एस. चन्द्रशेखर भौतिकी विभाग

S. Chandrasekhar Department of Physics

CURRICULA & SYLLABI

Master of Science (M.Sc.) in PHYSICS

राष्ट्रीय प्रौद्योगिकी संस्थान पुदुच्चेरी

(शिक्षा मंत्रालय के अधीन राष्ट्रीय महत्व का एक संस्थान, भारत सरकार)

तिरुवेट्टाकुडी, कराईकल - 609 609

NATIONAL INSTITUTE OF TECHNOLOGY PUDUCHERRY

(An institute of National Importance under Ministry of Education, Govt. of India)

Thiruvettakudy, Karaikal – 609 609

1. PG PROGRAMMES OFFERED BY PHYSICS DEPARTMENT:

The department offers following postgraduate programme:

Sl. No.	Program	Description
1.	PG PROGRAM	M.Sc. Physics

2. MINIMUM CREDITS REQUIREMENT FOR AWARD OF DEGREE

Name of the Degree	Required Credits
M.Sc. Physics	80 Credits

4. CURRICULUM OF THE COURSES OF STUDY

Duration of the course: 2 years (4 semesters), LTP: Lecture- Tutorial- Practical

Semester Wise Break-up for credit requirements

Semester	Core Courses	Electives	Lab courses	Seminar & Project	Total
1st	16	0	3	0	19
2nd	16	3	3	0	22
3rd	12	3	3	0	18
4th	0	6	0	15	21
Total	44	12	9	15	80

Courses to Register in First year M. Sc. Physics

1st Semester						
CORE & ELECTIVES						
S. No	Code	Course Title/ Name	Courses Category	L-T-P	Credits	Page No.
1	PH6101	Mathematical Physics I	Core	3-1-0	4	6
2	PH6102	Classical Mechanics	Core	3-1-0	4	8
3	PH6103	Electronics	Core	3-1-0	4	10
4	PH6106	Quantum Mechanics I	Core	3-1-0	4	14
5	PH6105	Electronics Laboratory	Core-Lab	0-0-6	3	12
	Total				19	

Courses to Register in First year M. Sc. Physics

2nd Semester						
CORE & ELECTIVES						
S. No	**Code**	**Course Title/ Name**	**Courses Category**	**L-T-P**	**Credits**	**Page No.**
1	PH6115	Mathematical Physics II	Core	3-1-0	4	27
2	PH6116	Quantum Mechanics II	Core	3-1-0	4	29
3	PH6108	Electrodynamics	Core	3-1-0	4	18
4	PH6107	Statistical Mechanics	Core	3-1-0	4	16
5	PH6109	Advanced Physics Laboratory	Core-Lab	0-0-6	3	20
6	PH60XX	Elective-I	Elective	3-0-0	3	
		Total			**22**	

Courses to Register in Second year M. Sc. Physics

3rd Semester						
CORE & ELECTIVES						
S. No	**Code**	**Course Title/ Name**	**Courses Category**	**L-T-P**	**Credits**	**Page No.**
1	PH6110	Atomic and Molecular Physics	Core	3-1-0	4	21
2	PH6111	Solid State Physics	Core	3-1-0	4	23
3	PH6117	Nuclear and Particle Physics	Core	3-1-0	4	31
4	PH6112	Materials synthesis and characterization Laboratory	Core Lab	0-0-6	3	25
5	PH60XX	Elective -II	Elective	3-0-0	3	
		Total			**18**	

Courses to Register in Second year M. Sc. Physics

4th Semester						
CORE& ELECTIVES						
S. No	**Code**	**Course Title/ Name**	**Courses Category**	**L-T-P**	**Credits**	**Page No.**
1	PH60XX	Elective III	Elective	3-0-0	3	
2	PH60XX	Elective IV	Elective	3-0-0	3	
3	PH6114	Project	Core	0-0-30	15	26
Total					**21**	

5. PROGRAMME CORE (PC)

PROGRAMME CORE (PC)						
S. No	**Code**	**Course Title/ Name**	**Pre-requisite**	**L-T-P**	**Credits**	**Page No.**
1.	PH6101	Mathematical Physics I		3-1-0	4	6
2.	PH6102	Classical Mechanics		3-1-0	4	8
3.	PH6103	Electronics		3-1-0	4	10
4.	PH6105	Electronics Laboratory		0-0-6	3	12
5.	PH6106	Quantum Mechanics I		3-1-0	4	14
6.	PH6107	Statistical Mechanics		3-1-0	4	16
7.	PH6108	Electrodynamics		3-1-0	4	18
8.	PH6109	Advanced Physics Laboratory		0-0-6	3	20
9.	PH6110	Atomic and Molecular Physics		3-1-0	4	21
10.	PH6111	Solid State Physics		3-1-0	4	23
11.	PH6112	Laboratory Materials synthesis and characterization		0-0-6	3	25
12.	PH6114	Project		0-0-30	15	26
13.	PH6115	Mathematical Physics II		3-1-0	4	27
14.	PH6116	Quantum Mechanics II		3-1-0	4	29
15.	PH6117	Nuclear and Particle Physics		3-1-0	4	31

* L - Number of Lecture Hours; T – Number of Tutorial Hours; P-Number of Practical Hours

6. PROGRAMME ELECTIVES (PE)

PROGRAMME ELECTIVE (PE)						
S. No	**Code**	**Course Title/ Name**	**Pre-requisite**	**L-T-P**	**Credits**	**Page No.**
1	PH6050	Numerical Methods		3-0-0	3	33
2	PH6051	Materials characterization techniques		3-0-0	3	35
3	PH6052	Semiconductor Physics and Devices		3-0-0	3	37
4	PH6053	Nano-Ionics		3-0-0	3	39
5	PH6054	Physics of Materials Synthesis		3-0-0	3	41
6	PH6055	Physics and Technology of Thin Films		3-0-0	3	43
7	PH6056	Resonance Spectroscopy		3-0-0	3	45
8	PH6057	Advanced Magnetism		3-0-0	3	46
9	PH6058	Introduction to Nano-electronics		3-0-0	3	47
10	PH6059	Advanced sensors and Actuators		3-0-0	3	49
11	PH6060	Scientific writing and Presentation		3-0-0	3	50

PH6101 Mathematical Physics I

	L	T	P	Credits
	3	1	0	4

Pre-requisite: None

Course Objectives: The objectives of the course are

1. To train the students to solve problems related to Vector calculus, curvilinear coordinate system and to introduce concept of tensor
2. To teach the students concepts of linear algebra
3. To teach about Dirac delta function and differential operators
4. To teach about ordinary differential equation and their applications
5. To teach about integral transforms.

Contents:

Vector Analysis- gradient, divergence and curl. Line, surface, and volume integrals, Curvilinear coordinate systems, Elements of tensor.

Linear Algebra- Linear vector spaces, Dirac notation. Basis sets, Inner Products. Orthonormality and completeness. Gram-Schmidt orthonormalization process. Linear operators, Matrix algebra, similarity transforms, diagonalization, orthogonal, Hermitian and unitary matrices. Spaces of square summable sequences and square integrable functions, generalized functions, Dirac delta function and its representations. Differential operators,

Ordinary differential equations- linear ODEs, Green functions, second order differential equations: classification of singularities and local solutions, Sturm-Liouville Theory—Orthogonal Functions, Self-Adjoint ODEs Hermitian Operators, Gram-Schmidt Orthogonalization, Completeness of Eigenfunctions, Green's Function—Eigenfunction Expansion

Integral transforms Laplace transforms and Fourier transforms. Parseval's theorem. Convolution theorem. Applications.

Course Outcomes:

- **CO1.** Apply vector calculus tools for problem solving various branches of Physics.
- **CO2.** Learn notions of Linear vectors space needed to understand and apply postulates of Quantum Mechanics, determining the Eigen values and Eigen vectors using matrix formulation.
- **CO3.** Apply ODE of eigenvalue type, primarily derive solutions to ODEs that students come across in courses such as Classical Mechanics, Electro-magnetic theory, etc.
- **CO4.** Should be able to apply Green's function to various applications
- **CO5.** Be able to calculate apply concepts of integral transforms in physics

Text books:

1. V Balakrishnan, Mathematical Physics with Applications, Problems and Solutions, Ane Books, ISBN: 978-9386761118
2. G. B. Arfken, H. J. Weber and F.E. Harris, Mathematical Methods for Physicists, Academic Press, ISBN: 978-9381269558.

3. B. D. Gupta, Mathematical Physics, Vikas Publication House Pvt Ltd; ISBN: 13: 978-8125930969.

References:

1. M. L. Boas, Mathematical Methods in Physical Sciences, John Wiley & Sons, ISBN: 978-8126508105.
2. S. Lang, Introduction to Linear Algebra, Springer, ISBN: 978-8181282606
3. E. A. Coddington, Introduction to Ordinary Differential Equations, Prentice Hall of India ISBN: 978-0486659428
4. Ian Naismith Sneddon Ian N Sneddon, Elements of Partial Differential Equations, Dover Publications, ISBN: 978-0486452975
5. P. Dennery & A. Krzywicki, Mathematics for Physicists, Dover Publications, ISBN: 978-0486691930

PH6102 Classical Mechanics

	L	**T**	**P**	**Credits**
	3	**1**	**0**	**4**

Pre-requisite: None

Course Objectives: This course enables the students:

1. To define the concepts of Lagrangian and Hamiltonian Mechanics.
2. To interpret the concepts of symmetry and conservation laws
3. To explain concepts of small oscillations and equation of motion of rigid body.
4. To explain generating function, canonical transformation & Poisson brackets.
5. To explain special relativity and introduce four vector notations

Contents:

Variational principle, Euler equation, Applications; Variation subject to constraints and Lagrange multipliers; The Lagrangian formulation: Generalised coordinates and velocities, the principle of least action and the Lagrange equations of motion -simple applications, Extension to constrained systems, Hamiltonian formulation.

Integration of the Lagrange equations of motion: Motion in one dimension - the two-body problem, reduced mass and the equivalent one-dimensional problem - Motion in a central field - Kepler's problem - Scattering.

Symmetry and conservation principles – *Noether*'s Theorem;
Generating function, Poisson bracket, Canonical invariants, Hamilton-Jacobi theory, Action angle variables.

Small oscillations: normal mode; rigid body motion - angular velocity, Inertia tensor and angular momentum, equation of motion, Euler angles, Motion of tops, Motion in a rotating frame - Coriolis force.

Special relativity: Internal frames. Principle and postulate of relativity. Lorentz transformations. Length contraction, time dilation and the Doppler effect, velocity addition formula. Four-vector notation. Energy-momentum four-vector for a particle. Relativistic invariance of physical laws.

Course Outcomes:

- **CO1.** Review Newtonian mechanics in depth, apply variational principle, Euler-Lagrange's equation of motion and symmetries for analysing the mechanical systems,
- **CO2.** Analyse motion of a rigid body (for example symmetrical top) within the Lagrangian formalism.
- **CO3.** Determine normal modes of various interacting systems of particles
- **CO4.** Analyse different kinds of mechanical systems within the Hamiltonian, Hamilton-Jacobi formalism approach from Classical Mechanics to Quantum Mechanics.
- **CO5.** Apply relativistic invariance of physical laws.

Text books:

1. H. Goldstein, C. P. Poole and J. Safko, Classical Mechanics, Pearson, ISBN:9788131758915
2. M. K. Verma, Introduction to Mechanics, CRC Press, ISBN:9781138116771
3. David Morin, Introduction to classical Mechanics with problems and solutions, Cambridge University Press, ISBN: 978-0521876223

References:

1. George Hrabovsky, Leonard Susskind, Classical Mechanics: The Theoretical minimum, Penguin, ISBN: 9780141976228
2. L. Landau and E. Lifshitz, Mechanics, Oxford, ISBN: 978-0750628969
3. N. C. Rana and P. S. Joag, Classical Mechanics, Tata McGraw Hill, ISBN: 9780074603154
4. F. Scheck, Mechanics: From Newton's Laws to Deterministic Chaos, Springer, ISBN: 978-3642053696

PH6103	Electronics	L	T	P	Credits
		3	1	0	4

Pre-requisite: None

Course Objectives: This course enables the students

1. To understand and apply the principles of circuit theory.
2. To understand the working and characteristics of basic semiconductor devices.
3. To familiarize the students with operational amplifiers and its applications
4. Various number systems and to simplify the mathematical Expressions using Boolean algebra– simple problems, Implementation of combinational circuits.
5. To explain the basics of communication system

Contents:

Circuit theory: lumped circuit approximation, circuit elements, Kirchhoff's current and voltage laws, resistive networks, node and loop analysis, Thevenin and Norton's theorem, time domain response of RL, RC and RLC circuits, frequency domain response, impedance, concept of transfer function.

Analog electronics: discrete devices, review of working principle of PN junction diode, LED and Zener Diode. Characteristics of Photo diode, Bipolar junction transistor (BJT), characteristics, CE, CB and CC configurations, biasing techniques., small and large signal response, amplifiers. Working principle and characteristics of Field effect transistors (FET), Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFET)

Operational amplifiers: device properties, integrator, differentiator, RC active filter, negative and positive feedback, oscillators.

Digital electronics: Review of Number system, Excess 3 and Gray codes, logic gates, truth table, simplification of logical expressions using Karnaugh Mapping (POS and SOP) multiplexer, Half and Full adder, combinatorial circuits, flip-flops, counters, and, Basic Memory structures and RAM. Programmable logic devices- Programmable introduction to Logic Array (PLA), Programmable Array Logic (PAL), Field Programmable Gate Arrays (FPGA).

Communication theory: Basic blocks of Communication System. AM, Linear Modulation – Frequency-Division Multiplexing, Methods of generation and detection, Frequency and Phase modulation. Transmission Bandwidth of FM signals, Methods of generation and detection.

Course Outcomes:

- **CO1.** Learn the concepts of network theorem in solving basic electronics circuits.
- **CO2.** Apply network theorems to reduce any two-terminal series-parallel circuit.
- **CO3.** Learn the concepts of semi-conductor devices including diodes, transistors, CMOS etc.

- **CO4.** Able to Solve/analyse/design the basic circuits utilizing. Karnaugh Map to reduce Boolean expressions
- **CO5.** Able to understand the basics of communication systems

Text books:

1. A. S. Sedra and K. C. Smith, Microelectronic Circuits: Theory and Applications, Oxford University Press ISBN: 978-0199476299
2. D. P. Leach, A. P. Malvino and G. Saha, Digital Principles and Applications, Tata McGraw Hill, ISBN: 978- 9339203405
3. R. Gaekwad, Op-Amps and Linear Integrated Circuits, Pearson, ISBN: 9788120320581

References:

1. R. L. Boylestad and L. Nashelsky, Electronic Devices and Circuit Theory, Prentice Hall, ISBN: 978- 0132504577, 2015
2. D. P. Leach, Experiments in Digital Principles, McGraw Hill, ISBN: 978-0070369184

PH6105	Electronics Laboratory	L	T	P	Credits
		0	0	6	3

Pre-requisite: None

Course objectives: This course enables the students

1. Understand the behaviour of electronic components and perform analysis and design of bias circuits for diodes, transistors etc.
2. To perform & learn through real-time data by using Practical set ups such as Amplifiers, Flip Flops, Multiplexers etc.
3. To set up testing strategies and select proper instruments to evaluate performance characteristics of electronic circuit.
4. To choose testing and experimental procedures on different types of electronic circuit and analyse their operation different operating conditions.

Contents:

List of typical Experiments

1. Clipping and clamping circuits (Diode)
2. Rectifier circuits (Diode)
3. Regulated power supply circuit (Zener)
4. Common emitter (single stage) amplifier
5. Common source JFET amplifier
6. Multivibrators (Astable, Monostable, and Bistable)
7. Phase shift oscillator
8. Operational amplifier applications
9. Single stage amplifier using a FET
10. Verification of TTL Ics
11. Universal Gates
12. Adders and Subtractors
13. 7-Segment Display
14. Encoder, Decoder, MUX and DEMUX
15. Arithmetic using Decoder Ics
16. Flip-Flpos (SR, JK, MS-JK)
17. Flip-Flop Ics, Ripple Counters
18. Synchronous counters (up/down/random)

Course Outcomes:

- **CO1.** Should be able to choose testing and experimental procedures on different types of electronic circuits
- **CO2.** To gain practical understanding of op-amps
- **CO3.** To practically perform the logic operations
- **CO4.** To gain practical understanding of electronic devices like switches, counters etc.

References:

1. P. B. Zbar and A. P. Malvino, Basic Electronics: a text-lab manual, Tata McGraw Hill, ISBN: 978-0074624982
2. D. P. Leach, Experiments in Digital Principles, McGraw Hill, ISBN: 978-0070369184
3. R. S. Gaonkar, Microprocessor Architecture: Programming and Applications with the 8085, Penram India, ISBN: 978-8190082877

PH6106 Quantum Mechanics I

	L	T	P	Credits
	3	**1**	**0**	4

Pre-requisite: None

Course objectives: This course enables the students

1. To develop the fundamental formalism of quantum mechanics, formalism to Ket–Bra notation
2. To understand the energy spectrum for particle in one-dimensional potentials
3. To gain knowledge to three dimensional potential problems
4. To understand an develop the ability to compute angular momentum techniques.
5. To understand the energy levels for non-degenerate and degenerate systems from perturbation theory.

Contents:

Basic notions (states, operators, time evolution): Basic principles of quantum mechanics. Probabilities and probability amplitudes. Linear vector spaces. Bra and Ket vectors. Completeness, orthonormality, basis sets. Change of basis. Eigenstates and eigenvalues. Position and momentum representations. Wavefunctions, probability densities, probability current. Schrodinger equation. Expectation values. Generalized uncertainty relation.

One-dimensional problems: Potential barriers. Tunnelling. Linear harmonic oscillator: wavefunction approach and operator approach, periodic potential, delta potential, Kronig-Penny model;

Three-dimensional problems: central force potential, the hydrogen atom, Charged particle in an electromagnetic field: gauge invariance, Symmetries and conservation laws in QM: Degeneracies, Discrete symmetries

Angular momentum in quantum mechanics: raising and lowering operators, angular momentum addition, Clebsch-Gordon coefficients; Tensor operators and Wigner-Eckart theorem.
Time-independent perturbation theory: non-degenerate and degenerate cases, Stark and Zeeman effects Semiclassical (WKB) approximation and variational methods

Course Outcomes:

- **CO1.**Compute expectation values, probability of measurement given wavefunction, Convert from wave function formalism to Ket –Bra notation
- **CO2.** Calculate the energy spectrum for particle in one-dimensional potentials
- **CO3.** Apply LHO, central potential and hydrogen atom spectrum to physical problems
- **CO4.** Apply addition of angular momentum techniques to physical systems
- **CO5.** Compute shift in energy for non-degenerate and degenerate levels from perturbation theory.

Text Books:

1. R. Shankar, Principles of Quantum Mechanics, Springer (India), ISBN978-1461576754

2. P. W. Mathews and K. Venkatesan, A Textbook of Quantum Mechanics, McGraw Hill education, ISBN: 978-0070146174
3. D. J. Griffiths, Introduction to Quantum Mechanics, Pearson Education, ISBN 978-1107189638

References:

1. J. J. Sakurai, Modern Quantum Mechanics, Pearson Education, ISBN: 978-110847322
2. Claude Cohen–Tannoudji, Bernard Diu, Frank Laloë, Quantum Mechanics, Volume- Wiley-VCH; ISBN: 978-3-527-34554-0

PH6107	**Statistical Mechanics**	**L**	**T**	**P**	**Credits**
		3	**1**	**0**	4

Pre-requisite: None

Course objectives: This course enables the students

1. To understand the dependence of equilibrium properties of various systems on their microscopic constituents and compute thermodynamic parameters by using classical statistics.
2. To learn to use methods of quantum statistics to obtain properties of systems made of microscopic particles which either obey Fermi-Dirac statistics or Bose-Einstein statistics.
3. To understand low-temperature thermodynamic behaviour of quantum ideal gases.
4. To understand non interacting quantum systems.
5. To grasp the concepts of first order and second order phase transitions and critical phenomena.

Contents:

Thermodynamics Thermodynamic entities- Thermodynamic processes and laws, Concept of entropy - principle of entropy increase - entropy and disorder. Enthalpy - Helmoltz and Gibb's functions. Thermodynamics interpretation of Lagrange's undetermined multiplier, Maxwell's relations - *TdS* equations - energy equations - Heat capacity equations - heat capacity at constant pressure and volume. Black body radiation and Planck's radiation;

Probability-Definitions and Basic Concepts, Permutations and Combinations, Discrete and Continuous, Binomial Distribution, The Poisson Distribution, The Gaussian Distribution, Distinguishable Objects, Indistinguishable Macro-states, micro-states and accessible microstates. Fundamental postulate of equilibrium statistical mechanics, Probability distributions, Boltzmann equipartition theorems. Brownian motion: Langevin equation for random motion, Random walk problem. Gibbs Paradox;

Quantum systems: systems of identical, indistinguishable particles, spin, symmetry of wavefunctions, Bosons and Fermions - Bose-Einstein and Fermi-Dirac distributions - degenerate Fermi and Bose gases. Bose-Einstein condensation. Derivation of occupation index

The Ensemble Method of Statistical mechanics Types of Ensembles, microcanonical, canonical and Grand canonical ensemble, Partition functions and properties, Statistical definition of temperature, pressure, and chemical potential. perfect gas in micro canonical ensemble. Application of Canonical and grand canonical ensembles for a system of Harmonics oscillator; statistics of para-magnetism, Specific heat models, and quantum theory of conductivity in metals.

Phase transitions: Examples of phase transition and critical phenomena, Magnetic phase transition, symmetry breaking and long-range order, Landau theory, basic ideas of $2^{nd}$and 1^{st}order transitions, concept of Ising Model.

Course Outcomes:

- **CO1.** Revisit the basics of thermodynamics**,** understanding the concepts using Maxwell's equations.
- **CO2.** Understanding the concepts of non-interacting systems
- **CO3.** Develop a partition function for various systems and evaluating thermodynamic entities of a system.
- **CO4.** Comparison and application of FD and BE statistics.
- **CO5.** Understand and classify phase transitions

Text books:

1. R. K. Pathria and P. D. Beale, Statistical Mechanics, Butterworth- Heinemann, ISBN: 978-0123821881
2. S. R. A. Salinas, Introduction to Statistical Physics, Springer, ISBN: 0387951199
3. Suresh Chandra and Mohit Kumar Sinha, A T.B. of Statistical Mechanics, CBS Publishers, ISBN-978-81-239-2858-6

References:

1. F. Reif, Fundamental of Thermal and Statistical Physics, Sarat Book Distributors, ISBN: 978- 938066314
2. Keith Stowe, An Introduction to thermodynamics and Statistical Mechanics, Cambridge University Press, ISBN: 978-0-521-86557-9
3. L. D. Landau and E. M. Lifshitz, Statistical Physics, cbspd, ISBN: 978-818147790
4. W. Greiner, L. Neise, and H. Stocker, Thermodynamics and Statistical Mechanics, Springer, ISBN: 978-0387942995
3. K. Huang, Statistical Mechanics, John Wiley Asia, ISBN: 978-0471815181.
4. F. Mandl, Statistical Physics, Wiley, ISBN: 978-0471915331

PH6108 Electrodynamics

	L	T	P	Credits
	3	1	0	4

Pre-requisite: None

Course objectives: This course enables the students

1. Introducing the mathematical tools used in electrodynamics.
2. Review of electrostatics and magnetostatics in matter.
3. Providing easy headway into the covariant formulation of Maxwell's equations
4. Teaching basic principles of waveguides and transmission lines
5. Rendering insights into fields generated by oscillating sources, and their applications.

Contents:

Quick review: Laplace and Poisson equations. Boundary value problems. Dirichlet and Neumann boundary conditions. Method of images. Concept of the Green function and its use in boundary value problems. Magnetostatics: Ampere's law and Biot-Savart's law.

Maxwell equations and electromagnetic waves. Maxwell equations (both differential and integral formulations). Boundary conditions on field vectors D, E, B and H. Vector and scalar potentials. Gauge transformations: Lorentz and Coulomb gauges. Green function for the wave equation. Poynting's theorem. Conservation laws for macroscopic media.

Propagation of plane waves and spherical waves in free space, dielectrics and conducting media. Reflection and refraction of electromagnetic waves. Superposition of waves.

Advanced and retarded green functions; Lienard-Wiechert potentials; dipole radiation and Larmor's formula; spectral resolution and angular distribution of radiation from a relativistic point charge; synchrotron radiation; Rayleigh and Thomson scattering; collision problems; Bremsstrahlung and Cerenkov radiation.

Scattering of electromagnetic waves: Rayleigh and Thomson scattering, radiation damping.

Course Outcomes:

- **CO1.** Derive the wave equation from Maxwell's equations and re-express it in terms of scalar and vector potentials, Derive the solution to wave equation in terms of electric and magnetic fields and potentials
- **CO2.** To derive Poynting Theorem, prove conservation of energy, linear momentum and angular momentum, and construct EM Stress tensor
- **CO3.** Application of plane wave solution to construct solutions describing polarized light and construct state of polarization using Poincare Sphere, Analyse propagation of EM waves in different media and apply it to phenomena of reflection, dispersion, skin effect
- **CO4.** Analyse the Lienard-Wiechert Potential and calculate fields due to moving charges, Analysis and calculate the radiation from an accelerating charge and oscillating dipole.

Text Books:

1. J. D. Jackson, Classical Electrodynamics, 3rd Edition, John Wiley & Sons, ISBN: 978-8126510948
2. David J. Griffiths, Introduction to Electrodynamics, Pearson Education India, ISBN: 978-9332550445
3. Mark A. Heald, Jerry B. Marion, Classical Electromagnetic Radiation, Dover Publications ISBN:978-0486490601

References:

1. H J W Muller Kirsten, Electrodynamics, World Scientific, ISBN: 978-9814340748
2. J. R. Reitz and F. J. Millford, Foundation of Electromagnetic Theory, Pearson India; ISBN:978-0321581747
3. W. Greiner, Classical Electrodynamics, Springer, ISBN: 978-1-4612-0587-6
4. L. D. Landau and E. M. Lifshitz, Electrodynamics of Continuous Media, cbspd; ISBN: 978-0-08-030275-1

PH6109	Advanced Physics Laboratory	L	T	P	Credits
		0	0	6	3

Pre-requisite: None

Course objectives: This course enables the students

1. To gain practical knowledge by applying the experimental methods to correlate with the theoretical physics.
2. To understand Optical, Magnetic and dielectric properties of materials.
3. Understand the principle of different spectroscopy techniques.
4. To understand optical and Acoustic phenomena.

Contents:

List of typical Experiments

1. Characteristics of Vacuum Pump
2. Ferroelectric transition
3. Ferromagnetic transitions
4. Temperature dependent characteristics of p-n junction.
5. Ultrasonic interferometer
6. Characteristics of LASER
7. Magnetic susceptibility of a liquid
8. Diffraction by grating, Fresnel Bi-prism, Michelson interferometer
9. Electrical resistivity of semiconductors, Hall effect in semiconductor
10. Study of magnetic Hysteresis
11. UV-VIS- IR spectroscopy
12. Fraunhofer diffraction and Bragg diffraction
13. Zeeman effect
14. X ray diffraction
15. Computer interfacing of instruments
16. Faraday Effect
17. Michelson Interferometer
18. Electron spin resonance (ESR) spectroscopy

Course Outcomes:

- **CO1.** Students will gain the skills related to research and education
- **CO2.** Students will be able to learn handling sophisticated instruments.
- **CO3.** Students will gain skills to estimate characteristic values related to electrical, magnetic and thermal properties of materials.
- **CO4.** Apply the analytical techniques and graphical analysis to the experimental data
- **CO5.** To develop communication skills and discuss the basic principles of scientific concepts

References:

1. A. C. Melissinos, Experiments in Modern Physics, Academic Press, ISBN: 0124898513
2. E. Hecht, Optics, Addison-Wesley; ISBN: 978-8131718070
3. Laboratory Manual with details about the experiments.

PH6110	Atomic and Molecular Physics	L	T	P	Credits
		3	1	0	4

Pre-requisite: PH6106 and PH6107

Course Objectives: This course enables the students:

1. To learn about the intricacies of spectra of Hydrogen-like atoms
2. To understand the details of rotational, vibrational and Raman spectra molecules.
3. To know the different regions of spectra, and the corresponding instrumentations.
4. To understand about laser cooling manipulation of neutral atoms
5. To learn the concept of laser, laser cooling, and scattering of cold atoms such as BE condensation

Contents:

Atomic physics: One electron atom- spin-orbit interaction, fine structure, Lamb shift, Zeeman effect, Stark effect.

Two electron atoms: spin wave functions, approximate handling of electron-electron repulsion. Coupling of angular momenta, multiplet structure, gyromagnetic effects. Hyperfine and nuclear quadrupole interactions.
Many electron atoms: central field approximation, Thomas-Fermi and Hartree-Fock methods.

Molecular physics: Born-Oppenheimer approximation, molecular structure, rotation and vibration of diatomic molecules, hydrogen molecular ion, vibrational-rotational coupling, effect of vibration and rotation on molecular spectra. Electronic structure- molecular orbital and valence bond theories.

Atoms and light: transition rates, dipole approximation, Einstein coefficients, radiative damping, optical absorption, ac Stark effect.

Laser: Life time of atomic and molecular states. Multilevel rate equations and saturation. Coherence and profile of spectral lines. Rabi frequency. Laser pumping and population inversion. Gain coefficient, Laser threshold, cavities, modes, examples- He-Ne Laser, Solid State laser, Free-electron laser. Laser cooling, Doppler limit temperature, optical traps, concept and technique of BE condensation

Course Outcomes:

- **CO1.** Apply perturbation theory to predict atomic spectra for spin orbit interactions, Zeeman and Stark (up to 2^{nd} order), Hyperfine interactions
- **CO2.** Gain a basic understanding of approximation methods in solving many electron systems; predict the spectra of Helium; Develop the LS and JJ coupling schemes and predict the term values of multi electron states
- **CO3.** Understand the use and validity of the Born Oppenheimer separation in treating electronic, vibrational and rotational structure of molecules, Predict the vibration and rotation spectra, rovibronic structure of diatomic molecules

- **CO4.** Gain an understanding of concepts like laser cooling and optical trap.
- **CO5.** Get introduced to BEC

Text books:

1. B. H. Bransden and C. J. Joachain, Physics of Atoms and Molecules, Pearson, ISBN: 978-0582356924
2. C. N. Banwell and E. M. McCash, Fundamentals of Molecular Spectroscopy, Tata McGraw Hill Education India, ISBN: 9352601734

References:

1. G. K. Woodgate, Elementary Atomic Structure, Clarendon Press, ISBN: 978-0198511564

PH6111	**Solid State Physics**	**L**	**T**	**P**	**Credits**
		3	**1**	**0**	4

Pre-requisite: PH6106

Course Objectives: This course enables the students:

1. To relate crystal structure to symmetry, recognize the correspondence between real and reciprocal space.
2. Acquire knowledge of the behaviour of electrons in solids based on classical & quantum theories.
3. To become familiar with the different types of magnetism and magnetism-based phenomenon.
4. To develop an understanding of the dielectric properties and ordering of dipoles in ferroelectrics.
5. To get familiarized with the different parameters associated with superconductivity and the theory of superconductivity.

Contents:

Structure: characterising structures-crystalline/amorphous/liquids, classification of periodic structures, reciprocal space, x-ray and neutron diffraction, defects and dislocations.

Crystal symmetry and macroscopic physical properties: tensors of various ranks: pyroelectricity, ferroelectricity, electrical conductivity, piezoelectricity and elasticity tensors. Propagation of elastic waves in crystals and measurement of elastic constants.

Lattice dynamics: monoatomic and diatomic lattices. Born-von Karman method. Phonon frequencies and density of states. Dispersion curves, inelastic neutron scattering, Specific heat. Thermal expansion. Thermal conductivity. Normal and Umklapp processes.

Electronic structure: free electrons - spectrum, density of states, thermodynamics, band electrons - nearly free electron and tight binding limits, Electron states and classification into insulators, conductors and semimetals. Effective mass and concept of holes. Fermi surface. Cyclotron resonance. Semiconductors: carrier statistics in intrinsic and extrinsic crystals, electrical conductivity.

Internal electric field in a dielectric: Clausius-Mossotti and Lorentz-Lorenz equations. Point dipole, deformation dipole and shell models. Dielectric dispersion and loss. Ferroelectrics: types and models of ferro electric transition.

Magnetism: Dia, para and spin para-magnetism, Crystal field effect and orbital quenching, itinerant-vs-localised electrons, Stoner and Heisenberg models, mean-field theory, spin waves.

Superconductivity: phenomenology, pairing interaction, BCS theory, Ginzburg-Landau theory and type II superconductors, HTc Superconductors.

Course Outcomes:

- **CO1.** Relate the scattering from planes of a crystal to form factor, structure factor and the crystal structure of the materials, appreciate the differences in nature of bonding in solids and its relevance to physical properties.
- **CO2.** Interpret the Phonon dispersion curves of solid-state systems in 3-D in first Brillouin zone, Calculate thermal and electrical properties in the free-electron model.
- **CO3.** Discuss the origin and significance of Band formation in contrasting various properties of metals, insulators and semiconductors.
- **CO4.** Explain the significance of different interactions and energies involved that explain the phenomena and properties of different types of magnetic materials
- **CO5.** Knowledge of developments in the field of superconductivity and describe the basic properties of Type I and Type II superconductors.

Text books:

1. C. Kittel, Introduction to Solid State Physics, Wiley India ed., ISBN: 978-8126578436
2. J. D. Patterson and B.C. Bailey, Solid State Physics, Springer, ISBN: 978- 3319753218
3. R J D Tielley, Understanding Solids- The Science of Materials, Wiley, ISBN: 978-1118423462

References:

1. Solid State Physics, N. W. Ashcroft and N. D. Mermin, Cengage, ISBN:978-8131500521
2. Solid State Physics, M. S. Rogalski and S. B. Palmer; Gordon and Breach Science Publishers, ISBN: 978-9056992736
3. Steven H. Simon, The Oxford Solid State Basics, Oxford university Press, ISBN:9780199680771

PH6112	Laboratory – Materials synthesis and Characterization	L	T	P	Credits
		3	1	0	4

Pre-requisite: None

Course Objectives: This course enables the students:

1. To learn the physics involved in materials synthesis and Characterization
2. To acquire advanced techniques for synthesis and Characterization of Materials.
3. To learn synthesis of materials and characterization
4. To train the students to with the skill sets required for career in research and industry.

Contents:

List of Typical Experiments

1. Solid state reaction
2. Sol-gel technique
3. Ball mailing
4. Thin film preparation
5. Synthesis of nano-materials
6. Preparation of glass
7. Conductivity measurement
8. Spectroscopic studies
9. X-ray diffraction studies
10. Scanning Electron Microscopy studies

Course Outcomes:

- **CO1.** students will be able to synthesize bulk and nano-materials
- **CO2.** will be able to understand the physics behind various synthesis techniques
- **CO3.** will be able to determine the structure, surface morphology
- **CO4.** Apply the analytical techniques and graphical analysis to the experimental data

Text books:

1. Solid State Chemistry and Its applications. A.R. West, John Wiley and Sons, ISBN: 978-1119942948

		L	T	P	Credits
PH6114	**Project**	**L**	**T**	**P**	**Credits**
		0	**0**	**30**	15

Prerequisite: None

Course Objective: This course enables the students

1. To identify a research problem and identifying methodology and carrying out the work.
2. To carry out a substantial research-based project in line with motivation
3. To Analyse data and synthesize research findings
4. Report research findings in written and verbal forms

Contents:

Students will be choosing a major project in different area in theoretical and experimental physics, subject to availability of experts. This project can be continuation of minor project PH619 as well. Such project will have short dissertation followed by presentation. This project can be carried out using institute facilities or during internship at leading research laboratories in India, inter-disciplinary fields of science and technology.

Course outcomes:

- **CO1.** students will be Apply foundational research skills to address a research question
- **CO2.** students will be able to demonstrate Project management skills
- **CO3**. students will gain ability to take up research as an independent and in a collaborative work culture, also acquire best ethical practices.
- **CO4.** students will be able to comprehend the research findings clearly.

PH6115 Mathematical Physics II

	L	T	P	Credits
	3	**1**	**0**	4

Prerequisite: PH6101

Course objectives: This course enables the students

1. To train the students to solve problems related to complex variables which contain real and imaginary parts.
2. To teach the use of partial different special functions in solving physical problems.
3. To provide an understanding of Riemann surfaces, conformal mapping.
4. To teach about an understanding of Group theory.
5. To give the basic knowledge of Lie algebra.

Contents:

Partial differential equations in Physics: Laplace, Poisson and Helmholtz equations; diffusion and wave equations.

Complex Analysis: functions of a complex variable, analytic functions, integral calculus, contour integrals, Taylor and Laurent series, singularities, residues, principal values, Riemann surfaces, conformal mapping, analytic continuation.

Special Functions: Hermite, Legendre, Laguerre and Bessel functions.

Group theory Definition and examples of groups. Isomorphism and homomorphism, automorphism, Rotation group & its applications, Permutation groups. Group representation: reducibility, equivalence, Schur's lemma. Lie groups and Lie algebras, SU(2) and SU(3). Representations of simple Lie algebras, SO(n), Lorentz group. Symmetries in physical systems.

Course Outcomes:

- **CO1.** Solve PDE by applying separation of variable method in the cases with rectangular and circular boundaries in 1, 2 and 3 dimensions.
- **CO2.** Analyse functions of a complex variable using series expansions, using line integrals and geometry, apply the methods of complex analysis to evaluate definite integrals and infinite series and contour integrals and residue theorem to analyse simple problems in theoretical physics.
- **CO3.** Apply the special functions, such as Hermite, Legendre in solving physics problems.
- **CO4.** Analyse theorems in Group theory and apply Matrix representation of groups for solving physics problems.
- **CO5.** Apply the concepts of Lie algebra in advanced physics theories.

Text books:

1. Brown and R. V. Churchill, Complex Variables and Applications, McGraw-Hill, ISBN: 9789354600364
2. A. W. Joshi, Elements of Group Theory, New Age Int., ISBN: 978-9386070944,

3. A. W. Joshi, Matrices and Tensors in Physics, New Age International ISBN: 978-9386070906

References:

1. M. L. Boas, Mathematical Methods in Physical Sciences, John Wiley & Sons, ISBN: 978-0471198260
2. G. B. Arfken, H. J. Weber and F. E. Harris, Mathematical Methods for Physicists, Academic Press, ISBN:978-9381269558
3. M. Hamermesh, Group Theory and Its Applications to Physical Problems, Dover Pubns. Inc. ISBN: 978-0486661810

PH6116 Quantum Mechanics II

	L	T	P	Credits
	3	1	0	4

Pre-requisite: PH6106

Course Objectives: This course enables the students:

1. To understand the phenomena of scattering in quantum systems
2. To understand time dependent perturbation theory and concept of path integral
3. To gain knowledge about quantum interaction and transition probabilities
4. Develop concept of Path Integral, propagators and second quantization
5. To understand the relativistic effect on quantum systems

Contents:

Laboratory and centre of mass frames, differential and total scattering cross-sections, scattering amplitude; Scattering by spherically symmetric potentials; Partial wave analysis and phase shifts; Ramsauer-Townsend effect; Scattering by a rigid sphere and square well; Coulomb scattering; Formal theory of scattering-Green's function in scattering theory; Born approximation; applications

Time dependent perturbation theory:1^{st} order perturbation, harmonic perturbation, transition to continuum states-Fermi Golden Rule, Rayleigh scattering, emission and absorption of radiation, Einstein's A and B coefficients, adiabatic and sudden approximation

Schrodinger and Heisenberg pictures; postulates of quantisation, Interaction picture, Path integrals: propagators, amplitudes as path integrals, semiclassical methods revisited Quantum mechanics of many particles, identical particles and symmetries of the wave-function, scattering of identical particles, second quantization.

Relativistic quantum mechanics, Klein-Gordon and Dirac equations and their solutions, gyromagnetic ratio of the electron, relativistic corrections to the Schrodinger equation.

Course Outcomes:

- **CO1.** Calculate scattering amplitude from Born approximation, partial wave analysis.
- **CO2.** Apply perturbation methods to study the behaviour of atoms in electric, magnetic field using perturbation.
- **CO3.** Calculate transition probabilities from Fermis Golden rule.
- **CO4.** Develop concept of Path Integral, propagators and second quantization
- **CO5.** Use the Dirac equation for the relativistic electron energy spectrum

Text books:

1. B. H. Bransden and C. J. Joachain, Quantum Mechanics, Pearson Education ISBN: 9780582356917
2. Claude Cohen–Tannoudji , Bernard Diu , Frank Laloë, Quantum Mechanics, Volume 2, Wiley-VCH; ISBN: 978-3-527-34554-0

References:

1. F. Schwabl, Quantum Mechanics, Narosa, ISBN: 978-1618307583

2. J. J. Sakurai, Jim Napolitano, Modern Quantum Mechanics, Cambridge University Press; ISBN: 978-1108473224
3. G. Baym, Lectures on Quantum Mechanics, CRC press, ISBN: 978-080530667

PH6117	Nuclear and Particle Physics	L	T	P	Credits
		3	1	0	4

Pre-requisite: PH6106

Course Objectives: This course enables the students:

1. To impart the knowledge regarding the fundamentals of Nucleus and its models.
2. To provide the knowledge of the Two-nucleus problem, concept of nuclear force.
3. To acquire knowledge about the nucleus by the study of scattering of particles.
4. To have an understanding of interaction of charged particles with matter.
5. To have an elementary idea of particles and their classification.

Contents:

Nuclear physics: basic facts about the nuclei: size, shape, binding energy, electric and magnetic moments; nuclear forces: charge independence, isospin symmetry, NN, pi-pi scattering, relations between scattering cross sections; the deuteron: models of n-p potentials; nuclear models: liquid drop and shell; elementary ideas of Effective Field Theory; elementary ideas on radioactivity: alpha, beta and gamma rays; nuclear fission and fusion; elementary ideas about nuclear reactors.

Fundamental forces in nature; classification of particles: bosons and fermions; hadrons and leptons; spin, addition of angular momentum, helicity and chirality; quark content of hadrons; isospin, flavour, and colour symmetry, particle quantum numbers, Gell-mann Nishijima formula. Real and virtual processes; matrix elements; relativistic kinematics of decay and interaction process ($1\rightarrow2$ and $2\rightarrow2$) illustrated with examples from electromagnetic, weak and strong processes; Scattering amplitudes, differential and total cross-sections, decay rates and life-times; Breit-Wigner formula.

Elementary introduction to accelerators including, event rates and luminosity; the interaction of particles with matter, scintillators and time-of-flight detectors, the principle of gas chambers, silicon detectors, calorimetry and detectors for particle identification. Large detector systems at electron-positron, electron-proton and hadron colliders.

Course Outcomes:

- **CO1.** Learn basic concepts of Nuclear Physics, including the concepts of scattering cross-section, properties of nuclei etc.
- **CO2.** Analyse the deuteron problem and n-p scattering to study two nucleon bound states. Identify the properties of nuclear forces.
- **CO3.** Understand nuclear models and predict nuclear spins and electromagnetic moments by applying Shell model.
- **CO4.** Apply quantum mechanical techniques to evaluate radioactive decay processes. Analyse Nuclear reactions and understand the concepts of nuclear reactors.
- **CO5.** Explain the basics of particle physics, particle decays, the relation between Symmetry, conservation laws and conserved quantum numbers and illustrate the manifestation of the Einstein mass-energy relation.

Text books:

1. K. S. Krane, Introductory Nuclear Physics, Wiley, ISBN: 978-8126517855
2. W. E. Burcham, Elements of Nuclear Physics, Longman, ISBN: 978-0582460270
3. W. N. Cottingham and D. A. Greenwood, An Introduction to Nuclear Physics, Cambridge University Press, ISBN: 978-0521651493
4. R. R. Roy and B. P. Nigam, Nuclear Physics: Theory and Experiment, New Age, ISBN: 978-0471743835

References:

1. Invariance Principles and Elementary Particles, Princeton University Press, I ISBN:978-0691651347
2. A. Das and T. Ferbel, Introduction to nuclear and particle physics, John Wiley, ISBN: 978-9812387448
3. M. A. Preston and R. K. Bhaduri, Structure of the nucleus, Addison-Wesley, ISBN: 9780201627299
4. I. S. Hughes, Elementary Particles, Cambridge, ISBN: 978-0521407397

ELECTIVE COURSES

PH6050	**Numerical Methods**	**L**	**T**	**P**	**Credits**
		1	**0**	**2**	3

Pre-requisite: None

Course Objectives: This course enables the students:

1. To learn about approximation techniques
2. To learn about curve fitting by different methods
3. To know about numerical differentiation and integration
4. To gain knowledge about Fast Fourier transforms
5. To gain familiarity Euler's method and Runge-Kutta method

Contents:

Approximation Methods and Errors: Truncation and round-off errors. Accuracy and precision. Roots of Equations: Bracketing Methods (false position. Bisection) Iteration Methods (Newton - Raphson and secant). Systems of linear algebraic equations inversion and LU decomposition methods. Gauss elimination, matrix.

Curve fitting: Least squares regression. Linear, multiple linear and nonlinear regressions. Cubic– spline. Interpolation Methods: interpolating polynomials. Newton's divided difference and Lagrange Fourier approximation: Curve fitting with oscillatory functions Frequency and time domains. Discrete Fourier and Fast Fourier transforms,

Numerical differentiation and integration: Divided difference method for differentiation. Newton-Cotes formula. Trapezoidal and Simpson's rules. Romberg and Gauss quadrature methods.

Ordinary differential equations: Euler's method and its modifications Runge-Kutta methods. Boundary value and Eigenvalue problems. Partial differential equations: Finite difference equations.

Course Outcomes:

- **CO1.** Be able to write codes using MATLAB/Python to solve numerical problems
- **CO2.** Write programs to solve transcendental equations, perform interpolation, numerical integrations etc. on computer.
- **CO3.** Numerically solve differential equations.
- **CO4.** Write computer program to solve linear equations using Matrix operations
- **CO5.** Write programs to fit the curve using least square, regression and spline method

Text books:

1. K. E. Atkinson, Numerical Analysis, John Wiley, Asia, ISBN: 978-0471500230
2. S. C. Chapra and R. P. Canale, Numerical Methods for Engineers, Tata McGraw-Hill, ISBN: 978-9814670876

References:

1. J. H. Mathews, Numerical Methods for Mathematics, Science, and Engineering, Prentice-Hall of India, ISBN: 978-0136249900

PH6051	**Material Characterization Techniques**	**L**	**T**	**P**	**Credits**
		3	**0**	**0**	3

Pre-requisite: None

Course Objectives: This course enables the students:

1. To provide an introduction to materials characterization and its importance.
2. To discuss different types of characterization techniques such as XRD, spectroscopy, microscopy, thermal analysis, electrical and magnetic measurements.
3. To review the topic of crystal structure and how structures can be determined using diffraction methods.
4. To describe the properties and behaviour of x-rays and their use in materials characterization.
5. To describe the operation and use of a TEM and a SEM.

Contents:

X-ray scattering: Introduction, X-Ray diffraction, Bragg's law; intensities of diffracted beams, scattering, form and structure factor; powder X-ray diffraction; grazing incidence Xray diffraction (GIXRD)

Spectroscopy: UV-visible spectroscopy; X-ray photo electron spectroscopy (XPS), Auger electron spectroscopy (AES), X-ray fluorescence spectrometry (XRF), energy dispersive Xray analysis (EDX), IR spectroscopy, Raman spectroscopy

Microscopy: Optical microscopy- instrumentation, sample preparation, imaging modes; electron microscopy- scanning electron microscopy (SEM)- instrumentation, operational principles, sample preparation; transmission electron microscopy (TEM) – instrumentation, sample preparation, image modes, high resolution TEM, selected area diffraction (SAD)

Thermal analysis: Common characteristics, instrumentation, experimental parameters, differential thermal analysis (DTA) and differential scanning calorimetry (DSC): measurement of temperature and enthalpy change applications, Thermogravimetry (TGA): instrumentation, interpretation of thermogravimetric curves.

Electrical and magnetic characterization: Resistivity in thin films, low and high resistance, Hall measurements, impedance spectroscopy, dielectric relaxation, vibrating sample magnetometer, SQUID magnetometer- principle and working

Course outcomes:

- **CO1.** To be able to explain the production of characteristic x-rays and to explain the principles of diffraction and its use in crystal structure determination.
- **CO2.** To be able to understand, use and interpret the results of spectroscopic techniques
- **CO3.** Able to understand the basic operational modes of a SEM, TEM
- **CO4.** Able to do Thermal analysis and interpret their outcomes
- **CO5.** Able to do electrical and magnetic characterization

Text books:

1. Yang Leng, Materials Characterization Introduction to Microscopic and Spectroscopic Methods, John Wiley & Sons (Asia) Pte Ltd. ISBN: 978-3-527-33463-6
2. Vitalij K. Pecharsky, Peter Y. Zavalij, Fundamentals of Powder Diffraction and Structural Characterization of Materials, Springer, ISBN: 978-0-387-09579-0
3. B.D. Cullity, Elements of X-Ray Diffraction (3rd ed.), Pearson ISBN: 978-9332535169

References:

1. C. R. Brundle, C. A. Evans, S. Wilson, Encyclopedia of materials characterization surfaces, interfaces, thin films, Material Characterization Series, Surfaces, Interfaces, Thin Films, Butterworth-Heinemann, Oxford, ISBN: 978-0750691680
2. P.E.J. Flewitt, R.K. Wild, Physical Methods for Materials Characterization, CRC Press ISBN: 978- 0750303200

PH6052	**Semiconductor Physics and Devices**	**L**	**T**	**P**	**Credits**
		3	**0**	**0**	3

Pre-requisite: PH6111

Course Objectives:

1. To know the fundamentals of density of states, carrier densities and governing models in conduction process.
2. To understand different types of semiconductors devices and working principles.
3. To understand the physics of opt0-electronic devices.
4. To get an exposure to the principles of quantum effect devices.

Contents:

Semiconductor Fundamentals -Energy bands, Density of States, Distribution Functions, Carrier Densities, Carrier Transport Recombination and Generation, Continuity Equation, Drift-Diffusion Model
Metal-Semiconductor Junctions - Structure and principle of operation, Electrostatic analysis, Schottky diode current.

p-n Junctions- Structure and principle of operation, Electrostatic analysis of p-n diode current, Breakdown, Optoelectronic devices, tunnel diode

Heterojunction Devices - Concept of a heterojunction, Energy band diagram. High electron mobility transistor (HEMT. Photonic Devices, Light emitting diode (LED), Laser diode

MOS Capacitors – Introduction, Structure, Analysis, Technology. MOS Field-Effect-Transistors – Introduction, Structure and principle of operation, MOSFET analysis, Threshold voltage, MOSFET circuits and technology

Quantum-Effect Devices - Tunnel effect, Low-dimensional devices. Energy bands, Density of states, Conductance of a 1D semiconductor sample. 2D and 1D MOS transistors, Single-electron transistor.

Course outcomes:

- **CO1:** Students will be able to estimate carrier concentrations, drift currents in intrinsic and extrinsic semiconductors.
- **CO2:** Students will be able to understand and compare the physics behind working of different semiconductor devices.
- **CO3:** Students will be able to understand the voltage and current controlled devices and their conduction mechanism.
- **CO4:** Students will get an exposure to quantum effect devices and their application.

Text Books:

1. S.M. Sze, Semiconductors Devices, Physics and Technology, Wiley, ISBN: 978-0470-53794-7,

2. B.G. Streetman, S.K. Banerjee: Solid state electronic devices, PHI, ISBN:9788131708125,
3. Donald Neamen and Dhrubes Biswas, Semiconductor Physics and Devices, McGraw Hill Education; ISBN: 978-0071070102

PH6053 Nano Ionics

	L	T	P	Credits
	3	**0**	**0**	3

Prerequisite: PH6111

Course Objectives: This course enables the students:

1. To understand the fundamentals, point defects and their role in ionic conductivity.
2. To know various types of electrolytes.
3. To know operation of various solid state Ionics applications including open circuit cells, cells using current, and cells generating current.
4. Select measurement techniques appropriate for investigating solid state electrochemical material/device behaviour and select materials appropriate for different functions within the devices

Contents:

Solid State Ionics– definition–comparison with Solid state electronics– Characteristics of Super–ionic conductors. Types of Ionic solids– Fast Ionics Solids-Point Defect type–Sub Lattice type – Fast Ionic materials – alkali metal ion conductors –β alumina– Silver ion conductors–Cation conductors–Anion conductors–Oxygen ion conductors – Halide ion conductors – Proton conductors –Electronic conductors with ionic transport–Mixed ion conductors– Positive and negative electrodes of a cell.

Various types of Solid-state electrolytes– Classification based on structure, phase and compositions. Ionic Materials Introduction to polymeric materials, Glassy electrolytes, ceramics and polymer electrolytes and composite electrolytes.

AC impedance spectroscopy; Transport properties and Ion dynamics; Ion transport in homogeneous and heterogeneous medium – Ion conducting glasses, ceramics, polymers and composites; Ion Transport Models Phenomenological models, Free volume theory, Configurational entropy model, jump relaxation and Ion hopping model, Bond percolation model and Effective medium theory; Concepts and feasibility of ion conducting polymer nanocomposites and nanocrystalline ceramics.

Ionic polarization–Transport number measurement– Calculation of open circuit voltage (OCV), short circuit current, resistivity, current density, power density and estimation of efficiency, V-I characteristics of fuel cells, Fundamentals of cyclic voltammetry- Fabrication and general aspects of solid-state batteries – electrolyte –interface between electrode and solid electrolyte.

Design of fabrication of primary and secondary batteries. Solid State Lithium Battery, Li-air battery, Li-water battery, Sodium ion batteries, Sulphur batteries, potassium ion battery, Electric double layer supercapacitors, Electrochemical pseduocapacitors, Fuel Cells (PEM Fuel cell, SOFC), Electrochromic display devices.

Course outcomes:

- **CO1.** Calculate point defect concentrations using formation energies, develop Brouwer diagrams, describe several means of tailoring point defect concentrations through independent variables, and apply equilibrium thermodynamics to the case of defective solids
- **CO2.** Write point defect reactions in Kroger-Vink notation to describe defect processes, and apply a nonequilibrium thermodynamics and chemical kinetics framework to describe defect reactions
- **CO3.** Describe operation of various solid state ionic applications (including open circuit cells, cells using current, and cells generating current)
- **CO4.** Able to do scientific research in the field of energy storage applications.
- **CO5.** Select measurement techniques appropriate for investigating solid state electrochemical material/device and their performances.

Text Books:

1. Superionic Solids: Principles and Applications, S. Chandra, North Holland, ISBN: 9780044860396
2. Solid State Ionics, T. Kudu and K. Fueki, Kodanasha-VCH, ISBN: 0-444-87469-0,
3. P.G. Bruce, Solid State Electrochemistry, Cambridge University Press, ISBN: 9780521599498

References:

1. Lithium Batteries: Research, Technology & Applications, Greger R. Dahlin, Kalle E. Strøm, Nova Science Pub Inc, ISBN: 978-1607417224
2. Energy Storage, R. A. Huggins, Springer, ISBN: 9781441910233
3. Electrochemical Supercapacitors: Scientific Fundamentals & Technological Applicatio B. E. Conway, Kluwer Academic, ISBN:978-0-306-45736-4
4. Fuel Cell Technology, Nigel Sammes (ed.), Springer, ISBN: 978-1-85233-974-6

		L	T	P	Credits
PH6054	**Physics of Material Synthesis**	**3**	**0**	**0**	3

Pre-requisite: PH6111

Course Objectives:

1. To understand the principles of synthesising solid materials through various routes.
2. To compare the advantage and disadvantage of various synthesis and characterisation methods.
3. To understand the principles behind various synthesizing techniques.
4. To understand the concept of control over particle size and microstructure using different synthesis techniques.

Contents:

Introduction to controlled synthesis of materials- Control over the composition-microstructure- phase and surface morphology, Classification of materials- based on electrical properties, dimensionality (1D, 2D, and 3D), control over particle size- surface morphology. different types of nano-oxides, Al_2O_3, TiO_2, ZnO etc. nanotube and wire formation, carbon nanotubes, graphene preparation, properties and application

Synthesis approach: physical and chemical techniques for synthesis, solid state reactions, sol-gel, hydrothermal, freeze drying, intercalation, attrition, mechanical alloying and mechanical milling, ion implantation, Gas phase condensation, Chemical vapour deposition, fundamentals of nucleation growth, controlling nucleation & growth.

Self-assembly: self-assembled monolayers (SAMs). Langmuir-Blodgett (LB) films, clusters, colloids, zeolites, organic block copolymers, emulsion polymerization, templated synthesis, and confined nucleation and/or growth. Biomimetic Approaches: polymer matrix isolation, and surface-template nucleation and/or crystallization. Electrochemical Approaches: anodic oxidation of alumina films, porous silicon, and pulsed electrochemical deposition. Electrospinning.

Physics of Thin films- Thermal evaporation, sputtering- (AC and DC), LASER ablations, spin coating, dip coating techniques and comparative studies. Vapor deposition and different types of epitaxial growth techniques, pulsed Laser Deposition, Micro lithography (photolithography, soft lithography, micromachining, e-beam writing, and scanning probe patterning).

Course Outcomes:

- **CO1.** The students will understand characteristic features of submicron- nanomaterials
- **CO2.** The students will get an exposure to various materials synthesis techniques.

- **CO3.** Students will be able to identify a synthesis technique to control phase and microstructure.
- **CO4.** Students will able to understand the physics of thin film synthesis techniques.
- **CO5.** Students will get the knowledge of recent advancements in materials handling and synthesis process to meet various requirements.

Text Books:

1. A.R. West, Solid-State Chemistry and Its Applications., John Wiley and Sons, ISBN: 978-8126511075
2. Elaine A. Moore, Lesley E. Smart, Solid State Chemistry: An Introduction, , CRC Press, ISBN: 978-0748740680

Reference Books:

1. W. Gaddand, D. Brenner, S. Lysherski and G. J. Infrate (Eds.), Handbook of NanoScience, Eng. and Technology, , CRC Press, ISBN: 9781439860151

PH6055	**Physics and Technology of Thin Films**	**L**	**T**	**P**	**Credits**
		3	**0**	**0**	3

Prerequisite: None

Course Objectives:

1. To understand and compare different types and thin film deposition techniques.
2. To understand the principle of various thickness measurement techniques.
3. To understand the mechanism of nucleation and growth of thin film.
4. To understand the electrical, optical and magnetic properties of thin films.

Contents:

Preparation methods: electrolytic deposition, cathodic and anodic films, thermal evaporation, cathodic sputtering, chemical vapour deposition. Molecular beam epitaxy and laser ablation methods.

Thickness measurement and monitoring: electrical, mechanical, optical interference, microbalance, quartz crystal methods.

Analytical techniques of characterization: X-ray diffraction, electron microscopy, high and low energy electron diffraction, Auger emission spectroscopy.

Growth and structure of films. General features. Nucleation theories Effect of electron bombardment on film structure. Post- nucleation growth Epitaxial films and growth. Structural defects.

Mechanical properties of films: elastic and plastic behaviour, Optical properties. Reflectance and transmittance spectra, Absorbing films, Optical constants of film material, Multilayer films.

Electric properties to films: Conductivity in metal, semiconductor and insulating films, Dielectric properties, Magnetism of films, Domains and Anisotropy in magnetic films. Applications of magnetic films.

Course outcomes:

- **CO1.** Students will be able to choose an appropriate thin film deposition technique for to coat a particular material, for a specific application.
- **CO2.** Student will be able to estimate the thickness of the thin both in-situ and post deposition process.
- **CO3.** Student can choose appropriate technique for characterization.
- **CO4.** Student will learn the structure- property relation by controlling the thickness of the thin film for a specific application.

References:

1. K.L. Chopra, Thin Film Phenomena, McGraw-Hill, ISBN: 978-1-4613-3684-6
2. L.I. Maissel and Glang (Eds.), Handbook of Thin film Technology, McGraw-Hill, ISBN 978- 007039742

PH6056	Resonance Spectroscopy	L	T	P	Credits
		3	0	0	3

Prerequisite: PH6101 and PH6110

Course Objectives:

1. To understand the principle of interaction of the EM waves with the matter
2. To understand the concept of resonance in various spectroscopic techniques 3. To compare different types of spectroscopy techniques and their applications.
4. To understand the role of spectroscopy in Structure of material

Contents:

Principles of magnetic resonance: resonance theory, relaxation times. Nuclear Magnetic Resonance (NMR): Bloch equations, magnetic dipole coupling, Chemical shift, Knight shift, Magic Angle Sample Spinning (MASS), Wide-line and high-resolution NMR. Electron Spin Resonance (ESR): Zeeman interaction (9 -tensor), Nuclear hyperfine interaction, Nuclear quadrupole interaction, Application to transition metal ions and free radicals. Principles of Nuclear Quadrupole Resonance (NOR): Zeeman effect, Phase transition.

Double resonances: Electron Nuclear Double Resonance (ENDOR), Electron Electron Double Resonance (ELDOR), Nuclear Magnetic Double Resonance (NMDR), Optical Detection of Magnetic Resonance (ODMR).

Zero Field Nuclear Magnetic Resonance, Ferromagnetic Resonance, Spin Wave Resonance.

Practical aspects of resonance spectrometers: NMR, ESR and ENDOR. Pulsed spectrometers: Measurement of relaxation times.

Course outcomes:

- **CO1.** Students will be able to understand the underlying principle in Spetroscopy
- **CO2.** Students will be able to identify a spectroscopic technique for structural analysis.
- **CO3.** Students will be able to list requirements of a particular spectroscopic tool.
- **CO4.** Students will be able to understand and appreciate the complementary aspects of spectroscopic findings.

References:

1. Carrington and A.D. McLechlan. Introduction to Magnetic Resonance with Application to Chemistry and Chemical Physics. Chapman & Hall, ISBN: 978-0412217005
2. P.C. Poole and H.A. Farach. Theory of Magnetic Resonance, John Wiley, ISBN: 978-0-471-81530-3

PH6057 Advanced Magnetism

	L	T	P	Credits
	3	0	0	3

Pre-requisite: PH6111

Course Objectives:

1. To know the origin of magnetism of matter
2. To know types of interactions and governing principles that explains magnetism in materials.
3. To understand different types of physical models that explain different types of magnetism.
4. To understand the magneto-electric properties

Contents:

Crystal fields, Origin of crystal fields, Orbital quenching, The Jahn-Teller effect, Magnetic resonance techniques- Nuclear magnetic resonance, Electron spin resonance

Magnetic dipolar interaction, Exchange interaction, Origin of exchange, Direct exchange, Indirect exchange in ionic solids: superexchange, Indirect exchange in metals, Double exchange, Anisotropic exchange interaction, Continuum approximation

Ferromagnetism, The Weiss model of a ferromagnet, Origin of the molecular field; Antiferromagnetism, Weiss model of an antiferromagnet, Magnetic susceptibility, effect of a strong magnetic field, types of antiferromagnetic order; Ferrimagnetism, Helical order, Spin glasses, measurement of magnetic order

Broken symmetry, Models, Landau theory of ferromagnetism, Heisenberg and Ising models, The one-dimensional Ising model (D = 1, d = 1), The two-dimensional Ising model (D = 1, d = 2), Consequences of broken symmetry, Phase transitions, Rigidity, Excitations, Magnons, The Bloch T3/2 law.

Magnetoresistance, Magnetoresistance of ferromagnets, Anisotropic magnetoresistance, Giant magnetoresistance, Exchange anisotropy, colossal magnetoresistance, Hall effect, Spin electronics

Course outcomes:

- **CO1.** Students will be able to identify nature of magnetism in given matter.
- **CO2.** Students will be able to understand magnetic interactions and couplings.
- **CO3.** Students will be able to correlate magnetism with phase and microstructure of magnetic materials.
- **CO4.** Students will be able to understand the magneto-restive property in magnetic materials.

References:

1. Stephen Blundell, Magnetism in condensed matter, OUP Oxford; ISBN 9780198505914
2. J. M. D. Coey, Magnetism and Magnetic Materials, Cambridge University Press, ISBN 978-1108717519

PH6058	Introduction to Nanoelectronics	L	T	P	Credits
		3	0	0	3

Pre-requisite: PH6111

Course Objectives: This course enables the students:

1. To introduce the students to nanoelectronics, nanodevices, spintronics and molecular electronics.
2. To identify quantum mechanics behind nanoelectronics
3. To gain knowledge about nanoelectronics device fabrication techniques.
4. To understand basics of spintronic materials & quantum transport in nanostructures.

Contents:

Density of states (DOS) as a consequence of free particle in a box, eigen states, boundary conditions- stationary, periodic-BVK, wavevector and momentum DOS, 3D energy DOS(BVK), Difference between DOS & density of electron states, relevance of density of electron states to electrons in nano-structure, DOS from the perspective of Pauli's exclusion principle, Identical particles (notions only), Notion of interchange-Fermions, bosons, ground state for N interacting electrons in a potential, energy per particle–Fermion, Total energy in terms of Fermi energy Problems: average energy of a N non interacting particles in 3D, 2D, 1D case, Quantized conductance-cancellation of 1D electron velocity and DOS- Extending the DOS idea to 0D-quantum dots, Quantum wells of hetero structures, laterally patterned quantum well- quantum wire (1D)

Nanostructure devices: Materials for nanoelectronics, semiconductor heterostructures, lattice matched and pseudo-morphic-heterostructure; Bulk crystal and heterostructure growth-MBE, CVD, Nanolithography, etching, and other means for fabrication of nanostructures and nanodevices Characterization techniques of nanostructures

Spintronics: Spin, role of spin in magnetism, consequences of spin along with charge - information processing with binary bits 0, 1; monolithic Spintronics & spin-based quantum computers, elementary ideas of Bloch sphere, ideas of spin-orbit interaction, elementary ideas of magneto-electric sub-bands in quantum confined structures in the presence of spin interaction, types of quantum Hall effect- Normal Hall effect, Anomalous Hall effect,
Intrinsic spin Hall effect

Quantum transport in Nano structures: Bulk semiconductor [quantum confinement review] ; 3D states in terms of dispersion relation (result); 2D- bulk dimension compressed to deBroglie wavelength 1D, 2D result of sheet, 0D- quantum dot-, standard examples: Electron sheet concentration in a well, Fermi level location in a quantum well, Intrinsic carrier concentration in 2D, relation between 2D and 3D density of states.

Nanostructured Devices: Resonant tunnelling diodes, FET, Single electron transfer device, Potential effect transistors, Light emitting diodes and LASERS.

Course Outcomes:

- **CO1.** Explain the fundamental science and quantum mechanics behind nanoelectronics, explain the concepts of a quantum well, quantum transport and tunnelling effects.
- **CO2.** Differentiate between microelectronics and nanoelectronics, describe the superposition of eigen functions and probability densities.
- **CO3.** Describe the spin-dependant electron transport in magnetic devices.
- **CO4.** Calculate the energy levels of periodic structures and nanostructures.
- **CO5.** Calculate the I-V characteristics of nano-electronic devices.

References:

1. Vladimir V. Mitin, Viatcheslav A. Kochelap, Michael A. Stroscio, "Introduction to Nanoelectronics: Science, Nanotechnology, Engineering, and Applications", Cambridge University Press, ISBN: 978-0521166843
2. Simon M. Sze, Kwok K. Ng, "Physics of Semiconductor Devices", Wiley; ISBN:978-0-470- 06832-8

PH6059	Advanced Sensors and Actuators	L	T	P	Credits
		3	0	0	3

Course Objectives:

1. To gain knowledge about sensors utilized in materials characterization techniques.
2. To get familiarize with advanced sensor's technological development.
3. To understand and realize the different applications of advanced sensor based technology.

General concepts & terminology, Transducers, Fundamentals of nano sensors, sensors and actuators, Static and dynamic characteristic of measurement systems, Sensing mechanism of Mechanical, Electrical, Thermal, Magnetic, Optical, Chemical and Biological Sensors. Fabrication methods: Sensor configurations and geometries, Use of nano-materials in sensors, Thin/thick film formation techniques (physical & chemical techniques)

Resistive and electromagnetic sensors: Strain gauges, Resistive temperature detectors, Thermistors, Magneto resistors, Light dependent resistors, resistive hygrometers, Capacitive sensors, inductive sensors, reluctance-variation sensors, eddy current sensors, linear variable differential transformers, magneto elastic sensors, Hall effect sensors.

Nanotransducers: Design of nanotransducers, nano-mechanical, Chemical and magnetic transducers, Thermoelectric sensors, Piezoelectric sensors, Pyroelectric sensors, Photovoltaic sensors, optical sensors, Carbon Nanotube Sensors.

Nanoactuaters: Integration of sensor with actuators and electronic circuitry, Cantilever sensors, Nano structured optical actuators, Multiferroic materials and their applications as sensors and actuators.

Course Outcomes:

1. Students will be skilled to design and develop sensors Technology.
2. Students will be able to apply the sensors technology for the society.
3. Students will be able to understand the importance of sensor technology through applications.

Text Books:

1. Handbook of Modern Sensors: Phys., Designs, and Appl., J. Fraden, Springer, 2010
2. Solid State Gas Sensors', (eds. P.T. Moseley, et al.), Bristol, Adam Hilger, 1987.

PH6060	Scientific writing and Presentation	L	T	P	Credits
		3	**0**	**0**	3

Pre-requisite: None

Course Objectives:
1. To become expertise in any one of the soft skills
2. To understand research papers and prepare presentation material
3. To improve oral communication skills through presentation
4. To prepare original technical write up on the presentation

Contents:
How to Survey literature, three pass approach to reading papers
Principles of effective writing, crafting better sentences and paragraphs, Organization and streamlining the writing process, Storing and management of data, Summary and Abstract writing, Data presentation, Discussion and conclusion writing, Reviews, commentaries, and opinion pieces; and the publication process.
Ethical Issues in scientific writing (plagiarism, authorship, ghost-writing, reproducible research)
Oral and Presentation skills, Elevator pitch, Slide preparation for presentation, usage of open-source-wares.

Course outcomes:
- CO1. Students will be skilled to write scientific concepts precisely.
- CO2. Students will be able to present the scientific idea to both focused and general audience.
- CO3. Students will able to use design principles in preparing Visuals for presentation.
- **CO4.** Students will be able to understand the ethical issues involved in scientific writing, and practice in academic and research activities.

References:
1. MLA Handbook for Writers of Research Papers, Modern Language Association of America, ISBN: 978-8176710619
2. Research Papers published in IEEE, ACM, Elsevier publishers, etc.

एस. चन्द्रशेखर भौतिकी विभाग

S. Chandrasekhar Department of Physics

CURRICULA & SYLLABI

Minor
in
Nanoscience and Technology

Academic Year 2024 onwards

राष्ट्रीय प्रौद्योगिकी संस्थान पुदुच्चेरी

(शिक्षा मंत्रालय के अधीन राष्ट्रीय महत्व का एक संस्थान, भारत सरकार)

तिरुवेट्टाकुडी, कराईकल - 609 609

NATIONAL INSTITUTE OF TECHNOLOGY PUDUCHERRY

(An institute of National Importance under Ministry of Education, Govt. of India)

Thiruvettakudy, Karaikal – 609 609

S. CHANDRASEKHAR DEPARTMENT OF PHYSICS

1. UG MINOR OFFERED BY PHYSICS DEPARTMENT:

The department offers following UG MINOR COURSES for BTech program:

Sl. No.	Program	Description
1.	UG PROGRAM	Minor in Nanoscience and technology

2. MINIMUM CREDITS REQUIREMENT FOR AWARD OF MINOR DEGREE

Name of the Degree	Required Credits
Minor in Nanoscience and technology	21 Credits

4. CURRICULUM OF THE COURSES OF STUDY

Duration of the course: 2 years (4 semesters), LTP: Lecture- Tutorial- Practical

Semester Wise Break-up for credit requirements

Semester	Core Courses	Electives	Lab courses	Total
5th	**0**	**6**	**0**	**6**
6th	**0**	3	**3**	**6**
7th	**0**	3	3	**6**
8th	**0**	3	**0**	**3**
Total	0	**15**	**6**	**21**

Course Level: B. Tech.

Category: Minor / electives

Discipline: All Engineering Branches

Course Content: Fundamental to Advanced Level

5. Courses to Register in 3rd year of B Tech with Minor in Nanoscience and technology

S. No	Course Code for BTech Minor	Course Code for MSc Elective	Title	L-T-P-C	Page no.
1	PH1501	PH6061	Basics of Nanoscience	3-0-0-3	03
2	PH1502	PH6062	Nanomaterial synthesis Techniques	3-0-0-3	05
3	PH1503	PH6063	Nanomaterial Characterization Techniques	3-0-0-3	06
4	PH1504	PH6064	Properties of nanomaterials	3-0-0-3	07
5	PH1505	PH6065	Nanomaterial applications	3-0-0-3	08
6	PH1506		Nanomaterial Synthesis Laboratory	0-0-6-3	10
7	PH1507		Nanomaterial characterization Laboratory	0-0-6-3	11
			Total Credits	**21**	

PH1501	Basics of Nanoscience	L	T	P	Credits
		3	0	0	3

Pre-requisite: None

Course Objectives: The objectives of the course are

1. to get fundamentals of quantum mechanics.
2. to understand quantum confinement effects.
3. to understand the quantum nanostructures, such as quantum dots, nanowires and quantum wells
4. to understand the electronic properties of materials
5. to know the types of nanomaterial.

Contents:

Review of basic quantum mechanics, Wave-particles duality, de-Broglie and Fermi Wavelengths Schrodinger time dependent and time independent wave equations, general postulates, operators, eigenvalue, eigenfunction, Hermitian operators, operators in quantum mechanics, measurement probability, electromagnetics and quantum mechanics, probability current density, spin and angular momentum.

Free and confined electron- free electron 1D, 3D; electrons in bounded region 1D,3D periodic; Fermi level and chemical potential, partially confined electrons-finite square well, periodic well, triangular well, tunnelling through barrier, electron confined to atoms. Quantum dots, wires, wells. Kronig-Penny model, band theory of solids, doping, effect of electric field on energy bands, band transition, density of states in lower dimension, carrier concentration.

Classical and semiclassical transport, ballistic transport, transport on nano wires and nano tubes, transport of spin and spintronics; Magnetic properties- Different kind of magnetism in nature: Dia, Para, Ferro, Antiferro, Ferri, Super-para; Optical Properties**-** Photoconductivity, Optical absorption & transmission, Photoluminescence, Fluorescence, Phosphorescence, Electroluminescence;

Types of Nanomaterials **-** Nanoclusters, Solid solutions, thin film, Core Shell Nanostructure, Buckyballs, Carbon nano tubes, Micelles, Porous Materials, Metal Nanocrystals, Semiconductor nanomaterials.

Course Outcomes:

CO1: Gain the concepts of quantum theory.
CO2: Understand the importance of Schrodinger wave equation & its applications.
CO3: Obtain the knowledge on quantum confinement effects.
CO4: gain knowledge of quantum dots, nanowires and quantum wells for device application
CO5: Understand the magnetic and optical properties.

Ref. books:

1. A. F. J. Levi, Applied Quantum Mechanics, 2nd edition, Cambridge University Press, 2006.
2. S. R. Elliott, The Physics and Chemistry of Solids, John Wiley & Sons, England, 1998.
3. Robert E. Newnham, Properties of Materials, , Oxford University Press, 2005.
4. Luis M. Liz-Marzán, Prashant V. Kamat, Nanoscale Materials, Springer-Verlag New York Inc.; 2003, ISBN 978-1402073663

PH1502	Synthesis of nanomaterials	L	T	P	Credits
		3	0	0	3

Pre-requisite: None

Course Objectives: The objectives of the course are

1. to get exposed to physical methods of synthesis of nanomaterials.
2. to get exposed to chemical methods of nanomaterial synthesis.
3. to know the concepts and process of self-assembly
4. to know the essentials of lithography
5. to get the knowledge to synthesize nanomaterials such as CNT, NW, Dots and Graphene

Contents:

Physical Methods: Physical Vapour Deposition (PVD), Inert gas condensation, Arc discharge, sputtering, Ion beam sputtering, Pulse Laser Deposition (PLD), Molecular beam epitaxy, Electro-deposition, Chemical vapour deposition (CVD), MOCVD, exfoliation,

Chemical methods: metal nanocrystals by reduction, sol-gel, solvothermal synthesis, hydrothermal, photochemical synthesis, Electrochemical synthesis, Nanocrystals of semiconductors and other materials by arrested precipitation, pyrolysis, microemulsion.

Self-assembly and special nanostructure materials: Process of self-assembly, colloidal dispersion, Quantum dot (QDs) synthesis. Carbon Nanotubes, (SWCNT, MWCNT), Graphene nanosheets.

Semiconductor device fabrication: Si crystal growth, doping, oxidation, film deposition, lithography, etching, pattern transfer, metallization.

Course Outcomes:

CO1: be able to identify suitable method of synthesis.
CO2: know various methods of nanomaterial synthesis.
CO3: Obtain the knowledge on self-assembly.
CO4: Understand the chemical processes of nanomaterial synthesis
CO5: know the synthesis of special nanostructures

Ref. books:

1. G. Cao, Nanostructure and Nanomaterials: Synthesis, Properties and Application, World Scientific Series in Nanoscience and Nanotechnology, 2011.
2. G.A. Ozin and A.C. Arsenault, Nano chemistry: A chemical approach to nanomaterials, Royal Society of Chemistry, 2009.
3. Subha k Kulkarni, nanotechnology- Principles and practices, 3rd edition, springer, 2015, ISBN-978-3-319-09170-9.

PH1503	**Nanomaterial Characterization Techniques**	**L**	**T**	**P**	**Credits**
		3	**0**	**0**	**3**

Pre-requisite: None

Course Objectives: The objectives of the course are

1. to get exposed to physical methods of synthesis of nanomaterials.
2. to get exposed to chemical methods of nanomaterial synthesis.
3. to know the concepts and process of self-assembly
4. to know the essentials of lithography
5. to get the knowledge to synthesize nanomaterials such as CNT, NW, Dots and Graphene

Contents:
Diffraction techniques: powder x-ray diffraction, grazing incidence x-ray diffraction, small angle x-ray scattering, thin film x-ray diffraction
Microscopic techniques: scanning electron microscopy, High resolution SEM, Transmission electron microscopy-TEM, HRTEM, Atomic Force Microscopy, Scanning probe microscopic techniques
Spectroscopic techniques: UV-visible spectroscopy; X-ray photo electron spectroscopy (XPS), Auger electron spectroscopy (AES), X-ray fluorescence spectrometry (XRF), energy dispersive X-ray analysis (EDX), FTIR spectroscopy, Raman spectroscopy, Surface enhanced Raman spectroscopy, fluorescence and photoluminescence spectroscopy

Dynamic light scattering, BET, Zeta potential, Surface plasmon resonance

Critical dimension (CD) – optical line width, defects, thickness and reflectance tools – ellipsometry, reflectometry, scatterometry, photoacoustic metrology

Electrical measurement-Dopant Concentration measurement techniques, Resistivity in thin films, low and high resistance, Hall measurements, impedance spectroscopy, dielectric relaxation; magnetic characterization: vibrating sample magnetometer, SQUID magnetometer.

Course Outcomes:
CO1: be able to determine crystal structure.
CO2: be able to characterize morphology of nanomaterials.
CO3: be able to analyse composition of nanomaterials.
CO4: be able to determine particle/ cluster size
CO5: able to measure magnetic property and conductivity of nanomaterials

Ref. books:

1. Vitalij K. Pecharsky, Peter Y. Zavalij, Fundamentals of Powder Diffraction and Structural Characterization of Materials, 2nd edition, Springer, 2009.
2. Yang Leng, Materials Characterization Introduction to Microscopic and Spectroscopic Methods, John Wiley & Sons (Asia) Pte Ltd. 2013.
3. Sverre Myhra, John C. Riviere, Characterization of Nanostructures, CRC press, 2013, ISBN- 978-1-4398-5417-4

PH1504	**Properties of nanomaterials**	L	T	P	Credits
		3	0	0	3

Pre-requisite: None

Course Objectives: The objectives of the course are

1. to understand the size and shape dependence of physical properties in nanomaterials.
2. to understand the chemical interactions at nanoscale.
3. to know the effect of nanoscale on transport properties
4. to know the effect of nanoscale on optical properties
5. to understand magnetic behaviour in reduced dimension

Contents:

Size and shape dependence properties, melting point, magnetism, conductivity, band gap Chemical interactions at nanoscale- electrostatic interactions, Van der Waals attractions, Hydrophobic effect

Electrical transport properties- surface scattering, change in electronic structure, density of states in low dimension, quantum transport, charge transport in organic materials, Coulomb staircase, Bloch oscillations, negative differential resistance

Optical properties- absorption and emission in quantum wells, inter sub-band transitions, surface plasmon resonance, quantum dots

Nanomagnetic materials, magnetism in reduced dimension-thinfilms, particles, fluids Ballistic magneto resistance, conductance quantization in confined semiconductors, Anisotropic magneto resistance and applications, magnetism of nanoparticles, nanoclusters, nanowires, hard and soft magnetic materials

Light and Matter on a nano scale – Nanophotonics classification – electron and light confinement – quantum optics – Nanoplasmonics - Electromagnetic properties of nanostructures – Wavelength - Dispersion laws for photons and electrons –Maxwell and Helmholtz equations – Photonic band-structure and photonic band gap - Propagation of light in periodic media – Bloch waves and Band structure in periodic media – 1D case – Origin and size of bandgap based on dielectric contrast – Evanescent Waves.

Course Outcomes:

CO1: gain knowledge of nano scale interactions.
CO2: get knowledge of low dimension effect on transport properties
CO3: get knowledge of low dimension effect on optical properties.
CO4: develop understanding of reduced dimensionality on magnetic properties
CO5: get understanding of optical properties of quantum dots

Ref. books:

1. David Schmool, The physics of Nanomaterials- Vol 2, Physical properties of nanostructured materials and applications, CRC Press, 2021, ISBN-9781771889490
2. Gabor L Hornyak, Harry F. Tibbals, Joydeep Dutta and John J. Moore, Introduction to Nanoscience and nanotechnology, Taylor & Francis, 2008. ISBN-981439889954

PH1505 **Nanomaterials Applications**

L	T	P	Credits
3	0	0	3

Pre-requisite: None

Course Objectives: The objectives of the course are

1. to get exposed to physical methods of synthesis of nanomaterials.
2. to get exposed to chemical methods of nanomaterial synthesis.
3. to know the concepts and process of self-assembly
4. to know the essentials of lithography
5. to get the knowledge to synthesize nanomaterials such as CNT, NW, Dots and Graphene

Contents:

Nanoelectronics devices: Tunnel junctions, gate oxide tunnelling and hot electron effects in MOSFET, double barrier tunnelling and resonant tunnelling diode, Coulomb Blocked - nanocapacitor, quantum dot circuit; Single electron transistor (SET), CNT transistor, Nanowire FET and SET,

Molecular nanowires, charge transport in organic materials, fabrication techniques for molecular electronics, organic LEDs, organic FETs

Fundamentals of sensors and actuators, Static and dynamic characteristic of measurement systems, Sensing mechanism of Mechanical, Electrical, Thermal, Magnetic, Optical, Chemical sensors. Fabrication methods: Sensor configurations and geometries

Nano-transducers: nano-mechanical, chemical and magnetic transducers, , Photovoltaic sensors, optical sensors, Carbon Nanotube Sensors; Nanoactuators- Integration of sensor with actuators and electronic circuitry, Cantilever sensors, Nano structured optical actuators

Energy Conversion and Storage Devices: Development and implementation of renewable energy technologies, Energy transport, conversion and storage,

Electrochemical Energy Storage Devices: Principle of battery, Rechargeable battery; Li- ion batteries, Nanostructured materials for Li-ion batteries, Principle of supercapacitor, Advanced supercapacitor technology Fuel Cells: Basics of Fuel cells -Nanostructures and electrode materials for fuel cell applications

Course Outcomes:

CO1: be able to determine crystal structure.
CO2: be able to characterize morphology of nanomaterials.
CO3: be able to analyse composition of nanomaterials.
CO4: be able to determine particle/ cluster size
CO5: able to measure magnetic and conductivity of nanomaterials

Ref. books:

1. Karl Goser, Peter Glosekotter, Jan Dienstuhl, Nanoelectronics and Nanosystems-From Transistors to Molecular and Quantum Devices, Springer-Verlag 2004
2. D. Patranabis, Sensors and Transducers, PHI Learning Private Limited, 2003
3. M. Wakihara, O. Yamamoto, (Eds.), Lithium-Ion Batteries: Fundamentals and Performance by Wiley –VCH, Weinheim,1998

4. Chunyi Zhi and Liming Dai (Eds) Flexible Energy Conversion and Storage Devices, Wiley Interntaional, 2018

PH1506 **Nanomaterials Synthesis Lab**

L	T	P	Credits
0	0	6	3

Pre-requisite: None

Course Objectives: The objectives of the course are

1. To give hands on exposure to synthesis of materials by spin coating, hydrothermal, .
2. To develop a work culture in nano synthesis lab

Contents:

1. Synthesis of LiCoO2 by a simple solution combustion method
2. Bioglass synthesis through sol-gel method.
3. Synthesis of semiconducting metal oxides by sono-chemical method
4. Preparation of metal oxide nanoparticles by hydrothermal method.
5. Synthesis of silver nanoparticles and its spectral analysis.
6. Preparation of metal chalcogenide nanocrystals/quantum dots and its spectral studies.
7. Hydrothermal Synthesis of Nanostructured Materials
8. Electrodeposition method

Course Outcomes:

CO1: be able to the student will be able to deal with advanced synthesis techniques

Ref. books:

1. Pradeep, T. A textbook of nanoscience and nanotechnology. Tata McGraw-Hill Education, 2017.

PH1507 **Nanomaterials Characterization Lab**

L	T	P	Credits
0	0	6	3

Pre-requisite: None

Course Objectives: The objectives of the course are

1. To get exposure to advanced characterization techniques

Contents:

1. X-ray diffraction
2. Optical microscopy
3. Raman spectroscopy
4. SEM and EDX
5. FTIR spectroscopy
6. UV-Visible spectroscopy
7. Conductivity measurement
8. Dielectric measurement

Course Outcomes:

CO1: Get experience to advanced characterization techniques, analyse the data and interpret the observed data.

Ref. books:

1. Pradeep, T. A textbook of nanoscience and nanotechnology. Tata McGraw-Hill Education, 2017.