M.Sc.

IN

PHYSICS

CURRICULUM AND SYLLABI

(Applicable from 2023 admission onwards)

Department of Physics
NATIONAL INSTITUTE OF TECHNOLOGY CALICUT
Kozhikode - 673601, KERALA, INDIA

The Program Educational Objectives (PEOs) of M.Sc. in Physics

PEO1	Graduates apply their knowledge in Physics and Mathematics to explain and appreciate the many aspects of fundamental Physics and its applications to natural phenomena.
PEO2	Graduates demonstrate sound scientific and mathematical aptitude with practical laboratory skills leading to a career in research and/or teaching of basic and applied physics.
PEO3	Graduates exhibit a competitive edge in technical, entrepreneurial and communication skills and interpersonal team-spirit to undertake challenging research projects in future educational/research/industrial careers.

Program Outcomes (POs) of M.Sc. in Physics

PO1	Ability to apply knowledge of Mathematics and basic Physics in understanding physical phenomena.
PO2	Ability to design experiments to measure and demonstrate fundamental physical phenomena in the laboratory.
PO3	Ability to identify, formulate and solve problems involving physics and allied areas.
PO4	Ability to analyze and interpret data and develop models of physical phenomena in nature with the help of mathematical, computational and experimental skills.
PO5	Ability to work in a team, communicate effectively and engage in life-long learning.

CURRICULUM

Total credits for completing M.Sc. in Physics is 75.

COURSE CATEGORIES AND CREDIT REQUIREMENTS:

The structure of M.Sc. program shall have the following Course Categories:

Sl. No.	Course Category	Minimum Credits
1.	Program Core (PC)	50
2.	Program Electives (PE)	12
3.	Institute Elective (IE)	2
4.	Projects	11

The effort to be put in by the student is indicated in the tables below as follows:
L: Lecture (One unit is of 50 minute duration)
T: Tutorial (One unit is of 50 minute duration)
P: Practical (One unit is of one hour duration)
O: Outside the class effort / self-study (One unit is of one hour duration)

PROGRAM STRUCTURE

Semester I

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	PH6301E	Mathematical Physics - I	3	0	0	6	3	PC
2.	PH6302E	Classical Mechanics	3	1*	0	5	3	PC
3.	PH6303E	Electromagnetic Theory - I	3	1*	0	5	3	PC
4.	PH6304E	Quantum Mechanics - I	3	0	0	6	3	PC
5.	PH6305E	Electronics: Theory and Lab	3	0	2	7	4	PC
6.	PH6306E	Computational Physics: Theory and Lab	2	0	2	5	3	PC
7.		Institute Elective	2	0	0	4	2	IE
		Total	**19**	**2***	**4**	**38**	**21**	**--**

Semester II

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	PH6307E	Mathematical Physics - II	3	0	0	6	3	PC
2.	PH6308E	Electromagnetic Theory - II	3	0	0	6	3	PC
3.	PH6309E	Quantum Mechanics - II	3	0	0	6	3	PC
4.	PH6310E	Atomic and Molecular Physics	3	0	0	6	3	PC
5.	PH6311E	Statistical Physics	3	0	0	6	3	PC
6.	PH6381E	General Physics Lab	0	0	3	3	2	PC
7.	PH6382E	Electromagnetics Lab	0	0	3	3	2	PC
8.	PH6391E	Mini Project	0	0	0	6	2	Projects
		Total	**15**	**0**	**6**	**42**	**21**	**--**

Semester III

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	PH7301E	Nuclear and Particle Physics	3	0	0	6	3	PC
2.	PH7302E	Condensed Matter Physics	3	1	0	8	4	PC
3.		Program Elective - I	3	0	0	6	3	PE
4.		Program Elective - II	3	0	0	6	3	PE
5.	PH7303E	Optics: Theory and Lab	1	0	3	5	3	PC
6.	PH7381E	Solid State Physics Lab	0	0	3	3	2	PC
7.	PH7391E	Project Phase - I	0	0	0	9	3	Projects
		Total	**14**	**0**	**6**	**43**	**21**	**--**

Semester IV

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.		Program Elective - III	3	0	0	6	3	PE
2.		Program Elective - IV	3	0	0	6	3	PE
3.	PH7392E	Project Phase - II	0	0	0	18	6	Projects
		Total	**6**	**0**	**0**	**30**	**12**	**--**

*- The tutorial session is not compulsory, and attendance will not be recorded. If the student is not attending the tutorial session, the corresponding units will be counted in category O.

List of Institute Electives

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1.	IE6001E	Entrepreneurship Development	2	0	0	4	2
2.	ZZ6003E	Research Methodology	2	0	0	4	2
3.	MS6174E	Technical Writing and Communication	2	1	0	4	2

List of Electives

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1.	PH7320E	General Theory of Relativity	3	0	0	6	3
2.	PH7321E	Experimental Techniques	3	0	0	6	3
3.	PH7322E	Physics of Climate	3	0	0	6	3
4.	PH7323E	Atmospheric Dynamics	3	0	0	6	3
5.	PH7324E	Advanced Topics in Condensed Matter Physics	3	0	0	6	3
6.	PH7325E	Phase Transitions and Critical Phenomena	3	0	0	6	3
7.	PH7326E	Organic Electronics	3	0	0	6	3
8.	PH7327E	Advanced Statistical Mechanics	3	0	0	6	3
9.	PH7328E	Laser Physics	3	0	0	6	3
10.	PH7329E	Photonic Band Gap Structures	3	0	0	6	3
11.	PH7330E	Topics in Particle Physics	3	0	0	6	3
12.	PH7331E	Quantum Field Theory	3	0	0	6	3
13.	PH7332E	Solar Physics	3	0	0	6	3
14.	PH7333E	Astrophysics	3	0	0	6	3
15.	PH7334E	Special Topics in Quantum Mechanics	3	0	0	6	3
16.	PH7335E	Advanced Mathematical Methods for Physicists	3	0	0	6	3
17.	PH7336E	Special Topics in Classical Mechanics	3	0	0	6	3
18.	PH7337E	Classical Field Theory	3	0	0	6	3
19.	PH7338E	Solid State Devices	3	0	0	6	3
20.	PH7339E	Gravitational Wave Physics	3	0	0	6	3
21.	PH7340E	Optical Waveguides	3	0	0	6	3
22.	PH7341E	Metamaterials	3	0	0	6	3
23.	PH7342E	Nonlinear Optics	3	0	0	6	3
24.	PH7343E	Physics and Technology of Thin Films	3	0	0	6	3
25.	PH7344E	Special Topics in Electromagnetic Theory	3	0	0	6	3

PH6301E MATHEMATICAL PHYSICS - I

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Use techniques in vector differential calculus to solve problems.
CO2: Test for linear independence of vectors, perform orthogonalisation of basis vectors and represent operators as matrices.
CO3: Apply the ideas of vector spaces to describe space of functions.
CO4: Examine the properties of ODEs and PDEs and apply them to some physical examples.

Vector Analysis – Gradient, Divergence and Curl – Gauss theorem, Stokes theorem, Green's theorem – Curvilinear coordinate systems – Coordinate transformations.

Linear Algebra: Sets, Compositions, Groups, Rings, Fields – Vector spaces – Span – Linear Independence – Bases – Linear Transformations – Operators – Matrix Representations – Dual vector spaces – Tensor product spaces – Bilinear forms – Gram-Schmidt orthogonalization – Eigenvalue problem, Diagonalization.

Infinite dimensional vector spaces, function space, L_2-spaces – Expansion in orthogonal functions, classical orthogonal polynomials, generating functions – Fourier series – Fourier transform – Dirac delta function.

Differential Equations – Second Order Differential Equations, Frobenius method, series solutions – Special functions, examples – Partial Differential equations – Separation of variables – Laplace equation – Heat Equation.

References:

1. Phillippe Dennery and Andre Krzywicki, *Mathematics for Physicists*, Dover publications, 1995.
2. K. F. Riley, M. P. Hobson and S. J. Bence, *Mathematical Methods for Physics and Engineering*, Cambridge University Press, 2006.
3. G. F. Simmons, *Differential Equations with Applications and Historical Notes*, McGraw Hill, 2017.
4. R. Bronson and G. B. Costa, *Differential Equations*, (Schaum's Series) McGraw-Hill, 2006.
5. M. R. Spiegel, *Vector Analysis*, (Schaum's Series) McGraw-Hill, 1959.

PH6302E CLASSICAL MECHANICS

Pre-requisites: Nil

L	T	P	O	C
3	1	0	5	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Use ideas of Calculus of Variations and Lagrangians for problems in Classical Mechanics.
CO2: Utilize the concepts of Hamiltonian, Symmetry properties, Canonical Transformations and Poisson Brackets to simplify the description of different systems.
CO3: Apply and extend ideas of Classical Mechanics to two body central force problems, small oscillations and rigid body dynamics to solve equations of motion
CO4: Examine the symmetries of phase space using the concepts of symplectic geometry.

Constraints – Generalized Coordinates – Virtual Displacements – D'Alembert's Principle – Calculus of Variations, examples – Lagrangian, Euler–Lagrange Equations, examples – Central force motion.

Legendre transformations – Hamilton's equations and examples – Cyclic coordinates – Symmetry – Conservation principles and Noether's theorem – Canonical transformations – Poisson bracket formulation

System of oscillators – eigenvalue problem and normal modes – damping – forced oscillations and resonance – the inertia tensor – Euler angles and equations of motion – Symmetric top.

Dynamical systems – stability analysis – phase space dynamics – Generating Functions – Hamilton–Jacobi equation – Action angle variables.

References:

1. Herbert Goldstein, *Classical Mechanics (II Ed.)*, Narosa Publishers, 2001.
2. Landau and Lifshitz, *Mechanics (III Ed.)*, Pergamon press, 2009.
3. D. Kleppner and R.J. Kolenkow, *An introduction to mechanics*, Cambridge University Press, 2010.
4. Spiegl M. R., *Theoretical mechanics*, (Schaum Series), McGraw Hill, 1982.
5. D. A. Wells, *Theory and Problems of Lagrangian Dynamics*, (Schaum Series) McGraw-Hill, 1967.

PH6303E ELECTROMAGNETIC THEORY - I

Pre-requisites: Nil

L	T	P	O	C
3	1	0	5	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Apply knowledge of vector calculus to describe and compute Electric and Magnetic fields.
CO2: Solve Laplace and Poisson equations for a given charge distribution and boundary conditions.
CO3: Formulate and solve problems involving time dependent electromagnetic fields using Maxwell's equations.
CO4: Analyze propagation of electromagnetic waves in vacuum.

Review of electrostatics : electric field and potential – Gauss law – Poisson and Laplace equations – Solution of Laplace equation in rectangular, cylindrical and spherical coordinates – method of Images – multipole expansion of potential – electric dipole and its field – electric fields in dielectric media – polarization – electrostatic boundary conditions – electrostatic energy of a charge distribution.

Review of magnetostatics : Current density, equation of continuity, force on a current carrying conductor, Biot–Savart law – divergence and curl of magnetic field – Ampere's circuital theorem – vector potential – multipole expansion of the vector potential – field due to a magnetic dipole – force on a dipole – magnetized materials – magnetization – magnetostatic boundary conditions.

Electromotive force – Faraday's law – Lenz law – Electromagnetic Induction – mutual and self– inductance – magnetostatic energy – Maxwell's equations – Maxwell's correction to Ampere's law – Displacement current – Electromagnetic field – Energy – Poynting's theorem.

Maxwell's equations in free space – wave equation – plane wave solution – structure of the electromagnetic wave – spherical waves.

References:

1. D. J. Griffiths, *Introduction to Electrodynamics (4th Edition)*, PHI Learning - New Delhi, 2012.
2. J. D. Jackson, *Classical Electrodynamics (3rd Edition)*, Wiley, 2007.
3. E. Purcell and D. Morin, *Electricity and Magnetism (3 rd Edition)*, Cambridge University Press, 2013.
4. R. P. Feynman, R. Leighton and M. Sands, *Feynman Lectures on Physics Vol.-II (Millenium Edition)*, Pearson, 2012.
5. J. Edminister, *Schaum's Outline: Theory and Problems in Electromagnetics (2nd Edition)*, McGraw-Hill, 1979.

PH6304E QUANTUM MECHANICS - I

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Compute probability distribution for observables of a system in a given quantum state.
CO2: Solve Schrodinger equation for simple one dimensional problems.
CO3: Analyze three dimensional central field problems and compute eigenvalues and eigenstates.
CO4: Investigate symmetries of a quantum system.

Postulates of Quantum Mechanics, Dirac formalism – bra-ket notation, states and observables, measurement theory, Born interpretation – Translation operator and momentum, canonical commutation relations – expectation values – uncertainty principle – matrix representation of operators, change
of basis, position and momentum representation – time evolution, Hamiltonian operator, Time dependent Schrödinger equation, Time independent Schrodinger equation – Schrödinger, Heisenberg and interaction pictures.

One dimensional time independent potential problems, general properties, bound and scattering solutions – Free particle – potential wells and barriers, tunneling – Simple harmonic oscillator: operator method and algebraic method – periodic potential, Bloch's theorem, band structure – symmetry, conservation laws – parity, time reversal.

Rotations, angular momentum operators, commutation relations, eigenvalues and eigenfunctions
– orbital and spin angular momentum – Addition of angular momenta, Clebsch-Gordon coefficients
– Composite systems, quantum entanglement – locality principle and Bell's inequalities – three dimensional time independent potential problems: central field problems, hydrogen atom.

References:

1.Richard L. Liboff, *Introductory Quantum Mechanics (4th Ed.)*, Pearson education, 2003.

2.J. J. Sakurai, , *Modern Quantum Mechanics (3rd Ed.)*, Addison Wesley, 1999.

3.R. Shankar, *Principles of Quantum Mechanics (2nd Ed.)*, Springer, 1994.

4. David. J. Griffiths, *Introduction to Quantum Mechanics (2nd Ed.)*, Pearson Education, 2005.

5. Nouredine Zettili, *Quantum Mechanics: Concepts and Applications (2nd Ed.)*, John Wiley, 2009.

6.P. M. Mathews and K. Venkatesan, *A Textbook of Quantum Mechanics (2nd Ed.)*, McGraw Hill, 2017.

PH6305E ELECTRONICS: THEORY AND LAB

Pre-requisites: Nil

L	T	P	O	C
3	0	2	7	4

Total Sessions: 39L + 26P

Course Outcomes:
CO1: Explore the fundamentals of Op-Amps and Realize Op-amp-based applications.
CO2: Express proficiency in the design of active filters and Realize oscillators and 555 timer- based circuits in physical measurements.
CO3: Express proficiency in Number Systems, Boolean algebra, Karnaugh maps, Combinatorial and multiplexer and demultiplexer circuits, and the construction of digital logic electronic circuits.
CO4: Apply the fundamentals of flip flops and Design Sequential circuits such as shift registers and counters.
CO5: Construct A/D and D/A converters, Voltage to Frequency and Frequency to Voltage converts and Apply ROM concept to realize various digital functions.

Lecture Sessions:

Introduction to Operational Amplifiers – Open and closed loop Op-Amp responses – Offset parametersFrequency response of an Op-Amp – DC and AC amplifiers – Voltage-controlled- current-source (VCIS) – Current-controlled-Voltage-Source (ICVS) – Current-controlled-Current source (ICIS) – Summing AmplifiersInstrumentation amplifier – Isolation amplifier – Integrator – Differentiator and wave-shaping circuits.

Filter theory – Transfer function – Pole-Zero Plot – Filter response characteristics – Active Filters – Low-pass, High-pass, Band-pass and Band-stop Filters – Oscillators: sinusoidal oscillator- relaxation oscillators – Comparators-Schmitt trigger-the 555 Timer-Astable, Monostable and Bistable Multivibrators – Phase locked loops (PLL) – Voltage Regulators: series, shunt and switching regulators, Applications of IC voltage regulators.

Number Systems – IEEE 754 Number format – Logic gates – Boolean algebra – Karnaugh maps – Combinatorial circuits: Binary adder and subtractor – Decoders and Encoders – Parity generators and checkersMultiplexers, Demultiplexers and their applications, Digital Logic electronic circuits with Diode – Resistor, and Transistor – Transistor Families, CMOS NOT Gate Construction.

Sequential circuits: SR and D latches – Flip – flops: edge triggered D, JK and T flip-flops – Master-slave flip flop – Registers: Register with parallel load-Shift registers: serial transfer- universal shift register, Ripple counter-Synchronous counters: mod (x) counter, D/A converters [Binary Weighted and R-2R Ladder], A/D converters [Successive approximation and counter methods], voltage to frequency (V/F) and frequency to voltage (F/V) converters – Read-only memory (ROM) and its applications

Practical Sessions:

List of Experiments

1. 1.Inverting, non-inverting and voltage follower circuits using op-amp IC 741 2.Integrator and Differentiator using IC 741
2. Instrumentation amplifier using IC741
3. Low-pass, High-pass, I order Butterworth filters and Notch Filter
4. Half-wave, full-wave active rectifiers and Triangular waveform generator 6.Astable multivibrator using IC741 and 555 timer
5. Schmidt Trigger
6. Verify the truth table of fundamental logic gates and verify the universality of NAND and NOR gates
7. Design combinatorial circuits (Half-adder, full-adder, half-subtractor and full-subtractor) 10.Design Parallel adder/subtractor circuits using IC7483
8. Construct code converters (Binary to Grey and Grey to Binary) and Parity generators and parity checkers
9. Construct and verify 4-to-1 multiplexer and 1-to-4 demultiplexer
10. Verify the truth table of RS, JK, JK master-slave, D, and T flip flops and demonstrate the RS latching.
11. Construct and verify 4-bit synchronous and asynchronous counters
12. 10 out 14 experiments to be done, Some Lectures will be given as a Demo Session

References:

1. Floyd T. L, and Buchla, *Basic operational Amplifiers and Linear Integrated Circuits*, Pearson Education Asia, 2003.

2. Gayakwad R.A., *Op-amps and Linear Integrated Circuits*, Prentice Hall of India, 2009.

3. R. F. Coughlin and Driscoll, *Op- Amps and Linear Integrated Circuits (4th Edition)*, Prentice Hall of India, 2003.

4. Adel, S. Sedra, Kenneth and C. Smith, *Microelectronic Circuits (6th Edition)*, Oxford University Press, 2011.

5. Anil K. Maini, *Digital Electronics, Principles, Devices and Applications*, John Wiley and Sons, 2007.

6. W. H. Gothmann, *Digital Electronics: An introduction to theory and practice*, Prentice Hall, 2000.

7. Morris Mano M., *Digital Logic and Computer Design*, Pearson Education India, 2016.

8. Malvino, Leach and Saha, *Digital Principles and Applications*, Tata Mc. Graw Hill, 2014.

9. Floyd T. L., *Digital Fundamentals (8th Edition)*, Pearson Education Asia, 2011.

10. John F. Wakerley, *Digital Design Principles, and Practices (4th Edition)*, Prentice Hall, 2006. 11.Virtual lab resources: https://www.vlab.co.in/broad-area-electronics-and-communications

PH6306E COMPUTATIONAL PHYSICS: THEORY AND LAB

Pre-requisites: Nil

L	T	P	O	C
2	0	2	5	3

Total Sessions: 26L + 26P

Course Outcomes:
CO1: Acquire basic programming skills for solving complex physics and engineering problems.
CO2: Apply numerical methods for solving systems of linear, and non-linear equations relevant to physics and engineering.
CO3: Apply interpolation and curve fitting methods for analyzing and interpreting scientific data.
CO4: Implement numerical methods for evaluating integrals and solving ordinary differential equations relevant to physics and engineering problems.

Lecture Sessions:

Programming with Python/Matlab: basics, operators, controls: if-else – loops: for and while – arrays and matrices – functions – plotting and graphics – good programming practices – testing and debugging..

Roots of non-linear functions: bisection method, Newton-Raphson and secant method, convergence – applications to quantum mechanics: finite potential well, double well, etc. – Systems of linear equations: Gauss and Gauss-Jordan elimination, matrix inversion – Simultaneous non-linear equations: Newton-Raphson method – applications: nonlinear dynamics, electrical networks, etc.

Interpolation: Newton's interpolation, Lagrange interpolation – Regressions and curve fitting: general (weighted) least square fitting, linear and non-linear, continuous functions and orthogonal polynomials.

Numerical integration: trapezoidal, Simpson's methods, errors and corrections, Romberg integration, adaptive step sizes – Ordinary differential equations: Euler's methods, Runge-Kutta methods, convergence – applications to classical and quantum mechanics.

Practical Sessions:

List of Experiments

1. Finding roots of non-linear equations: bisection, Newton-Raphson method, secant method ,Linear Algebra and matrix methods.
2. Solving linear equations (Gaussian elimination, Gauss -Jordan method, etc.) and matrix eigenvalue problems.
3. Integration and methods: Trapezoidal rule and Simpsons' rule
4. Solving ODE: Euler's method, Modified Euler's method, Runge-Kutta method.
5. Interpolation: Newton interpolation and Lagrange interpolation.
6. Least squares curve fitting

References:

1. Paul DeVries and Javier Hasbun, *A First Course in Computational Physics, 2nd edition*, Jones and Bartlett, 2010.

2. Tao Pang, *An Introduction to Computational Physics, 2nd edition*, Cambridge University Press, 2006.

3. S. S. Shastry, *Introductory methods of numerical analysis, 3rd edition*, Prentice-Hall of India, 2003.

4. Steven C. Chapra, *Applied Numerical Methods, 3rd edition*, McGraw Hill, 2011.

PH6307E MATHEMATICAL PHYSICS - II

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Identify and analyse properties of functions of complex variables.
CO2: Employ relevant theorems of Complex Analysis in applications such as evaluation of integrals, inverse Laplace transforms, etc.
CO3: Handle application problems involving random variables and functions of random variables.
CO4: Identify group theoretic properties and utilize it to solve problems.

Complex plane - Complex functions - Limits, Continuity and Derivatives of Complex functions - Singularities, Branch Cuts and Branch points - Analytic functions - Cauchy-Riemann conditions - Contours and Contour Integrals - Cauchy-Goursat Theorem - Cauchy Integral Formula - Power Series, Taylor and Laurent Series - Residues and Poles - Residue theorem and application to evaluation of integrals - Inverse Laplace transforms - Applications in finding Green's functions.

Probability distributions and probability densities - Discrete and continuous probability distributions, examples of discrete and continuous distributions: Binomial, Geometric, Poisson, normal - central limit theorem.

Elements of group theory - Discrete groups with examples - finite groups - Abelian and non- Abelian groups - Representations - Characters - Continuous groups - Generators - Rotations and SO(3) Group - SU(2) - Applications to angular momentum in Quantum Mechanics.

References:

1. J. Brown and R. V. Churchill, *Complex Variables and Applications*, McGraw-Hill, 2013.
2. M. R. Spiegel, S. Lipschutz, J. J. Schiller and D. Spellman, *Complex Variables*, (Schaum's Series) McGraw-Hill, 2009.
3. S. M. Ross, *Introduction to Probability Models*, Elsevier, 2007.
4. H. Georgi, *Lie Algebras in Particle Physics*, Westview Press, 1999.

PH6308E ELECTROMAGNETIC THEORY - II

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Analyze propagation of electromagnetic waves in dielectric, conducting media, wave guides and cavities.
CO2: Formulate and solve problems involving time dependent electromagnetic fields using potential formalism.
CO3: Compute radiation fields and energy transfer for time varying charge and current distributions or accelerated charges.
CO4: Apply principles of relativity to electromagnetic fields and formulate these in a relativistically covariant manner.

Propagation in dielectric medium – refractive index – reflection and refraction at dielectric interfaces,normal and oblique angles – Fresnel equations – plane EM waves in conducting media – skin depth
Dispersion of electromagnetic waves – frequency dependent dielectric constant – wave groups and group velocity
Wave propagation in rectangular metallic wave guides – propagation modes in wave guides
– resonant modes in cavities.

Electric and Magnetic fields – Maxwell's equations – boundary conditions – scalar and vector potentials – gauge invariance – Lorentz and Coulomb gauge – inhomogeneous wave equation and solutions – retarded potentials – Jefimenko's equations – Lienard–Wiechert potentials – fields due to moving charges – electromagnetic radiation – electric and magnetic dipole radiation
– Larmor formula – Radiation reaction.

Special theory of relativity – Lorentz transformation – relativistic mechanics and dynamics – four– vectors inelectrodynamics – electromagnetic field tensor and Maxwell's equations – transformation of fields – fields of uniformly moving particles.

References:

1. D. J. Griffiths, *Introduction to Electrodynamics (4th Edition)*, PHI Learning - New Delhi, 2012.
2. J. D. Jackson, *Classical Electrodynamics (3rd Edition)*, Wiley, 2007.
3. D. J. Cheng, *Field and Wave Electromagnetics (2nd Edition)*, Pearson, 2014.
4. L. D. Landau and E. M. Lifshitz, *The Classical Theory of Fields (4th Edition)*, Elsevier, 1980.
5. J. Edminister, *Schaum's Outline: Theory and Problems in Electromagnetics (2nd Edition)*, McGraw-Hill, 1979.

PH6309E QUANTUM MECHANICS - II

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Investigate quantum mechanical systems using approximation methods.
CO2: Apply basic group theoretic techniques to simplify Quantum mechanical problems.
CO3: Analyze non-relativistic scattering problems using Born series and partial wave method.
CO4: Apply density matrix formalism and idea of entanglement to study simple systems.
CO5: Solve free Dirac and Klein - Gordon equation and interpret their solutions.

Time independent perturbation theory, degenerate perturbation theory – charged particle in electromagnetic fields – Time dependent perturbation theory, Dyson series, transition rate, examples
– sudden and adiabatic approximations – Fermi's golden rule – variational method, application to ground state of He-atom – WKB method.

SU(2) and angular momenta – tensor operators, Wigner-Eckart theorem – Identical particles, distinguishable and indistinguishable particles, symmetric and anti-symmetric wave functions – exchange degeneracy – bosons and fermions – Slater determinant – Pauli's exclusion principle
– incompletely known systems and density matrix, pure and mixed states – entropy, connection to partition functions.

Scattering theory, scattering cross section – Born approximation – partial wave analysis, hard sphere scattering.

Relativistic effects – Klein-Gordon equation – Dirac equation, Dirac matrices – spinors – positive and negative energy solutions – physical interpretation – non-relativistic limit of the Dirac equation

References:

1. Richard L. Liboff, *Introductory Quantum Mechanics (IV Ed.)*, Pearson education, 2003.
2. J. J. Sakurai , *Modern Quantum Mechanics (III Ed.)*, Addison Wesley, 1999.
3. R. Shankar, *Principles of Quantum Mechanics (II Ed.)*, Springer, 1994.
4. David. J. Griffiths, *Introduction to Quantum Mechanics (II Ed.)*, Pearson Education, 2005.
5. Nouredine Zettili, *Quantum Mechanics: Concepts and Applications (II Ed.)*, John Wiley, 2009.
6. J. D. Bjorken and S. D. Drell, *Relativistic Quantum Mechanics*, McGraw-Hill, 1964.
7. P. M. Mathews and K. Venkatesan, *A Textbook of Quantum Mechanics (II Ed.)*, McGraw Hill, 2017.
8. Albert Messiah, *Quantum Mechanics (II Ed.),Vol 1 and 2 combined edition*, Dover publishers, 1995.

PH6310E ATOMIC AND MOLECULAR PHYSICS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Analyze one-electron atoms quantum mechanically in increasing levels of complexity starting from the coarse structure to fine and hyperfine structure.
CO2: Interpret the spectrum of one-electron atoms in static magnetic and electric fields.
CO3: Compute quantum mechanically the rates of absorption, stimulated emission, and spontaneous emission in one-electron atoms interacting with electromagnetic waves.
CO4: Compute the spectrum of simple many-electron atoms using central field approximation.
CO5: Analyze spectral properties of diatomic molecules using quantum mechanical techniques.

Schrödinger equation for one-electron atoms, eigenfunctions of bound states, expectation values and virial theorem – Fine structure of hydrogenic atoms, fine structure splitting – Lamb shift – hyperfine structure and isotope shifts, magnetic dipole and electric quadrupole hyperfine structure
– Interaction of one-electron atoms with external electric and magnetic fields: linear and quadratic stark effect, Zeeman effect, Paschen – Back effect, anomalous Zeeman effect, quadratic Zeeman effect

Charged particles in electromagnetic field – transition rates: absorption, stimulated emission, spontaneous emission, Dipole approximation, Einstein coefficients – selection rules – spin of photon, Beth's experiment – line intensities and lifetimes of excited states – line shapes and width, pressure and Doppler broadening.

Two-electron atoms – many electron atoms – spin orbitals, Slater determinants – central field approximation – corrections to the central field approximation: L-S coupling and J-J coupling – Hartree Fock method – Thomas Fermi model of an atom – Density Functional theory.

Molecular symmetry – rotational spectroscopy – vibrational spectroscopy – Raman spectroscopy
– electronic spectroscopy of molecules – Frank-Condon principle – spin resonance spectroscopy.

References:

1. B. H. Bransden and C. J. Joachain, *Physics of Atoms and Molecules (II Ed.)*, Pearson Education , 2004.

2. R. Eisberg and R. Resnick, *Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles (II Ed.)*, Wiley, 2006.

3. C. J. Foot, *Atomic Physics*, Oxford University Press, 2005.

4. C. N. Banwell and E. M. McCash, *Fundamentals of Molecular Spectroscopy*, Tata McGraw Hill, 1994.

5. P. W. Atkins and R.S.Friedman, *Molecular Quantum Mechanics (III Ed.)*, Oxford Univ. Press, 1997.

PH6311E STATISTICAL PHYSICS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Apply the concepts of statistical ensemble theory to connect thermodynamic properties of systems to the statistical distribution of the microstates of the system.
CO2: Analyse properties of thermodynamic systems using microcanonical, canonical, and grand canonical ensembles.
CO3: Apply concepts of quantum statistical physics to various problems such as free electrons, photon gas, specific heat of solids, Bose-Einstein condensate.
CO4: Apply methods of statistical mechanics to characterize first-order and continuous phase transitions in liquid-gas and magnetic systems

Need for statistical physics – review of thermodynamics and basic probability theory – macro states and microstates: phase space, Liouville's theorem – fundamental postulate of equilibrium statistical mechanics – Ensemble Theory: microcanonical ensemble, Gibbs paradox, enumeration of microstates, canonical ensemble, partition function, free energy, calculation of thermodynamic quantities, entropy, fluctuations, grand canonical ensemble.

Classical ideal gas: Maxwell-Boltzmann distribution, equipartition theorem, virial theorem, specific heat of gases – Real gases – Magnetic system: Paramagnetism, Langevin and Brillouin functions, Curie's law – negative temperature concept – system of harmonic oscillators.

Systems of identical, indistinguishable particles: spin, symmetry of wavefunctions, bosons, fermions, Pauli's exclusion principle, Bose-Einstein and Fermi-Dirac distributions, degeneracy – Ideal Fermi gas and ideal Bose gas, Bose-Einstein condensation, Applications: free electron gas, radiation, specific heat of crystalline materials: Einstein and Debye theories, electronic contribution to specific heat of metals.

Introductory ideas on phase transitions – first-order phase transition – theory of Yang and Lee– Weiss theory of ferromagnetism – second-order phase transition – Landau theory – critical point exponents.

References:

1.R. K. Pathria, *Statistical Mechanics (2nd Edition)*, Butterworth-Heinemann, 1996.

2.K. Huang, *Statistical Mechanics (2nd edition)*, John Wiley, 1987.

3.F. Reif, *Fundamentals of Statistical and Thermal Physics*, McGraw Hill, 1985.

4.M. Kardar, *Statistical Physics of Particles*, Cambridge University Press, 2007.

5.H. B. Callen, *Thermodynamics and An Introduction to Thermostatics (2nd edition)*, Wiley, 1985.

6.E. A. Jackson, *Equilibrium Statistical Mechanics*, Prentice-Hall, 1968.

PH6381E GENERAL PHYSICS LAB

Pre-requisites: **Nil**

L	T	P	O	C
0	0	3	3	2

Total Practical Sessions: 39

Course Outcomes:
CO1: Apply principles of mechanics, quantum, atomic and nuclear theory for experimentation.
CO2: Develop skills for data analysis and interpretation.
CO3: Set up experiments, take observations and relate it with a suitable theory.
CO4: Build ability for group discussion and critical thinking for collaborative work.

List of Experiments:

1. Study of magnetoresistence of a semiconductor
2. Energy band gap - Four probe method
3. Zeeman effect
4. e/m of electron
5. Frank – Hertz experiment
6. Elastic constants – Cornu's method
7. Michelson's interferometer
8. GM counter
9. Dipolemeter
10. Measurement of thermal conductivity

References:

1.B. L. Worsnop and H. T. Flint, *Advanced Practical Physics for students*, Asia Publishing House, 1971.

2.S.L. Gupta and V. Kumar, *Practical Physics*, Pragathi Prakashan, 2005.

PH6382E ELECTROMAGNETICS LAB

Pre-requisites: Nil

L	T	P	O	C
0	0	3	3	2

Total Practical Sessions: 39

Course Outcomes:
CO1: Apply principles electromagnetic theory and characterize rectangular waveguides.
CO2: Measure unknown impedance and characterize microwave devices such as multihole directional coupler, magic-T, attenuators and horn-antenna.
CO3: Measure dielectric constant of low-loss dielectric materials.
CO4: Analyze experimental data, draw inferences and prepare reports; develop soft skills necessary for working effectively in a team environment.
CO5: Simulate electromagnetic phenomena and design advanced electromagnetic wave components.

List of Experiments

1. Study of Klystron Characteristics (AM and FM Mode) and Measurement of Frequency and Wavelength in a Rectangular Waveguide.
2. Measurement of VSWR and Reflection Coefficient
3. Impedance Measurement and Smith Chart
4. Study of Fixed and Variable Attenuators
5. Characteristics of Multihole-Directional Coupler
6. Study of Magic-T
7. Horn Antenna Obtain the radiation pattern both experimentally and computationally))
8. Measurement of Dielectric Constant (Solid and Liquid)
9. Simulation: Study the electrodynamics of negative index medium with 2-D numerical computations
10. Compute the electromagnetic bandstructure of a 2-D photonic crystal and verify the bandgap through transmission/reflection calculation
11. Design dielectric and metallic cavity resonators and solve their eigenmodes numerically
12. .Solve 3-D electrostatic boundary value problem numerically for a given set of boundaryconditions.
13. Obtain surface plasmon polariton resonances using Kretschmann-Raether and Otto configurations. Compute the dispersion relation of hyperbolic metamaterial and study its electromagnetic response at microwave frequencies.

References:

1. R. S. Rao, *Microwave Engineering*, Prentice Hall India, 2012.
2. Raymond C. Rumbpf, *Electromagnetic and Photonic Simulation for the beginner*, Artec Press, 2022.
3. MIT Photonic Bands (Open Solver): https://mpb.readthedocs.io/en/latest/
4.Comsol RF Module: www.comsol.com

PH6391E MINI PROJECT

Pre-requisites: Nil

L	T	P	O	C
0	0	0	6	2

Course Outcomes:
CO1: Carry out literature review and collate information from multiple sources.
CO2: Identify research gaps.
CO3: Explain their research findings in written/oral modes.

The ’Mini Project’ aims at introducing the students to various areas of research in Pure and Applied Physics. The student shall choose a topic in consultation with their guide(s), carry out extensive literature survey from books, journals and other sources and identify research gaps. For the course evaluation, the student shall submit a written report as well as an oral presentation to a duly constituted committee.

PH7301E NUCLEAR AND PARTICLE PHYSICS

Pre-requisites: PH6309E

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: use different nuclear models to explain the properties of various nuclei
CO2: apply ideas of quantum mechanics to analyse the radioactive decay of nuclei
CO3: explain the working of nuclear reactors, particle detectors and accelerators
CO4: organise various elementary particles in terms of the quantum numbers

General properties of nuclei: decay, binding energies and forces – isospin symmetry – magic numbers – nuclear models: liquid drop model, shell model – the shell model potential, spin-orbit potential – ground state spins and parities of nuclei – excited states.

Nuclear decay: alpha, beta and gamma emission – theory of alpha decay and barrier penetration – basic beta decay process – energy release in beta decay – Fermi's theory of beta decay – non- conservation of parity in beta decay – energetic of gamma decay – angular momentum and parity selection rules – life times for gamma emission.

Nuclear reactions: classification and kinematics – nuclear fission – chain reactions – criticality and multiplication – nuclear reactors – nuclear fusion – radiation interaction with matter – radiation detection – detectors and counters: gas-filled counters, scintillation detectors, semiconductor detectors – particle accelerators: linear accelerator, cyclotron, synchrotron.

Elementary particles: interaction, strength and classification – symmetries and conservation laws – angular momentum – baryon number – lepton number – isospin and SU(2) – eight-fold way and the quark model – color quarks and gluons – parity, charge conjugation and time reversal – neutral kaons and CP violation – CPT theorem.

References:

1. K. S. Krane, *Introductory Nuclear Physics*, John Wiely & Sons, 1988.
2. K. Heyde, *Basic Ideas and Concepts in Nuclear Physics: An Introductory Approach (III Ed.)*, IOP publishing, 2004.
3. W. N. Cottingham and D. A. Greenwood, *An Introduction to Nuclear Physics (II Ed.)*, Cambridge University Press, 2001.
4. F. Halzen and A. D. Martin, *Quarks and Leptons (II Ed.)*, Wiley, 2008.
5. D. H. Perkins, *Introduction to High Energy Physics (IV Ed.)*, Cambridge, 2000.
6. D. Griffths, *Introduction to Elementary Particles (II Ed.)*, Wiley, 2008.

PH7302E CONDENSED MATTER PHYSICS

Pre-requisites: Nil

L	T	P	O	C
3	1	0	8	4

Total Lecture Sessions: 39

Course Outcomes:
CO1: Differentiate between different lattice types and explain the concepts of reciprocal lattice and crystal diffraction.
CO2: Distinguish different excitations in crystals and explain the specific heat.
CO3: Apply free electron model and interpret the properties of metals.
CO4: Explain the concept of energy bands and use it to find electrical properties of materials.
CO5: Explain electrical and magnetic properties of materials.

Crystal Physics: a brief overview of crystal structure, reciprocal lattice, Bragg's law of diffraction – Lattice Vibrations and Thermal Properties – Monoatomic and diatomic lattices, normal modes of lattice vibration, phonons and density of states, dispersion curves – Specific heat: classical, Einstein and Debye models – Thermal conductivity.

Free Electron theory: Dependence of electron energy on the wave vector, E-k diagram – Free electron theory of metals- Thermal and Electrical transport properties, Electronic specific heat, Fermi surface – Failures of free electron theory – Bloch theorem – Nearly free electron model and origin of energy bands.

Energy Band Theory: Kronig-Penney Model, tight binding approximation – Motion of electrons in bands and effective mass – Semiconductors: Intrinsic and extrinsic semiconductors, Charge carrier density in intrinsic semiconductors, Doping, Carrier densities in doped semiconductors.

Dielectric properties of insulators – Pizoelectric and Ferroelectric materials – Optical properties of solids – Magnetism-exchange interaction, diamagnetism, paramagnetism, ferromagnetism and antiferromagnetism.

References:

1.C. Kittel, *Introduction to Solid State Physics*, Wiley, 2007.

2.N. D. Mermin and N. Ashcroft, *Solid state Physics*, Thomson, 2007.

3.H. Iback and H. Lüth, *Solid State Physics*, Springer, 2009.

4.S. Elliot, *The Physics and Chemistry of Solids*, John Wiley & Sons, 1998.

5.A. Omar, *Elementary Solid State Physics*, Addison-Wesley , 2005.

PH7303E OPTICS: THEORY AND LAB

Pre-requisites: Nil

L	T	P	O	C
1	0	3	5	3

Total Sessions: 13L + 39P

Course Outcomes:
CO1: Apply the concepts of ray optics, electromagnetic theory, interference, diffraction and polarization to design basic optical instruments.
CO2: Apply the concepts of interference and diffraction to gain the basics of optical instrumentations.
CO3: Apply the principles of polarization to develop different instruments based on polarizers.
CO4: Apply the principle of fiber optics to design optical instruments for various applications.

Lecture Sessions:

Geometrical and physical optics – Fermat's principle and applications – matrix methods in paraxial optics – aberrations: classifications and correction methods – Fresnel equations – reflection: external and internal – phase changes on reflection – Principle of superposition – Michelson, Fabry-Perot and Mach-Zehnder interferometers – Optical cavity – Coherence – single slit diffraction
– beam spreading – rectangular and circular apertures – Rayleigh's criterion of resolution of optical instruments – diffraction grating – production of polarized light – dichroism – birefringence
– phase plates and optical activity – fiber optics – laser safety protocol.

Practical Sessions:

List of Experiments

1.Reflection, Refraction and Fresnel coefficients

2.Michelson Interferometer

3.Mach Zehnder interferometer (with digital data analysis)

4.Fabry-Pérot interferometer

5.Diffraction experiments: Gratings, slits and apertures

6.Production and characterization of polarized light

7.Electro-Optic effect

8.Faraday Effect

9.Fiber optics: Numerical aperture and coupling losses

10.Cavity-enhanced/cavity-ring down absorption spectroscopy

Students are required to perform six experiments from the above list.

References:

1.F. L. Pedrotti, L. M. Pedrotti and L. S. Pedrotti, *Introduction to Optics (3rd Edition)*, Cambridge University Press, 2017.

2.Hecht, E., *Optics,* Pearson Education, 2003. 3.Ghatak,

A., *Optics*, Tata McGraw-Hill, 2010.

4.Ghatak, A. and Thyagarajan, K., *Introduction to Fiber Optics*, Cambridge University Press, 2011.

PH7381E SOLID STATE PHYSICS LAB

Pre-requisites: Nil

L	T	P	O	C
0	0	3	3	2

Total Practical Sessions: 39

Course Outcomes:

CO1: Apply principles of solid state physics and characterize materials.
CO2: Set up experiments and measure physical quantities.
CO3: Analyze experimental data, draw inferences and relate them with a suitable theory.
CO4: Develop skills for group discussion and critical thinking for collaborative work

List of Experiments

1. Measurement of specific heat capacity
2. Measurement of temperature coefficient of resistance
3. Study the variation of dielectric constant with temperature and determine the Curie temperature
4. Study the variation of junction voltage of a diode with temperature and determine the forbidden energy gap
5. Measurement of magnetic susceptibility by Quinck's tube method
6. Measurement of magnetic susceptibility by Gouy's balance method
7. Determine the Curie temperature of a given ferrite sample using magnetic hysteresis loop tracer experiment
8. Measurement of dielectric constant as a function of frequency
9. Hall effect at various temperatures
10. Study of magneto-resistance
11. Thin film deposition and characterization A total of eight experiments to be done.

References:

1. Dieter K. Schroder, *Semiconductor Material and Device Characterization (3rd Edition)*, Wiley, 2008.
2. Kittel C, *Introduction to Solid State Physics*, Wiley, 2007.
3. Milton Ohring, *The Materials Science of Thin Films*, Academic Press, 1992.

PH7391E PROJECT PHASE I

Pre-requisites: Nil

L	T	P	O	C
0	0	0	9	3

Course Outcomes:
CO1: Identify research problems and carry out literature survey.
CO2: Analyse and solve research problems.
CO3: Document research findings as documents and explain them in presentations.

The student, in consultation with their guide(s), shall identify a problem and carry out re- search work on it. The evaluation will be based on the internal evaluation by the guide, a written report documenting the work they have carried out and an oral presentation to a duly constituted committee.

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PH7392E PROJECT PHASE II

Pre-requisites: Nil

L	T	P	O	C
0	0	0	18	6

Course Outcomes:
CO1: Identify research problems and carry out literature survey.
CO2: Analyse and solve research problems.
CO3: Document research findings as documents and explain them in presentations.

The student, in consultation with their guide(s), shall identify a problem and carry out research work on it, or shall carry out an internship at a reputed organization. The evaluation will be based on the internal evaluation by the guide, a written report documenting the work they have carried out and an oral presentation to a duly constituted committee

IE6001E ENTREPRENEURSHIP DEVELOPMENT

Pre-requisites: Nil

L	T	P	O	C
2	0	0	4	2

Total Lecture Sessions: 26

Course Outcomes:
CO1: Describe the various strategies and techniques used in business planning and scaling ventures.
CO2: Apply critical thinking and analytical skills to assess the feasibility and viability of business ideas.
CO3: Evaluate and select appropriate business models, financial strategies, marketing approaches, and operational plans for startup ventures.
CO4: Assess the performance and effectiveness of entrepreneurial strategies and actions through the use of relevant metrics and indicators.

Entrepreneurial Mindset and Opportunity Identification
Introduction to Entrepreneurship Development – Evolution of entrepreneurship, Entrepreneurial mindset, Economic development, Opportunity Recognition and Evaluation – Market gaps – Market potential, Feasibility analysis – Innovation and Creativity in Entrepreneurship – Innovation and entrepreneurship, Creativity techniques, Intellectual property management. .

Business Planning and Execution
Business Model Development and Validation – Effective business models, Value proposition testing, Lean startup methodologies – Financial Management and Funding Strategies – Marketing and Sales Strategies – Market analysis, Marketing strategies, Sales techniques – Operations and Resource Management – Operational planning and management, Supply chain and logistics, Stream wise Case studies.

Growth and Scaling Strategies
Growth Strategies and Expansion – Sustainable growth strategies, Market expansion, Franchising and partnerships – Managing Entrepreneurial Risks and Challenges – Risk identification and mitigation, Crisis management, Ethical considerations – Leadership and Team Development – Stream wise Case studies.

References:

1. Kaplan, J. M., Warren, A. C., and Murthy V., *Patterns of entrepreneurship management (Indian Adoption),* John Wiley & Sons, 2022.
2. Kuratko, D. F., *Entrepreneurship: Theory, process, and practice*, Cengage learning, 2016.
3. .Barringer, B. R., *Entrepreneurship: Successfully launching new ventures*, Pearson Education India, 2015.
4. Rajiv Shah, Zhijie Gao, and Harini Mittal, *Innovation, Entrepreneurship, and the Economy in the US, China, and India,* Academic Press, 2014.
5. Sundar, K., *Entrepreneurship Development (2nd Edition)*, Vijaya Nichkol Imprints, Chennai, 2022.

6.E. Gordon, and Dr. K. Natarajan., *Entrepreneurship Development*, 6th Edition, Himalya Publishers, Delhi.2017

7.Debasish Biswas and Chanchal Dey, *Entrepreneurship Development in India*, Taylor & Francis, 2021.

ZZ6003E RESEARCH METHODOLOGY

Pre-requisites: Nil

L	T	P	O	C
2	0	0	4	2

Total Lecture Sessions: 26

Course Outcomes:
CO1: Explain the basic concepts and types of research.
CO2: Develop research designs and techniques of data analysis.
CO3: Execute efficient and optimum methods of data collection and analysis.
CO4: Carry out effective data interpretation and to consolidate research reports

Exploring Research Inquisitiveness
Philosophy of Scientific Research – Role of Research Guide – Planning the Research Project – Research Process – Research Problem Identification and Formulation – Variables – Framework development – Research Design: Types of Research, Sampling, Measurement, Validity and Reliability, Survey – Designing Experiments, – Research Proposal – Research Communication
– Research Publication: Structuring a research paper, structuring thesis/ dissertation.

Systematics and Ethics of Research
Hypothesis–driven research: experiment design, improving experiments – Codes of ethics: scientific misconduct, Plagiarism, Authorship, Regulation of research – Intellectual property rights: copyright, patents, designs – Peer review – Citation metrics – Safety measures: laboratory, human, animal and environment.

Sample Surveys and Test of Hypotheses
Design of Sampling: Introduction, Sample Design, Sampling and Non–sampling Errors, Sample Survey versus Census Survey – Measurement and Scaling: Qualitative and Quantitative Data, Classifications of Measurement Scales – Selection of Appropriate Method for Data Collection – Testing of Hypotheses, P–Value approach, Test of Independence of Attributes, Test of Goodness of Fit, Chi Square Tests – Correlation and Regression – Simple regression analysis.

References:

1. Krishnaswamy, K. N., Sivakumar, A. I., and Mathirajan, M., *Management Research Methodology*, Pearson Education, 2006.
2. Leedy, P, D., *Practical Research: Planning and Design (12th Edition)*, Pearson, 2018.
3. Michael P. Marder, *Research Methods for Science*, Cambridge University Press, 2011.
4. C.R. Kothari and Gaurav Garg, *Research Methodology: Methods and Techniques (4th Edition)*, New Age International, 2018.
5. Ranjit Kumar, *Research Methodology: A Step-bystep Guide for Beginners (3rd Edition)*, Sage Publications Ltd, 2011.
6. Trochim, *Research Methods: The Concise Knowledge Base*, Atomic Dog Publishing, 2005.

MS6174E TECHNICAL COMMUNICATION AND WRITING

Pre-requisites: Nil

L	T	P	O	C
2	0	0	4	2

Total Lecture Sessions: 26

Course Outcomes:
CO1: Apply effective communication strategies for different professional and industry needs.
CO2: Collaborate on various writing projects for academic and technical purposes.
CO3: Combine attributes of critical thinking for improving technical documentation.
CO4: Adapt technical writing styles to different platforms.

Technical Communication
Process(es) and Types of Speaking and Writing for Professional Purposes – Technical Writing: Introduction, Definition, Scope and Characteristics – Audience Analysis – Conciseness and Coherences – Critical Thinking - Accuracy and Reliability – Ethical Consideration in Writing – Presentation Skills – Professional Grooming – Poster Presentations.

Grammar, Punctuation and Stylistics
Constituent Structure of Sentences – Functional Roles of Elements in a Sentence – Thematic Structures and Interpretations – Clarity – Verb Tense and Mood – Active and Passive Structures – Reporting Verbs and Reported Tense – Formatting of Technical Documents – Incorporating Visuals Elements – Proofreading.

Technical Documentation
Types of Technical Documents: Reports, Proposals, Cover Letters – Manuals and Instructions – Online Documentation – Product Documentation – Collaborative Writing: Tools and Software – Version Control Document Management – Self Editing, Peer Review and Feedback Processes.

References:

1. Foley, M., and Hall, D., *Longman advanced learner's grammar, a self-study reference & practice book with answers*, Pearson Education Limited, 2018.
2. Gerson, S. J., and Gerson, S. M., *Technical writing: Process and product*, Pearson, 2009.
3. Kirkwood, H. M. A., and M., M. C. M. I., *Hallidays introduction to functional grammar (4th Edition)*, Hodder Education, 2013.
4. Markel, M., *Technical Communication (10th Edition)*, Palgrave Macmillan, 2012.
5. Tuhovsky, I., *Communication skills training: A practical guide to improving your social intelligence, presentation, Persuasion and public speaking skills*, Rupa Publications India, 2019.
6. Williams, R., *The Non-designer's Design Book*, Peachpit Press, 2014.

PH7320E GENERAL THEORY OF RELATIVITY

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Perform calculations compatible with special relativity and examine classical field theories.
CO2: Analyse manifolds using the techniques of Riemannian geometry.
CO3: Obtain Einstein Field Equations or generalizations thereof.
CO4: Solve simple systems of relevance in Gravitational physics.

Review of Special Relativity (SR) – Global inertial frames, four-vectors and tensors in SR, covariant vectors and tensors – Covariance of equations under Lorentz transformations

Classical field theory of a real scalar field: action, Lagrangian density, Euler-Lagrange field equation – The mass-less vector field: Lagrangian – Conserved currents and Noether's theorem – Stress energy tensor – Perfect fluids.

General coordinate invariance, Principle of Equivalence – Tensors in curved space-time, connection, parallel transport, geodesics, covariant derivative, Curvature tensors, Lie Derivatives – Bianchi identities – Einstein's field equations.

Schwarzschild solution, Birkoff theorem – Precession of the planetary orbits, bending of light, the gravitational red shift – Gravitational waves and their signatures.

References:

1. B. Schutz, *A first course in General Relativity*, Cambridge University Press, 1985.
2. S. M. Carroll, *Spacetime and Geometry*, Cambridge University Press, 2019.
3. S. Weinberg, *Gravitation and Cosmology*, John Wiley & Sons, 1972.
4. R. Wald, *General Relativity*, The Unviersity of Chicago Press, 1984.
5. C. W. Misner, K. Thorne, J. A. Wheeler, *Gravitation*, Princeton University Press, 2017.

PH7321E EXPERIMENTAL TECHNIQUES

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Analyses of IR and Raman data using the basic principle of vibrational spectroscopy.
CO2: Analyses of the resonance spectroscopy and photoelectron spectroscopy data.
CO3: Understand the basic operation principle of optical microscopy and its design.
CO4: Understand the principle of operation of electron microscopy and the interpretation of data.

Infra-red spectroscopy, vibrations of polyatomic molecules, normal modes of vibration in crystals, isotope effect, Fourier transform IR, IR spectrophotometer, analysis of IR spectrum – Raman Spectroscopy, theory of Raman scattering, rule of mutual exclusion principle, Resonance Raman scattering, major components of Raman spectrometer, sampling handling techniques, fluorescence problems, Raman microscopy, analysis of Raman data.

Electronic spectroscopy of molecules, photoluminescence spectroscopy – Nuclear magnetic resonance spectroscopy, resonance condition, NMR instrumentation, relaxation systems – Electron spin resonance spectroscopy principle, ESR spectrometer, hyperfine structure, ENDOR – Surface spectroscopy, photoelectron spectroscopy, instrumentation, analysis of XPS/UPS data.

Optical imaging and microscopy, basic optical microscope, finite tube length microscopes, infinity corrected microscopes, Kohler illumination, critical illumination – Bright field microscopy, dark field microscopy, phase-contrast microscopy, confocal microscopy.

Scanning electron microscopy (SEM), BSE and SE image formation, SEM image interpretation, energy dispersive x-ray spectrum – Transmission electron microscopy (TEM), modes of operation of a TEM, SAED, z-contrast imaging – Scanning tunneling microscopy (STM), principle of operation
– Atomic force microscopy (AFM), modes of operation of AFM.

References:

1. Colin Banwell and Elaine Mccash, Fundamentals of Molecular Spectroscopy, McGraw Hill Education; Fourth edition (2017).
2. John Ferraro, Introductory Raman Spectroscopy, Academic Press (1994).
3. Peter Larkin, Infrared and Raman Spectroscopy Principles and Spectral Interpretation, Elsevier, (2011).
4. Jan Toporski, Thomas Dieing, Olaf Hollricher, Confocal Raman Microscopy, Springer Cham (2018).
5. Douglas B. Murphy, Michael W. Davidson, Fundamentals of Light Microscopy and Electronic Imaging, Second Edition, Wiley-Blackwell, 2013.
6. Tomasz S. Tkazyk, Field Guide to Microscopy, SPIE Press Bellingam, USA (2010).
7. Joseph I. Goldstein, Dale E. Newbury, Joseph R. Michael, Nicholas W.M. Ritchie, John Henry J. Scott, David C. Joy, Scanning Electron Microscopy and X-Ray Microanalysis, Springer, (2018).
8. Brent Fultz James M. Howe, Transmission Electron Microscopy and Diffractometry of Materials, Springer Nature (2013).

PH7322E PHYSICS OF CLIMATE

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Understand the components of the global climate system.
CO2: Understand the physical principles behind the dynamics of climate system.
CO3: Understand the radiation balance and processes contributing to greenhouse effect.
CO4: Understand atmospheric general circulation and climate variability.

Components of climate system: Structure and composition of the atmosphere – the hydrosphere: properties of water, the hydrologic cycle, measuring the water content of the atmosphere – cryosphere – biosphere – Radiation- Sun as primary source of energy for the earth, black body radiation and solar radiation spectrum, albedo, radiation balance at the Earth's surface and determination of surface temperature, UV radiation, ozone layers and depletion, greenhouse effect, the carbon cycle, atmospheric aerosols and their effect on radiation balance.

Laws of thermodynamics – energy transfers: conduction, convection, radiation, evaporation – ideal gas model: virtual temperature – the hydrostatic equation: geopotential, hypsometric equation, thickness and heights of constant pressure surfaces – exponential variation of pressure with height – temperature structure and lapse rate – Stability: unsaturated air, saturated air, conditional and convective instability – Applications of second law – Cloud microphysics: nucleation, growth of droplets in warm clouds: growth by condensation, growth by coalescence.

Atmospheric dynamics: Navier Stokes theorem, continuity equation, general idea about synoptic and meso-scale disturbances – Entropy in the climate system – Winds in the atmosphere: measuring wind, origin of winds: the atmosphere as a heat engine – the principal forces acting on an air parcel – divergence, vorticity and momentum balance – cyclones and anticyclones, thermal gradients and winds – global convection, and global circulation – Angular momentum cycle – Energetics: energy equations, observed energy balance, polar energetic – nature of climate system: climate state and climate variability, inter annual and inter decadal variability – climate cycles: El Nino, North Atlantic Oscillation – the Ocean structure and the thermohaline circulation.

References:

1. J. P. Peixoto and A. H. Oort, *Physics of Climate*, AIP & Springer Verlag, 1992.
2. N. Mason and P. Hughes, *Introduction to Environmental Physics: Planet Earth, Life and Climate*, Taylor and Francis, 2001.
3. M. L. Salby, *Physics of the Atmosphere and Climate*, Cambridge University Press, 2012.
4. Boeker and van Grondelle, *Environmental Science: Physical Principles and Applications*, Wiley, 2001.

PH7323E ATMOSPHERIC DYNAMICS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Describe the dynamics of weather systems on a synoptic scale and apply dynamic meteorology on synoptic weather.
CO2: Account for processes influencing the development of high and low pressure systems.
CO3: Account for the effect that the earth's surface has on the atmospheric circulation.
CO4: Interpret and analyse synoptic weather charts.

Introduction: The scope of dynamical meteorology, scales and types of motion in the atmosphere – Continuum Hypothesis, Lagrangian and Eulerian frames of references – velocity potential, stream function, two dimensional potential flows, Bernoulli's equation – Forces in geophysical fluids, scale analysis, structure of the atmosphere, coordinate systems – Conservation laws: Momentum equation in rotating coordinates, hydrostatic balance, continuity equation, thermodynamic energy equation – Viscous forces and diabatic processes.

Basic applications: Geostrophic wind and thermal wind balance – Ageostrophic flow and secondary circulation – Elements of weather analysis (maps) – Dry / moist thermodynamics and vertical stability – Mesoscale thermal circulations – Vorticity: Circulation and vorticity, barotropic vorticity, potential vorticity, Ertel-Rossby potential vorticity – Perturbation theory and atmospheric oscillations: Phase velocity, Group Velocity, Dispersion, Sound waves, Gravity waves, Inertial Waves, Rossby waves, Rossby-Haurwitz waves, Mountain waves, Lee waves, Stationary planetary waves.

Momentum and energy transports by waves in the horizontal and the vertical – Log-Pressure Coordinate System, Equatorial Beta plane Approximation – Atmospheric Kelvin and Mixed Rossby Gravity Waves – Quasi-geostrophic theory: QG scale analysis and approximations – Towards a prognostic set of equations: QG tendency and potential vorticity equations – Diagnosing vertical motion: the omega equation (Q-vectors vs traditional form).

Baroclinic instability: Introducing turbulence on a planetary scale, polar front and storm tracks – Features of extratropical cyclones – Cyclogenesis theory – Introduction to general circulation: the planetary atmospheric circulation, observed features and example theoretical models (e.g., the Rossby model for stationary eddies) – Variability at different time scales.

References:

1. J. R. Holton, *Introduction to Dynamical Meteorology (4th Edition)*, Academic Press, 2004.
2. J. Marshall and R. A. Plumb, *Atmosphere, Ocean, And Climate Dynamics: An Introductory Text*, Elsevier Academic Press, 2008.
3. M. L. Salby, *Physics of the Atmosphere and Climate*, Cambridge University Press, 2012.
4. M. Mak, *Atmospheric Dynamics*, Cambridge University Press, 2011

PH7324E ADVANCED TOPICS IN CONDENSED MATTER PHYSICS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Analyze the dielectric properties of materials and the physics of ferroelectricity.
CO2: Apply the quantum mechanical model to analyze the magnetic properties of materials.
CO3: Analyze the superconductivity in materials and evaluate its potential applications.
CO4: Use the transport models to analyze the charge transport through mesoscopic systems.

Band theory of solids- a brief overview – Elementary ideas of band structure calculations – Concept of effective mass – Effective mass of electron and hole in semiconductors, Hall effect measurement – Dielectric properties-dielectric constant and polarizability, local electric field, Clausius-Mossotti equation, classical theory of dipolar polarizability, ionic polarizability, electronic polarizability – Ferroelectricity, ferroelectric domains, multiferroics.

Magnetism- Langevin’s classical theory of diamagnetism, Quantum theory of diamagnetism and paramagnetism, Hund’s rules – Pauli paramagnetism – Ferromagnetism – Heisenberg model, mean field theory, spin waves, giant and colossal magnetoresistance.

Superconductivity- Basic properties of the superconducting state, Meissner effect, critical field– London equation – Type I and II superconductor – Isotope effect, Penetration depth, Coherence length, Thermodynamics of superconducting transition, superconducting band gap – Concept of Ginzburg Landau theory – Cooper pairs, BCS theory (qualitative), flux quantization, Josephson effect, SQUID, High temperature superconductors – Applications- Magnetic Shielding, Power Transmission and Medical Applications.

Electron Phonon interaction- Polarons, transport phenomena – Boltzmann transport equation, relaxation time approximation, application to lattice and electronic conduction in insulators and metals – Disorder in condensed matter, Anderson localization and hopping transport – Transport in mesoscopic systems – Quantum Hall effect.

References:

1.Kittl C., *Introduction to Solid State Physics*, Wiley, 2007.

2.N. D. Mermin and N. Ashcroft, *Solid state Physics*, Thomson, 2007.

3.H. Iback and H. Lüth, *Solid State Physics*, Springer, 2009. 4.Michael

P. Marder, *Condensed Matter Physics*, Wiley, 2000.

5.Michael Tinkham, *Introduction to superconductivity (2nd Edition)*, Dover Books, 2004.
6.J. Robert Schrieffer, *Theory of Superconductivity*, CRC Press, 1964.

7.T. V. Ramakrishnan and C. N. R. Rao, *Superconductivity Today*, Wiley, 1992.

8.Supriyo Dutta, *Electronic Transport in Mesoscopic Systems*, Cambridge University Press, 1995.

PH7325E PHASE TRANSITIONS AND CRITICAL PHENOMENA

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Characterize phase transitions and analyze stability of thermodynamic systems.
CO2: Apply the concept of Ising Model to understand phase transitions in model systems.
CO3: Setup transfer matrices and calculate free energies and correlation functions in model systems.
CO4: Apply Monte Carlo methods to discrete spin models.

Critical Phenomena: Phase transitions in different systems – First order and second order – Thermodynamics and statistical mechanics of phase transition – Critical point exponents and exponent inequalities.

Models: Spin-1/2 and Spin-l Ising Models – q-state Potts model – X-Yand Heisenberg models – Universality – Mean Field Theory: Mean Field Theory for Ising model – Landau theory – Correlation functions – Classical mean field theories – Scaling hypothesis

Transfer matrix: Setting up the transfer matrix – Calculation of free energy and correlation functions – Results of Ising model. Series Expansion- High and low temperature series – application in I-d Ising model – Analysis of series.

Monte Carlo: Importance sampling – Metropolis algorithm – Data analysis – statistical error – finite-size effect – Examples - Renormalization Group: Definition of a RG transformation – Flow in parameter space – Universality – Scaling and critical exponents – scaled variables – Application in 1-d Ising model.

References:

1. H. E. Stanley, *Introduction to Phase transitions and Critical Phenomena*, Oxford, 1971.
2. J. M. Yeomans, *Statistical Mechanics of Phase Transtions,* Oxford, 1992.
3. K. Huang, *Statistical Mechanics*, John Wiley, 2000.

PH7326E ORGANIC ELECTRONICS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Explain about structure and properties of organic materials and their application in various electronic devices.
CO2: Apply the charge transport mechanism in various organic semiconducting systems and devices.
CO3: Apply impedance analysis on various organic and inorganic semiconducting devices.
CO4: Explain the optical properties of organic semiconducting materials and their application in devices such as light emitting diode, solar cell, etc.

Electronic structure: hybridization of atomic orbitals, molecular orbitals – Traditional polymers and conducting polymers – Electronic structure of trans-polyacetylene – Peierls instability – Conjugational defects, Solitons and Polarons – Doping of conducting polymers – Examples of organic semiconductors and methods of developing organic semiconductor

Charge transport in organic semiconductors- effect of disorder – Anderson localization, variable range hopping – Measuring conductivity- four probe measurements – Impedance measurements – Charge carrier mobility and experimental methods for measuring carrier mobility – Time of flight and Field effect transistor mobility measurements.

Organic semiconducting devices- Charge injection at metal/organic interface – Schottky and Ohmic contacts – Metal/organic/metal junctions, organic diodes, space charge and trap limited currents – Top and bottom contact organic field effect transistors (OFETs) – Thin film coating techniques for devices fabrication.

Organic light emitting diodes (OLEDs): principle and device architecture – Efficiency of OLED and factors affecting efficiency – White light emission – Organic solar cells- operating principles and device architectures – Light absorption and exciton formation, exciton diffusion and dissociation, charge transport and collection – Factors affecting efficiency and stability.

References:

1. S. Roth and D. Carroll, *One-Dimensional Metals (2nd Edition)*, Wiley VCH, 2004.
2. W. Brutting and C. Adachi (Editors), *Physics of Organic Semiconductors (2nd Edition)*, Wiley VCH, 2012.
3. A. J. Heeger, E. B. Namdas, and N. S. Sariciftci, *Semiconducting and Metallic Polymers*, Oxford Graduate Texts, 2010.
4. Hagen Klauk (Editor), *Organic Electronics: Materials, Manufacturing and Applications*, Wiley VCH, 2006.
5. H. S. Nalwa (Editor), *Handbook of Advanced Electronic and Photonic Materials and Devices*, Academic Press, 2000.

PH7327E ADVANCED STATISTICAL MECHANICS

Pre-requisites: Statistical Mechanics

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Apply the concept of mean-field theory for qualitative description of phase transitions.
CO2: Analyze critical behaviour of model systems using exact calculations and approximation methods.
CO3: Apply Monte-Carlo methods for studying properties of physical models near phase transitions.

Mean-field theory for continuous phase transition: Ising model, Bragg-Williams approximation, Bethe approximation, critical behaviour, Landau theory of phase transitions, Landau-Ginzburg theory for fluctuations – Exactly solvable models: one dimensional and two dimensional Ising model – Series expansions: high temperature expansion, low temperature expansion – Numerical simulations: thermal averages, importance sampling, Monte-Carlo method - Metropolis method, critical slowing down.

Scaling hypothesis: The homogeneity assumption, dimensional analysis, scaling form, universality – Real space renormalization: Kadanoff block spins, fixed points - general discussion, critical exponents, application of real space renormalization - one dimensional and two dimensional Ising model, Monte-Carlo renormalization group.

Momentum space renormalization: formal discussion, Gaussian model - direct solution and renormalization group approach – Perturbative renormalization group: Expectation values in the Gaussian model, expectation values in perturbative theory, diagramatic representation of perturbation theory, susceptibility, first order perturbative RG, second order perturbative RG, ϵ-expansion.

References:

1. M. Plischke and B. Bergersen, *Equilibrium Statistical Physics (3rd Ed.)*, World Scientific, 2006.
2. M. Kardar, *Statistical Physics of Fields*, Cambridge University Press, 2007.
3. R. K. Pathria, *Statistical Mechanics (2nd Ed.)*, Elsevier, 1996.
4. J. J. Binney, N. J. Dowrick, A. J. Fisher, and M. E. J. Newman, *The Theory of Critical Phenomena*, Oxford Science Publications, 1992.
5. K. Huang, *Statistical Mechanics (2nd Ed.)*, Wiley, 2000.

PH7328E LASER PHYSICS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Describe and explain fundamental concepts in laser physics.
CO2: Distinguish between different line broadening mechanisms and apply in laser systems.
CO3: Design stable optical laser cavities and predict their performances.
CO4: Develop continuous and pulsed laser system with various gain media and assess their appropriate uses.
CO5: Assess different types of laser systems and their potential applications.

Laser fundamentals – Absorption – Spontaneous and stimulated emission – Einstein's coefficients – Optical gain – Electron oscillator model – Line broadening mechanisms and line shapes – Homogeneous and inhomogeneous broadening – Natural, Doppler and Collision broadening – Pumping schemes – Laser rate equations: two-level, three-level and four-level laser systems – Gain saturation – Saturable absorbers – Spectral and spatial hole burning – concept of a light amplifier.

Plane mirror resonator – Resonance frequencies – Cavity loss – Cavity lifetime – Quality factor – Spherical mirror resonators – Ray paths in the resonator – ABCD Matrices – Cavity stability criteria – Optical cavity with amplifying media – Threshold population inversion – Variation of laser power around threshold – Optimum output coupling – CW and Transient laser operations – Q-switching – Techniques for Q-switching – Mode-locking mechanism – Active and passive mode locking.

Semiclassical theory of Laser: Cavity modes in presence of an active medium – Polarization associated with the cavity medium – Two state atoms in electromagnetic field – Rabi frequency – Density matrix – First order theory – Higher order theory – Single mode operation.

Specific laser systems: Ruby laser – Nd-YAG – Titanium-Sapphire – He-Ne laser – Argon-ion laser – Semiconductor laser – Fiber laser – Excimer laser – Free electron laser – Applications of lasers: Spatial frequency filtering – Holography – LiDAR – Medicine and surgery – Remote sensing – Pump-probe spectroscopy – Harmonic generation – Material processing and electronics industry.

References:

1. A. Ghatak and K. Thyagarajan, *Optical Electronics*, Cambridge University Press, Delhi, 2009.
2. W. T. Silfvast, *Laser Fundamentals*, Cambridge University press, 2003.
3. A. E. Siegman, *Lasers*, University, Science Books Mill Valley, C. A., 1986.
4. M. Eichhorn, *Laser Physics: From Principles to Practical Work in the Lab*, Springer, 2014.
5. A. Yariv, *Quantum Electronics (3rd Edition)*, John Wiley and Sons, New York, 1989.
6. M. Sargent III, M. O. Scully and W. E. Lamb Jr., *Laser Physics*, CRC Press, New York, 1974.

PH7329E PHOTONIC BANDGAP STRUCTURES

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Formulate and explore the physics of photonic bandgap structures for modern photonics applications.
CO2: Calculate photonic bandstructures of 1-D, 2-D, and 3-D photonic crystal structures.
CO3: Express proficiency in the concepts of photonic bandgap, light localization, design of photonic crystal fiber, wavevector diagrams, near-bandgap phenomena, and anomalous dispersion.
CO4: Design and Simulate photonic crystal-based optical elements computationally for all-optical applications.

Physics of linear photonic crystals-Review of Electrodynamics – Maxwell's equations-wave propagation in periodic systems, Photonic crystals-1D, 2D and 3D systems, Bloch's theorem, the electromagnetic Eigenvalue problem, band diagrams, the variational theorem, origin of the photonic band gap
– Computation of bandstructures and wavevector (Eigenfrequency contours) diagrams, semi- analytical methods using perturbation theory, scaling properties of the Maxwell equations, and discrete and continuous frequency ranges.

Photonic-crystal slabs: index-guiding in periodic systems, projected band diagrams, Point defects (cavities) and line defects (waveguides)-waveguides-cavities-and losses, omnidirectional mirrors with 1d crystals – Coupled-mode theory and projected band structures – Hybrid structures
lacking a complete band gap-waveguide bends-channel-drop filters-waveguide crossings, Mechanisms for high-Q with Incomplete gaps.

Resonant cavities, Photonic-crystal, and micro-structured fibers -Bragg (and Omniguide) fibers- 2d-crystal fibers-holey (index-guided) fibers, perturbation theory in electromagnetism, band gaps
of Bragg fibersguided modes of Bragg fibers-losses in hollow-core fibers-cladding losses-intermodal coupling.

Technology-materials-and fabrication of photonic crystals, Choice of materials-semiconductors- polymers, fabrication of Photonic band gap structures: 1D-2D-and-3D systems, Photonic integrated circuits, channel waveguides, coupled-cavity waveguides, add/drop multiplexers, Photonic crystal optical elements, polarization filters.

References:

1. John D. Joannapoulos, Steven G. Johnson, Joshua N. Winn and Robert D. Meade, *Photonic crystals molding the flow of light*, Princeton University Press, 2008.
2. K. Sakoda, *Optical Properties of Photonic Crystals*, Springer, 2000.
3. R. Kashyap, *Fiber Bragg Gratings*, Academic Press, San Diego, 1999.
4. K. Yasumoto, *Electromagnetic Theory and Applications for Photonic Crystals (Optical Science and Engineering)*, Taylor & Francis Group, 2006.
5. A. Bjarklev and J. Broeng, *Photonic Crystal Fibers*, Springer, 2003.
6. Qihuang Gong , Xiaoyong Hu, *Photonic Crystals: Principles and Applications*, Pan Stanford Publishing Pte Ltd, 2014.
7. Open-source photonic bandstructure solver: MPB. https://mpb.readthedocs.io/en/latest/

PH7330E TOPICS IN PARTICLE PHYSICS

Pre-requisites: PH6309E/PH2112E

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Identify fundamental particles and their interactions
CO2: Develop the idea of mathematical formulation of various symmetries of nature
CO3: Analyze the basic ingredients of the standard model of particle physics
CO4: Interpret spontaneous symmetry breaking and Higgs mechanism

Fundamental interactions in nature – elementary particles – particle classification: leptons and hadrons, mesons and baryons, bound states and resonance states – quantum numbers and conservation laws – concept of isospin, quarks and colors, quark model – the eightfold way, hadron structure, proton form-factors – parton model – Bjorken scaling.

Space time and internal symmetries – Lie groups: algebra and generators, SU(2) irreducible representation, isospin and SU(2), weight diagram, SU(3) generators – U and V spin, raising and lowering operators, root diagram – dimensionality multiplets of SU(N) – baryons and mesons in quark model – baryon magnetic moments – symmetry breaking and Gell-Mann-Okubo mass formula.

Discrete symmetries: parity (P), charge conjugation (C) and time reversal (T), transformation of spinor bilinears under C, P and T – parity non-conservation in weak interactions – CP violation in Kaon system – the CPT theorem, G-parity.

Gauge Symmetry: Noether's theorem, U(1) gauge theory and QED – Fermi theory of beta decay, Gamow-Teller correction – Non-Abelian gauge theories: SU(2) and SU(3) gauge theories – spontaneous symmetry breaking, Goldstones theorem – Higgs mechanism – Glashow-Weinberg- Salam Model.

References:

1. W. E. Burcham and M. Jobes, *Nuclear and Particle Physics (2nd Edition)*, Pearson, 1994.
2. F. Halzen and A. D. Martin, *Quarks and Leptons (2nd Edition)*, Wiley, 2008.
3. D. H. Perkins, *Introduction to High Energy Physics (4th Edition)*, Cambridge, 2000.
4. D. Griffths, *Introduction to Elementary Particles (2nd Edition)*, Wiley, 2008.

PH7331E QUANTUM FIELD THEORY

Pre-requisites: PH6309E/PH2112E

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Demonstrate relativistic equations and their solutions
CO2: Identify symmetries and associated conservation laws
CO3: Analyze the quantization techniques in real scalar, complex scalar, Dirac & Maxwell fields
CO4: Calculate scattering cross section for simple scattering processes using Feynman diagrams

Klein-Gordon equation – Dirac equation – positive and negative energy solutions, antiparticles, Dirac's hole theory, properties of gamma-matrices, Lorentz covariance of Dirac equation, plane wave solution, bilinear covariants – projection operators – helicity and chirality.

Lagrangian and Hamiltonian formulations – Euler-Lagrange equation of motion for fields – symmetries and conservation laws, Noether's theorem – canonical quantization of scalar field, complex scalar field, field decomposition, creation and annihilation operators – interacting fields: $\lambda\phi^4$ theory – Wick's theorem – S-matrix.

Dirac field and electromagnetic field – gauge transformations – problem in quantizing electromagnetic field – Gupta-Bleuler method.

Quantum electrodynamics – Feynman rules (without derivation) – Feynman diagrams, Compton scattering, Möller scattering, Bhabha scattering.

References:

1.M. E. Peskin and D. V. Schroeder, *An introduction to Quantum Field Theory*, Taylor & Francis, 2005.

2.L. H. Ryder, *Quantum Field Theory (2nd Edition)*, Cambridge, 1996.

3.C. Itzykson and J. B. Zuber, *Quantum Field Theory*, Dover, 2006.

4.P. Ramond, *Field Theory: A Modern Primer (2nd Edition)*, Westview, 1988.

5.J. D. Brojken and S. D. Drell, *Relativistic Quantum Mechanics*, McGraw-Hill, 1964.

PH7332D SOLAR PHYSICS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Coherently explain the observational properties of the Sun, instruments for modern solar research, ground and space based observatories.
CO2: Understand the solar surface features such as granule, sunspots, etc. source of solar magnetic fields, dynamo action and solar cycle.
CO3: Theoretically model the interior of stars like the Sun, energy generation and transportation from solar interior to its outer atmosphere, analyse the solar interior properties using surface oscillations.
CO4: Explain solar atmospheric activities such as flares, coronal mass ejections, solar wind,atmospheric heating, and solar terrestrial relations.

Why study the Sun? Characteristics of the Sun - mass, radius, luminosity, spectral energy distribution – Internal structure, surface and atmosphere – Instruments for modern solar research, ground and space-based observatories – Radiative transfer in the solar atmosphere, Spectroscopy and Polarimetry –

Dynamics of solar plasma, solar model equations - conservation laws, energy transport, equation of state, nuclear energy, opacity, boundary conditions, hydrostatic equilibrium – Internal characteristics - temperature, density, pressure, etc – Solar p-mode oscillations, helioseismology, direct modelling and inversion techniques, convection zone depth, chemical constituents

Surface features - granules, sunspots, plages and faculae, Evershed effect – Solar differential rotation – Magnetism - solar magnetohydrodynamic (MHD), induction equation, the electrical conductivity of the Sun, frozen-in magnetic field, magnetic force, flux tube, dynamo action and solar cycle.

Solar atmosphere - chromosphere, transition region, corona, solar wind and heliosphere – Coronal MHD waves and oscillations – Solar activities - prominences, magnetic reconnection, flares, coronal mass ejections and radio emissions – Atmospheric heating – Solar terrestrial relations.

References:

1.Michel Stix, *The Sun - An Introduction (2nd Edition)*, Springer, 2012.

2.Piter V. Foukal, *Solar Astrophysics (3rd Edition)*, Wiley VCH, 2013.

3. Arvind Bhatnagar and William Livingston, *Fundamentals of Solar Astronomy*, World Scientific Pub Co Inc., 2005.

4. Eric Priest, *Magnetohydrodynamics of the Sun (2nd Revised ed. Edition)*, Cambridge University Press, 2014.

5.H.M. Antia, A. Bhatnagar and Peter Ulmschneider, *Lectures on Solar Physics*, Springer, 2003.

PH7333E ASTROPHYSICS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Understand the processes by which astronomers determine the celestial objects. They will be able to identify celestial objects in the night sky, constellations and classifications of stars in the Milky Way.
CO2: Coherently explain the properties of celestial objects, such as, planets, stars, galaxies, etc., cause or nature of astronomical phenomena.
CO3: Interpret the basic properties of the Sun and other stars, such as mass, radius, temperature and luminosity. Birth of stars and their evolution with time and decay.
CO4: Explain the distribution of stars in the Milky Way and in external galaxies. Interpret the evolution of the expanding universe by applying the concept of big-bang theory and observations.

Overview of the major constituents of the universe, our place in space – understanding the scale of the universe – Solar system, planets and exoplanets – Basic astronomical motions – Earth's orbital motion – Laws of planetary motion – Spherical triangle, co-ordinate systems- altazimuth, equatorial, ecliptic and galactic; coordinate conversions – Sidereal time, ephemeris and universal time – Astronomical instruments – ground and space based telescopes and mountings.

Black body radiation-specific intensity, luminosity, apparent and absolute magnitude systems, terrestrial and celestial distances - trigonometric parallaxes of stars, method of luminosity distance, temperature and colour of stars, spectral types, masses and radii of stars, Boltzmann excitation equation, Saha's theory of thermal ionisation and their applications, Hertzsprung-Russell diagram
– Identification of stars, constellations.

Stellar atmospheres, basics of radiative transfer, models of stellar atmosphere, line strength and source function – Stellar interiors – equations of stellar structure, energy of stars - PP and CNO cycles, hydrostatic equilibrium, stability conditions for convective and radiative equilibrium, stellar models, polytrophic model, Lane-Emden equation – Stellar evolution - birth, life, and death of stars – Main sequence stars, dwarfs and black holes, supernovae, neutron stars – The Sun - physical properties, interior and atmosphere, magnetism, activities.

Milky way- distribution of stars, interstellar gases and dusts, luminosity function, star counts, spiral structure – External galaxies: Hubble classification of galaxies – spiral galaxies, elliptical galaxies, Irregular galaxies, active galaxies – Cosmology: theoretical foundation, some specific cosmological models (big-bang model, steady state theory) – Gravity waves and their measurements.

References:

1. K. D. Abhyankar, *Astrophysics - Stars and Galaxies*, Universities Press, 2001.
2. Frank H. Shu, *The Physical Universe – An Introduction to Astronomy*, University Science Books, 1982.
3. W. M. Smart and R. M. Green, *Textbook on Spherical Astronomy (6th Edition)*, Cambridge University Press, 1977.
4. Bradely W. Carrol and Dale A. Ostlie, *An Introduction to Modern Astrophysics (2nd Edition)*, Pearson Addison Wesley, 2006.
5. S. Chandrasekhar, *An Introduction to the study of the stellar structure*, Dover Publications Inc., 2003.

PH7334E SPECIAL TOPICS IN QUANTUM MECHANICS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Interpret behavior of physical systems based on symmetry principles, density matrix, path integral formalism, and idea of entanglement.
CO2: Solve problems concerning quantum mechanical systems using symmetry principles, density matrix and path integral formalism.
CO3: Analyze entanglement of states in quantum mechanical systems
CO4: Illustrate the idea of geometrical phase and Berry's phase.
CO5: Solve problems concerning quantum mechanical systems undergoing adiabatic change.

Symmetry – invariance – continuous symmetries – rotation – symmetry and degeneracy – discrete symmetries – parity – lattice translation – time reversal symmetry – Gauge invariance in Electrodynamics – gauge transformations in Quantum Mechanics – Aharonov-Bohm effect – magnetic monopoles.

Pure states – density operator – matrix representation – mixed states – ensembles – fractional population – ensemble average of an observable – trace of the density matrix – time evolution and Liouville's theorem – density matrix and the partition function – quantum statistical mechanics. Path Integral formalism: Propagator in quantum mechanics – propagator as a transition amplitude – Feynman's sum over path approach – action – variational approach in classical mechanics – Feynman path integral – example of the Gaussian wave packet and the one-dimensional harmonic oscillator.

Entangled States and Bell inequalities: Origin of entanglement idea – EPR proposal – Einstein's locality principle – two particle spin states – measures of entanglement – Bell's inequalities – implications to interpretations of quantum mechanics – applications to quantum information.

Adiabatic processes in classical physics, examples – time evolution in quantum mechanics – adiabatic theorem – geometric phase – Berry's formulation – geometric phase and the solid angle – degeneracy and geometric phase – experimental realizations – Pancharatnam phase.

References:

1. J. J. Sakurai and J. J. Napolitano, *Modern Quantum Mechanics (2nd Edition)*, Pearson, 2013.
2. D. J. Griffiths, *Introduction to Quantum Mechanics (2nd Edition)*, Pearson Education, 2005.
3. R. Shankar, *Principles of Quantum Mechanics (2nd Edition)*, Springer, 1994.
4. L. Susskind and A. Friedman, *Quantum Mechanics - The Theoretical Minimum (1st Edition)*, Penguin Books, 2015.
5. R. P. Feynman and A. R. Hibbs, *Quantum Mechanics and Path Integrals (Emended Edition by D. F. Styer)*, McGraw Hill, 2005.

PH7335E ADVANCED MATHEMATICAL METHODS FOR PHYSICISTS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Describe characteristics of manifolds and calculate their attributes using the tools of differential geometry.
CO2: Calculate curvature and geodesics of a general Riemannian manifold.
CO3: Describe the properties of groups in both discrete and continuous contexts.
CO4: Construct irreducible representations of groups using young tableau and tensor methods.

Topological spaces, compactness, connectedness, homeomorphism, topological invariants – paths and loops, homotopy: definition and examples – Manifolds – differentiable maps – vectors, one-forms, tensors – flows and lie derivatives – differential forms – exterior derivative – integration of forms – Physical examples.

Riemannian geometry: Riemannian and pseudo Riemannian manifolds – metric tensor – connections, parallel transport and geodesics – covariant Derivative – curvature and torsion tensors and its geometrical meaning – Ricci tensor and scalar curvature.

Discrete groups: Definition of a group – subgroup – class – Lagrange's theorem – invariant subgroup – Homomorphism and isomorphism between two groups – Representation of a group, unitary representations, reducible and irreducible representations – Schur's lemmas – orthogonality theorem – character table – reduction of Kronecker product of representations – Representation theory of permutation group.

Continuous groups: Infinitesimal generators, Lie algebra – Rotation group, representations of the rotation group – Definition of SU(2) and SU(3) groups – Lie algebra of SU(2) – Relation between SU(2) and rotation group – Lie algebra of SU(3)- Gellmann's matrices, Cartan form of SU(3) – Young tableaux and tensor methods – Roots and Weights – Representation theory of Lorentz and Poincare groups.

References:

1. Michio Nakahara, *Geometry, topology and physics (2nd Edition)*, IoP publishing, 2003.
2. Bernard F. Schutz, *Geometrical methods of mathematical physics* , Cambridge university press, 1980.
3. Sunil Mukhi, N Mukunda, *Lectures on advanced mathematical methods for physicists*, Hindustan book agency, world Scientific publishing, 2010.
4. Theodore Frankel, *The geometry of Physics* , Cambridge University Press, 1997.
5. Howard Georgi, *Lie algebras in particle physics* , Westview Press, 1999.
6. J. Fuchs and C. Schweigert, *Symmetries, Lie Algebras and Representations: A Graduate Course for Physicists*, Cambridge University Press, 2003.

PH7336E SPECIAL TOPICS IN CLASSICAL MECHANICS

Pre-requisites: Nil

Total Lecture Sessions: 39

L	T	P	O	C
3	0	0	6	3

Course Outcomes:

CO1: Identify symmetries of a classical system and utilize them to simplify their description.
CO2: Analyze classical systems with constraints and local symmetries.
CO3: Distringuish between integrable and Chaotic systems.

Canonical Transformations and the Symplectic group – Time evolution as a Canonical Transformation – Hamilton-Jacobi Equation – Poincaré-Cartan Integral Invariants – Universal Integral Invariants of Poincaré – Generalized Conservative Systems – Marpetuis-Lagrange Principle of Least Action.

Classification of Constraints – Physical Interpretation of Singular theories – Theories with Second- Class constraints, examples of system with kinematic constraints – Dirac brackets – Theories with First-Class constraints, examples of Electrodynamics and Non-Relativistic Spin – Local symmetries and constraints, conserved charges – Extended Lagrangians.

Periodic motion – Perturbations and Kolmogrov-Arnold-Moser Theorem – Attractors – Chaotic Trajectories and Lyapunov exponents – Poincaré maps – Hénon-Heiles Hamiltonian – Bifurcation, Driven damped Harmonic Oscillators – Parametric Resonance.

References:

1. E. C. G. Sudarshan and N. Mukunda, *Classical Dynamics: A Modern Perspective*, John Wiley & Sons, 1974.
2. A. Deriglazov, *Classical Mechanics: Hamiltonian and Lagrangian Formalism*, Springer- Verlag, 2010.
3. L. D. Landau and E. M. Lifshitz, *Mechanics (3rd Edition)*, Pergamon press, 2009.
4. H. Goldstein, *Classical Mechanics (2nd Edition)*, Narosa Publishers, 2001.

PH7337E CLASSICAL FIELD THEORY

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Formulate dynamics of continuum systems using classical field theory
CO2: Analyze fluid systems and describe key properties of their dynamics
CO3: Interpret electromagnetic theory and general relativity using techniques of classical field theory.

Transition from discrete to continuous systems – Lagrangian formulation of continuous systems – Stress-Tensor and Conservation Theorems – Noether's Theorem – Hamiltonian formulation – Relativistic field theory.

Hydrodynamics – Water waves – Solitonic water waves and KdV equation – Ideal Fluid Equation – Viscous fluids and Navier-Stokes Equation – Vorticity and Helicity of Ideal Fluids – Fluid Vortices and Waves.

Electromagnetic Field Theory: Lagrangian – Stress tensor, Belinfanté Tensor – Coupling to matter: Complex scalar fields – Gravitational Action: Einstein-Hilbert action – Palatini formulation – Gibbons-Hawking-York Boundary term.

References:

1. H. N ăstase, *Classical Field Theory*, Cambridge University Press, 2019.

2. D. Soper, *Classical Field Theory*, Courier Dover Publications, 2008.

3. L. D. Landau and E. M. Lifshitz, *Mechanics (3rd Edition)*, Pergamon press, 2009.

4. H. Goldstein, *Classical Mechanics (2nd Edition)*, Narosa Publishers, 2001.

PH7338E SOLID STATE DEVICES

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Understand intrinsic and extrinsic semiconductors and the role of doping in engineering the properties of semiconductors.
CO2: Analyse the formation of p-n junctions, electrical characteristics, and p-n junction devices.
CO3: Analyse the formation of bipolar junction transistors and their characteristics.
CO4: Analyze the structure and principle of operation of JFET and MOSFET.

Semiconductor materials, energy bands, direct and indirect band gap semiconductors – Density of states, Fermi-Dirac statistics, intrinsic carrier concentration, ionization of impurities – Femi level, quasi-Fermi level – Vacuum level, work function, electron affinity – Generation and recombination of carriers, concept of lifetime – Mobility of carriers, effect of temperature and doping – Drift current, diffusion current, Einstein's relation, continuity equation, diffusion length.

p-n junction under thermal equilibrium condition, built-in potential, concept of space charge layer and electric field – p-n junction under applied bias, depletion capacitance and storage capacitance – static current-voltage characteristics of p-n junction – Transient analysis – Breakdown mechanisms, Zener breakdown, Avalanche breakdown – Variable capacitor, tunnel diode, solar cell and photodiode, light emitting diode and semiconductor laser.

BJT principle of operation, current components in a BJT, basic BJT parameters – Different modes of operation, current-voltage characteristics of common-base and common emitter configurations; frequency response and switching of bipolar transistors.

Metal-semiconductor junction, energy band diagram of M-S junction, I-V characteristic of M-S junction, ohmic contacts, Schottky barriers – JFET structure, principle of operation, I-V characteristics of JFET – MESFET structure – MOSFETS, the two terminal MOS structure, energy band diagram, MOS capacitor, concept of accumulation, depletion and inversion, four terminal structure – MOSFET I-V characteristics, drain current equation in terms of W/L, second order effects – Types of MOSFETS, depletion and enhancement type, NMOS and CMOS, power MOSFET construction.

References:

1. Sze S. M., Semiconductor Devices, *Physics and Technology*, John Wiley and Sons, 2002.
2. Sedra A. S. and Smith K. C., *Microelectronic Circuits (2nd Edition)*, Holt, Rinehart and Winston, 1987.
3. Ben G. Streetman and Sanjay Banerjee, *Solid State Electronic Devices*, Pearson Education, 2002.
4. Donald A Neaman, *Semiconductor Physics and Devices*, McGraw Hill, 2003
5. M.S.Tyagi, *Introduction to Semiconductor Materials and Devices*, Wiley,2008
6. Nandita Dasgupta, Amitava Dasgupta, Semiconductor Devices: Modelling and Technology, Prentice-Hall of India Pvt.Ltd, 2004

PH7339E GRAVITATIONAL WAVE PHYSICS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Explain fundamentals of gravitational waves
CO2: Describe astrophysical sources of gravitational wave and corresponding waveforms
CO3: Interpret LIGO-Virgo data and perform basic data analysis

Review of general theory of relativity:- The Einstein field equation - Black hole solutions - Linearized Einstein equation - Wave solution - Quadrupole formula - Effects of Gravitational Waves

Sources of gravitational wave:- Coalescing Binaries, Burst, Continues, Stochastic sources etc - Waveforms from coalescing binary systems - Newtonian waveform - Restricted post-Newtonian waveform - Stationary phase approximation - Review of Black Hole Perturbation and numerical relativity - Review of phenomenological waveforms

Gravitational wave detection:- Review of detectors: Resonant mass detectors; Interferometric detectors; Pulsar timing array - Antenna response functions - Random Process - Power Spectrum - Gaussian Noise - Hypothesis testing - Optimal Detection Statistic - Matched Filter - Bayesian Model Selection - Parameter estimation - Sampling Algorithms - Review of LIGO/Virgo observations.

References:

1. Jolien D. E. Creighton and Warren G. Anderson, *Gravitational-Wave Physics and Astronomy*, WILEY-VCH Verlag GmbH & Co., 2011.
2. Michele Maggiore, *Gravitational Waves: Theory and Experiments (Vol-I)*, Oxford University Press, 2008.
3. B. F. Schutz, *A first course in General Relativity*, Cambridge university press, 1985.

PH7340E OPTICAL WAVEGUIDES

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Design and analyze different waveguide structures and fibers.
CO2: Evaluate the optical power losses by understanding different loss mechanism in a waveguide.
CO3: Assess the usefulness of waveguides and fibers in optical communication by studying the dispersion phenomena.
CO4: Build different integrated optical devices utilizing the knowledge of wave propagation and coupled mode theory in waveguides.

Concept of waveguide structure and guided modes – Numerical aperture – Goos-Hänchen shift – Planar Waveguide – Transverse electric (TE) and Transverse magnetic (TM) modes – Symmetric and asymmetric step-index planar waveguide – V-number and cut off frequency – Power of a mode – Evaluation of propagation constant – Rectangular waveguide – Ridge waveguide – Multimode interference waveguide.

Loss mechanisms in waveguides – Quasi modes in a leaky planar waveguide – Matrix method for determining the waveguide loss – Evaluation of bending loss – Concept of discrete rays in waveguides – Mode dispersion – Material dispersion – Concept of zero dispersion – Group delay – Optical pulse broadening – Birefringent waveguides – Plasmonic waveguides: surface plasmon polaritons (SPPs) at single and multiple interfaces of metal and insulator – Excitation of SPPs by prism coupling: Otto and Kretschmann configurations – Grating coupling and near field excitation – plasmonic slot waveguides – metal strip waveguides.

Optical fiber – Step index optical fiber – Bessel functions – Hybrid modes – Linearly polarized (LP) modes – Parabolic-index fibers – Triangular-index fibers – Multimode and single mode fibers – Splice loss – WKB analysis of graded-index planar waveguides and fibers – brief overview of photonic crystal fibers – Applications of optical waveguides and fibers.

Coupled mode theory – Derivation of coupled mode equations – Codirectional and contra- directional coupler – Bragg grating – Evaluation of reflection and transmission of Bragg grating – Calculation of coupling coefficients in planar waveguides and fibers – Coupling coefficients of mode interference – Optical waveguide coupler based devices: Power coupler – Wavelength division multiplexer (WDM) – Mach-Zehnder interferometer – Ring resonator.

References:

1. K. Okamoto, *Fundamentals of Optical Waveguides (2nd Edition)*, Academic Press, London, 2006.

2.A. Ghatak and K. Thyagarajan, *Optical Electronics*, Cambridge University Press, Delhi, 2009.

3.W. S. C. Chang, *Fundamentals of Guided-Wave Optoelectronic Devices*, Cambridge University Press, Delhi, 2010.

4.A. W. Snyder and J. D. Love, *Optical Waveguide Theory*, Chapman and Hall, London, 1983.

5.R. G. Hunsperger, *Integrated Optics: Theory and Applications (6th Edition)*, Springer, Berlin, 2005.

6.A. Ghatak and K. Thyagarajan, *Introduction to Fiber Optics*, Cambridge University Press, Delhi, 2011.

7.S. A. Maier, *Plasmonics: Fundamentals and Applications*, Springer, New York, 2007.

PH7341E METAMATERIALS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Explore electrodynamics of negative index medium.
CO2: Design metamaterials starting from permittivity and permeability negative media and realize double negative metamaterials for microwave, terahertz, and optical regimes.
CO3: Apply parameter retrieval methods to extract constitutive parameters of metamaterials.
CO4: Realize various kinds of metasurfaces including chiral metasurfaces, spatially-modulated digital metasurfaces, and time-modulated metasurfaces.
CO5: Design cloaking-invisibility devices, electromagnetic wave transformers, and energy concentrators using the coordinate transformation method.

Electrodynamics of negative index medium – Veselago's proposals-Wave propagation in left- handed media-Energy density and group velocity – Negative refraction-Modified Snell's law- Double Focusing-Flat lens – Inverse Doppler Shift – Backward Cerenkov radiation – Negative Goos-Hänchen shift – Losses and dispersion – Indefinite media and their examples.

Realization of bulk metamaterials – negative permittivity medium – thin wire structure and electric plasmas – negative permeability medium – Split Ring Resonators (SRR) and magnetic plasmas- Types of SRRs – Realization of negative index medium – Parameters Retrieval Procedure and Effective parameters – Homogenization procedure – 3-D metamaterials.

Metasurfaces – Electric and magnetic dipole interactions – Chiral metasurface-Optical activity and circular dichroism – Bianisotropy in metasurfaces and various new polarization phenomena – Perfect absorber – Flat lens design – Zero-refractive index Metasurface – Dielectric metasurfaces – Concepts of spatial and time-modulated metasurfaces.

Coordinate transformation method and transformation optics – Cloaking and invisibility devices – Electromagnetic energy concentrators and illusion optics techniques using metamaterials.

References:

1. Anantha Ramakrishna and Tomasz M. Grzegorczyk, *Physics and Applications of Negative Refractive Index Materials,* SPIE and CRC Press, Taylor and Francis Group, 2009.
2. Ricardo Marques, Ferran Martin and Mario Sorolla, *Metamaterials with Negative Parameters*, John Wiley and Sons, 2008.
3. T. J. Cui, D. R. Smith, R. Liu, *Metamaterials, Theory, Design and Applications,* Springer, 2010.
4. M. A. Noginov, and V. A. Podolskiy, *Tutorials in Metamaterials,* CRC Press, Taylor and Francis Group, 2012.
5. A. B. Shvartsburg and A. A. Maradudin, *Waves in Gradient Metamaterials*, World Scientific Publishing Singapore, 2013.

PH7342E NONLINEAR OPTICS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Apply Maxwell's equation in nonlinear media and explain nonlinear phenomenon.
CO2: Analyse nonlinear properties by evaluating higher order susceptibilities.
CO3: Evaluate nonlinear coefficient by setting up appropriate experiments in nonlinear optics.
CO4: Designing of optical elements using nonlinear properties of materials.

Nonlinear optical Susceptibility, formal definition of the nonlinear susceptibility – Electromagnetic waves in nonlinear media, the coupled wave equations for sum and difference frequency generation.

Manley-Rawe relations, second harmonic generation – Nonlinear optical interaction with Gaussian Beam, nonlinear optics at interface – Quantum mechanical theory of the nonlinear optical susceptibility, Symmetry properties, density matrix and perturbative approach, Feynman diagram.

Three waves and four waves mixing, harmonic generation, parametric processes, optical phase conjugation, optical bistability, stimulated Raman and Brillouin processes, self-focusing, z-scan experiment for evaluation of nonlinear parameters.

Photorefractive crystals, linear and nonlinear interference filters, electro optics, magneto optics and acoustooptic effects and devices, optical rectification, optical modulators, multiphoton processes.

References:

1.Robert W. BoydNonlinear OpticsAcademic Press2003

2.Y. R. ShenThe principles of Non linear OpticsJohn Wiley1984

3.A. YarivQuantum ElectronicsJohn Wiley1985

4.Y.V.G.S Murti and C VijayanEssentials of Nonlinear opticsWiley, Ane Books Pvt.Ltd.2014

PH7343E PHYSICS AND TECHNOLOGY OF THIN FILMS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Choose and apply appropriate vacuum techniques for thin film deposition and characterizations.
CO2: Analyze the physics of various thin film deposition techniques.
CO3: Evaluate and use models for nucleation and growth of thin films.
CO4: Apply different characterization techniques to analyze the physical properties of thin films.

The necessity of vacuum, classification of vacuum ranges, gas transport and pumping in vacuum systems, conductance and pumping speed – Production of vacuum, rotary vane pumps, diffusion pump, turbo molecular pump, sorption pump, ion pump, cryopump, titanium sublimation pump
– Operation of high vacuum, and ultrahigh vacuum (UHV) systems – Pressure measurement, capacitance gauge, thermocouple gauge, pirani gauge, cold cathode and hot cathode ionization gauges, Bayard-Alpert gauge – Designing a vacuum system, vacuum materials and components, leak detection.

Physical vapor deposition techniques – Thermal evaporation, theory of evaporation, Hertz-Kundsen equation, cosine law, evaporation system, problems in evaporation of alloys/compounds, resistance/induction heating sources, e-beam evaporation, molecular beam epitaxy (MBE) – Pulsed laser deposition (PLD), modeling of PLD process, large area PLD – Sputtering, physics of sputtering, DC, RF, reactive, and magnetron sputtering – Hybrid PVD processes, ion plating, activated reactive evaporation (ARE), ionized cluster beam deposition (ICB), ion beam assisted deposition (IBAD).

Chemical vapor deposition techniques, mechanism, process, chemistry of CVD, reaction types – Thermodynamics of CVD, gas transport and kinetics of CVD – Classifications of CVD, atmospheric pressure CVD (APCVD), low pressure CVD (LPCVD), plasma enhanced CVD (PECVD), hot filament CVD (HFCVD), metal organic CVD (MOCVD), Atomic Layer Deposition (ALD) – Design of CVD reactors, uniform deposition on the interior surfaces and complex geometries, large area deposition.

Theory of nucleation, capillarity theory, atomistic nucleation process, cluster coalescence and depletion, thin film nucleation and growth, grain structure of thin films – Characterizations, in- situ crystal thickness monitor, ex-situ surface profilometer, optical techniques, ellipsometry, x-ray reflectivity – Electrical transport measurements, linear probe resistivity, Van-der-Pauw resistivity, Hall effect, D.C conduction mechanisms, A.C conduction mechanisms – Mechanical properties, hardness, adhesion, residual stresses, porosity – Application of thin films, thin film devices: LED, TFT, Solar cells, optical and decorative coatings, dichroic coatings, biomedical coatings, tribological coatings.

References:

1. Milton Ohring, *The Materials Science of Thin Films*, Academic Press, 1992.
2. Donald L. Smith, *Thin Film Deposition: Principles and Practice*, McGraw Hill, 1995.
3. K. L. Chopra, *Thin Film Phenomena*, McGraw Hill, 1969.
4. V. V. Rao, T. B. Ghosh, K. L. Chopra, *Vacuum Science and Technology*, Allied Publishers Limited, 1998.
5. Donald L. Smith, *Thin Film deposition principle and Practice's*, McGraw Hill International Edition, 1995.

PH7344E SPECIAL TOPICS IN ELECTROMAGNETIC THEORY

Pre-requisites: Nil

Total Lecture Sessions: 39

L	T	P	O	C
3	0	0	6	3

Course Outcomes:
CO1: Utilize Green's function and multipole expansions to comprehensively study radiation.
CO2: Analyze classical scattering of electromagnetic waves.
CO3: Apply ideas of topology and duality in analyzing electromagnetic systems.

Green's Functions – Retarded and Advanced Potentials – Multipole Expansions of Electromagnetic fields – Properties: Energy and Angular Momentum of Multipole radiation – Angular Distribution of Multipole Radiation – Multipole Moments.

Thomson Scattering – Scattering by bound charge and dielectric sphere – Radiation damping – Partial Wave decomposition – Interior of conducting Sphere – Rayleigh Scattering – Integral equations – Optical Theorem.

Classical Electromagnetic Duality – Magnetic Monopoles – Dirac quantisation condition – 't-Hooft Polyakov Monopole – Georgi-Glashow Model – Topological origin of magnetic charges.

References:

1. J. D. Jackson, *Classical Electrodynamics*, Wiley, 1998.
2. J. Schwinger, L. L. Deraad, K. Milton, W. Tsai and J. Norton, *Classical Electrodynamics*, CRC Press, 2019.
3. J. M. Figueroa-O'Farrill, *Electromagnetic Duality for Children*: https://www.maths.ed.ac.uk/~jmf/Teaching/Lectures/EDC.pdf