Proceedings of Board of Studies Meeting
(Held on Jan 27, 2024)

Course Structure & Syllabus for the programs

Master of Science in Physics
(Specialization in Materials Science & Nanotechnology)

(As per the Ordinances for Master of Science as per Academic Council, w.e.f. 2024-25)

Offered By

DEPARTMENT OF PHYSICS
HARCOURT BUTLER TECHNICAL UNIVERSITY,KANPUR-208002, UP
January 2024

Department of Physics

CURRICULA & SYLLABI

M.Sc. Physics (Specialization in Materials Science & Nanotechnology)

Vision: To catalyze transformative teaching and research endeavors in Physics through exceptional education, fueled by an invigorating academic environment, propelling the department to the forefront of academic excellence.

Mission:

1. **Fostering Expertise in Physics:** Equip students with a comprehensive understanding of both theoretical and experimental physics, empowering them to navigate the scientific landscape with confidence and dexterity.
2. **Bridging Physics and Practice:** Instill a forward-thinking perspective by exposing students to cutting-edge advances in physics, enabling them to seamlessly translate theoretical concepts into practical solutions, rivaling the skillset of seasoned engineering professionals.
3. **Ethical Navigators in Scientific Exploration:** Champion the highest ethical standards in scientific research, nurturing critical thinkers and socially aware individuals, prepared to adapt and lead amidst evolving social, scientific, technological, and educational landscapes.
4. **Igniting Change with Physics:** Cultivate students' innate creativity, empowering them to translate their grasp of physics into tangible solutions that improve the lives of others and leave a lasting impact on society.
5. **National Champions, Global Catalysts:** Inspire and equip students to tackle the challenges facing our nation head-on, while simultaneously nurturing their capacity to become responsible and engaged global citizens, actively contributing to a better future for all.

Programme Outcome (POs)

1. This program of M.Sc. Physics opens doors to Ph.D. studies, research fellowships, or exciting scientific adventures in national/international labs.
2. This degree will unlock the potential of students and student can find opportunities into cutting-edge fields like materials physic, energy storage and conversion technology, semiconductor technology, batteries, solar cells, nanotechnology, and more, at top institutes globally.
3. This Program will inspire future minds to become passionate physics teachers, shaping young minds in schools, colleges or universities across the world.
4. This program will harness physics expertise and build a career in material science and nanotechnology, tackling real-world challenges with powerful knowledge.
5. Students would unravel the mysteries as a scientist in R&D labs and research centers, both in India and Abroad.
6. The student will be empowered with knowledge and skills that can solve societal problems with professional integrity and a deep sense of social responsibility as a physicist.

Programme Educational Objectives (PEO)

1. Develop a comprehensive understanding of physics principles, spanning from fundamental concepts to cutting-edge research areas.
2. Empowering problem-solving with robust analytical, numerical, and computational skills to tackle challenging problems in physics and engineering.
3. Gain proficiency in using, calibrating, and manipulating scientific instruments with precision and meticulousness.
4. Bridging knowledge and responsibility to connect diverse areas of physics and responsible application of knowledge.
5. Leading with ethics and shaping the future of physics through responsible research, ethical conduct, and impactful contributions to society.

Programme Specific Outcome (PSOs)

PSO 1: Master foundational physics and explore cutting-edge applications and latest advancements, particularly in material science and nanotechnology.

PSO 2: Cultivate critical thinking and develop research skills & a passion for exploration, potentially leading to higher studies in physics or related fields.

PSO 3: Prepare for competitive careers like CSIR-NET, GATE, and JEST and future roles in research, industry, or academia.

PSO 4: Embrace lifelong learning and proactive contributors to society, using their knowledge to address real-world needs.

Syllabus and Credit structure: Credit Structure for M. Sc. Physics (Specialization in Materials Science & Nanotechnology) (For newly admitted students from Session 2024-2025)

Category	I	II	III	IV	Total
Programmes Core Courses (PCC)	16	16	8	4	44
Programmes Elective Courses (PEC)	-	-	4	4	08
Engineering Sciences Courses (ESC)	4	4	4	4	16
Internship /Seminar Courses (ISC)			2	-	02
Project			2	8	10
Total	20	20	20	20	80

Curriculum for M.Sc. in Physics
(For newly admitted students from Session 2024-2025)

Semester-I

S. N.	Course Type	Subject Code	Course Title	L	T	P	Credits
1.	PCC	NPH-501	Mathematical Physics	3	1	0	4
2,	PCC	NPH-503	ClassicalMechanics	3	1	0	4
3.	PCC	NPH-505	Quantum Mechanics	3	1	0	4
4.	PCC	NPH-507	Electronics	3	0	2	4
5.	ESC	NPH-509	Materials Science and Technology	3	0	2	4
			Total Credit	15	3	2	20

Semester-II

S. N.	Course Type	Subject Code	Course Title	L	T	P	Credits
1.	PCC	NPH-500	Electromagnetic Theory	3	1	0	4
2.	PCC	NPH-502	Thermodynamics and Statistical Mechanics	3	1	0	4
3.	PCC	NPH-504	Solid State Physics	3	0	2	4
4.	PCC	NPH-506	Nuclear and Particle Physics	3	1	0	4
5.	ESC	NPH-508	Physics of Semiconducting Devices & Technology	3	0	2	4
			Total Credit	15	3	2	20

Semester-III

S. N.	Course Type	Subject Code	Course Title	L	T	P	Credits
1.	PCC	NPH-601	Atomic, Molecular Physics and Lasers	3	0	2	4
2.	PCC	NPH-603	Nano Science and Technology	3	1	0	4
3.	ESC	NPH-605	Materials for Energy Storage and Devices Technology	3	0	2	4
4.	ISC	NPH-607	Internship/Seminar	0	0	4	2
5.	PEC	NPH-609*	Elective-I	3	1	0	4
6.	PCC	NPH-611	Minor Project	0	0	4	2
			Total Credit	12	2	6	20

* One course from Program Electives-I

Semester-IV

S. N.	Course Type	Subject Code	Course Title	L	T	P	Credits
1.	PCC	NPH-600	Advanced Characterization Techniques in Materials Science	3	0	2	4
2.	ESC	NPH-602	Science and Technology of Thin Films	3	1	0	4
3.	PEC	NPH-604*	Elective-II	3	1	0	4
4.	PCC	NPH-606	Capstone Project	0	0	16	8
			Total Credit	9	2	9	20

**One course from Program Electives-II

Programme Electives Courses-I (PEC-I)

S. N.	Course Type	Subject Code	Course Title	L	T	P	Credits
1.	NPH-609	Computational Physics		3	1	0	4
2.	NPH-613	Advanced Condensed Matter Physics		3	1	0	4
3.	NPH-615	Advanced Electronics Devices		3	1	0	4
4.	NPH-617	Computational Methods		3	1	0	4

Programme Electives Courses-II (PEC-II)

S. N.	Course Type	Subject Code	Course Title	L	T	P	Credits
1.	NPH-604	Advance Quantum Mechanics		3	1	0	4
2.	NPH-608	Advanced Energy Storage Devices		3	1	0	4
3.	NPH-610	Physics of Nanomaterials		3	1	0	4
4.	NPH-612	Science and Technology of Solar Energy, Hydrogen and other Renewable Energies		3	1	0	4

Table 1: Evaluation Scheme for Various Courses

S.N.	Course Title	Credits	Sessional Marks				ESM	Total Marks
			MSE	TAQ	Lab	Total		
1	Theory Courses	4(3-1-0)	30	20	-	50	50	100
2	Theory cum Lab Courses	4(3-0-2)	15	20	15	50	50	100
3	Project / Lab	2(0-0-4)	-	50	-	50	50	100
4	Internship/Seminar (ISC)	2(0-0-4)	-	50	-	50	50	100
5	Capstone Project/Lab	8(0-0-16)	-	50	-	50	50	100

MSE: Mid Semester Exam
TAQ: tutorials/Assignments, Quizzes, Attendance
ESM: End Semester Exam

SYLLABUS

NPH-501: Mathematical Physics

Course Category	Paper Code	Subject Name	L	T	P	Credits
PCC	NPH-501	Mathematical Physics	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. Gain a strong understanding of the mathematical tools used in physics, including vector calculus, linear algebra, and eigenvalue analysis.
2. Learning problem-solving tools related to vector algebra and differential equations.
3. To learn the basics of complex analysis and various series
4. To gain knowledge about the Tensors
5. To acquire proficiency in integral transform

UNIT I
Vector Algebra and Calculus: Vector algebra, vector calculus, Green's theorem, Stokes' theorem, Linear algebra, Matrices: operations, determinants, eigenvalues and eigenvectors, diagonalization, linear systems, Cayley-Hamilton Theorem and its applications, Fourier series, Fourier transform. Laplace transform.

UNIT II
Differential Equations and Special Functions: Linear ordinary differential equations, separable equations, integrating factor methods, linear equations, exact equations, homogeneous and non-homogeneous equations, solution methods (undetermined coefficients, variation of parameters), Runge-Kutta method, Bessel functions, Hermite functions, Legendre polynomials, Laguerre polynomials, Properties and applications of these functions.

Unit III
Complex Analysis: Elements of complex analysis, analytic functions; Taylor & Laurent series; poles, residues, and evaluation of integrals. Elementary probability theory, random variables, binomial, Poisson, and normal distributions. Central limit theorem.

UNIT IV
Tensor Analysis: Tensor Algebra, Linear combinations, direct product, contraction, tensor densities, the transformation of affine connection, covariant differentiation, gradient, curl, and divergence,

UNIT-V
Green's Functions and Group Theory: Introduction to Green's function method, Green's function as a solution to Poisson's equation with a point source, symmetry of Green's function, forms of Green's functions, spherical polar coordinate expansion, Dirac delta function. Introductory group theory: SU(2), O(3). Young diagrams for Unitary groups and their simple application for SU (2) and SU (3).

UNIT V
Integral Transform: Development of Fourier Integral, Fourier Transform-inversion theorem, convolution theorem, momentum representation, transfer functions, Neumann Series, separable Kernels, Hilbert-Schmidt Theory.

NPTEL courses and resources:

- **Selected Topics in Mathematical Physics:** https://archive.nptel.ac.in/courses/115/106/115106086/
- **Mathematics Methods in Physics:** https://archive.nptel.ac.in/courses/115/105/115105097/
- **Mathematical Methods in Physics and Engineering:** https://archive.nptel.ac.in/courses/115/105/1151050

Reference:

1. G. B. Arfken, Mathematical Methods for Physicist (Academic Press), 7th edition, 2011, Elsevier
2. A. W. Joshi, Elements of Group Theory for Physicist (New Age)
3. Mary L. Boas, Mathematical Methods in the Physical Sciences, 4th edition, 2019, Wiley
4. Heather Whitney, and Joshua Whitney, Handbook of Mathematical Methods, and Problem-Solving Tools for Introductory Physics, 2009, IOP Publishing Ltd.
5. Richard Courant and David Hilbert, Methods for Mathematical Physics, 2nd edition, 2000, Wiley-VCH.

NPH-503 Classical Mechanics

Course Category	Paper Code	Subject Name	L	T	P	Credits
PCC	NPH-503	ClassicalMechanics	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. To study the dynamics, stability, and conservation laws of systems.
2. To study the rigid body dynamics.
3. To analyze a classical system under Lagrangian formalisms.
4. To study and apply variational principle in classical systems.
5. To study and apply the principles of special theory of relativity

Unit-I

Mechanics of a Single Particle and of System of Particles: Newton's laws of motion, motion of a charged particle in an electromagnetic filed, motion of a system with variable mass, Dynamical systems, Phase space dynamics, stability analysis, Equivalent one-body problem, Motion in a central force field, equation of orbit, Kepler's law of planetary motion, two body Collisions - scattering in laboratory and Centre of mass frames.

Unit-II

Rigid body Dynamics: Euler's theorem, angular momentum and kinetic energy, the inertia tensor, Euler's angles, motion of a symmetric top non-inertial frames and pseudoforces. Variational principle: configuration space, techniques of the calculation of variation, applications of variational principle.

Unit-III

Lagrangian Formalism: Constraint, Generalized coordinates, D'Alembert's principle, Lagrange's equations, symmetries and conservation laws, cyclic coordinates. Lagrange's Equations for Magnetic Forces, Nonuniqueness of the Lagrangian

Unit-IV

Variational Principle: Configuration space, Applications of variational principle, Hamilton's principle, Hamilton's equations of motion, applications of Hamilton's formulation. Phase space.

Unit-V

Special Theory of Relativity: Michelson-Morley experiment, Lorentz transformations and its consequences, relativistic kinematics, Addition of velocities, Variation of mass with velocity, mass–energy equivalence, Minkowski four-dimensional continuum, four vectors.

NPTEL courses and resources:

- **Mechanics:** https://nptel.ac.in/courses/122106027
- **Lagrangian and Hamiltonian Mechanics:** https://archive.nptel.ac.in/courses/115/105/115105098/
- **Classical Mechanics:** https://nptel.ac.in/courses/122106027

Reference Books:

1. Mechanics: Course of Theoretical Physics, Volume 1, Sixth Edition, Elsevier Butterworth-Heinemann, 2017
2. Classical Mechanics and Relativity, Herald J. W. Muller-Kirsten, (World Scientific, 2008)
3. Classical Mechanics, H. Goldstein, (3rd Edition, Addison-Wesley, 2001)
4. Classical Mechanics of Particles and Rigid bodies, K. C. Gupta, (John Wiley, 1988)
5. Advanced Classical and Quantum Dynamics, W. Dittrich, W. M. Reuter, (Springer, 1992)
6. Classical Mechanics, T. W. Kibble, Frank H. Berkshire, (Imperial College Press, 2004)
7. Mathematical Methods of Classical Mechanics, V. I. Arnold, (Springer, 1989)
8. Classical Mechanics, Rana & Joag, (Tata McGraw Hill, 2001)
9. Classical Mechanics by J.C. Upadhyaya, Himalaya Publishing House

NPH-505 Quantum Mechanics

Course Category	Paper Code	Subject Name	L	T	P	Credits
PCC	NPH-505	Quantum Mechanics	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. The students will develop the foundation for understanding Quantum Mechanics.
2. The student will understand the concepts of quantum mechanics and solving operator equations for different quantum problems.
3. Apply the Schrödinger Equation to analyze the simple harmonic oscillator.
4. The students will understand wave mechanical formulation of quantum particles and various rules arising out of it.
5. Understand the concept of adding angular momenta and apply the general formalism of angular momentum algebra.

Unit-I

Mathematical Preliminaries: Concept of Hilbert Space, dimension and basis of a vector space, linearly independent and dependent vectors, Wave functions, Dirac's bra and ket notations, Properties of kets, bras, and bra-kets operators, linear operators, Hermitian Adjoint, Hermitian and skew-Hermitian operators, projection operators, properties of projection operators, matrix representation of kets, bras, and operators, matrix representation of the eigenvalue problem

Unit-II

Applications of the Schrödinger Equation: Schrodinger Equation: the free particle solution, wave packets, the potential barrier problem, transmission and reflection through a potential barrier, the tunnelling effect, particle in a square well potential, simple harmonic oscillator

Unit-III

Theory of Orbital Angular momentum: Angular momentum, orbital angular momentum, orbital, spin and total angular momentum operators, commutation relations, general formalism of angular momentum, eigenstates and eigenvalues equations of the angular momentum operator

Unit-IV

Theory of Spin Angular momentum: Electron spin hypothesis, spin angular momentum, relation between spin angular momentum and total angular momentum operators, commutation relations, general theory of spin, Pauli's spin matrices and eigen value equations, general formalism, eigenstates and eigenvalues equations of the spin momentum operator.

Unit-V

Addition of Angular Momentum: Addition of angular momenta, general formalism in angular momentum algebra, eigenvalues of J_2 and J_z, Clebsch-Gordon coefficients

NPTEL courses and resources:

- **Quantum Mechanics I:** https://onlinecourses.nptel.ac.in/noc22_ph06/preview
- **Quantum Mechanics II:** https://archive.nptel.ac.in/courses/122/106/122106034/
- **Foundations of Quantum Mechanics:** https://onlinecourses.nptel.ac.in/noc22_ph06/preview

Books & References:

1: Modern Quantum Mechanics by J. J. Sakurai (Pearson Education India), 3rd Edition (2014)
2: Quantum Mechanics: Concepts & Applications, Nouredine Zettili (John Wiley & Sons), 2nd Edition (2017)
3: Quantum Mechanics, Vol. (I) by Albert Messiah (North Holland Publishing Company, Amsterdam, 1961)
4: Concepts in Quantum Mechanics by V. S. Mathur and Surendra Singh (CRC Press), 2nd Edition (2013)
5: Quantum Mechanics by L.I. Schiff (Mc-Graw Hill Inc.)
6: Quantum Mechanics by B. K. Agarwal and Hari Prakash (Prentice-Hall of India Pvt Ltd, New Delhi, 2005)
7. Qunatum Mechanics by Ajoy K Ghatak (McMillan Co. of India), 2005

NPH-507 Electronics

Course Category	Paper Code	Subject Name	L	T	P	Credits
PCC	NPH-507	Electronics	3	0	2	4

Course Assessment:
Continuous/Sessional assessment through
One Mid Semester Exam (1 Hrs each): 15 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
Lab Exam: 15 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. Understand various types of semiconducting materials, p-n junctions, and various breakdown mechanisms.
2. Learn the concepts of BJT and FET structure, their working mechanism, and various characteristics.
3. Develop understanding about Operational amplifiers in various configuration mode, their use for practical applications.
4. Understand and learn about basic concepts number systems, combinational and sequential circuits for digital circuits applications.
5. Develop basic understanding of advance electronic devices based on semiconductor materials.

Unit-I **Semiconductor Physics**

Intrinsic and extrinsic semiconductors, charge densities in p and n type semiconductors, conduction by charge drift and diffusion, the p-n junction, energy level diagrams of pn-junction under forward and reverse bias conditions, derivation of pn-diode equation, Zener and avalanche breakdowns,

Unit-II **Semiconductor Devices**

The basic working principle of bipolar junction transistor, configurations and characteristics, Transistor hybrid model, h parameters, Analysis of a Transistor amplifier circuit using h parameters. Field-Effect Transistors (FET) Structure, Working, Construction and characteristics of JFET, transfer characteristic, Measurement of gm and rd, JFET fixed bias, Self-bias and voltage divider configurations, JFET source follower (Common-Drain) configuration, JFET Common-Gate configuration.

Unit-III **Operational Amplifier Circuits**

Basic Characteristics and parameters of Operational Amplifier (Op-Amp), ideal characteristics, Op-Amp as inverting amplifier, effect of finite open loop gain, generalized basic equation of op amp with impedances, integrator and differentiator, inverting and non-inverting summer, voltage follower. Op Amp parameters, offset voltage and current, slew rate, full wave BW, CMRR. OP AMP as voltage regulator.

Unit-IV **Digital Circuits**

Number systems, Logic simplification using K-maps, SOP and POS design of logic circuits, Demultiplexer, Decoder, Encoder, Latches, Flip flops-SR, JK, D, T, and Master Slave –characteristics table and equation-clock timing Diagrams. Shift register, serial and parallel configuration. Shift register Counters - Ring counter, Johnson counter, Asynchronous ripple or serial counter- Asynchronous Up/Down counter.

Unit-V

Semiconductor Devices

Light emitting diodes (LED), Tunnel diode, Gunn diode, Semiconductor laser, Photodiodes, Solar cell, IMPATT devices, Liquid crystal displays (LCD).

NPTEL courses and resources:

- **Basic Electronics:** https://nptel.ac.in/courses/122106025
- **Analog Electronics:** https://nptel.ac.in/courses/108102112
- **Digital Electronics:** https://nptel.ac.in/courses/108105132

Books & References:

1. Solid State Electronic Devices, B.G. Streetman and S. Banerjee, Prentice Hall, 2000
2. Milman J. and Halkias C.C., Electronic Devices and Circuits, Tata McGraw Hill, 1993
3. Semiconductor Physics and Devices by D.A. Neamen, (3rd Ed.,Tata McGraw-Hill), 2002.
4. Electronic Principles by A.P. Malvino (Tata McGraw, New Delhi), 7th edition, 2009.
5. Electronic Devices and Circuits Theory: Boylested and Nashelsky, (Pearson Education) 10th ed. 2009.

List of Experiments

1. Identification of basic electronic component and measurement of frequency of Cathode Ray Oscilloscope (CRO).
2. Study of Full-wave and Half wave rectifier with Capacitor filter.
3. To measure and analyze current-voltage (I-V) characteristics of p-n junction and Zener diode.
4. Analysis of I-V characteristics of LEDs and determination of Planck's constant.
5. Input and output characteristics of Bipolar Junction Transistor (BJT) in CE configuration.
6. Study the function of Operational Amplifier (Op-Amp) as an Inverter, Non-inverter and Buffer.
7. Design and study application of Op-Amp as a Schmitt Trigger and multi-vibrators.
8. Study the Flip-Flop circuit using basic Elementary gates.

Books & References:

1. Milman J. and Halkias C.C., Electronic Devices and Circuits, Tata McGraw Hill, 1993
2. Semiconductor Physics and Devices by D.A. Neamen, (3rd Ed., Tata McGraw-Hill), 2002.
3. Electronic Principles by A.P. Malvino (Tata McGraw, New Delhi), 7th edition, 2009.
4. Electronic Devices and Circuits Theory: Boylested and Nashelsky, (Pearson Education) 10th ed. 2009.
5. OPAMPS and Linear Integrated circuits: Ramakant A Gayakwad (Prentice Hall), 1992.
6. Digital Design by M. Morris Mano, Michael D. Ciletti, (Prentice Hall of India Pvt. Ltd.), 2008.

NPH-509 Materials Science and Technology

Course Category	Paper Code	Subject Name	L	T	P	Credits
ESC	NPH-509	Materials Science and Technology	3	0	2	4

Course Assessment:
Continuous/Sessional assessment through
One Mid Semester Exam (1 Hrs each): 15 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
Lab Exam: 15 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs): The students will be able to

1. Understand the fundamental principles of materials science: (e.g., crystal structures, bonding, electronic structure, phase transformations, electrical and optical behavior, etc.)
2. Evaluate different synthesis and processing techniques for various materials.
3. Analyze and anticipate future trends in materials science and engineering.
4. Explore emerging applications of materials in diverse fields: (e.g., energy, electronics, healthcare, aerospace, etc.)
5. Develop critical thinking and problem-solving skills in the context of materials engineering and become familiar with the latest advancements and research trends in materials science and technology.

Unit-I:
Foundations of Materials Science: Introduction to Materials Science, Crystal Structures and Bonding, Electronic Structure and Properties, Thermal Behavior: Phase Diagrams and Transformations, Electrical and Optical Properties of Materials

Unit-II:
Materials Processing and Characterization: Synthesis and Processing Methods, Advanced Characterization Techniques, Functional Materials and Applications: Electronic Materials and Applications, Ionic Materials and Devices, Energy Materials and Technologies, Advanced Composite Materials and Structures

Unit III:
Functional Materials and Applications: Electronic Materials and Applications: Semiconductors, conductors, insulators, and their applications in devices, Ionic Materials and Devices: Batteries, fuel cells, and other electrochemical devices, Energy Materials and Technologies: Solar cells, and supercapacitors, Advanced Composite Materials and Structures: Composites design, properties, and applications.

Unit-IV:
Emerging Trends and Future Directions: Nanomaterials and Nanotechnology, Sustainable Materials and Green Technologies, Ethical and Societal Implications of Materials Technologies, Future Directions in Materials Science and Engineering

Unit-V:
Fundamentals of Different Materials for Technological Applications: Fundamentals of Energy Materials, Introduction to Energy Storage and technologies: Electrolytes, Cathode materials, Anode materials, Binders and Separators, batteries, supercapacitors, fuel cells, Importance of energy storage, Emerging Energy Technologies, Computational Materials Science.

Lab Work: Implementation of any 1-2 Experiments/Methods/Techniques from each **Unit** (Selected by the instructor) based on the course.

NPTEL courses and resources:

- **Introduction to Materials Science:** https://archive.nptel.ac.in/courses/113/102/113102080/
- **Materials Science and Engineering-I:** https://archive.nptel.ac.in/courses/113/102/113102080/
- **Advanced Materials Science:** https://onlinecourses.nptel.ac.in/noc19_mm13/preview
- **Materials Characterization Techniques:** https://archive.nptel.ac.in/courses/113/105/113105101/
- **Materials Science and Engineering-II:** https://onlinecourses.nptel.ac.in/noc22_mm05/preview

Books & References:

1. B.S. Murthy, "Advances in Materials Science and Engineering", Elsevier, 2014.
2. J.H. Simmons and W.D. Callister Jr., "Materials Science for Engineers An Interactive Learning Approach", 3rd Edition, Wiley, 2013.
3. Luque, A., & Hegedus, S. (2011). Handbook of photovoltaic science and engineering. John Wiley & Sons.
4. Vielstich, W., Lamparter, A., & Gasteiger, H. (2013). Handbook of fuel cells: Fundamentals, technology and applications. John Wiley & Sons.
5. Sze, S. M. (2022). Physics of semiconductor devices
6. Goodenough, J. B. (2012). Why batteries matter: The science and economics of the energy revolution. Yale University Press.
7. Dresselhaus, M. S., & Mavronicolas, V. P. (2010). Materials science of semiconductors: Volume 1. Springer.
8. W.D. Callister Jr., "Materials Science and Engineering: An Introduction", 9th Edition, Wiley, 2013

NPH-500 Electromagnetic Theory

Course Category	Paper Code	Subject Name	L	T	P	Credits
PCC	NPH-500	Electro Magnetic Theory	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. Apply vector algebra operations, differential/integral calculus, and curvilinear coordinates (spherical and cylindrical) to analyze and solve problems in electrodynamics.
2. Grasp the fundamentals of electric fields and their practical applications.
3. Explore the core principles of magnetic fields and their real-world uses.
4. The students will understand various physics of electromagnetic waves.
5. The students will be able to demonstrate problem-solving abilities and analyze scenarios involving electromagnetic phenomena.

UNIT- I **Mathematical Preliminaries & Formulations in Electrodynamics with Vector Analysis**

Vector Algebra, operations, separation vectors, Differential Calculus, gradient, The operator del, The divergence, the curl, product rule, Integral calculus, Line, Surface and Volume integrals, Curvilinear coordinates, Spherical polar coordinates, cylindrical coordinates.

UNIT- II **Electrostatics**

The Electric field, principle of superposition, Coulomb’s Law, The Electric Field, Continuous Charge Distributions, Field Lines, Flux and Gauss’s Law, Divergence of Electrostatic Field, Applications of Gauss’s Law, Solving electrostatic problems in cartesian, spherical and cylindrical coordinates.

UNIT- III **Magnetostatics**
Biot-Savart Law, Gauss's Law for magnetostatics, physical interpretation, Electromagnetic induction, Faraday's law, Ampere's law, modification in Ampere's law, concept of displacement current, Differential and Integral form of all four electromagnetic equations and its physical significance

UNIT- IV **Electromagnetic Waves**
Maxwell's equations, Maxwell's wave equations in free space and physical significance, energy transmitted by a plane wave, Poynting theorem, Electromagnetic waves in free space and dielectrics, Waves in conducting media, skin depth.

Unit V: **Applications of Electrodynamics**
Apply previous concepts to real-world examples in various fields, Demonstrate problem-solving abilities and analyze scenarios, Explore recent advancements and emerging applications

NPTEL courses and resources:

- **Electromagnetic Theory course:** https://onlinecourses.nptel.ac.in/noc23_ee97/preview
- **Introduction to Electromagnetic Theory:** https://onlinecourses.nptel.ac.in/noc21_ee83/preview
- **Introduction to Electromagnetic Theory:** https://archive.nptel.ac.in/courses/108/104/108104087/

Books & References:

1. David J. Griffith-Introduction to Electrodynamics, Fourth Edition, Prentice Hall, 2013
2. L.D. Landau & E.M. Lifshitz- Electrodynamics of Continuous Media, Pergamon Press 1960
3. J.D. Jackson, Classical Electrodynamics, Wiley
4. Andrew Zangwill, . Modern Electrodynamics, Cambridge University Press, 2013, United Kingdom,
5. Parcell, Edward M., Electricity and Magnetism, 2nd Edition, McGraw-Hill Company, 1985
6. S.P. Puri, Classical Electrodynamics, (Narosa Publishing House) 2011.
7. A.Z. Capri and P.V. Panat, Introduction to Electrodynamics, (Narosa Publishing House) 2010
8. Saroj K. Dash & Smruti R. Khuntia-Fundamentals of Electromagnetic Theory, PHI
9. Edward C. Jordan, Electromagnetic Waves and Radiating System, Prentice Hall Electrical Engineering Series.

NPH-502 Thermodynamics and Statistical Mechanics

Course Category	Paper Code	Subject Name	L	T	P	Credits
PCC	NPH-502	Thermodynamics and Statistical-Mechanics	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. To acquire knowledge about the behaviors of gases
2. To gain knowledge about the fundamentals of thermodynamic systems
3. To understand the applicability of various empirical relations of thermodynamics
4. Understanding the basics of statistical physics
5. To learn the applications of classical and quantum statistics

UNIT I

Behavior of Gas: Maxwell's velocity distribution, average speed, rms speed, most probable speed, the energy distribution of molecules, temperature dependence, degrees of freedom and equipartition of energy, mean free path, collision probability. Transport phenomena: viscosity, diffusion, transport coefficients and size of molecules, relationship between transport coefficients, Brownian motion, vertical distribution of Brownian particles, Einstein's Theory of Brownian motion. The behavior of Real Gases, isotherms, and deviations from the perfect gas equation, virial coefficients, van der Waals' equation of state, van der Waals' constants, and critical constants.

UNIT II

Thermodynamic Systems: Thermodynamics equilibrium, thermodynamic processes, the first law of thermodynamics, the difference between specific heats (Mayer's relation), thermodynamics potentials, elasticities of a perfect gas, and work done in different processes. Second law of thermodynamics, Carnot cycle, heat engines, thermal efficiency, refrigerator, different statements of the second law, Carnot's theorem, reversible and irreversible processes, entropy, entropy change in reversible processes.

UNIT III

Entropy: The principle of increase of entropy, Joule expansion, entropy change of an ideal gas and Vander Waals' gas, entropy and disorder, heat death. Heat Engines: Rankine cycle, Otto cycle, Diesel cycle. Low-Temperature Physics: Joule-Thomson effect for a real gas, Joule-Thomson effect for a Vander Waals' gas, regenerative cooling, adiabatic demagnetization, third law of thermodynamics and its consequences.

UNIT IV

Micro and Macro States: Classical Phase space, Number of Microstates, Ideal gas, Entropy: Gibbs' Paradox, Liouville's Theorem in Classical Statistical Mechanics, Micro-canonical, canonical and grand-canonical ensembles, and partition functions; Free energy and its connection with thermodynamic quantities; Classical and quantum statistics. Boltzmann Limit, Sackur-Tetrode equation.

UNIT V

Phase Transitions: Degenerate Fermi gas, Ideal Bose and Fermi gases, Principle of detailed balance, Blackbody radiation and Planck's distribution law, Bose-Einstein condensation, Diamagnetism, paramagnetism, and ferromagnetism, White Dwarf Stars, and Saha-Ionization Equation. First- and second-order phase transitions. phase equilibria, critical point. Introduction to nonequilibrium processes, Ising model. Diffusion equation. Random walk and Brownian motion.

NPTEL courses and resources:

- **Thermodynamics course:** https://archive.nptel.ac.in/courses/112/103/112103275/
- **Statistical Mechanics course:** https://archive.nptel.ac.in/courses/115/106/115106126/

Books & References:

1. Frederick Reif, Fundamentals of Statistical and Thermal Physics, Waveland Pr Inc, 2008.
2. F. W. Sears and G.L. Salinger Thermodynamics Kinetic Theory and Statistical Thermodynamics, Narosa Publishing House, 1998
3. Kerson Huang, Statistical Mechanics, Wiley, 2nd Ed., 1987.
4. R K Pathria, Paul D. Beale, Statistical Mechanics, Academic Press, 3rd Ed., 2011.
5. Statistical Mechanics, Richard P. Feynman, Westview Press, USA, 2008

NPH-504 Solid State Physics

Course Category	Paper Code	Subject Name	L	T	P	Credits
PCC	NPH-504	Solid State Physics	3	0	2	4

Course Assessment:
Continuous/Sessional assessment through
One Mid Semester Exam (1 Hrs each): 15 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
Lab Exam: 15 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. Understand fundamental knowledge about crystal structures and defects in solids.
2. Learn concepts of X-ray diffraction and various bonding mechanism in crystals
3. Develop understanding about the behavior of electrons in solids and fundamental equations.
4. Learn various magnetic properties of solids, their origin, and fundamental concepts.
5. Learn various properties and applications of superconducting materials.

Unit-I

Crystalline and Amorphous Solids: Crystal structures, Bravais lattices, basis vectors, unit cell, various symmetry operations, Point groups and space groups, Miller indices, Directions and planes in crystals, Inter-planar spacings, Simple Crystal (SC), BCC and FCC crystal structures. Miller indices, X-ray diffraction by crystals. Various kinds of crystal imperfections, point defect, Schottky and Frenkel defect, Dislocations, edge and screw dislocation, grain boundary.

Unit-II

X-ray Diffraction and Various Bonds: Bragg's law, Laue pattern, X-ray diffractometer, determination of lattice parameter using XRD, absorption of X-rays, absorption edge. Primary and secondary bonds, ionic bond, covalent bond, metallic bond, hydrogen bond, Vander-waals bond, forces between atoms, bond dislocation energy, cohesive energy.

Unit-III

Band Theory: Electrons in a periodic potential, Bloch theorem, Free electron model, tight binding method, Band theory of solids, elementary idea of semiconductor superlattices, Kramers-Kronig relations, electronic transport from classical kinetic theory, Boltzmann transport equation, electrical and thermal conductivity of metals and Hall effect.

Unit-IV

Magnetic Properties of Materials: Magnetic Properties of Materials, Diamagnetism, Langevin equation, Quantum theory of Para magnetism, Curie law, paramagnetic in rare earth and iron group ions, Elementary idea of crystal field effects, Ferromagnetism, Curie-Weiss law, Anti-ferromagnetism, Neel Temperature, . Ferroelectricity: Ferroelectric materials; their properties and classification.

Unit-V

Superconductivity: Superconductors, Type– I and Type – II superconductors, Meissner effect, BCS Theory, Coherence and phase of cooper pairs, London's equations, penetration depth, Thermodynamic properties of superconductors: Entropy and specific heat, Application of superconductors: Josephson effect: dc and ac effects, superconducting quantum interference device (SQUID).

NPTEL courses and resources:

- **Solid State Physics course:** https://nptel.ac.in/courses/115105099
- **Physics of Solids course:** https://nptel.ac.in/courses/115105099

Books & References:

1. Introduction to Solid State Physics, C. Kittel (Wiley, New York 2019)
2. Principles of the Theory of Solids, J. Ziman (Cambridge University Press, 1972)
3. Solid State Physics, H. Ibach and H. Luth (3rd edition Springer Berlin, 2002)
4. Solid State Theory, Walter A. Harrison (Tata McGraw-Hill, New Delhi 1970)

List of Experiments

1. To determine the type of charge carrier and carrier concentration of a given semi-Conductor Materials using Hall effect.
2. To measure the resistivity of a Ge/Si semiconductor using four probe method with Varying temperature and calculate the band gap.
3. Study of B-H curve and hysteresis loss in ferromagnets.
4. Analysis of Magnetic Susceptibility

References:

1. Introduction to Solid State Physics by C. Kittel (Wiley Eastern, New Delhi)
2. Solid State Physics by N.W. Ashcroft and N.D. Mermin, Brooks/Cole
3. Elementary Solid-State Physics: Principle and Application by Omar Ali (Addison Wesley, London)
4. Quantum Theory of Solid by C. Kittel (John Wiley and Sons, London)

NPH-506 Nuclear and Particle Physics

Course Category	Paper Code	Subject Name	L	T	P	Credits
PCC	NPH-506	Nuclear and Particle Physics	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):
1. To analyze nuclear structure its energy and conservation laws.
2. Analysis of various kinds of nuclear models.
3. To study and analyze nuclear radiations
4. Elementary particles and their characteristics.
5. Applications nuclear reactions for energy production

UNIT I
Basic Nuclear Properties: size, mass, density, shape, energy, charge and charge distribution, Binding energy, mass defect packing fraction, fusion and fission, nuclear angular momentum, nuclear moments, magnetic dipole moment, electric quadrupole moment, spin and parity.

UNIT II
Nuclear Models: Liquid drop model, semi- empirical mass formula, Mass of most stable isobars, Achievements and Failures of Liquid Drop Model. Nature of the nuclear force, form of nucleon-nucleon potential, charge-independence, and charge-symmetry of nuclear forces. Deuteron problem. shell model; The Square Well Potential, The Harmonic Oscillator potential, spin-orbit coupling, Evidence of shell structure, single-particle shell model, achievements, and failures of Shell Model. Rotational spectra.

UNIT III
Nuclear Radiations: Laws of Disintegration, Radioactive Series, Law of Successive Disintegration, alpha emission, Alpha Spectrum, Gamow Theory of Alpha Decay, Beta decay; Conditions for Spontaneous Emission, Electron Capture, Neutrino Antineutrino, and their detection. Gamma decay; Internal Conversion, Internal Pair Conversion, selection rules of alpha, beta, and gamma decay. Fission and fusion. Nuclear reactions, Types of Nuclear Reactions, Nuclear Reaction Cross-Section reaction mechanism, compound nuclei and direct reactions.

UNIT IV
Elementary Particles: Classification of fundamental forces, Types of Interactions, Elementary particles and their Classification Mass Spectra and Decays of Elementary Particles, Leptons, Hadrons, Mesons, Baryons quantum numbers (charge, spin, parity, isospin, strangeness, etc.). Gell Mann-Nishijima formula. Quark model, baryons and mesons. C, P, and T invariance. Application of symmetry arguments to particle reactions. Parity non-conservation in weak interaction. Relativistic kinematics.

UNIT V
Applications: Applications of Radioactivity, production of energy and thermonuclear reactions, energy of stars, thermonuclear reactions on the earth.

NPTEL courses and resources:

- **Introduction to Nuclear and Particle Physics:** https://archive.nptel.ac.in/noc/courses/noc20/SEM2/noc20-ph19/
- **Nuclear Physics:** https://archive.nptel.ac.in/courses/115/103/115103101/

Books & References:
1.Concepts of Nuclear Physics by B.L. Cohen (Tata McGraw Hill)
2: Nuclear Physics by I. Kaplan (Addison-Wesley)
3: Introduction to Elementary Particles by D. Griffiths (Academic Press, 2nd ed. 2008)
4: Nuclear and Particle Physics: An Introduction by B. R. Martin (Wiley, 2006)
5: Physics of Nuclei and Particles by Pierre Marmier and Eric Sheldon (Elsevier)
6: Nuclei and Particles by Emilio G. Segre (2nd ed. Basic Books)
7: Introduction to Nuclear and Particle Physics by A. Das and T. Ferbel (World Scientific)

NPH-508 Physics of Semiconducting Devices & Technology

Course Category	Paper Code	Subject Name	L	T	P	Credits
ESC	NPH-508	Physics of Semiconducting Devices & Technology	3	0	2	4

Course Assessment:
Continuous/Sessional assessment through
One Mid Semester Exam (1 Hrs each): 15 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
Lab Exam: 15 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs): Students will be able to
1. Learn fundamental knowledge about metal-semiconductor junctions.
2. Develop basic concepts of Homojunction and Heterojunctions devices.
3. Learn fundamental concepts of BJTs, MOS capacitor, and MOSFETs.
4. Develop fundamental understanding of MOSFET and their characteristics.
5. Understand fundamentals of various devices of technological importance.

Unit-I
Metal-Semiconductor junction: Band diagram, depletion region and junction capacitance, junction breakdown, Ohmic and rectifying contacts, Schottky Diodes, Schottky diode under bias, Fermi level pinning & surface states, image force lowering.

Unit-II
Homojunction and Heterojunction: p-n junction, band diagram and potential profiles in p-n junctions, depletion capacitance, p-n junctions under various biasing conditions, diode characteristics, diffusion capacitance, degenerate p-n junctions: tunnel diode, I-V characteristics, heterojunctions, types of heterojunctions, concept of 2DEG, modulation doping.

Unit-III
Transistors: BJT: basic working principle, current components in BJT: common emitter, common base operation, early effect & its consequences, different modes of operation, input & output characteristics, MOS capacitor: energy bands; concept of inversion and deep depletion, C-V characteristics. MOSFET: structure and operating principle, construction & principle of operation of p- & n-channel enhancement & depletion mode, pinch-off and saturation. MOSFET: derivation of I-V, Gradual Channel Approximation, sub-threshold current & SS slope; device scaling and Moore's law.

Unit-IV

MOSFET: structure and operating principle, construction & principle of operation of p- & n-channel enhancement & depletion mode, pinch-off and saturation. MOSFET: derivation of I-V, Gradual Channel Approximation, sub-threshold current & SS slope; device scaling and Moore's law.

Unit-V

Device of Technological importance: Light Emitting Diodes (LEDs), Solar cell, photodiode, phototransistor, Single electron transistors (SET), High electron mobility transistor (HEMT), Heterojunction Bipolar Transistor (HBT), Resonant Tunneling Diode (RTD), Spintronic devices.

Lab Work: Implementation of any 1-2 Experiments/Methods/Techniques from each **Unit** (Selected by the instructor) based on the course.

NPTEL courses and resources:

- **Introduction to Semiconductor Devices:** https://archive.nptel.ac.in/courses/108/108/108108122/
- **Physics of Semiconductors:** https://archive.nptel.ac.in/courses/108/108/108108122/
- **Electronic Devices and Circuits course:** https://archive.nptel.ac.in/noc/courses/noc21/SEM2/noc21-ee86/
- **Physics of Semiconductor Devices course:** https://onlinecourses.nptel.ac.in/noc23_ee82/preview

Books & References:

1. Solid State Physics by A-J. Dekkar (McMillan and Co., London)
2. Introduction to Solid State Physics by C. Kittel (Wiley Eastern, New Delhi)
3. Semiconductor Physics and Devices by D.A. Neamen, (3rd Ed., Tata McGraw-Hill), 2002.
4. Fundamental of Semiconductor Fabrication by S M Sze
5. The Science and Engineering of Microelectronic Fabrication by Stephen A Campbell
6. Semiconductor Material and Device Characterization, 3rd Edition, D. K. Schroder, Wiley-IEEE Press (2006).

NPH-601 Atomic, Molecular Physics and Lasers

Course Category	Paper Code	Subject Name	L	T	P	Credits
PCC	NPH-601	Atomic, Molecular Physics and Lasers	3	0	2	4

Course Assessment:
Continuous/Sessional assessment through
One Mid Semester Exam (1 Hrs each): 15 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
Lab Exam: 15 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. To study the basics of spectroscopy.
2. To analyze the spectral components of Helium and alkali atoms.
3. To study the spin-orbit interaction
4. To study molecular spectral components.
5. To study lasers and their applications.

Unit- I

Basics of Spectroscopy: Quantum states of an electron in an atom, Solution of the Radial Equation, Quantum Numbers and Wave Functions of the H Atom, Spatial Distributions and Expectation Values of the Electron in Different Quantum States. Electron spin; Einstein–de Haas Effect, Unit-II:

Spectroscopy of Helium and Alkali Atoms: Spectrum of helium; Symmetry of the Wave Function, Energy Levels of the Helium Atom, Alkali atom. Relativistic corrections for energy levels of hydrogen atom, hyperfine structure; Fermi-contact Interaction, Magnetic Dipole-Dipole Interaction, Zeeman Effect of Hyperfine Structure Levels, and isotopic shift, width of spectrum lines.

Unit-III

Spin-Orbit Interaction Spectroscopy: Fine structure, Anomalous Zeeman Effect, LS & JJ couplings. Zeeman, Paschen-Bach & Stark effects. Electron spin resonance. Nuclear magnetic resonance, chemical shift. Frank-Condon principle. Born-Oppenheimer approximation.

Unit-IV

Molecular Spectral Analysis: Electronic spectra: Order of Electronic States, Symmetry Properties of Electronic States, Multiplicity and Fine Structure Splitting, Rotational and vibrational Spectra of diatomic molecules: Selection Rules Centrifugal Distortion, Vibrational Angular Momentum, The Adiabatic Approximation, The Rigid Rotor, Vibrations of Diatomic Molecules, Rotational Barrier, Raman spectra of diatomic molecules, selection rules. Selection Rules Centrifugal Distortion, Vibrational Angular Momentum

Unit-V

Lasers: Physical Principles, spontaneous and stimulated emission, Einstein A & B coefficients. Optical pumping, Generation of Population Inversion, rate equation. Optical Resonators, The Quality Factor of Resonators, Modes of Open Resonators, The Frequency Spectrum of Optical Resonators and coherence length, Different Types of Lasers

NPTEL courses and resources:

- **Atomic Physics:** https://archive.nptel.ac.in/noc/courses/noc15/SEM1/noc15-ph03/
- **Atomic and Molecular Physics:** https://archive.nptel.ac.in/courses/115/105/115105100/

Books & References:

1: Physics of Atoms and Molecules by B.H. Bransden and C.J. Joachain, Pearson
2: Quantum Chemistry by I.N. Levine, Prentice Hall
3: Quantum Mechanics by L.D. Landau and E.M. Lifshitz, Pergamon Press
4: Molecular Quantum Mechanics by P.W. Atkins and R.S. Friedman, Oxford University Press
5: Atomic & Molecular Spectra: Laser by Rajkumar, Kedar Nath and Ram Nath, Meerut.
6: Introduction to Spectroscopy by Donald L. Pavia, Gary M. Lampman, George S. Kriz, James R. Vyvyan, Cengage Learning Pvt. Limited.
7: Molecular Structure and Spectroscopy by G. Aruldhas, PHI, Learning Pvt. Limited.
8: Atomic, Laser and Spectroscopy by S. N. Thakur and D. K. Rai, Perntice Hall of India, New Delhi, India

List of Experiments

1. Measurement of Planck's constant using photoelectric effect.
2. To study Zeeman effect using Na lamp.
3. Experiment with liquid/solid using UV/Fluorescence spectroscopy
4. Measurement of FTIR/Raman spectrum of some solid and liquid material.

Books & References:

1. Physics of Atoms and Molecules: Bransden and Joachain.
2. Lasers - Theory and Applications: K. Thyagarajan and A.K. Ghatak.
3. Introduction to Atomic Spectra: H.E. White.

4. Introduction to Atomic Spectra: HG Kuhn
5. Modern Spectroscopy: J.M. Hollas
6. Fundamentals of Molecular Spectroscopy: C.N. Banwell.

NPH-603 Nano Science and Technology

Course Category	Paper Code	Subject Name	L	T	P	Credits
PCC	NPH-603	Nano Science and Technology	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs): Students will be able to
1. Master the fundamental concepts and principles of nanoscience and technology
2. Gain comprehensive knowledge of various nanofabrication and characterization techniques: Explore different methods for creating and analyzing nanomaterials.
3. Identify and analyze the potential applications of nanotechnology in physics-related discipline.
4. Stay informed about the latest advancements and ethical considerations in nanoscience and technology and
5. To develop critical thinking and problem-solving skills in the context of nanoscience and nanotechnology.

Unit-I
Introduction to Nanoscience and Technology: History and evolution of nanoscience and technology, Basic principles of quantum mechanics and their relevance to nanoscale phenomena, Classification of nanomaterials: zero-dimensional, one-dimensional, two-dimensional, and three-dimensional,

Unit-II
Unique Properties of Nanomaterials: size-dependent properties, quantum confinement, and surface effects, Classification of nanomaterials: nanoparticles, nanowires, nanotubes, thin films

Unit-III
Synthesis and Processing of Nanomaterials: Physical methods: top-down and bottom-up approaches to nanomaterial synthesis, Chemical methods: sol-gel synthesis, hydrothermal synthesis, and chemical vapor deposition (CVD), Lithography techniques: Nanolithography

Unit-IV
Applications of Nanomaterials in Physics: Nanoelectronics and nanoscale devices: transistors, sensors, and flexible electronics, Nanostructured materials for energy applications: batteries, supercapacitors, fuel cells and solar cells, Nanomedicine, and drug delivery: targeted drug delivery,

Unit V
Future Trends, Ethics, and Research Discussions: Emerging areas and future trends in nanoscience and technology, Ethical considerations and potential risks associated with nanotechnology, Discussion and presentations on recent research advancements in specific areas of interest

NPTEL courses and resources:

- **Introduction to Nanoscience and Nanotechnology:** https://nptel.ac.in/courses/113106093
- **Nano Science and Technology:** https://nptel.ac.in/courses/113106093

Books & References:

1. Nanotechnology: Principles and Applications by Richard Bandyopadhyay (Springer, 2013)
2. Introduction to Nanoscience and Nanotechnology by Gabor F. Somorjai (Wiley, 2010)
3. Physics of Nanomaterials by Hari Singh Nalwa (Academic Press, 2004)
4. Characterization of Nanoparticles: Physicochemical Techniques by Ivan Kralchevsky et al. (Elsevier, 2017)
5. Nanoworld: Science and Technology in the Nanoscale by Michael S. Dresselhaus et al. (Springer, 2014)
6. The Fundamentals of Nanoscience and Nanotechnology" by C.P. Poole Jr. and Frank J. Owens
7. "Introduction to Nanoscience" by James F. Jones
8. "Nanoscale Science and Technology" by Robert K. Sharma and Michael R. Köhler

NPH-605 Materials for Energy Storage and Devices Technology

Course Category	Paper Code	Subject Name	L	T	P	Credits
ESC	NPH-605	Materials for Energy Storage and Device Technology	3	0	2	4

Course Assessment:
Continuous/Sessional assessment through
One Mid Semester Exam (1 Hrs each): 15 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
Lab Exam: 15 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. The foundation for understanding of different properties of polymers and their applications.
2. The student will be able to analyze the properties of super ionic solids for their applications.
3. The students will be able to understand ion transport mechanisms in fast ion conductors. of different properties of Ionic liquid
4. The foundation for understanding of different properties of Ionic liquid and properties.
5. Ion conducting materials, Method of preparation of ionogels and their applications will be explored.

Unit-I
Physics of polymers: Introduction to Polymers, Definition, Structure, properties, polymerization, polymer blends, biopolymers, Biopolymer-polymer blend, physico-chemical properties of polymer materials

Unit-II
Physics of polymer-based electrolytes: Classification of Polymer Electrolytes, Solid Polymer Electrolytes, Gel or Plasticized Polymer Electrolytes, Composite Polymer Electrolytes, Polymer Blend Electrolytes, Biopolymer electrolytes, Application of polymer/polymer blend electrolytes.

Unit-III
Ion transport mechanism: Definition, Classification, Conduction in fast ion conductors, synthesis, Characteristic features and properties, Importance and Applications.

Unit-IV

Ionic Liquid: Ionic liquid, Importance of ionic liquids, synthesis and characterizations of ionic liquid-based materials, thermal, electrical, optical and structure behavior,

Unit-V

Application of Ionic Liquid in Solid Devices: Types of ions conducting polymers, Polymer complexes with salt/acid/fillers/plasticizers. Method of preparation of polymeric films, Ionogels, solid electrolytes based on ionic liquids, Application of ionic liquid in solid devices.

Lab Work: Implementation of any 1-2 Experiments/Methods/Techniques from each **Unit** (Selected by the instructor) based on the course.

NPTEL courses and resources:

- **Materials for Energy Storage:** https://archive.nptel.ac.in/courses/113/105/113105102/
- **Special Topics in Materials Science: Materials for Energy Storage and Conversion:** https://archive.nptel.ac.in/courses/113/105/113105102/
- **Physics of Renewable Energy Systems:** https://onlinecourses.nptel.ac.in/noc21_ph33/preview

Books & References:

- F.M. Grey, (1991), Solid Polymer Electrolytes Fundamentals and Technological Application VCH Publishers, Inc
- Farzad Nasipouri and Alain Nogaret (2010), Nanomagnetsim and Spintronics (Fabrication, Materials, Characteization and Applications), World Scientific Company
- C. Pratt, Application of Conducting Polymers
- J. Przyluski and S. Roth, (1993), Conducting Polymers-Transport Phenomena, Trans. Tech. Pub.

NPH-600 Advanced Characterization Techniques in Materials Science

Course Category	Paper Code	Subject Name	L	T	P	Credits
PCC	NPH-600	Advanced Characterization Techniques in Materials Science	3	0	2	4

Course Assessment:
Continuous/Sessional assessment through
One Mid Semester Exam (1 Hrs each): 15 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
Lab Exam: 15 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. Analyze the structure of materials using X-ray diffraction, microscopy techniques, and surface analysis methods.
2. The foundation for understanding different types of Characterization techniques and their applications.
3. The student will be able to understand different characterization techniques for devices and their applications.
4. The foundation for understanding of Experimental methods for characterizing and their applications.
5. The student will be able to analyze the properties of materials using computational and theoretical methods and also understand the measurements of the physical properties of thin films.

Unit-I
Determination of crystal structure: X-ray diffraction (XRD), Microscopy techniques: Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM).

Unit-II
Structural Characterization and Surface analysis: Energy dispersive X-ray microanalysis (EDS), X-ray photoelectron spectroscopy (XPS), Atomic Force Microscopy (AFM)

Unit-III
Optical Characterization Tools: Basics of FTIR, Photoluminescence and Raman Spectroscopy, UV-visible, optical properties, and determination of band gap

Unit-IV
Electrical Characterization: Experimental methods for characterizing ion conducting materials, Electrochemical characterization techniques: Electrochemical Impedance spectroscopy (EIS), Cyclic Voltammetry (CV), galvanostatic charge-discharge (GCD), ionic transference number measurement.

Unit-V
Magnetic and Thermal Characterization: Vibrational magnetometer, SQUID, ferromagnetic resonance (FMR), thermal characterization of ionic materials: differential scanning calorimetry (DSC), Thermogravimetric analysis (TGA)

Lab Work: Implementation of any 1-2 Experiments/Methods/Techniques from each **Unit** (Selected by the instructor) based on the course.

NPTEL courses and resources:

- **Advanced Materials Characterization by IIT Kanpur:** https://nptel.ac.in/courses/113104004

Books & References:
1. S.M. Sze, "Physics of Semiconductor Devices", John Wiley & Sons, Inc, 2012
2. K.L. Chopra, (2008), Thin Film Phenomenon, Krieger Pub. Co.
3. Characterization of Materials (Materials Science and Technology: A Comprehensive Treatment, vol 2A & 2B, VCH (1992)
4. Semiconductor Material and Device Characterization, 3rd Edition, D. K. Schroder, Wiley-IEEE Press (2006).
5. F.M. Grey, (1991), Solid Polymer Electrolytes Fundamentals and Technological Application VCH Publishers, Inc
6. K. L. Chopra and S. R. Das, "Thin Film Solar Cells", Springer, 1983.
7. "Energy Storage: Technologies and Materials" by Robert A. Huggins (2014, Cambridge University Press)
8. "Supercapacitors: Materials, Systems and Applications" by Peter Kurzweil (2015, John Wiley & Sons)

NPH-602 Science and Technology of Thin Films

Course Category	Paper Code	Subject Name	L	T	P	Credits
ESC	NPH-602	Science and Technology of Thin Films	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):
1. Understand the fundamentals of magnetic materials.
2. To understand the principle of various spintronics devices
3. Understand the fabrication of tunnel magnetoresistance devices.
4. To learn about the magnetic dynamics in magnetic multilayers
5. Learning of applications of thin films

UNIT I

Basics of Thin Films: Thin and Thick Films, fabrication methods of thin films, Chemical methods of thin film deposition, chemical vapor deposition, physical vapor deposition methods and requirement of vacuum, thermal evaporation, sputtering, and LASER ablation

UNIT II

Nucleation and Growth Mechanism: Various types of growth mechanisms of thin films, nucleation and growth of thin films, post-deposition process, and their outcomes, different types of structural defects, Epitaxial thin films, polycrystalline and amorphous thin films, molecular beam epitaxy, atomic layer deposition

Unit III

Thickness Measurement: Measurement of thickness of thin films, Different methods, and instruments for thickness measurements, Quartz crystal monitor, optical, mechanical, electrical, and structural properties of thin films

UNIT IV

Sensors and Device Fabrication: Deposition of various magnetic materials, anisotropy in magnetic thin films, domains in thin films, magnetic sensors fabrications, fabrications of Perovskite and oxide thin films, fabrication of tunnel junction devices

UNIT V

Applications of Thin Films: Decorative coatings, hard coatings, oriented controlled organic thin films, semiconductors thin films, thin films for large area electronics

NPTEL courses and resources:

- **Thin Film Technology:** https://nptel.ac.in/courses/113104075

Books & References:

1. K. L. Chopra and S. R. Das, "Thin Film Solar Cells", Springer, 1983.
2. L. I. Maissel and Glang, "Handbook of Thin Film Technology", McGraw Hill Higher Education, 1970.
3. J. C. Anderson, "The Use of Thin Films in Physical Investigation", Academic Press Inc., 1966.
4. J. J. Coutts, "Active and Passive Thin Film Devices", Academic Press Inc., 1978.
5. R.W. Berry, P.M. Hall, and M.T. Harris, "Thin Film Technology", Van Nostrand, 1968.

Pools of Programme Electives Courses

There are two pools of programme elective courses PEC-I and PEC-II

First Pool of Programme Electives Courses-I (PEC-I)

NPH-609 Computational Physics

Course Category	Paper Code	Subject Name	L	T	P	Credits
PEC	NPH-609	Computational Physics	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. Understand the basic concepts of periodic solids, band structure and electron behavior inside the solids.
2. Learn the fundamental concepts and theorem of Density Functional theory (DFT).
3. Develop understanding about exchange-correlation (XC) functionals, their types and uses.
4. Learn fundamentals of basis set and Pseudopotential methods in DFT analysis.
5. Basic concepts to calculate and analyze the electronic structure of materials.

Unit-I:
Band Structures: Basic concepts of periodic solids and band structure of metal, insulator and semiconductor, the reciprocal lattice and Brillouin zone, Bloch theorem, Basic equations for interacting electrons and nuclei, Coulomb interaction in condensed matter, one dimensional Schrodinger equation for a particle.

Unit-II:
Many-body Problem: Approximation methods for many electron systems, Born-Oppenheimer approximation, Foundations of Density Functional Theory (DFT): Thomas-Fermi-Dirac approximations: example of a functional, Hohenberg-Kohn (HK) theorem, The self- consistent Kohn-Sham equations.

Unit: III:
Computational and Theoretical Methods: Basic introduction to Density Functional Theory (DFT), various Computational tools for DFT analysis, Computational methods, Modeling, KS equation, Density functional theory (DFT), Basis sets, pseudopotentials, Exchange-Correlation (XC) Functional, local density approximation (LDA), Generalized-gradient approximation (GGAs), LDA and GGA expressions for the potential, strengths of DFT, DFT- hybrid, Geometry Optimization, Determination of band gap, Density of states (DOS)

Unit-IV:
Basis sets: Linear combination of atomic orbitals (LCAO) and Plane waves (PW) methods, Basics - The independent particle Schrodinger equation in a plane wave basis. Pseudopotential method - Projector augmented waves (PAWs) etc.

Unit-V:
Electronic Structure Calculations: Linear combination of atomic orbitals (LCAO) and Plane waves methods, Basics - The independent particle Schrodinger equation in a plane wave basis. Pseudopotential method - Projector augmented waves (PAWs) - Simple crystals: structures, bands, - Definition of Supercells: Geometry optimization, total energy, force, and stress - illustrative examples - square lattice and any 2D materials planes - Examples of bands: semiconductors and metal, electronic structure of nanomaterials.

NPTEL courses and resources:

- Introduction to Computational Physics: https://archive.nptel.ac.in/courses/115/106/115106118/
- Computational Methods for Physics and Engineering: https://nptel.ac.in/courses/115106121

Books & References:

1. Density Functional Theory of atoms and Molecules by Robert G. Parr and Weitao Yang
2. Lily Chen, "Computational Materials Science: Theory and Applications", Willford press, 2018. Martin E. Glicksman, James E. Mark, Steven P. Marsh,"
3. Computational Methods in Materials Science", Materials Research Society,1992.

NPH -613 Advanced Condensed Matter Physics

Course Category	Paper Code	Subject Name	L	T	P	Credits
PEC	NPH -613	Advanced Condensed Matter Physics	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. Understand the electrical transport properties of solids.
2. Learn about various optical properties and optical transitions in solids.
3. Understands fundamentals and working mechanism of various optical detectors.
4. Develop understanding about various advance concepts of magnetism.
5. Learn about fundamental and advance topics in superconductivity.

Unit-I:
Transport Properties of Solids: Resistivity of metals and semiconductors, Fermi surface, Landau levels, De Hass van Alphen effect, Quantum Hall effect- Integral quantum Hall effect and Magnetoresistance.

Unit-II:
Optical properties: Optical constants and their physical significance, Reflectivity in metals, plasmonic properties of metals, determination of band gap in semiconductors: direct and indirect band gap, defect mediated optical transitions, excitons and photoluminescence.

Unit-III
Optical detectors: Photodetectors, type of photo detectors, basic characteristics of photo detectors, photo transistors and photo conductor, definition of various photodetectors parameters: Responstivity, Quantum efficiency, Photo gain, Detectivity, etc.

Unit: IV:
Magnetism: Quantum theory of diamagnetism, Landau diamagnetism, Paramagnetism, Pauli Paramagnetism, Ferromagnetism, Cuire-weiss Law, temperature dependence of magnetization, Heisenberg's exchange interaction, Ferromagnetic domains, Magnetic domains–exchange energy, magnetostatic energy, wall energy, magnetostrictive energy.

Unit-V:
Superconductivity: Meissner effect. London's equations, Thermodynamics of the superconducting phase transition: Free energy, entropy and specific heat jump. Ginzburg-Landau theory of superconductivity: Type-I

and Type II superconductors, The Cooper problem, BCS ground state and energy gap, Cooper pairs, coherence, vortex states, Josephson effect: dc and ac effects.

NPTEL courses and resources:

- Advanced Condensed Matter Physics: https://archive.nptel.ac.in/courses/115/103/115103102/

Books & References:

1. Solid state physics, N.N. Ashcroft and N.D. Mermin
2. Solid State Physics – A.J. Dekker.
3. Magnetism and Magnetic Materials, B. D. Cullity
4. Optical Properties of Solids, Frederick Wooten, Ac Press (New York) 1972

NPH -615 Advanced Electronics Devices

Course Category	Paper Code	Subject Name	L	T	P	Credits
PEC	NPH -615	Advanced Electronics Devices	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. Learn fundamental concepts of semiconductor heterojunction.
2. Understand basic concepts of metal-semiconductor contacts
3. Understand concept of superlattices and quantum well based devices.
4. Understand and learn working principles of high frequency electronic devices.
5. Develop understanding about basic concepts of emerging materials and devices.

Unit-I:
Heterojunctions: Semiconductor heterojunctions Type I, Type II and Type III heterointerfaces, Built-in strain in heterostructures, energy band diagram, Anderson's rule

Unit-II:
Metal-Semiconductor contacts: Ohmic and Schottky contacts, Band diagram, depletion region, junction capacitance and junction breakdown, Fermi level pinning & surface states, image force lowering.

Unit-III:
Quantum Confinement: Quantum Well based device, Concept of quantum confinement - wave mechanical description of free particles, Bound particles, Concept of super lattice (SL), Compositionally graded SL and doping SL, Quantum well (QW) based devices.

Unit: IV:
Electronic Devices: High Frequency Devices- Heterojunction Bipolar transistor (HBT), Metal semiconductor field effect transistor (MESFET), High electron mobility transistor (HEMT), Resonant tunnelling diode (RTD).

Unit-V:
Fundamentals of Emerging Devices: Single electron Transistor (SET)-working principle, Spintronic devices, Graphene and 2D materials and van der Waals Heterostructures.

NPTEL courses and resources:

- Advanced Electronic Devices: https://archive.nptel.ac.in/courses/113/106/113106062/
- Fundamentals of Micro and Nano Electronics: https://onlinecourses.nptel.ac.in/noc19_bt29/preview

Books & References:

1. S. M. Sze and Kwok K. Ng, Physics of Semiconductor Devices,
2. The Physics of Low dimensional Semiconductors, An Introduction, Cambridge University Press 1998

NPH-617 Computational Methods

Course Category	Paper Code	Subject Name	L	T	P	Credits
PEC	NPH-617	Computational Methods	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):
1. Understand the basic concepts of group theory and apply them to analyze symmetry in physical systems.
2. Apply Fourier series to analyze periodic functions and solve differential equations.
3. Classify integral equations based on kernel types and understand their properties.
4. Gain an understanding of finite difference methods and their applications in solving partial differential equations.
5. Learn various simulation technique to perform computational experiments and match with real experimental data.

Unit-I
Group Theory: Basic concepts, Multiplication table, conjugate elements and classes, subgroups, Isomorphism and Homomorphism, definition of representation and its properties, Reducible and irreducible representations, Schur's lemmas (only statements), characters of a representation. Example of C4v, Topological groups and Lie groups, three dimensional rotation group, special unitary groups SU(2) and SU(3).
Tensors: Introduction, definitions, contraction, direct product, Quotient rule, Levi-Civita symbol, non-cartesian tensors, metric tensor, Covariant differentiation.

Unit-II
Fourier Series and Integral Transforms: Fourier series, Dirichlet conditions, General properties, advantages and applications, Gibbs phenomenon, Fourier transforms, Development of the Fourier integral, Inversion theorem, Fourier transforms of derivatives; Momentum representation, Laplace transforms, Laplace transforms of derivatives, Properties of Laplace transform, Inverse Laplace transformation.

Unit: III

Advance Integral Equations: Definitions and classifications, integral transforms and generating functions, Neumann series, Separable Kernels, Hilbert-Schmidt theory, Green's functions in one dimension.

Unit-IV

Numerical Techniques: Roots of functions, Interpolation, Extrapolation, Differentiation, integration by trapezoid and Simpson's rule, Runge Kutta method and finite difference method.

Unit V:

Simulation Techniques: Monte Carlo methods, molecular dynamics, simulation methods for quantum-mechanical problems, time-dependent Schrödinger equation

NPTEL courses and resources:

- Computational Methods in Science and Engineering: https://archive.nptel.ac.in/courses/103/106/103106074/
- Introduction to Numerical Methods: https://archive.nptel.ac.in/courses/111/107/111107105/

Books & References:

- Group Theory for Physicists: A.W. Joshi (Wiley Eastern, New Delhi, 2011)
- Mathematical Methods for Physicists, G. Arfken and H.J. Weber, (7th edition Academic Press, San Diego, 2012)
- Matrices and Tensors in Physics, A.W. Joshi (Wiley Eastern, New Delhi, 2005)
- Numerical Mathematical Analysis, J.B. Scarborough (4th edition Oxford Book Co., Kolkata)
- A First Course in Computational Physics, P.L. Devries (Wiley, New York, 1994)
- Introduction to Mathematical Physics, C. Harper (Prentice Hall of India, New Delhi, 2006)

Second Pool of Programme Electives Courses-II (PEC-II)

NPH-604 Advance Quantum Mechanics

Course Category	Paper Code	Subject Name	L	T	P	Credits
PEC	NPH-604	Advance Quantum Mechanics	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):
1. The students will learn the advanced concepts of quantum mechanics and its application to understand molecular structure.
2. Formulate the Dirac equation and explain its mathematical framework.
3. Apply the Dirac equation to a free particle and discuss the significance of helicity.
4. Apply quantization to the Klein-Gordon field and interpret the resulting physical quantities.
5. Be prepared for research in molecular, atomic and particle physics.

Unit-I

Formulation of Relativistic Quantum Theory: Relativistic Notations, Need of relativistic quantum mechanics, difference from Quantum mechanics, The Klein-Gordon equation, Physical interpretation, Probability current density & Inadequacy of Klein-Gordon equation, Negative energy states.

Unit-II

Dirac Equation: Dirac relativistic equation & Mathematical formulation, α and β matrices and related algebra, Properties of four matrices α and β, Matrix representation of $\alpha_i^{\prime s}$ and β, True continuity equation and interpretation.

Unit-III

Covariance of Dirac Equation: Covariant form of Dirac equation, Dirac gamma (γ) matrices, Representation and properties, Trace identities, fifth gamma matrix γ^5, Solution of Dirac equation for free particle (Plane wave solution), Dirac spinor, Helicity operator, Explicit form

Unit-IV

Field Quantization: Introduction of basic concepts of quantum field theory, Lagrangian field theory, Euler-Lagrange equations, significance in field theory, Hamiltonian formalism, Quantized Lagrangian field theory, canonical commutation relations.

Unit-V

The Klein-Gordon Field: The Klein-Gordon field, Second quantization, Hamiltonian and Momentum, Normal ordering, Fock space, The complex Klein-Gordan field: complex scalar field

NPTEL courses and resources:

- **Advance Quantum Mechanics:** https://nptel.ac.in/courses/115106066 (Focuses on Schrodinger equation, operators, angular momentum, and more)

Books & References:
1: Advance Quantum Mechanics by J. J. Sakurai (Pearson Education India)
2: Relativistic Quantum Mechanics by James D. Bjorken and Sidney D. Drell (McGraw-Hill Book Company; New York, 1964).
3: An Introduction to Relativistic Quantum Field Theory by S.S. Schweber (Harper & Row, New York, 1961).
4: Quantum Field Theory by F. Mandl & G. Shaw (John Wiley and Sons Ltd, 1984)
5: A First Book of Quantum Field Theory by A. Lahiri & P.B. Pal (Narosa Publishing House, New Delhi, 2000)

NPH-608 Advance Energy Storage Devices

Course Category	Paper Code	Subject Name	L	T	P	Credits
PEC	NPH-608	Advance Energy Storage Devices	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):
1. To provide students with a comprehensive understanding of the principles, materials, and design considerations for various energy storage technologies.
2. Understand the working principles of batteries and supercapacitors, including the role of electrodes and electrolytes.
3. Identify key materials used in batteries and supercapacitors, including electrolytes, cathodes, anodes, binders, and separators.
4. Understand the principles and applications of various characterization (experimental and computational) techniques for energy storage materials and device designing.
5. Understand and critically evaluate future advancements in energy storage technologies.

Unit-I
Fundamental to Energy Storage: Overview of energy storage technologies: batteries, supercapacitors, fuel cells, Classification based on power density and energy density, Importance of energy storage in present and future energy scenarios, Basic principles of batteries and supercapacitors, Key components and their functions, Charge and discharge mechanisms, Identify and explain material properties relevant to energy storage: electronic conductivity, ionic conductivity, and their impact on performance, Mechanical properties for durability and safety, Influence of material microstructure on performance.

Unit-II
Materials for Energy Storage: Key materials used in batteries and supercapacitors, Electrolytes: liquid, solid, gel types and their properties, Cathode materials: different chemistries and performance trade-offs, Anode materials: lithium vs. alternative options, Binders, separators, and their roles in battery performance, Materials for supercapacitors, Carbon-based materials: activated carbon, carbon nanotubes, graphene, Conducting polymers: polyaniline, polypyrrole Metal oxides: RuO_2, MnO_2, factors affecting performance of batteries and supercapacitors: Energy density, power density, cycle life, and safety considerations, Impact of material properties and device design on performance.

Unit: III

Experimental Characterization Techniques: X-ray diffraction (XRD), Scanning electron microscopy (SEM), Transmission electron microscopy (TEM), X-ray photoelectron spectroscopy (XPS), Electrochemical characterization techniques: cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), electrochemical impedance spectroscopy (EIS),

Unit-IV

Computational Tools for Characterization: Computational and Theoretical Methods: Density functional theory (DFT) for electronic structure calculations, Molecular dynamics (MD) for simulating atomic interactions, Monte Carlo (MC) simulations for statistical analysis, Machine learning for predicting material properties and discovering new materials.

Unit-V

Design and Optimization of Energy Storage Devices: Cell design, electrode engineering, electrolyte selection, safety considerations, Supercapacitor Design and Optimization: Electrode design, electrolyte selection, device configuration, Computational Modeling of Energy Storage Materials: Predicting material properties, designing new materials, understanding reaction mechanisms, Emerging Technologies: Lithium-ion batteries, Sodium-ion batteries, Potassium-ion batteries, Lithium-sulfur batteries, Metal-air batteries, all-solid-state batteries, flexible and printed batteries, supercapacitors for energy harvesting, Electrical double-layer capacitors

NPTEL courses and resources:

- **Advanced Energy Storage Devices:** https://archive.nptel.ac.in/courses/113/105/113105102/ (Discusses batteries, supercapacitors, fuel cells, and hydrogen storage)
- **Advanced Energy Storage Devices by Professor S. Sundaresan:** https://archive.nptel.ac.in/courses/113/105/113105102/ (Focuses on electrochemical energy storage principles and applications)
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Books & References:

- "Energy Storage: Technologies and Materials" by Robert A. Huggins (2014, Cambridge University Press)
- “Supercapacitors: Materials, Systems and Applications" by Peter Kurzweil (2015, John Wiley & Sons)
- "Lithium-Ion Batteries: Science and Technologies" by Nazrin Mercouriou and M. Armand (2014, Springer)
- "Handbook of Solid-State Materials" by Vol. IV, Electro ceramics (2000, Elsevier)
- "Computational Materials Science: An Introduction" by Richard Martin (2004, Elsevier)

NPH-610 Physics of Nanomaterials

Course Category	Paper Code	Subject Name	L	T	P	Credits
PEC	NPH-610	Physics of Nanomaterials	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. To study the basics of nanotechnology.
2. To study different characterization techniques of nanomaterials.
3. To study various nanofabrication techniques of nanomaterials.
4. To study various electronic confinements.
5. To be study the potential of nanomaterials in various engineering and research fields.

Unit-I

Introductory Aspects: Basic principles of nanoscience and technology, preparation, structure and properties of fullerene and carbon nanotubes.

Unit-II

General Characterization Techniques: Determination of particle size, study of texture and microstructure, increase in x-ray diffraction peaks of nanoparticles, shift in photo luminescence peaks, variation in Raman spectra of nanomaterials, photoemission, microscopy, scanning force microscopy.

Unit-III

Nanofabrication Techniques:

Lithography techniques; optical lithography, e-beam lithography, focused ion beam lithography, X-ray lithography Ething techniques.

Unit-IV

Confinement of Electrons: Electron confinement in infinitely deep square well, confinement in one and two-dimensional wells, idea of quantum well structure, Examples of quantum dots, spectroscopy of quantum dots.

Unit-V

Applications of Nanomaterials: Engineering and medical applications, applications carbon nanotubes and nanofibers, Nanosized metal particles, Nanostructured polymers, Nanostructured films, and Nano structured semiconductors.

NPTEL courses and resources:

- **Physics of Nanomaterials:** https://nptel.ac.in/courses/118104008 (Explores properties, synthesis, and applications of nanomaterials)
- **By Professor S. K. Joshi:** https://nptel.ac.in/courses/118104008 (Covers topics like nanostructures, quantum confinement, and characterization techniques)

Books & References:

1. Nanotechnology - Molecularly Designed Materials, G.M. Chow & K.E. Gonsalves (American Chemical Society, 1996)
2. Nanotechnology Molecular Speculations on Global Abundance, B.C. Crandall (MIT Press, 1996)
3. Quantum Dot Heterostructures, D. Bimerg, M. Grundmann and N.N. Ledentsov (Wiley, 1998)
4. Nanoparticles and Nanostructured Films–Preparation, Characterization and Application: J.H. Fendler (Wiley, 1998)
5. Nanofabrication and Bio-system, H.C. Hoch, H.G. Craighead and L. Jelinski (Cambridge Univ. Press, 1996)
6. Physics of Semiconductor Nanostructures: K.P. Jain (Narosa, 1997)
7. Physics of Low-Dimension Semiconductors, J.H. Davies (Cambridge Univ. Press 1998)
8. Advances in Solid State Physics (Vo.41), B. Kramer (Springer, 2001)

NPH-612 Science and Technology of Solar Energy, Hydrogen and other Renewable Energies

Course Category	Paper Code	Subject Name	L	T	P	Credits
PEC	NPH-612	Science and Technology of Solar Energy, Hydrogen and other Renewable Energies	3	1	0	4

Course Assessment:
Continuous/Sessional assessment through
Two Mid Semester Exam (1 Hrs each): 15+15=30 Marks,
TAQ (Tutorials, Assignments, Quizzes): 20 Marks
and End Semester Examination (2.5 Hours): 50 Marks

Course Outcomes (COs):

1. To study the fundamentals of energy conversion.
2. To study about solar energy conversion.
3. To study advanced solar cells.
4. To study about hydrogen energy production and storage.
5. To study material properties for the storage of hydrogen.

Unit-I
Fundamental and Material Aspects: Fundamentals of photovoltaic Energy Conversion Physics and Material Properties, Basics of Photovoltaic Energy Conversion: Optical properties of Solids. Direct and indirect transition semiconductors, interrelationship between absorption coefficients and band gap recombination of carriers.

Unit-II
Solar Energy: Different Types of Solar Cells: Types of Solar Cells, p-n junction solar cell, Transport Equation, Current Density, Open circuit voltage and short circuit current, Brief description of single crystal silicon and organic and Polymer Solar Cells,

Unit-III
Advanced Solar Cells: Elementary Ideas of Advanced Solar Cells e.g. Tandem Solar cells, Solid Liquid Junction Solar Cells, Nature of Semiconductor, Principles of Photo-electrochemical Solar Cells.

Unit-IV
Hydrogen Energy: Fundamentals, Production and Storage: Relevance in relation to depletion of fossil fuels and environmental considerations. Solar Hydrogen through Photo electrolysis

Unit-V
Hydrogen Storage: Physics of material characteristics for production of Hydrogen storage, Brief discussion of various storage processes, special features of solid hydrogen storage materials, Structural and electronic characteristics of storage materials. New Storage Modes.

NPTEL courses and resources:

- **Science and Technology of Solar Energy, Hydrogen and other Renewable Energies by Professor V. N. Shukla:** https://nptel.ac.in/courses/103103206 (Focuses on solar, wind, biomass, geothermal, and hydrogen energy)
- **By Professor Arunachalam Kumar:** https://archive.nptel.ac.in/courses/115/103/115103123/ (Specifically covers solar energy technologies and applications)

Books & References:

- Solar Cell Device Physics, Stephen J. Fonash, Current Edition: 4th Edition (2020), Publisher: Wiley-IEEE Press
- Fundamentals of Solar Cells, Alvin L. Fahrenbruch and Richard H. Bube, 3rd Edition (2016), Springer
- Photoelectrochemical Solar Cells, S. Chandra, 1st Edition (1984), Publisher: Elsevier
- Hydrogen as an Energy Carrier Technologies Systems Economy, Christine Winter and Merle Nitz (Eds.): 2nd Edition (2019), Publisher: Wiley-VCH
- Hydrogen as a Future Energy Carrier, Andreas Züttel, Andreas Borgschulte, and Louis Schlapbach, 1st Edition (2012), Publisher: Wiley-VCH