M.Sc. Degree

in

Physics

SYLLABUS

FOR

CREDIT BASED CURRICULUM

(From the academic year 2024-25 onwards)

DEPARTMENT OF PHYSICS

National Institute of Technology, Tiruchirappalli – 620015

TAMILNADU, INDIA

THE INSTITUTE

Vision

To be a university globally trusted for technical excellence where learning and research integrate to sustain society and industry.

Mission

- To offer undergraduate, postgraduate, doctoral and modular programmes in multi-disciplinary / inter-disciplinary and emerging areas.
- To create a converging learning environment to serve a dynamically evolving society.
- To promote innovation for sustainable solutions by forging global collaborations with academia and industry in cutting-edge research.
- To be an intellectual ecosystem where human capabilities can develop holistically.

THE DEPARTMENT

Vision

- Provide a world class scientific platform for scientists and engineers.

Mission

- Establish the department as a global player in Science and Technology.
- Excel in scientific R&D and consultancy.
- Create an environment for society aimed at knowledge enhancement.

Pogramme Educational Objectives (PEOs)

PEO1	To produce physics graduates who are globally acceptable professionals for government, corporate and research organizations, along with skills for entrepreneurial pursuits in multidisciplinary areas.
PEO2	To prepare the graduates to work in an interdisciplinary background and contribute significantly to reliable and quality research through lifelong learning.
PEO3	To develop the graduates with strong academic excellence, practical knowledge, interpersonal skills with integrity and ethical values so that they become successful professionals and responsible physicists.

Programme Outcomes (POs)

PO1	An ability to independently carry out research /investigation and development work to solve practical and fundamental problems.
PO2	An ability to write and present a substantial technical report/document.
PO3	Students should be able to demonstrate a degree of mastery in the area of physics and related subjects.

CURRICULUM

Total minimum credits required for completing M.Sc. programme in Physics is **80**.

SEMESTER I

CODE	COURSE OF STUDY	L	T	P	C
PH651	Mathematical Physics	3	1	0	4
PH653	Classical Mechanics	3	1	0	4
PH655	Quantum Mechanics	3	1	0	4
	Elective - I	3	0	0	3
	Elective - II	3	0	0	3
PH657	General Physics Laboratory	0	0	4	2
	TOTAL CREDITS				**20**

SEMESTER II

CODE	COURSE OF STUDY	L	T	P	C
PH652	Electromagnetic Theory	3	1	0	4
PH654	Statistical Mechanics	3	1	0	4
PH656	Solid State Physics	3	1	0	4
	Elective - III	3	0	0	3
PH658	Computational Laboratory	0	0	4	2
PH662	Electronics Laboratory	0	0	4	2
	TOTAL CREDITS				**19**

SUMMER TERM (Evaluation in the III Semester)

CODE	COURSE OF STUDY	L	T	P	C
PH697	Internship/ Academic Attachment	-	-	-	2
	TOTAL CREDITS				**2**

SEMESTER III

CODE	COURSE OF STUDY	L	T	P	C
PH661	Project Work (Phase-I)	-	-	-	10
PH659	Nuclear and Particle Physics	3	1	0	4
PH675	Atomic and Molecular Spectroscopy	3	1	0	4
	TOTAL CREDITS				**18**

SEMESTER IV

CODE	COURSE OF STUDY	L	T	P	C
PH660	Project Work (Phase -II)	-	-	-	12
	Elective – IV	3	0	0	3
	TOTAL CREDITS				**15**

OPEN ELECTIVES / ONLINE COURSES (To be completed between I to IV semester)

CODE	COURSE OF STUDY	L	T	P	C
	Open Elective/Online Course#	3	0	0	3
	Open Elective/Online Course * #	3	0	0	3
	TOTAL CREDITS				**6**

* A student may register for one 2 credit course and one 1 credit course instead of one 3 credit course.

Every semester, a list of approved online courses will be made available for students to register.

LIST OF ELECTIVES

	CODE	COURSES
1.	**PH671**	Electronics
2.	**PH672**	Instrumentation
3.	**PH673**	Numerical Methods
4.	**PH674**	Nanoscience and Technology
5.	**PH611**	Digital Signal and Image Processing
6.	**PH613**	Basics of Engineering Materials
7.	**PH676**	Advanced Mathematical Physics
8.	**PH677**	Waveguides and Modern Optics
9.	**PH678**	Astrophysics and Cosmology
10.	**PH679**	Solar Photovoltaic Technology
11.	**PH680**	Computational Techniques
12.	**PH681**	Advanced Electromagnetic Theory
13.	**PH682**	Non-destructive Testing
14.	**PH683**	Fiber Optic Sensors
15.	**PH684**	Quantum Electronics and Lasers Applications
16.	**PH685**	Sensors and Transducers
17.	**PH686**	Advanced Statistical Methods and Phase Transition
18.	**PH687**	Physics and Technology of Thin Films
19.	**PH688**	Semiconductor Physics
20.	**PH689**	Magnetic Characterization and Superconducting Materials
21.	**PH690**	Quantum Computation and Information
22.	**PH691**	Micro-Electro-Mechanical Systems
23.	**PH692**	Carbon Nanomaterials and their Applications
24.	**PH693**	Fluid Mechanics and Characteristics of Nanofluids
25.	**PH694**	Advanced Electronic Materials and Devices
26.	**PH695**	Nanophotonics
27.	**PH618**	Introduction to Data Analytics

Note: Electives are not limited to the given list. Courses from other PG programmes can also be chosen as subjects of study. The courses will be offered based on the availability of the faculty concerned.

SEMESTER I

PH651 – MATHEMATICAL PHYSICS

Course Objectives:

To develop mathematical skills in the following topics:

1. *vector spaces and its applications to physical systems.*
2. *applications of Linear algebra to physics problems.*
3. *finding solutions of ordinary differential equations.*
4. *study of special functions as solutions of differential equations.*

Vector Analysis

Scalar and vector product – triple products – gradient, divergence, curl – vector integration – Gauss's theorem – Green's theorem – Stokes' theorem – Dirac delta function – Helmholtz theorem.

Curved coordinates, Tensors

Orthogonal coordinates – differential vector operators: gradient, divergence, curl – special coordinate systems: rectangular, spherical, cylindrical – tensors: contraction, direct product, quotient rule, symmetric and antisymmetric tensors, metric tensor, covariant and contravariant tensors, differential operators in tensor form

Linear Algebra

Linear independence of vectors – inner product – Orthonormality- Gram-Schmidt orthonormalization, orthogonal, unitary, Hermitian matrices - symmetry properties – Euler angles –eigenvalue equation and diagonalization – Cayley-Hamilton theorem – functions of matrices

Ordinary Differential Equations

First order equation – second order homogeneous equation – Wronskian – second solution – inhomogeneous equation – forced oscillation and resonance – power series method – Hermite and Legendre equations – Frobenius method – Bessel equation.

Special Functions

Bessel function, Neumann function, Henkel function, Hermite function, Legendre function, Spherical Harmonics, Laguerre function, Gamma and Beta functions.

Textbooks

1. G. B. Arfken and H.J. Weber, Mathematical Methods for Physicists, 5th edition, Academic Press (2001).
2. E. Kreyszig, Advanced Engineering Mathematics, 8th edition, John Wiley & Sons Inc. (1999).
3. Mary L. Boas, Mathematical Methods in the Physical Sciences, 3rd edition,

Wiley-India(2011).
4. B. S. Grewal, Advanced engineering mathematics, 43rd edition, Khanna Publications (2015).

Reference Books

1. L.A. Pipes and L.R. Harvill, Applied Mathematics for Engineers and Physicists,Dover (2014).
2. S. Lipschutz, D. Spellman and M. Spiegel, Schaum's Outline of Vector Analysis -, 2nd edition, Tata McGraw-Hill (2009).
3. V. Balakrishnan, Mathematical Physics with Applications, Problems and Solutions,Ane Books (2017).
4. S. Lang, Introduction to Linear Algebra, Second Edition, Springer (2012).
5. Schaum's outline series, Mcgraw Hill (1964): (i) Vector and tensor analysis (ii) Linear Algebra (iii) Differential Equations, iv) Fourier Analysis with applications to boundary valueproblems (for special functions).

Course Outcomes:

After successfully completing the course, the students will be able to:

1. *analyze and apply principles of vector spaces to physical systems.*
2. *apply the theoretical framework of Linear algebra to physics problems.*
3. *recognize and find solutions to ordinary differential equations.*
4. *identify special functions as solutions of differential equations.*

PH653 – CLASSICAL MECHANICS

Course Objectives:

1. *To demonstrate a basic knowledge and understanding of the following fundamental concepts:*
   - *The dynamics of the system of particles*
   - *Lagrangian and Hamiltonian formulation of mechanics*
   - *Oscillating Systems*
   - *Motion of a rigid body*
   - *Special Theory of Relativity*
2. *To represent the equations of motion for complicated mechanical systems using the Lagrangian and Hamiltonian formulations.*
3. *Understand the motivation for developing the Special Theory of Relativity.*
4. *To develop math skills as applied to the formulation of mechanics.*

Lagrangian Formulation

Mechanics of a system of particles, Degrees of freedom, Constraints, Generalized coordinates, Virtual work, D'Alembert's principle, Euler-Lagrange equations of motion, Applications of the Lagrangian formalism, Cyclic coordinates, Generalized momenta, Symmetries and conservation laws, and Energy function.

Central Force Problem
Reduction to the equivalent one-body problem, Differential and integral equations of orbit, Conditions for bounded orbits and closed orbits, Kepler problem, Scattering in a central potential, and Rutherford scattering.

Small Oscillations
Coupled oscillators and normal modes, Lagrangian formulation of linearly coupled systems, and examples.

Hamiltonian Formulation

Calculus of variations, Hamilton's principle and equations of motion, Applications to systems with one and two degrees of freedom, Phase space, Phase trajectories, Liouville's theorem.

Canonical transformations
Poisson brackets, Action angle variables, and Hamilton-Jacobi equation.

Rigid Body
Frames of reference, Accelerating and rotating frames, pseudo-forces, Elements of rigid body dynamics, Orthogonal transformations, Euler angles and equations, Torque motion of a symmetric top, and examples.

Special Theory of Relativity
Internal frames, Principle and postulate of relativity, Lorentz transformations, Length contraction, Time dilation, Velocity addition formula, Relativistic kinematics, Mass-energy equivalence.

Textbooks

1. H. Goldstein, C. Poole and J. Safko, *Classical Mechanics*, 3rd edition, Addison & Wesley (2011).
2. W. Greiner, *Classical Mechanics*, Springer-Verlag New York Inc., (2003).
3. W. Greiner, *Classical Mechanics – Point particles and Relativity*, Springer-Verlag New York Inc., (2003).
4. J. C. Upadhayaya, *Classical Mechanics*, Himalaya Publishing House (2014).
5. D. Morin, *Introduction to Classical Mechanics: With Problems and Solutions*, Cambridge University Press (2008).
6. N. C. Rana and P. S. Joag, *Classical Mechanics*, 25th edition, Mc Graw Hill India (2013).
7. J. R. Taylor, *Classical Mechanics*, University Science Books (2005).
8. Leonard Susskind and George Hrabovsky, *Classical Mechanics: the theoretical minimum*, Penguin UK (2014).

Reference Books

1. I.C. Percival and D. Richards, *Introduction to Dynamics*, Cambridge University Press (1983).

2. J.V. Jose and E.J. Saletan, *Classical Dynamics: A Contemporary Approach*, Cambridge University Press (1998).
3. E.T. Whittaker, *A Treatise on the Analytical Dynamics of Particles and Rigid Bodies*, 4th edition, Cambridge University Press (1989).

Course Outcomes:

After completing the course, the students will be able to:

1. *describe basic concepts of advanced classical mechanic formulations.*
2. *compare the Lagrangian and Hamiltonian formulations to solve the motion of complex classical dynamical systems such as central force problems, oscillating systems, and rigid body motions.*
3. *design the original classical problem using the principles of Lagrangian and Hamiltonian formulations.*
4. *solve the transformation equations for velocity and acceleration.*

PH655 – QUANTUM MECHANICS

Course Objectives:

1. *To introduce the mechanics of mater-waves necessary for uncovering the mysteries of matter at the atomic scale.*
2. *To outline mathematical tools to understand quantum mechanics.*
3. *To learn about solvable systems like Harmonic oscillator and Hydrogen atom using the Schrödinger method.*
4. *To learn about angular momentum for matrix representation and introduce various approximate methods useful for more complex problems.*

Schrödinger Equation

Inadequacy of classical theory – de-Broglie hypothesis of matter waves – Heisenberg's uncertainty relation – Schrödinger's wave equation – physical interpretation and conditions on wave function – eigenvalues and eigenfunctions – particle in a square-well potential – potential barrier – tunneling.

Operators and Eigenfunctions

Linear operator – orthogonal systems and Hilbert space – expansion in eigenfunctions – Hermitian operators – canonical commutation – commutations and uncertainty principle – state with minimum uncertainty.

Solvable Problems

Harmonic oscillator – operator method – Schrödinger equation for spherically symmetric potentials – angular momentum operator – condition on solutions and eigenvalues – spherical harmonics – rigid rotor – radial equation of central potential – hydrogen atom – degenerate states.

Angular Momentum and Spin

Eigenvalues of angular momentum J – matrix representation of J – electron spin – Stern – Gerlach experiment – Zeeman effect – addition of angular momentum – Clebsh-Gordan coefficients – identical particles with spin – Pauli exclusion principle.

Approximation Methods
Perturbation theory for non-degenerate states – removal of degeneracy – Stark effect – variation method – WKB approximation – Bohr-Summerfield quantum condition –perturbative solution for transition amplitude – selection rules – Fermi Golden rule – scattering of a particle by a potential.

Textbooks

1. P.M. Mathews and K. Venkatesan, A Textbook of Quantum Mechanics, Tata McGraw-Hill (1976).
2. J.L. Powell and B. Crasemann, Quantum Mechanics, Narosa Publishing House (1993).
3. J.J. Sakurai, Modern Quantum Mechanics, Addison-Wesley (1999).
4. Quantum Mechanics, Aruldhas, Prentice Hall of India (2006).

Reference Books

1. L.I. Schiff, Quantum Mechanics, McGraw-Hill (1968).
2. D.J. Griffiths, Introduction to Quantum Mechanics, Pearson Education (2005).
3. N. Zettili, Quantum Mechanics: Concepts and Applications, John Wiley (2009).
4. L.D. Landau and E.M. Lifshitz, Quantum Mechanics (Non-relativistic Theory), 3rd edition, Elsevier (2011).

Course Outcomes:

After successful completion of the course, the students will be able to:

1. *know the concept of quantum mechanics for uncovering the mysteries of matter at the atomic scale.*
2. *apply mathematical tools to understand eigenfunctions and eigenvalues.*
3. *understand the spectrum of hydrogen using solvable methods.*
4. *determine angular momentum matrix representation and apply approximate methods for simple and complex problems.*

PH657 – GENERAL PHYSICS LABORATORY

Course Objectives:

1. *To introduce the basic concepts of physics through hands-on experience.*
2. *To impart general physics experimental skills to the students.*
3. *To impart experimental research skills.*
4. *To understand the factors and errors that affect the experimental results.*

List of Experiments

1. Half-shade polarimeter- specific rotation of liquid
2. Determination of Planck's constant- Photoelectric effect
3. Heat capacity of solids-Calorimeter
4. Michelson interferometer
5. Determination of Rydberg constant using hydrogen spectra
6. Determination of magnetic susceptibility- Gouy's balance
7. Cornu's interference method- Determination of Young's Modulus of a beam.
8. I-V characteristics of a Solar cell
9. Determination of the numerical aperture of an optical fiber
10. Electrical conductivity- Four Probe Method
11. Hall effect in semiconductor
12. GM Counter
    (i) Determination of the plateau and optimal operating voltage of a GM counter.
    (ii) Verify the inverse square relationship between the distance and intensity of radiation
    (iii) measure the half-life of the radioactive source
13. Gamma Ray Spectrometer
    (i) Study of energy resolution characteristics of a scintillation spectrometer as a function of applied high voltage
    (ii) Study of Cs-137 spectrum and calculation of FWHM and resolution for a given scintillation detector
    (iii) Study of Co-60 spectrum and calculation of resolution of a detector in terms of energy
14. Electron Spin Resonance
15. Kerr effect –determination of Kerr constant of a Liquid
16. Pockel effect- electro-optic property of a crystal
17. Two Probe Method for Resistivity Measurement
18. Acoustic Diffraction
19. Zeeman effect
20. Forbe’s Method – Thermal Conductivity of Metal
21. Curie Temperature of Magnetic Materials
22. Dielectric Constant and Curie Temperature of Ferroelectric Ceramics
23. Millikan Oil Drop Experiment – e/m of Electron
24. Stefan’s Constant
25. Magnetic Susceptibility of Liquids – Quincke’s Method
26. Velocity of sound in air- Kundt's tube experiment.

Textbook

1. General Physics Laboratory Manual, Department of Physics, NIT-T.

Reference Books

1. R. A. Dunlap, Experimental Physics: Modern Methods, Oxford University Press, New Delhi (1988).
2. E.V. Smith, Manual for Experiments in Applied Physics, Butterworths (1970).
3. D. Malacara (ed.), Methods of Experimental Physics, Series of Volumes, Academic Press Inc. (1988).

Course Outcomes:

The students will be able to:

1. *understand the fundamental physics behind many scientific discoveries through hands-on experience.*
2. *acquire general physics experimental skills.*
3. *research skills in experimental physics.*
4. *get knowledge on the factors and errors that affect the experimental results.*

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SEMESTER II

PH652– ELECTROMAGNETIC THEORY

Course Objectives:

1. *To understand static electric fields and solve related problems.*
2. *To understand the magnetic induction and Ampere's law.*
3. *To learn the Faraday's law of induction and the energy of the electromagnetic field.*
4. *To learn the wave propagation of electromagnetic fields through different media.*

Electrostatics
Electric field – divergence and curl – electric potential – Gauss's law – electric dipole – multipole expansion – solutions to Laplace equation – separation of variables – polarization – field of polarized object – electric displacement – Gauss's law in dielectric – dielectric constant – point charge in dielectric – dielectric sphere in uniform field – boundary conditions – electrostatic energy density – capacitors –thermodynamic interpretation.

Magnetostatics
Current density and equation of continuity – Lorentz force – magnetic induction – Biot-Savart law – application to the circular coil and solenoid – Ampere's circuital law – magnetic flux – vector potential – magnetization – magnetic intensity – susceptibility – boundary conditions – types of magnetic materials.

Maxwell's Equations
Faraday's law – inductance and magnetic energy – generalization of Ampere's law – Maxwell's equations – boundary conditions – scalar and vector potentials – gauge invariance – electromagnetic energy – Poynting's theorem.

Electromagnetic Waves
Electromagnetic wave equation (without source) – solution of 3D wave equation – propagation of EM waves in non-conducting media – waves in conducting media – polarization of EM waves.

Waves in Bounded Region
Reflection and refraction at the boundary of non-conducting media – Fresnel's coefficients – Brewster's angle and critical angle – reflection from a conducting plane – wave guide – TE and TM waves – rectangular wave guide.

Textbooks

1. D. J. Griffiths, Introduction to Electrodynamics, Prentice Hall of India, 4th edition (2015).
2. J.R. Reitz., F.J. Milford and R.W. Christy, Foundations of Electromagnetic Theory, 4th

edition,Pearson (2010).

Reference Books

1. J.D. Jackson, Classical Electrodynamics, Wiley-India, (2020).
2. E.C. Jordon and K.G. Balmain, Electromagnetic Waves and Radiating Systems, 2nd edition,Prentice Hall of India (1998).
3. W. Greiner, Classical Electrodynamics, 3rd edition, Springer (2010).
4. L.D. Landau and E.M. Lifshitz, Electrodynamics of Continuous Media, 2nd edition, Elsevier (2008).

Course Outcomes:

Upon successful completion of the course, the students will be able to:

1. *understand electric and magnetic force fields and the intricate connection between them.*
2. *understand the energy of electromagnetic fields.*
3. *appreciate the electromagnetic nature of radiation and its propagation in media.*
4. *solve practical problems involving electromagnetic potentials and the associated fields.*

PH654 – STATISTICAL MECHANICS

Course Objectives:

1. *To learn the connection between macroscopic and microscopic states of a system of a large number of particles and to understand the concept of ensemble average.*
2. *To understand the thermodynamic equilibrium of a system from a statistical point of view.*
3. *Calculate the microcanonical, canonical, grand-canonical and isothermal-isobaric partition functions.*
4. *Learn Maxwell-Boltzmann, Bose-Einstein and Fermi-Dirac distribution functions and compute the thermodynamic variables for a wide range of natural systems.*

Review of Thermodynamics
Zeroth, First, Second and Third Laws – Entropy and Clausius' inequality – Concept of Thermodynamic Equilibrium - Thermodynamic potentials – Maxwell's Relations –– Ideal and Real gases – Phase transition

Theory of Ensembles
Need for Statistical Mechanics - *Postulates:* phase space, microstates, density of states, ensemble average – Liouville's theorem – microcanonical ensemble – quantum phase space – canonical ensemble – partition function (N particle) – ideal gas law – thermal wavelength – grand canonical ensemble – isothermal-isobaric ensemble.

Maxwell-Boltzmann Statistics

Boltzmann system – Maxwell-Boltzmann distribution – Lagrange's multipliers – partition function (single particle) – thermodynamics of gases – velocity distribution – equipartition of energy – paramagnetism – Einstein model of solid.

Bose-Einstein Statistics
Principle of indistinguishability – Bosons – Bose-Einstein distribution – Planck's law of radiation – Stefan's law – Debye's theory of heat capacity – Bose-Einstein condensates.

Fermi-Dirac Statistics
Fermions – Fermi-Dirac distribution – Fermi energy – electron gas in metals – electron gas in white dwarf stars – Polytropic Equation of State - electronic specific heat – thermionic emission – Pauli paramagnetism – Landau diamagnetism.

Textbooks

1. M. W. Zeemansky and R.H. Dittman, Heat and Thermodynamics, 8th edition, Mc-Graw Hill (2011).
2. K. Haung, Statistical Mechanics, 2nd edition, Wiley India (2010).
3. F.W. Sears and G.L. Salinger, Thermodynamics, Kinetic Theory and Statistical Thermodynamics, 3rd edition, Narosa Publishing House (1998).
4. F. Mandl, Statistical Physics, 2nd edition, Wiley (2002).

Reference Books

1. Enrico Fermi, Thermodynamics, Dover (1956).
2. R.K. Pathria and Paul D. Beale, Statistical Mechanics, 3rd edition, Academic Press (2011).
3. F. Reif, Fundamentals of Statistical and Thermal Physics, International Students edition, Tata McGraw-Hill (1988).
4. S.J. Blundell and K.M. Blundell, Concepts in Thermal Physics, Oxford University Press (2006).
5. L.D. Landau and E.M. Lifshitz, Statistical Physics – Part I, 3rd edition, Elsevier (2010).

Course Outcomes:

After successful completion of the course, the students will be able to:

1. *know the concept of thermodynamic equilibrium of a system and the corresponding thermodynamic variables and the relations between them.*
2. *understand the theory of ensembles governing the equal a priori probabilities of the microstates of a system corresponding to a given microstate.*
3. *find the partition function of any thermodynamic system consisting of classical particles (Maxwell-Boltzmann) and quantum particles (Bose-Einstein and Fermi-Dirac) in various ensembles (microcanonical, canonical, grand-canonical and isothermal-isobaric).*
4. *get the required thermodynamic variables from the partition function and apply this procedure to get the general properties of various physical, chemical and biological systems.*

PH656 SOLID STATE PHYSICS

Course Objectives:

By taking this course, the students will:

1. *appreciate the crystal structure of all materials.*
2. *compare the properties of different types of materials, such as conductors, semiconductors, and dielectrics.*
3. *imbibe the significance of lattice with various models.*
4. *recognize the origin of magnetism and develop a basic interest in superconductivity.*

Introduction
Solids – crystalline and amorphous – crystal structure and symmetries – reciprocal lattice – defects and dislocations – Brillouin Zone and its properties – Bonding in Solids – atomic scattering factor – geometric structure factor – X-ray diffraction – powder-Laue and rotation or oscillation method– liquid crystals.

Conductors, Semiconductors and Dielectrics
Conductors: Free electron theory – classical and quantum theory, band theory of solids –Tight binding model -effective mass of an electron– Fermi surface - Bloch theorem – Kronig-Penny model– Hall effect. *Semiconductors:* Types – carrier and Fermi level statistics for intrinsic and extrinsic semiconductors – electrical conductivity. *Dielectrics:* Types of polarization – frequency dependence of polarization – local electric field – dielectric constant and polarizability – Clausius-Mossotti equation, piezo and ferroelectricity.

Transport and Thermodynamic Studies
Lattice vibrations – concept and momentum of phonons – vibrations of mono and di-atomic lattices, heat capacity – Einstein and Debye models - Dulong and Petit's law – Weidemann-Franz law – electronic heat capacity – experimental heat capacity of metals – heavy Fermions –resistivity – residual resistivity ratio – experimental electrical resistivity of metals – Matthiessen's rule – Magnetoresistance – Giant and colossal magnetoresistance.

Magnetism
Magnetic terminologies – types of magnetism – dia, para, ferro, ferri and anti-ferromagnetism Atomic theory of magnetism– Hund's rules – Curie-Weiss law – Langevin's classical and quantum theories of dia and para magnetism –Weiss Molecular field - concept of domain and hysteresis of ferromagnetism – Heisenberg model of exchange interaction – antiferro and ferrimagnetism

Superconductivity
Superconductivity – Meissner and isotope effect – thermodynamical and optical properties –– Coherence length -London's equations and penetration depth - critical field – types of superconductors –flux quantization – BCS theory- –Normal tunneling and Josephson Junctions – AC and DC – high Tc superconductors -superfluidity.

Textbooks

1. Charles Kittel, Introduction to Solid State Physics, Wiley Eastern, 5th edition, (1983).
2. T.H.K. Barron and G.K. White, Heat capacity and Thermal Expansion at Low Temperatures, Kluwer Academic/Plenum Publishers, New York (1999).
3. N.W. Ashcroft and N.D. Mermin, Solid State Physics, Cengage Learning (2010).
4. Ali Omar, Elementary Solid State Physics, Pearson Education India (1999).
5. J.S. Blakemore, Solid State Physics, 2nd edition, Cambridge University Press (1974).

Reference Books

1. B.S. Saxena, R.C. Gupta, P.N.Saxena, Fundamentals of solid state physics, Pragati Prakashan, 7th edition (1999).
2. A.J. Dekker, Solid State Physics, Prentice Hall of India (1971).
3. Helmut Kronmüller, Stuart Parkin, Handbook of Magnetism and Advanced Magnetic Materials, Wiley (2007).
4. Laurent-Patrick Lévy. Magnetism and superconductivity, Springer (2000).

Course Outcomes:

By the end of this course, the students will be able to:

1. *grasp the significance of the structure and property relationship.*
2. *describe the classification of materials with the theories for applications.*
3. *understand the transport and thermodynamic properties of materials and the underlying physics.*
4. *realize different types of magnetic phenomena in classical and quantum aspects.*
5. *design superconducting materials for future technology.*

PH658 COMPUTATIONAL LABORATORY

Course Objectives:

To introduce various concepts of basic electronics and circuits through elementary software skills and to impart basic computation skills.

List of Experiments

1. MATLAB-1: Spectrum Analysis using Fast Fourier Transform
2. MATLAB-2: Solving Partial Differential Equation using Finite Difference Method
3. MATLAB-3: Solving Non-Linear Equations
4. MATLAB-4: Non-Linear Harmonic Oscillator – Frequency Amplitude Response
5. MATLAB-5: Artificial Neural Network – Pattern Recognition, Classification and Time Series Analysis.
6. MATLAB-6: MEMS - Dynamics of Microcantilever
7. MATLAB-7: Modelling LCR circuit in Simulink
8. MATLAB-8: Dispersion Curve of Optical Waveguide

9. MATLAB-9: Lorenz System – Chaotic Dynamics
10. MATLAB-10: Fractal – Cluster Formation using Diffusion Limited Aggregation
11. MATLAB-11: Clustering Analysis using Principal Component Analysis
12. MATLAB-12: Linear and Non-linear Optimization Problems
13. PYTHON-1: Root finding method for algebraic equations
14. PYTHON-2: System of linear equations
15. PYTHON-3: Interpolation and curve fitting
16. PYTHON-4: Numerical integration and differentiation

Textbook/Reference Books

1. MATLAB Programming Fundamentals – © 1984–2021 by The MathWorks, Inc.
2. LabVIEW^{TM} Getting Started with LabVIEW © National Instruments.
3. Computational Physics, Nicholas J. Giordano, Prentice Hall (1997).

Course Outcomes:

The student will be able to understand the fundamental physics behind electronic circuits used in many modern devices through programming and simulation. They shall also acquire basic computation skills.

PH662 ELECTRONICS LABORATORY

Course Objectives:

To introduce various concepts of basic electronics and circuits through hands-on experience.

List of Experiments

1. Single-stage and multistage amplifiers
2. Op-amp inverting and non-inverting amplifier
3. Integrator and differentiator circuits
4. Filter circuits
5. Multivibrators
6. Logic gates and universality of gates
7. Multiplexers and demultiplexers
8. Verification of De-Morgan’s theorem
9. Adder and Subtractor circuits
10. Flip flops
11. Solving Simultaneous Equations
12. Voltage Controlled Oscillator
13. Op-Amp Arithmetic Operations
14. Op-Amp Square, Ramp Generator and Wien Bridge Oscillator
15. Op-Amp Precision Full Wave Rectifier

16. Regulated Power Supply using IC 723
17. Phase Shift Oscillator
18. Wien's Bridge oscillator using operational amplifier

Textbook

1. Electronics Laboratory Manual, Department of Physics, NIT-T.

Reference Books

1. B.K. Jones, Electronics for Experimentation and Research, Prentice-Hall (1986).
2. P.B. Zbar, A.P. Malvino and M.A. Miller, Basic Electronics: A Text-Lab Manual, TataMc-Graw Hill, New Delhi (1994).

Course Outcomes:

The student will be able to understand the fundamental physics behind electronic circuits used in many modern devices through hands-on experience.

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SEMESTER III

PH659 – NUCLEAR AND PARTICLE PHYSICS

Course Objectives:

1. *Introduce students to the global properties of the nucleus.*
2. *To understand the nuclear models.*
3. *To study radioactivity and nuclear reactions.*
4. *Introduce students to the world of elementary particles and their interactions.*

Nuclear Properties and Forces

Nuclear radius and charge distribution – angular momentum – parity – electromagnetic moments-isospin – binding energy – nature of the nuclear force – Yukawa's hypothesis – Deuteron and its properties – properties of nuclear forces – spin dependence – internucleon potential – charge independence and charge symmetry-polarization.

Nuclear Models

Liquid drop model – semi-empirical mass formula – shell model – experimental evidence – magic numbers – spin-orbit coupling – angular momentum of the energy states – magnetic moments and Schmidt lines – electric quadrupole moments – excited states – collective model – nuclear vibration and rotation.

Radioactivity

Measurements of lifetimes – multipole moments – theoretical prediction of decay constants – selection rules – angular correlations – internal conversion – Geiger-Nuttel law – barrier penetrations applied to alpha, decay and beta decay – simple theory – Kurie plots – comparative half-life – selection rules – internal conversion.

Nuclear Reactions

Reaction dynamics – Q-equation – theory of nuclear reaction – reaction cross sections- Rutherford cross section – compound nucleus reactions– direct reactions – resonance reaction – fission process – energy in fission and absorption cross section – neutron sources–fusion fundamentals – Lawson criterion – solar fusion.

Elementary Particles

Classification of elementary particles – types of interactions – conservation laws –momentum-parity and spin – isospin – baryon and lepton numbers – Gell-Mann-Nishijima relationship – mesons and baryons – CPT invariance – detection and properties of neutrino – concept of antiparticles – tau-theta puzzle – neutral kaon – quark model.

Textbooks

1. Kenneth S. Krane, Introductory Nuclear Physics, John Wiley & Sons, New York (1988).
2. D. Griffiths, Introduction to Elementary Particles, Harper and Row, New York (1987).

Reference Books

1. B. L. Cohen, Concepts of Nuclear Physics, Mc-Graw Hill, New York (1971).
2. Kaplan, Nuclear Physics, Addison-Wesley, London (1977).
3. D. H. Perkins, Particle Astrophysics, Oxford University Press, New York (2003)
4. Samuel S. M. Wong, Introductory Nuclear Physics, Wiley, Weinheim (2004).

Course Outcomes:

Upon completion of the course, the students will be able to:

1. *identify and analyze the global properties of the nucleus.*
2. *compare and contrast various nuclear models.*
3. *apply the concept of radioactivity and to compute energy released in nuclear reactions.*
4. *explain and classify elementary particles and their interactions.*

PH661–PROJECT WORK (PHASE-I)

Course Objectives:

To undertake independent research on a topic and to enhance critical thinking, presentation and communication skills.

Literature survey – Undertaking independent research showing competence in the design of experiments- data analysis – Finding new results and comparing with literature- Attending and presenting the results in a Workshop/Seminar/Conference- Defend the research work during viva-voce.

Course Outcomes:

The students shall be able to conduct independent research, plan experiments, communicate the results, and write research articles and reports.

PH675 ATOMIC AND MOLECULAR SPECTROSCOPY

Course Objectives:

1. *To gain insight into the physics governing atomic and molecular spectroscopy.*
2. *Basics quantum numbers of atoms relevant to spectral designation will be introduced.*
3. *Working of various types of spectroscopy methods will be introduced in detail.*
4. *Students will be instructed to analyze sample spectra to gain hands-on experience.*

Atomic Spectra
Quantum states of the electron in atoms– hydrogen atom spectrum– electron spin – Stern Gerlach Experiment – spin-orbit interaction – Lande interval rule– two-electron systems – LS-JJ couplingschemes–fine structure– spectroscopic terms and selection rules – hyperfine structure – exchangesymmetry of wave function– Pauli's exclusion principle – the periodic table.

Atoms in External Fields and Resonance Spectroscopy
Zeeman and Paschen Back Effect of one and two electron systems – selection rules – Stark effect– inner shell vacancy– X-ray– Auger transitions – Compton Effect – NMR – basic principles – classical and quantum mechanical description – spin-spin and spin-lattice relaxation times – magnetic dipole coupling – chemical shift – Knight shift – ESR – basic principles – nuclear interaction and hyperfine structure – g-factor – zero-field splitting.

Microwave Spectroscopy and IR Spectroscopy
Rotational spectra of diatomic molecules – rigid rotator – effect of isotropic substitution – non-rigid rotator – rotation spectra of polyatomic molecules – linear, symmetric top and asymmetric top molecules – experimental techniques – diatomic vibrating rotator– linear, symmetric top molecule – analysis by infrared techniques – characteristic and group frequencies.

Raman Spectroscopy
Raman effect– quantum theory of Raman effect– rotational Raman spectra – vibrational Raman spectra – Raman spectra of polyatomic molecules – Raman spectrometer – hyper- Raman effect – experimental techniques.

Electronic Spectroscopy
Electronic spectra of diatomic molecules – Frank-Condon principle – dissociation energy and dissociation products – rotational fine structure of electronic vibration transitions – Fortrat Diagram predissociation.

Textbooks

1. C.N. Banwell, Fundamentals of Molecular Spectroscopy, 4th edition, McGraw-Hill, New York (2004).
2. G. Aruldhas, Molecular Structure and Spectroscopy, Prentice Hall of India, New Delhi (2002).
3. E. H. White, Introduction to Atomic Spectra, McGraw-Hill (2005).

Reference Books

1. Manas Chanda, Atomic Structure and Chemical Bond, Tata McGraw-Hill, New Delhi (2003).
2. B.P. Straughan & S. Walker, Spectroscopy: Vol. I, Chapman and Hall (1976).
3. G.M Barrow, Introduction to Molecular Spectroscopy, McGraw Hill (1986).

<u>Course Outcomes:</u>

The students will be able to:

1. *gain sufficient knowledge on the most common atomic and molecular spectroscopic methods.*
2. *understand the structure of atoms and molecules.*
3. *acquire physical insights on quantum mechanical methods applied to different spectroscopy.*
4. *apply spectroscopy methods to different forms of matter.*

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SEMESTER IV

PH660– PROJECT WORK (PHASE-II)

Course Objectives:

To undertake independent research on a topic and to enhance critical thinking, presentation and communication skills.

Literature survey – Undertaking independent research showing competence in the design of experiments - data analysis – Finding new results and comparing with literature- Attending and presenting the results in a Workshop/Seminar/Conference- Defend the research work during viva-voce.

Course Outcomes:

The student shall be able to conduct independent research, plan experiments, communicate the results, and write research articles and reports.

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ELECTIVES

PH671 – ELECTRONICS

Course Objectives:

1. *To learn about the circuit theorems and their applications.*
2. *To acquire basic knowledge of the Physics of diodes and transistors.*
3. *To learn about the working mechanism of oscillators and operational amplifiers.*
4. *To familiarize with different digital circuits.*

Circuit Theorems
Kirchhoff's voltage law-voltage division- power in series circuit- Kirchhoff's current law –parallel resistance – current division – Star-Delta Transform – Thevenin's and Norton's theorems, superposition and reciprocity theorems with examples - maximum power transfer theorem.

Semiconductor Devices: Diodes and Transistors
p-n junction diodes – Zener diode – tunnel diode – Schottky barrier diode – varactor diode – UJT. Transistors – Biasing characteristics of junction transistors – analysis using re model-fixed bias-voltage divider bias-emitter bias – feedback in amplifiers – effect of negative feedback in amplifiers – FETs – different types – introduction to semiconductor fabrication - applications.

Oscillators
Oscillator principle – oscillator types – frequency stability, RC oscillators – phase shift oscillator – Wein bridge oscillator – LC tunable oscillators – limitations – multivibrators – monostable and astable – 555 IC timer – sine wave and triangular wave generation – crystal oscillators and their applications.

Operational Amplifiers
Basis of operational amplifier – characteristics – CMRR – inverting and non-inverting modes- sum and difference amplifiers – integrating and differentiating circuits – feedback types – current to voltage (ICVS) and voltage to current (VCIS) conversion — op-amp application – instrumentation amplifiers – low pass and high pass active filters.

Digital Circuits
Logic gates: De Morgan's law, binary adder, comparators, decoders, multiplexers. *Flip-flops:* RS flip-flop, JK flip-flop, JK master-slave flip-flop, T flip-flop, D flip-flop. Shift registers – synchronous and asynchronous counters – registers – A/D and D/A conversion.

Textbooks

1. J. Milman and C.C. Halkias, Electronic Devices and Circuits, McGraw-Hill (1981).

2. Albert Malvino, David J Bates, Electronics Principles, 8th edn., McGraw-Hill Education (2015).
3. R.J. Higgins, Electronics with Digital and Analogue Integrated Circuits, Prentice Hall (1983).

Reference Books

1. R. L. Boylsted and L. Nashelsky, Electronic Devices and Circuits, Pearson Education (2003).
2. C. L. Wadhwa, Network Analysis and Synthesis, New Age International Publishers, (2007).
3. G.B. Calyton, Operation Amplifiers, ELBS (1980).

Course Outcomes:

On successful completion of this course, the students will be able to:

1. *describe the circuit theorems and apply them for network analysis.*
2. *explain the working mechanism and characteristics of diodes and transistors.*
3. *discuss the different types of oscillators and amplifiers.*
4. *describe the design and applications of various digital circuits.*

PH672 – INSTRUMENTATION

Course Objectives:

1. *Study the major characteristics of measurement systems and the errors involved.*
2. *Understand the production and measurement of lowtemperatures and high pressure.*
3. *Read various spectroscopic techniques and detectors.*

Generalized Characteristics of Instruments

Static characteristics: accuracy, precision, repeatability, reproducibility, resolution, sensitivity, linearity, drift, span, range. *Dynamic characteristics*: transfer function, zero-order instruments, first-order instruments – step, ramp, frequency responses– second-order instruments – step-ramp response – dead time elements. *Types of Errors:* gross, systematic, random.

Vacuum Systems

Principle and operation of various pumps: rotary, diffusion, sorption, turbo-molecular ionization and cryo-pumping. *Gauges*: McLeod, diaphragm, thermocouple, Pirani, Penning, ionization and hot and cold cathodes – design of high vacuum systems – high-pressure cells – measurements at high pressures.

Thermal Systems

Temperature scales – liquefaction of gases, achieving low temperature – design of cryostats. *High temperature furnaces:* resistance, induction and arc furnaces – high-temperature measurements – pyrometers – total and selective radiation pyrometers –optical pyrometer.

Detectors and Spectroscopy

Detectors: pyro-electric, thermo-electric, photo-conducting, photo-electric, photo-multiplier, scintillation types of detectors, photon counters. *Spectroscopy:* principles of atomic absorption spectroscopy – instrumentation – single and double beam spectrometers – theory and components of nuclear quadrupole resonance technique –applications.

Signal Conditioning and Error Analysis

Signal conditioning: Impedance matching, filtering, clipping and clamping, attenuators and its types, amplitude modulation and demodulation, lock-in detector, box-car integrator. *Error analysis*: Linear and nonlinear curve fitting, chi-square test.

Textbooks

1. A.K. Sawhney and Puneet Sawhney, A Course in Mechanical Measurement and Instrumentation, Dhanpat Rai & Sons, New Delhi (2000).
2. Dennis Roddy and John Coolen, Electronic communication, 4thedition, PHI private Ltd.,(1999).
3. C.S. Rangan, G.R. Sharma and V.S.V. Mani, Instrumentation Devices and Systems, TataMcGraw-Hill (1983).
4. H.H. Willard, L.L. Merrit and John A. Dean, Instrumental Methods of Analysis, 6thedition,CBS Publishers & Distributors (1986).

Reference Books

1. D.V.S. Murty, Transducers and Instrumentation, Prentice – Hall of India(P) Ltd., New Delhi (1995).
2. Ernest O. Doebelin, Measurement System Applications and Design, McGraw Hill InternationalBook Company, Singapore (1983).

Course Outcomes:

The students will be able to:

1. *appreciate various techniques involved in the production of vacuum and low temperatures.*
2. *handle various instruments in a better way.*
3. *understand the characteristics of instruments and analysis of errors in interpreting the obtained data more efficiently.*

PH673 – NUMERICAL METHODS

Course Objectives

To learn various numerical and computational techniques to handle complex problems (where exact solutions are not possible), like

1. *finding the roots of an equation*

2. *linear algebraic equations*
3. *interpolation and approximation of data*
4. *solving differential equations.*

Roots of Equations
Introduction – floating point arithmetic – computer word – propagation of errors – secant method – Newton-Raphson method – rate of convergence – polynomial equation – Horner's method – Muller method – the system of equations.

Linear Equations and Matrices
Gauss-elimination method – pivoting – LU decomposition – inverse and determinant of a matrix – eigenvalue equation – Jacobi method for symmetric matrices – Hermitian matrices – power method – singular value decomposition.

Interpolation and Approximation
Lagrange interpolation – Newton's divided difference – finite difference methods – cubic spline – method of least squares: linear and nonlinear – Gram-Schmidt process – Legendre and Chebyshev polynomials.

Differentiation and Integration
Numerical differentiation by interpolation – method of finite differences – integration by Simpson's rule – estimation of errors – double integration – Monte Carlo method.

Differential Equations
Initial and boundary value problems – Euler method – Runge-Kutta methods: second and fourth orders – finite difference method – collocation method – Rayleigh-Ritz method – Galerkin method.

Textbooks

1. Numerical Methods using MATLAB, 4th edition, J. H. Mathews and K.D. Fink, PHI Learning (2004).
2. M.K. Jain, S.R.K. Iyengar, R.K. Jain, Numerical Methods for Scientific and Engineering Computation, New Age International (2016).
3. E. Kreyszig, Advanced Engineering Mathematics, 8th edition, Wiley India (2008).
4. S.S. Sastry, Introductory Methods of Numerical Analysis, Prentice-Hall of India (2005).

Reference Books

1. W.H. Press, S.A. Teukolsky, W.T. Vetterling and B.P. Flannery, Numerical Recipes in C: The Art of Scientific Computing, Cambridge University Press (1992).
2. Samuel D. Conte and Carl de Boor, Elementary Numerical Analysis, 3rd edition, Tata McGraw-Hill (2010).
3. R.L. Burden and J.D. Faires, Numerical Analysis, 9th edition, Brooks/Cole - Cengage Learning (2011).
4. L.A. Pipers and L.R. Harvill, Applied Mathematics for Engineers and Physicists, Dover Publications (2014). Ch. 14.

Course outcomes

Students will be equipped with the necessary computational techniques to handle various *problems like roots of an equation, large sets of linear equations, modelling of data and differential equations.*

PH674 – NANOSCIENCE AND TECHNOLOGY

Course Objectives:

1. *To impart basic knowledge on exotic properties of materials at nanoscale, and synthesis methods.*
2. *To teach various techniques available for the processing and characterization of nanostructured materials.*
3. *To impart knowledge on materials, their behaviors at mesoscopic scale, magnetic measurements and applications in magnetic recording technology.*
4. *To help students to understand the developments in nanoelectronics and biomedical field.*

Nanomaterials: Introduction & Synthesis
Structure and bonding in nanoscale- size effect on physical properties – Graphene, Fullerene, CNT – Quantum dots - Synthesis: top-down, bottom-up: nucleation & growth, gas condensation, Sol-gel, Chemical Vapor Deposition, Molecular Beam Epitaxy methods

Characterization Tools
Electron Microscopy Techniques – Scanning Electron microscopy, Tunneling Electron Microscopy, X-ray methods – optical methods: fluorescence Microscopy – single molecule surface enhanced resonance – Raman spectroscopy – Scanning probe Microscopy: Scanning Tunneling Microscopy, Atomic Force Microscopy.

Nanomagnetism
Mesoscopic magnetism – mesoscopic magnetic materials –magnetic measurements: miniature Hall detector, integrated DC SQUID Microsusceptometry – magnetic recording technology: Giant Magnetoresistance, Tunneling magnetoresistance, magnetic read/write - biological magnets.

Nanoelectronics and Integrated Systems
Basics of nanoelectronics -single electron transistor – quantum computation & parallel architecture for nanosystems, MEMS/NEMS: micromachining-LIGA- Nano/Microfluidics: behavior of liquid in micro or nanosystems- lab-on-chip application

Biomedical Applications of Nanotechnology
Biological structures and functions – bio molecular motors: myosin, kinesin, ATP Synthase – drug delivery systems – organic-inorganic nanohybrids biosensors, magnetic hyperthermia

Textbooks

1. C.P. Poole and F.J. Ownes, Introduction to Nanotechnology, Wiley India (2007).
2. Cao G, Nanostructures and Nanomaterials: Synthesis, properties and applications, Imperial College Press (2004).
3. N. John Dinardo and Weinheim Cambridge, Nanoscale Characterisation of Surfaces & Interfaces, 2nd edition, Wiley-VCH (2000).

4. Jan Korvink and Andreas Greiner, Semiconductors for Micro and Nanotechnology – an Introduction for Engineers, Weinheim Cambridge: Wiley-VCH (2001).
5. Molecular Sensors and Nanodevices; Principles; Designs and Applications in Biomedical Engineering; JXJ Zhang, K Hoshino, Elsevier (2014).

Reference Books

1. Dieter Vollath, Nanomaterials: An Introduction to Synthesis, Properties and Applications, John Wiley and Sons (2013).
2. G. Timp (ed), Nanotechnology, AIP Press, Springer (1999).
3. M. Wilson, K. Kannangara, G. Smith, M. Simmons and B. Raguse, Nanotechnology: Basic Sciences and Energy Technologies, Overseas Press (2005).
4. M. S. Ramachandra Rao, Nanoscience and Nanotechnology: Fundamentals to Frontiers, Wiley (2013).
5. Nguyen, N-T and Wereley, S "Fundamentals and Applications of Microfluidics", 2nd Edition, Artech House, Boston (2019).
6. H. Baltes et al, Enabling technology for MEMS and Nanodevices, Wiley-VCH (2008).

Course Outcomes:

On successful completion of this course, the students will be able to:

1. *describe material behaviors at the nanoscale and important experimental tools in the fields of nano-science.*
2. *understand the quantum mechanical tunneling of electrons, oscillatory coupling GMR effect, and related applications in devices and MEMs.*
3. *familiarize with the applications of nanotechnology in magnetic recording, quantum computation, and nanofluidics.*
4. *understand specific applications in biological devices, drug delivery, biosensors, and magnetic hyperthermia.*

PH611 – DIGITAL SIGNAL AND IMAGE PROCESSING

Course Objectives:

1. *Introduce discrete signal and image processing concepts and their application.*
2. *To understand the basic mathematics necessary for signal processing and image processing.*
3. *Know different techniques for designing digital filters.*
4. *Have knowledge of different Image enhancement techniques and analysis.*

Discrete Time Signal and Systems

Basics of signals – Periods, frequency, phase – Mathematical representation of signals – Discrete time signals, data acquisition – Sequences – Linear shift-invariant systems – Stability andCausality – Linear constant Co-efficient difference equations – Frequency-domain – Representation of Discrete-time systems and signals – Representation of discrete-time signals by Fourier transform

– signal analysis - time-domain analysis- determination of signal power and energy – gating methods – time gate – peak determination- echo detection – time-frequency analysis – short time Fourier transform – wavelet.

Transform Analysis of Linear Time-Invariant Systems
Z-transform – Region of convergence – Relation between Z-transform and Fourier Transform – Frequency response –Phase distortion and delay – system functions – Frequency response of rational system functions–first-order systems – Basic Digital filter structures – FIR and IIR filters.

Filter Design Techniques and Fast Fourier Transform
Signal noise – inherent noise, EMI noise, random noise, speckle noise, process-induced noises etc – Design of FIR filters by window method – Rectangle – Hanning – Hamming – Kaiser – IIR Filters design – Bilinear Transformation – Discrete Fourier Transform – Computation of DFT-Applications in NDT.

Continuous and Digital Image Characterization
Image representation - 2D-systems - 2D-Fourier Transform - Light perception - Eye Physiology - Visual phenomena - Monochrome vision model - 2D Image sampling & reconstruction - Image sampling systems - Aliasing effects - Image reconstruction systems - Vector-space Image representation - Image Quantization.

Linear Image Processing Methods and Image Enhancement
Introduction to image representation – spatial and frequency domain –. Generalized 2D Linear operator - Superposition – Filtering – Convolution and De-convolution - Unitary transformations - Fourier Transform - Cosine Transformation - Image reconstruction and Enhancement - Contrast manipulation - Histogram modification - Noise cleaning – Image analysis – Edge detection and crispening –contour quantification –texture analysis– statistical analysis- Applications in NDT.

Textbooks

1. A.V. Oppenheim and R. W. Schafer, Discrete-Time Signal Processing, Pearson India (2014).
2. Vinay K. Ingle and John G. Proakis, Digital Signal Processing Using MATLAB: A Problem Solving Companion Paperback – Cengage India Private Limited (2017).
3. W. K. Pratt, Digital Image Processing, John Wiley & Sons,4th edition, (2010).
4. R. C. Gonzalez and R. E. Woods, Digital Image Processing, Pearson Education,4th edition. (2018).

Reference Books

1. L.R. Rabiner and B. Gold, Theory and Applications of Digital Signal Processing, Pearson India, (2015).
2. T. Bose, Digital Signal and Image Processing, Wiley student edition (2010).
3. A.V. Oppenheim, A. S. Will Sky and S. H. Nawab, Signals and Systems, Prentice-Hall of India, 2nd edition, (2008).
4. N. Efford, Digital image processing: a practical introduction using Java, Addison-Wesley, (2000).

Course Outcomes:

Upon completion of the course, the student will be able to:

1. *understand basic principles of discrete-time signals and systems.*
2. *design and analyze various types of frequency digital filters.*
3. *use different Digital image processing techniques for specific applications.*
4. *apply signal processing to ultrasonic signals and image processing to radiographic images.*

PH613 BASICS OF ENGINEERING MATERIALS

Course Objectives:

This introductory course is aimed to:

1. *obtain knowledge of the basics of metals, dislocations, reactions and phase diagrams.*
2. *familiarize heat treatment of steels, TTT and CCT diagrams.*
3. *understand the mechanical properties and testing of materials.*
4. *introduce non-ferrous metals, ceramics, light weight structures.*

Structure of Metals

Crystal structure– Imperfections in crystals – dislocation theory - Principles of Alloying – Solid solutions– Gibb's phase rule and equilibrium diagram - types of binary phase diagrams – Eutectic – Peritectic and eutectoid reactions.

Steel and Heat Treatment of Steels

The Iron-carbon system – structural changes on slow and rapid cooling - martensitic transformation –concept of hardenability – TTT and CCT diagrams. Effects of carbon and alloying elements – Classification of steels. *Heat Treatment of Steels:* Annealing -normalizing, quenching and tempering – Case hardening, Austempering and martempering – Solidification of Metals and alloys – Nucleation and crystal growth from the liquid phase –Segregation effects and grain size control – strength mechanisms – solute, dispersion and precipitation hardening.

Mechanical behavior of materials

Elements of elastic and plastic deformation – stress-strain relation-work hardening, recovery, recrystallization and grain growth. Fracture-ductile fracture, brittle fracture, Griffith's criterion-toughness- fatigue, creep fracture- - Failure analysis and testing.

Non-Ferrous Metals & Ceramics

Significance of light metals in engineering industries, Aluminum, Aluminum alloys, strengthening mechanism of aluminum alloys and heat treatment methods- Copper & Copper Alloys- Titanium & Titanium Alloys, Advantages & Applications. Industrial importance of engineering ceramic materials, refractories and their application. Cement and concrete, damages and degradation of concrete.

Composites

Importance of composites – constituents – functions of fiber and matrix –types of fibers-glass fiber, carbon fiber, metallic fibers, ceramic fibers-Matrix materials – Metallic and Polymer matrix composites – Manufacture methods – hand lay up & prepeg techniques pulforming, therforming, resin-transfer moulding, injection moulding.

***Textbooks*:**

1. W. D. Callister, Materials Science and Engineering: An Introduction, Wiley, 7th edition, (2006).
2. V. Raghavan, Materials Science and Engineering, Prentice Hall of India, 5th edition (2013).
3. G.E. Dieter, Mechanical Metallurgy, Mc-Graw Hill, 3rd edition (2004).
4. A.V.K. Suryanarayana, Testing of Metallic Materials, Prentice -Hall of India, 2nd edition (2007).
5. V. B. John, Introduction to Engineering Materials, Palgrave Macmillan Limited, 3rd edition, (1992).

***Reference Books*:**

1. Robert E. Reed Hill and R. Abbaschian, Physical Metallurgy Principles, PWS-Kent Publishing Company 3rd edition (1992).
2. L. H. Van Vlack, Elements of Materials Science and Engineering, Addison Wesley, 6th edition (1989).
3. I. J. Polmear, Light Alloys: Metallurgy of the Light Metals, Wiley, 3rd edition (1995).
4. V. Raghavan, Physical Metallurgy: Principles and Practice, PHI Learning Private Limited, 2nd edition (2006).

Course Outcomes:

Upon completion of the course, the students will be able to:

1. *acquire knowledge of various materials and emphasize the need for modern materials other than conventional metals and alloys for specific engineering applications.*
2. *understand the heat treatment of steels, TTT and CCT diagrams.*
3. *evaluate mechanical properties and analyze the various metallurgical factors influencing the performance of materials for different structural engineering applications.*
4. *appreciate the non-ferrous metals, ceramics, light weight structures and their properties for engineering applications.*

PH676 ADVANCED MATHEMATICAL PHYSICS

Course Objectives:

1. *To introduce different infinite series and understand their convergence conditions*
2. *To analyze complex variables and understand integral formulas in the complex domain.*
3. *To understand different integral transforms and learn the basics of different symmetric groups.*
4. *To form a state equation which is two dimensions, for physical systems.*

Infinite Series
Fundamental concepts – convergence test: Cauchy's ratio test, Gauss's test – alternating series – algebra of series – Taylor expansion – Binomial theorem – power series – asymptotic series – Stirling's formula.

Complex Analysis
Functions of complex variable – derivative and Cauchy-Riemann equation–line integral – Cauchy's integral theorem – Cauchy's integral formula –Laurent series – Cauchy's residue theorem – poles– evaluation of residues – evaluation of definite integrals.

Integral Transforms
Fourier series – convergence– functions of any period –complex form – Fourier integral theorem– Fourier transform – Dirac delta function –Laplace transform – convolution theorem –transform of derivatives – application to the differential equation.

Group Theory
Introduction to group theory – generators of continuous groups – rotation groups and angular momentum – SU(2)-SO(3) homomorphisms – orbital angular momentum – discrete groups – character table – irreducible representation.

Partial Differential Equations
Vibrating string – d'Alembert's solution of wave equation – diffusion equation – solution by Fourier series – Poisson equation – method of separation of variables – Green's function method– introduction to nonlinear equations and chaos.

Textbooks

1. G. B. Arfken and H.J. Weber, Mathematical Methods for Physicists, 7th edition, Academic Press (2012).
2. E.Kreyszig, Advanced Engineering Mathematics, 10th edition, John Wiley & Sons Inc. (2015).
3. Mathematical Methods in the Physical Sciences, 3rd edition, Mary L. Boas, Wiley-India (An Indian Adaptation) (2023).
4. V. Balakrishnan, Mathematical Physics with Applications, Problems and Solutions, Ane Books (2023).

Reference Book

1. L. A. Pipes and L. R. Harvill, Applied Mathematics for Engineers and Physicists, 3rd edition, Dover (2014).

Course Outcomes:

Students will be knowing through:

1. *infinite series and Integral transforms to solve differential equations.*
2. *complex analysis to solve indefinite integrals.*
3. *group theory to understand the structural characteristics of different molecules.*
4. *partial differential equations to form a state equation for waves and heat conduction (two dimensions).*

PH677 WAVEGUIDES AND MODERN OPTICS

Course Objectives:

The course aims to:

1. *expose students to applications of electromagnetic theory concepts.*
2. *develop wave guides for communication and optical applications.*
3. *familiarize with advanced technologies such as optical image processing, non-linear optics in modern optics and the latest technologies.*

Electromagnetic Fields and Waves

Maxwell's equations and boundary conditions – energy density and poynting vector – monochromatic filed and complex function formalism – wave equation and monochromatic plane waves – chromatic dispersion and group velocity.

Waves in Dielectric Slabs

Introduction – TE and TM confined modes in symmetric slab – waveguides –TE And TM confined modes in asymmetric slab waveguides.

Anisotropic Media

Plane-wave in homogeneous media and normal surface – orthogonality of normal modes (eigenmodes) – classification of media – the index ellipsoid – plane waves in uniaxially anisotropic media phase retardation.

Nonlinear Optics

Introduction – physical origin of nonlinear polarization –second-order nonlinear phenomena – general methodology –electromagnetic formulation and optical second – harmonic generation – other second-order nonlinear processes –quasi phase matching – third order nonlinear optical processes – stimulated Brillouin scattering – four-wave mixing and phase conjugation – frequency tuning in parametric oscillation.

Fourier Optics

One-dimensional transforms – transform of Gaussian function – two-dimensional transforms –

transform of cylinder function – lens as a Fourier transformer – Dirac delta function – displacements and phase shifts – sines and cosines – optical application – transfer function.

Textbooks

1. Amnon Yariv and Pochi Yeh, Photonics – Optical Electronics in Modern Communication, 6th edition, Oxford University Press (2007).
2. Eugune Hecht and A.R. Ganesan, Optics, 4th Edition, Pearson Education Inc. (2002).
3. Clifford R. Pollock and Richard D. Irwin, Fundamentals of Optoelectronics (1995).

Course Outcomes:

Students will be able to:

1. *understand design concepts in optical waveguides.*
2. *appreciate the generation of stimulated lights, optical non-linear phenomena.*
3. *apply the knowledge in advanced optical technologies.*

PH678 ASTROPHYSICS AND COSMOLOGY

Course Objectives:

To introduce basic theoretical, experimental and observational concepts in the fields of planetary, stellar and galactic astrophysics and cosmology.

Observational Astronomy and Detection Techniques

Astronomical Coordinates−Celestial Sphere, Horizon, Equatorial, Ecliptic and Galactic Systems of Coordinates−Conversion from one system of coordinates to another−Parallax−Astronomical Time Systems−Optics−Telescopes and their types s−Optical, Infrared, Radio, X−ray and Gamma−ray astronomy−Detectors−CCD Camera and its characteristics−Photometry, Spectroscopy, Polarimetry, Astrometry, Interferometry−Gravitational wave astronomy − Gravitational wave detectors−Data analysis.

Planetary Astrophysics

Review of Kepler Problem−Virial Theorem−Types of planetary orbits−2−body and 3−body problem−Tidal forces−Lagrange Points−Precession and Nutation of Planets−Planetary Resonance−The Solar System.

Stellar Astrophysics

Stars as Blackbodies−Blackbody Radiation−Absolute, apparent and bolometric luminosity and magnitude−Spectral classification−Hertzsprung−Russell diagram−Stellar Evolution−Birth of Stars−Protostars−Main Sequence−Hydrostatic equilibrium−Saha Equation−Nucleosynthesis−Red Giant Branch−Asymptotic Giant Branch−Supernova−Heavy element formation−Compact stars−brown dwarfs−white dwarfs−neutron stars and pulsars−Dense matter Equation of State−Chandrasekhar and Tolman−Oppenheimer−Volkoff limits−Schwarzschild's Interior solution−Buchdahl's theorem−Gravitational collapse−Schwarzschild Black Hole−Binary Compact Stars−Gravitational Waves.

Galactic Astrophysics

Formation and classification−Density wave theory of the formation of spiral arms−Rotation curves−Missing mass and dark matter− Quasars and active galactic nuclei−Milky Way Galaxy−Oort's constants−magnetic fields.

Cosmology

Hubble's law and expansion of the Universe−Cosmic Microwave Background Radiation−Standard Model of Big Bang−Friedmann's equations−Radiation and Matter dominated phases−FRW models−Early Universe−Big Bang Nucleosynthesis−Dark matter and Dark Energy−ΛCDM Model−Recent observational results.

Text and Reference Books

1. Bradley Carroll & Dale Ostlie, An Introduction to Modern Astrophysics, Second Edition,Pearson, Addison Wesley (2007).
2. Frank Shu, The Physical Universe, University Science Books (1982).
3. T. Padmanabhan, Theoretical Astrophysics−Volume I, Cambridge University Press (2000).
4. T. Padmanabhan, Theoretical Astrophysics−Volume II, Cambridge University Press (2001).
5. T. Padmanabhan, Theoretical Astrophysics−Volume III, Cambridge University Press (2002).
6. Max Camenzind, Compact Objects in Astrophysics: White Dwarfs, Neutron Stars and BlackHoles, Cambridge University Press (2007).
7. Steven Weinberg, Cosmology, Oxford University Press (2008).

Course Outcomes:

Students will acquire:

1. *an overview of observational astronomy.*
2. *introductoryknowledge of astronomical instrumentation and observation techniques.*
3. *the basic and advanced theoretical concepts in planetary, stellar,galactic astrophysics and cosmology.*

PH679 SOLAR PHOTOVOLTAIC TECHNOLOGY

Course Objectives:

1. *To introduce the need for renewable energy sources and its potential.*
2. *To introduce the basics of semiconductor physics for solar photovoltaic technology.*
3. *To introduce the growth of semiconductors for photovoltaic technology.*
4. *To understand the fabrication and characterization of different solar cell technologies.*

The Sun Light

World Energy scenario – Advantages and challenges of solar energy harnessing - Source of radiation – solar constant– solar intensity at earth's surface – direct and diffuse radiation – apparent motion of sun-solar insolation data –solar charts – measurement of diffuse, global and direct solar radiation: pyrheliometer, pyranometer, pyregeometer, net pyradiometer-sunshine recorder.

Semiconductors
Crystals structures, atomic bonding, energy band diagram – direct & indirect band gap –p & n doping and carrier concentration – intrinsic&extrinsic semiconductor – compound semiconductors – diffusion and drift of carriers, continuity equation – optical absorption – carrier recombination – effect of temperature – p-n junction in equilibrium conditions – p-n junction in non-equilibrium condition – p-n junction under illumination.

Semiconductors for Solar Cell
Silicon: preparation of metallurgical, electronic and solar grade silicon -*Production of single crystal silicon:* Czokralski (CZ) and Float Zone (FZ) method– imperfections – carrier doping and lifetime – Germanium –compound semiconductors – growth & characterization– amorphous materials – transparent conducting oxides – anti-reflection principles and coatings – organic materials.

Characterization and Analysis
Device isolation & analysis – ideal cell under illumination – solar cell parametersshort circuit current, open circuit voltage, fill factor, efficiency; optical losses, electrical losses, surface recombination velocity, quantum efficiency – measurements of solar cell parameters; I-V curve & L-I-V characteristics, internal quantum yield measurements – effects of series and parallel resistance and temperature.

Design of Solar Cells
Upper limits of solar cell parameters – losses in solar cells – Solar Cell design: Design for High Isc – Design for High Voc – Design for High FF – Si-based solar cell Technology: process flow of commercial Si Cell Technologies – high-efficiency Si Solar cells. Thin film solar cell technologies: Common features of thin film Technologies – aSi technology – CdTe, CIGS, Epitaxial Si. Other technologies: DSSC.

Textbooks

1. Chetan Singh Solanki, Solar Photovoltaics: Fundamentals, Technologies And Applications 2nded., Prentice Hall of India, New Delhi (2011).
2. H. J. Moller, Semiconductors for solar cells, Artech House Inc., MA, USA (1993).
3. Martin Green, Solar Cells: Operating principles, Technology and Systems Applications, UNSW, Australia (1997).

Reference Books

1. Solar Cells and their Applications, Larry D. Partain (ed.), John Wiley and Sons, New York (1995).
2. J. Nelson, The Physics of Solar Cells, Imperial College Press (2006).
3. Photovoltaic Materials, Richard H. Bube, Imperial College Press (1998).

Course Outcomes:

Students will be able to:

1. *understand the need for renewable solar-based technologies.*
2. *appreciate various material properties which are used in photovoltaic.*
3. *appreciate the science and technology of solar cells, their design and characterization.*
4. *understand various upcoming technologies in this area.*

PH680 COMPUTATIONAL TECHNIQUES

Course Objectives:

1. *To learn the MATLAB environment and its basic commands.*
2. *To learn how MATLAB can be used for basic mathematical applications and machine learning techniques.*
3. *To learn the principle of the finite element method and its types.*
4. *Learn how to solve physical problems using the finite element method.*

Introduction to MATLAB:
MATLAB environment – working with data sets – data input/output – logical variables and operators – array and X-Y Plotting – simple graphics – data types: matrix, string, cell and structure– file input and output – MATLAB files – simple programs.

Applications of MATLAB:
Matrices and array operation – elemental matrix functions – file functions – application of MATLAB – solving linear algebraic equations – curve fitting – interpolation – numerical integration – basic 2D Plots – overlay plots – specialized 2D plots – 3D plots – view.

Specialized Applications using MATLAB:
Fast Fourier Transform - Fuzzy Logic - Artificial Neural Network (ANN): Neural Net Fitting, Neural Net Pattern Recognition, Neural Net Time Series.

Finite Element Method
Introduction to FEM: Method of Weighted Residuals – Galerkin's Finite Element Formulation – Variational Method – Rayleigh-Ritz Finite Element Method.

Application of FEM:
Structural mechanics and wave propagation problems in 2D - solving ordinary and partial differential equations - Fluid-structure interaction.

Textbooks

1. R. Pratap, Getting Started with MATLAB: A Quick Introduction for Scientist andEngineers, Oxford University Press (2010).
2. D. W. Pepper and J. C. Heinrich, The Finite Element Method: Basic Concepts and Applicationswith MATLAB, MAPLE, and COMSOL, 3rd edition, CRC Press (2017).
3. H. Bang and Y. W. Kwon, The Finite Element Method Using MATLAB, CRC Press (2018).

Reference Books

1. Introduction to COMSOL Multiphysics – © 1998–2020 COMSOL
2. MATLAB Programming Fundamentals – © 1984–2021 by The MathWorks, Inc.

Course Course Outcomes:

Upon completion of this course, the students will be able to:

1. *identify and describe the syntax of MATLAB.*
2. *solve different mathematical problems and demonstrate basic machine learning techniques in MATLAB.*
3. *describe and explain the finite element method principle and its different variants.*
4. *solve different physical problems using FEM.*

PH681 ADVANCED ELECTROMAGNETIC THEORY

Course Objectives:

1. *To introduce elementary ideas of plasma and its oscillation.*
2. *To understand the phenomena of normal and anomalous optical dispersion.*
3. *To solve inhomogeneous wave equations and the principle of radiating system.*
4. *To introduce the relativity in field equations.*

Physics of Plasmas
Electrical neutrality in plasma – particle motion in an electric field – Larmor radius – particle incrossed electric and magnetic fields – hydromagnetic equation – plasma oscillations and waves.

Optical Dispersion
Drude-Lorentz harmonic oscillator model – resonance absorption by bounded charges – normal and anomalous dispersion – Cauchy relation – plasma frequency – skin depth – dielectric relaxation.

Potentials and Fields
Maxwell's equation – scalar and vector potentials – gauge invariance – Coulomb gauge and Lorentz gauge – solution of inhomogeneous wave equation– retarded potentials.

Radiating System
Radiation from an arbitrary source – special cases: oscillating dipole, accelerated point charge – radiation damping – Thomson cross-section.

Special Theory of Relativity
Lorentz transformation and Einstein's postulates – geometry of space-time – Lorentz

transformation as orthogonal transformation – covariant form of electromagnetic equations – transformation laws for electromagnetic fields – field of a moving point charge.

Textbooks

1. J.R. Reitz., F.J. Milford and R.W. Christy, Foundations of Electromagnetic Theory, 4th edition, Pearson (2010).
2. D. J. Griffiths, Introduction to Electrodynamics, Prentice Hall of India, 4th edition (2014).

Reference Books

1. J.D. Jackson, Classical Electrodynamics, John Wiley & Sons, 2nd edition (1990).
2. E.C. Jordon and K.G. Balmain, Electromagnetic Waves and Radiating Systems, 2nd edition,Prentice Hall of India (1998).
3. L.D. Landau and E.M. Lifshitz, The Classical Theory of Fields, 4th edition, Elsevier (2010).

Course Outcomes:

Upon completion of the course, the students will be able to understand:

1. *the basics of plasma oscillations*
2. *optical properties of media*
3. *basics of antennas and*
4. *relativistic nature of electromagnetic fields.*

PH682 NON DESTRUCTIVE TESTING

Course Objectives:

1. *To introduce the importance of non-destructive testing and its basic concepts.*
2. *To introduce the concepts of ultrasonic testing and radiographic testing.*
3. *To introduce the basics of electromagnetic NDE methods.*
4. *To introduce various advanced NDE methods used in industry.*

Introduction

Introduction to NDT – Surface NDT - Principles – types and properties of liquid penetrants - developers – advantages and limitations of various methods - preparation of test materials - units and lighting for penetrant testing - dye penetrant process- Leak testing- MPI.

Ultrasonic Testing

Nature of sound waves, wave propagation - modes of sound wave generation - various methods of ultrasonic wave generation - piezo electric effect, piezo electric materials and their properties – the principle of pulse-echo method, through transmission method, resonance method – advantages, limitations – contact testing, immersion testing, couplants – data presentation A, B and C scan displays –Time of Flight Diffraction (TOFD).

Radiography

Geometric exposure principles, shadow formation, shadow sharpness, etc – radioisotopic sources – types and characteristics – production and processing of radioisotopes – radiographic cameras – X-ray sources generation and properties – industrial X-ray tubes – target materials and characteristics – high energy X-ray sources – linear accelerators –principles and applications of fluoroscopy/real-time radioscopy – advantages and limitations – recent advances, intensifier tubes, vidicon tubes etc.

Eddy Current

Generation of eddy currents – effect of created fields – effect of change of impedance on instrumentation – properties of eddy currents – eddy current sensing elements, probes, type of arrangement – a) absolute b) differential lift off, operation, applications, advantages, limitations – through encircling or around coils – type of arrangements a) absolute b) differential fill factor, operation, application, advantages, limitations.

Advanced NDT

*Thermography:*Contact and non-contact inspection methods – heat sensitive paints and other coatings – heat sensitive papers – advantages and limitations, instrumentations and methods, applications.*Optical holography:* recording and reconstruction – holographic interferometry – real-time, double-exposure & time-averaged techniques – holographic NDT – methods of stressing and fringe analysis. *Acoustical Holography:* Liquid Surface Acoustical Holography – optical system – reconstruction.

Reference Books

1. American Metals Society, Non-Destructive Examination and Quality Control, Metals Hand Book, Vol.17, 9thedition, Metals Park, OH (1989).
2. Krautkramer, Josef and Hebert Krautkramer, Ultrasonic Testing of Materials, 3rd edition, New York, Springer-Verlag (1983).
3. R. Halmshaw, Industrial Radiography, Applied Science Publishers Inc., Englewood, NJ (1982).
4. Baldev Raj, T. Jayakumar and M. Thavasimuthu, Practical Non-Destructive Testing, 3rd edition, Narosa Publishing House (2007).
5. Charles J. Hellier, Handbook of Non-destructive Evaluation, 2nd edition, McGraw-Hill (2013).

<u>**Course Outcomes:**</u>

Students will be able to:

1. *understand the basics of non-destructive testing used in industry.*
2. *understand the basic concepts of conventional NDT like ultrasonic testing, radiography etc.*
3. *appreciate the electromagnetic methods used in NDT.*
4. *understand the concepts of advanced NDE techniques.*

PH683 FIBER OPTIC SENSORS

Course Objectives:

Introduce fiber optics sensors and expose the fundamentals, design principles, characteristics and applications of fiber optic sensors.

Characteristics of Light
Introduction – plane polarized wave – propagation of a light through a quarter wave plate – reflections at a plane interface – Brewster angle – total internal reflection-interference- refraction – concept of coherence – diffraction of Gaussian beam.

Fiber Optic Fundamentals
Numerical aperture – attenuation in optical fibers – pulsed dispersion in step-index optical fiber – loss mechanisms – absorptive loss – radiative loss- principle of optical waveguides – characteristics of fibers – pulsed dispersion in planar optical waveguide – modes in planar waveguides – sTE, TM modes – propagation characteristics of step index and graded index optical fibers.

Fiber Optic Sensors
Intensity-modulated sensors – transmission concept – reflective concept – micro bending concept- intrinsic concepts – transmission and reflection with other optical effects – the source of error and compensation schemes – phase modulation mechanisms in optical fibers- optical fiber interferometers – optical fiber phase sensors for mechanical variables – the optical fiber signal interferometer – optical fiber interferometric sensors.

Frequency Modulation in Optical Fiber Sensors
Introduction – optical fiber Doppler system – development of the basic concepts. polarization modulation in fiber sensors- introduction – optical activity – Faraday rotation – electro-gyration – electro-optic effect- Kerr effect – photoelastic effect – polarization modulation sensors.

Wavelength Distribution and Bragg grating Sensors
Wavelength distribution sensor – introduction – techniques for color modulation – color probes – Bragg grating concept – introduction – fabrication – application.
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Reference Books

1. D.A.Krohn,Fiber Optic Sensors: Fundamentals and Applications, 2nd edition, Instrument Society of America (1992).
2. B.Culshaw, Optical Fiber Sensing and Signal Processing, Peter Peregrinus Ltd. (1984).
3. Djafar K.Mynbaev and Lowell L. Scheiner,Fiber-Optic Communications Technology, Pearson Education Asia (2001).

Course Outcomes:

Students will be able to propose new designs of sensors for various applications.

PH684 QUANTUM ELECTRONICS AND LASER APPLICATIONS

Course Objectives:

To introduce the basics and usage of lasers in science and industry.

Quantum Mechanics of Radiation and Matter

Wave particle dualism, Concept of wave packet, Boltzmann distribution law- Atoms –molecules energy transition, Spontaneous and stimulated emission Einstein's coefficients –Lifetime of excited state – Line Broadening mechanisms – Condition for producing laser – population inversion, gain and gain saturation – saturation intensity.

Cavity Optics and High-Power Lasers

Requirements for resonator –gain and loss in a cavity -characterization of resonator –resonator stability for Gaussian beams –common cavity configurations. Q switching-Modelocking- Types: ruby laser, helium-neon laser, CO_2 laser, semiconductor lasers

Holography and Fiber Optics

Construction –reconstruction-inline, off axis holography applications of holography –HNDT (Holographic Non-Destructive Testing). *Fibre Optics:* Optical fibre principle – types of fibres – properties–fiber optical communication–fibre amplifiers. *Fiber-optic sensors:* intensity-phase polarization and frequency dependent techniques.

Lasers in Science

Nonlinear optics, basics SHG –THG – excited state spectroscopy – time domain and its applications – Laser induced fluorescence spectroscopy, stimulated Raman emission –medical applications, photo-chemical applications.

Lasers in Industry

Materials processing, Lasers in 3D Machining –drilling, cutting, welding –hardening, alloying – annealing –Lasers in Non-destructive Evaluations: Ultrasonics, Laser Profilometry, Digital shearography

Textbooks

1. K. Thyagarajan and A.K. Ghatak, Lasers Theory and Applications, Mcmillan (1981).
2. K. Koebner (ed.), Industrial Applications of Lasers, Wiley (1984).

Reference Books

1. J.T. Cuxon and D.E. Parker, Industrial Lasers and their Applications, Prentice Hall (1985).
2. B. Culshaw, Optical Fiber Sensing and Signal Processing, Peter Peregrinus Ltd. (1984).
3. 3.F.C.Appard, Fiber Optics Handbook, McGraw-Hill (1989).

Course Outcomes:

Students will understand wide applications of lasers in opto-electronic, nondestructive testing, materials processing industry and its potential use as a scientific tool.

PH685 SENSORS AND TRANSDUCERS

Course Objectives:

1. *To introduce the basic concepts of various sensor transducers used in industrial applications.*
2. *To introduce the concepts of thermal, position, displacement, acceleration, and pressure sensors.*
3. *To introduce the physics of flow, acoustic, humidity, and chemical sensors.*
4. *To introduce the concepts of smart sensors.*

Temperature Sensors

Introduction to sensors – classification of sensor – sensor characteristics– thermal sensors -gas thermometric sensors – thermal expansion type sensors – thermo-resistive sensors – resistance temperature detectors –thermistors – thermoelectric contact sensors –thermocouples – thermocouple assemblies – semiconductor p-n junction sensors – optical temperature sensors - acoustic temperature sensor

Position and Displacement Detectors

Ultrasonic sensors – microwave motion detectors – capacitive occupancy detectors – tribo electric detectors – optoelectronic motion detectors – visible and near-infrared light motion detectors – far-infrared motion detectors – potentiometric sensors – gravitational sensors – capacitive sensors – inductive and magnetic sensors – LVDT and RVDT – Hall effect sensors – magnetoresistive sensors – magnetostrictive detector – optical sensors.

Acceleration and Pressure Sensors

Accelerometer characteristics – capacitive accelerometers – piezo-resistive accelerometers – piezoelectric accelerometers –gyroscopes – rotor gyroscope - monolithic silicon gyroscopes – optical gyroscopes. Strain Gauges - tactile sensors – piezoelectric force sensors – pressure gauges: mercury pressure sensor – bellows, membranes and thin plates – piezo-resistive sensors – capacitive sensors.

Flow, Acoustic and Humidity Sensors

Basics of flow dynamics – pressure gradient technique – thermal transport sensors –ultrasonic sensors – electromagnetic sensors – microflow sensors. Acoustic sensors: resistive microphones – condenser microphones – fiber optic microphone – fiezoelectric microphones – electric microphones – solid state acoustic detectors – humidity and moisture sensors – concept of humidity – capacitive sensors – electrical conductivity sensors – thermal conductivity sensor.

Chemical Sensors and Smart Sensors

Chemical sensor characteristics – classification of chemical-sensing mechanisms-direct sensors –

metal-oxide chemical sensors – chemfet – electrochemical sensors – potentiometric sensors – conductometric sensors – amperometric sensors - thermal sensors – optical chemical sensors – biochemical sensors – enzyme sensors – smart sensors – MEMS sensors – nano sensors.

Textbooks

1. D. Patranabis, Sensors and Transducers, 2nd ed., Prentice-Hall of India (2005).
2. Jacob Fraden, Handbook of Modern Sensors: Physics, Design, and Application, 3rd edition, Springer (2004).

Reference Books

1. Ernest O. Deoblin, Measurement Systems, 6th ed., Tata Mc-Grow Hill (2012).
2. Ian R. Sinclair, Sensors and Transducers, 3rd ed., Newnes (2001).
3. M. J. Usher, Sensors and Transducers, Macmillan, London (1985).

Course Outcomes:

Students will be able to:

1. understand the working principle and applications of various types of sensors.
2. appreciate the concepts of sensors used for temperature, pressure, position, and displacement.
3. understand the basics of flow, acoustic, humidity and chemical sensors.
4. understand the functioning of smart sensors.

PH686 ADVANCED STATISTICAL METHODS AND PHASE TRANSITION

Course Objectives:

1. *To introduce the statistical methods and numerical tools needed to solve phase transitions of various kinds.*
2. *To learn the methods of constructing model systems and finding analytical solutions to these models.*
3. *understand the phase transitions and critical phenomena around these transition points.*

Probability and Random Process
Fluctuations and random processes – Brownian motion – diffusion – random walks – Langevin equation – fluctuation-dissipation theorem – irreversibility – Markov processes – master equation – Fokker -Planck equation.

Phase Transition Theories
Examples of first-order and continuous phase transitions – mean field (van der Waals and Weiss molecular field) theories – fluid-magnet analogy – correlations – classical (Ornstein -Zernicke) theory.

Statistical Mechanical Models
Ising, lattice gas, Heisenberg, XV and Potts models – transfer matrix method –illustration using

one-dimensionallising model – duality in the two-dimensionallsing model – high and low-temperature series expansions.

Critical Phenomena
Long-range order, order parameter, scaling, universality, critical exponents – Peierls argument for phase transitions – spontaneous breakdown of symmetry – Landau theory of phase transitions – role of fluctuations, lower and upper critical dimensions – Ginzburg-Landau model – Higgs mechanism – examples – Mermin-wagner theorem – topological (Berezinski-Kosterlitz-Thouless) phase transition.

Renormalization Group Theory
Elements of re-normalization group approach to continuous phase transitions –flows in parameter space, fixed points, epsilon expansion, real-space re-normalization – connection with Euclidean field theories – elementary ideas on percolation.

Textbooks

1. N.G. Van Kampen, Stochastic Processes in Physics and Chemistry, North-Holland (1985).
2. H.E. Stanley, Introduction to Phase Transitions and Critical Phenomena, Clarendon Press,Oxford (1971).
3. J.M. Yeoman, Statistical Mechanics of Phase Transitions, Clarendon Press, Oxford (1992).

Reference Books

1. C.W. Gardiner, Handbook of Stochastic Methods, Springer-Verlag (1983).
2. C.J. Thompson, Classical Equilibrium Statistical Methods Springer-Verlag (1988).
3. D. Stauffer, Introduction to Percolation Theory, Taylor and Francis (1985).

Course Outcomes:

Students will gain confidence to pursue research careers in any area of theoretical condensed matter physics.

PH687 PHYSICS AND TECHNOLOGY OF THIN FILMS

Course Objectives:

1. *To understand the basic concept and kinetics of the thin films.*
2. *To learn different thin film growth techniques.*
3. *To study different characterization techniques of thin films.*
4. *To gain knowledge on thin film device fabrication.*

Preparation of Thin-films
Classifications of vacuum ranges –Vacuum pumps - Rotary, Diffusion, Turbomolecular and Ion Pumps –Thin film (epitaxy) – definition & advantages – Types of epitaxy. Different Growth Techniques: Liquid Phase Epitaxy, Vapour Phase Epitaxy, Molecular Beam Epitaxy, Metal Organic Vapour Phase Epitaxy, Sputtering (RF & DC), Pulsed Laser Deposition. Thickness Measurement: Microbalance technique, Photometry, Interferometry (MBI, FECO).

Kinetics of Thin films

Nucleation Kinetics: types of nucleation – kinetic theory of nucleation – energy formation of a nucleus – critical nucleation parameters; spherical and non-spherical nucleus (cap, disc and cubic shaped) on the substrates.

Growth Kinetics: Kinetics of binary (GaAs, InP, etc.), ternary ($Al_{1-x}Ga_xAs$, $Ga_{1-x}In_xP$, $InAs_{1-x}P_x$, etc.) and quaternary ($Ga_{1-x}In_xAs_{1-y}P_y$, etc.) semiconductors – derivation of growth rate and composition expressions.

Characterization

X-ray diffraction –Photoluminescence –UV-Vis-IR spectrophotometer – Atomic Force Microscope –Scanning Electron Microscope – Hall effect – Vibrational Sample Magnetometer – Secondary Ion Mass Spectrometry.

Properties of Thin films

Dielectric properties – Important parameters, Measurement of dielectric properties- Effect of annealing and film thickness. Optical properties – Optical constants, determination of optical constants by Brewster angle method, Normal incidence method and graphical method. Mechanical properties – Concept and origin of stress and strain, Lattice misfit, Thermal misfit, Hardness test and Bulge test.

Applications

Optoelectronic devices: LED, LASER and Solar cell – Micro Electromechanical Systems (MEMS)– Fabrication of thin film capacitor – application of ferromagnetic thin films; Data storage, Giant Magnetoresistance (GMR).

Textbook

1. A. Goswami, Thin Film Fundamentals, New Age international (P) Ltd. Publishers, New Delhi (1996).

Reference Books

1. K. L. Chopra, Thin Film Phenomena, McGraw- Hill book company New York, (1969).
2. Ludminla Eckertova, Physics of Thin Films, Plenum press, New York (1977).
3. Hari Singh Nalwa (ed.), Hand Book of Thin Films, Vol. 1 – 5, Academic Press (2002).
4. Milton Ohring, Material Science of Thin films, 2nd Edition Academic Press (2002)

Course Outcomes:

By successful completion of this course, the students will:

1. *have thorough knowledge on the fundamental concept of thin films.*
2. *have clear exposure and knowledge of different thin film growth techniques.*
3. *earn good knowledge on the characterisation of thin films to investigate its properties.*
4. *be moulded to do high-level research in thrust areas like LEDs, Laser, solar cells, storage devices etc.*

PH688 SEMICONDUCTOR PHYSICS

Course Objectives:

1. *To introduce the basic properties of semiconductor materials.*
2. *To introduce the physics of carrier transport phenomena in equilibrium and non-equilibrium conditions in semiconductors.*
3. *To introduce various types of p-n junctions.*
4. *To introduce various types of semiconductor devices.*

Properties of Semiconductors

Crystalline and amorphous semiconductors – band structure – semiconductor in equilibrium – charge carriers in semiconductors – intrinsic Fermi level position – dopant atoms and energy levels - extrinsic semiconductor– statistics of donors and acceptors –charge neutrality –position of Fermi energy level.

Carrier Transport Phenomena

Carrier drift – drift current density – mobility effects –conductivity –carrier diffusion –diffusion current density – total current density – graded impurity distribution –induced electric field – Einstein relation –Hall Effect.

Nonequilibrium Excess Carriers

Carrier generation and recombination – semiconductor in equilibrium – excess carrier generation and recombination – characteristics of excess carriers –continuity equations –time-dependent diffusion equations –Ambipolar transport – derivation of the Ambipolar transport equation – dielectric relaxation time constant – quasi-Fermi levels.

The p-n Junction

Basic Structure of the p-n Junction – zero applied bias –built-in potential barrier – electric field – space charge width –reverse applied bias – space charge – width and electric field – junction capacitance –one-sided junctions – current – voltage characterization – photo –diodes – avalanche photodiode – semi-conductor lasers – transition process – population inversion – gain junction lasers – threshold current density.

Semiconductor Devices

Metal-semiconductor and Semiconductor heterojunctions – Schottky Barrier Diode –metal-semiconductor ohmic contacts –heterojunctions –bipolar transistor – Metal-Oxide-semiconductor Field-Effect Transistor – Junction Field-Effect Transistor – Solar cell- basic characteristics – spectral response – recombination current and series resistance.

Textbooks

1. R.A. Smith , Semiconductors, Academic Publishers, Kolkota (1989).
2. Donald A. Neamen, Semiconductor Physics and Devices 4th ed., Tata Mc-Graw Hill (2012).

Reference Books

1. S.M. Sze and Kwok K. Ng, Physics of Semiconductor Devices, 3rd Ed., Wiley (2012).
2. M.S. Tyagi, Introduction to Semiconductor Materials and Devices 1st Ed., John Wiley and Sons (1991).

Course Outcomes:

Students will be able to:

1. *understand the basics of the physics of semiconductors and its properties.*
2. *appreciate transport phenomena in semiconductors.*
3. *understand the science of p-junction devices.*
4. *understand the functioning of various important semiconductor devices.*

PH689 MAGNETIC CHARACTERIZATION AND SUPERCONDUCTING MATERIALS

Course Objectives:

This course aims to:

1. *comprehend the types of magnetism and various magnetic phenomena.*
2. *understand various magnetic characterization techniques.*
3. *evaluate the magnetic properties of various materials.*
4. *identify various types of superconducting materials and their applications.*

Fundamentals of Magnetism

Magnetic moment – magnetic field – field produced by electromagnets– VSM- AGM - Faraday method- Guoy method- field and moment measurement – demagnetizing field – origin of magnetism – g-factor – FMR – theory of diamagnetism.

Types of Magnetism

Langevin's theory of paramagnetism – quantum theory of paramagnetism – Brillouin function – molecular field theory of ferromagnetism – exchange interaction –Bethe-Slater – sublattice magnetization – internal fields – Antiferromagnetic susceptibility- crystal field effects- magnetism in metals and alloys-Slater-Pauling curve.

Magnetic Phenomena

Magnetic anisotropy – magnetocrystalline and shape anisotropy – Torque magnetometry- random anisotropy model – magnetostriction – domains – rotation- curling-buckling- pinning- mechanism -effects on hysteresis loop– fine particle magnetism – magnetocaloric effect.

Magnetic Characterization

Mössbauer effect – Instrumentation – isomer shift- quadrupole splitting – hyperfine splitting – applications – muon spin resonance – spin precession and relaxation – muonium – applications in magnetism – Neutron diffraction.

Superconducting Materials
Superconductivity basics – physical properties below T_c –duration of persistent currents –Magnetic field effects on superconductors –high Tc Superconductors – cuprate superconductors –wires and tapes – MgB_2– iron and carbon-based superconductors – superconducting magnets- Levitation -types -Maglev vehicle.

Textbooks

1. B. D. Cullity and C.D. Graham, Introduction to Magnetic Materials, Wiley (2009).
2. S. Blundell, Magnetism in Condensed Matter, Oxford University Press (2001).
3. C. Kittel, Introduction to Solid State Physics, 7th edition, Wiley (2006).

Reference Books

1. S. Chikazumi, Physics of Ferromagnetism, Oxford University Press (1997).
2. Ed. Charles P. Poole, Jr., Handbook of Superconductivity, Academic Press (2000).
3. Nicola. A. Spaldin, Magnetic Materials: Fundamentals and Applications, 2nd Edn., CambridgeUniv. Press (2002).
4. G. K. Wertheim, Mössbauer Effect: Principles and Applications, Academic Press Inc. (1964).
5. F. C. Moon, Superconducting Levitation, Wiley (2004).

Course Outcomes:

After completion of the course, the students will be able to:
1. *define various types of magnetism and magnetic phenomena.*
2. *recognize ferromagnetic and superconducting materials.*
3. *develop knowledge about various magnetic characterization techniques.*
4. *analyze the origin of magnetism in various materials.*

PH690 QUANTUM COMPUTATION AND INFORMATION

Course Objectives:

1. *To introduce the notion of qubit, density operator and measurement.*
2. *To introduce basic quantum gates.*
3. *To learn a few quantum algorithms.*
4. *To learn the basics of quantum information.*

Preliminaries
Postulates of quantum mechanics – qubit – Bloch sphere presentation – density operator – measurement – tensor product – composite system – reduced state – Schmidt decomposition – Bell's inequality.

Quantum Gates

Models for computation – computational complexity – energy and computation – single qubit gates – two-qubit gates – toffoli gate – universal quantum gates – no cloning theorem.

Quantum Algorithms
Super-dense coding – teleportation – quantum parallelism – Deutsch-Jozsa algorithm – Grover's quantum search.

Quantum Noise and Information
Environment and quantum operations – operator sum representation – examples of quantum noise – distance measures – trace distance – fidelity – Shannon entropy and properties – Von Neumann entropy and properties.

Physical Realization
Condition for computation – optical photon – optical cavity – ion traps – nuclear magnetic resonance – superconductors – physical apparatus and drawback.

Reference Books

1. M.A.Neilsen, I.L Chuang, Quantum Computation and Quantum Information, Cambridge University Press, Cambridge (2000).
2. J.Preskill, Lecture notes for Physics, Quantum computation (1999).http://theory.caltech/edu/~preskill/ph229.
3. A. Peres, Quantum Theory: Concepts and Methods, Kluwer Academic Publishers, New York (2002).
4. P. Kaye, R. Laflamme and M. Mosca, An Introduction to Quantum Computing, Oxford University Press (2007).

Course Outcomes:

Upon completion of the course, the students will be able to understand:

1. *density operator, tensor product and state of composite systems.*
2. *the importance of basic quantum gates.*
3. *tools for quantum information.*
4. *possible physical realization of qubits.*

PH691 MICRO ELECTRO MECHANICAL SYSTEMS

Course Objectives:

1. *To introduce the basics of micro electro mechanical systems.*
2. *To introduce the concept of Bulk Micro Machining.*
3. *To introduce the concept of Surface Micro Machining.*
4. *To introduce various types of lithographic tools and MEMS devices and simulation tools.*

MEMS Basics
Emergence – devices and application – scaling issues – materials for MEMS – thin film deposition

– lithography and etching.

Bulk Micro Machining
Introduction – etch-stop techniques – dry etching – buried oxide process – silicon fusion bonding and anodic bonding.

Surface Micro Machining
Introduction – sacrificial layer technology – material systems in sacrificial layer technology – plasma etching – combined IC technology and anisotropic wet etching.

Microstereo Lithography
Introduction – scanning method – projection method – applications – LIGA process: introduction, basic process and application.

MEMS Devices
Electronic interfaces – design, simulation and layout of MEMS devices using CAD tools.

Textbooks

1. M. Elwenspoek and R.Wiegerink, Mechanical Microsensors, Springer-Verlag (2001).
2. Massood Tabib-Azar, Microactuators - Electrical, Magnetic, Thermal, Optical, Mechanical, Chemical and Smart structures, Kluwer Academic Publishers (1997).

Reference Books

1. S.M. Sze, Semiconductor Sensors, John Wiley & Sons (1994).
2. Eric Udd, Fiber Optic Smart Structures, John Wiley & Sons (1995).

Course Outcomes:

Students will be able to:

1. understand the basics of physics of micro electro mechanical systems.
2. appreciate the concepts of bulb micro machining and surface micro machining.
3. understand the concepts of MEMS devices.
4. apply the knowledge of device fabrication tools.

PH692 CARBON NANOMATERIALS AND THEIR APPLICATIONS

Course Objectives:

The objectives of this course are to:

1. acquire basic knowledge of carbon materials and its structure.
2 know various synthesis methods.
3. familiar with purification, dispersion, functionalization and characterization of different carbon nanomaterials.
4. identify suitable carbon materials for optoelectronics and sensor devices.

Fundamentals of Carbon Materials
Bonding of carbon atom – hybridization: sp, sp^2 and sp^3 – allotropes of carbon – structure and properties of single-walled carbon nanotubes (SWCNT), multi-walled carbon nanotubes (MWCNT), fullerene, graphene, graphene oxide and carbon dots.

Synthesis Methods
Growth of carbon nanotubes (CNT): vacuum techniques- arc discharge – laser ablation. CNT and graphene growth from chemical vapour deposition (CVD), plasma enhanced CVD and mechanical exfoliation of graphene.
Synthesis of graphene oxide (GO) and reduced graphene oxide (rGO): wet methods – Hummer's method and modified Hummer's method, synthesis of carbon dots: chemical method.

Purification, Dispersion and Characterization
Purification of CNT, graphene, GO – dispersion of CNT, GO and rGO-Characterization tools: micro-Raman, direct imaging techniques: FE-SEM, HR-TEM, thermal analysis: TGA and powder XRD.

Functionalization and Carbon Nanocomposites
Functionalization of SWCNT, MWCNT, GO and rGO- CNT- metal and metal oxides nanostructures, polymer composites – electrical and optical properties – applications in gas sensors, energy storage and harvesting devices.

Fabrication of Devices
Field emission display and X-ray production. Thin film fabrication methods - spray pyrolysis and spin coating –transparent conducting films (TCF) - electrical and optical properties- applications of TCF in solar cells, display, optoelectronics, sensors and electro thermal devices.

Reference Books

1. M.Meyyappan, "Carbon Nanotubes Science & Applications", CRC Press, London (2005).
2. Yury Gogotsi, "Carbon Nanomaterials", CRC Press, London (2006).
3. Michel J. O. Connel, "Carbon Nanotubes Properties and Applications", CRC Press, London (2006).
4. R. Saito, G. Dresselhaus & M S Dresselhaus, "Physical Properties of Carbon Nanotubes", Reprinted, Imperial College Press, London (2003).
5. Rainer Waser, "Nanoelectronics and Information Technology Advanced Electronics Materials and Novel Devices", WILEY–VCH Verlag GmbH & Co KGHaA, Weinheim, Germany (2003).
6. Liming Dai, "Carbon Nanotechnology Recent Developments in Chemistry, Physics, Materials Science and Device Applications", Elsevier, The Netherlands, 1st Edition, (2006).

<u>Course Course Outcomes:</u>

Upon completion of the course, the student will be able to:

1. *select suitable carbon materials and emphasize the need for modern materials*

other than conventional materials for specific science and engineering applications.
2. *understand the basics of carbon nanostructures and their synthesis approach/methods.*
3. *acquire knowledge about the functionalization of carbon nanomaterials and the formation of nanocomposites.*
4. *fabricate devices for display, electrical, optoelectronics and sensor applications.*

PH693 FLUID MECHANICS AND CHARACTERISTICS OF NANOFLUIDS

Course Objectives:

To impart the basic knowledge on fluid mechanics and nanofluid characteristics which include the flow, rheological, thermophysical behaviours and practical applications.

Introduction to nanofluids, properties, Hydrodynamic boundary condition: slip vs. non-slip, electro kinetic effects: electrophoresis, electro osmotic effect, electro viscous effect, zeta potential, synthesis: Micro emulsion, solvothermal methods, Types of nanofluids, Ferrofluids, Issues on stability, dispersability, compatibility

Rheological properties, Newtonian/non-Newtonian behavior, Navier – Stokes equation, Andrade's equation, Effects of volumetric concentration and temperature on nanofluid viscosity, Magneto viscous effects, Measurement and apparatus: Viscometers, rheometers/magnetorheometers

Thermophysical properties: Conduction in nanofluids, thermal conductivity and specific heat, convection in nanofluids, Hamilton Crosser equation, Experimental methods of determining the thermal conductivity and convective heat transfer coefficient of nanofluids.

Laminar, Turbulant flows, Effects of thermophysical properties on the thermal diffusivity, the Prandtl number, the Reynolds number and the Nusselt number, the Peclet number. Fluid dynamic losses, pumping power required in heat transfer systems. Nanofluid flows in mini and microchannel

Practical application to heat exchangers in industries, building heating and cooling, automobile radiators, Lab-on-the chip, biosensors, drug delivery, Performance of nanofluids versus conventional heat transfer fluids.

Textbooks

1. F. M. White, Fluid Mechanics, McGraw-Hill Series, Seventh edition, (2009).
2. PatricTabeling, Introduction to Microfluids", Oxford U. Press, New York, (2005).
3. Sarit K. Das, Stephen U. Choi, Wenhua Yu and T. Pradeep, Nanofluids: Science and Technology, John Wiley & Sons, First edition, (2007).
4. Nam-Trung Nguyen and Steven T. Wereley, Fundamentals and Applications of Microfluidics, Artech House Publishers, Third Edition, (2019).

Reference Books

1. W. J. Minkowycz, E M Sparrow, J. P. Abraham, Nanoparticle Heat Transfer and Fluid Flow, CRC Press, (2012).
2. A. Bejan, Convection Heat Transfer, John Wiley & Sons; Fourth Edition edition, (2013).
3. Stefan Odenbach, Magnetoviscous Effects in Ferrofluids, Springer-Verlag Berlin Heidelberg, First edition, (2002).
4. Brian J. Kirby, Micro- and Nanoscale Fluid Mechanics: Transport in Microfluidic Devices, Cambridge University Press, Reprint edition, (2013).

Course Outcomes:

On successful completion of this course, the students would be able to:

1. *understand the basics of nano and ferrofluids.*
2. *describe rheological, thermophysical and flow behaviors at nanoscale.*
3. *familiarize with the applications of nano-fluids in industries, Lab-on-the chip,biosensors and drug delivery.*

PH694 ADVANCED ELECTRONIC MATERIALS AND DEVICES

Course Objectives:

1. *To provide an overview of advanced electronic materials, related technology and analyses.*
2. *To describe the fundamentals of chemical, biosensors, information display materials and technology.*
3. *To expose the students to flexible and wearable electronics, conjugated polymers and composites.*

Fundamentals of Materials

Materials considerations: Overview, inorganics, semiconductors, dielectrics, ferroelectrics, conductors - Electronic properties and quantum effects, organic molecules- Electronic structures, properties and reactions, polymers-conducting polymers.

Technology and Analyses

Synthesis, purification of organic, inorganic and hybrid materials, processing, film deposition methods, lithography, etching, chemical and mechanical polishing, analysis by direct and indirect methods.

Chemical, Bio Sensors, Information Display Materials and Technology

Introduction – systems design- challenges in chemical and biochemical sensing- Sensors and materials- obtained parameters -application areas and future scope.

Principles of liquid crystal display, organic light emitting diodes, field emission, plasma display-materials – challenges and opportunities.

Flexible and Wearable Electronics

History of flexible electronics - Materials for flexible electronics: degrees of flexibility, Substrates-Materials and Technologies - Fabrication technology for flexible electronics - Fabrication on sheets by batch processing, fabrication on web by Roll-to-Roll processing - Additive printing. Wearable haptics- attributes of wearables – examples, challenges and opportunities.

Conjugated Polymers and Composites

Inorganic and organic polymers–conducting polymers-organic molecule composites- Organic Polymer–Inorganic nanomaterial composites- Metallic Nanoparticles Embedded-Organic Polymer. Polymer–Carbon Allotropes Composites-Bucky ball Cluster Composites-Carbon Nanotube Composites-Graphene Sheet Composites-Polymer–Ionic Liquid Composites.

Reference Books

1. Pradeep Fulay, Electronic, Magnetic and Optical Materials, CRC Press, Boca Raton (2010).
2. William S. Wong, Alberto Salleo, "Flexible Electronics: Materials and Applications",1st Edition, Springer, New York (2011).
3. Edward Sazonov, Michael R. Newman, "Wearable Sensors: Fundamentals, Implementation and Applications", 1st Edition, Academic Press, Cambridge (2014).
4. Rainer Waser, "Nanoelectronics and Information Technology Advanced Electronic Materials and Novel Devices", WILEY-VCH Verlag GmbH & Co. Weinheim, Germany(2003).
5. Gregory P. Crawford, "Flexible Flat Panel Displays", John Wiley & Sons Ltd., England (2005).
6. Yury Gogotsi, "Carbon Nanomaterials", CRC Press, Taylor & Francis group, Boca Raton,London, New York (2006).

Course Outcomes:

Upon completion of the course, the students will be able to:

1. *choose suitable materials and emphasize the need for modern materials for specific applications.*
2. *appreciate the fundamentals of advanced materials and their preparation/processing methods.*
3. *acquire knowledge about the sensors, wearable and flexible devices.*
4. *formulate devices for electronic and biological applications.*

PH695 NANOPHOTONICS

Course Objectives:

To introduce the basics of light and nanomaterials interaction and introduce applications of *photonics in nanomaterials*

Light interaction with Matter: Electromagnetic Aspects

Maxwell's equations- plane wave- wave propagation in free space- di-electric and conducting dieelctric.

Basics of Nanomaterials Optics
Electrons in one dimensional quantum wells, two dimensional thinfilms and graphene -Spherically symmetric potential-Local field effects-Classical aspect-First principles

Nanoscale Optics
Plasma excitations in optics-Plasmon resonance in spherical, rod shaped metallic nanoparticles-Electromagnetic field enhancement in metallic nanostructures-Plasmons in hollow nanoparticles Light absorption and emission from nanoparticles- Metallic and Semiconductor nanoparticles

Near Field Optics And Nanoscopy
Near field optics-confinement of Photons and electrons – Tunneling –Band gap- Nanoscale optical interaction- Near field microscopy- Scanning confocal microscopy- Scanning probe microscopy.

Optics of Photonic Crystals and Carbon-Based Nanostructures
Basic concepts-Photonic crystals- Methods of fabrication-Photonic crystal optical circuitry-Photonic crystal fibres -Optical communication- optical properties carbon based nanostructures-CNT,DWNT, MWNT, C60, Graphene.

Textbooks

1. D.J. Griffiths , Introduction to Electrodynamics, Pearson Education, Inc, (2013).
2. Vladimir I. Gavrilenko, Optics of Nanomaterials, Jenny Stanford Publishing, (2019).

Reference Book

1. D.W. Pohl, D. Courjon, Near-field optics:, Springer (1993).

Course Outcomes:

Students will understand wide applications of photonics, opto-electronic processes at nano level.

PH618 INTRODUCTION TO DATA ANALYTICS

Course Objectives:

1. *To introduce the language and core concepts of probability theory.*
2. *To understand basic principles of statistical inference.*
3. *To perform linear regression and apply various classification techniques using software.*
4. *To apply resampling methods to enhance model performance.*

5. *To introduce tree-based methods and foundational concepts in deep learning, including neural networks and convolutional networks.*

Tools of Probability: Concept of Probability, Random variables, central limit theorem, conditional probability, total probability theorem, Bayes theorem, Collecting Data, Summarizing and Exploring Data

Statistical Inference: Basic Concepts of Inference, Inferences for Single Samples, Interference for two samples, z-test, student's t-test, implementation in R.

Linear Regression: Simple linear regression, Multiple linear regression, qualitative predictors, few applications using a programming language. Classifications; qualitative variables, logistic regression, linear discriminant analysis, quadratic logistic regression, naive Bayes, and K-nearest neighbors.

Resampling methods: validation approach, leave out cross validation, boot strap. Linear model selection and regularization; subset selection, stepwise selection, shrinkage methods. Nonlinear regression; Polynomial, step function and splines.

Tree base methods: Decision trees, bagging. Deep learning; single layer neural networks, multilayer neural networks, convolution neural networks

Textbook

1. Gareth James, Daniela Witten, Trevor Hastie, Robert Tibshirani, An Introduction to Statistical Learning with applications in R (2nd Edition), Springer, (2021).

Course Outcomes:

After successful completion of the course, the students will be able to:

1. *gain a foundational understanding of probability concepts and apply these concepts to real-world data problems.*
2. *develop skills in summarizing and exploring data, and perform basic inferential statistics to draw conclusions from samples.*
3. *apply regression analysis and classification methods to solve practical data analysis problems.*
4. *learn and implement various resampling methods, such as validation approach, cross-validation, and bootstrapping, to evaluate model performance.*
5. *build and interpret decision trees, and gain an introduction to neural networks and deep learning.*

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