M.Sc. Degree

IN

<u>Physics</u>

SYLLABUS

FOR

CREDIT BASED CURRICULUM

(From the academic year 2022-23 onwards)

DEPARTMENT OF PHYSICS

National Institute of Technology, Tiruchirappalli – 620015

TAMILNADU, INDIA

THE INSTITUTE

Vision

To provide valuable resources for industry and society through excellence in technical education and research.

Mission

- To offer state-of-the-art undergraduate, postgraduate and doctoral programmes.
- To generate new knowledge by engaging in cutting-edge research.
- To undertake collaborative projects with academia and industries.
- To develop human intellectual capability to its fullest potential.

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.

CURRICULUM

Total minimum credits required for completing M.Sc. Programme in Physics is **66**.

SEMESTER I

CODE	COURSE OF STUDY	L	T	P	C
PH651	MATHEMATICAL PHYSICS	3	0	0	3
PH653	CLASSICAL MECHANICS	3	0	0	3
PH655	QUANTUM MECHANICS	3	0	0	3
	ELECTIVE I	3	0	0	3
	ELECTIVE II	3	0	0	3
PH657	GENERAL PHYSICS LABORATORY	0	0	8	3
	TOTAL CREDITS				**18**

SEMESTER II

CODE	COURSE OF STUDY	L	T	P	C
PH652	ELECTROMAGNETIC THEORY	3	0	0	3
PH654	STATISTICAL MECHANICS	3	0	0	3
PH656	SOLID STATE PHYSICS	3	0	0	3
	ELECTIVE – III	3	0	0	3
	ELECTIVE – IV	3	0	0	3
PH658	ELECTRONICS & COMPUTATIONAL LABORATORY	0	0	8	3
	TOTAL CREDITS				**18**

SEMESTER III

CODE	COURSE OF STUDY	L	T	P	C
PH659	NUCLEAR AND PARTICLE PHYSICS	3	0	0	3
PH661	MINI RESEARCH PROJECT	1	-	-	6
	ELECTIVE – V	3	0	0	3
	ELECTIVE – VI	3	0	0	3
	TOTAL CREDITS				**15**

SEMESTER IV

CODE	COURSE OF STUDY	L	T	P	C
PH660	RESEARCH PROJECT AND VIVA-VOCE	-	-	-	12
	ELECTIVE – VII	3	0	0	3
	TOTAL CREDITS				**15**

LIST OF ELECTIVES

1. PH671 ELECTRONICS
2. PH672 INSTRUMENTATION
3. PH673 NUMERICAL METHODS
4. PH674 NANOSCIENCE AND TECHNOLOGY
5. PH675 ATOMIC AND MOLECULAR SPECTROSCOPY
6. PH611 DIGITAL SIGNAL AND IMAGE PROCESSING
7. PH613 BASICS OF ENGINEERING MATERIALS
8. PH676 ADVANCED MATHEMATICAL PHYSICS
9. PH677 WAVEGUIDES AND MODERN OPTICS
10. PH678 ASTROPHYSICS AND COSMOLOGY
11. PH679 SOLAR PHOTOVOLTAIC TECHNOLOGY
12. PH680 COMPUTATIONAL TECHNIQUES
13. PH681 ADVANCED ELECTROMAGNETIC THEORY
14. PH682 NON-DESTRUCTIVE TESTING
15. PH683 FIBER OPTIC SENSORS
16. PH684 QUANTUM ELECTRONICS AND LASERS APPLICATIONS
17. PH685 SENSORS AND TRANSDUCERS
18. PH686 ADVANCED STATISTICAL METHODS AND PHASE TRANSITION
19. PH687 PHYSICS AND TECHNOLOGY OF THIN FILMS
20. PH688 SEMICONDUCTOR PHYSICS
21. PH689 MAGNETIC CHARACTERIZATION AND SUPERCONDUCTING MATERIALS
22. PH690 QUANTUM COMPUTATION AND QUANTUM INFORMATION
23. PH691 MICRO-ELECTRO-MECHANICAL SYSTEMS
24. PH692 CARBON NANOMATERIALS AND THEIR APPLICATIONS
25. PH 693 FLUID MECHANICS AND CHARACTERISTICS OF NANOFLUIDS
26. PH 694 ADVANCED ELECTRONIC MATERIALS AND DEVICES
27. PH 695 NANOPHOTONICS
28. PH 618 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 availability of the faculty concerned.

I SEMESTER

PH651 – MATHEMATICAL PHYSICS

Objective: *To introduce basic mathematical topics necessary to understand and appreciate various physical laws of nature.*

Vector Analysis
Scalar and vector product – triple products – gradient, divergence, curl – vector integration – Gauss's theorem – Green's theorem – Stoke's 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 value problems (for special functions)

Outcome: *Students will be capable of handling variety of courses on mechanics and electromagnetic theory.*

PH653 – CLASSICAL MECHANICS

Objectives:

1. *To demonstrate knowledge and understanding of the following fundamental concepts in:*
   - *the dynamics of system of particles,*
   - *Lagrangian and Hamiltonian formulation of mechanics*
   - *Oscillating Systems*
   - *motion of rigid body*
   - *Special Theory of Relativity*
2. *To represent the equations of motion for complicated mechanical systems using the Lagrangian and Hamiltonian formulation of classical mechanics.*
3. *To develop math skills as applied to physics.*

Lagrangian Formulation

Mechanics of a system of particles – degrees of freedom -constraints – generalised coordinates. Lagrangian – virtual work - D'Alembert's principle – Euler-Lagrange equations of motion –– applications of the Lagrangian formalism – cyclic coordinates- symmetries and conservation laws – generalised momenta – energy function, and Gauge freedom of Lagrangian.

Oscillating Systems

Coupled oscillators and small oscillations – Lagrangian formulation of linearly coupled systems – normal modes and normal frequencies. Examples.

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 – Rutherford formula – scattering cross section.

Hamiltonian Formulation

Action principle, Hamiltonian, Hamilton's equations of motion- Phase space- Phase trajectories- Liouville's theorem – applications to systems with one and two degrees of freedom – Canonical transformations and generators, Poisson bracket invariance, and Jacobi's identity- Hamilton-Jacobi equation – action angle variables.

Rigid Body

Frames of reference -accelerating and rotating frames and pseudo-forces. Elements of rigid body dynamics –orthogonal transformations- parallel axis theorem- the body frame, Euler angles and Euler equations– symmetric top and applications.

Special Theory of Relativity

Internal frames – principle and postulate of relativity – Lorentz transformations – length contraction, time dilation – velocity addition formula – the Doppler effect – relativistic invariance of physical laws.

Textbooks

1. H. Goldstein, C. Poole and J. Safko, Classical Mechanics, 3rd edition, Addison & Wesley (2000).
2. W. Greiner, Classical Mechanics, Springer-Verlag (2003).
3. W. Greiner, Classical Mechanics – Point particles and Relativity, Springer (1989).
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).

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, 4thedition, Cambridge University Press (1989).

Outcome: *After successfully completing the course, students will be able to effectively learn items 1, 2 and 3 will enable the students to understand the complicated classical dynamical problems and find possible solutions for these problems.*

PH655 – QUANTUM MECHANICS

Objectives:

1. To introduce the mechanics of mater-waves necessary for uncovering the mysteries of matter at atomic scale.
2. To understand the spectrum of hydrogen.
3. To 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-Sommerfeld 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. Aruldhas, Quantum Mechanics, 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), 3rdedition, Elsevier (2011).
5. R. Shankar, Principles of Quantum Mechanics, 2nd edition, Springer (2012).

Outcome: *Intriguing probabilistic nature of matter at atomic scale will be understood. Students will be capable of handling courses like Statistical Mechanics, Solid State Physics, Spectroscopy and Nuclear Physics.*

PH657 – GENERAL PHYSICS LABORATORY

Objective: *To introduce the basic concepts of physics through hands on experience and impart experimental skill to students.*

List of Experiments

1. Hall Effect in Semiconductor
2. Non-Destructive Testing – Ultrasonics
3. Two Probe Method for Resistivity Measurement
4. Wavelength Measurement of Laser using Diffraction Grating
5. Numerical Aperture of an Optical Fiber
6. Electron Spin Resonance
7. Specific Heat Capacity of Solids
8. Half Shade Polarimeter and Strain Viewer
9. Michelson Interferometer
10. Acoustic Diffraction
11. Vacuum Pumps – Low Pressure Measurement and Determination of Pumping Speed
12. Zeeman effect
13. Hydrogen Spectra and Rydberg Constant
14. Forbe's Method – Thermal Conductivity of Metal
15. Kundt's Tube
16. Solar-Cell Characteristics
17. Magnetic Susceptibility of Liquids – Quincke's Method
18. Curie Temperature of Magnetic Materials
19. Dielectric Constant and Curie Temperature of Ferroelectric Ceramics
20. Hysteresis (B – H Curve)

21. Helmholtz Galvanometer
22. Faraday Effect
23. Millikan Oil Drop Experiment – e/m of Electron
24. Determination of Planck's Constant
25. Cornu's Method – Determination of Elastic Constants of Transparent Materials
26. Stefan's Constant
27. Gouy Balance
28. Experiments using Geiger Muller Counter (GM)
    a. Efficiency of GM counter for various sources
    b. Shelf Ratio and verification of inverse square law
    c. Backscattering
    d. Absorption coefficient
    e. Half-life of Ba-137
29. Anderson Bridge
30. Kerr effect –determination of Kerr constant of a Liquid
31. Pockel effect- electro-optic property of a crystal

Textbook

1. General Physics Laboratory Manual, Department of Physics, NITT.

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).

Outcome: *The student will be able to understand the fundamental physics behind many scientific discoveries through hands on experience.*

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II SEMESTER

PH652– ELECTROMAGNETIC THEORY

Objective: *To understand the nature of electric and magnetic force fields and the intricate connection between them.*

Electrostatics

Electric field – divergence and curl – electric potential – work and energy – conductors and capacitance – Laplace's equation – uniqueness theorems – separation of variables: Cartesian and spherical coordinates – multipole expansion – field of an electric dipole – polarization – field of polarized object – electric displacement and Gauss's law – linear dielectrics – electrostatic energy density – boundary value problems.

Magnetostatics and Maxwell's equations

Lorentz force – magnetic induction – electric current – equation of continuity – Biot-Savart law – magnetic potential – magnetization – Ampere's law in magnetized material – linear and nonlinear media. Faraday's law – inductance and magnetic energy –– boundary conditions- generalization of Ampere's law – Maxwell's equations– scalar and vector potentials – gauge invariance – electromagnetic energy – Poynting's theorem – conservation of momentum.

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.D. Jackson, Classical Electrodynamics, Wiley-India, (2020).

Reference Books

1. J.R. Reitz., F.J. Milford and R.W. Christy, Foundations of Electromagnetic Theory, 4th edition, Pearson (2010).
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).

Outcome: *Electromagnetic nature of radiation and its propagation in media will be understood. Students will be able to appreciate the theory of relativity in electrodynamics perspective.*

PH654 – STATISTICAL MECHANICS

Objectives:

1. *To learn the connection between macroscopic and microscopic state of a system of large number of particles.*
2. *To understand thermal equilibrium of a system in statistical sense.*
3. *Gain preliminary knowledge about phase transition and critical phenomena.*

Theory of Ensembles

Review of Thermodynamics – Zeroth, First, Second and Third Laws – Thermodynamic potentials – Maxwell's Relations – 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.

Maxwell-Boltzmann Statistics

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

Phase Transition

Phase transitions in thermodynamics and statistical mechanics – real gas phase transition – Clausius-Clapeyron equation – first and second order (continuous) phase transitions – Ising model – Mean field theory – Critical exponents and scaling relations.

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).

Outcome: *Students will be able to understand various properties of matter and radiation in thermal equilibrium through appropriate statistics. Students will be prepared to understand Solid State Physics.*

PH656 – SOLID STATE PHYSICS

Objective: *Students will have an appreciation on the physics and properties of different types of materials such as conductors, semiconductors, dielectric, magnetic and superconducting.*

Introduction
Solids – crystalline and amorphous – types of bonds - crystal structure and symmetries – defects and dislocations – reciprocal lattice – X-ray diffraction – atomic scattering factor – geometric structure factor – Laue Equations.

Conductors, Semiconductors and Dielectrics
Conductors: Free electron theory – classical and quantum theory, band theory of solids – effective mass of electron – Kronig-Penny model – Brillouin Zone – Bloch theorem – 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 – heat capacity – Einstein and Debye models – Dulong and Petit’s law – Weidemann-Franz law – electronic heat capacity –Heavy Fermion– experimental heat capacity of metals – resistivity – residual resistivity ratio – experimental electrical resistivity of metals – Matthiessen’s rule – Magnetoresistance.

Magnetism
Magnetic terminologies – types of magnetism – dia, para, ferro, ferri and anti-ferromagnetism – Hund’s rules – Curie-Weiss law – Langevin’s classical and quantum theories of dia and para

magnetism – Weiss theory of ferromagnetism – Heisenberg model of exchange interaction – concept of domain and hysteresis

Superconductivity

Superconductivity– Meissner and isotope effect – thermodynamical and optical properties –Flux Quantization – Critical Field – Types of Super Conductors– London's Penetration Depth – BCS Model –Josephson Junctions – AC and DC.

Textbooks

1. Charles Kittel, Introduction to Solid State Physics, Wiley Eastern, 8thedition, (2012).
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, 2ndedition, Cambridge University Press (1974).

Reference Books

1. B.S. Saxena, R.C. Gupta, P.N.Saxena, Fundamentals of solid state physics, Pragati Prakashan, 7thedition (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).

Outcome: *Grasping the significance of transport and thermodynamic properties of materials will enable students to understand the basics in physics of condensed matter.*

PH658– ELECTRONICS AND COMPUTATIONAL LABORATORY

Objective: *To introduce the various concepts of basic electronics and circuits through hands on experience along with elementary software skills.*

List of Experiments

1. Solving Simultaneous Equations
2. Voltage Controlled Oscillator
3. Op-Amp Arithmetic Operations
4. Op-Amp Square, Ramp Generator and Wien Bridge Oscillator
5. Op-Amp Precision Full Wave Rectifier
6. Multiplexer and De-multiplexer

7. Regulated Power Supply using IC 723
8. UJT-Characteristics of Relaxation Oscillator
9. Logarithmic and Anti-logarithmic Amplifier
10. Phase Shift Oscillator
11. Astable and monostable Multivibrator using IC555
12. Combinational Logic Circuit Design
13. IC 555 timer – Schmitt Trigger
14. Wien's Bridge oscillator using operational amplifier
15. Characteristics of Photo Diode, Photo Transistor, LDR, LED
16. Series and Parallel Resonant Circuits
17. Silicon Diode as a Temperature Sensor
18. RC Coupled CE amplifier – Two stages with feedback – Frequency response and voltage gain
19. Push-pull amplifier using complementary – symmetry transistors power gain and frequency response.
20. Active filters – low pass and high pass-first and second order frequency response and roll off rate.
21. MATLAB-1: Non-Linear Harmonic Oscillator – Frequency Amplitude Response
22. MATLAB-2: Spectrum Analysis using Fast Fourier Transform
23. MATLAB-3: Artificial Neural Network – Pattern Recognition, Classification and Time Series Analysis.
24. MATLAB-4: MEMS - Dynamics of Microcantilever
25. MATLAB-5: Modelling LCR circuit in Simulink
26. MATLAB-6: Dispersion Curve of Optical Waveguide
27. MATLAB-7: Lorenz System – Chaotic Dynamics
28. MATLAB-8: Fractal – Cluster Formation using Diffusion Limited Aggregation
29. MATLAB-9: Clustering Analysis using Principal Component Analysis
30. MATLAB-10: Linear and Non-linear Optimization Problems
31. MATLAB-11: Solving Partial Differential Equation using Finite Difference Method
32. PYTHON-1: Root finding method for algebraic equations
33. PYTHON-2: System of linear equations
34. PYTHON-3: Interpolation and curve fitting
35. PYTHON-4: Numerical integration and differentiation

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, Tata Mc-Graw Hill, New Delhi (1994).
3. MATLAB Programming Fundamentals – © 1984–2021 by The MathWorks, Inc.
4. LabVIEW™ Getting Started with LabVIEW © National Instruments.
5. Computational Physics, Nicholas J. Giordano, Prentice Hall (1997).

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

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III SEMESTER

PH659 – NUCLEAR AND PARTICLE PHYSICS

Objectives:

1. *Introduce students to the fundamentals of nuclear and particle physics.*
2. *To understand the applications of nuclear and particle physics.*

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).

Outcome:
1. *The students would have understood the fundamentals of nuclear and particle physics.*
2. *The role of nuclear and particle physics in applications such as radioactivity and nuclear reactions shall be understood.*

PH661– MINI RESEARCH PROJECT

Objective: *To introduce research methods, analytical skills, choose a research topic, enhance the critical thinking, data collection and presentation skills.*

Course content

Literature survey - Data analysis - Technical writing and presentation – independent learning from online lectures/courses- Attending and presenting in a Workshop/Seminar/Conference- Research techniques.

Outcome: The student shall be in a position to identify research topic through literature review, plan experiments, write reports of the research work and analyse the results.

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IV SEMESTER

PH660– RESEARCH PROJECT AND VIVA VOCE

Objective: *To undertake independent research in a topic and to enhance the critical thinking, presentation and communication skills.*

Course content

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

Outcome: *The student shall be in a position to conduct independent research, plan experiments, communicate the results, write research articles and reports.*

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ELECTIVES

PH 671 – ELECTRONICS

Objective: *To impart a diversified knowledge on circuit analysis, the semiconductor devices, FETs, operational amplifiers and digital circuits and their applications.*

Circuit Theorems

Kirchoff's voltage law-voltage division- power in series circuit- Kirchoff'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 –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 Device 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).

Outcome: *On successful completion of this course, students would be able i) to understand the construction, working function, characteristics and applications of various semiconductor devices and ii) to describe the design and applications of various digital circuits.*

PH672 – INSTRUMENTATION

Objectives:

1. *Students will study the major characteristics of measurement systems and errors involved in them.*
2. *Students will gain an understanding related to production and measurement of low temperatures and high pressure.*
3. *Student will 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 ionisation and cryo-pumping. *Gauges*: McLeod, diaphragm, thermocouple, pirani, penning, ionisation 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).(Unit – II)
3. C.S. Rangan, G.R. Sharma and V.S.V. Mani, Instrumentation Devices and Systems, Tata McGraw-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 International Book Company, Singapore (1983).

Outcomes:

1. *To fully appreciate the various techniques involved in production of vacuum and low temperatures, which will benefit the students to handle various instruments in a better way.*
2. *To really understand the characteristics of instruments and analysis of errors will help them in interpreting the obtained data more efficiently.*

PH673 – NUMERICAL METHODS

Objective: *To introduce various numerical and computational methods useful to handle complex problems.*

Roots of Equations

Computer arithmetic – mathematical preliminaries – computation of errors – secant method – Newton-Raphson method – rate of convergence – polynomial equation – Horner's method – Muller method – system of equation.

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. M.K. Jain, S.R.K. Iyengar, R.K. Jain, Numerical Methods for Scientific and Engineering Computation, New Age International (2016).
2. E. Kreyszig, Advanced Engineering Mathematics, 8th edition, Wiley India (2008).
3. 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 - Cengare Learning (2011).
4. L.A. Pipes and L.R. Harwill, Applied Mathematics for Engineers and Physicists, Dover Publications (2014) Ch. 14.

Outcome:

Students could solve various numerical and computational methods useful to handle complex problems.

PH674 – NANOSCIENCE AND TECHNOLOGY

Objective:
To impart the basic knowledge on nanoscience and technology which includes the exotic properties of materials at nanoscale, various techniques available for the processing and characterization of nanostructured materials, applications in selected fields such as magnetic recording technology, electronics 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 Microscoy, 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 nanosystem - MEMS/NEMS: micromachining-LIGA- Nano/Microfluidics: behaviour of liquid in micro or nanosystems- lab-on-chip application.

Biomedical Applications of Nanotechnology
Biological structures and functions – biomolecular motors: myocin, 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, Enanabling technology for MEMS and Nanodevices, Wiley-VCH, 2008

Outcome:

On successful completion of this course, students would be able to:
1. describe material behavious at nanoscale and important experimental tools in the fields of nano-science
2. understand the quantum mechanical tunnelling of electrons, oscillatory coupling GMR effect and related applications in devices and MEMs
3. familiarize with the applications of nano-technology in magnetic recording, quantum computation, drug delivery, nanofluidics and biological devices.

PH675 – ATOMIC AND MOLECULAR SPECTROSCOPY

Objective: *To understand in detail the structure of atoms and molecules.*

Atomic Spectra

Quantum states of electron in atoms– hydrogen atom spectrum– electron spin – Stern Gerlach Experiment – spin-orbit interaction – Lande interval rule– two electron systems – LS-JJ coupling schemes–fine structure– spectroscopic terms and selection rules – hyperfine structure – exchange symmetry of wave function– Pauli's exclusion principle – 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, NewDelhi (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, Chapmen and Hall (1976).
3. G.M Barrow, Introduction to Molecular Spectroscopy, McGraw Hill(1986).

Outcome: *The student will be able to gain sufficient knowledge on most common atomic and molecular spectroscopic methods and properties derived from them.*

PH611 – DIGITAL SIGNAL AND IMAGE PROCESSING

Objective: *To introduce discrete signal and image processing concepts and their application.*

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 and Causality – 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).

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

1. *Design digital signals filters.*
2. *Use different image processing techniques for specific applications.*
3. *Apply applications like signal processing of ultrasonic signals and image processing of radiographic images.*

PH613– BASICS OF ENGINEERING MATERIALS

Objectives: *This introductory course is aimed to obtain basic exposure to the concepts of crystalline solids, its imperfections and basics of various advance engineering materials finding wide spread application in several industries. Understanding these material systems are vital for investigating the defects and their nature on these classes of materials.*

Structure of Metals

Crystal structure– Imperfections in crystals – dislocation theory - Principles of Alloying – Solid solutions– Gibbs 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, re-crystallization and grain growth, types of fractures in materials and their identification.

Non-Ferrous Metals and 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, cement and concrete, damages & degradation of concrete. Application of engineering ceramic materials**.**

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).

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

1. *Select different materials and emphasis the need of modern materials other than conventional metals and alloys for specific engineering applications.*

2. *Understand the heat treatment of steels using TTT and CCT diagrams.*
3. *Analyze the various metallurgical factors influencing the performance of materials for different structural engineering applications.*
4. *Define various mechanical properties of materials and their importance in materials selection criteria.*
5. *Classify different mechanical properties and how they can influence the materials behavior with respect to applied load.*

PH676– ADVANCED MATHEMATICAL PHYSICS

Objective:

To introduce advanced mathematical topics necessary to understand and appreciate various physical laws of nature.

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 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 (2011).
4. V. Balakrishnan, Mathematical Physics with Applications, Problems and Solutions, Ane Books (2017).

Reference Book

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

Outcome: *Students will understand advanced mathematical topics and appreciate various physical laws of nature.*

PH677– WAVEGUIDES AND MODERN OPTICS

Objectives: *The course aims at to expose students to applications of electromagnetic theory concepts in developing wave guides for communication, optical applications. Advanced technologies such as optical image processing, non-linear optics are covered in modern optics for students learning 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, sPhotonics – Optical Electronics in Modern Communication, 6^{th} edition, Oxford University Press (2007).
2. Eugune Hecht and A.R. Ganesan, Optics, 4^{th} Edition, Pearson Education Inc. (2002).
3. Clifford R. Pollock and Richard D. Irwin, Fundamentals of Optoelectronics,(1995).

Outcome: *Student will be able to understand design concepts in optical wave guides as well as generation of stimulated lights, optical non-linear phenomena.*

PH678 – ASTROPHYSICS AND COSMOLOGY

Objective: *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 Black Holes, Cambridge University Press (2007).
7. Steven Weinberg, Cosmology, Oxford University Press (2008).

Outcomes:
1. *Students will get an overview of observational astronomy and also get an introductory knowledge on astronomical instrumentation and observation techniques.*
2. *Students will be able to study the basic and advanced theoretical concepts in planetary, stellar, galactic astrophysics and cosmology.*

PH679 – SOLAR PHOTOVOLTAIC TECHNOLOGY

Objective: *To introduce the basic physics and technology of photovoltaic science and systems for solar energy harnessing.*

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.

Text Books

1. Chetan Singh Solanki, Solar Photovoltaics: Fundamentals, Technologies And Applications 2nd ed.,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).

Outcome: *Students will be able to understand the science and technology of solar cells and its design. Students can also appreciate various material properties which are used in photovoltaic devices.*

PH680 COMPUTATIONAL TECHNIQUES

Objective: *To introduce programming in MATLAB and basics of Finite Element Method which will be useful for further research studies.*

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 using COMSOL:

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 and Engineers, Oxford University Press (2010).
2. D. W. Pepper and J. C. Heinrich, The Finite Element Method: Basic Concepts and Applications with 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.

Outcome: *Upon completion of this course, the student will be familiarized with the computational tools available in MATLAB and COMSOL for varieties of physical problems.*

PH681 – ADVANCED ELECTROMAGNETIC THEORY

Objectives:

1. *To introduce elementary ideas of plasma, method of solving inhomogeneous wave equation, basics of radiating source and field equations in different inertial frames.*
2. *To understand optical dispersion of radiation in a media.*

Physics of Plasmas

Electrical neutrality in plasma – particle motion in electric field – Larmor radius – particle in crossed 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).

Outcome*: Optical properties of a media, basics of antennas and relativistic nature of EM-field will be understood.*

PH682 – NON DESTRUCTIVE TESTING

Objective: *It is one of the applied physics subjects and conventional NDT techniques are widely practiced in industries.*

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 – 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 limitation, 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).

Outcome: *Students are taught working principles of different NDT methods and exposed to instrumentation.*

PH683 – FIBER OPTIC SENSORS

Objective: *Fiber optics sensors are widely used and students are exposed to 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 – TE,TM modes – propagation characteristics of step index and graded index optical fibers.

Fiber Optic Sensors
Intensity-modulated sensors – transmission concept – reflective concept – microbending concept- intrinsic concepts – transmission and reflection with other optical effects – 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 sagnac 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 colour modulation – colour probes – Bragg grating concept – introduction – fabrication – application.

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).

Outcome: *Students will be able to propose new design of sensors for various applications.*

PH684 – QUANTUM ELECTRONICS AND LASER APPLICATIONS

Objective: *To introduce 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.F.C. Appard, Fiber Optics Handbook, McGraw-Hill (1989).

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

PH685– SENSORS AND TRANSDUCERS

Objective: *To introduce the basic concepts and technology of modern sensors used in industrial applications and in scientific equipments.*

Temperature Sensors
Introduction to sensors – classification of sensor – sensor characteristics– thermal sensors -gas thermometric sensors – thermal expansion type sensors – thermoresistive 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, 3rdedition, 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).

Outcome: *Students will be able to understand many modern devices and technologies used in sensors. Student can also appreciate various material properties which are used in engineering applications and devices.*

PH686 – ADVANCED STATISTICAL METHODS AND PHASE TRANSITION

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 to 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).

Outcome: *Students will gain confidence to pursue research careers in any areas of theoretical condensed matter physics.*

PH687 – PHYSICS AND TECHNOLOGY OF THIN FILMS

Objective: *To cater the post graduate students about fundamental to applications of thin films.*

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)

Outcome: *Students are moulded to do high level research in thrust areas like LEDs, Laser, solar cells, storage devices etc.*

PH688 – SEMICONDUCTOR PHYSICS

Objective: *To introduce the basic properties of semiconductors and modern devices based on semiconductor materials.*

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, 3rdEd., Wiley(2012).
2. M.S. Tyagi**,** Introduction to Semiconductor Materials and Devices 1st Ed.,John Wiley and Sons (1991).

Outcome: *Students will be able to understand and appreciate the functionality of modern semiconductor devices.*

PH689 – MAGNETIC CHARACTERIZATION AND SUPERCONDUCTING MATERIALS

Objective: *To understand magnetic characterization techniques suitable to evaluate the magnetic properties and to know about various superconducting materials.*

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 Tc –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., Cambridge Univ. Press (2002).
4. G. K. Wertheim, Mössbauer Effect: Principles and Applications, Academic Press Inc. (1964).
5. F. C. Moon, Superconducting Levitation, Wiley (2004).

Outcome: *The origin of various magnetic phenomena, characterization techniques and superconducting materials shall be understood.*

PH690 – QUANTUM COMPUTATION AND QUANTUM INFORMATION

Objective: *To introduce fundamental ideas of computation using quantum mechanics.*

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).

Outcome: *Students will appreciate that quantum mechanics can be exploited for useful information processing tasks.*

PH691 – MICRO ELECTRO MECHANICAL SYSTEMS

Objective: *To introduce the basic concepts of Micro-system and micro-sensors and their applications in modern scientific equipments and industrial products.*

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).

Outcome: *The student will be able to understand the fundamentals of various technologies involved in the fabrication of MEMS sensor, which are used in many common applications.*

PH692– CARBON NANOMATERIALS AND THEIR APPLICATIONS

Objectives:
It is aimed to acquire basic knowledge and understanding of carbon based nanomaterials, their synthesis methods, purification, dispersion, functionalization and nanocomposites. These carbon materials are finding extensive applications in various science and technology.

Essentials 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 Pres, Boca Ranton, London, New York, Washington D.C. (2005).
2. Yury Gogotsi, "Carbon Nanomaterials", CRC Press, Taylor & Francis group, Boca Raton, London, New York (2006).
3. Michel J. O. Connel, "Carbon Nanotubes Properties and Applications", CRC Press, Taylor & Francis group, Boca Raton, London, New York (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).

Outcome:

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

1. *Select suitable carbon materials and emphasis the need of 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 functionalization of carbon nanomaterials and formation of nanocomposites.*
4. *Analyze the structure and properties of various carbon configurations.*
5. *Fabricate devices for display, electrical, optoelectronics and sensor applications.*

PH693– FLUID MECHANICS AND CHARACTERISTICS OF NANOFLUIDS

Objective:
To impart the basic knowledge on fluid mechanics and nanofluid characteristics which includes 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).

Outcome:

On successful completion of this course, students would be able to:
1. understand the basics of nano and ferrofluids
2. Describe rheological, thermophysical and flow behaviors at nanoscale and
3. familiarize with the applications of nano-fluids in industries, Lab-on-the chip, biosensors and drug delivery.

PH694– ADVANCED ELECTRONIC MATERIALS AND DEVICES

Objectives:

It is aimed to provide the overview of advanced electronic materials, related technology and analyses.
To describe the fundamentals of chemical, bio sensors, information display materials and technology.
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).

Outcome:

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

1. *Choose suitable materials and emphasis the need of 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

Objective: *To introduce 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 circuirty- -Photonic crystal fibres-Optical communication- optical properties carbon based nanostructures-CNT,DWNT, MWNT, C_{60}, Graphene.

Text Books

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).

Outcome:

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

PH618– INTRODUCTION TO DATA ANALYTICS

Objectives: *To introduce the language and core concepts of probability theory. To understand basic principles of statistical inference. Learn to build a starter statistical toolbox with appreciation for both the utility and limitations of these techniques. Use software and simulation to do statistics.*

Tools of Probability and Statistics: Concept of Probability, Bayes Theorem, Random variables, central limit theorem, Collecting Data, Summarizing and Exploring Data, Basic Concepts of Inference, Inferences for Single Samples, Interference for two samples.

Linear Regression; Simple linear regression, Multiple linear regression, qualitative predictors, few application 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. Non linear regression; Polynomial, step function and splines.

Tree Base Methods; Decision trees, bagging. Deep learning; single layer neural networks, multilayer neural networks, convolution neural networks.

Reference Books

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

Outcome:

Upon completion of this course, students will be able to work in the interdisciplinary research areas like Linear Regression, Various statistical Resampling methods, Linear model selection and regularization, Deep learning in data science/engineering.

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