SYLLABUS

For

M. Sc.

in

PHYSICS

(Effective from the academic session 2020 – 2022 and onwards)

DEPARTMENT OF PHYSICS

THE UNIVERSITY OF BURDWAN

THE UNIVERSITY OF BURDWAN
SYLLABUS FOR
EFFECTIVE FROM 2020 – 2022 SESSION

Course Structure in Physics

1 credit = 1 hour/week for theory; 2 hours/week for practical

Duration of examination for a course of 4 credits will be 2 hours for theory papers and 4 hours for practical papers.

SEMESTER – I (TOTAL MARKS 300) (CREDIT 24)

Course				Marks			Credit
Course code	Type	T/P	Name	I.A.	E.T	Total	
MSPH101	Core	T	Mathematical Methods	10	40	50	4
MSPH102	Core	T	Classical Mechanics, General Relativity &Astrophysics	10	20 20	50	4
MSPH103	Core	T	Quantum Mechanics	10	40	50	4
MSPH104	Core	T	Classical Electrodynamics	10	40	50	4
MSPH105	Core	P	Practical-I	10	40	50	4
MSPH106	Core	P	Practical-II	10	40	50	4
				Total credit			24

I.A.: Internal Assessment, E.T.: End Term

SEMESTER – II (TOTAL MARKS 300) (CREDIT 24)

Course				Marks			Credit
Course code	Type	T/P	Name	I.A.	E.T	Total	
MSPH201	Core	T	Atomic Spectroscopy & Laser physics	10	20 20	50	4
MSPH202	Core	T	Solid State Physics	10	40	50	4
MSPH203	Core	T	Nuclear & Particle Physics	10	40	50	4
MSPH204	Core	T	Electronics	10	40	50	4
MSPH205	Core	P	Practical-I	10	40	50	4
MSPH206	Core	P	Practical-II	10	40	50	4
				Total credit			24

SEMESTER – III (TOTAL MARKS 300) (CREDIT 24)

Course				Marks			Credit
Course code	Type	T/P	Name	I.A.	E.T	Total	
MSPH301	Core	T	Statistical Mechanics	10	40	50	4
MSPH302	Core	T	Group Theory &Nonlinear dynamics	10	20 20	50	4
MSPH303	Core	P	Advanced General Practical	10	40	50	4
MSPH304 Or MSWM304	GE	T	MSPH304: Condensed Matter & Nano Physics MSWM304: May be opted from SWAYAM	5	20	25	2
MSPH305	DE	T	MSPH305-1: Advanced Electronics-I MSPH305-2: Laser Physics-I MSPH305-3: Materials Science-I MSPH305-4: Condensed Matter Physics-I MSPH305-5: Nuclear & Particle Physics-I MSPH305-6: Astrophysics & Cosmology-I	10	40	50	4
MSPH306	DE	T	MSPH306-1: Applied Electronics MSPH306-2: Advanced Solid State Physics MSPH306-3: Materials Physics MSPH306-4: Selected Topics in Nuclear & Particle Physics MSPH306-5: Lasers and Laser Spectroscopy MSPH306-6: Special Topics in General Relativity and Astrophysics MSPH306-7: Relativistic Quantum Mechanics& Quantum Field Theory MSPH306-8: May be opted from SWAYAM	10	40	50	4
MSPH307	Core	P	Community Engagement Activities (CE)	5	20	25	2
				Total credit			24

DE: Discipline-centric Elective; GE: Generic Elective

STUDENTS HAVE TO CHOOSE EITHER 'ADVANCED ELECTRONICS-I' OR 'LASER PHYSICS-I' OR 'MATERIALS SCIENCE-I' OR 'CONDENSED MATTER PHYSICS-I' OR 'NUCLEAR & PARTICLE PHYSICS-I' OR 'ASTROPHYSICS & COSMOLOGY-I' IN MSPH305

The following are the options for students for MSPH306 As per their choice in MSPH305:

Opted as DE (MSPH305)	DO NOT OPT FOR
Advanced Electronics-I	MSPH306-1: Applied Electronics
Laser Physics-I	MSPH306-5: Lasers & Laser Spectroscopy
Materials Science-I	MSPH306-3: Materials Physics
Condensed Matter Physics-I	MSPH306-2: Advanced Solid State Physics
Nuclear & Particle Physics-I	MSPH306-4: Selected Topics in Nuclear & Particle Physics
Astrophysics & Cosmology-I	MSPH306-6: Special tropics in General Relativity and Astrophysics

SEMESTER – IV (TOTAL MARKS 300) (CREDIT 24)

Course				Marks			Credit
Course code	Type	T/P	Name	I.A.	E.T	Total	
MSPH401	Core	T	Molecular Spectroscopy	10	40	50	4
MSPH402	Core	T	Advanced Quantum Mechanics &Computational Physics	10	20 20	50	4
MSPH403	Core	P	Advanced General Practical	10	40	50	4
MSPH404	DE	T	MSPH404-1: Advanced Electronics-II MSPH404-2: Laser Physics-II MSPH404-3: Materials Science-II MSPH404-4: Condensed Matter Physics-II MSPH404-5: Nuclear & Particle Physics-II MSPH404-6: Astrophysics & Cosmology-II	10	40	50	4
MSPH405	DE	T	MSPH405-1: Advanced Electronics-III MSPH405-2: Laser Physics-III MSPH405-3: Materials Science-III MSPH405-4: Condensed Matter Physics-III MSPH405-5: Nuclear & Particle Physics-III MSPH405-6: Astrophysics& Cosmology-III	10	40	50	4
MSPH406	Core	P	Term paper/ Project	10	40	50	4
				Total credit			24

The following are the options for students for Discipline-centric Electives in Semester-IV as per their choice in Semester-III:

Opted in Semester-III	**Option to be offered in Semester-IV**
Advanced Electronics-I	Advanced Electronics-II & Advanced Electronics-III
Laser Physics-I	Laser Physics-II & Laser Physics-III
Materials Science-I	Materials Science-II & Materials Science-III
Condensed Matter Physics-I	Condensed Matter Physics-II &Condensed Matter Physics-III
Nuclear & Particle Physics-I	Nuclear & Particle Physics-II &Nuclear & Particle Physics-III
Astrophysics & Cosmology-I	Astrophysics & Cosmology-II &Astrophysics & Cosmology-III

SEMESTER – I

Course code: MSPH101 (Mathematical Methods)

1. (a) Functions of a complex variable. Brief review of the topics included in the honours syllabus: analytic functions, Cauchy-Riemann equations, integration in the Complex plane, Cauchy's theorem, Cauchy's integral formula.

(b) Proof of Taylor and Laurent expansions. Singular Points and their classification. Branch point and branch cut. Riemann sheets. Application of residue theorem to the evaluation of definite integrals and the summation of infinite series. Integrals involving branch point singularity.

2. Fourier and Laplace transforms. Inverse transforms. Convolution theorem. Solution of ordinary and partial differential equations by transform methods.

3. Green's functions for ordinary and partial differential equations of mathematical physics. Integral equations. Fredholm and volterra equations of the first and second kinds. Solution of integral equations by using Integral transforms, Generating functions, Neumann series, Separable (degenerate) kernels methods. Hilbert – Schmidt theory.

4. Linear vector spaces. Subspaces. Bases and dimension. Linear independence and orthogonality of vectors. Gram-Schmidt orthogonalisation procedure. Matrix representation. The algebra of matrices. Special matrices. Rank of a matrix. Elementary transformations. Elementary matrices. Equivalent matrices. Solution of linear equations. Linear transformations. Change of Basis. Eigenvalues and eigenvectors of matrices. The Cayley-Hamilton theorem. Diagonalisation of matrices. Bilinear and Quadratic forms. Principal axis transformation. Functions of matrices. Powers of a matrix. Roots of a matrix. Exponential of a matrix. Logarithm of a matrix.

5. Tensor analysis. Coordinate transformations. Scalars. Covariant and Contravariant tensors. Addition, subtraction, outer product, inner product and contraction. Symmetric and antisymmetric tensors. Quotient law. Metric tensor. Conjugate tensor. Length and angle between vectors. Associated tensors. Raising and lowering of indices. Tensor calculus. Differentiation of a tensor. The Christoffel symbols and their transformation laws. Covariant derivative of tensors.

Books Recommended:

1. M. R. Spiegel (Schaum's outline series) – Theory and Problems of Complex Variables.
2. George B. Arfken and Hans J. Weber (Academic Press) – Mathematical Methods for Physicists.
3. J. Mathews and R. I. Walker (Benjamin) – Mathematical Methods of Physics.
4. P. Dennery and A. Krzywicki (Harper and Row) – Mathematics for Physicists
5. W. Joshi (Wiley Estern) – Matrices and Tensors

<u>Learning outcomes</u>

Mathematical Methods are very essential for solving advanced problems in physics. After successful completion of this course, the student will be able to know the complex variables in solving physical problems. They will learn about the fundamentals and applications of Fourier and Laplace transforms, their inverse transforms and convolution theorem. The student is expected to become familiar with the method of Green's function to solve linear differential equations with inhomogeneous term. They will get knowledge to find solutions of integral equations by using different methods. The students will acquire the concepts of linear vector spaces and special type of matrices that are relevant in physics. They will also get knowledge of the tensor analysis and tensor calculus for formulating and solving problems in areas of physics.

Course code: MSPH102

Classical Mechanics

An overview of the Lagrangian formalism

Variational principle and review of Lagrangian formalism in mechanical systems with dissipation and for systems subject to non-holonomic constraints, Hamiltonian for relativistic particles.

Canonical Transformation:

Equations of point and Canonical transformations; generating functions; examples of canonical transformation; group property; Integral variants of Poincare; generators of infinitesimal symmetry transformation; Noether’s theorem, Lagrange and Poisson brackets and their applications; Invariance of Poisson bracket under canonical transformation; Equations of motion in Poisson Bracket; Conservation theorems, Jacobi’s identity and angular momentum relations in Poisson brackets; Liouville’s theorem.

Hamilton-Jacobi Theory:

Hamilton-Jacobi equation for Hamilton’s principal and characteristics functions; Physical significance of these functions; Application of Hamilton-Jacobi equation in linear harmonic oscillator, particle falling under gravity etc; action and angle variables; importance of action-angle variables; Applications of action-angle variables; Kepler problem-Staekel condition, Canonical perturbation theory. Passage from classical to quantum mechanics.

Rigid body motion:

Euler’s theorem, Euler angles, Infinitesimal rotation. Heavy symmetrical top with one point fixed on the axis. Fast and sleeping top.

Elements of Fluid Mechanics and Navier-Stokes Equation

Books Recommended:

1. Classical mechanics-Goldstein
2. Introduction to advances dynamics-McCuskey
3. Mechanics- Landau and Liftshitz.
4. Classical Mechanics- K.C. Gupta
5. Classical Mechanics- Rana and Jog

<u>Learning outcomes</u>:

Following core areas of Classical Mechanics will be learnt by students in a systematic manner:

(a) A thorough review of Limitations of Newtonian Mechanics, concept of Virtual displacement along with Virtual work, and different aspects of Lagrangian formulation.

(b) In the second phase of this course students acquire the knowledge of different features of Hamilton's Principle and Hamilton's formulation to develop the foundation of Canonical Transformation.

(c) In the third phase students obtain the thorough understanding of Action-Angle variable and Hamilton-Jacobia formalism. The transition from Classical to quantum concept has also been introduced rigorously.

(d) Parall,elly the students are also acquainted with the concept of formulation of the equation of rigid body dynamics and demonstration of different examples of non-inertial frames of references. In this direction fluid mechanics is also taught to these students along with the knowledge of fundamental and systematic understandings of basic physics.

(e) At the end of the Course, the students are able to develop their potential to solve basic problems of different competitive examinations like UGC-NET CSIR, GATE, SET, etc. including the problems of Masters level. The students are confident to apply techniques for analyzing the typical problems encountered in the subject.

(f) It has been observed that the students are able to enhance their potential to apply Course specific knowledge, including self-directed research in the scientific literature.

(g) The subject is aimed at giving the basic knowledge for accomplishment in diverse directions of Classical Mechanics.

General Relativity and Astrophysics

1. Brief review on Minkowski's Four Dimensional Space-time.

2. Tensor calculus and curved space:

Vectors and Tensors, Idea of parallel transport and covariant derivatives, covariant derivative of $g_{\mu\nu}$, Geodesics, Curvature tensor and its properties, Bianchi Identities, Ricci tensor, Einstein tensor.

3. Einstein's equation of Gravity:

Principles of equivalence, Principle of general covariance, Metric tensors and Newtonian Gravitational potential, Logical steps leading to Einstein's equations of gravitation, Weak gravitational field approximation.

4. Applications of general relativity:

Schwarzschild's exterior solution, singularity, event horizon and concept of black holes, Birkhoff's theorem, Observational tests of Einstein's theory – Bending of light rays in a gravitation field, Gravitational Red shift, Precession of Perihelion of the planet Mercury.

5. Stellar Structure and Evolution:

Star formation, Stellar Magnitudes, Classification of stars: H-D classification, Hertzsprung-Russell (H-R) diagram: Pre-main sequence evolution, Post main sequence stage; Equations of stellar structure. Virial theorem and it's application in stellar physics

6. Cosmology:

Expanding Universe, Cosmological Principles, Weyl postulate, Hubble's law. Robertson-Walker metric (derivation is not required), Cosmological parameters, Static Universe, Cosmic Microwave Background Radiation.

Books Recommended:

1. A short course in General Relativity, J. Foster and J. D. Nightingle (Longman Inc., New York, 1979)
2. Introduction to Cosmology – J. V. Narlikar (Cambridge University Poress)
3. General Relativity, Astrophysics and Cosmology, A. K. Raychaudhuri, S. Banerji and A. Banerjee (Springer-Verla, 1992)
4. General Relativity and Cosmology, S. Banerji and A. Banerjee (Elsevier, 2007)
5. General Relativity and Cosmology, J. V. Narlikar (MacMillion, 1978)
6. An Introduction to Relativity, J. V. Narlikar (Cambridge University Poress, 2010)
7. Introduction to Theory of Relativity, P. G. Bergmann (Prentice-Hall, 1969)
8. Introduction to Special Theory of Relativity, R. Resnick (John Wiley & Sons, New York, 1998)
9. The Special Theory of Relativity, S. Banerji and A. Banerjee (Prentice Hall of India, 2002)
10. Textbook of astronomy and astrophysics with elements of cosmology, V. B. Bhatia, (Narosa publishing house, 2001)

Learning outcomes

The syllabus contained in this unit is designed in such a way that the academic standard of this course must ensure the global competitiveness, and to facilitate student/graduate mobility for further higher study. In this course students learn about the physics of space-time if we include gravity that is absent in under graduate Special Theory of Relativity (STR). In this course students also learn the applications how the methodology of the basic conception of GTR can be used and applied to understand the Astrophysics and the basic of Cosmology.

Course code: MSPH103 (Quantum Mechanics)

Operator Algebra:

Vector space, concept of state vectors, principle of superposition of states, basis functions, change of basis, Ket vector and its characteristics, Bra vector and its characteristics, orthonormility, completeness condition and closure property, Hilbert space, Hermitian adjoint operator, Hermitian operator, Fundamental postulates of Quantum mechanics, eigenvalue equation, Real eigenvalues of Hermitian operator, orthogonality of eigenkets for non-degenerate eigenvalues for Hermitian operator, expectation value, projection operator, theorems of commutations of two operators, Uncertainty relation between two canonically conjugate operators using the concept of expectation value, Closure property for continuously varying Kets. Unitary operator and its characteristics, relation between wave function (Ψ) and state vector $I\Psi$>, operator representation of position and momentum, relation between $\Psi(x)$ and $\Psi(p)$. Use of operator algebra for finding the angular momentum of electron in a spherically symmetric potential. Angular wave functions of the electron in a hydrogen like atom.

Stationary states problem: (a) one dimensional problem, (b) δ function potentials and barriers, (c) three dimensional problems- spherical oscillator, Hydrogen problem.

Harmonic oscillator with operator algebra:

Creation and annihilation operators, Oscillator algebra, Hamiltonian of harmonic oscillator in terms of creation and annihilation operators, Number operator, solution of energy eigenvalues, Selection rule, solution of wave functions, Coherent state, Coherent state as a normalized state, Coherent state is a state of minimum uncertainty product of position and momentum.

Angular momentum, Generator, Symmetry: General formalism of angular momentum**,** Matrix representation of angular momentum operators, Rotation and angular momentum, Spin angular momentum, Pauli spin matrices, Rotation of spin states, Addition of two angular momentum, Clebsch-Gordan Coefficients, Applications,

Approximation methods: Time independent perturbation theory for non-degenerate (Correction of energy eigenvalues upto second order and wave functions upto first order) and degenerate states (only first order correction), Applications: Anharmonic oscillator, Stark effect in hydrogen atom, Ground state energy of Helium atom, Variational method and its applications: Ground state energy of Helium atom, WKB method and its applications, Time dependent perturbation theory: Harmonic perturbation, Fermi's golden rule, Adiabatic and Sudden approximations.

Scattering theory: Scattering of a particle by a fixed centre of force, Scattering amplitude, Differential and total cross sections, Partial wave analysis for elastic scattering: Optical theorem, Scattering by a hard sphere, Scattering from a potential well, The Born approximation: The first Born approximation, Validity of the first Born approximation, Scattering from Yukawa and Coulomb potential.

Books Recommended:

1) Quantum Mechanics by Claude Cohen-Tannnoudji, Bernard Diu, Franck Laloë (Volumes I and II).
2) Quantum Mechanics Concepts and Applications, Second Edition by NouredineZettili.
3) Quantum Mechanics by V.K. Thankappan.
4) Problems and Solutions on Quantum Mechanics, Edited by Yung-Kuo Lim.
5) Quantum Physics' by Robert Eisberg and Robert Resnick (John Wiley and sons).
6) 'Quantum Theory' by D. Bohm (Prentice-Hall).
7) 'Quantum Mechanics: Theory and Applications' by A. K. Ghatak and S. Lokanathan (Macmillan India Ltd.).
8) 'Quantum Mechanics' by L. I. Schiff (McGraw-Hill Book, New York).
9) PrabirGhosh, Quantum mechanics, Narosa Publication

Learning outcomes

Quantum Mechanics is a very important portion used in almost all branches of Physics. After going through this paper/course, the students will get knowledge how to use vector algebra in solving different quantum mechanical problems like Harmonic oscillator, Coherent states, uncertainty calculations of quantum mechanical operators. hydrogen atom problems, Unitary transformations etc. They also can find the concept of functioning Angular momentum operator in different rotational bodies (Particles). Again they will be able to get the basic knowledge in quantum mechanical approaches in scattering theory for various applications. Students will know different approximation theories also in quantum mechanical perspective for dealing various practical issues. However, this course can be considered as a bridge to proceed for the higher quantum mechanics.

Course code: MSPH104 (Classical Electrodynamics)

Green function, Inhomogeneous wave equation: it's solution. Lineard-Wiechart potentials, Fields of a uniformly moving charge, Fields of an accelerated charge: Fields, radiation (power) and angular distribution from a charge at low velocity (non-relativistic), radiation (power) from a charge at linear motion and circular motion or orbit, angular distribution of power for linearly linearly accelerated charges, relativistic correction, Bremsstrahlung-Cerenkov radiation. Radiation from a localised oscillating charges, near and far zone field, multipole expansion, dipole and quadrupole radiation, centre-fed linear antenna, classical theory of electron: radiation reaction from energy conversation: Lorentz theory, self force.

Dispersion: Dispersion and absorption: Lorentz electromagnetic theory. Kramers-Kronig relation.

Magnetohydrodynamics:

Magnetohydrodynamic (MHD) equations, magnetic, viscosity, pressure, Reynold number, etc. MHD waves. Alfven waves and velocity, Hartmann flow and Hartmann number

Plasma Physics:

(a) Orbit theory of drift motions in a plasma. Pinch effect.Instability in pinched plasma column. Plasma oscillations, short wavelength of plasma oscillation and Debye screening length

(b) Propagation of EM waves through plasma. Effect of external magnetic field on wave propagations: ordinary and extraordinary rays.

Waveguide: Wave guides and resonant cavities: Basic concept of wave guides, TE & TM modes, Rectangular waveguide, circular waveguide, resonat cavities, rectangular cavity resonator-TE, TM modes. Power loss in a cavity-Q of a cavity.

Books Recommended:

1. Marion- Classical Electrodynamics
2. Jackson- Classical Electrodynamics
3. Panofsky & Phillips- Classical Electrodynamics

4. Chen- Plasma Physics
5. Griffith-Electrodynamics

LEARNING OUTCOMES

After successful completion of this course the students will learn
(i) the fundamental of the Electrodynamics which deals with the LW potentials, radiation emitted by a charged particle in linear as well as in circular path and its applications.
(ii) they will also learn about the propagation of electromagnetic radiation through different waveguides.
(ii) they will learn about the electronic explanation of dispersion and magnetohydronamics as well as the plasma physics.

Course code: MSPH105 (Practical-I)

Group A

1. Determination of mean wavelength and separation of wavelengths of sodium light by Fabry Perot/Michelson interferometer
2. Study of dispersion relation in a periodic electrical circuit: an analog of monatomic and diatomic lattice vibrations.
3. To study the effect of magneto-striction of a given material.
4. Measurement of thickness of a thin foil by Jamin's interferometer
5. Determination of (i) Rydberg constant, (ii) ionisation potential and (iii) quantum defect of an alkali atom.

Group B

1. Study of the current mirror biasing and V_{BE} multiplier based voltage reference.
2. To draw the LDR characteristics at different intensities and to find out the “b” value and the dark resistance of the LDR.
3. Characteristics and Study of CE amplifier circuit (AC mode) with and without feedback.
4. To Study the amplitude modulation technique and determination of the modulation index.
5. To study the characteristics of an All Pass Filter using Op-Amp.

Course code: MSPH106 (Practical-II)

Group A

1. Determination of particle size by diffraction using a laser source.
2. Determination of Bohr magneton of an electron
3. To draw the plateau curve of a GM counter and hence to determine the statistical variation of counts of the GM Counter.
4. Determination of wavelength of sodium light using Lloyd's mirror.
5. Determination of Lande splitting factor by ESR Spectrometer.

Or

Measurement of transverse magnetoresistance of a semiconducting material.

Group B

1. To study the characteristics of an Op-amp based nonlinear amplifier.
2. To study the input and output voltage characteristics of Schmitt trigger circuit.
3. To study the operation of Pre-emphasis and De-emphasis circuits by plotting frequency response using Op-amp.
4. To study the characteristics of an Op-amp based RC-Phase-Shift Oscillator.
5. To study the transfer characteristics of different passive networks and the phase transfer characteristics of a given two-port network (RC).

LEARNING OUTCOMES

A number of experiments are so designed that the students have in hand experience to learn and realize the different physical processes, the focus of experiments are mainly using optical as well as non-optical phenomena. These experiences help them in involving more into the core of the subject.

All the students will be divided into two groups i.e. Group A & Group B and that will be decided by the Department

SEMESTER – II

Course code: MSPH201

Atomic Spectroscopy

Brief overview of spectra of one –electron atoms; Spectral characteristics; Relativistic correction to the energy; Spin –Orbit interaction, Fine structure of Spectral lines; Application to hydrogen like atoms; Alkali spectra and quantum defect. Lamb Shift. Hyperfine Structure and Isotope shift.

Many electron atoms: Independent particle model and central field approximation. Application to Helium atom, Singlet and triplet states of Helium. Central field approximation for many electron atom; Origin of L-S and j-j coupling, Equivalent and nonequivalent electrons; Energy levels and spectra; Branching Rule, Spectroscopic terms, Hund’s rule; Lande interval rule.

Spectra in presence of external magnetic field (Quantitative Discussion) --- Strong, moderate and Weak fields. X-ray Spectra; Fine structure. Regular and Irregular doublet Laws; Auger Effect.

Laser in Spectroscopy: Broadening of spectral lines, Absorption spectroscopy, excitation spectroscopy, ionization spectroscopy, saturation absorption spectroscopy, photo acoustic spectroscopy, Opto-galvanic spectroscopy, Tera Hertz spectroscopy.

Recommended books:

1. Introduction to Atomic Spectra by H E White, 1934, McGrawhill Books
2. Atomic and Laser Spectroscopy by Alan Corney, Clarendon Press, Oxford.

3. Lasers in Chemistry by D L Andrews, 1997, Springer-Verlag, Berlin Heidelberg.
4. Physics of Atoms and Molecules by B. H. Bransden and C. J. Joachim, 2nd Edition, 2015, Pearson Education
5. Basic Atomic and Molecular Spectroscopy by J. Michael Hollas, 2011, Royal Society of Chemistry Publication.
6. Atomic Spectra and Atomic Structure by G. Herzberg, Dover Publication, 1944

LEARNING OUTCOMES

This course gives a thorough account of the processes occurring at the atomic level. Both experimental and theoretical approaches are discussed at length. The students will have a detailed understandings of the basic processes (at the electronic level) occurring inside an atom, when it is isolated as well as when it is under a force field. Various spectroscopic techniques in the syllabus will help them in a long way to enter into research arena as well as in industrial sectors involving R&D in various fields.

Laser physics

1. Basic Laser Theory: Einstein coefficients and stimulated light amplification: population inversion, creation of population inversion in three level & four level lasers. .Rate Equations for Three-level and Four-level lasers, Optimum output power Laser pumping requirements, Temporal coherence and spatial coherence.
2. Basic Laser Systems: Gas Laser: CO_2 laser, Solid State Laser: Host material, Nd:YAG laser, Liquid laser: Dye laser, Semiconductor laser, Excimer laser, Free electron laser
3. Laser Beam Propagation: Ray transfer matrix, ABCD law, Laser beam propagation, properties of Gaussian beam, resonator, stability, various types of stable resonators, unstable resonators.
4. Nonlinear Optics: Origin of nonlinearity, anharmonic oscillator model, susceptibility tensor, phase matching, second harmonic generation, frequency mixing processes, Introduction to four wave mixing.
5. Holography: Importance of coherence, Principle of holography and characteristics, Recording and reconstruction, classification of hologram and application, holographic optical elements, non-destructive testing, Holographic interferometry,
6. Q-Switching: Principle of Q-switching, different methods of Q-switching, electro-optic Q-switching, Pockels cell
7. Integrated optics: Dielectric slab waveguide, modes in the symmetric slab waveguide, TE and TM modes, modes in the asymmetric slab waveguide, coupling of the waveguide (edge, prism, grating), dispersion and distortion in the slab waveguide, integrated optics components (active, passive), optical fibre waveguides (step index, graded index, single mode), attenuation in fibre, couplers and connectors, LED, injection laser diode (double heterostructure, distributed feedback).
8. Detection of optical radiation: Human eye, thermal detector (bolometer, pyro-electric), photon detector (photoconductive detector, photo voltaic detector and photoemissive detector), p-i-n photodiode, Avalanche Photo Diode.

Books recommended:
1. Principles of Lasers: O Svelto
2. Solid-State Laser Engineering: W Koechner
3. Optical Electronics: A K Ghatak and K Thyagarajan
4. Springer Handbook of Lasers and Optics: F Träger (Ed.)
5. Handbook of Nonlinear Optics: R L Sutherland
6. Laser and Electro-Optics: C C Davis
7. Quantum Electronics: A Yariv

Learning Outcome

1. Will be able to understand basic laser theory that includes population inversion, rate equations for three and four level lasers as well as details of temporal and spatial coherence. Furthermore, they will get familiar with different types of lasers, propagation of laser beams, properties of Gaussian beams as well as different types of laser resonators including unstable resonators. They will further learn about different methods of Q-switching to realise high peak power from suitable lasers.
2. Will be familiar with basic theory of nonlinear frequency conversion techniques. They will also understand different aspects of Holography and some of its important applications.
3. Will learn about different detectors of optical radiation and their working principles.
4. Will be familiar with dielectric slab waveguides, modes of propagation through them and different integrated optical active and passive components. They will also learn about fiber optic communication, different types of fibers, and also about fiber couplers, connectors, multiplexers etc.

Course code: MSPH202 (Solid State Physics)

1. Crystal structure and X-ray diffraction: Lattices and Unit cells, Macroscopic and microscopic symmetry elements, Point groups, Space groups, Equivalent points, Structure factor calculations of some novel metals and compounds with SC, BCC, FCC, HCP, NaCl, ZnS and diamond crystal structures, X-ray diffraction techniques, Laue, Rotation and Debye-Scherrer camera (qualitative), electron diffraction, SEM, TEM and neutron diffraction and magnetic structure.
2. Imperfection in solids: Different types of defects and dislocation, point defects and line defects, Frenkel and Schottky defects, defects by non stoichiometry; electrical conductivity of ionic crystals; classifications of dislocations; role of dislocations in plastic deformation and crystal growth; Colour centers and photoconductivity; Luminescence and phosphors; Alloys, Hume-Rothery rules; electron compounds; Bragg - Williams theory, order-disorder phenomena, superstructure lines.
3. Crystal binding: General considerations about bonding: ionic bonds, covalent bond, van der Walls-Fluctuating dipole forces-or molecular bonding, metallic bonding, hydrogen bonds

4. Magnetic properties of solids: Diamagnetism, paramagnetism – semiclassical treatment-paramagnetism for J=1/2, Brillouin function-van Vleckparamagnetism; ground state of an ion and Hund's rules, crystal field-quenching of orbital momentum, ferromagnetism-Weiss model, magnetic susceptibility, effect of a magnetic field, origin of the molecular field, antiferromagnetism-Weiss model, magnetic susceptibility, types of antiferromagnetic order, ferrimagnetism, ferromagnetic domains and domain walls, exchange interactions. Colossal and Giant magnetoresistance.
5. Magnetic resonances: Nuclear magnetic resonances, paramagnetic resonance, Bloch equation, longitudinal and transverse relaxation time; spin echo; motional narrowing in line width; absorption and dispersion; Hyperfine field; Electron-spin resonance.
6. Quantized free electron theory; Fermi energy; wave vector; velocity and temperature, density of states. Electronic specific heats. Pauli spinparamagnetism. Sommerfeld’s model for metallic conduction. AC conductivity and optical properties, plasma oscillations.Thermoionic emission. Hall effects.
7. Intrinsic and extrinsic semiconductors. carrier concentration and Fermi levels of intrinsic and extrinsic semi-conductors Bandgap. Direct and indirect gap semiconductors. Hydrogenic model of impurity levels.
8. Energy bands in solids**:** The Bloch theorem; Bloch functions; Review of the Kronig-Penney model; Brillouin zones; Band gap in the nearly free electron model;The tight binding model; Empty lattice band; Number of states in a band; Effective mass of an electron in a band: concept of holes; Classification of metal, semiconductor and insulator; Electronic band structures in solids - Nearly free electron bands; Tight binding method – application to a simple cubic lattice; Band structures in copper, GaAs and silicon; Topology of Fermi-surface; Electron dynamics in an electric field.Cyclotron resonance and determination of Effective mass. Concept of hole. Boltzmann Transort Equation, Sommerfeld theory of electrical conductivity.
9. Dielectric and optical properties of solids**:** Dielectric constant and Polarizability; Electronic, ionic, and orientational polarization; static dielectric constant of gases and solids; Complex dielectric constant and dielectric losses, relaxation time; Debye equations; Cases of distribution of relaxation time; Cole - Cole distribution parameter; Dielectric modulus; Ferroelectricity; displacive phase transition; Landau Theory of Phase Transition.
10. Phenomenological description of superconductivity: occurrence of superconductivity; destruction of superconductivity by magnetic field; Thermodynamics of superconductivity; Gibbs free energy;entropy; heat capacity; qualitative description of formation cooper pair and outline of BCS theory and BCS Hamiltonian; energy gap and its experimental evidences; Giavertunnelling; Flux quantisation; a.c. and d.c. Josephson effect; Vortex state (qualitative discussions); High Tc superconductors (information and qualitative description).

Books recommended:

1. F.C.Phillips: An introduction to crystallography (wiley)(3rd edition)
2. Charles A Wert and Robb M Thonson: Physics of Solids
3. J. P. Srivastava: Elements of solid state physics (Prentice Hall India; 2nd edition).

4. Christmaan-solid state physics (academic press)
5. A R Verma& O N Srivastava, Crystalolgraphic application to solid state physics
6. John Singleton: Band theory and Electronic properties of Solids (Oxford University Press; Oxford Master Series in Condensed Matter Physics).
7. Ibach&Luth:Solid State Physics
8. M. Ali Omar: Elementary solid state physics (Addison-wesley)
9. C. Kittel: Solid-state physics (Wiley eastern)(5th edition).

LEARNING OUTCOMES

The syllabus of this paper is composed of detailed structural characterization of some common metals, ionic crystals using X-ray, electron and neutron diffraction techniques, explicit crystal symmetries, different kinds of crystal bonding, different kinds of lattice imperfections and their correlations with optical and electrical properties. In this paper, students of SEMESTER –II will acquire the knowledge of behaviour of electrons in solids based on classical and quantum theories. Students will be able to explain how the electronic properties of solids differ in the classical free electron theory, quantum free electron theory and the nearly free electron model. Students will learn the fundamental concept of semiconductor physics. Students would be familiar with the classification of solids using band theory. After completion of this course, students will be able to classify materials like metals, insulators and semiconductors and sketch the band diagram for each. Students will be able to develop an understanding of the dielectric and optical properties of solids. Students will learn about detailed magnetic properties, dielectric properties and superconducting properties of different kinds of solids.

Course code: MSPH203 (Nuclear and Particle Physics)

1. Static and dynamic properties of nuclei: Introduction, parity and isospin of nuclei, Nuclear radius and charge distribution; Mirror nuclei, Muonic atoms and electron scattering methods, charge form factor. Magnetic dipole moment and electric quadrupole moment; Experimental determination using Rabi's method and NMR.

2. Two-nucleon problem and nuclear forces: Deuteron problem: Properties of deuteron; Solution of Schrödinger equation for deuteron ground state and excited states; range and depth of nuclear potential; deuteron radius.

Two-nucleon scattering: Partial wave analysis; phase-shift; scattering length and significance of its sign; Low and high energy n-p and p-p scattering, spin dependence, charge symmetry and charge independence of nuclear forces; Exchange nature of nuclear forces and singlet and triplet potentials; the necessity of tensor forces; Yukawa's meson theory and form of Yukawa potential.

3. Nuclear models: Need for models; Independent Particle and Strong Interaction models. Fermi gas model: Derivation of Fermi energy and ground state kinetic energy for nucleons; Shell model: Extreme single-particle model: Spin-orbit interactions and reproduction of magic numbers; Predictions of shell model (Ground state spin parity; magnetic moment-Schmidt lines and electric quadrupole moment); Single-particle model, Total spin 'J' for various configurations; electric quadrupole moment; configuration mixing; independent particle model, Nilsson model; Introduction to Collective model.

4. Nuclear reactions: Different kinds of nuclear-reactions, Direct reactions: Kinematics and theory of stripping, pick up and reverse reactions; Reciprocity theorem; experimental verification of Bohr's independence-hypothesis, resonance reactions, Breit-Wigner one-level formula, Transfer reactions; Optical model of nuclear reaction; Heavy-ion induced nuclear reaction and various phenomena.

5. Particle accelerators: Pelletron, tandem principle, Synchrotron and synchrocyclotron: strong and weak focusing types; colliding beam machines, threshold energy for particle production.

6. Beta and Gamma decay: Beta spectrum and energetics; Fermi's theory of beta decay, Columb correction and Fermi-Kurieplot; allowed and forbidden transitions, selection rules; Non-conservation of parity in beta decay: Wu's experiment; detection of the neutrino and its helicity; Gamma–decay: multipolarity and selection rules.

7. Nuclear detectors: Different mechanisms of interaction of radiation with matter; Bohr's Ionization formula, Radiation detectors – Multi-wire proportional counter (MWPC), Cerenkov detector; Scintillation detectors; solid state detectors; detection of neutrons; elementary idea about pulse height analysis.

8. Reactor Physics: Slowing down of neutrons in a moderator; average log decrement of energy; slowing down power and moderating ratio, Fermi age equation; Four-factor formula; buckling and critical size of reactors.

9. Particle physics: Classification of elementary particles; types of interaction in nature: typical strengths, range, time-scales; conservation laws, charge-conjugation, Parity and Time reversal, CPT theorem; CP violation in K^0 decay; Gell-Mann-Nishijima formula; resonances; relativistic kinematics; Symmetry classification of elementary particles: baryon and meson octet and decuplet; quark hypothesis, charm, beauty and truth, gluons, quark-confinement, asymptotic freedom.

Books Recommended:

1. Nuclear Physics- S. N. Ghoshal (S. Chand Publications)
2. Nuclear Physics- D. C. Tayal (Himalaya Publications)
3. Introductory Nuclear Physics- K. S. Krane (Wiley India)
4. Nuclear Physics: Theory and Experimental- H. S. Hans (New Age International)
5. Nuclear Physics: Theory and Experiment- R. R. Roy and B. P. Nigam (John Wiley and Sons)

LEARNING OUTCOMES

After completing the course of MSPH203, the Semester -II students will have a detailed knowledge about the basics of nuclear and particle physics. They will learn the basic properties of the nucleus as well as different methods to determine them. Also the knowledge of two nucleon scattering will give them a basic idea of nuclear force. The accelerator physics will enable them to have an idea about the different accelerators which will be useful for them if they join any accelerator based institute including the medical facilities. The idea about the detectors will enable the students about vivid knowledge regarding detection of radiation which will enable them to pursue any carrier regarding radiation measurements. The basic knowledge about elementary particles and interactions will be useful for the students for future theoretical or experimental research in high energy physics.

Course code: MSPH204 (Electronics)

Passive Networks: Four-terminal two-port network – parameters for symmetrical and unsymmetrical networks; image, iterative and characteristic impedances; propagation function; lattice network; Bisection theorem and its application.

L-C filters-LPF, HPF, BPF and BRF type constant-k prototype filters; m-derived filters (principle only), Attenuators.

High Frequency Transmission Line: Distributed parameters; primary and secondary line constants; Telegraphers' equation; Reflection co-efficient and VSWR; Input impedance of loss-less line; Distortion of em wave in a practical line.

Semiconductor Devices: (a) p-n junction physics- Fabrication steps; thermal equilibrium condition; depletion capacitance; current-voltage characteristics; charge storage and transient behavior; junction breakdown; heterojunction. (b) Characteristics of some semiconductor devices- BJT, JFET, MOSFET, MISFET, LED, Solar cell, Tunnel diode, Gunn diode and IMPATT.

Active Circuits: Transistor amplifiers- Basic design consideration; high frequency effects; video and pulse amplifier; resonance amplifier; feedback in amplifiers.

Harmonic self-oscillators - Steady state operation of self-oscillator; nonlinear equation of self oscillator; examples.

Op-Amp Based Circuits:

Characteristics of ideal and practical op-amp; Nonlinear amplifiers using op-amps- log amplifier, anti-log amplifier, regenerative comparators; Active filters; precision rectifiers; ADC and DAC circuits; Op-amp based self oscillators: sinusoidal and relaxation oscillators; Voltage regulator.

Elements of Communication Electronics: Principles of analog and Digital modulation; comparison among different techniques; power, bandwidth and noise immunity consideration; Generation of transmitted carrier and suppressed carrier type AM signals; principles of FM and PM signal generation. Principles of detection of different types of modulated signals (TC and SC types). Modulation techniques in some practical communication systems: AM and FM radio, VSB AM and QAM technique in TV broadcasting. Digital modulation: ASK, FSK, PSK.

Digital Circuits: Logic functions; Logic simplification using Karnaugh maps; SOP and POS design of logic circuits; MUX as universal building block. RCA, CLA and BCD adder circuits; ADD-SHIFT and array multiplier circuits.

Registers and counters.

Books Recommended:

1. J D Ryder, Electronics Fundamental and application, PHI
2. S.M. Sze, Physics of semiconductor devices.
3. Milman and Grable, Microelectronics. Tata MacGraw Hill.
4. B. C. Sarkar and S. Sarkar, Analog Electronics, DamodarPrakashani
5. B. C. Sarkar and S. Sarkar, Digital Electronics.
6. D. RoyChowdhuri and Jain, Analog integrated circuits, New age Publishers
7. Chattopadhyay and Rakshit, Electronic Circuit analysis
8. Roddy and Coolen, Electronic Communication systems. PHI.

LEARNING OUTCOMES

At the end of the course

1. Students will recognize the underlying physics of semiconductor devices.
2. The course enable students to solve voltage current equations in transistor and operational amplifier circuits.
3. Students will be able to understand and solve problems from digital electronics.
4. The course will develop skill to apply their knowledge in engineering fields and industry.

Course code: MSPH205 (Practical-I)

Group A

1. Determination of mean wavelength and separation of wavelengths of sodium light by Fabry Perot/ Michelson interferometer
2. Study of dispersion relation in a periodic electrical circuit: an analog of monatomic and diatomic lattice vibrations.
3. To study the effect of magneto-striction of a given material.
4. Measurement of thickness of a thin foil by Jamin's interferometer
5. Determination of (i) Rydberg constant, (ii) ionisation potential and (iii) quantum defect of an alkali atom.

Group B

1. Study of the current mirror biasing and V_{BE} multiplier based voltage reference.
2. To draw the LDR characteristics at different intensities and to find out the “b” value and the dark resistance of the LDR.
3. Characteristics and Study of CE amplifier circuit (AC mode) with and without feedback.
4. To Study the amplitude modulation technique and determination of the modulation index.
5. To study the characteristics of an All Pass Filter using Op-Amp.

Course code: MSPH206 (Practical-II)

Group A

1. Determination of particle size by diffraction using a laser source.

2. Determination of Bohr magneton of an electron
3. To draw the plateau curve of a GM counter and hence to determine the statistical variation of counts of the GM Counter.
4. Determination of wavelength of sodium light using Lloyd's mirror.
5. Determination of Lande splitting factor by ESR Spectrometer.

Or

Measurement of transverse magnetoresistance of a semiconducting material.

Group B

1. To study the characteristics of an Op-amp based nonlinear amplifier.
2. To study the input and output voltage characteristics of Schmitt trigger circuit.
3. To study the operation of Pre-emphasis and De-emphasis circuits by plotting frequency response using Op-amp.
4. To study the characteristics of an Op-amp based RC-Phase-Shift Oscillator.
5. To study the transfer characteristics of different passive networks and the phase transfer characteristics of a given two-port network (RC).

LEARNING OUTCOMES

A number of experiments are so designed that the students have in hand experience to learn and realize the different physical processes, the focus of experiments are mainly using optical as well as non-optical phenomena. These experiences help them in involving more into the core of the subject.

All the students will be divided into two groups i.e. Group A & Group B. Those students who have done Group A experiments in Semester-I will have to opt Group B experiments in Semester-II and vice versa

SEMESTER – III

Course code: MSPH301 (Statistical Mechanics)

1. Scope and aim of statistical mechanics. Transition from thermodynamics to statistical mechanics. Review of the ideas of phase space, phase points, Ensemble, Density of phase points. Liouville's equation and Liouville's theorem.

2. Stationary ensembles: Micro canonical, canonical and grand canonical ensembles. Partition function formulation. Fluctuation in energy and particle. Equilibrium properties of ideal systems: ideal gas, Harmonic oscillators, rigid rotators. Para magnetism.

3. Density matrix: Idea of quantum mechanical ensemble. Statistical and quantum mechanical approaches, Properties. Pure and Mixed states.

Density matrix for stationary ensembles.Application to a free particle in a box, an electron in a magnetic field. Density matrix for a beam of spin ½ particles. Construction of the density matrix for different states (pure and mixture) and calculation of the polarization vector.

4. Distribution functions. Bose-Einstein and Fermi-Dirac statistics. General equations of state for ideal quantum systems.

5. Introduction to ideas of cooperative and emergent phenomena, indistinguishability of identical particles in quantum many body systems, onset of Fermi and Bose statistics, statement and resolution of Gibbs paradox and the Sackur-Tetrode equation.

6. Length scales and the role of degeneracy in Statistical Mechanics, Thermal de-Broglie wavelength and interparticle spacing, onset of quantum degeneracy in energy space.

7. Ideal quantum systems:

a. Partition function of an ideal Bose gas and evaluation of number density and chemical potential: Bose-Einstein condensation and condensate fraction. Equation of state of an ideal Bose gas.

b. Properties of an ideal Fermi gas: Fermi energy, equation of state of an ideal Fermi gas, Sommerfeld Expansion, evaluation of chemical potential and specific heat of an ideal Fermi gas.

8. Strongly interacting systems:

c. Bose-Einstein Condensation of a quantum system of repulsively-interacting bosons using the Hartree approximation and the pseudopotential interaction model. Gross-Pitaevski equation and the Thomas-Fermi solution.

d. Superfluidity in Bose gases using the Gross-Pitaevski equation and the Bogoliubov approximation, Landau criterion. Transition in liquid He-4, Superfluidity in He-4.

e. Ising model. Idea of exchange interaction and Heisenberg Hamiltonian. Ising Hamiltonian as a truncated Heisenberg Hamiltonian.

f. Solution of Ising model using the mean field theory and expression for critical temperature. Thermodynamic properties of Ising model in the mean field. Expansion of free energy in the mean field approximation. Exact solution of one-dimensional Ising system. Comparison of mean field theory with exact solution in one-dimension. Peierls domain-wall argument for estimating critical temperature of Ising model in two-dimensions.

9. Phase transitions: Landau theory of phase transitions: First and Second order phase transitions, Spontaneous and Explicit Symmetry Breaking in Landau Theory. Onset of hysteresis in first order phase transitions. Critical phenomena and critical indices.

Books Recommended

1. K. Huang, Introduction to Statistical Mechanics, Taylor and Francis, 2nd Ed.
2. Silvio R. A. Salinas, Introduction to Statistical Mechanics. Springer
3. F. Reif, Fundamentals of Statistical and Thermal Physics.MacGrowHill.
4. Kadanoff, Statistical Mechanics. World Scientific.
5. L.E. Reichl, A Modern course in statistical physics, Wiley-VCH, 4th Ed.
6. R. K. Pathria and P.D. Beale, Statistical Mechanics, Academic press, 3rd Ed.
7. R. Kubo, Statistical Mechanics: An Advanced Course with Problems and Solutions, Elsevier, 1st Ed.
8. S.K. Ma, Modern Theory of Critical Phenomena, Westview Press, 1st Ed.

LEARNING OUTCOMES:

- Give an account of the relevant quantities used to describe macroscopic systems, thermodynamic potentials and ensembles.
- Give an account of the macroscopic and microscopic description of temperature, entropy and free energy and their descriptions in terms of probabilities.
- Give an account of the theory of statistical mechanics and the approximations making a statistical description possible.
- Explain statistical physics and thermodynamics as logical consequences of the postulates of statistical mechanics.
- Apply the theory to understand gases and crystals and, in addition, be able to construct microscopic models, and from these derive thermodynamic observables.
- Describe the importance and consequences of quantum mechanics for macroscopic particle systems, both for ideal gases and strongly interacting systems.
- Understand the role of cooperative physics in emergent phenomena such as quantum magnetism and phase transitions.
- Understand and appreciate the role of symmetry in facilitating universality during phase transitions in many-particle systems, as well as give an account of critical phenomena and corresponding scaling laws.
- Understand the strengths and limitations of the models used and be able to compare different microscopic models

Show an analytic and computational abilities to solve problems relevant to statistical mechanics

Course code: MSPH302

Group Theory

1. Abstract Group Theory:

Introduction to Symmetry and its role in Physics, Group postulates. Finite and infinite groups, Order of a group, Rearrangement theorem, Multiplication Table. Subgroups and Cosets, Lagrange‟s theorem, Order of an element. Conjugate elements and classes. Cyclic groups. Permutation groups, Invariant subgroups, factor groups, Generators. Isomorphism and Homomorphism; Illustrations with point symmetry groups

2. Representation theory.

Definition of representation, Faithful and unfaithful Representations, Reducible and Irreducible representations; Schur‟sLlemmas, Great orthogonality theorem and its significance; First and second orthogonality theorems of characters and its significance; Regular representation, celebrated theorem and its implication; Construction of character tables of simple groups.

3. Continuous group

Lie groups. Generators; Axial rotation group SO(2), Rotation group SO(3). Special Unitary groups SU(2) and SU(3) and their application in Physics.

4. Application in Physics

Group of Schrodinger equation and degeneracy, Reduction due to symmetry, Applications; Determination of molecular point groups for simple systems

Books Recommended:

1. Group Theory and its applications to Physical Problems by M. Hammermesh, Dover Publications
2. Group Theory and Quantum Mechanics by M. Tinkham; Dover Publications.
3. Group Theory and Chemistry by David M. Bishop, Dover Publications.
4. Elements of Group Theory for Physicists by A. W. Joshi, New Age International.
5. Chemical Application to Group Theory by F. A. Cotton, Wiley Eastern Limited.

LEARNING OUTCOMES:

Symmetry is a core area in various branches of science. The detailed discussion about the application of symmetry help students to understand the behavior of various natural phenomena in different fields in physics.

Nonlinear Dynamics

1. Dynamical System, constants of motion, phase space, fixed points. Nonlinear dynamical systems in Physics, biology, engineering, etc. Dynamical equations and Stability for linear systems. Flow defined by nonlinear systems of ODEs, linearization and stable manifold theorem. Hartman-Grobman theorem. Stability and Lyapunov functions.

Bifurcation theory: saddle-node, pitchfork, and transcritical bifurcations. Normal forms.

Applications in: laser model, magnetism, population dynamics.

2D linear flows: saddle point, nodes, foci, centers and nonhyperbolic critical points.

2D nonlinear flows: stability analysis, Conservative systems: Pendulum equation and double well potential. Applications in: Josephson junction.

2. Limit cycle oscillations and Chaos: Concept of limit cycle, Hopf bifurcation, Poincare-Bendixon theorem; role of nonlinearity: From harmonic oscillator to Van der Pol oscillator, Chaos, Lorenz equation and Rossler equation. Applications in: Chaos in electronic oscillators, chaos in Laser system.
3. Discrete time nonlinear systems: logistic map, sine circle map, linear stability analysis and the existence of 2-cycles; numerical analysis of the logistic map; universality and the Figenbaum numbers; bifurcation and chaos, intermittency, crises; Applications in: population dynamics, discrete phase-locked loop system, power electronics.
4. Dispersion, Dissipation and nonlinearity, Korteweg–de Vries (KdV) equation, solitory waves and soliton interaction, Application of KdV equation.
5. Pattern formation: Turing pattern. Reaction Diffusion theory. Diffusion driven instability.

Books Recommended:

1. Steven Strogatz. "Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering", Levant Publishers, 1994.
2. Edward Ott**,** Chaos in Dynamical Systems**,** Cambridge University Press.
3. Dominic Jordan, Peter Smith, "Nonlinear Ordinary Differential Equations: An Introduction for Scientists and Engineers" (Oxford Texts in Applied and Engineering Mathematics)
4. R. C. Hilborn, Chaos and Nonlinear Dynamics, Oxford University Press

LEARNING OUTCOMES:

At the end of the course
1. Students will recognize the impact of nonlinearity on the natural phenomena.
2. Students will be able to solve paradigmatic problems in physics that can not be solved using the conventional linear approach.
3. Students can apply the knowledge to understand the problems from biology, chemistry, and engineering.
4. Since this course is inherently interdisciplinary, therefore, it will help students for developing skills to pursue research in the multidisciplinary fields.

Course code: MSPH303 (Advanced General Practical)

List of Experiments

Group A:

I.

1. Determination of temporal coherency of a coherent (laser) light and compare it with incoherent light (sodium)
2. Study of magneto-optic effect (Faraday effect)
3. Study of electro-optic effect (Pockels effect)
4. Measurement of bending loss in a multi-mode optical Fiber.
5. Study of characterization of antenna
6. Design of active filters (a) band-pass filter, (b) all pass filters
7. Studies of nonlinear electronic circuits and design of chaotic electronic oscillator
8. Studies on LED modulation characteristics
9. Arc emission and absorption measurements using CCD based Constant Deviation Spectrometer.
10. Band gap evaluation of a semiconductor by studying temperature variation of resistance.

II. Computer Assignment: Numerical experiments and assignments

Group B:

I.

1. Study of ultrasonic diffraction using a laser
2. Study of gamma ray spectrum of radioactive nuclides with NaI (Tl) scintillators & SCA
3. Study of beta-ray absorption & determination of mass absorption co-efficient of the given absorber material.
4. Study of gamma-ray absorption & determination of gamma ray energy
5. Determination of particle size of an unknown powder specimen using Scherrer equation from supplied XRD pattern
6. Phase identification of an unknown sample from its X-ray diffraction pattern
7. Identification of liquid, solid or powder samples using Laser Raman Spectrometer.
8. Study of NMR.
9. Intensity dependent nonlinear susceptibility of nonlinear liquid by Z-Scan technique.
10. Determination of grove spacing of a CD by diffraction method and hence determination of wavelength of unknown source.

II. Computer Assignment: Numerical experiments and assignments

LEARNING OUTCOMES

This course contains some state of the art experiments for introducing students to the modern research laboratories. The students are highly benefited from these experiments some of which are even used by our research scholars. This course contains experiments from different areas in Physics which enables students to have an overall exposure to the advanced level of equipments and technologies.

All the students will be divided into two groups i.e. Group A & Group B and that will be decided by the Department

Course code: – MSPH304

General Elective (GE) (Condensed Matter & Nano Physics)

1. Structure of Matter (bulk and nano): Amorphous, crystalline, crystals, polycrystals, symmetry, Unit Cells, Crystal Structures (Bravais Lattices), Crystallographic Directions, Crystallographic Planes, Miller Indices, Single Crystal and Powder X-ray Diffraction, Structure factor, determination of some simple structures.
2. Microstructural and electrical characterization of nanomaterials: X-ray diffraction, theory and method of particle size analysis, Scherrer equation, electron microscopy, (SEM, TEM).
3. Magnetic Properties: Fundamentals of magnetism, Different kinds of magnetism in nature: Dia, Para, Ferro,Antiferro, Ferri, Superpara. Important properties in relation to nanomagnetism.Spinel ferrites, Application of Mössbauer spectroscopy in nanocrystalline ferrites.
4. Dielectric and ferroelectric properties: Dielectric constant, electric polarization, polarizability, different sources of polarizability, spontaneous polarization and ferroelectricity.
5. Superconductivity: Survey of important experimental results. Critical temperature, Meissner effect. Type I and type II superconductors, isotope effect, thermodynamics of superconducting transition, High-Tc superconductors.

Books recommended:

1. Ibach&Luth: Solid State Physics
2. M. Ali Omar: Elementary solid state physics (Addison-wesley)
3. C. Kittel: Solid-state physics (Wiley eastern)(5th edition).
4. J. P. Srivastava: Elements of solid state physics (Prentice Hall India; 2nd edition).
5. Christmaan-solid state physics (academic press)
6. A R Verma& O N Srivastava, Crystalolgraphic application to solid state physics
7. S. Chikazumi: Physics of Magnetism.

Learning outcome

The general elective paper is opted by students of other disciplines. Primarily students from different science disciplines (apart from Physic) will go through the paper. They will get a flavor of some important areas of physics which can help them in their future research.

Course code: MSPH305

Discipline Specific Elective (DE)

MSPH305-1: Advanced Electronics-I

1. Microwave Devices: Problems of microwave generation in conventional oscillators.
2. Vacuum tube devices : Klystron and Reflex Klystron , Magnetrons, Slow wave structure and Travelling wave tubes,
3. Solid state devices : Gunn diode, Impatt, Trapatt ,High speed transistors.
4. Optical Devices: Laser and Laser resonator, LEDs, Photodiodes, Photo conductor. Quantum well laser.
5. Microwave measurements (Frequency, power, impedance).
6. Optical modulator: Electro optics modulation (amplitude and phase).
7. Optical coupler: Coupling of light from one fiber to other with the use of evanescent wave
8. Analysis of networks and systems: Sample data system. Z- transform, Fourier and Laplace transforms.
9. Microwave Transmission lines and Waveguides: Transmission lines, Standing wave ratio, Quarter wave transformer, Smith Chart, Stub matching. Wave guides coaxial, rectangular and cylindrical; Waveguide attenuation, Resonators.
10. Antenna theory: Antennas-dipole, Antenna arrays, reflectors, steering strip, microstrip and coplanar structure.
11. Feed back control systems: Feed back system, stability, performance criteria, servo systems, automatic control principle.

Books Recommended

1. P. Bhattacharya - Semiconductor opto electronics devices.
2. R E Collin - Foundations of Microwave engineering.
3. S.Y.Liao – Microwave Devices on circuits.
4. J. Ryder – Networks, Lines and Field.
5. A. Papoulis – Signal Analysis
6. Electronic and Radio Engineering – F. E Terman.
7. Microwaves – K . C. Gupta.
8. Optoelectronics andFibre Optic Communication –C. Sarkar.
9. Photonics – A. Yariv and P. Yeh.

LEARNING OUTCOMES:

In Electronic Communication Microwave is a very important signal used for various long distance and reliable communications. After going through this paper Students can know various types of developing of Microwave sources (like Klystron, Reflex Klystron, Magnetron, Gunn diode, Advanced Bipolar transistors etc.) as well as Microwave Detectors. They can also get knowledge on the advantages of Optical communications in modern days and hence they will get ideas of developing different Optical/Optoelectronic sources and high-speed detectors in optical regime. Again they can get the concepts of high s[peed Electro-optic switching operations. At the same time the Students will gather knowledge on working principle of Transmission lines and wave guides, Antenna etc.

MSPH305-2: **Laser Physics –I**

1. Basic Laser Principle: Quantum theory for evaluation of the transition rates and Einstein A and B coefficients, allowed and forbidden levels-metastable state; population inversion; rate equations for three level and four level lasers, threshold of power calculation, various broadening mechanism, homogeneous and inhomogeneous broadening Lamb dip and active stabilization of laser frequency

2. Basic Laser System: Basic concept of construction of laser system, various pumping system (incoherent and coherent), pumping cavities for solid state laser system, characteristics of host materials and doped ions.

3. Optical beam propagation: Paraxial ray analysis, wave analysis of beams and resonators, propagation and properties of Gaussian beam, Gaussian beam in lens like medium, ABCD law, Gaussian beam focusing, M^2 parameter.

4. Resonators: Stability of resonators,'g' parameters, various types of stable resonators, evaluation of beam waist of such combination, design aspect of resonator for various types of lasers, unstable resonator and their application, Ring Resonator.

5. Q-switching: Different active and passive Q-switching techniques: mechanical Q-switching, electrooptic Q-switching, Pockels and Kerr Q-switching, acousto-optic Q-switching, dye Q-switching, Raman-Nath effect. Brief idea on giant pulse theory.

6. Ultrafast Phenomenon: Principle of generation of ultrafast pulses, Mode-locking: pico second and femtosecond pulse generation, Basic concepts for measurement of fast processes, Streak technique, Stroboscopes, sampling technique, nonlinear optical methods for measuring ultrashort pulses

7. Different laser systems:

Gas Laser: (i) molecular gas lasers- CO_2 laser & N_2laser; (ii) ionic gas laser – Ar^+ laser
(iii) gas dynamic laser; (iv) high pressure pulsed gas laser

Solid State Laser: (i) Nd:YAG laser, (ii) Nd:Glass laser, comparison of performances
(iii) Tunable solid state laser: Ti:sapphire laser; Alexandrite laser

Chemical Laser: HF laser, HCl laser

Excimer laser; Fibre laser**,** Free electron laser; semiconductor laser

Books Recommended:

1. Principles of lasers- O Svelto
2. Solid State Laser Engineering- W Koechner
3. Quantum Electronics- A Yariv
4. The Physics and Technology of Laser Resonator- D R Hall & P E Jackson
5. Introduction to optical electronics- K A Jones
6. Gas laser- A J Boom

LEARNING OUTCOMES:

On successful completion of the course, the students:
1. Will be able to describe requirements for a system to act as a laser and how lasers work.
2. Will have good understanding on design aspect of different kinds of resonators for various types of lasers and thus will be able to differentiate the various types of lasers and their means of excitation.
3. Will have the knowledge of getting high energy as well as high peak power from suitable lasers.
4. Will be able to explain how ultrashort pulses are generated and how to confirm their pulse widths and some important applications of ultrashort pulses from a laser.

MSPH305-3: Materials Science-I

Applied crystallography in materials science
Noncrystalline and semicrystalline states, Lattice. Crystal systems, unit cells.Indices of lattice directions and planes.Coordinates of position in the unit cell, Zones and zone axes.Crystal geometry. Symmetry classes and point groups, space groups. Glide planes and screw axes, space group notations, Equivalent points. Systematic absences, Determination of crystal symmetry from systematic absences.Stereographicprojections.Standard projection of crystals.
Introduction to materials
Classification of materials: Crystalline & amorphous materials, high T_c superconductors, alloys & composites, semiconductors, solar energy materials, luminescent and optoelectronic materials, Polymer, Liquid crystals and quasi crystals, Ceramics.
Preparation techniques of materials
Preparation of materials by different techniques:Sol-gel, polymer processing. Preparation of ceramic materials.
Synthesis of nanomaterials
Top down and bottom up approaches of synthesis of nano-structured materials, nanorods, nanotubes/wire and quantum dots. Fullereness and tubules, Single wall and multiwall nanotubes.
Phase transition in materials
Solid solutions, Phases, Thermodynamics of solutions, Phase rule, Binary phase diagrams, Binary isomorphous systems, Binary eutectic systems, ternary phase diagrams, kinetics of solid reactions.Order disorder phenomenon in binary alloys, long range order, super lattice, short range order.

Books Recommended:

1. Materials science and Engineering by *V. Raghavan*, Prentice-Hall Pvt. Ltd.
2. Thin Solid Films by *K. L Chopra*
3. Elements of X-ray diffraction by *B. D. Cullity*, Addison-Wesley Publishing Co.
4. Elements of crystallography by *M. A. Azaroff*
5. Engineering Materials by *Kenneth G. Budinski*, Prentice-Hall ofIndia Pvt. Ltd.

LEARNING OUTCOMES:

This syllabus has been designed for Materials Science students to get them acquainted with the detailed crystal structures of various crystalline materials like metals, alloys, intermetallics, composites, compounds, polymers, liquid crystals, ceramics, quasicrystals, nanocrystals, and graphene etc. These materials are being used in different kinds of present-day applications. Emphasis has been given to the identification, synthesis of materials by various physical and chemical routes. As the crystal structure directly impacts different physical and chemical properties, emphasis has also been given to the deep understanding of crystal structure to establish structure-property correlations. The knowledge of crystallography will lead the students to identify the crystal structures, help to synthesize a variety of materials with desired properties. Students will learn to synthesize materials of different kinds with improved and new properties and will be able to interpret the results in terms of structural modifications/changes.

MSPH305-4: Condensed Matter Physics-I

Diffraction of x-rays by crystals - Scattering of X-rays by an atom and by a three dimensional crystal, Laue equations, Bragg's law, Ewald construction, Width of diffraction maxima, Crystal structure factor, Space group extinctions, Patterson function, Effect of temperature on the intensity of Bragg reflections, Debye-Waller factor.
Crystal defects- Lattice imperfections, Vacancies and interstitial defects, Dislocations, Crystal growth, Color centers.
Alloys and Solid Solutions - Structure of metals and solid solutions, Hume Rothary rules, Order-disorder phenomena in binary alloys, Long-range and short-range order, Elementary theory of ordering, Super-lattice lines.
Crystal elasticity - Generalized Hooke's law, Strain energy density function Cauchy relations, Propagation of elastic waves through cubic crystals, Determination of elastic constants.
Band theory and dynamics of an electrons in a crystal: Electrons in periodic potential and single particle Schrödinger equation for all electrons, Bloch electrons and band structure**, O**rthogonalized plane waves (OPW); Phillops-Kleinman's cancellation; Augmented plane waves (APW); Core States and the Pseudopotential; dynamics of electrons; Wannier functions and equations of motion in Wannier representation.
Electrons in magnetic field and the Fermi Surface: Model Hamiltonian and its digonalization; Landau levels, quantization of orbits and its degeneracy; Cyclotron resonance and electron sapin resonance; filling factor and quantum Hall effect; Density of states; Fermi surface and its experimental determination; Pauli spin paramagnetism; Landau Diamagnetism; the de Haas-van Alphen effect.
Dielectric and Ferroelectrics – Ferroelectricity Piezoelectricity, Pyroelectric materials, Nature of phase transitions: Order-disorder, Polarization catastrophe, Landau Theory.

Nanostructured system: Properties of nanoparticles; quantum wells, wires, quantum confinement and dots; shape, size and dimensionality effects; Over view of carbon nanotubes and grapheme; properties and applications of spintronics and multiferroics in nano-dimension.

Books recommended:

1. X-ray diffraction:B. E. Warren
2. Introduction to Solid State Physics: C. Kittel
3. Solid State Physics: Askroft and Mermin
4. Electron Paramagnetic Resonance: Pake
5. Theory of Solids: J.M. Ziman
6. A quantum approach to the Solid State: Philip L. Taylor

LEARNING OUTCOMES:

This course is meant for the students opting Condensed Matter Physics as “Major Elective”. The students will learn about the X-ray diffraction technique used for the determination of crystal structure as well as the defects in crystal structure. The students will be confident to apply such technique for analyzing the typical problems encountered in the subject. The course also intends to impart knowledge about alloys and solid solutions. Two important properties of solid namely, the elasticity and the dielectric property are a part of the course. An important part of the course is the dynamics of electrons in a crystal in the absence of a field as well as in the presence of a magnetic field. This will give an idea about the band structure and the Fermi surface of solids. A concise but a very important part of the course is the effect of reducing the size to nano-order in different dimensions. At the end of the course, the students will be able to develop their potential to carry out any project work in the advanced level which are treated as a gateway towards research in condensed matter physics and materials Science. The course is also aimed at giving the basic knowledge for the accomplishment of programs in diverse directions of condensed matter physics.

MSPH305-5: Nuclear and Particle Physics-I

1. Two-nucleon bound state problem: deuteron ground state, singlet state, spin-dependence of nuclear force, magnetic dipole and electric quadrupole moments of the deuteron, D-state admixture, tensor interaction, concept of isospin, generalized Pauli principle and its consequence, exchange nature of nucleon-nucleon interaction – its experimental signatures, photo-disintegration of the deuteron. Meson theory of nucleon-nucleon interaction – Yukawa’s potential from time-independent Klein-Gordon equation with a source term.

2. Two-nucleon scattering-partial wave analysis, effective range theory, coherent scattering, spin-flip and polarization, High energy scattering.

3. Nuclear many-body problem:Hartree-Fock (HF) theory – derivation of HF equation, symmetries of HF orbits, angular momentum projection to get the physical nuclear state of the nucleus from the intrinsic state, energy of the projected state.

Concept of quasiparticles; second quantization formalism in nuclear physics; Wick's theorem, normal ordered products and contractions, pairing density and pairing potential; BCS quasiparticle transformations, HF-BCS theory, consequences of the fermionic properties of the quasiparticles. BCS ground state.

4. Importance of electron scattering in probing the structures of nucleon and nucleus, elastic electron scattering on the proton, Lorentz-invariant transition four- current, form factors and anomalous magnetic moment of the proton, electric and magnetic form factors in the Breit frame of reference; Inelastic scattering of unpolarized electron on unpolarized nucleus – Coulomb and magnetic form factors of the nucleus, the differential scattering cross-section in terms of the form factors.

5. Shell model: nucleons in a harmonic oscillator potential, radial density distribution, an estimate of oscillator frequency, spin-orbit potential, Predictions of spin, magnetic and electric quadrupole moment of nuclei, Nordheim's rules; residual interaction and configuration mixing, Evaluation of matrix elements of one and two-body operators, antisymmetrization of wave functions, CFP, single particle model, seniority and reduced iso-spin; many-particle shell model, Nilsson model.

6. Collective model: Collective Hamiltonian, vibrational spectra, Ellipsoidally deformed nuclei, total deformation parameter and non- axiality parameter, Moment of inertia –rigid and irrotational values. Rotational models of even-even and odd A nuclei. High Spin states, qualitative explanation, VMI; Coriolis anti-pairing, Cranking formula for the moment of inertia of deformable nucleus, Bohr-Wheeler's theory of nuclear fission. Fission isomers.

Books Recommended:

1. Nuclear Physics: Theory and Experiment: R R Roy and B P Nigam (New Age International)
2. Elements of Nuclear Theory: S N Mukherjee (CBS Publisher)
3. Introduction to Nuclear Physics: H. Enge
4. Theoretical Nuclear Physics: John M Blatt and Victor F Wiesskopf
5. Structure of the Nucleus: M A Preston and R K Bhaduri

LEARNING OUTCOMES:

After completing the course in MSPH305-5, the students will have an in-depth knowledge about basic nuclear structure, nuclear forces and many-body problems. The students will learn the two body problems using bound and un-bound states like scattering. They will have a vivid knowledge about the scattering experiments and out comes as well as how to calculate them theoretically. The knowledge of nuclear models will help them to understand the different nuclear properties including the anomalies arising due to complex structure of the nucleus. The many body calculations will enable them to apply the procedure in solving different complex problems specifically in theoretical physics research.

MSPH305-6: **Astrophysics & Cosmology -I**

1. Introduction

Stellar magnitudes. Spectral features of a star. Saha Equation of ionization and its consequences. HD classification. HR diagram.

2. Stellar Evolution: From birth to Pre-Main sequence

Virial theorem for star and its consequences. Average temperature in stellar interior. Jean's criteria for star formation. Fragmentation and Cloud collapse. Protostar. Failed Star. Hayashi and Henyey tracks.

3. Stellar Structure

Local thermodynamic equilibrium. Energy equation and equation of motion. Hydrostatic equilibrium. Virial theorem. Total energy of star. Equations governing composition changes. Dynamical, thermal and nuclear timescales. Equation of state (EOS) of non-degenerate gas of electrons and ions. Radiation pressure. Radiative and Convective energy transport in stars. Scaling relations for Main sequence stars. Polytropic gas spheres. Eddington's model and Homologous model. Secular and dynamical stability of stars. Stability of supermassive stars.

4. Nuclear Astrophysics

Abundance of elements. Rate of thermonuclear reactions in stars, Astrophysical S factor, Gamow window. Electron screening. pp chain and CNO cycle. Helium burning, Be bottleneck. Carbon burning and above. r, s & p processes. Solar neutrinos and neutrinos from supernovae.

5. Post-Main sequence evolution and Relativistic astrophysics

Evolution of stars of various masses. Red giant phase. Horizontal branch. Asymptotic giant branch and planetary nebula phase.

Onset of degeneracy. White dwarf: Equation of state for cold electrons, mass-radius relation, Chandrasekhar mass limit, cooling. Neutron star: neutronization, Equation of state for cold neutrons. Tolman-Oppenheimer-Volkoff (TOV) equation, its consequences and Newtonian limit. Interior structure and maximum mass of neutron star. Pulsar. Nova and X-ray burst. Supernova – types and mechanism. Schwarzschild and Kerr black holes. Penrose process. No Hair theorem.

6. Accreting Systems

Accretion disk formation in close binary systems through mass transfer. Roche model. Steady disk accretion. Rayleigh criterion for stability, Disk dynamics. Effect of viscosity. Spherical Accretion. Accretion onto compact objects.

7. Plasma Astrophysics

Basic equations of fluid mechanics and magneto hydrodynamics. Flux freezing and its implications. Sunspots and magnetic buoyancy, Dynamo theory. Second and first order acceleration theories for cosmic rays.

Books Recommended:

1. Stellar Structure and Evolution - R. Kippenhahn and A. Weigert (Springer)
2. Theoretical Astrophysics (vol 2) – T. Padmanabhan (Cambridge University Press)
3. Physics of Stars - A.C. Phillips (Wiley)
4. Astrophysics for Physicists - A. Raichoudhuri (Cambridge University Press)
5. Black holes, White dwarfs and Neutron stars - S.L Shapiro and S.A. Teukolsky (Wiley)
6. General Relativity and Cosmology – S. Banerji and A. Banerjee (Elsevier)

7. High Energy Astrophysics – J. I. Katz (Addison-Wesley Publishing Company)
8. Accretion power in Astrophysics - J. Frank, A. King, D. Raine (Cambridge University Press)
9. Plasma Physics for Astrophysics - R.M. Kulsrud (New Age International Publ.)
10. Astrophysics: Stars and Galaxies – K.D. Abhyankar (Universities Press)

LEARNING OUTCOMES

(1) Learn the principles of stellar classification, structure and evolution of stars.
(2) Also learn about Accretion and Plasma astrophysics.
(3) Identify which principles should be applied to a specified situation
(4) Show familiarity with astronomical observables and their physical origin.
(5) Understand and apply basic physics techniques to solve problems in astrophysics, and interpret the results.
(6) Demonstrate the ability to link observation and theory.
(7) Demonstrate the ability to draw qualitative conclusions from quantitative information, and vice versa.

Course code: MSPH306

Discipline Specific Elective (DE)

MSPH306-1: Applied Electronics

1. Analysis of networks and systems: Sample data system. Z- Transform, Fourier and Laplace transforms.
2. Microwave Transmission lines and Waveguides: Transmission lines, Standing wave ratio, Quarter wave transformer, Smith Chart, Stub matching, Wave guides coaxial, rectangular and cylindrical; Waveguide attenuation, Resonators.
3. Microwave Devices: Problems of microwave generation in conventional oscillators (A) Vacuum tube devices: Klystron , Reflex Klystron , and Magnetrons (B) Solid state device: Gunn diode.
4. Optical/ Optoelectronic Devices: LEDs, Semiconductor Junction Laser, sand Photodiodes.
5. Optical modulator: Electro optic Phase modulation.
6. Antenna theory: Antennas-dipole, Antenna arrays, reflectors, steering strip, micro strip and coplanar structures.
7. Digital integrated circuit: asynchronous and synchronous counters. Design of sequence counting circuit.
8. Memory devices: ROM, RAM, and sequential memory. Brief introduction to microcontroller.

Books recommended:

1. R.C. Collin -Foundations of Microwave engineering.
2. S.Y.Liao- Microwave Devices on circuits.
3. J. Ryder – Networks, Lines and Field.
4. F. E Terman -Electronic and Radio Egineering.
5. K . C. Gupta- Microwaves. (New Age International Publishers Limited)
6. C. K. Sarkar and D.C. Sarkar - Optoelectronics and Fibre Optic Communication.(New Age International Publishers Limited) .
7. A. Yariv and P. Yeh- Photonics. (Oxford University Press).
8. Geiger, Allen and Strader – VLSI – Design Techniques for Analog and Digital Circuits.
9. Gray and Meyer – Analysis and Design of Analog Integrated Circuits.
10. A P Mathur – Microprocessors.
11 .Milman and Grable , Microelectronics – Tata McGraw Hill.
12. A. Papoulis- Signal Analysis.

LEARNING OUTCOMES

This course/paper will focus light on some important issues of modern electronics and electronic technology to the Students. Students will learn the theory for developing high frequency (Microwave) transmission lines and wave guides and its characteristic features. They can get knowledge on electronic network analysis, and theories behind antenna. The Students can get the ideas of developing some important Microwave sources and detectors in the context of present-day application of Microwaves in communication. They will learn also the characteristic features and techniques of development of high sped optical/opto-electronic sources, detectors and switches, which give a tremendous application in modern day Fiber-optic communication. Finally, they can get the ideas on high speed and high capacity electronic memory devices, Digital integrated circuits and Microcontroller.

MSPH306-2: Advanced Solid State Physics

Study of Crystal Structure- Scattering of X-rays by an atom and by a three dimensional crystal, Laue equations, Bragg's law, Ewald construction, Width of diffraction maxima, Crystal structure factor, Effect of temperature on the intensity of Bragg reflections, Debye-Waller factor.

Lattice dynamics - One dimensional chain of coupled harmonic oscillators with alternating masses and stiffness, dispersion relations, acoustic and optical modes, obtaining atomic force constants from the dispersion relation. Classical vibrations of a lattice in higher dimensions and the harmonic approximation, dynamical matrix, central and non-central forces, dispersion relation. Dispersion relations for two dimensional square lattice with monoatomic and diatomic basis, acoustic and optical branches, polarization of lattice vibrations in the long wavelength limit, brief remarks on the vibrational properties of cubic lattices. Einstein theory of specific heats. Thermodynamic functions of a vibrating solid in the harmonic approximation, density of states (*i.e.* frequency distribution function) therein. General result for phonon contribution to the specific heat of a crystal, Debye theory of specific heats in three and lower dimensions, combining Einstein and Debye models for vibrating lattices with both acoustic and optical branches.

Many body techniques: Introduction to Second Quantization (SQ) and the occupation number representation,creation and annihilation operators for fermions and bosons, SQ rules for states, operators and Hamiltonians, Wick's Theorem (without proof). Introduction to the coulombic many body problem (CMB), Born-Oppenheimer Approximation, Jelium Model, Hartree and Hartree-Fock (HF) equations, HF approximations for the electron gas, Lindhard dielectric function. Exchange hole, exchange energy. Density Functional Theory (DFT), Hohenberg and Kohn theorems, obtaining approximate expressions for the ground state energy of the CMB problem using density functionals, Thomas-Fermi (TF) theory for CMB, static screening via linearization of the TF equation, TF momentum. Kohn-Sham (KS) approach to DFT, exchange correlation functional and the Local Density Approximation (LDA), idea of KS pseudopotentials and introduction to ab-initio problems, computational resources for ab-initio DFT (mention VASP, Espresso etc.).

Band theory and dynamics of an electron in a crystal: Electrons in periodic potential and single particle Schrödinger equation for all electrons, Bloch electrons and band structure**,** Orthogonalized plane wave (OPW) method: Idea of pseudo-potential, Band electrons in a magnetic field, Landau levels and its degeneracy, filling factor and idea of quantum Hall effect, Pauli spin paramagnetism, Landau Diamagnetism, the de Haas-van Alphen effect.

Superconductivity: Ginzburg-Landau theory of Superconductivity, G-L Equations, Fluxoid quantization, BCS theory: Cooper pairing, Instability of the Fermi sea, BCS Hamiltonian and its diagonalization by Bogoliubov-Valatin transformation, Ground state energy, Gap equation, Critical temperature, Isotope effect. Josephson junction and Josephson effect, Applications: Detailed description of SQUID, Coexistence of superconductivity and magnetism, High T_c superconductors.

Nanostructured system: Properties of nanoparticles; quantum wells, wires, quantum confinement and dots; shape, size and dimensionality effects; Over view of carbon nanotubes and grapheme; properties and applications of spintronics and multiferroics in nano-dimension.

Dielectric and Ferroelectrics – Ferroelectricity Piezoelectricity, Pyroelectricity Materials, Nature of phase transitions: Displacive, Order-disorder, Polarization catastrophe, Landau Theory.

Ordered magnetic Systems – Origin of Ferromagnetism, Spin dependent Hamiltonian of a two-electron system, Heisenberg Model, Exchange interactions: Direct and Indirect (R.K.K.Y. and Superexchange), Spin wave theory of ferromagnetism, magnons, Magnetic phase transitions: Mean Field theory, Landau theory, Critical phenomena, Importance, basic theory and applications of neutron diffraction technique to identify magnetic ordering, Demagnetizing fields and origin of domains, Structure of magnetic domains and domain walls, Magnetization procedure and hysteresis of a ferromagnet.

Optical properties of solids –Interband transition processes, Semiconductors: Direct and indirect interband transitions, Kramers-Kronig relations, Optical properties and band structure, Excitons: Mott-Wannier excitons, Frenkel excitons.

Books recommended:

1. X-ray diffraction:B. E. Warren
2. Introduction to Solid State Physics: C. Kittel
3. Solid State Physics: Askroft and Mermin
4. Electron Paramagnetic Resonance: Pake
5. Theory of Solids: J.M. Ziman
6. A quantum approach to the Solid State: Philip L. Taylor
7. Condensed Matter Physics, Michael P. Marder Wiley, New York.
8. Condensed Matter in a Nutshell, Gerald D. Mahan, Princeton University Press.
9. Solid State Physics Suppplееnt-2(Paramagnetic Resonance in Solids): William Low
10. Magnetism in Condensed Matter: Stephen Blundell
11. Solid State Physics An Introduction to Principles of Materials science: H. Ibach& H. Luth
12. Introduction to Solid-State Theory: Otfried Madelung

LEARNING OUTCOMES

This course is meant to give a flavor of advanced topics in Solid State Physics to the students who have not opted Condensed Matter Physics as “Major Elective”. The course starts with an introduction to the crystal structure through the X-ray diffraction technique. The lattice vibration and its effect on different properties is a part of this course. Through this course, the students will learn important techniques like “Second Quantization” and “Density Functional Theory” to treat many electron systems. Electron dynamics in a crystal and the associated band structure will be taught in this course. Students will gain knowledge about the theory as well as the properties associated with superconductivity. The course has been structured to make the students aware of a few important properties of solids: dielectric, magnetic, and optical properties of solids. Through this course, the students will also learn about the effect of reducing the size to nano-order in different dimensions. Students will be able to enhance their ability in discipline-specific knowledge, including the direct applications of quantum mechanics in condensed matter physics problems. Moreover, using many body techniques, they will be able to gather understanding of the microscopic/atomic processes acting between atoms/molecules that produce the typical properties of different solid-state materials.

MSPH306-3: Materials Physics

Noncrystalline and semicrystalline states, Crystal systems and unit cells, Coordinates of position in the unit cell. Zones and zone axes, Crystal geometry, Symmetry classes and point groups, space groups, Glide planes and screw axes, space group notations, Equivalent points. Systematic absences, Determination of crystal symmetry from systematic absences.

Introduction to materials

Classification of materials: Crystalline & amorphous materials, high T_c superconductors, alloys & composites, semiconductors, solar energy materials, luminescent and optoelectronic materials, Polymer, Liquid crystals and quasi crystals, Ceramics.

Preparation techniques of materials

Preparation of materials by different techniques: Sol-gel, polymer processing. Preparation of ceramic materials. Top down and bottom up approaches of synthesis of nano-structured materials

Characterization techniques of materials

Diffraction techniques: interpretation of x-ray powder diffraction patterns, Identification & quantitative estimation of unknown samples by X-ray powder diffraction technique. Scanning electron microscopy (SEM), Transmission electron microscopy (TEM). Electron & neutron diffraction.

Properties of materials

Electrical properties of metals, conductivity in semiconductors.

Optical properties of semiconductors: Direct and indirect band gap semiconductor.

Mechanical Properties of metals and ceramics

Concepts of stress & strain, stress-strain behavior, anelasticity, Plastic deformation, Strength of metals and alloys, Hardness measurement instruments.

Thermal properties of metals & alloys

Temperature effects on the intensities of Bragg reflections. Influence of temperature on diffraction of X-rays: Debye-Waller temperature factor, Debye's method of calculating isotropic, DTA, TGA, DSC (Outline only).

Books Recommended:

1. Materials science and Engineering by *V. Raghavan*, Prentice-Hall Pvt. Ltd.
2. Thin Solid Films by *K. L Chopra*
3. Elements of X-ray diffraction by *B. D. Cullity*, Addison-Wesley Publishing Co.
4. Elements of crystallography by *M. A. Azaroff*
5. Engineering Materials by *Kenneth G. Budinski*, Prentice-Hall ofIndia Pvt. Ltd.
6. Crystallography applied to Solid State Physics, A.R. Verma, O.N. Srivastava, New-Age Publishers.

LEARNING OUTCOMES:

The syllabus of this paper has been designed for the rest of the students who have not opted for Materials Science as the major elective to get them acquainted with the materials world like metals, alloys, composites, compounds, ceramics, liquid crystals, quasicrystals, nanomaterials etc. With the knowledge of detailed crystallography, students will be able to identify different kinds of crystalline materials, nanomaterials. Students will learn about different routes of synthesis of nanocrystals. Emphasis has been given on the material structural characterizations using several high-end and sophisticated instruments, measuring electrical, optical, mechanical and thermal properties with an object to correlate different properties with the structure and microstructure of synthesized materials.This knowledge will help students to synthesize materials with desired physical properties.

MSPH306-4: Selected Topics in Nuclear & Particle Physics

Nuclear structure and Models:

Two-nucleon bound state problem: deuteron ground state, singlet state, spin-dependence of nuclear force, magnetic dipole and electric quadrupole moments of the deuteron, D-state admixture, tensor interaction, concept of isospin, generalized Pauli principle and its consequence, photo-disintegration of the deuteron.

Two-nucleon scattering-partial wave analysis, effective range theory, coherent scattering, spin-flip and polarization, High energy scattering.

Shell model: nucleons in a harmonic oscillator potential, radial density distribution, an estimate of oscillator frequency, residual interaction and configuration mixing, anti-symmetrization of wave functions, single particle model; many-particle shell model.

Collective model: Collective Hamiltonian, vibrational spectra, Ellipsoidally deformed nuclei, total deformation parameter and non- axiality parameter, Rotational models of even-even and odd A nuclei. High Spin states,Bohr-Wheeler's theory of nuclear fission. Fission isomers.

Experimental Techniques:

Radiation detectors - general properties, modes of operation. Pulse height spectra, energy resolution, detector efficiency, peak-to-total ratio. X-ray, gamma-ray and charged particle spectrometers.

Nuclear Electronics - Pre-amplifier, Amplifier, Discriminators, Time to amplitude converter, Data acquisition systems.

Particle Physics:

Structure of Hadrons. High energy electron-proton elastic scattering - kinematics, differential cross-section, Rosenbluth formula. High energy electron-proton inelastic scattering - Bjorken variable, Inelasticity. Electron-proton deep-inelastic scattering - differential cross-section and structure functions, Bjorken scaling and Callan-Gross relation. Naive Parton Model,

Weak interaction. Strangeness-conserving and strangeness-violating weak interactions. Goldhaber's experiment to determine the neutrino helicity, the two-component theory of neutrino, V-A form of weak interaction amplitude, Parity violations in Λ^0, K^0 decays. Strangeness oscillation. Regeneration phenomenon, CP violation in K^0 decay. CPT theorem (statement only).

Neutrino mass and neutrino oscillation. Derivation of the intensity of ν_e - ν_μ. Atmospheric, solar and Supernova neutrinos. Solar neutrino problem.

Recommended books:

1. Nuclear Physics: Theory and Experiment: R R Roy and B P Nigam (New Age International)
2. Elements of Nuclear Theory: S N Mukherjee (CBS Publisher)
3. Introduction to Nuclear Physics: H. Enge
4. Theoretical Nuclear Physics: John M Blatt and Victor F Wiesskopf
5. Nuclear radiation detection, Measurement and Analysis - K.M. Varier (Narosa)
6. Techniques for Nuclear and Particle Physics Experiments - W.R. Leo (Springer)
7. Radiation detection and Measurement - G.F. Knoll (Wiley)
8. Modern Particle Physics - Mark Thomson (Cambridge University Press)
9. Introduction to High Energy Physics - D.H. Perkins, (Addison Wesley)
10. Introduction to Elementary Particles - David Griffiths (Wiley-VCH)

LEARNING OUTCOMES

After completing the course in MSPH306-4, the students will have an in-depth knowledge about basic nuclear structure, nuclear forces, some advanced experimental techniques and a glimpse of strong and weak interactions. The students will learn the two body problems using bound and un-bound states like scattering. They will have a vivid knowledge about the scattering experiments and out comes as well as how to calculate them theoretically. The students will have an overall knowledge on different types of weak interactions, parity violation as well as neutrino oscillation and solar neutrino problem.

MSPH306-5: Lasers and Laser Spectroscopy

1. Laser Safety:

Various hazards due to laser radiation-eye, skin, chemical etc., high voltage hazards, safety measures and standard

2. Nonlinear Optics:

Introduction, nonlinearities of the polarization, Anharmonic oscillator model, coupled amplitude equation, Intensity expression for generated frequency, Manley-Rowe relation. SHG, SFG & DFG.

3. Phase Matching:

Basic idea of phase matching, quasi-phase matching method, critical and noncritical phase matching, collinear and non-collinear phase matching, Type-I & II Phase matching angles calculation, effective nonlinearity calculation.

4. Techniques of generation of tunable short and long wavelength radiation:

Idea on tunable second harmonic, sum frequency and difference mixing techniques; basic equation of SHG, its conversion efficiency and parameters affecting doubling efficiency, various methods of enhancing conversion efficiency,

5. Laser instrumentation: Principle of measurement with laser beam, distance measurement, rotation, fluid velocity measurement, Advantages of remote monitoring of the atmosphere by laser, principles of remote monitoring, different lidar systems.

6. Chemical Application: Selective excitation reaction, different separation processes, principle of isotope separation, uranium enrichment, Ultrashort pulses in chemical reaction, AVLIS

7. Laser spectroscopy: Application of Lasers in Molecular Spectroscopy: Perspective, Understanding the molecular structure in its Ground and Excited States, Vibrational Spectra — Spectroscopy of Molecular Beams. Fluorescence Excitation (FE) Spectroscopy and Dispersed Fluorescence (DF) Spectroscopy. Understanding the intramolecular and intermolecular interactions. Hydrogen bonding.

Time resolved spectroscopy, Degenerate Four Wave Mixing and Coherent anti-Stokes Raman Spectroscopy and there applications

Books Recommended:

7. Principles of lasers- O Svelto
8. Solid State Laser Engineering- W Koechner
5. Methods of Experimental Physics Vol. 15B ed. By C L Tang
6. Industrial Application of Lasers – J F Ready
7. Laser remote Sensing:- R M Measures
8. Handbook of Nonlinear Optics- R L Sautherland
9. Laser and electrooptics- C C Davis
10. Molecular Physics----Wolfgang Demtroder, WILEY-VCH Verlag GmbH**,** ISBN-13: 978-3-527-40566-4

LEARNING OUTCOMES

On successful completion of the course, the students:

1. Will be able to identify hazard for eye and skin when irradiated different laser radiations and how such lasers are categorized from Class I to Class IV based on international safety standards.
2. Will have good understanding on how one can obtain suitable widely tunable coherent sources in both ultraviolet as well as infrared regions of electromagnetic spectrum utilising lowest order nonlinear effects in different materials and also how the tunability of the existing lasers can be extended using the same processes.
3. Will have the knowledge of using laser beams to measure distance, fluid velocity, remote monitoring etc apart from being familiar with different lidar systems. They will further learn the process of laser isotope separation with specific importance on AVLIS.

In this paper students will learn about the various hazards that can occur owing to laser radiation as well as laser system and also the precautions needed to adopt during working with radiation source. They will learn about the various techniques of generation of tunable coherent radiation by nonlinear optical mixing process in the spectral region where laser source as such is not available and its theory, phase matching techniques etc. This paper also deals with the technique of generation of ultra -short laser pulse. This paper also give an idea about various measurement techniques for distance, velocity, rotation, pollutants detection by remote monitoring process, the initiation of various chemical reactions and also various spectroscopic studies (both atomic & molecular) using laser radiation.

Will have a good understanding of laser application in molecular spectroscopy with considerable acquaintance in different techniques like time-resolved spectroscopy, degenerate four-wave mixing etc.

MSPH306-6: Special topics in General Relativity and Astrophysics

1. Introduction to General Theory of Relativity:

In consistencies of Newtonian gravitation with Special Theory of Relativity, Need for a curved space-time, Principle of equivalence, Inertial and gravitational mass, Geodesic Equation (Lagrangian formulation), Curvature tensors and Energy-Momentum tensors, Principle of general covariance, Heuristic derivation of Einstein's Field equation, Weak field approximation of Einstein's gravity

2. Schwarzschild Solutions of Einstein's Field Equations:

Line element for spherical symmetric objects, Schwarzschild exterior solution, Birkhoff's theorem, Isotropic coordinates, singularity, Schwarzschild radius and event horizon Geodesic equation in Schwarzschild space-time, **Tests of General theory of Relativity**: Bending of light rays in a gravitation field, gravitational red shift, Precession of Perihelion of Mercury

3.Observational Cosmology:

Expanding Universe, Models of F-R-W universes (k=0,+1,-1), density and volume of the universe, Open and Closed universe, Cosmological red shift, Hubble time and age of the universe, Red shift – magnitude relation, Hubble diagram using type I_a supernova, number counts of extra galactic objects, Last scattering surface, Cosmic Microwave Background Radiation.

4. Prelude of stellar physics:

Astronomy and Astrophysics, Classification of stars, Stellar magnitudes, Stellar distances: Distances indicators - SNIa, Cepheid variables

5. Stellar Structure

Saha Equation of ionization and its consequences, Equations of mass & energy conservation. Hydrostatic and Thermal equilibrium. Equation of state. Radiation pressure. Energy transport inside stars. Schwarzschild stability condition. Convective and Radiative stars. Polytropic model. Scaling relations for Main sequence stars.

6. Nuclear Astrophysics

Abundance of elements. Rate of thermonuclear reactions in stars, Gamow window. Hydrogen and Helium burning. Carbon burning and above. r, s & p processes. Solar neutrino problem and it's solution.

7. Stellar Evolution and Relativistic Astrophysics

Virial theorem for star and its consequences. Jean’s criteria for star formation. Fragmentation and Cloud collapse. Protostar. Failed Star. Hayashi and Henyey tracks. Evolution of stars of different masses.

Red giant phase. Onset of degeneracy. Electron and neutron degeneracy. White dwarf: mass-radius relation, Chandrasekhar mass limit. Neutron star: composition, Tolman-Oppenheimer-Volkoff (TOV) equation and its consequences. Pulsar. Nova and Supernova. Schwarzschild black hole, Collapse in a spherically symmetric space-time, Event horizon.

References:

1. A short course in General Relativity, J. Foster and J. D. Nightingle (Longman Inc., New York, 1979)
2. Introduction to Cosmology, J. V. Narlikar (Cambridge University Poress)
3. The Structure of the Universe, J. V. Narlikar (CUP, 1978)
4. General Relativity and Cosmology, J. V. Narlikar (MacMillion, 1978)
5. Theory of Relativity - S. Weinberg (Wiley, 1972).
6. Introduction to Theory of Relativity, P. G. Bergmann (Prentice-Hall, 1969)
7. Textbook of astronomy and astrophysics with elements of cosmology, V. B. Bhatia, (Narosa publishing house, 2001)
8. Stellar Structure and Evolution - R. Kippenhahn and A. Weigert (Springer)
9. Physics of Stars - A.C. Phillips (Wiley)
10. Black holes, White dwarfs and Neutron stars - S.L Shapiro and S.A. Teukolsky (Wiley)
11. Astrophysics for Physicists - A. Raichoudhuri (Cambridge University Press)
12. Astrophysics: Stars and Galaxies – K. D. Abhyankar (Universities Press)

LEARNING OUTCOMES

In this paperMSPH306-6, the students of SEMESTER-III learn the special topics in General Theory of Relativity (GTR) and Astrophysics. This is Discipline-centric Elective (DE) course in Semester-III and this course is designed for the students of other Disciplined students in Semester-III. The students who have taken their DE courses e.g. Material Science, Advanced Optics, Condensed Matter Physics can opt this course. Thus other disciplined students can opt and learn this advanced topics of GTR and Astrophysics specially Schwarzschild Black Hole, Nuclear Astrophysics, Relativistic Astrophysics and may develop their advanced knowledge and improve skill to opt their further future doctoral study.

MSPH306-7: Relativistic Quantum Mechanics &Quantum Field Theory

1. The Klein Gordon (KG) equation. Covariant notations. Free particle energy, negative energy and negative probability density, KG equation in em field.

2. The Dirac equation. Properties of the Dirac matrices.The Dirac particle in an external electromagnetic field.The non-relativistic limit of the Dirac equation and the magnetic moment of the electron.

3. Covariant form of the Dirac equation. Lorentz covariance of the Dirac equation. Boost as hyper rotation, boost, rotation, parity and time reversal operation on the Dirac wave function.

4. Conjugate Dirac spinor and its Lorentz transformation. The γ^5 matrix and its properties.Bilinearcovariants and their properties.

5. Boosting the wave function from the rest frame. Plane wave solutions of the Dirac equation and their properties.Energy and spin projection operators.

6. Dirac's hole theory and charge conjugation. Feynman-Stuckelberg interpretation of antiparticles.

7. Foldy-Wuthuysen transformations: free particle transformation, the transformation, to the hamiltonian with an electromagnetic field, relativistic correction to mass, spin-orbit interaction, Darwin term, Zitterbewegung

8. The Hydrogen atom problem: the Dirac theory with central force, the Coulomb potential, the energy eigenvalues, spin-orbit splitting, ground state wave function.

9. Concepts of fields. Lagrangian dynamics of Classical fields.Derivation of the Euler-Lagrange equation from Hasmilton'svariationalprinciple.Lagrangians and equations of motion of fundamental fields.

10. Noether's theorem. Invariances.Conserved currents and charges.Energy-momentum tensors and energy of fields.

11. Canonical quantization and particle interpretation of the real Klein-Gordon field. Fock space of bosons.Energy of the real Klein Gordon field.Normal ordering.

12. Introduction of antiparticle. Charge of quantum complex Klein-Gordon field.

13. Canonical quantization and energy of the Dirac field. Anti-commutators.Pauliprinciple.Equal time anti-commutator between the Dirac field and the canonically conjugate momentum field.14. Coulomb gauge quantization and energy of the Electromagnetic field.

15. A comparison between non-covariant and covariant quantization of the electromagnetic field. Features of covariant quantizations : Derivation of equal-time commutators between the components of fields and canonically conjugate momentum fields, (Derivation of energy operator not needed) special properties of time-like photons. Gupta-Bleuler formalism.

17. Basic ideas of the path integral formalism in quantum mechanics and quantum field theory.

18. Interacting fields (mainly electromagnetic interaction). Lagrangian and equations of motion of a system of interacting electrons and photons.Covariant perturbation theory.Derivation of the s-matrix operator.Time-ordering.Application to Compton scattering.Wick's theorem (statement only). Enumeration of terms of s-matrix element and corresponding Feynman diagrams. Statement of Feynman rules of graphs in quantum electrodynamics. Vacuum

polarization diagram in Hydrogen atom, Charge renormalization and Lamb shift. (Detailed derivations of integrals not needed). Drawing of diagrams and statement of anomalous magnetic moment of electron.

Books recommended:

1. Relativistic Quantum Mechanics – J.D.Bjorken and S.D.Drell, McGraw-Hill, New York (1964).
2. Relativistic Quantum Mechanics- Walter Greiner, Springer-Verlag (1990)
3. Advanced Quantum Mechanics – J.J.Sakurai, Addison-Wesley Publishing Company, Inc. (1967).
4. Relativistic Quantum Mechanics and Quantum Fields – T-Y Wu and W-Y Pauchy Hwang, Allied Publishers Limited (2001).
5. Relativistic Quantum Fields - J. D. Bjorken and S. D. Drell, McGraw-Hill (1965)
6. Quantum Field Theory - Lewis H Ryder, Cambridge University Press (1985)
7. Quantum Field Theory - Claude Itzyksen and Jean-Bernard Zuber, McGraw Book Co. (1985)
8. Quantum Field Theory in a nutshell - A. Zee, Princeton University Press (2003).
9. A First Book of Quantum Field Theory – A. Lahiri and P. B. Pal, Narosa Publishing House (2001).

LEARNING OUTCOMES

This is a basic-level course comprising the aspects of the unification of Quantum Mechanics and Special Theory of Relativity and its ramifications into Quantum Field Theory. This course may be considered as a gateway to modern physics and contains the prerequisites for studying the theoretical and experimental developments in Nuclear and Particle Physics, High Energy Physics, Cosmology and Astrophysics.

MSPH306-8: May be opted from SWAYAM

Course code: MSPH307 Community Engagement Activities

SEMESTER IV

Course code: MSPH401

Molecular Spectroscopy

1. Born-Oppenheimer approximation and separation of electronic and nuclear motions in molecules. Band structures of molecular spectra.
2. Microwave and far infrared spectroscopy : Energy levels of diatomic molecules under rigid rotator and non-rigid rotator models. Selection rules. Spectral structure. Structure determination. Isotope effect. Rotational spectra of polyatomic linear and symmetric top molecules. Stark effect.
3. Infrared spectra : Energy levels of diatomic molecules under simple harmonic and anharmonic (no deduction necessary for this one) models. Selection rules and spectral structures. Morse potential energy curves. Dissociation energies.Isotopeeffect.Rotational – vibrational coupling.P and R branches of lines, Band origin, Parallel and perpendicular modes.Symmetry properties of molecular wave functions and absence of spectral lines.

4. Raman spectroscopy. Rotational, Vibrational, Rotational-Vibrational Raman spectra. Stokes and anti stokes Raman lines. Selection Rules.Spectralstructures.Nuclear spin and its effect on Raman spectra.
5. Vibrational spectra of poly atomic molecules. Normal modes. Selection rules for Raman and infrared spectra. Complementarity of Raman and infrared specra.Normal modes of CO_2molecule.Normal modes of other simple triatomic molecules.
6. Electronic spectra of diatomic molecules:
   (a) Vibrational band structure. Progressions and sequences. Isotope shifts. Deslandrestables.Molecular constants in the ground and excited electronic states and crude idea of molecular bonding.
   (b) Rotational structure of electronic spectra. P-, Q- and R- branches. Band head formation and shading of bands.
   (c) Intensity distribution in the vibrational structure of electronic spectra and Franck-Condon principle. Hund's coupling. Experimental determination of dissociation energy.

   (d) Hydrogen molecule ion and molecular orbitals. Valence Bond approach in hydrogen molecule. Coulomb and exchange integrals. Electronic structures of simple molecules. Chemical bonding. Hybridizations.
   (e) Basic aspects of photo physical processes: radiative and non-radiative transitions; fluorescence and phosphorescence; Kasha's rules. Nuclear Magnetic resonance spectroscopy. Electron spin resonance spectroscopy. Fourier transform spectroscopy. Photo acoustic spectroscopy. Photo electron spectroscopy. Mossbauer spectroscopy.
   (f) Application of group theory to spectroscopy.

7.Nonlinear spectroscopy: Laser Raman spectroscopy.

Books Recommended:

1. G. Herzberg. ‘Molecular Spectroscopy (Diatomic Molecules)’ Van-Nostrand.
2. G. M. Barrow. ‘Molecular Spectroscopy’.McGraw-Hill.
3. J.MichaelHollas. ‘ Modern spectroscopy’. John-Wiley & sons.
4. C. L. Banwell and E. M. McCash. ‘Fundamentals of Molecular Spectroscopy’ Tata- McGraw-Hill..
5. G.Aruldhas ‘Molecular Spectroscopy’.
6. Bransden and Joachin. ‘Atoms and Molecules’
7. F.A.Cotton. ‘Chemical application to Group theory’.

LEARNING OUTCOMES

Molecular Spectroscopy is a very old branch of basic physics. Going through this course/Paper the Students can get knowledge on different internal motions of molecules and their interactions. The can get ideas/concepts on the role of Molecular rotations, vibrations, electronic motions in various types of absorption and emission spectra from molecules and their practical applications. They can get knowledge on Raman Spectroscopy and also their practical implications. The Students can get expertise to analyze the molecular spectrum based on orbital theory as well as valance band theory of molecules. Some ideas on nonlinear spectroscopy and stimulated Raman Spectroscopy (Laser Raman Spectroscopy) will also be given to them.

Course code: MSPH402

ADVANCED QUANTUM MECHANICS

Symmetries Invariance Principle and Conservation Laws - Generator of finite and infinitesimal transformations,Invariance principle and Conservation laws. Space translation, Time translation, Space inversion, Time reversal.
Scalar, Vector and Tensor Operators: Scalar operators, Vector operators, Reducible and I rreducible spherical tensor operators, Wigner-Eckert theorem for spherical tensor operators.
Quantum Dynamics: The equations of motion, theSchrodinger picture, the Heisenberg picture, the Interaction picture.
Identical Particles: The identity of particles, Spins and Statistics, Exchange degeneracy, Symmetrization Postulate, Wave function of two-particle system, Wave function of many-particle system, Example.
Relativistic Quantum Mechanics The Klein Gordon (KG) equation, Covariant notations, Free particle energy, Negative energy and negative probability density, KG equation in em field.

The Dirac equation, Properties of the Dirac matrices, The Dirac particle in an external electromagnetic field, The non-relativistic limit of the Dirac equation and the magnetic moment of the electron, Covariant form of the Dirac equation, Lorentz covariance of the Dirac equation.

Books Recommended:

1) Quantum Mechanics by Claude Cohen-Tannnoudji, Bernard Diu, Franck Laloë (Volumes I and II).
2) Quantum Mechanics Concepts and Applications, Second Edition by NouredineZettili.
3) Quantum Mechanics by V.K. Thankappan.
4) Problems and Solutions on Quantum Mechanics, Edited by Yung-Kuo Lim.
5) Relativistic Quantum Mechanics- Walter Greiner, Springer-Verlag
6) Advanced Quantum Mechanics – J.J.Sakurai, Addison-Wesley Publishing Company, Inc.
7) Relativistic Quantum Mechanics –J.D.Bjorken and S.D.Drell, McGraw-Hill, New York.

LEARNING OUTCOMES:

The students will learn about the "Generator" of infinitesimal and finite space translation, time translation and rotation. Invariance principles and related conservation laws will be taught along with time reversal operation. Quantum mechanical scalar, vector and tensor operators along with Wigner-Eckert theorem for spherical tensor operators will be taught. "Quantum dynamics", including the Schrodinger picture, the Heisenberg picture and the Interaction picture and the identical particles in quantum mechanics are within the syllabus. Finally, the course contains an introduction to relativistic quantum mechanics.

COMPUTATIONAL PHYSICS

Computational Physics

1. Introduction to Python programming: The Python Interpreter, Python console, Jupyter and python IDEs; Setting up and using python on GNU/Linux, Windows and Android operating systems; Simple Input and Output; Variables; Mathematical Operators; list, string, tuple, set, dictionary; Control flow and decision control: logical loop structure; Functions and lambdas; Object and class; Files: reading and writing. Python namespaces, installation, design and import of modules in python.

2. Scientific Computing in Python: Introduction to the Numerical Python (numpy), Scientific Python (scipy), and matplotlib modules**.**Numpy arrays; Initialization and basic operations; resizing; slicing of arrays; array as a matrix; 2D plotting with matplotlib; plot with external data. Fast Fourier Transform (FFT) and the Danielson-Lanczos/Cooley-Tukey algorithms. Implementation of FFT using numpy/scipy. Sparse matrices in scipy, types of sparse matrices. Linear algebra operations withnumpy arrays using numpy-BLAS. Determination of eigenvalues and eigenfunctions of simple Fermionic and Bosonic systems.

3. Numerical Methods in Scientific Computing with Python: Representation of real and complex numbers, statistical calculations, factorial, infinite series, iterative methods: logistic map; binary search. Imprecisions in integer and floating point arithmetic. Interpolation of datasets using the Lagrange polynomial**.** Numerical root finding: Bisection method, False position method, Newton-Raphson method.Solution of system of simultaneous linear equations: Gauss elimination, Gauss-Seidel method**,** LUdecomposition algorithm. Numerical integration using Newton-Cotes quadratures: Trapezoidal and Simpson's $1/3^{rd}$ methods.

4. Numerical solutions of Differential Equations: Ordinary Differential Equations: Simple Euler and Runge-Kutta methods. Application in physics problems: damped harmonic oscillator, forcing and resonance; self sustained oscillation (van der Pol oscillator, Lorenz and Roessler oscillator); Henon-Heiles potential problem; visualization in phase space and Poincare sections. Partial Differential Equations: Laplace and Wave equations. Schrodinger equation and solutions to the eigenvalue problem for simple systems.

5. Monte Carlo Simulations: Deterministic Randomness; Random Sequences; Monte Carlo Applications: A Random Walk Problem, Radioactive Decay. The Metropolis algorithm and a brief exposition to numerical solution of Ising spin model, Bose-Einstein condensation using the Metropolis algorithm

(1. Instructor should demonstrate the installation of Python, Matplotlib, NumPy, and Scipy in Windows and Linux. 2. Emphasis will be given to solve physical problems and their visualizations. 3. Assignments should be given to the students at a regular interval.)

References:

1. Numerical Python: Scientific Computing and Data Science Applications with Numpy, SciPy and Matplotlib, R. Johansson, 2019, Apress.
2. Computational Physics: Problem Solving with Python, 3rd Edition, Rubin H. Landau, Manuel J Páez, Cristian C. Bordeianu, 2015, Wiley.
3. Scientific Computing in Python, Abhijit Kar Gupta, Techno world, 2019.
4. Let Us Python, 2nd Edition, Y. Kanetkar, A. Kanetkar, 2020, BPB Publications.
5. Computational Physics, N.J. Giordano, 1997, Prentice-Hall.
6. Python and matplotlib essentials for scientists and engineers, Matt A. Wood, 2015, Morgan and Claypool Publishers.
7. Introducing Python: Modern Computing in Simple Packages, B. Lubanovic, 2015, O'Reilly Media, Inc.

LEARNING OUTCOMES

On completion of the course, the student should be able to:

- Translate a theoretical or algorithmic model into code that enables computation, logically subdivide a computational model into a set of manageable computational tasks, and organize their code accordingly, choose among computational algorithms and computational tools to produce a solution, debug, test, and validate computational models, and extract physical insight from a computation.
- Use the Python programming language to numerically solve physics problems, focussing on the use of Python's numeric modules SciPy (Scientific Python), Numpy (Numerical Python), and graphics module Matplotlib (MATLAB-like Plotting Library).

- Apply Monte Carlo simulations, curve-fitting and interpolation of datasets, numerically solve systems of nonlinear equations, ordinary differential equations, multiple integrals, perform computational linear algebra, solve optimization problems, perform signal analysis using Fast Fourier Transforms etc
- Formulate and computationally solve any tractable problem in physics,

Course code: MSPH403

Advanced General Practical

List of Experiments

Group A:

I.

1. Determination of temporal coherency of a coherent (laser) light and compare it with incoherent light (sodium)
2. Study of magneto-optic effect (Faraday effect)
3. Study of electro-optic effect (Pockels effect)
4. Measurement of bending loss in a multi-mode optical Fiber.
5. Study of characterization of antenna
6. Design of active filters (a) band-pass filter, (b) all pass filters
7. Studies of nonlinear electronic circuits and design of chaotic electronic oscillator
8. Studies on LED modulation characteristics
9. Arc emission and absorption measurements using CCD based Constant Deviation Spectrometer.
10. Band gap evaluation of a semiconductor by studying temperature variation of resistance.

II. Computer Assignment: Numerical experiments and assignments

Group B:

I.

1. Study of ultrasonic diffraction using a laser
2. Study of gamma ray spectrum of radioactive nuclides with NaI (Tl) scintillators & SCA
3. Study of beta-ray absorption & determination of mass absorption co-efficient of the given absorber material.
4. Study of gamma-ray absorption & determination of gamma ray energy
5. Determination of particle size of an unknown powder specimen using Scherrer equation from supplied XRD pattern
6. Phase identification of an unknown sample from its X-ray diffraction pattern
7. Identification of liquid, solid or powder samples using Laser Raman Spectrometer.
8. Study of NMR.
9. Intensity dependent nonlinear susceptibility of nonlinear liquid by Z-Scan technique.

10. Determination of grove spacing of a CD by diffraction method and hence determination of wavelength of unknown source.

II. Computer Assignment: Numerical experiments and assignments.

LEARNING OUTCOMES

This course contains some state of the art experiments for introducing students to the modern research laboratories. The students are highly benefited from these experiments some of which are even used by our research scholars. This course contains experiments from different areas in Physics which enables students to have an overall exposure to the advanced level of equipments and technologies.

All the students will be divided into two groups i.e. Group A& Group B. Those students who have done Group A experiments in Semester-III will have to opt Group B experiments in Semester-IV and vice versa.

Course code: MSPH404

Discipline Specific Elective (DE)

MSPH404-1: Advanced Electronics -II

1. IC Technology: Hybrid and monolithic IC; Semiconductor processing diffusion, implanation, oxidation, epitaxy, lithography; Si IC technology-MOS and Bipolar; Packaging and testing.
2. Analog Integrated Circuits. Differential amplifier, OP-AMP comparator; continuous time filters, switched capacitance implementation of sample data filters; analog multiplexers, PLL and frequency synthesizer.
3. Digital Integrated Circuits: Logic families – TTL, ECL, MOS, MESFET; design of combinational and sequential circuits – MUX, decoder/ encoder, registers, counters, gate arrays; programmable logic devices – PAL, GAL, PLA, Programmable gate arrays.
4. Application specific ICs: ICs for analog communication; Digital signal processing ICs; Speech and image processing.
5. Memories: Sequential and Random access memories; RAM bipolar and MOS static and dynamic memories; programmable memories PROM, EPROM, EEPROM.
6. Microprocessor and their applications: Architecture of 8 bit (8085) and 16 bit (8086) microprocessors; addressing modes and assembly language programming of 8085 and 8086. 8086 machine cycles and their timing diagrams; Interfacing concepts memory and I/O interfacing; Interrupts and interrupt controllers; microprocessor based system design; comparison of different microprocessors.

Books Recommended:

1. Milman and Grable, Microelectronics. Tata MacGraw Hill.
2. Geiger, Allen and Strader – *VLSI – Design Techniques for Analog and Digital Circuits*.
3. Gray and Meyer – *Analysis and Design of Analog Integrated Circuits*.
4. A P Mathur – *Microprocessors.*
5. R S Gaonkar – *Microprocessor Architecture, Programming and Applications with 8085/ 8085A* (2^{nd} Ed.).
6. S Soelof – *Applications of Analog Integrated Circuits*.

LEARNING OUTCOMES

1. Students will learn the internal circuit and design of digital integrated circuit.
2. It will enable students to develop skills digital circuits for electronics and communications applications.
3. The holistic approach of the course will contribute towards the skill development of the students such that they can apply the acquired knowledge in research and development sector.

MSPH404-2: Laser Physics –II

1. Laser Safety:

Various hazards due to laser radiation-eye, skin, chemical etc., high voltage hazards, safety measures and standard

2. Nonlinear Optics:

Introduction, nonlinearities of the polarization, generation of second harmonic, D.C., sum and difference frequency generation, anharmonic oscillator model, Miller's rule, crystal symmetry, coupled amplitude equation, Manley-Rowe relation

3. Phase Matching:

Basic idea of phase matching, quasi-phase matching method, various methods of phase matching (angle, temperature, birefringence etc.) critical & noncritical phase matching, collinear and non-collinear phase matching, expression of angle band-width (Δ□) and wavelength band-width (Δ□) in phase matched second harmonic generation, idea of tangential and dispersion phase matching.

4. Second Harmonic Generation and OPO:

Basic equation, conversion efficiency and parameters affecting doubling efficiency, various methods of enhancing conversion efficiency, second harmonic generation with Gaussian beam, intra-cavity second harmonic generation

Optical parametric oscillations: threshold, output, efficiency, merits and demerits over other tunable lasers, a glimpse of THz radiation.

5. Higher Order Nonlinear Processes:

Four wave mixing processes-third harmonic generation, resonance enhancement of nonlinear susceptibilities, different phase matching techniques, generation of tunable deep UV and IR radiation, stimulated Raman scattering, inverse Raman scattering, anti-stokes coherent Raman scattering, application in spectroscopy

6. Chemical Application:

Selective excitation reaction, different separation processes, principle of isotope separation, uranium enrichment, Ultrashort pulses in chemical reaction, AVLIS

7. Laser in Spectroscopy: Two-photon spectroscopy, multi-photon spectroscopy, saturation spectroscopy, opto-galvanic spectroscopy, photo-acoustic spectroscopy, Terahertz spectroscopy

8. Stimulated Raman Scattering:

Introduction, Quantum theory of stimulated Raman scattering, phase matching, Coherent anti-stoke Raman scattering, inverse Raman scattering, competition effect, Tunable infrared and UV radiation using stimulated Raman scattering, application of stimulated Raman scattering.

9. Laser speckle:

Spatial frequency filtering- principle and its application

Books Recommended:

1. Methods of Experimental Physics Vol. 15B ed. By C L Tang
2. Industrial Application of Lasers – J F Ready
3. Solid State Laser Engineering- W Koechner
4. The Principle of Nonlinear Optics- Y R Shen
5. Handbook of Nonlinear Optics- R L Sautherland
6. Laser and electrooptics- C C Davis

LEARNING OUTCOMES:

In this paper students will learn about the various hazards that can occur owing to laser radiation as well as laser system and also the precautions needed to adopt during working with radiation source. They will learn about the various techniques of generation of tunable coherent radiation by nonlinear optical mixing process in the spectral region where laser source as such is not available by exploiting second order and third order nonlinearity of an anisotropic & isotropic dielectric material and its theory, phase matching techniques etc. This paper also give an idea about the initiation of various chemical reactions and also various spectroscopic studies (both atomic &molecular) including Raman effect using laser radiation. The student also get an idea about the spatial filtering process studying this paper.

MSPH404-3: Materials Science II

X-ray scattering from crystalline, nanocrystalline and noncrystalline materials

Continuous spectrum and characteristic spectrum, Duane-Hunt law. X-ray energy level schemes, diagram and non-diagram lines, Absorption of X-rays and theory of filters.

X-ray scattering: General description of scattering process, coherent and incoherent scattering, total scattering from a spherically symmetric electron cloud, Atomic scattering factor. Coherent and incoherent scattering from hydrogen atom, scattering from many electron atom (outline). Perfect crystal theory: Intensity form a small single crystal, integrated intensity from a small perfect crystal (no deduction), integrated reflection from Mosaic and powder crystal.

Lattice Imperfections

Point defect and line defect. Dislocations, Burger vectors.Alloys and solid solutions, composition.Surface energy for solids.

Microstructure characterization by direct & indirect methods

Diffraction techniques: interpretation of x-ray powder diffraction patterns, Identification & quantitative estimation of unknown samples by X-ray powder diffraction technique. Theory and method of particle size analysis.

Scanning electron microscopy (SEM), Transmission electron microscopy (TEM).Electron and neutron diffraction.

Computational methods in Materials Physics

Density Functional Theory: Basics of DFT, Comparison with conventional wave function approach, Hohenberg-Kohn Theorem; Kohn-Sham Equation; Thomas-Fermi approximation and beyond; Practical DFT in a many body calculation and its reliability.

Books Recommended:

1. X-ray diffraction by *B. E. Warren*, Addison-Wesley Publishing Co.
2. An Introduction to Metallurgy by *Sir Alan Cottrell*, University Press
3. The Structure & Properties of Materials (Volume II) by *J. H. Brophy, R. M. Rose and J. Wulff*, Wiley Eastern Ltd.
4. Structure of Metals, *C. S. Barrett & T. B. Massalski*, McGraw-Hill Book Company.

LEARNING OUTCOMES

In this course students primarily learn about theory scattering fundamentals as applied to x-rays. A general knowledge about x-ray scattering will also enrich them about scattering of electromagnetic radiation in general. Use of x-ray for structural characterization as an indirect technique will be taught as well as direct techniques of characterization techniques will also be covered in this course.

MSPH404-4: Condensed Matter Physics-II

Lattice dynamics - Vibrations of a crystal lattice. Classical vibrations of coupled harmonic oscillators in one dimension. One dimensional chain of coupled harmonic oscillators with alternating masses and stiffness, dispersion relations, acoustic and optical modes, obtaining atomic force constants from the dispersion relation. Classical vibrations of a lattice in higher dimensions and the harmonic approximation, dynamical matrix, central and non-central forces, dispersion relation. Dispersion relations for two dimensional square lattice with monoatomic and diatomic basis, acoustic and optical branches, polarization of lattice vibrations in the long wavelength limit, brief remarks on the vibrational properties of cubic lattices. Second quantisation of lattice vibrations as phonons, diagonalization of the quantum Hamiltonian for a vibrating lattice. Quantum thermodynamics of phonons in the long wavelength limit, contribution of zero point energy, Einstein theory of specific heats. Thermodynamic functions of a vibrating solid in the harmonic approximation,density of states (*i.e.* frequency distribution function) therein. General result for phonon contribution to the specific heat of a crystal, Debye theory of specific heats in three and lower dimensions, combining Einstein and Debye models for vibrating lattices with both acoustic and optical branches. Beyond the Einstein and Debye models: Density of states and van-Hove singularities. Anharmonic interaction and thermal expansion, Gruneisen parameter, Mie-Gruneisen equation of state. Inelastic neutron scattering from phonons, formal theory for the cross section of Neutron scattering. Averaging of exponentials using Wick's theorem and Zassenhaus formula, evaluation of Debye-Waller factor. Evaluation of structure factor, elastic scattering from the zeroth order expansion of the structure factor, multi-phonon processes from higher order terms in the structure factor.

Transport properties of solids: Boltzmann transport equation and its linearization, Relaxation time approximation, Temperature dependence of resistivity of a metal, Variational method for the solution of the linearized Boltzmann equation, Electron-phonon interaction, Limitations of the Boltzmann transport equation, Kubo formula for electrical conductivity, Transport coefficients of metals and semiconductors in presence of magnetic field.

Ordered magnetic Systems – Origin of Ferromagnetism, Spin dependent Hamiltonian of a two-electron system, Heisenberg Model, Exchange interactions: Direct and Indirect (R.K.K.Y. and Superexchange), Spin wave theory of ferromagnetism, magnons, Spin waves in Antiferromagnets. Band model of ferromagnetism – Temperature behaviour of a ferromagnet in the band model, Magnetic phase transitions: Mean Field theory, Landau theory, Critical phenomena, Importance, basic theory and applications of neutron diffraction technique to identify magnetic ordering.

Magnetic domains and interactions –Demagnetizing fields and origin of domains, Structure of magnetic domains and domain walls, Magnetization procedure and hysteresis of a ferromagnet

Optical properties of solids –Interband transition processes, Semiconductors: Direct and indirect interband transitions, Kramers-Kronig relations, Optical properties and band structure, Excitons: Mott-Wannier excitons, Frenkel excitons

Books Recommended:

Basic Solid State Physics: Arun Kumar Raychaudhuri
Magnetism in Condensed Matter: Stephen Blundell
Condensed Matter Physics: Michael P. Marder
Solid State Physics An Introduction to Principles of Materials science: H. Ibach and H. Luth
Introduction to Solid-State Theory: Otfried Madelung

LEARNING OUTCOMES

The course treats models of solids by interacting systems of electrons and ionized atoms in a crystalline lattice. Approaches include applications of classical and quantum mechanics, statistical physics and electromagnetism. The spatial and magnetic orderings in the different systems are taught using the quantum and statistical physics. The phenomenon of superconductivity, the related models are within the course content. The subject is aimed at giving the basic knowledge for pursuing higher studies in condensed matter physics.

MSPH404-5: Nuclear and Particle Physics-II

1. Nuclear Reaction:

Reaction and scattering cross sections. Compound nuclear reactions. Resonance reactions. Optical model. Direct nuclear reaction, PWBA, DWBA and Coupled channel calculations. Coulomb excitation. Heavy ion reactions - types of Interactions, Semi-classical treatment and diffraction models, Angular Momentum dependence of various types of reactions. Heavy Ion fusion and high spin states. Sub-barrier fusion. Deep Inelastic collision.

2. Experimental Techniques:

(a) Radiation detectors - general properties, modes of operation. Pulse height spectra, energy resolution, detector efficiency, peak-to-total ratio. X-ray, gamma-ray and charged particle spectrometers. Compton-suppressed germanium detectors, various channel selection devices, multi-detector array. Calorimeter.

(b) Nuclear Electronics - Pre-amplifier, Amplifier, Discriminators, Time to amplitude converter, Data acquisition systems. Brief discussion on electronic circuit diagram for two and three detector set-ups.

(c) Energy, timing and position sensitive spectroscopy. Measurement of level spin, linear polarization and lifetime.

3. Nucleosynthesis:

Abundance of elements. Source of Stellar energy. Barrier penetration and quantum tunnelling. Fusion cross-sections and Reaction rates. Non-resonant and resonant thermonuclear Reaction rate. Electron screening. Hydrogen burning: pp chain and CNO cycles, other cycles. Helium burning, Be bottleneck. Electron degeneracy and Helium flash. Advanced and Explosive burning. Neutron capture nucleosynthesis. Solar neutrinos. Origin of light elements Li, Be and B.

4. Health Physics:

Exposure, Roentgen, Exposure rate, Absorbed Dose, Relative Biological Effectiveness, Equivalent Dose, Effective dose, Dose limits. Dosimetry from radiation inside and outside the body. Biological half-life. Biological Effects of radiation. Radiation shielding and its safety. Estimation of radiation level near a radioactive source using a radiation detector. Pocket Ionization Dosimeter.

5. Physics of Medical Imaging:

1D & 2D Radiography. Computed Tomography (CT), Single-Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET). Compton camera. Magnetic Resource Imaging (MRI). Radiotherapy.

Books Recommended:

1. Introduction to Nuclear Reactions - C.A. Bertulani and D. Danielewicz (CRC Press)
2. Nuclear Reactions - R. Singh and S.N. Mukherjee (New Age International Pvt. Ltd.)
3. Elements of Nuclear Theory - S.N. Mukherjee (CBS)
4. Nuclear radiation detection, Measurement and Analysis - K.M. Varier (Narosa)
5. Techniques for Nuclear and Particle Physics Experiments - W.R. Leo (Springer)
6. Radiation detection and Measurement - G.F. Knoll (Wiley)
7. Nuclear Physics of Stars - C. Iliadis (Wiley-VCH)
8. Cauldrons in the Cosmos: Nuclear Astrophysics - C.E. Rolfs and W.S. Rodney (University of Chicago Press)
9. Introduction to Radiation Protection Dosimetry, J. Sabol & P. S. Weng (World Scientific).
10. Radioactive Isotopes in Biological Research, William R. Hendee (John Wiley and Sons).
11. Introductory Nuclear Physics - K.S. Krane (Wiley)
12. Concepts of Nuclear Physics - B.L. Cohen (TMH)

LEARNING OUTCOMES

(1) Learn the principles of nuclear reaction and nucleosynthesis and how to link the relevant theory with experimental observations.
(2) Learn the basics of radiation detectors with the aim of properly choosing the right detector for a particular experimental set up.
(3) Learn fundamental principles of two important topics of applied nuclear physics – health physics and medical imaging.
(4) Identify which principles should be applied to a specified situation
(5) Demonstrate the ability to link observation and theory.

MSPH404-6: **Astrophysics & Cosmology -II**

1. Review of Mechanics of Continuous Media:
Equation of continuity, 4-D formulation, comoving coordinate system, Energy momentum tensor of continuous media,

2. Space-Time Geometry:
A critical review of space, time and gravity, Euclidean and non-Euclidean space-time, Parallel transport in flat and curved Spaces, affine connection, Covariant derivatives, covariant derivative of vectors, covariant derivative of tensors, metric tensors, Geodesics, Geodesics on spherical surface, Riemann Christoffel tensor, Ricci tensor, Bianchi Identities, Einstein tensor, necessary and sufficient condition for flatness of space-time, Newtonian gravity in metric tensor form.

3. Einstein's Gravity:

Inconsistencies of Newtonian gravitation with Special Theory of Relativity, Need for a curved space-time, Principle of equivalence, Inertial and gravitational mass, connection between Inertia and gravitation, Principle of general covariance, heuristic derivation of Einstein's law of gravitation, weak field approximation of Einstein's gravity.

4. Solutions of Einstein's Field Equations and Static Black Holes:

Schwarzschild solution, exterior solution, isotropic coordinates, singularity, Schwarzschild radius and event horizon, Schwarzschild interior solution, Schwarzschild solution in other coordinate systems, Birkhoff's theorem. Conflict between Minkowski metric and equivalence principle, Circular geodesic of a particle in Schwarzschild space – time, minimum radius, motion of a test particle, trajectories of photons; Geodesic equation in Schwarzschild space-time, Bending of light rays in a gravitation field, gravitational red shift, Precession of perihelion of Mercury, Analogues of Keplar's laws, Charged black hole (R – N metric).

5. Rotating Black Holes:

Kerr black hole (derivation is not required), distinguished surfaces of Kerr black hole, event horizon, infinite red shift surface, ergosphere, Kerr – Newmann metric (derivation is not required), No hair theorem, Cosmic censorship hypothesis.

6. Black hole physics:

Laws of black hole thermodynamics, Surface gravity, Energy extraction from a black hole- Penrose mechanism, Irreducible mass, Detection of black holes, White Holes. Elementary discussion on Hawking radiation.

7. Gravitational waves :

Introduction, Gravitational wave equation, plane waves, polarization; radiation of gravitational waves, detection of Gravitational waves.

References:

1.A short course in General Relativity, J. Foster and J. D. Nightingle (Longman Inc., NY, 1979)

2. Theoretical Astrophysics (Vols. I, II, III) , T. Padmanavan

3. General Relativity, Astrophysics and Cosmology, A. K. Raychaudhuri, S. Banerji and A. Banerjee (Springer-Verla, 1992)

4. General Relativity and Cosmology, S. Banerji and A. Banerjee (Elsevier, 2007)

5. An Introduction to Relativity, J. V. Narlikar (Cambridge University Poress, 2010)

6. General Relativity and Cosmology, J. V. Narlikar (MacMillion, 1978)

7. Theory of Relativity - S. Weinberg (Wiley, 1972).

8. Introduction to Theory of Relativity, P. G. Bergmann (Prentice-Hall, 1969)

9. Astrophysics for Physicists, Arnab Rai Choudhuri (Cambridge University Press 2012)

10. Gravitation, C. W. Misner, K. S. Thorne and J. A. Wheeler (Princeton University Press, 2017)

LEARNING OUTCOMES:

Astrophysics & Cosmology-II is a Discipline-centric Elective (DE) course in Semester-IV. The students who opted this course have to study advanced topics on General Relativity and its application on Astrophysical tests and Gravitational wave as well as Rotating Black Hole and Black Hole physics. This course is designed to ensure the global competitiveness for higher study.

Paper: MSPH405

Discipline Specific Elective (DE)

MSPH405-1: Advanced Electronics-III

Review of CW Modulation Technique:
Linear modulation DSB, SSB, VSB, QAM techniques, Exponential modulation FM and PM; AM and FM modulators and demodulators.

Pulse Modulation and Demodulation Techniques:
Sampling the rein PAM, PWM, PPM, Pulse code modulation – coding technique modulation and Demodulation.Quantization error.

Digital Modulation Techniques:
ASK, FSK, CPFSK, PSK, DPSK, QPSK, MSK, Principle, modulators and demodulators. Bandwidth calculation.

Effect of Noise on Communication System:
Characteristics of additive noise; Performance of AM, FM and PCM receivers in the face of noise; Multi-path effect.

Elements of Information Theory:
Information, average information, information rate, Effect of coding on average information per bit; Shannon's theorem; Channel capacity, an optimum modulation system.

TV Systems:
Color TV standards – NTSC, PAL, SECAM; Transmission format of intensity and color signal; Transmitter and receiver systems of broadcast TV; Advanced TV; Cable TV.

RADAR System: Basic pulsed radar system – modulators, duplexer indicators, radar antenna CW radar; MTI radar FM radar; chirped pulse radar.

Optical Communication: Planar wave guide, concept of mode, V-parameter, Multi-path and material dispersion; Power budget equation; Wavelength Division Multiplexing; Quantum limit; Bit error rate and maximum bit rate.

Satellite Communication:
Orbits, Station keeping; Satellite attitude; Path loss calculation; Link calculation; Multiple access techniques; Transponders; Effects of nonlinearity of transponders.

Specialized Communication Systems:
Mobile Communication – Concepts of cell and frequency reuse description of cellular communication standards; Pagers. Computer communication – Types of networks; Circuit message and packet switched networks; Features of network, design and examples of ARPANET, LAN, ISDN, Medium access techniques – TDMA, FDMA, ALOHA, Slotted ALOHA, CSMA/CD; Basics of protocol.

Books Recommended

1. A B Carlson – *Communication Systems.*
2. D Roddy and J Coolen – *Electronic Communications.*
3. Franz and Jain – *Optical Communication Systems.*
4. A M Dhake – *Television and Video Engineering*.
5. Gulati – *Monochrome and Color TV*.
6. Kennedy and Davis – *Electronic Communication Systems*.
7. Taub and Schilling – *Principle of Communication Systems*.

LEARNING OUTCOMES:

High speed and secured communication are very important parts in modern civilization. Reading this course / paper the Students can understand the theory working behind the meaningful and reliable communications. They can get the concepts/ ideas on various types of analog, pulse, and digital communications. The ideas/concepts of modulation as well as de-modulation circuits in the above three branches of communication processes will be possible to be gathered by them. The Students will get knowledge on information theory working behind any digital communication process. They will get also ideas on Different issues of fiber-optic communications, Satellite Communications, Television Communication, Radar systems for long range detection, Some aspects of specialized communications like cellular network, LAN, ISDN, Packet Switches etc.

MSPH405-2: Laser Physics-III

1. Frequency conversion and higher harmonic generation:

Sum frequency generation, limitation to upconversion, introductory theory, infrared detection, effect of phase matching, difference frequency generation, effect of phase matching, evaluation of $\Delta\theta$ and $\Delta\lambda$, Applications in Nonlinear Optics, Self-focusing and self-defocusing, measurement of second and third order optical nonlinear susceptibility.

2. Optical communication:

Optical fibre waveguide, Electromagnetic analysis of simple optical waveguide: Basic waveguide equation, Group velocity dispersion and dispersion compensation, pulse distortion and information rate in optical fibres, distortion in single modefibre, fibre losses, coupling of source with fibre, modulation, PCM, multiplexing, WDM, TDM, solitons.

3. Nonlinear materials:

UV-VIS-NIR crystals, assessment of nonlinear crystals (Kurtz powder method, Maker fringe method Z-scan), Chalcopyrites and their characteristics.

4. Methods of semiconductor crystal growth:

Outline of crystal growth and Phase-Diagrams, Bridgman-Stockbarger method, Czochralski method,Kyropoulos method, Molecular Beam Epitaxy.

5. Laser instrumentation:

Principle of measurement with laser beam, distance measurement, rotation, fluid velocity measurement, surface velocity measurement using speckle patterns, measurements of rate and rotation using laser gyroscope

Advantages of remote monitoring of the atmosphere by laser, principles of remote monitoring, different lidar systems: single beam, dual beam, sources of noise and its remedial measures, Raman back scattered lidar

7. Material processing:

Laser in drilling, cutting, welding, marking and annealing

8. Optical bistability& phase conjugation:

Principle of optical bistability, different optical logic gates, optical phase conjugation, production of phase conjugated beam, self focusing, optical computing, Illustrative applications.

9. Laser in medical science:

Laser tissue interaction, physical effects on human skin of laser beam reflection, absorption, scattering, different interaction mechanism, different surgical treatment. Effects of ultrashort pulses.

10. Laser cooling & BE Condensation:

Principle of laser cooling & trapping, optical molasses, cooling below Doppler limit, magnetic trapping, applications.

Books Recommended:

1. Methods of Experimental Physics Vol. 15B ed. By C L Tang
2. Industrial Application of Lasers – J F Ready
3. Laser remote Sensing:- R M Measures
4. Optical bistability- H M Gibbs
5. Handbook of Nonlinear Optics- R L Sutherland
6. Laser and electrooptics- C C Davis
7. The Principles of Nonlinear Optics, Y. R. Shen, Wiley-Interscience , 2003
8. A. H. Cherin: An Introduction to Optical Fibres,(McGraw Hill, 1983).

LEARNING OUTCOMES:

On successful completion of the course, the students:

1. Will be able to understand the processes of different frequency conversion methods and how to optimise them to get large conversion efficiencies in those processes along with different techniques of growing large nonlinear crystals for the purpose. They will also be conversant with Molecular Beam Epitaxy method.

2. Will have good understanding on theory of electromagnetic analysis of communication through optical fiber, details of different distortions associated with such communication as well as different multiplexing techniques. They will also have preliminary understanding of using solitons in fiber optics applications.

3. Will be familiar with different applications using lasers that include lidar remote sensing, distance measurement, fluid velocity measurement, laser gyroscope and material processing. The students will also be familiar with some of the effects of laser radiation on human body.

4. Will be familiar with differentaspects of optical bistability and optical phase-conjugation as well as laser cooling and BE condensation.

MSPH405-3: Materials Science-III

Optical and dielectric properties of materials

Theory of electronic polarization and optical absorption, ionic polarization, orientational polarization. Optical phonon model in an ionic crystal; Interaction of electromagnetic waves with optical modes, Polaritons, Dispersion curves of transverse optical (TO) phonon and optical photon in a diatomic ionic crystal, LST relation; Metal-insulator transition. Optical properties of metals & nonmetals- Luminescence, photoconductivity.

Electrical properties of materials

Conductivity in metals, conductivity in semiconductors and effects of high fieds, electrical conduction in ionic ceramics.Band gap determination in semiconductors using electrical and optical methods.Tensor Properties of Materials; Tensor representation of electrical conductivity.

Physics of Semiconductors: Electrical and structural property of semiconductors. Band formation, valence band and conduction band. Direct and indirect band gap semiconductor. Examples and applications. Physics of p-n junction. Energy band diagram. P-n junction diodes. LED, solar cell and laser diode.

Mechanical Properties of metals and ceramics

Concepts of stress & strain, stress-strain behavior, anelasticity, Plastic deformation, Hardness-Knoop&Vicker's hardness test.

Thermal properties of metals & alloys

Temperature effects on the intensities of Bragg reflections. Influence of temperature on diffraction of X-rays: Normal coordinates of lattice vibration and X-ray scattering from a vibrating lattice and origin of thermal diffuse spots. First order TDS. Debye-Waller factor' Debye's method of calculating isotropic temperature factor for a cubic crystal. DTA, TGA, DSC (Outline only).

Structure - Property correlation, application aspects of material

Correlation of structure with physical properties of materials, application prospects of materials in different areas.Functional and smart materials.

Books recommended:

1. Introduction to Ceramics by *W. D. Kingery, H. K. Bowen and D. R. Uhlmann,* John Wiley & Sons
2. Diffraction analysis of the microstructure of materials by E. J. Mittemeijere and P. Scardi, Springer
3. Materials Science & Engineering by William D. Callister, John Wiley & Sons, Inc.
4. Modern techniques of surface science by *D. P. Woodruff & T. A. Delchar*, Cambridge University Press
5. X-ray spectroscopy by B. K. Agarwal, Springer-Verlag.

LEARNING OUTCOMES

Students will have a detailed knowledge about the optical properties, dielectric properties, electrical properties and mechanical properties from this course. Additionally they will have an understanding of semiconductor physics. P-n junction diodes are fundamental to many application aspects of semiconductors in electronic and optoelectronic devices.

MSPH405-4: Condensed Matter Physics-III

Many body techniques: Introduction to Second Quantization (SQ) and the occupation number representation,creation and annihilation operators for fermions and bosons, SQ rules for states, operators and Hamiltonians, Wick's Theorem (without proof). Introduction to the coulombic many body problem (CMB), Born-Oppenheimer Approximation, Jelium Model, Hartree and Hartree-Fock (HF) equations, HF approximations for the electron gas, Lindhard dielectric function. Exchange hole, exchange energy. Density Functional Theory (DFT), Hohenberg and Kohn theorems, obtaining approximate expressions for the ground state energy of the CMB problem using density functionals, Thomas-Fermi (TF) theory for CMB, static screening via linearization of the TF equation, TF momentum. Kohn-Sham (KS) approach to DFT, exchange correlation functional and the Local Density Approximation (LDA), idea of KS pseudopotentials and introduction to ab-initio problems, computational resources for ab-initio DFT (mention VASP, Espresso etc.).

Magnetic anisotropy: Magnetic susceptibility tensor, Quadratic representation, Correlation of principal susceptibilities with crystallographic axes in different crystal systems using magnetic ellipsoid, Correlation of magnetic anisotropy of molecules and ions in a unit cell with those of crystals, Measurements of principal anisotropies of crystals belonging to different systems, Structural information from measurement of magnetic anisotropy.

Crystal Field theory: Free ion and Crystal field Hamiltonians, Steven's operators, Operator equivalent method, Splitting of 3d ions in octahedral and tetrahedral field, Crystal field splitting of Ce^{3+} in ethyl sulfate and derivation of susceptibility of Ce^{3+} ethyl sulfatelattice, Kramer's theorem, J-T effect.

Mössbauer Spectroscopy and Hyperfine interactions: Problems of nuclear γ-ray resonance absorption and Mössbauer's discovery, Recoil-less fraction and its temperature dependence, Mössbauer source for iron rich samples, Isomer shift, Application of Mössbauer effect to solid state physics, Quadrupole interaction, EFG tensor, Splitting of nuclear levels of iron. Application of Mössbauer spectroscopy in magnetic nanocrystalline ferrites, NMR and EPR.

Superconductivity: Electron-Phonon interactions and the Frölich Hamiltonian; the superconducting state and the cooper pair; the BCS Hamiltonian; the Bogoliubov-Valatin transformation; the ground state wave function and the energy gap equation; the transition temperature; tunneling experiments; Flux quantization and the Josephson effect and applications; SQUID magnetometer; Coexistence of superconductivity and magnetism; Ginzburg-Landau theory of Superconductivity, G-L Equations, Isotope effect. High T_c superconductors.

Books recommended:

1. Condensed Matter Physics, Michael P. Marder Wiley, New York.
2. Condensed Matter in a Nutshell, Gerald D. Mahan, Princeton University Press.
3. Solid State Physics Suppleent-2(Paramagnetic Resonance in Solids): William Low

LEARNING OUTCOMES:

This course is meant for the students opting Condensed Matter physics as "Major Elective". A part of this course deals with vibrations of lattice. This part contains both the classical and quantum mechanical approach to treat lattice vibrations of both nature harmonic as well as an-harmonic, and the effect of these vibrations on the thermal properties of solids. Students will learn about the electrical and thermal transport properties of solids, including important topics like Boltzmann transport equation, Electron-phonon interaction, Kubo formula *etc.* Magnetism, an important topic is a part of this course. Students will learn about different kinds of magnetic ordering, their origin and temperature dependence. The role of magnetic domains will also be taught. Optical properties with an emphasis for the semiconductors will be taught in this course. At the end of the Course, the students will be able to develop their potential to carry out Project work in advanced level and this may be treated as a gateway towards research in Condensed Matter Physics and Materials Science.

MSPH405-5: Nuclear and Particle Physics-III

1. Primary objectives of high energy physics. A brief overview of four fundamental interactions and their characteristics, elementary particles and their characteristics.
2. Static model ($SU(3)_f$) of quarks. Baryon and meson supermultiplets. Basic quark model. Isospin and flavour symmetry. Spin-flavour state functions of baryon decouplets, baryon octets and meson nonets. Colour wave functions. Evidence for quark, color and gluon. Magnetic moments of baryons. Drawbacks of SU(3)f quark model. Principles of discoveries of heavy flavours: Charm, bottom and top. Summary of quantum numbers of all quark flavours. Vector mesons and their decays. Zweig rule.
3. Gauge theories of fundamental interactions. Concept of field, relation between particle and field. Lagrangian and various relativistic fields. Internal symmetries. Global and local gauge invariances. U(1) and $SU(3)_c$ symmetries. Quantum Electrodynamics and Quantum Chromodynamics. Charge screening and anti-screening. Running coupling constants. Ultraviolet breakdown. Asymptotic freedom. Infrared slavery.
4. Structure of Hadrons. High energy electron-proton elastic scattering - kinematics, differential cross-section, Rosenbluth formula. High energy electron-proton inelastic scattering - Bjorken variable, Inelasticity. Electron-proton deep-inelastic scattering - differential cross-section and structure functions, Bjorken scaling and Callan-Gross relation. Naive Parton Model,

Quantifying the charge of partons. Scaling violations and QCD improved Parton model. Altarelli–Parisi equation.

5. Weak interaction. An analogy with electromagnetic interaction.Four-fermion point interaction of Fermi.Weak interaction amplitude in terms of bilinear covariants.Parityviolation.τ-θ paradox, Wu's experiment.Goldhaber's experiment to determine the neutrino helicity, the two-component theory of neutrino.Correlationdata.V-A form of weak interaction amplitude. Parity violations in Λ^0, K^0 decays. Strangeness oscillation.Regenerationphenomenon.CP violation in K^0decay.CPT theorem (statement only).Strangeness-conserving and strangeness-violating weak interactions.Cabbibo theory.
6. Gauge theory of weak interaction. Spontaneous symmetry breaking and Higgs mechanism.Electroweakunification.Glashow-Weinberg-Salam model of electroweak symmetry breaking.W^0, Z^0 masses. Basic ideas of a Grand Unified Theory, SU(5) theory and its predictions. Inclusion of gravity. Planck scale. Brief chronology of events in the early universe.
7. Neutrino mass and neutrino oscillation. Derivation of the intensity of ν_e - ν_μ.Atmospheric, solar and Supernova neutrinos.Solar neutrino problem.

Books recommended:

1. Modern Particle Physics - Mark Thomson (Cambridge University Press)
2. Introduction to High Energy Physics - D.H. Perkins, (Addison Wesley)
3. Introduction to Elementary Particles - David Griffiths (Wiley-VCH)
4. Quarks and Leptons: An introductory course in modern particle physics - F. Halzen and A.D. Martin (John Wiley & Sons)
5. Nuclear and Particle Physics - W.E. Burcham and M. Jobes (Addison Wesley)
6. An Introduction to Particle Physics - M.P. Khanna (PHI Learning)
7. Nuclear and Particle Physics: An Introduction - B.R. Martin (Wiley)
8. Lie Algebras in Particle Physics - Howard Georgi (CRC Press)
9. The ideas of Particle Physics: An introduction for Scientists - G.D. Coughlan, J.E. Dodd and B.M. Gripaios (Cambridge University Press)
10. Facts and Mysteries in elementary particle physics - MartinusVeltman (World Scientific)

LEARNING OUTCOMES:

After completing the course in MSPH405-5, the students will have an in-depth knowledge about strong and weak interactions. The students will have an overall knowledge on different types of weak interactions, parity violation as well as neutrino oscillation and solar neutrino problem. They will learn how to utilize gauge theories in determining the symmetry breaking in particle physics. This will be helpful for their future research work in theoretical high energy physics.

MSPH405-6: Astrophysics & Cosmology -III

1. Introduction:

Large scale structure of the universe, Cosmological scales, Weyl postulates, Cosmological Principles, Static Universe model – Einstein Model, de-Sitter Model, Properties of Einstein and de-Sitter universes, cosmological constant and its significance, Mach principle (elementary discussions), Discussion on Newtonian cosmology, red shift.

2. Non static model of the universe:

Friedmann model of the universe, Field equations, Energy-Momentum tensors (perfect fluid) of the universe, Friedmann-Robertson-Walker metric (derivation is not required), Cosmological parameters, Static Universe and Expanding universe, Hubble' law, scale factor, present day scale factor, Models of F-R-W universes (k=0,+1,-1), density and volume of the universe, Open and Closed universes, Cosmological red shift, Hubble time and age of the universe, cosmological models with Λ-term, Particle Horizon and Event Horizon, Olber's Paradox.

3. Early Universe:

Big Bang, Early universe, Thermal history, Entropy – Temperature and Time – Temperature relations, photons, primordial neutrinos, neutrino decoupling, decoupling of matter and radiation, electrons, positrons, protons, neutrons, synthesis of lighter nuclei, primordial nucleosynthesis, radiation dominated and matter dominated universe,

Qualitative discussions on: very early universe, vacuum energy, false vacuum energy, Grand Unified Theory (GUT),

4. Problems of Standard Cosmology:

Some problems of Standard Cosmology. Flatness problem, Horizon problem, Entropy problem, and Monopole problem, Elementary discussion on inflationary universe.

5.Observational Cosmology:

Red shift – magnitude relation, Hubble diagram using type I_a supernova, number counts of extra galactic objects, last scattering surface, Cosmic Microwave Background Radiation.

Brief reviews on: counts of galaxies, counts of radio sources, age of the universe. Gamma ray burst.

6. Dark Energy and Dark matter:

Elementary analysis on Dark Energy and Dark Matter, evidences in support of Dark Energy and Dark Matter. Origin and nature of Dark Energy, galaxy rotation curves.

7. Singularity in Cosmological Models:

A brief discussion on Raychaudhuri equation and Hawking – Penrose singularity theorem.

Books Recommended

1. An Introduction to Relativity, J. V. Narlikar (Cambridge University Poress, 2010).
2. S. Banerji and A. Banerjee – The Special Theory of Relativity (Prentice Hall of India, 2002)
3. P. G. Bergmann- Introduction to Theory of Relativity (Pren tice-Hall, 1969).
4. J. V. Narlikar- General Relativity and Cosmology (MacMillion, 1978).
5. S. Banerji and A. Banerjee, General Relativity and Cosmology – (Elsevier, 2007)

6. A. K. Raychaudhuri, S.Banerji and A. Banerjee General Relativity, Astrophysics and Cosmology – (Springer-Verla, 1992)
7. J. V. Narlikar –Introduction to Cosmology (Cambridge Univ, Press, 2003).
8. S. Weinberg- Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity (Wiley, 1972).
9. V. B. Bhatia - Textbook of astronomy an astrophysics with elements of cosmology, Narosa publishing house, (2001).
10. E. W. Kolb and M. S. Turner - The Early Universe –(Addison-Wesley Reading, 1990)

LEARNING OUTCOMES

Astrophysics & Cosmology-III is a Discipline-centric Elective (DE) course in Semester-IV. The students who has opted this course have to study advanced topics on Cosmology and its application to understand the physics of large scale universe specially, expanding universe, standard model of universe, early history of the universe as well as observational aspects of the cosmology. The students can develop their concept and basics understanding from the course and make their mind set to fit with the global competitiveness such that one can go for higher doctoral study.

Paper: MPHYS0406

Project/Term Paper

The project work or term paper in experimental/theoretical area should be designed in such a way that it acts as a bridge between pass out PG students and PhD incumbents.

LEARNING OUTCOME

Form various experimental/theoretical term papers in different disciplines, the students will gain experience in research. They will understand the research methodology and will help them in their future research career.