretical and experimental topics in solid state physics by covering electrical transport, dielectric, optical, and magnetic properties of solids.

Contents:

Unit I **(9 lectures)**

Transport Properties of Solids: Boltzmann transport equation, resistivity of metals and semiconductors, Fermi surfaces – determination, Landau levels, de Hass van Alphen effect, Quantum Hall effect- Integral quantum Hall effect and. Magnetoresistance.

Unit II **(9 lectures)**

Dielectric Properties of Solids: Dielectrics and ferroelectrics, macroscopic electric field, local field at an atom, dielectric constant and polarizability, ferroelectricity, antiferroelectricity, piezoelectric crystals, ferroelasticity, electrostriction.

Unit III **(8 lectures)**

Optical properties: Optical constants and their physical significance, Reflectivity in metals, plasmonic properties of metals, determination of band gap in semiconductors: direct and indirect band gap, defect mediated optical transitions, excitons, photoluminescence, Electroluminesence

Unit IV **(10 lectures)**

Magnetism: Types of magnetic materials, Quantum theory of paramagnetism, Hund's rule, Ferromagnetism, antiferromagnetism: molecular field, Curie temperature. Domain theory, Magnetic Anisotropy, Magnetic interactions, Heitler-London method, exchange and superexchange, magnetic moments and crystal-field effects, spin-wave excitations and thermodynamics, antiferromagnetism, Magnetostriction.

Unit V **(9 lectures)**

Superconductivity: Phenomenological theories of superconductivity, BCS theory, two fluid and Pippard's theory, London equations Flux quantization, BCS ground state and energy gap, Cooper pairs, coherence, vortex states Ginzburg-Landau theory, Josephson effect, SQUID, introduction to high-temperature superconductors.

Course Learning Outcomes

Thestudents should able to elucidate the important features of advanced topics in solid state physics by covering dielectric and optical properties, magnetism, and superconductivity.

Suggested Readings

1. *Solid State Physics*, N. W. Ashcroft and N.D. Mermin(Ist Ed., Cengage Learning, 2003)
2. *Elementary Excitations in Solids*, D. Pines (CRC press, 1999)
3. *The Wave Mechanics of Electrons in Metals*, S. Raimes (North-Holland, 1970)
4. *Lecture Notes on Electron Correlation & Magnetism*, P. Fazekas (World Scientific, 1999)
5. *Introduction to Superconductivity*,M. Tinkham (Dover Publications Inc., 2004)
6. *Condensed Matter Physics*,M. Marder(2nd Ed., John Wiley & Sons, 2010)
7. *Principles of Condensed Matter Physics*,P.M. Chaikin and T.C. Lubensky (Cambridge University Press, 1995)

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET520

Course Name: Advanced Solid State Physics– I (Lab.)

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

To carry out advanced level experiments to determine the optical, dielectric and magnetic properties of the materials. Also, to expose the students to various materials characterisation techniques.

Contents:

LIST OF EXPERIMENTS

1. Set the c-axis of the given crystal perpendicular to the incident x-ray beam.
2. Obtain the Laue photograph of the given single crystal, draw gnomonic projection, and index the reflections.
3. Obtain an oscillation photograph of the given single crystal about c-axis, calculate the c- dimension of the unit cell, and index the reflections.
4. Determine the cell dimensions and establish the face centring of copper by Debye-Scherrer method (Powder method).
5. Determine the value of the Hall coefficient for the given sample and calculate the value of the mobility of the carriers and the carrier concentration. (Transverse magneto-resistance coefficient is given)
6. Determine the transverse magneto-resistance coefficient and the resistivity for the given sample and calculate the value of the mobility of the carriers and the carrier concentration. (R_H is given).
7. Measure Hall coefficient, dc conductivity and mobility of a semiconductor at different temperatures (77 K to room temperature).
8. Determine the relaxation time (EPR) for a given sample and find the value of 'g'.
9. Determine the wavelength of the microwave output of a given reflex klystron oscillator and also to determine its repeller mode pattern.
10. Calibrate a cooper resistance thermometer and use it to measure temperature from 77 K to room temperature.
11. Calibrate a silicon resistance thermometer and use it to measure temperature from 77 K to room temperature.
12. Determine the specific heat of a given sample at room and liquid nitrogen temperature.
13. Determine the Curie temperature of a given ferroelectric material.
14. Programming and interfacing with a given microprocessor.
15. Measurement of the critical temperature of a HTc-sample.

16. Study the Thermoluminescence of F-centres in alkali halide crystals.

NOTE

This list is tentative; changes in the list of experiments may be made, depending on the availability of the equipment and other relevant considerations. Interested students may be allowed to do project work

Course Learning Outcomes

The students will get a better understanding of the concepts studied by them and correlate both theory and experiments. The students will learn about the various materials characterization techniques and analysis.

Suggested Readings

1. *Optical Properties of Photonic Crystals*, K. Sakoda (Springer, 2001)
2. *The Rietveld method*, R.A.Young (IUCR-Oxford University Press, 1995)
3. *Fundamentals of Crystallography*, C.Giacovazzo (IUCR-Oxford University Press, 2002)
4. *Characterization of nanophase materials*, Zhon Ling Wang (Wiley-VCH Verlag GmbH, 2000)
5. *Physical Properties of Semiconductors*, C. M. Wolfe, J.R.N.Holonyak and G.E.Stillman (Prentice Hall International Inc., London, 1989).
6. *Handbook on Semiconductors, Vol. 1-4.*, T.S. Moss, Ed., by S.P.Keller (North-Holland, Amsterdam, 1980)

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET531

Course Name: General Theory of Relativity and Cosmology-I

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The primary objective is to teach the students the physical and mathematical basis of Einstein's relativistic theory of gravitation

Contents:

Unit I **(5 lectures)**

Equality of gravitational and intertial masses, Equivalence principle, Principle of general covariance.

Unit II **(9 lectures)**

Tensor Analysis: covariant and contravariant tensors. Tensors of arbitrary rank. Metric tensor. Parallel transport and covariant differentiation. Affine connection and its relation to metric tensor. Curvature tensor and its symmetries. Bianchi identities. Weyl tensor and conformal invariance.

Unit III **(15 lectures)**

Geodesics: Equation of motion of particles. Weak fields and Newtonian approximation. Time and distance in general theory, gravitational red and blue shifts, experimental verification, Einstein's field equation - Newtonian gravity as an approximation, Schwarzschild solution, Radial motion towards centre. Nature of singularities, black holes, even horizon, Kruskal co-ordinates

Unit IV **(8 lectures)**

General orbits, constants of motion, deflection of light, precession of perihelion and radar echo. Standard, isotropic and harmonic coordinates. Parametrized post-Newtonian formalism and status of observational verification. Mach's principle.

Unit V **(8 lectures)**

Energy momentum tensor for a perfect fluid, equation of motion from field equation for equation for dust. Action principle for field equations. Conservation laws in curved space and pseudo energy tensor for gravitational field

Course Learning Outcomes

Students will be trained in tensor analysis and tensor calculus. This course will teach the formalism of general relativity (GR). They will learn how to obtain an exact solution of GR, namely, the Scwarzschild solution.

Suggested Readings

1. *Introducing Einstein's Relativity*, Ray D'Inverno (Clarendon Press, 1992)
2. *Principles of Gravitation and Cosmology*, M. Berry (Cambridge University Press, 1976)
3. *Introduction to General Relativity & Cosmology*, Steven Weinberg (John Wiley & Sons, 1972)
4. *The Classical Theory of Fields*, L.D. Landau and E. M. Lifshitz (Pergamon, 1975)
5. *Classical Fields: General Relativity and Gauge Theory*, Moshe Carmeli (World Scientific, 2001)
6. *General Theory of Relativity*, P.A. M. Dirac (John Wiley, 1975)
7. *Gravity, Black Holes and the Very Early universe: An Introduction to General Relativity and Cosmology*, Tai L. Chow (Springer, 2008)

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MASTER of SCIENCE in PHYSICS

Semester III

Course Code:PH-ET532

Course Name:Astrophysics - I

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This course covers a survey of modern astronomy basics from an observer's perspective, how data from distant sources is obtained through modern telescopes and detectors and is then interpreted.

Contents:

Unit I **(18 lectures)**

Observational Data: Astronomical Coordinates- Celestial Sphere, Horizon, Equatorial, Ecliptic and Galactic Systems of Coordinates, Conversion from one system of co-ordinates to another, Magnitude Scale- Apparent and absolute magnitude, distance modulus. Determination of mass, luminosity, radius, temperature and distance of a star, Colour Index, Stellar classification – Henry-Draper and modern M-K Classification schemes, H-R Diagram, H-R Diagram of Clusters, Empirical mass- luminosity relation.

Unit II **(12 lectures)**

Telescopes & Instrumentation: Different optical configurations for Astronomical telescopes, Mountings, plate scale and diffraction limits, telescopes for gamma ray, X-ray, UV, IR, mm and radio astronomy, Stellar Photometry - solid state, Photo-multplier tube and CCD based photometers, Spectroscopy and Polarimetery using CCD detectors.

Unit III **(8 lectures)**

Sun: Physical Characteristics of sun- basic data, solar rotation, solar magnetic fields, Photosphere - granulation, sunspots, Babcock model of sunspot formation, solar atmosphere – chromosphere and Corona, Solar activity- flares, prominences, solar wind, activity cycle, Helioseismology.

Unit IV **(7 lectures)**

Variable Stars & Asteroseismology: Photometry of variable stars, differential photometry, extinction coefficients, Classes of variable stars, Period-Mean density relationship, Classical Cepheids as distance indicators, pulsation Mechanisms.

Course Learning Outcomes

Students will demonstrate a basic understanding of various aspects of observational astronomy. How data is acquired and interpreted to obtain physical properties of a variety of astronomical objects.

Suggested Readings

1. *Astronomy, The Evolving Universe*, M. Zeilik (Cambridge University Press, 2002)
2. *Introduction to Astronomy & Cosmology*, I. Morrison (Wiley, 2008)
3. *Telescopes and Techniques*, C. R. Kitchin (Springer, 1995)
4. *Astronomical Photometry*, A. A. Henden & R. H. Kaitchuk (Willmann-Bell, 1990)
5. *An Introduction to Astronomical Photometry*, E. Budding (Cambridge University Press, 1993)
6. *Universe,* R. A. Freedman & W. J. Kaufmann (W. H. Freeman & Co., 2008)
7. *Fundamental Astronomy*, H. Karttunen et al. (Springer, 2003)
8. *Solar Astrophysics*, P. V. Foukal (Wiley-VCH, 2004)
9. *Fundamentals of Solar Astronomy*, A. Bhatnagar & W.C. Livingston (World Scientific, 2005)

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET533

Course Name: Condensed Matter Physics-I

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

Utilizing the basic concepts of solid state physics, the quantum theory of lattice dynamics and thermal neutron scattering would be extensively discussed in this course. The detailed theory of Mossbauer Effect would also be discussed.

Contents:

Unit I (**13 lectures**)

Lattice dynamics in 3-dimensions. Relations among atomic force constants under various general operations. Acoustic and optical modes. Normal modes. Quantization of lattice vibrations. Phonons, zero-point energy, quantum crystals. Stefan-Boltzmann law. Van Hove singularities. Lindemann melting criterion.

Unit II (**13 lectures**)

Theory of Thermal Neutron Scattering : Double differential scattering cross-section. Space-time dependent correlation functions and their properties. Dynamical structure factor of (i) a harmonic crystal, zero phonon and one phonon processes, (ii) non-interacting gas and (iii) a simple liquid.

Unit III (**10 lectures**)

Mossbauer Effect: Lamb-Mossbauer recoilless fraction. Atomic motions, Isomer shift. Quadrupole splitting. Magnetic splitting. Second order Doppler shift.

Unit IV (**10 lectures**)

Free electron Green's function, its Fourier transform and their relationships to the density of states. Green function of a system subject to small perturbation Rigid band model and other applications to alloys etc.

Course Learning Outcomes

A student of this course is expected to understand thoroughly the concepts of lattice dynamics and neutron scattering theory along with their application in Mossbauer spectroscopy. In addition, the students would be able to perform various analytical as well as numerical calculations needed for understanding the quantum theory of solids.

Suggested Readings

1. *Solid State Physics*, Neil W. Aschroft & N. David Mermin (Harcourt Publishers, 1976)
2. *Solid State Physics*, Gerald Burns (AcademicPress, 1985)
3. *Solid State Physics*, Wlater A. Harrison (Dover Publications, 1980)

4. *Solid State Physics: An introductlion to Principles of Materials Science*, Harald Ibach andHans Luth (Springer, 2003)
5. *Solid State Physics, Advances in research and applications, Supplement 3*, *F. Seitz and D.Turnbull (Eds.) Theory of lattice dynamics in harmonic approximation*, A.A. Maraduddin, E.W. Montroll and G.H. Weiss (Academic Press, 1963)
6. *Theory of thermal neutron scattering*, W. Marshall & S.W. Lovessey (Oxford Univ. Press,1971)
7. *Quantum Theory of Solids Part A & B*, Callaway (Academic Press, 1974)
8. *Mossbauer Effect : Principles and Applications*, G. K. Wertheim (Academic Press, 1964)
9. *The Mossbauer Effect*, Hans Fraunfelder (W.A. Benjamin, 1963)
10. *Quasielastic neutron scattering for the investigation of diffusive motions in solids and liquidsSpringer tracts in modern physics Vol. 64*, Tasso Springer (Springer-Verlag, 1972)
11. *Superconductivity*, V.L. Ginzburg and E.A. Andryushin (World Scientific, 1994)
12. *Introduction to Superconductivity and high-Tc materials*, Michel Cyrot and Davor Pavuna, (World Scientific, 1992)

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MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET534

Course Name: Plasma Physics -I

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

Plasma physics is an important subject for a large number of research areas, including space plasma physics, solar physics, astrophysics, controlled fusion research, high-power laser physics, plasma processing, and many areas of experimental physics. The primary learning outcome for this course is for the students to learn the basic principles and main equations of plasma physics, at an introductory level, with emphasis on topics of broad applicability.

Contents:

Unit I **(14 lectures)**

Definition and properties of plasma, Plasma production in laboratory and diagnostics. Microscopic description, Motion of a charged particle in electric and magnetic fields-curvature, gradient and external force drifts. Controlled thermonuclear devices, magnetically confined open and closed systems (linear pinch, mirror machine and Tokamak). Laser-plasmas: inertially confined system.

Unit II **(16 lectures)**

Statistical description of plasmas, B.B.G.K.Y. hierarchy of equations, Boltzmann-Vlasov equation, Equivalence of particle orbit theory and the Vlasov equation, Boltzmann and landau collision integral H-theorem, B.G.K. model, Fokker-Planck term, Solution of Boltzmann equation (brief outline), Transport coefficient-electrical conductivity, diffusion.

Unit III **(15 lectures)**

Small amplitude plasma oscillations. Oscillations in warm field free plasma. Landau damping. Nyquist method-Penrose criterion of stability. Two stream stability (linear and quasi linear theory). Vlasov theory of magnetized plasma. Loss cone instabilitly. Quasilinear theory of gently bump instability. Non-linear electrostatic waves, BCK waves.

Course Learning Outcomes

On completion of the course the student shall be able to: Define, using fundamental plasma parameters, under what conditions an ionised gas consisting of charged particles (electrons and ions) can be treated as a plasma. Distinguish the single particle approach, fluid approach and kinetic statistical approach to describe different plasma phenomena. Classify the electrostatic and electromagnetic waves that can propagate in magnetised and non-magnetised plasmas, and describe the physical mechanisms generating these waves. Define and determine the basic transport phenomena such as plasma resistivity, diffusion (classical and anomalous) and mobility as a function of collision frequency and of the fundamental parameters for both magnetised and non-magnetised plasmas. Formulate the conditions for a plasma to be in a state of thermodynamic equilibrium, or non-equilibrium, and analyse the stability of this equilibrium and account for the most important plasma instabilities. Explain the physical mechanism behind Landau damping and make calculations in this area using kinetic theory

Suggested Readings

1. *Introduction to Plasma Physics*, F. F. Chen (Plenum Press, 1984)
2. *Principles of Plasma Physics*, N. A. Krall and Trivelpiece (San Fransisco Press, 1986)
3. *Physics of High temperature Plasmas*, G. Schimdt (2nd Ed., Academic Press, 1979)
4. *The framework of Plasma Physics*, R.D. Hazeltine & F.L. Waelbroeck (Perseus Books, 1998)
5. *Introduction to Plasma Physics*, R.J. Goldston and P.H. Rutherford (IOP, 1995)

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MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET535

Course Name: Particle Physics -I

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This course is designed to provide a balanced introduction to the elementary particle physics, covering the theoretical concepts and with the range of observable phenomena related to particle physics. Further, the students will be able gain knowledge on important topics in particle physics including Kinematics of Decays and Cross-section, Space-time Symmetries, and Processes in QED.

Contents:

Unit I **(5 lectures)**

Fundamental Building Blocks and their nature of Interactions, Conservation Laws: Fundamental Building Blocks and their nature of Interactions, Conservation Laws: Energy, Angular Momentum, electromagnetic Charge, Lepton flavor and Baryon Numbers.
Natural Units system. Order of Magnitude estimation a) Bohr's atomic radius, b)Compton wavelength of electron, c) cross-section in relativistic and non-relativisttic limit $e^-\gamma \to e^-\gamma$, $e^+e^- \to \gamma^* \to \mu^+\mu^-$. Estimation of the radius associated with lightest hadron, Estimation of Decay width of a particle from decay time.

Unit II **(8 lectures)**

Kinematics of Decays and Cross-section: Relativistic Kinematics: Momentum and Energy Covariance, Mandelstam variables s, t, u for 2→2
Kinematics for decay/scattering to n (> 2) particles. Dalitz plots, Boost invariant quantities and their importance p_T, pseudo-rapidity η, and azimuthal angle ϕ.
Flux of initial particles in scattering and measured integrated Luminosity. Decay width of particle decaying into 2 and 3 particles. Two and Three body Phase space Integrals, Multiparticle production as cascading decays, Fermi's Golden rule and Definition of scattering cross-section.

Unit III **(7 lectures)**

Space-time Symmetries: Angular momentum; Parity Transformation of Fields and particle states, Charge Conjugation of Fields and Particle States Determination of spin, intrinsic parity and charge conjugation of $\pi^0, \pi^\pm$, neutrino, Multi-Photon States
CP Symmetry, Time-Reversal and CPT Symmetries, CPT Theorem, Signature of Parity Violation.

Unit IV **(15 lectures)**

Isospin and Charge Independence of Nuclear Force, Isospin-SU(2); SU(2) quadratic Casimir and importance of I_3, $SU(2)_I$ multiplets, Iso-spin of pions and anti nucleons, Isospin addition rule, Isospin states for Nucleon -Nucleon system and Pion Nucleon system, Isospin

amplitudes of Nucleon Nucleon scattering and Pion Nucleon scattering, Qualitative Discussion of Baryon and Meson Resonances.
Strangeness and Hypercharge Quantum Number, Gell-Mann- Nishijima Relation, $SU(2)_I \times Y$ as symmetry group for hadrons with $\mathbf{I_3}$ and **Y** quantum number as generators.
Motivation for Higher symmetry: Clustering of multiple states with same spin-parity, Appearance of light hadronic states with multiplicity 8.
SU(3) symmetry, Gell-Mann matrices and properties of structure constants, Representations of SU(3): Conjugate and adjoint
Wavefunctions of mesons and baryons in terms of quarks and antiquarks Necessity of color

Unit V (**10 lectures**)

Matrix element, cross-sections and helicity structures in

$$e^+ + e^- \rightarrow \mu^+ + \mu^-$$

Bhabha scattering, Compton scattering. Phenomenological lagrangians and their use to describe meson decays

Course Learning Outcomes

Relativistic dynamics, esp. in the context of multiparticle interactions. The role of symmetries, both discrete and continuous in understanding particle interactions and their classification. SU(3) and quark model. Based on observables, drawing up a theory of particle interactions. Fermi theory of beta decay.

Suggested Readings

1. *An Introductory Course of Particle Physics*, Palash B. Pal (CRC Press, 2015)
2. *Introduction to Elementary Particles*, D. Griffiths (2nd Ed., Wiley-VCH, 2008)
3. *Quarks & Leptons*, F. Halzen and A. D. Martin (John Wiley, 1984)
4. *Elementary Particle Physics*, S. Gasiorowicz (John Wiley, 1966)
5. *Elementary Particles and the Laws of Physics,* R. P. Feynman and S. Weinberg (CambridgeUniversity Press, 1999)
6. *Introduction to Elementary Particle Physics*, A. Bettini (Cambridge University Press, 2008)

Pre-requisite: This course is aimed at people who have a basic education in physics, especially classical mechanics, special relativity, quantum mechanics and electrodynamics.

Co-requisite: Quantum Field Theory 1.

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET536

Course Name: Quantum Field Theory-I

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

Quantum Field theory is one of the foundational fields in Theoretical High Energy physics. It bridges together Quantum Mechanics and Special Relativity using new mathematical tools. The aim of part one of this course is to introduce these mathematical formalisms to the students and to teach them their applications.

Contents:

Unit I **(4 lectures)**

Quantum mechanics of many particle systems The need for QFT (relativity, many-body and interactions) Review of Lagrangian of continuous systems. Canonical fields as generalized coordinates. Euler-Lagrange equations, Noether's theorem: examples in non-relativistic and relativistic field theories; translation, rotation, Lorentz boost/Galilean transformation and internal symmetry transformations.

Unit II **(8 lectures)**

Canonical quantization of the free scalar field Commutation relations, Energy-momentum tensor, Normal ordering Propagators, Causality n-point Green's function of elementary and composite operators.

Unit III **(10 lectures)**

Interacting scalar fields Perturbation Expansion of correlation functions Time-ordering and Wick's theorem S-matrix and Cross-sections Feynman diagrams and calculation of cross-sections Crossing sysmmetry.

Unit IV **(8 lectures)**

Irreducible representations of the Lorentz group, connection to quantum fields Symmetry of a complex scalar field Lagrangian and Maxwell field Need for gauge-fixing Quantizing the Maxwell-field in a covariant gauge; physical state condition; spectrum;
The Dirac field as a representation of SO(3,1) (notion of SL(2,C)) Weyl, Majorana and Dirac fermions Quantization of the Dirac field

Unit V **(5 lectures)**

Quantum Electrodynamics; Feynman rules, S-matrices and tree-level cross-sections for simple processes

Unit VI **(10 lectures)**

Gaussian integrals and power series expansion; Path integrals in Quantum Mechanics and Field Theory; Functional differentiation and integration (free scalar, vector and spinor)

Course Learning Outcomes

The students will learn about the role played by symmetries in studying classical and Quantum Field theories. Two different formalisms namely covariant quantization and path-integral quantization will be taught. They will learn how to apply these in computing tree-level scattering amplitudes and cross-sections in various quantum Field theories including Quantum Electrodynamics.

Suggested Readings

1. *The Quantum Theory of Fields, Volume 1: Foundations*, Steven Weinberg (Oxford UniversityPress, 2005)
2. *Lectures on Quantum Field Theory*, Ashok Dass (World Scientific, 2008)
3. *Reletivistic Quantum Mechanics*, J.D. Bjorken and S. Drell (Mcgraw-Hill, 1964)
4. *Reletivistic Quantum Fields*, J.D. Bjorken and S. Drell (Mcgraw-Hill, 1964)
5. *Quantum Field Theory*, C. Itzykson and J-B Zuber (McGraw-Hill, 1980)
6. *Introduction to Relativistic Quantum Field Theory*, S. Schweber (Row, Peterson, 1961)
7. *Quantum Field Theory*, L. H. Ryder (Cambridge University Press, 1996)
8. *Quantum Field Theory*, F. Mandl and G. Shaw (Wiley, 1993)
9. *Introduction to Quantum Field Theory*, P. Roman (John Wiley, 1969)
10. *The Quantum Theory of Fields, Vol.2: Modern Applications*, S. Weinberg (Oxford Univ.Press, 2005)
11. *Introduction to the Theory of Quantized Fields*, N.N. Bogoliubov & D.V. Shirkov (Nauka, Moscow, 1984)
12. *An Introduction to Quantum Field Theory*, M. E. Peskin & D.V. Schroeder (Westview Press,1995)

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-ET537

Course Name: Advance Mathematical Physics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The course will introduce to the students basic concepts of finite and infinite groups. Examples from various fields will be considered. Techniques for solving integral equations will be learnt. Introduction to Green functions and its construction will be studied.

Contents:

Unit I **(15 lectures)**

Finite discrete Group: Group Theory: Abstract groups: subgroups, classes, cosets, factor groups, normal subgroups, direct product of groups; Examples: cyclic, symmetric, matrix groups, regular n-gon. Mappings: homomorphism, isomorphism, automorphism. Representations: reducible and irreducible representation, unitary representations, Schur's lemma and orthogonality theorems, characters of representation, direct product of representations.

Unit II **(13 lectures)**

Continuous Group: Review of the continuous groups: Lie groups, rotation and unitary groups. Applications: point groups, translation and space groups, representation of point groups; introduction to symmetry group of the Hamiltonian.

Unit III **(10 lectures)**

Integral Equations: Conversion of ordinary differential equations into integral equations, Fredholm and Volterra integral equations, separable kernels, Fredholm theory, eigen values and eigen functions.

Unit IV **(7 lectures)**

Green function:Boundary Value Problems: boundary conditions: Dirichlet and Neumann; self-adjoint operators, Sturm-Liouville theory, Green's function, eigenfunction expansion.

Course Learning Outcomes

The understanding of the classification of finite groups will be achieved. Upon completion of this course, students should be able to use these concepts in various fields, particularity in crystallography. Students will be able to learn the different analytical techniques for solving integral equations and construct Green's functions for many important boundary value problems.

Suggested Readings

1. *Elements of Group Theory for Physicists*, A.W. Joshi (John Wiley, 1997).
2. *Groups and Symmetry*,M. A. Armstrong(Springer, 1988).
3. *Advanced Method of Mathematical Physics*, R. S. Kaushal & D. Parashar (Narosa, 2008).
4. *Group Theory and Its Applications to Physical Problems*, M. Hamermesh (Dover, 1989).
5. *Chemical Applications of Group Theory*, F. Albert Cotton (John Wiley, 1988).
6. *Mathematical Methods for Physicists*,G. Arfken, H. Weber, & F. Harris (Elsevier, 2012).
7. *Linear Integral Equations*, W. V. Lovitt (Dover, 2005).
8. *Introduction to Integral Equations with Applications*, A. J. Jerri (Wiley-Interscience, 1999).

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MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-OT541

Course Name: Radiation Safety

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This course is aimed to introduce the student to practical aspects of nuclear radiation with an understanding of basic quantities and doses, the role of fundamental processes involved in the interaction of X- rays, gamma-rays, charged particles and neutrons with matter, the principles underlying the operation of nuclear detection/dosimetry instruments, areas of applications, awareness of the need and methods for safety protocols for radioactive material and environmental safety.

Contents:

Unit I (**8 lectures**)

Basics of Radiation: Origin of radiation, binding energy and Q-value, stable and unstable isotopes, radioactive decay (alpha, beta, neutron and electromagnetic transitions), mean life and half life, nuclear reactions, concept of cross sections and attenuation co-efficients, Neutron flus, kinematics of nuclear reactions. Slowing down and moderation. Basic idea of different units of activity, radiation quantities: exposure, absorbed dose, equivalent dose, effective dose, collective equivalent dose, quality factor, radiation and tissue weighting factors, KERMA, Annual Limit of Intake (ALI) and Derived Air Concentration (DAC).

Unit II (**10 lectures**)

Devices for radiation measurement and survey: Radiation interaction with matter, Introduction to types of radiation detectors: semiconductor, scintillator and gas detectors (Geiger-Muller counters, ionisation chamber and proportional counters) Principles of radiation counting statistics, dead time and calibration standards.

Types of Radiation Dosimeters: thermoluminescence, radiographic films, calorimetry, semiconductor diodes; Relation between detection and dosimetry; exposure measurements with free air chamber.Interaction ofionising and non-ionising radiation at the cellular level.

Unit III (**5 lectures**)

Application of Nuclear techniques: Medical science (e.g., MRI, PET, Projection Imaging Gamma Camera, radiation therapy), Art & Archaeology, Art, Crime detection, Oil &Mining, Water assessment, Industrial Uses: Tracing, Gauging, Material Modification, Sterilization, Food preservation.

Unit IV (**12 lectures**)

Radiation Protection Standards: Classification of radioactive sources, Radiation dose to individuals from natural radioactivity in the environment and man-made sources, Basic concept of radiation protection standards: historical background, International Commission of Radiological Protection and its recommendations, the system of radiological protection, justification of practice, optimization of protection and individual limits, radiation and tissue weighting factors, committed equivalent dose, committed effective dose, concept of collective dose, potential exposures, dose and dose constraints, system of protection for invention-categories of exposures-Occupational, Public and Medical exposures, Permissible levels for neutron flux, factors governing internal exposure-Radionuclide concentration in air and water –ALI, DAC and contamination levels, effects of inhaled radionuclides on biological systems, impact on humans and society.

Unit V (**10 lectures**)

Regulations, Monitoring, & Radioactive Waste Management: Evaluation of external radiation hazard-effect of distance, tome and shielding, shielding calculation, personnel and area monitoring-internal radiation hazards, radio toxicity of different radio nuclides and the classification of laboratories, control of contamination-bioassay and air monitoring, chemical protection, Radiation accidents and disaster monitoring, Sources & classification of Radioactive waste, permissible limits for disposal of waste, general method of disposal, storage management of radioactive waste in facilities. Responsibilities of operator, regulatory bodies, and government.

Course Learning Outcomes

A knowledge of the principle of operation of various radiation detectors, understanding of radiation dose calculation and permissible doses for different levels of users, and radiation effects, an understanding of instrumentation in practical situations, awareness about the management of radioactive material, and adherence to safety protocols,

Suggested Readings

1. *Nuclear and Particle Physics*, W. E. Burcham and M. Jobes (Pearson Education, 1995)
2. *Radiation detection and measurement*, G. F. Knoll (4th Ed., Wiley, 2010)
3. *Thermoluninescense Dosimetry*, Mcknlay, A. F., Bristol, Adam Hilger (Medical Physics Hand book 5)
4. *Fundamental Physics of Radiology*, W. J. Meredith and J. B. Massey (John Wright and Sons, 1989)
5. *An Introduction to Radiation Protection*, A. Martin and S. A. Harbisor (John Willey & Sons, 1981)
6. *Medical Radiation Physics*, W. R. Hendee (Medical Publishers Inc., 1981)
7. *Nuclear Physics : Principles and applications*, John Lilley (Wiley, 2001)
8. *Physics and Engineering of Radiation Detection*, Syed Naeem Ahmed (2nd Ed., Elsevier, 2014)
9. *Techniques for Nuclear and Particle Physics Experiments*, W.R. Leo (2nd Ed., Springer, 2013)
10. *IAEA Publications* : (a) General safety requirements Part 1, No. GSR Part 1 (2010), Part 3 No. GSR Part 3 (Interium) (2010); (b)Safety Standards Series No. RS-G-1.5 (2002), Rs-G-1.9 (2005), Safety Series No. 120 (1996); (c) Safety Guide GS-G-2.1 (2007).
11. *AERB Safety Guide (Guide No. AERB/RF-RS/SG-1), Security of radioactive sources in radiation facilities*.
12. *AERB Safety Standard No. AERB/SS/3 (Rev. 1), Testing and Classification of sealed Radioactivity Sources.*

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-OT542

Course Name: Introductory Astronomy

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

Since this course is an open elective, with students from diverse background opting for it, the primary objective is to impart a basic knowledge about the oldest branch of physical science through a conceptual mode, relying less on mathematics and more on physical understanding. Since exciting new developments have been taking place in the astronomy of 20-th and 21-st centuries, with India playing crucial roles, the idea is to enable students to have a flavour of both historical and modern aspects so that they acquire a perspective of their place in the universe..

Contents:

Unit I (**3 lectures**)

Antiquity of astronomy: Planets and stars in Egyptian and Babylonian civilizations; Possible reference to stars and planets in Indus Valley Civilization; stars and constellations in Rig Veda as well as in other vedic literature; reference to Halley's comet in a Babylonian clay tablet; Far Eastern astronomy - comets and Crab supernova; reference to cosmic objects in mythologies, classic literature and science fictions.

Unit II (**4 lectures**)

Early astronomical measurements: Measurement of Earth's radius by Eratosthenes; Lunar and solar motion studies by Hipparchus - equinoxes and solstices, lunar and solar eclipses; Aryabhatta I and his seminal contributions to astronomy - relative motion, spinning Earth, eclipses, etc.; Varahamihira, Brahmagupta and other siddhantic astronomers of India; symbiotic relation between mathematics and astronomy; evidence of the precession of equinox from vedic literature; Jai Singh and his Jantar Mantar.

Unit III (**4 lectures**)

Solar system: geocentric model - Ptolemy, Tycho Brahe and Samanta Chandrasekhar; retrograde motion of Mars and theory of epicycles; Copernicus and the heliocentric model; Kepler's laws of planetary motions - a formulation based on a set of mathematical laws for the first time in physical sciences; Galileo's pioneering work - length and time measurements, telescope, lunar craters, moons of Jupiter, rings of Saturn, corroboration of Copernican model, Pisa tower and equivalence principle.

Unit IV (**6 lectures**)

Laws of gravitation- motion of the Moon around the Earth, falling bodies, Newton's genius; Halley's comet and laws of gravity; importance of gravity as a force in astronomy; Physics of the Sun; Thermonuclear reactions; discovery of Neptune and Pluto; asteroid belt, meteors and comets; Tidal forces and the oceanic tides; precession of equinox and change of seasons; dating Rig veda using the precession of equinox; Distances - parallax method; standard candles - Cepheid variables and Henrietta Leavitt, Type Ia Supernovae; Spectroscopy - atomic spectra, emission and absorption lines, their widths and Doppler shifts.

Unit V **(8 lectures)**

Stellar population and Hertzsprung-Russell diagram; Meghnad Saha, ionized element, Saha equation and birth of astrophysics; Wilson-Bappu effect and stellar distances; Stellar structure and evolution- evolution of low mass stars and high mass stars; white dwarfs - Fowler, Chandrasekhar and Eddington; Chandrasekhar's mass limit; Baade and Zwicky - supernova and neutron stars; supernova explosion; pulsars.

Unit VI **(10 lectures)**

Milky Way and other galaxies: Shapley-Curtis debate; measurement of Doppler shift in emission lines by Humason, Slipher and Hubble; Cepheid variable and distances of galaxies; Classification of galaxies - spirals, ellipticals, irregulars, dwarfs, lenticulars, etc.; Hubble's law and birth of cosmology as a scientific discipline; big bang and steady state models; Hoyle-Narlikar cosmology;radio source counts, evolution of radio-sources and setback to steady-state theory; angular resolution, radio interferometry and large baselines; detection of apparent superluminal motion; radio telescopes in India - Govind Swarup and his collaborators

Unit VII **(6 lectures)**

The Universe: Penzias, Wilson and the cosmic microwave background; corroboration of thermal history in big bang cosmology as predicted by Gamow and his collaborators; Big bang model, singularity and Raychaudhuri equation; clusters of galaxies; Zwicky and the dark matter; the observed large scale structure; Vera Rubin and the evidence of dark matter from galactic rotation curves; Type Ia supernovae and accelerating universe; the puzzle of dark energy; new astronomy - X-ray and gamma ray astronomy, gravitational waves, neutrino astronomy, thirty metre telescope and the square kilometre array; discovery of exoplanets.

Course Learning Outcomes

A historical perspective of the development of Astronomy. Conceptual understanding of basic principles involved. A flavour of current developments in this field and India's role in them. Appreciation of laws of nature that are discovered on Earth but which explain successfully distant cosmic objects and the universe as a whole

Suggested Readings

1. *The Physical Universe*, Frank Shu (University Science Books, 1982)
2. *Cosmology: The Science of the Universe,* Edward Harrison (Cambridge University Press, 2000)
3. *From Black Clouds to Black Holes*, J. V. Narlikar (World Scientific, 1985)
4. *Archeoastronomy- Introduction to the Science of Stars and Stones*, Giulio Magli (Springer, 2016)

MASTER of SCIENCE in PHYSICS

Semester III

Course Code: PH-OT543

Course Name: Complex System & Networks

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This course deals with the interdisciplinary subject of complex systems, that include, among others, living organisms, ecosystems and human societies. The course emphasizes a unifying theme – complex networks – that cuts across all these systems. It develops the mathematical tools of graph theory and dynamical systems to provide insight into the structure, dynamics and evolution of a variety of complex systems in the physical sciences, life sciences, social sciences and engineering.

Contents:

Unit I **(7 lectures)**

Overview: Examples of complex systems: organisms, brains, ecosystems, societies, the internet. Components of these systems: molecules, cells, species, agents, computers. Collective phenomena exhibited by these systems. Contrast with other collective phenomena in physics such as phase transitions. Adaptive nature of these systems.

Unit II (**10 lectures**)

Graph theory and the network structure of complex systems: Complex networks of interaction as a unifying theme underlying complex systems. Undirected, directed and bipartite graphs, hypergraphs. Adjacency matrix of a graph. Graph theoretic measures of network structure. Random graph ensembles, small-world, scale-free, hierarchical and autocatalytic graphs. Network motifs. Nature of graphs that arise in various complex systems

Unit III (**14 lectures**)

Dynamics of complex systems: Dynamics on a fixed network. Examples of continuous and discrete dynamical systems to be taken from various complex systems such as chemical networks, metabolic networks, ecological food webs, genetic regulatory circuits, neural networks, social and economic networks, epidemiological networks. Fixed point and limit cycle attractors of these systems. The influence of network structure on dynamics.

Unit IV (**14 lectures**)

Evolution of complex systems: How networks change over time. Preferential attachment model of scale free networks. The origin of life puzzle. Model of autocatalytic network evolution and self-organization of a complex network. Community assembly models in ecology. Evolution of biological and social networks. Crashes and recoveries in complex systems. Robustness and fragility of complex systems.

Course Learning Outcomes

Being able to appreciate that complex networks of interacting components underlie many complex systems studied under different disciplines. Learning the similarities and differences between complex systems from the perspective of network structure.Learning certain mathematical methods of graph theory and dynamical systems.Being able to apply these methods to characterize the structure of various complex systems and to model certain phenomena exhibited by them.

Suggested Readings

1. *Networks: An Introduction*, M. E. J. Newman (Oxford University Press, 2010).
2. *Origins of Order*, Stuart Kauffman (Oxford University Press, 1993).
3. *Handbook of Graphs and Networks: From the Genome to the Internet*, S. Bornholdt and H.-G.Schuster (Wiley-VCH, 2003).
4. *Dynamics of Complex Systems*, Yaneer Bar Yam (Perseus Books, 1997)

Prerequisites for the course: Student should have taken Mathematics as a subject in high school (Class XI and XII).

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-CT503

Course Name: Atomic and Molecular Physics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The main objective is to teach the students the basic atomic and molecular (diatomic) structures with quantum mechanical approach leading to their fundamental spectroscopies. The fundamentals and properties of a coherent light source as Laser (various types) will also be taught.

Contents:

Unit I **(13 lectures)**

Atomic Physics : Fine structure of hydrogenic atoms, Mass correction, spin-orbit term, Darwin term. Intensity of fine structure lines. Effect of magnetic and electric fields: Zeeman, Paschen-Bach and Stark effects. The ground state of two-electron atoms – perturbation theory and variational methods. Many-electron atoms – Central Field Approximation-LS and jj coupling schemes, Lande interval rule. The Hartrec-Fock equations. The spectra of alkalis using quantum defect theory. Selection rules for electric and magnetic multipole radiation. Auger process.

Unit II **(10 lectures)**

Molecular Structure : Born-Oppenheimer approximation for diatomic molecules, rotation, vibration and electronic structure of diatomic molecules. Spectroscopic terms. Centrifugal distortion. Electronic structure-Molecular symmetry and the states. Molecular orbital and valence bond methods for H_2^+ and H_2. Morse potential. Basic concepts of correlation diagrams for heteronuclear molecules.

Unit III **(11 lectures)**

Molecular Spectra : Rotational spectra of diatomic molecules-rigid and non-rigid rotors, isotope effect, Vibrational spectra of diatomic molecules- harmonic and anharmonic vibrators, Intensity of spectral lines, dissociation energy, vibration-rotation spectra, Electronic spectra of diatomic molecules- vibrational structure of electronic transitions (coarse structure)-progressions and sequences. Rotational structure of electronic bands (Fine structure)-P,Q,R branches. Fortrat diagram. Intensities in electronic bands-The Franck-Condon principle.The electron spin and Hund's cases. Raman Effect. Electron Spin Resonance. Nuclear Magnetic Resonance.

Unit IV **(11 lectures)**

Lasers : Life time of atomic and molecular states. Multilevel rate equations and saturation. Coherence and profile of spectral lines. Rabi frequency. Laser pumping and population inversion. He-Ne Laser, Solid State laser, Free-electron laser. Non-linear phenomenon. Harmonic generation. Liquid and gas lasers, semiconductor lasers.

Course Learning Outcomes

Students will learn the details of atomic and diatomic molecular (diatomic) structures in terms of quantum mechanical treatment elaborately beyond the basic models. It will give the descriptions of fine structure of atoms and rotational, vibrational and electronic energies of molecules manifesting in their respective spectroscopies.

The details of these spectroscopies would serve as the fundamentals for various concerned experimental results. The basic principles of light coherence as laser with their types and variants will also be covered exposing the students to the important modern spectroscopic tool.

Suggested Readings

1. *Physics of Atoms and Molecules,* B. H. Bransden and C. J. Jochain (2nd Ed., Pearson Education, 2003)
2. *Atomic Spectra and Atomic Structure*, G. Herzberg (Dover Publications, 2003)
3. *Molecular Spectra and Molecular Structure*, G. Herzberg (Van Nostrand, 1950)
4. *Atoms, Molecules and Photons*, W. Demtroder (Springer, 2006)
5. *Fundamentals of Molecular Spectroscopy*, C. N. Banwell (McGraw Hill, 1983)
6. *Basic atomic & Molecular Spectroscopy*, J. M. Hollas (Royal Society of Chemistry, 2002)
7. *Principles of Lasers*, O. Svelto (5th Ed., Springer, 2010)
8. *Laser Spectroscopy*, W. Demtroder (3rd Ed., Springer, 2003)
9. *Molecular Quantum Mechanics*, P Atkins & R. Friedman (Oxford Univ. Press, 2005)
10. *Quantum Chemistry*, I. N. Levine (7th Ed., Pearson, 2016)

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MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET551

Course Name: Physics at the Nanoscale – II (Theory)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

Themain goal of this subject is to provide basic understanding of fabrication and characterization of nano structured materials by different analytical methods. More importantly, the students will have enriched knowledge on the properties of materials at the nanoscale and implementing it for various applications.

Contents:

Unit I (**13 lectures**)

Growth: Synthesis of metal, semiconductor, carbon and bio nanomaterials. Grains and grain boundaries, distribution of grain sizes, pores, strains. Thin film preparation methods by thermal evaporation, sputtering and pulsed laser deposition methods. Gas phase synthesis of nanopowders, chemical and colloidal methods, mechanical milling, dispersion in solid-doped glasses and sol gel method; Functionalization of nanoparticles.

Unit II (**7 lectures**)

Structure and thermodynamics at nanoscale: specific features of the nanoscale growth, control of size, nucleation, growth and aggregation. Crystalline phase transitions and geometric evolution of the lattice in nano crystals, thermodynamics of very small systems. Self-assembling nanostructured molecular materials and devices.

Unit III (**5 lectures**)

Characterization: Characterization by diffraction method and optical methods. Chemical characterizations-Raman spectroscopy, XPS, XAS and EXAFS.

Unit IV (**10 lectures**)

Properties: Chemical- reactivity, Mechanical properties at nanoscale; Mechanical-superplasticity. Magnetism at nanoscale; Magnetic and electron transport- GMR and Optical-linear and nonlinear.

Unit V (**10 lectures**)

Applications of nanomaterials: Electronics and Electromagnetics-ceramic capacitors and magnetic recording Optics-nanophosphors and photonic crystals Mechanics- Biology and environment. Nanomaterial Devices: Quantum dot heterostructure lasers, all optical switching and optical data storage.

Course Learning Outcomes

Learner will be able to comprehend basic knowledge on the fabrication and characterization of nanomaterials by different methods. The students will have enhanced knowledge on the physics of nanomaterials and its applications in emerging technological applications.

Suggested Readings

1. *Nanostructured Materilas and Nano technology*, H. S. Nalwa (Ed.) (Academic Press, 2002)
2. *Nanomaterila and Nanochemistry*, C. Brechignac, P. Houdy and M. Lahmani (Springer, 2006)
3. *Characterization of Nanophase Materials*, Z. L. Wang (Ed.) (Wiley-VCH, 2000)
4. *Semiconductor Nanocrystal Quantum Dots*, A. L. Rogach (Ed.) (Springer Wien NY, 2008)
5. *Introduction to Nanotechnology*, C. P. Poole Jr. & F. J. Owens (Wiley-Interscience, 2003)
6. *Carbon Nanotubes*, S. Reich, C. Thomsen & J. Maultzsch, (Wiley-VCH, 2004)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET552

Course Name: Nanomaterials– II (Lab.)

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

The main goal of this subject is to synthesis of different class of materials by various methods. As synthesised nano materials will be characterized by different analytical techniques and analysed with respect to size reduction in the respective physical properties.

Contents:

LIST OF EXPERIMENTS

1. Growth of nanoparticles by chemical routes.
2. Growth of nanophase by sputtering.
3. Growth of quantum dots by thermal evaporation.
4. Growth of nanoparticles by mechanical milling/attrition.
5. Growth of nanomaterials by nanopores-template method.
6. Growth of semiconductor quantum dots in matrices (glass/polymer etc).
7. Structural characterization of nanomaterials by XRD- determination of average grain size, lattice parameters, strains etc.
8. Structural characterization of nanomaterials by TEM - determination of grain size and its distribution.
9. Surface morphological characterization of nanomaterials by AFM.
10. Surface morphological characterization of nanomaterials by SEM.
11. Surface morphological characterization of nanomaterials by TEM.
12. Determination of pores size of nanomaterials.
13. Measurement and analyses of UV/vis Absorption spectrum of nanomaterials.
14. Measurement and analysis of Photoluminescence spectrum of nanomaterials.
15. Measurement and analysis of Raman spectrum of nanomaterials.
16. Measurement and analysis of photoluminescence/Absorption spectrum of nanomaterials at low temperatures.
17. Determination of optical constants of nanomaterials by ellipsometry.
18. Measurement of sensor property of nanomaterials.
19. Determination of stoichiometry of nanomaterials by XPS/EDAX/ESCA.
20. Measurement and analysis of ferroelectric properties of nanomaterials.
21. Thermal characterization of polymers by DSC technique.

Course Learning Outcomes

The students will get a better understanding of the concepts studied by them in the theory course and correlate with experimental observations. In addition, the students are exposed with thermal, microscopic, electrical and spectroscopic methods of characterization of nanomaterials.

Suggested Readings

1. *Nanotechnology*,G.Timp (AIP press, Springer-Verlag, New York, 1999)

2. *Nanostructured materials and nanotechnology,*Hari Singh Nalwa. (Academic Press, USA, 2002)
3. *Hand book of Nanostructured Materials and Technology. Vol.1-5,* Hari Singh Nalwa. (Academic Press, USA, 2000)
4. *Handbook of Nanoscience, Engineering and Technology,*W.Gaddand, D.Brenner, S.Lysherski and G.J.Infrate. *(Electrical Engineering Handbook)* (CRC Press, 2012)
5. *Sol-Gel Science*,C.J. Brinker and G.W. Scherrer(Academic Press, Boston, 1994)
6. *Nanoscale Characterization of Surfaces & Interfaces,*N John Dinardo,(Weinheim Cambridge: Wiley-VCH, 2000)
7. *Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM*, Ray F. Egerton (Springer, 2005)
8. *Scanning Probe Microscopy: Analytical Methods* (NanoScience and Technology), Roland Wiesendanger (Springer, 1968)
9. *Chemistry of nanomaterials: Synthesis, properties and applications*, CNR Rao et.al. (Wiley-VCH, 2004)

MASTER of SCIENCE in PHYSICS

Semester IV
Course Code: PH-ET553
Course Name: Advanced Electronics – II (Theory)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

To give anunderstanding about generation, propagation, reception and detection of electromagnetic waves in free space and optical signals in guided media relating to fiber optic communication. Analyze the contribution of inherent noise produced by components, devices and circuits commonly used in instrumentation/communication systems and learn the effective methods of noise reduction.

Contents:

Unit I (**12 lectures**)

Communication: EM wave propagation: transmission lines, coaxial cable, waveguide, optical fiber and free space. Propagation of ground wave, space wave and Sky wave. Characteristic impedance, reflection coefficient, Standing wave ratio (microwave components) and measurement of impedance in various media. Fiber optic and wireless communication.

Unit II (**6 lectures**)

Antennas : Linear dipole antennas, Antenna array techniques, Systems and characterization antenna matching and basic antenna types.

Unit III (**5 lectures**)

Pulse-Digital Modulation: Elements of Pulsed-Code Modulation (PCM). Channel capacity of a PCM system, Digital Multiplexers. Digital transmission and demodulation

Unit IV (**16 lectures**)

Digital Signal Processing (DSP): Converting analog to digital signals and vice versa. Time-domain and frequency-domain representation of discrete time signals. Finite and infinite impulse response and digital filter design. Correlation, autocorrelation and cross-correlation of periodic and aperiodic functions.

Unit V (**6 lectures**)

Noise: Signal to noise ratio (SNR) and enhancement of SNR in instrumentation and communication. Noise reduction in electronic circuits. Principles of phase locking and lock-in amplifier, Sample and hold circuits.

Course Learning Outcomes

Students will have learnt the basic concepts involved with analog to digital conversion of signals, the coding techniques and basic mathematical tools/techniques used for processing of digital signals, signal transmission and high speed data transfer in modern day communication systems and networks.

Suggested Readings

1. *Digital Signal Processing*, J. G. Proakis and D. G. Manolakis (4th Ed., Pearson, 2007)
2. *Electronic Communication*, D. Roddy and J. Coolen (4th Ed., Pearson, 1995)
3. *Measurement, Instrumentation and Experimental Design in Physics and Engineering*, M.Sayer and A. Mansingh (PHI Learning, 2000)
4. *Discrete Time Signal Processing*, A.V. Oppenheim and R. W. Schafer (2nd Ed., Pearson, 2006)
5. *Electronic Communication systems*, W. Tomasi (5th Ed., Peason, 2008)

1.

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET554

Course Name: Advanced Electronic– II (Lab.)

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

Contents:

Group A :

Computer aided design using standard software for integrated circuit and device fabrication.

Group B :

Electronic material and device fabrication and characterization (p-n junction, diffusion thin film sensors, optical memory etc.).

Course Learning Outcomes

Suggested Readings

1. *Measurement, Instrumentation and Experimental Design in Physics and Engineering,* M. Sayer and A. Mansingh (Prentice Hall India, 2010)
2. *Solid State Electronic Devices*, B.G. Streetman (Prentice Hall India, 2000)
3. *Introduction to Semiconductor Materials and Devices*, M.S. Tyagi (John Wiley & Sons, 2008)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET555

Course Name: Advanced Nuclear Physics II(Theory)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The course will provide a understanding about behaviour of the nuclei by studying nuclear reaction and nuclear structure models. A physical understanding of nuclear process has been introduced with appropriate mathematical basics.

Contents:

Unit I (**19 lectures**)

Nuclear Reaction: Types of reaction, Briet-Winger and Resonances, Direct reaction-elastic and inelastic scattering, Transfer reaction (semi-classical approach), Fusion, Break-up, coupled channel approach, Compound nuclear reaction and statistical models, Coulomb excitation and its applications.

Unit II (**19 lectures**)

Nuclear Structure: Shell model: Review of shell Model, magic numbers, single particle shell model, Self-consistent approach, basic concept of Hartee-Fock and Hartee-Fock-Bogallibog methods,Shell correction, Quasi-particle, Seniority Scheme, M and J-scheme, Transformation from M-scheme to J-Scheme, D-Matrix, Collective Model of Nucleus, Rotational and Vibrational Spectra (brief derivation). Beta and Gamma vibration, Nuclear moment of inertia, band head & back bending, Variable moment of inertia Models for normal and deformed nuclei, Nilsson Models and Nilsson Diagram, Particle Rotor Model, Deformed and Rotational Alignment, Nuclear isomers.

Unit III (**7 lectures**)

Exotic Nuclei: Nuclear landscape and drip lines, Production of exotic nuclei – ISOL and Fragmentation technique, Super Heavy Element (SHE) production, Structure of exotic nuclei and application in astrophysics, break down of magic numbers, exotic shapes, Halo nuclei, neutron skin, GDR and soft dipole resonance (reaction point of view).

Course Learning Outcomes

After completion of course the student will gain knowledge about the structure of nuclei through nuclear models, nuclear reaction dynamics and its mechanism. A brief idea about present challenges in modern nuclear physics including, exotic nuclei and their production will be imparted.

Suggested Readings

1. *Theory of Nuclear Structure*, M.K. Pal (Affiliated East-Wast Press,1982)
2. *Nuclear Structure from a Simple Perspective*, R. F. Casten (Press, 2nd Ed., Oxford Univ. 2000)

3. *Theoretical Nuclear Physics, Vol. I, Nuclear Structure*, DeShalit & Feshbach (Wiley - Interscience , 1998)
4. *Nuclear Reaction and Nuclear Structure*, P.E. Hodgson (Clarendon Press, 1971)
5. *Heavy ion reactions, Vol. I & II*, R. A. Broglia & Aage Winther (Benjamin/Cummings, 1981)
6. *Physics with Radioactive Beams*, C. A Bertulani, M.S. Hussein, G. Munzenberg (Nova Science, 2002)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET556

Course Name: Advanced Nuclear Physics-II (Lab.)

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

It will impart the skill on the experimental technique and will provide a hand on experience about different nuclear detector, Nuclear electronics and data acquisition system.

Contents:

LIST OF EXPERIMENTS

1. Study of radioactive isotopes by thermal neutron activation analysis (Neutron flux, growth of activity and half-life measurements).
2. Determination of the absolute disintegration rate of natural ^{40}K source using UX2 source as a standard. Deduction of the partial beta-decay half life of ^{40}K.
3. Absorption of gamma-rays in material media at different energies.
4. Investigation of energy response and calibration of a NaI (TI) scintillation spectrometer based on Gamma-rays spectroscopy.
5. Detection of gamma ray in different scintillation based detectors and their Comprising. (Energy response, energy resolution).
6. Determination of detection efficiencyof a NaI (TI) scintillation spectrometer.
7. Gamma-rays spectroscopy using a single crystal HPGe detector : a) energy response, b) energy resolution and c) detection efficiency determination.
8. Beta-ray spectroscopy using an anthracene scintillation spectrometer (energy calibration and end-point energy measurement by Kurie-plot).
9. Study of angular distribution of Compton scattered gamma rays using a scintillation spectrometer and the deduction of total scattering cross-section.
10. Resolving time of a fast and slow coincidence circuit by the method of random coincidence using scintillation detectors and measurement of absolute source strength.
11. Study of fast-slow delayed coincidence system (resolving time as a function of clipping length, true-to-chance-ratio and coincidence efficiency).
12. Directional correlation measurements of cascading gamma rays and the determination of the cascade anisotropy using ^{60}Co source.
13. Proportional counter, its energy response and low energy X-ray measurements.
14. Determination of gas pressure in a vacuum chamber with different pumps and vacuum pressure gauges.
15. Alpha spectroscopy using a Si surface-barrier detector: Energy response & Energy resolution measurements.
16. Measurement of stopping power of an alpha particle using Si surface-barrier detector.
17. Energy determination of alpha particles emitted in the thorium decay using nuclear emulsion plates.

NOTE

This list is tentative; changes in the list of experiments may be made, depending on the availability of the equipment and other relevant considerations. Interested students may be allowed to do project work.

Course Learning Outcomes

Student will gain practical knowledge of radiation sources and ability to identify various types of particles and radiations using different detectors. Experimental skill development by performing basic practical on γ,β radiation and they will gain a hands on experience with nuclear electronics including data acquisition and data processing

Suggested Readings

1. *Radiation Detection and Measurement*, G. F. Knoll (John Wiley & Sons, Inc. 3rd Ed.,2000)
2. *Physics & Engineering of Radiation Detection,* S. N. Ahmed (Academic Press 2007)
3. *Techniques for Nuclear and Particle Physics Experiments*, W.R. Leo (Springer-Verlag 1987)
4. *Nuclear Physics, Principles and Applications*, J.S. Lilly (John Wiley & Sons, Inc. 2002)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET557

Course Name: Lasers & Spectroscopy-II (Theory)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

To familiarize the student with the fundamentals of the characteristics of lasers, their use for experiments in the time domain, the role of lasers in cooling, introduction of a few spectroscopic probes for characterization of condensed matter.

Contents:

Unit I (**9 lectures**)

Non-linear spectroscopy: Phase matching, second harmonic generation, sum and frequency generating, optical parametric oscillator

Unit II (**10 lectures**)

Time resolved laser spectroscopy: Generation and measurement of ultra-short pulses and life time measurements with lasers, pump and probe techniques.

Unit III (**9 lectures**)

Optical cooling: Photon recoil, optical molasses, magneto-optical trap, limits of cooling

Unit IV (**6 lectures**)

Nuclear Magnetic Resonance Spectroscopy: General theory of high resolution NMR spectroscopy, experimental technique, analyses of NMR spectra, spin-spin coupling, chemical shift

Unit V (**6 lectures**)

Electron Spin Resonance Spectroscopy: Experimental methods, derivative spectra, hyperfine structure, anisotropic systems

Unit VI (**5 lectures**)

X-ray Photo-electron Spectroscopy: Instrumentation, XPS spectra and its interpretations, chemical shift, oxidation state analysis

Course Learning Outcomes

Advanced knowledge about principles and instrumentation for spectroscopic investigations of atoms/molecules/condensed media; time-resolved studies in the femtosecond regime , non-linear optical phenomena, optical cooling and trapping of ions/atoms as an example of state-of-the-art applications of lasers

Suggested Readings

1. *Laser Spectroscopy*, W. Demtroder (3rd Ed., Springer, 2003)

2. *Modern Spectroscopy*, J. M. Hollas(4^{th} Ed., John Wiley, 2004)
3. *Electron Paramagnetic Resonance*, J. A. Well & J. R. Bolton (2^{nd} Ed.,Wiley, 2007
4. *Electronic & Photoelectron Spectroscopy*, A. M. Ellis, M. Feher & T. G. Wright (Cambridge Univ. Press, 2005)
5. *Introduction to Spectroscopy,* D. L. Pavia, G. M. Lampman & G. S. Kriz (Thomson Learning, 2001)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET558

Course Name: Lasers and Spectroscopy – II (Lab.)

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

Provide an exposure to instrumentation such as light sources, spectrometers, optical detectors, optical and opto-mechanical components, gain experience in spectroscopic techniques for measurement, analyses of various kinds of spectra

Contents:

LIST OF EXPERIMENTS

1. White light reflection holography.
2. Transmission holography.
3. Birefringence and photoelasticity.
4. Kerr effect.
5. Pockels effect.
6. Measurement of radiant flux density and luminous intensity of an emission source.
7. Prism spectrometer.
8. Grating spectrometer.
9. Interferometric method for film thickness measurement.
10. Interferometric method for residual strain measurement in the film.
11. Measurement and analyses of atomic spectra.
12. Measurement and analyses of electronic spectra of molecules and liquids.
13. Measurement and analyses of vibrational spectra of molecules and liquids.
14. Measurement and analyses of rotational spectra of molecules and liquids.
15. Measurement and analyses of absorption/transmission spectra of solids.
16. Measurement and analyses of reflection spectra of solids.
17. Determination of optical constants of thin films by ellipsometry.
18. Measurement and analyses of Raman spectra of liquids/solids.
19. Measurement and analyses of fluorescence spectra of liquids/solids.
20. Measurement of absorption/transmission/reflection spectra at low temperatures.
21. Measurement and analyses of photoluminescence spectra of nanomaterials.
22. Measurement and analyses of XPS of nanomaterials/thin films/bulk samples.

NOTE

This list is tentative; changes in the list of experiments may be made, depending on the availability of the equipment and other relevant considerations. Interested students may be allowed to do project work.

Course Learning Outcomes

The student would be equipped with an in-depth knowledge of laser-based metrologies; spectroscopic techniques that can be applied in wide-ranging fields spanning semiconductors, pharmaceutical, chemical, food-processing industries, to name a few.

Suggested Readings

1. *Lasers: Fundamental and Applications*, *Graduate Text in Physics, 2nd edition*, K. Thyagarajan, Ajoy ghatak (Springer, 2002)
2. *Polarization of light*, by Ajoy Ghatak and Arun Kumar (Mc GrawHill Education, 2012)
3. *Introduction to Fibre Optics*, Ajoy Ghatak and K. Thyagarajan, (Cambridge University Press, 2000)
4. *Teaching laser physics by experiments*, Am. J. Phys., (2011), http://doi.org/1-3488984
5. *Infrared Spectroscopy, Fundamentals and Applications*, Barbara Stuart, (Wiley & Sons, 2004)
6. *Modern Raman Spectroscopy-a practical approach*, E. Smith and G. Dent (John Wiley & Sons, 2004)
7. *Spectroscopic Ellipsometry: Principles and Applications*, H. Fujiwara(Wiley& Sons, 2007)
8. *Introduction to Holography*, Vincent Toal, (CRC Press, 2012)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET559

Course Name: Advanced Solid State Physics-II (Theory)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This courseintends to provide knowledge of emerging topics in condensed matter physics. In addition, this course aims to provide a general introduction to theoretical and experimental aspects of advanced topics by covering glasses and polymers, liquid crystals, carbon-based materials, and surface physics. More importantly, the students will be exposed to different characterization techniques used in experimental condensed matter physics.

Contents:

Unit I **(8 lectures)**

Glasses and Polymers: Glass formation, types of glasses and glass transition, radial distribution function and amorphous semiconductors, electronic structure of amorphous solids, localized and extended states, mobility edges, Density of states and their determination, transport in extended and localized states, Optical properties of amorphous semiconductors. Structure of polymers, polymerization mechanism, characterization techniques, optical, electrical, thermal and dielectric properties of polymers.

Unit II **(7 lectures)**

Liquid crystals: Liquid Crystals. Structural peculiarities and applications, Thermotropic liquid crystals; Classification, Phases and phase transitions; anisotropic materials; symmetry aspects; optics; electro-optics of liquid crystals; ferro-, and antiferroelectric liquid crystals; examples of LCs in nanoscience, photonics and microwave electronics, display devices.

Unit III **(6 lectures)**

Carbon based materials: Fullerenes, C60, C80 and C240 Nanostructures; Properties and Applications (mechanical, optical and electrical). CNT-single walled and multiwalled, graphene.

Unit IV **(6 lectures)**

Phase transitions in solids: Landau's theory, first order and second order transition, order parameter and critical exponents, examples of phase transition: Solid-liquid, ferroelectric – paraelectric, ferromagnetic – paramagnetic, superconducting transition, liquid crystals.

Unit V **(6 lectures)**

Introduction to Surface Physics: Reconstruction and relaxation, surface electronic structure; Hetrostructures; Self-assembled monolayers, Electrified interfaces, Charge transfer at the liquid-solid interfaces. Thin film deposition methods: thermal evaporation and sputtering.

Unit VI **(12 lectures)**

Material characterization: X-ray diffractometer: Determination of lattice parameters, crystallite size, Texture analysis, thin film diffraction and thickness measurements. Electron Diffraction: Basics of electron microscopes, electron beam specimen interaction, Scanning Electron Microscopy and Transmission Electron Microscopy; Transport measurements: Two probe, four probe - Vander Pauw techniques; Scanning probe techniques: Principles of STM and AFM.

Course Learning Outcomes

Thestudents should able to elucidate the important features of advanced topics in experimental condensed matter physics.

Suggested Readings

1. *Physics of Amorphous Solids*, R. Zallen (John Wiley and sons, 1983)
2. *Introduction to Polymer Physics*, Ulrich Eisele and Stephen D. Pask (Springer-Verlag, 1990)
3. *The physics of liquid crystals*, Pierre-Gilles de Gennes (2nd Ed., Oxford Universty Press, 2003)
4. *Introduction to Liquid Crystals*, Peter J. Wojtowicz, E. Priestly, Ping Sheng (Plenum press, 1975)
5. *Carbon Nanotubes: Properties and Applications*, Michael J. O'Connell (CRC press, 2006)
6. *The Physics of Phase Transitions - Concepts and Applications*, P. Papon**,** J**.** Leblond**,** andPaul H. E. Meijer(2nd Ed., Springer-Verlag, 2006)
7. *Physical Methods for Materials Characterization*, P. E. J. Flewitt, R. K. Wild, (2nd Ed., CRC Press, 2015)
8. *Encyclopedia of materials characterization: surfaces, interfaces, thin films*, R. C. Brundle et al. (Butterworth-Heinemann, 1992)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET560

Course Name: Advanced Solid State Physics-II (Lab.)

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

To carry out advanced level experiments to determine the optical, dielectric and magnetic properties of the materials. Also, to expose the students to various materials characterisation techniques.

Contents:

LIST OF EXPERIMENTS

1. Set the c-axis of the given crystal perpendicular to the incident x-ray beam.
2. Obtain the Laue photograph of the given single crystal, draw gnomonic projection, and index the reflections.
3. Obtain an oscillation photograph of the given single crystal about c-axis, calculate the c- dimension of the unit cell, and index the reflections.
4. Determine the cell dimensions and establish the face centring of copper by Debye-Scherrer method (Powder method).
5. Determine the value of the Hall coefficient for the given sample and calculate the value of the mobility of the carriers and the carrier concentration. (Transverse magneto-resistance coefficient is given)
6. Determine the transverse magneto-resistance coefficient and the resistivity for the given sample and calculate the value of the mobility of the carriers and the carrier concentration. (R_H is given).
7. Measure Hall coefficient, dc conductivity and mobility of a semiconductor at different temperatures (77 K to room temperature).
8. Determine the relaxation time (EPR) for a given sample and find the value of 'g'.
9. Determine the wavelength of the microwave output of a given reflex klystron oscillator and also to determine its repeller mode pattern.
10. Calibrate a cooper resistance thermometer and use it to measure temperature from 77 K to room temperature.
11. Calibrate a silicon resistance thermometer and use it to measure temperature from 77 K to room temperature.
12. Determine the specific heat of a given sample at room and liquid nitrogen temperature.
13. Determine the Curie temperature of a given ferroelectric material.
14. Programming and interfacing with a given microprocessor.
15. Measurement of the critical temperature of a HTc-sample.
16. Study the Thermoluminescence of F-centres in alkali halide crystals.

NOTE

This list is tentative; changes in the list of experiments may be made, depending on the availability of the equipment and other relevant considerations. Interested students may be allowed to do project work

Course Learning Outcomes

The students will get a better understanding of the concepts studied by them and correlate both theory and experiments. The students will learn about the various materials characterization techniques and analysis.

Suggested Readings

1. *Optical Properties of Photonic Crystals*, K. Sakoda (Springer, 2001)
2. *The Rietveld method*, R.A.Young (IUCR-Oxford University Press, 1995)
3. *Fundamentals of Crystallography*, C.Giacovazzo (IUCR-Oxford University Press, 2002)
4. *Characterization of nanophase materials*, Zhon Ling Wang (Wiley-VCH Verlag GmbH, 2000)
5. *Physical Properties of Semiconductors*, C. M. Wolfe, J.R.N.Holonyak and G.E.Stillman (Prentice Hall International Inc., London, 1989).
6. *Handbook on Semiconductors, Vol. 1-4.*, T.S. Moss, Ed., by S.P.Keller (North-Holland, Amsterdam, 1980)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET561

Course Name: Advanced Numerical Techniques (Theory)

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This course is intended to provide an insight into the advanced numerical methods, like Interpolation, Solution of Linear Equations, Monte Carlo Methods, Curve-Fitting techniques etc. This will also allow students to develop computing algorithms and programs (in C/C++) for various numerical techniques.

Contents:

Unit I **(10 lectures)**

Error analysis – round-off and truncation errors. Elements of Numerical Integration, Error estimates of Trapezoidal rule, Simpson midpoint and 3/8 rules, Composite Numerical Integration. Gaussian Quadrature using interpolating polynomials, special polynomials like Legendre polynomials etc., Multisimensional integrals - Two and three dimensional integration. Interpolation – Introduction, Polynomial interpolation; Lagrange Interpolatiion polynomial; Cubic Spline Interpolation.

Unit II **(10 lectures)**

Solution of Linear Algebraic Equations – Introduction, Augmented Matrix, Gaussian Elimination with Backward substitution, Pivoting strategies – partial and complete, Gauss-Jordan Elimination Method, Operation Counts, Tridiagonal Systems of Linear Equations, Inverse of a matrix, LU Decomposition.

Unit III **(8 lectures)**

Numerical Differentiation,Partial differential equations – elliptic equations; boundary conditions; Finite Difference method; Forward and Backward difference methods, Few examples: Heat equations, Wave equations; Introduction to Finite Element method.

Unit IV **(12lectures)**

Monte Carlo Methods – Introduction; Random Numbers – Uniform and other random deviates, Generation of Random Numbers, Random walk problem in 1, 2, 3 and n-dimensions, Simulation – Introduction, Few examples: Coin toss and dice throws, Radioactive Decay Chain, Two-Level Spin System, Ising Model, Scattering - Toy model; Law of Large Number and Central Limit Theorem; Random number generation using arbitrary distributions – inverse transform method and acceptance-rejection method, generating discrete distributions, Monte Carlo Integration Methods.

Unit V **(8 lectures)**

Curve fitting methods – Modeling of Data, Maximum Likelihood Estimator; Pearson chi-square; Least Squares method – both without and with errors in dependent variable; Parameter estimations and errors; General Linear Least Squares.

Course Learning Outcomes

Students are expected to learn advanced numerical techniques which are useful in various disciplines of Physics and Mathematics. Students shall be able to develop algorithms based on these numerical methods, which may be implemented using computer programming languages.

Suggested Readings

1. *Numerical Recipes 3rd Edition*: *The Art of Scientific Computing*, William H. Press, Saul A. Teukolsky, William T. Vetterling , Brian P. Flannery (3rd Ed., Cambridge University Press, 2007)
2. *Numerical Analysis*, Richard L. Burden, J. Douglas Faires, Annette M. Burden (10th Ed., Cengage Learning, 2016)
3. *Data Reduction and Error Analysis for the Physical*, Philip Bevington and D. Keith Robinson (3rd Ed., McGraw Hill Education, 2003)
4. *Monte Carlo Simulation in Statistical Physics: An Introduction*, Binder, Kurt, Heermann, Dieter (5th Ed., Springer, 2010)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-EL562

Course Name: Advanced Numerical Techniques (Lab)

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

This Lab course is designed to develop computer programming skills (primarily C/C++ based) for implementing advanced numerical methods like Interpolation, Solution of Linear Equations, Monte Carlo Methods, Curve-Fitting techniques etc.

Contents:

LIST OF EXPERIMENTS

1. Integration – Quadrature formulas; Matrices – determinant, multiplication, inversion, eigenvalues, etc.
2. Interpolation – Lagrange interpolating polynomial.
3. Solution of algebraic equation using Gauss elimination with back substitution.
4. Applying pivoting strategies in solving linear algebraic equations.
5. Implementing Tridiagonal systems of equations for linear algebraic equations.
6. Cubic spline interpolation.
7. Random number generation and tests of randomness.
8. Implementing random walk problem in 1-, 2- and 3- dimensions.
9. Implementing Inverse Transform and Acceptance Rejection algorithms.
10. Modeling of data – chi square fitting and least square fit for linear and general equations.
11. A project based on developing algorithm for any generalized numerical method, which may be related with any of the topics covered in theory classes.

Course Learning Outcomes

Through this course, students shall be able to develop and implement C/C++ routines and programs for solving advanced numerical methods, which are faced in several branches of physics and mathematics. Further, students shall be able to learn and develop general algorithms and implement it using C/C++.

Suggested Readings

1. *Numerical Recipes 3rd Edition*: *The Art of Scientific Computing*, William H. Press, Saul A. Teukolsky, William T. Vetterling , Brian P. Flannery (3rd Ed., Cambridge University Press, 2007)
2. *Numerical Anal*ysis, Richard L. Burden, J. Douglas Faires, Annette M. Burden (10th Ed., Cengage Learning, 2016)
3. *Numerical Recipes in C++: The Art of Scientific Computing*, William H. Press , Saul A. Teukolsky, William T. Vetterling , Brian P. Flannery (2nd Ed., Cambridge University Press, 2002)
4. *Numerical Recipes in C: The Art of Scientific Computing*, William H. Press , Brian P. Flannery, Saul A. Teukolsky, William T. Vetterling (2nd Ed., Cambridge University Press, 2002)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-EL564

Course Name: Observational Astronomy Lab.

Marks: 100 **Duration: 120 Hrs (8P/Week)**

Course Objectives

The goal of the course is to provide some hands on training in astronomical data acquisition and analysis through a variety of instruments (telescopes, photometers, CCD cameras).

Contents:

LIST OF EXPERIMENTS

(*Students will be assigned one or more of the following observational astronomy experiments*)

1. Polar aligning a telescope and measuring declination of polaris.
2. Calibration of plate scale of a given astronomical telescope
3. Determination of diameter of moon by transit.
4. Determination of diameter of sun by transit
5. Calibration of a photometer for astronomical measurements
6. Measuring distance to moon by parallax method.
7. Measuring limb-darkening of sun.
8. Finding rotation period of sun by measuring motion of sun-spots.
9. Measuring relative sensitivity of B.V. and R band of a photometer with sun and using this to find temperature of filament of a lamp.
10. Measuring color of a star by differential photometry.
11. Measuring extinction of the atmosphere in B.V. and R bands.
12. Characterizing the CCD camera for gain, read-noise linearity and flat field.
13. Estimating atmospheric seeing by measuring different zenith angles
14. Application of Image Processing Software (IRAF) to determine magnitudes of different stars in a star field.
15. Application of Image Processing Software (IRAF) to determine angular separations of different stars in a star field.

NOTE:

Students will be required to make night observations at the Astronomical Observatory of the department. In addition, telescope time will be made available to them on IUCAA telescope as well as other national and international facilities. The work done during the entire semester is to be submitted in the form of a Dissertation. Also the above list is tentative; changes in the list of experiments may be made, depending on the availability of the equipment and other relevant considerations.

Course Learning Outcomes

Students will gain experience with measurement techniques and equipment in astronomy, and develop the ability to assess uncertainties and assumptions. Demonstrate the ability to present the results of investigations orally and in writing.

Suggested Readings

1. *Astrophysical Techniques*, C.R. Kitchin (CRC press, 1995)
2. *Observational Astrophysics*, R. C. Smith (Cambridge Univ. Press, 2000)
3. *Telescopes and Techniques*, C.R.Kitchin (Springer, 1995)
4. *Observational Astronomy*, D.S. Birney, G Gonzalez & D Oesper (Cambridge Univ. Press,2006)
5. *Observational Astrophysics*, P. Lena (Springer, 1986)
6. *Practical Astronomy with your calculator*, P. Duffet-Smith (Cambridge Univ. Press, 1988)
7. *Astronomical Photometry*, A. A. Henden & R.H. Kaitchuk (Willmann-Bell, 1990
8. *Photoelectric Photometry*, D.S. Hall & R.M. Genet (Willmann-Bell, 1988)
9. *Astronomical Spectroscopy*, C.R. Kitchin (IOP, 1995)
10. *Spectrophysics*, A.P. Thorne (Chapman & Hall, 1988)
11. *Electronic Imaging in Astronomy-Detectors and Instrumentation*, I.S. Mclean (Springer- Praxis, 2008)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET571

Course Name: General Relativity and Cosmology-II

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The primary objective is to teach the students application of general relativity to relativistic stars, cosmology and gravitational waves. Rotating black holes that ensue from Einstein's relativistic theory of gravitation is also discussed.

Contents:

Unit I **(17 lectures)**

Relativistic Astrophysics: Schwarzschild solution for star, Birkhoff's theorem, Oppenheimer – Volkoff and Tolman equation. Metric for uniform density stars. Polytropic stars, their potential and kinetic energies and stability. Radial oscillations and maximum rotational frequency. White dwarfs, neutron stars and pulsars. Stability of supermassive stars. Kerr metric. Reissner-Nordstrom metric

Unit II **(17 lectures)**

Cosmology: Cosmological principle, maximally symmetric spaces, Killing vectors, Robertson- Walker metric. Redshift of galaxies and Hubble's law. Magnitude-red shift relation, Hubble's constant and deceleration parameter. Friedmann equations and standard models. Closed, flat and open universes. Age of the universe, critical density. Galaxy clusters and problem of missing mass or missing light, dark matter. Thermal history of early universe, helium formation, decoupling of matter and radiation, microwave background radiation. Cosmological constant and the late time acceleration.

Unit III **(11 lectures)**

Gravitational Radiation: Weak field approximation and linear wave equation. Plane waves, their polarization, helicity and energy momentum tensor. Emission of radiation by a rotating source. Effect of radiation on a test particle. Detection of gravitational radiation.

Course Learning Outcomes

Students will learn how to use general relativity to study relativistics stars, Cosmology based on general relativity will teach how to study the origin, composition and evolution of the universe, Gravitational wave detectors are being installed in India. The last part of the course will provide the students exposure to this field.

Suggested Readings

1. *Introduction to Cosmology*, J. V. Narlikar (Cambridge University Press, 2002)
2. *Cosmology*, Steven Weinberg (Oxford University, 2008)
3. *Gravitation*, C.W. Misner, K.S. Thorne and J.A. Wheeler (W.H. Freeman and Co, 1970)

4. *Classical Fields: General Relativity and Gauge Theory*, Moshe Carmeli (World Scientific, 2001)
5. *Gravity, Black Holes and the Very Early universe: An Introduction to General Relativity andCosmology*, Tai L. Chow (Springer, 2008)
6. *Spacetime and Geometry,* Sean M. Carroll (Pearson, 2016)
7. *A first course in general relativity*, Bernard Schutz (Cambridge University Press, 2009)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET572

Course Name: Astrophysics -II

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The goal of the course is to understand the formation, structure and evolution of stars and how stars of different masses end up in a variety of compact objects. In addition, the course will provide a general introduction to galaxies and an overview of modern astronomy.

Contents:

Unit I (**20 lectures**)

Stellar Structure and Evolution: Virial Theorem, Formation of Stars, Hydrostatic Equilibrium, Integral Theorems on pressure, density and temperature, Homologous Transformations, Polytropic gas spheres – Lane Emden Equation and its solution, Energy generation in stars, P-P and C-N cycles, Radiative and Convection transport of energy, Equations of stellar structure and their solution, Evolution of stars of different masses, pre- and post main-sequence evolution.

Unit II (**8 lectures**)

Compact objects: Fate of massive stars, Degenerate electron and neutron gases, White dwarfs – mass limit, mass-radius relation, Neutron stars and pulsars.

Unit III (**9 lectures**)

Galaxies: The milky way Galaxy, Distribution of stars, Morphology, Kinematics, Interstellar medium, Galactic center. Classification of galaxies, Hubble sequence, Ellipticals, Lenticulars and spiral galaxies and their properties, distribution of light and mass in galaxies.

Unit IV (**8 lectures**)

Overview of Modern Astronomy: 21-cm hydrogen line, cosmic radio sources, quasars, gravitational lensing, Expansion of the Universe and determination of Hubble's constant, gamma ray bursters. Sources of Gravitational Waves

Course Learning Outcomes

Students will demonstrate an understanding of the processes of star formation and evolution off and on the main sequence and the stellar end states. In addition, students will be able to describe modern concepts like expansion of the Universe and the detection of gravitational waves.

Suggested Readings

1. *Stellar Interiors - Physical Principles, Structure, and Evolution*, C. J. Hansen, S. D. Kawaler, V. Trimble (Springer, 2004)

2. *Stellar Structure and Evolution*, R. Kippenhahn and A. Weigert (Springer, 1996)
3. *Basics of Astronomy -- IGNOU course book PHE-15 Astronomy and Astrophysics*, 2006
4. *Modern Astrophysics,* Carrol & Ostlie (Addison Wesley, 1996)
5. *The Physical Universe*, F. Shu (University Science Books, 1982)
6. *Principles of Stellar Structure Vol. I & II,* J. P. Cox & R. T. Giuli (Gordon & Breach, 1968)
7. *An Introduction to the Study of Stellar Structure*, S. Chanrdrasekhar (Dover, 1968)
8. *Stellar Interiors*, D. Menzel, P. L. Bhatnagar & H. K. Sen (Chapman & Hall, 1963)
9. *Galactic Astronomy*, J. Binney & M. Merrifield (Princeton Univ. Press, 1998)
10. *Textbook of Astronomy & Astrophysics*, V. B. Bhatia (Narosa, 2001)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET573

Course Name: Condensed Matter Physics-II

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The main objective of this course is to impart the quantum theory of some of the advanced topics such as the magnetism, superconductivity and quantum hall effect.

Contents:

Unit I **(22 lectures)**

Magnetic properties of solids: Diamagnetism, Paramagnetism of atoms with permanent magnetic moment, Pauli paramagnetism of conduction electrons, magnetic exchange interaction, Heisenberg model for ferro and antiferromanetic insulators, magnons in ferro and antiferro-magnets, magnon contribution to specific heat, Stoner theory of ferro-magnetism of itinerant electrons (brief), second quantization (brief), local moment formation in metals, brief discussion of Kondo effect and Heavy fermion systems.

Unit II **(12 lectures)**

Superconductivity: Introduction and materials, Meissner effect, thermodynamics of superconductors, London's phenomenological theory, flux quantization, Copper instability, BCS theory of superconductivity, Coulomb pseudo-potential, strong coupling effects, Josephson effects, Ginzburg- Landau theory.

Unit III **(11 lectures)**

Special topics: Integral and fractional quantum Hall effect: electron in a strong magnetic field, Landau levels and their degeneracy, simple explanation of IQHE; Metal-Insulator transitions: Mott- Hubbard and impurity induced; Landau theory of Fermi liquid, Mott variable range hopping, Bose- Einstein condensation.

Course Learning Outcomes

A student of this course is expected to understand extensively the basic as well as the advanced theoretical treatments involved in magnetism, superconductivity and Hall effect. Further, the students are encouraged to widen their research interests in these topics.

Suggested Readings

1. *Solid State Physics*, Neil W. Aschroft & N. David Mermin (Ist Ed., Cengage Learning, 2003)
2. *Solid State Physics*, Gerald Burns (Academic Press, 1985)
3. *Solid State Physics*, Wlater A. Harrison (Dover Publications, 1980)
4. *Solid State Physics* : An introductlion to Principles of Materials Science, Harald Ibach and Hans Luth (Springer, 2003)

5. *Solid State Physics, Advances in research and applications, Supplement* 3, F. Seitz and D. Turnbull (Eds.) (Academic Press, 1958)
6. *Theory of lattice dynamics in harmonic approximation*, A.A. Maraduddin, E. W. Montroll and G.H. Weiss (Academic Press, 1963)
7. *Theory of thermal neutron scattering*, W. Marshall & S.W. Lovessey (Oxford Univ. Press, 1971)
8. *Quantum Theory of Solids Part A & B*, Callaway (Academic Press, 1974)
9. *Mossbauer Effect : Principles and Applications*, G. K. Wertheim (Academic Press, 1964)
10. *The Mossbauer Effect*, Hans Fraunfelder (W. A. Benjamin, 1963)
11. *Quasielastic neutron scattering for the investigation of diffusive motions in solids and liquids-Springer tracts in modern physics Vol. 64*, Tasso Springer (Springer-Verlag, 1972)
12. *Superconductivity*, V. L. Ginzburg and E. A. Andryushin (World Scientific, 1994)
13. *Introduction to Superconductivity and high-Tc materials*, Michel Cyrot and Davor Pavuna, (World Scientific, 1992)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET574

Course Name: Plasma Physics -II

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The primary learning outcome for this course is for the students to learn the plasma stability and its application to fusion plasmas. The course covers the main aspects of plasma physics with emphasis on nuclear fusion, plasma confinement and computational plasma physics.

Contents:

Unit I **(13 lectures)**

Fluid description of plasmas, Moment equations. MHD equations. Generalized Ohm's law, flux conservation, Decay of fields. Pressure balanced and force free fields.

Unit II **(12 lectures)**

Alfven waves, Dissipative effect, Magneto-acoustic waves, Hydro-magnetic shocks, KDV equation, Linear and nonlinear ion-acoustic waves, dusty and strongly coupled plasma

Unit III **(12 lectures)**

Magneto-hydrodynamic instabilities, Energy principle, Normal mode analysis and its application to Rayleigh-Tayler and Kelvin Helmholtz instabilities, Pinch instability, Jean's instability.

Unit IV **(4 lectures)**

Plasma applications to medicines, material sciences, waste treatment and Plasma Applications to RF heating and current drive.

Unit V **(4 lectures)**

Computational methods in plasma physics, Plasma simulation via particle-in-cell simulations, mathematics and physics behind the algorithms.

Course Learning Outcomes

On completion of the course the student shall be able to: Understand the plasma confinement in a magnetized plasma and implications to fusion machine. Understand the plasma stability in a magnetic field. Classify the energy transfer in MHS via Alfven and magnetosonic waves. Define and determine the basic of MHS stability through energy principle. Formulate the conditions for a plasma instability in magnetized plasmas. Explain the physical mechanism behind nonlinear wave excitation in plasmas. Understand the computational plasma physics. Define the applications of non-thermal plasma.

Suggested Readings

1. *Introduction to Plasma physics*, F. F. Chen (Plenum Press, 1984)

2. *Principles of Plasma Physics*, N. A. Krall and Trivelpiece (San Fransisco Press, 1986)
3. *Physics of High temperature Plasmas*, G. Schimdt (2nd Ed., Academic Press, 1979)
4. *The framework of Plasma Physics*, R.D. Hazeltine & F.L. Waelbroeck (Perseus Books, 1998)
5. *Introduction to Plasma Physics*, R.J. Goldston and P.H. Rutherford (IOP, 1995)
6. *Plasma Physics via Computer Simulation*, C.K. Birdsall, A.B Langdon (CRC Press 2004)
7. *Plasma Physics and Engineering*, A. Fried and L.A. Kennedy (Taylor and Francis Group-2011).

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET575

Course Name: Particle Physics -II

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The main objective of this course is to provide deep knowledge in emerging topics in particle physics. More specifically, the students will have excellent opportunity to get acquainted with our current understanding of the most fundamental constituents of matter and the primary forces of nature. In addition, the course would cover briefly and discuss quark model and develop the concept of non-abelian gauge theories based on SU(2) and SU(3). After a discussion of Spontaneous Symmetry Breaking (SSB) and Higgs Mechanism, the learners will be able to construct the electroweak model.

Contents:

Unit I **(15 lectures)**

Number of colors, R-ratio, pion-decay Why $SU(3)_c$?

Rutherford and Mott cross sections; electron-muon scattering; Electron-proton scattering : elastic and inelastic Structure functions

Deep-inelastic scattering and the quark hypothesis

Gluon emission and three-jets

Drell-Yan, neutrino-DIS and the extraction of parton densities Bjorken and Ellis-Jaffe sum rules

Unit II **(18 lectures)**

Four-fermi theory; Charged– and neutral-currents, CVC and PCAC, Sudarshan-Marshak theory, Unitarity and need for intermediate vector bosons; electroweak scale, The need to go beyond IVB theory,

Why SU(2) X U(1) ?

Fermion quantum number assignments, Spontaneous Breaking of SU(2) X U(1);

Determination of W, Z and Higgs properties (masses, mixings, decays etc)

Unit III **(8 lectures)**

Fermion Mass generation and mixing;

Mixing in the Kaon-system, GIM mechanism and the necessity of charm.

CP violation and the necessity of the third generation, Neutrino oscillations.

Unit IV **(4 lectures)**

Running of gauge couplings in the SM Running of Higgs mass and self-coupling

Need for physics beyond SM. Preliminary discussion of some possibilities.

Course Learning Outcomes

CVC and PCAC as tools to understanding weak interactions. Intermediate Vector bosons. Formulation of the electroweak theory, including the Higgs mechanism. Phenomenological understanding of meson mixing and CP violation. Microscopic derivation within the

Standard Model. Unraveling the structure of proton through high-energy electron-proton scattering. QCD

Suggested Readings

1. *An Introductory Course of Particle Physics*, Palash B. Pal (CRC Press, 2015)
2. *Quarks & Leptons: An Introductory Course in Modern Particle Physics*, Halzen, F., and A. D. Martin (John Wiley & Sons, 1984)
3. *Gauge Theory of Elementary Particle Physics: Problems and Solutions*, T. P. Cheng and Ling-Fong Li (Oxford, 2000)
4. *Introduction to Elementary Particles*, Griffiths D. (Wiley-VCH 2008)

Pre-requisite: Particle Physics I and Quantum Field Theory I

Co-requisite: Quantum Field Theory II

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET576

Course Name: Quantum Field Theory -II

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This course is in continuation to Quantum Field Theory I and advanced topics in the field will be presented. By introducing more techniques deeper problems in Quantum Field theory will be addressed. The aim is to broaden the understanding of the students so that they are able to appreciate and address these problems.

Contents:

Unit I **(12 lectures)**

Green's functions in functional integrals; Non-abelian gauge theories Path integral quantization of vector fields (Fadeev Popov) ; Dyson-Schwinger and Ward identities.

Unit II **(6 lectures)**

Spontaneous breaking of symmetry; Goldstone Theorem; Higgs mechanism in U(1)
Higgs mechanism in U(1).

Unit III **(12 lectures)**

Loop diagrams : Counting of Ultraviolet Divergences Regularization in ϕ^4 theory : Cut-off, Pauli-Villars and Dimensional Renormalization of pure-scalar theory
Renormalization in QED Lamb shift and anomalous magnetic moment of the electron.

Unit IV **(5 lectures)**

LSZ Reduction Theorem, Optical Theorem

Unit V **(10 lectures)**

Renormalization Group and Effective Field Theories Beta-function for ϕ^4 and QED Bremsstrahlung and other soft divergences.

Course Learning Outcomes

The students will learn various new techniques and examples in Quantum Field Theory. Ultraviolet and Infrared Divergences in Quantum field theory will be introduced and methods to address these fundamental issues will be taught. The understanding of the students will further be enhanced through concepts such as Spontaneous Symmetry Breaking, Renormalization Group and Effective Field Theories.

Suggested Readings

1. *The Quantum Theory of Fields*, *Volume 1: Foundations*, Steven Weinberg (Oxford UniversityPress, 2005)
2. *Lectures on Quantum Field Theory*, Ashok Dass (World Scientific, 2008)
3. *Relativistic Quantum Mechanics*, J.D. Bjorken and S. Drell (Mcgraw-Hill, 1964)

4. *Relativistic Quantum Fields*, J.D. Bjorken and S. Drell (Mcgraw-Hill, 1964)
5. *Quantum Field Theory*, C. Itzykson and J-B Zuber (McGraw-Hill, 1980)

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MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET581

Course Name: Nonlinear Dynamics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The course will introduce the students to the basic concepts of nonlinear systems, dynamical theory, chaos, and soliton. These concepts will be demonstrated using simple models based on ordinary & partial differential equations and discrete maps. Properties of coupled systems also will be explored.

Contents:

Unit I **(9 lectures)**

Introduction to ordinary differential equations (ODEs): linear and nonlinear, systems of ODEs, existence and uniqueness theorems, conservative versus dissipative systems, invariant curves and quasiperiodicity, review of KAM theorem, integrable and non-integrable syste

Unit II (**12 lectures**)

Phase space analysis & Bifurcations: Phase portrait, linear stability, fixed points, periodic orbits, limit cycles, Poincaré-Bendixson theorem, Lyapunov functions, gradient systems. Saddle-node, transcritical, pitchfork, Hopf, period doubling, intermittency, local and global bifurcations; center manifold and normal form, structural stability.

Unit III (**12 lectures**)

Discrete systems, Strange attractors & Coupled systems: Poincaré crossections, linear stability and cobweb analysis; universality; logistic, tent, and Henon maps.
Unstable periodic orbits, chaotic motions; characterization: fractal dimension and Lyapunov exponents; Cantor set and Koch curve.
Introduction to synchronization and pattern formation.

Unit IV (**12 lectures**)

Partial different equations & Solitons:linear and nonlinear, diffusive and dispersive; boundary value problems; methods of separation of variables, characteristics; inverse scattering; symbolic computation; similarity and Backlund transformations.
Soliton theory: periodic, cnoidal and solitary wave solutions of Korteweg-de Vries, Nonlinear Schroedinger and sine-Gordon equations; conserved densities.

Course Learning Outcomes

The knowledge and familiarity about concepts and methods of dynamical system theory that acquired during this course will be useful and applicable in almost all branches of science: from systems of Nano to astrophysical scales. Students will be able to learn the different analytical techniques and the geometrical intuition of local & global behaviour to understand the evolution of complex nonlinear systems.

Suggested Readings

1. *Elementary Differential Equations and Boundary Value Problems*, W. E. Boyce and R. C.DiPrima (Wiley, 2003).
2. *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, andEngineering*, S. H. Strogatz (Westview Press, 2001).
3. *CHAOS: An Introduction to Dynamical Systems*, K. Alligood, T. Sauer and J.A. Yorke (Springer, 1996).
4. *Solitons: An Introduction*, P. G. Drazin & R. S. Johnson (Cambridge University Press, 1989).
5. *Nonlinear Science:Emergence and Dynamics of Coherent Structures,* by A. Scott (Oxford Univ. Press, 2^{nd} edition, 1999).
6. *Advanced Methods of Mathematical Physics,* R. S. Kaushal and D. Parashar (Narossa, 2008).
7. *Nonlinear dynamics: Integrability, Chaos and Patterns*, M. Lakshmanan and S. Rajasekar, (Springer-Verlag, 2003).

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET582

Course Name: String Theory

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

(Super)string theory describes quantum gravity consistently. The course on bosonic string theory is believed to strengthen an young mind conceptually with various theoretical innovations. It may provide clues to explore different branches of physics through the quantum gravity.

Contents:

Unit I **(15 lectures)**

Fundamental (F) string and its significance, closed and open bosonic strings, mass-less (free) scalar field theory in (1+1)-dimension and its generalization to string world-sheet action, Nambu-Goto action, Polyakov closed and open string actions, dilaton and string coupling, world-sheet global and local symmetries, canonical analysis, equations of motion, string mode expansion and commutation relations, Energy-Momentum tensor, Virasoro algebra and physical states, masses of closed/open string states, tachyon, derivation of linear and angular momentum.

Unit II **(12 lectures)**

Closed bosonic string world-sheet action in light-cone coordinates, Virasoro conditions and residual symmetries, interacting (non-linear sigma model) closed and open string actions in presence of all the mass-less background fields, mixed boundary conditions, canonical analysis, vertex operators, global aspects of string world-sheet, Klein bottle, Mobius strip.

Unit III **(12 lectures)**

D-brane and its tension, Open strings between parallel D-branes Maxwell fields coupling to open strings, (Dirac) Born-Infeld action, longitudinal and transverse linear momenta in presence of a constant two form, gauge invariance with a constant two-form on a D-brane, derivation of non-commutative coordinates on a D-brane world-volume, D-brane and F-string bound state, D-instanton, Toroidal compactification and T-duality.

Unit IV **(6 lectures)**

Glimpses on superstring theories and D-branes therein.

Course Learning Outcomes

The course would likely to provide a sound working knowledge in theoretical physics and may generate a deep enthusiasm to explore further in natural sciences.

Suggested Readings

1. *Superstring Theory, Volume-I,* Michael B. Green, John H. Schwarz and Edward Witten (Cambridge Monograph on Mathematical Physics, 1988)
2. *String Theory, Volume-I,*Joseph Polchinski (Cambridge University Press, 1998)
3. *A First Course in String Theory,*Barton Zwiebach (Cambridge University Press, 2004)
4. *Introduction to Strings and Branes*, Peter West (Cambridge University Press, 2012)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET583

Course Name: Superconductivity, Superfluidity & Critical Phenomena

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This courseintends to provide knowledge of Superconductivity, Superfluidity & Critical Phenomena in terms of theoretical aspects.

Contents:

Unit I (**7 lectures**)

Hartee Fock approximation (HFA), Exchange energy of electron gas in HFA, Shortcomings of HFA, Screening in an electron gas, Thomas Fermi approximation.

Unit II (**12 lectures**)

Isotope effect- BCS model of superconductivity, Bogoliubov-Vallatin transformation, solution of BCS gap equation, energy gap as a function of temperature. Applications of electron band structure results to calculate electron-phonon coupling constant McMillan's formula – GLAG theory – recent theories on high Tc materials, Coherence length, expression for critical temperature Tc, critical field Hc, critical current Jc – heavy fermion superconductivity.

Unit III (**6 lectures**)

Ginzburg-Landau theory of type II superconductors. Hc1 and Hc2. High Tc superconductors: properties of the normal and superconducting states, introduction to possible theories.

Unit IV (**6 lectures**)

Superfluidity of liquid 3He. Phases of superfluid 3He. Singlet and triplet state pairing.

Unit V (**8 lectures**)

Landau's theory of phase transitions. Critical exponents. Ginzburg Criterion. Critical dimensionality, Examples of different types of transition: solids-liquid, liquid-gas, magnetic transitions, Ferroelectric-paraelectric, superconducting transition, glass transitions.

Unit VI (**6 lectures**)

Kadonoff's scaling hypothesis. The renormalization group, renormalization group for the Ising chain. Fixed points. Calculation of fixed point for the 2D Ising model on the triangular lattice.

Course Learning Outcomes

The students will understand the basic concepts of superconductivity and superconducting materials.

Suggested Readings

1. *Superfluidity and Superconductivity*, D. R.Tilley and Tilley Adam Hilger (3rd Ed., IOP Publishng Ltd., 1990)
2. *Superconductivity and its Applications*, H. S. Kowk and D. T. Shaw (Springer, 1989)
3. *Introduction to Superconductivity*, M. Tinkham (CBS Publishers & Distributors, 2008)
4. *Superconductivity: A Very Short Introduction*, S. Blundell (Oxford University Press, 2009)
5. *Theory of Superconductivity*, J. R. Schrieffer (CRC Press, 2018)

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MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET584

Course Name: Soft Matter Physics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This course intends to provide knowledge of Soft Matter Physics in terms of theoretical aspects.

Contents:

Unit I (**7 lectures**)

Introduction: Characteristics of soft condensed matter, States of matter and phase transition, review of statistical mechanics relevant to the study of soft materials, soft materials in industry, nature and biology.

Unit II (**6 lectures**)

Forces and Energy scales: Atomic and molecular forces, van der Waals forces, casimir forces, hard core repulsion, shapes of molecules, entropy.

Unit III (**6 lectures**)

Capillarity and wetting: Surface and interfacial tension, dynamics of wetting, viscosity capillary rise and meniscus, shapes of droplets – solid substrates and liquid substrates, droplet spreading dynamics, Wetting of films and fibres and dewetting.

Unit IV (**6 lectures**)

Colloids: Interparticle interactions, particle packing and frustration, phase diagram of hard spheres, thermodynamics of colloidal system, dynamics of small particles – diffusion equation, The Langevin equation and viscosity, aggregation, rheology. Applications in inks, food colloids, sedimentation and flotation. Simple methods of preparation of colloidal particles.

Unit V (**9 lectures**)

Polymers: The ideal chain structure, statistical mechanics of chain structure, polymer solution and melts, fractals in polymers – disorder and scale invariance, random aggregation, diffusion limited aggregation (DLC) and DLCA, glass transition, amorphous and crystalline polymers, block polymers. Applications rubbers, plastics, biopolymers like proteins, DNA, viscoelastic fluids and synthetic materials Simple experimental methods of preparation of some of the polymers

Unit VI (**7 lectures**)

Liquid crystals: Classification, Nematic liquid crystals order, singularity, elasticity, display application, lamellar properties, Cholesterics, Lamellar systems – structures and properties, chiral systems. Smectics and Columnar systems – structures and properties, phase transitions, preparation of liquid crystals and application to liquid crystal displays.

Unit VII **(4 lectures)**

Amphiphiles: Miscellar shape and phase behavior, giant miscelles, fluid membranes, bilayers and vesicles, microemulsions, Langmuir Monolayers, self-assembly. Applications – soaps and detergents, thin films, foams and biological cells.

Course Learning Outcomes

The students will understand the basic concepts of soft matter physics in terms of theoretical aspects.

Suggested Readings

1. *Soft Condensed Matter*, Richard A. L. Jones (Oxford University Press, 2002)
2. *Structured Fluids: Polymers, Colloids, Surfactants,* Thomas A. Witten (Oxford University Press, 2004)
3. *Scaling concepts in Polymers*, P. G. De Gennes (Cornell University Press, 1979)
4. *Principles of condensed matter, Sections 1,2 and 6*, P M Chaikin, T C Lubensky (Cambridge University Press, 1995)
5. *Soft Matter Physics: An Introduction*, Maurice Kleman, Oleg D Laverntovich, J. Firedel, (Springer, 2000)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET585

Course Name: Fluid Dynamics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

The primary objective is to teach the students the Physics of studying fluid motion. This is a useful course for those who would like go for higher studies/research Astrophysics, Plasma Physics as well as those who might like to do M.Tech in Engineering courses.

Contents:

Unit I (**6 lectures**)

Fluid particle and fields: Stream-line, particle-path and streak-line , Lagrange derivative, Decomposition of velocity field Continuum and transport phenomena , diffusion , ideal fluid and Newtonian viscous fluid ,Viscousstress.

Unit II (**9 lectures**)

Ideal and Viscous Fluids:Equations of ideal fluids: Continuity and Navier's Stokes equation, Conservation laws. Energy Flux. Viscous fluids, Equation of motion, Energy and Entropy, Reynolds slaw , Parallel shear and Rotating flows, Low Reynolds number flows.

Unit III (**5 lectures**)

Flows of ideal fluids: Bernoulli's equation, Kelvin's circulation theorem, vortex lines Potential flows , Irrotational incompressible flows (3D), source in a uniform flow.

Unit IV (**5 lectures**)

Water waves: deep water and KdV equation for long waves on shallow water,
Sound waves, Shock waves.

Unit V (**4 lectures**)

Vorticity: equation governing vorticity, Biot–Savart's law for velocity, Invariants of motion, 1. Material line element and vortex-line, Helmholtz's vortex theorem.

Unit VI (**6 lectures**)

Complex formulation of 2D flows: Sources and Sinks. Two-dimensional vortex motions , vorticity equation, Velocity field at distant points Point vortex, Vortex sheet,N point vortices.

Unit VII (**10 lectures**)

Misc. topics: Geophysical flows, Taylor–Proudman theorem, A model of dry cyclone (or anticyclone) Rossby waves, Stratified flows Linear stability theory, Kelvin–Helmholtz instability, Introduction to turbulence.

Course Learning Outcomes

Students will be equipped for higher studies in Astrophysics and Plasma Physics. This will be value addition for those who plan to join DRDO, ISRO, BARC etc.

Suggested Readings

1. *Elementary Fluid Mechanics*, Tsutomu Kambe (World Scientific, 2007)
2. *Principles of Astrophysical Fluid Dynamics,* Cathie Clarke, Bob Carswell (Cambridge University Press, 2007)
3. *Fluid Mechanics*, Landau and Lifshitz (Pergamon Press, 2013)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET586

Course Name: Nuclear Astrophysics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

It is an emerging filed in physics. The course will address one of the particularly important problems to determine rates for the nuclear reactions that occur in astrophysical environments. It will provide the idea of synthesize heavier elements in the universe.

Contents:

Unit I **(14 lectures)**

A Introduction to nuclei in Cosmos: A background to nuclear Astrophysics: a physical introduction to the star, Stellar interior, Abundances and nuclear physics aspect, Thermonuclear reaction, source of nuclear energy, Stellar reaction rates and it's determination, astrophysical S-factors, Forward and reverse reactions, Non-resonant and resonant reactions, mean lifetime, Maxwll-Boltzmann velocity distribution, Gamow peak

Unit II **(5 lectures)**

Stallar structure: H-R diagramClassical stars, Degenerate stars. Main sequence, Contraction of main sequence, Advance stellar evaluation.

Unit III **(9 lectures)**

Cosmological Nucleosynthesis: Helium production: p-p chain, CNO cycles, other cycles like NeNa, MgAl, Abundance of light elements, Be bottleneck, Creation and survival of ^{12}C.

Unit IV **(6 lectures)**

Nuclear burning stages:Stellar (hydrostatic) nucleosynthesis:H burning, He burning, Advanced nuclear burning, Core collapse, solar neutrinos.

Unit V **(6 lectures)**

Explosive nucleosynthesis: Abundance of elements,Nucleosynthesis beyond the Fe Peak: Silicon burning, Supernovae, core collapse, and supernova,Neutron Star, Production of nuclei, r-, s- and γ-processes.

(5 lectures)

Unit VI

Experimental methods in Nuclear Astrophysics: Coulomb dissociation, Trojan Horse Method, ANC method, recent applications using Radioactive beams.

Course Learning Outcomes

The student should be able to account for the theoretical models that explain the origin of elements in the universe, nucleosynthesis processes. They will gain knowledge about relevant nuclear and astrophysical measurements and observations and by using some of the relevant theoretical models to perform basic calculations of nuclear astrophysical processes.

Suggested Readings

1. *Supernovae and Nucleosynthesis*, D. Arnett (Princeton University Press, Princeton 1996)
2. *Nuclear Physics of Stars*, Christian Iliadis (Wiley-VCH 2007)
3. *An Introduction to Nuclear Astrophysics*, Richard N. Boyd (The University of Chicago Press, 1988)
4. *Nuclear Reactions for Astrophysics*, I. J. Thompson and F. M. Nunes (Cambridge University Press, 2009)
5. *Principles of Stellar Evolution and Nucleosynthesis*, D. Clayton (The University of Chicago Press, 1983)
6. *Cauldrons in the Cosmos: Nuclear Astrophysics (Theoretical Astrophysics Series)*, C E Rolfs & W S. Rodney (The University of Chicago Press, 1988)

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET587

Course Name: Nuclear Safety and Security

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

Introduction to radioactive sources/materials and their classification; technical aspects of research reactors; awareness of the wide-ranging of scenarios pertaining to nucear safety and security; appraisal of national and international frameworks, legislations and regulations.

Contents:

Unit I **(6 lectures)**

Radioactive Sources: Radioactive sources/materials and their applications, Radiation Basics and Consequences of Exposure to Radiation, Categorization of Radioactive Sources, overview of Nuclear and Radiation facilities.

Unit II **(7 lectures)**

Reactor Fundamentals: Introduction to Reactor physics, neutron induced fission, energy release in fission, concept of neutron flux and cross-section, neutron cycle in thermal reactors, criticality, nuclear power output calculation, breeder reactions. fissile and fertile materials. thermal and fast reactors; plutonium and higher isotopes, Reactor control and operation, neutron lifetime and delayed neutrons.

Unit III **(24 lectures)**

Safety and Security Frameworks: Introduction to and overview of IAEA Nuclear Safety and Security Series Publications, Treaties, auditing and review legal compliance of nuclear establishments, ISO Standards Concept of safety, security and safeguards

Nuclear Safety; Fundamentals of Nuclear Safety; Nuclear Safety Standards, Defense in the Depth approach, Safety classification, Mitigation of radiological consequences of significant release, Human performance and surveillance programs, Emergency preparedness and Response in a nuclear/radioactive event/emergency.

Nuclear Security: Overview of Nuclear Security Principle, Nuclear Security Threats and Risks in Nuclear Materials and Facilities, Physical Protection, Transport Security, Nuclear Material Accounting and Control, Preventive and Protective Measures against Insider Threats, Nuclear Security of Materials Outside of Regulatory Control**,** Use of Radiation Detection Instruments in Nuclear security**,** Radiological Crime Scene Management,

Impact minimization, case studies, Safety and security of sources during storage, use, transportation and disposal, administrative and technical provisions, Radioactive waste management (modern and accelerators driven techniques), graded approach in security and safety waste management.

Unit IV **(8 lectures)**

National &International Resources and Legislations: Atomic Energy Regulatory Board (AERB), International Atomic Energy Agency (IAEA), Codes, standards, guidelines, manuals, Regulatory Controls; Licensing, inspection and enforcements, Responsibilities of

Employers, Licensee, Radiological Safety officer (RSO) and radiation workers. Import and export procedures, Importance of International Cooperation, Knowledge sharing, Best practices.

Course Learning Outcomes

The student would have technical knowledge about radioactive sources/materials and research reactors;quantitative idea about permissible doses for different levels of users; knowledge about various regulatory authorities, understanding of multi-dimensional aspects of nuclear safety and security, national and international legislation, regulations and resources; knowledge about the management of radioactive material and adherence to safety protocols.

Suggested Readings

1. *Introduction to Nuclear Reactor Physics*, Robert E. Masterson (CRC Press, 2017)
2. *Understanding Radioactive Waste*, Taylor Francis, R. L. Murray (4th Ed., Battelle Press, 1994)
3. *Radiation Biophysics*, Edward L Alpen (2nd Ed., San Diego Academic Press, 1998)
4. *Nuclear Fuel Management*, H. W. Graves (John Wiley & Sons, 1979)
5. *IAEA Publications* : (a) General safety requirements Part 1, No. GSR Part 1 (2010), Part 3 No. GSR Part 3 (Interium) (2010); (b)Safety Standards Series No. RS-G-1.5 (2002), Rs-G-1.9 (2005), Safety Series No. 120 (1996); (c) Safety Guide GS-G-2.1 (2007).
6. *AERB Safety Guide* (Guide No. AERB/RF-RS/SG-1), Security of radioactive sources in radiation facilities.
7. *AERB Safety Standard* No. AERB/SS/3 (Rev. 1), Testing and Classification of sealed Radioactivity Sources.

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-ET588

Course Name: Applied Physics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This courseintends to impart knowledge of conceptual physics and its applications relevant to various streams of engineering and technology. More specifically, the student will be able to understand the properties of materials being used in various applications including transduces, sensors and detectors, cryogenics and energy harvesting, energy storage and conversion devices.

Contents:

Unit I (**10 lectures**)

Transducers: Fundamentals of transducer, classifications and general characterises; displacement transducers, strain gauges, pressure and force transducers, torque transducers, flow transducers, transducers for biomedical applications. Microelectromechanical systems (MEMS); microfabrication and micromachining, advanced lithography techniques, diffusion & ion implantation, and high aspect ratio processes.

Unit II (**12 lectures**)

Sensors: Resistive, capacitive, inductive, electromagnetic, thermoelectric, piezoelectric, piezoresistive, photosensitive and electrochemical sensors; Toxic gas monitoring; thermal conductivity analysers, colorimetric determination, sorption type dosimeters; non-dispersive infrared and ultraviolet sensors; flame ionisation detectors; semiconductor sensors. Lasers for optical communication system – Applications of optical fibre - Fibre optic communications.

Unit III (**10 lectures**)

Cryogenics: Cryogenics: Production of vacuum and measurements. Measurement of low pressure, calibration of vacuum gauges, general principle of mass flow measurement and control. Basic cryogenics science, cryostat design properties of material at low temperature. Measurement system for low temperatures; Applications of cryogenics – PPMS and MPMS; principle and working. Safety in handling of cryogens.

Unit IV (**13 lectures**)

Alternate Energy Storage and Harvesting: Electrochemical energy storage devices - EMF, reversible and irreversible cells, free energy, thermodynamic calculation of the capacity of a battery, calculations of energy and power density of cells. Types of batteries, factors affecting battery capacity, voltage and current level; types of discharge: Applications of lithium ion batteries in electronic devices, and electric vehicle. Supercapacitors and fuel cells: basics of fuel cells, types of fuel cells and technology development. Solid and polymer electrolyte and solid oxide fuel cells. Basics of solar energy; brief history of solar energy utilization; various approaches of utilizing solar energy. Formation of solar cell and its equation; fill factor and maximum power; silicon solar cell; tandem solar cell; dye sensitized solar cell; organic solar cell.

Course Learning Outcomes

Learner will be able to comprehend basic physics principles used in emerging technological devices. The students will have the enriched knowledge on physics of materials and that will be used by them in different engineering and technological applications.

Suggested Readings

1. *Handbook of Transducers*, H. N. Norton (Prentice Hall, 1989)
2. *An introduction to Microelectromechanical Systems Engineering*, N. Maluf(Artech House Publishers, 2000)
3. *Microsensors: Principles and Applications*, J. W. Gardner (John Wiley, 1994)
4. *Sensor Technology and Devices*, L. R. Ristic (Artech House publishers, 1994)
5. *Vacuum Technology* by Roth (Elsevier, 1990)
6. *Experimental Techniques in Low Temperature Physics*, G. K. White (4^{th} Ed., Oxford University Press, 2002)
7. *The Physics of Solar Cells*, Nelson (Imperial College Press, 2003)
8. *Solid State Electronic Device*, G. Streetman and S. Banerjee (6^{th} Ed., Prentice Hall, 2006).

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-OT591

Course Name: Biological Physics

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This open elective course will introduce students to selected biological phenomena from the point of view of physics, emphasizing quantitative regularities. It will enable students from non-biology backgrounds to gain an overview of living systems, and those from biology backgrounds to perform mathematical modelling of certain biological processes.

Contents:

Unit I **(10 lectures)**

Length and time scales in biology: Types, sizes and roles of biomolecules - metabolites, proteins, RNA, and DNA. Ranges of cell sizes and interdivision time scales,. Ranges of organism sizes and lifetimes, Scaling laws in biology, Complexity of living systems, Timeline of life on Earth,Time scales in biological evolution.

Unit II **(13 lectures)**

Cellular dynamics: Dynamical systems, Coupled ordinary differential equations, Experiments on cellular physiology, Phenomena and models of intracellular chemical dynamics, metabolism and gene regulation, cell growth and division.

Unit III **(8 lectures)**

The brain: Dynamics of a single neuron, Neural networks, Learning, Memories as attractors of neural network dynamics.

Unit IV **(6 lectures)**

Ecosystems: Growth of a bacterial colony, Ecological interactions, Lotka-Volterra and other ecological dynamics, models of ecosystems.

Unit V **(8 lectures)**

Information in living systems: Probability, entropy and information, Applications of information theory in genetics, neuroscience, and ecology.

Course Learning Outcomes

Gain knowledge of structures and processes in living systems at multiple length and time scales, including at the level of molecules, cells, multi-cellular organisms and ecosystems, Appreciate that life is a consequence of physical processes at the molecular level. Learn certain mathematical methods of dynamical systems, probability and information theory. Be able to apply these methods to model certain biological phenomena.

Suggested Readings

1. *Physics in Molecular Biology*, Kim Sneppen and Giovanni Zocchi (CUP 2005).

2. *Biological Physics: Energy, Information, Life*, Philip Nelson (W. H. Freeman &Co, NY, 2004).
3. *Biophysics: Searching for Principles*, William Bialek (Princeton University Press, 2012).
4. *Physical Biology of the Cell (2nd Edition)*, Rob Phillips et al (Garland Science, Taylor & Francis Group, 2013).

5. *An Introduction to Systems Biology*, Uri Alon (Chapman and Hall/CRC, 2013).
6. *Mathematical Biology: I. An Introduction*, J. D. Murray (3rd Ed., Springer, 2004).

Prerequisites for the course: Student should have taken Mathematics as a subject in high school (Class XI and XII).

MASTER of SCIENCE in PHYSICS

Semester IV

Course Code: PH-OT592

Course Name: Physics Education

Marks: 100 **Duration: 60 Hrs (45L+ 15T)**

Course Objectives

This Discipline Specific Elective Course will develop pedagogic knowledge for teaching-learning of physics informed by global best praxis. It will delineate procedural and content knowledge for meaningful laboratory work; and design of appropriate technology enhanced active learning environments.

Contents:

Unit I **(5 lectures)**

Foundations of Teaching-Learning of Physics: Goals of physics teaching. Beliefs and Epistemological Expectations and how they impact teaching-learning of physics. Theoretical models of student learning. Structure of knowledge. Difference between novice learners and experts. Theories of cognition. Constructivist and social theories of learning. Guided Enquiry and Active Learning. Engendering cognitive change.

Unit II **(12 lectures)**

Effective Teaching-Learning Strategies: Models of Classroom. Traditional instructor centred environment vs Active engagement student centred environment. Physics Education Research (PER): What works and what does not work. Designing Lecture based effective instruction methods: Concept Tests; Peer Instruction; Interactive Lecture demonstrations; Just in Time Teaching; Interactive Tutorials; Cooperative Problem Solving. Modeling. Problem Solving. Enhancing learning through peer, group and collaborative work. Cognitive Apprenticeship. Research-based curricula: Developing hands-on activities. Developing Interactive worksheets/Tutorials.

Unit III **(12 lectures)**

Evaluating Conceptual Learning: Formative and Summative evaluation. Designing examinations. Types of questions: MCQ, Representation-translation questions, ranking tasks, context-based reasoning problems, estimation problems, qualitative questions, essay questions. Domain knowledge content surveys and concept probes (Mechanics, Electricity and Magnetism, Vectors, Quantum Mechanics etc).

Unit IV **(10 lectures)**

Learning in the Lab: Students understanding of nature of scientific investigation and its influence on lab work. Student's perception of concepts of statistics, errors of observation, reliability and validity of observations; graphical representation of data and impact on performance. Developing Procedural and Conceptual Knowledge (PACK) in the Laboratory. Learning to design open-ended experiments and verify hypotheses. Assessment of performance.

Unit V **(6 lectures)**

Technology Enhanced Learning Environments: Appropriate use of technology. Developing Demonstration experiments and hands-on activities for conceptual learning. Sensor based Data Acquisition Laboratories. Integrating Simulations, Visualization, Video, Modeling for conceptual learning. Designing Technology Enhanced Active Learning. Future of classroom.

Course Learning Outcomes

Understanding theoretical framework of how students learn; familiarity with range of effective strategies for teaching-learning; evaluating and enhancing student's conceptual understanding of physics and problem solving abilities; developing effective learning in the lab and open-ended investigations; designing technology enhanced active learning environments;. Designing effective assessment and evaluation tools for student learning; developing innovative teaching-learning resources and curricula.

Suggested Readings

1. *Teaching Introductory Physics*, Arnold Arons (John Wiley and Sons, Inc., 1997)
2. *Teaching Physics with the Physics Suite*, Edward F. Redish (John Wiley and Sons Inc., 2003)
3. *Teaching and Learning in the Science Laboratory*, Dimitris Psillos and Hans Niedderer (Editors) (Kluwer Academic Publishers, 2002)
4. *Understanding Basic Mechanics*, Frederick Reif (John Wiley and Sons Inc., 1995)
5. *Peer Instruction*, Eric Mazur (Prentice Hall. 1997)
6. *Physics by Inquiry. Vol. I and II.*, Lillian C. Mc Dermott (John Wiley and Sons Inc., 1996)
7. *Workshop Physics. The Physics Suite. Priscilla*, W. Laws (John Wiley and Sons Inc., 2004)
8. *Real Time Physics Active Learning Laboratories. The Physics Suite*, David R. Sokoloff, Ronld K. Thornton, Priscilla W. Laws (John Wiley and Sons Inc., 2004)
9. *Activity Based Tutorials. The Physics Suite*, Michael C. Wittmann, Richard N. Steinberg, Edward F. Redish and the University of Maryland Physics Education Research Group (John Wiley and Sons Inc., 2004)
10. *Tutorials in Introductory Physics*, Lillian C. Mc Dermott, Peter S. Shaffer and the Physics Education Research Group (John Wiley and Sons Inc., 2003)
11. *Modelling in Physics and Physics Education, Proceedings of the GIREP Conference 2006*. Ed van den Berg, Ton Ellermeijer and Onne Slooten. GIREP 2006.
12. *Five Easy Lessons: Strategies for Successful Physics Teaching*, Randall D. Knight.

Prerequisites for the course: Student should have taken Physics as a one of subject in Graduation (B.Sc.).