गोंय विद्यापीठ
ताळगांव पठार
गोंय - ४०३ २०६
फोन: +९१-८६६९६०९०४८

Goa University
Taleigao Plateau, Goa - 403 206
Tel : +91-8669609048
Email : registrar@unigoa.ac.in
Website: www.unigoa.ac.in

(Accredited by NAAC)

GU/Acad –PG/BoS -NEP/2023/81/3 Date:26.05.2023

Ref: GU/Acad –PG/BoS -NEP/2022/339/8 dated 19.08.2022

CIRCULAR

In supersession to the above referred Circular, the updated approved Syllabus with revised Course Codes of the **Master of Science in Physics** Programme is enclosed.

The Dean/ Vice-Deans of the School of Physical and Applied Sciences are requested to take note of the above and bring the contents of the Circular to the notice of all concerned.

ASHWIN VYAS LAWANDE Digitally signed by ASHWIN VYAS LAWANDE Date: 2023.05.26 15:48:41 +05'30'

(Ashwin Lawande)
Assistant Registrar – Academic-PG

To,

1. The Dean, School of Physical and Applied Sciences, Goa University.
2. The Vice-Deans, School of Physical and Applied Sciences, Goa University.

Copy to:

1. The Chairperson, Board of Studies in Physics.
2. The Programme Director, M. Sc. Physics, Goa University.
3. The Controller of Examinations, Goa University.
4. The Assistant Registrar, PG Examinations, Goa University.
5. Directorate of Internal Quality Assurance, Goa University for uploading the Syllabus on the University website.

Goa University

M.Sc. Physics Syllabus from Academic year 2022-23

The syllabus of M.Sc. Physics consists of five categories of courses:

Type of Course	Required Credits	Course Codes
Discipline Specific Core Course	32	PHY-500 to PHY-507
Discipline Specific Elective Course	08	PHY-521 to PHY-526
Research Specific Elective Course	12	PHS-601 to PHS-610, PHC-601 to PHC-607, PHB-601 to PHB-602
Generic Elective Course	12	PHS-621 to PHS-630, PHC-621 to PHC-624, PHB-621 to PHB622
Dissertation	16	PHY-651
Bridge course	Audit	PHY-001 to PHY-005 and PHY-010

<table>
<tr><th>Code</th><th colspan="3">Title</th><th>Credits</th><th>Hours</th></tr>
<tr><td>PHY-001</td><td colspan="3">Bridge Course in Mathematical Methods</td><td>2</td><td>30</td></tr>
<tr><td>PHY-002</td><td colspan="3">Bridge Course in Thermal Physics</td><td>2</td><td>30</td></tr>
<tr><td>PHY-003</td><td colspan="3">Bridge Course in Optics</td><td>2</td><td>30</td></tr>
<tr><td>PHY-004</td><td colspan="3">Bridge Course in Quantum Mechanics</td><td>2</td><td>30</td></tr>
<tr><td>PHY-005</td><td colspan="3">Bridge Course in Electrostatics and Magnetostatics</td><td>2</td><td>30</td></tr>
<tr><td>PHY-010</td><td colspan="3">Introduction to Biology and Biophysics</td><td>3</td><td>45</td></tr>
<tr><td colspan="6">Semester I</td></tr>
<tr><td>PHY-500</td><td colspan="3">Mathematical Methods of Physics</td><td>4</td><td>60</td></tr>
<tr><td>PHY-501</td><td colspan="3">Classical Mechanics</td><td>4</td><td>60</td></tr>
<tr><td>PHY-502</td><td colspan="3">Electromagnetic Theory</td><td>4</td><td>60</td></tr>
<tr><td>PHY-503</td><td colspan="3">Electronics</td><td>4</td><td>60</td></tr>
<tr><td>PHY-521</td><td colspan="3">Electronics Practical</td><td>2</td><td>60</td></tr>
<tr><td>PHY-522</td><td colspan="3">Computer Programming in Fortran Practical*</td><td>2</td><td>60</td></tr>
<tr><td>PHY-523</td><td colspan="3">Computer Programming in C Practical*</td><td>2</td><td>60</td></tr>
<tr><td>PHY-524</td><td colspan="3">Computer Programming in Python Practical*</td><td>2</td><td>60</td></tr>
<tr><td colspan="6">*Any one course</td></tr>
<tr><td colspan="6">Semester II</td></tr>
<tr><td>PHY-504</td><td colspan="3">Quantum Mechanics</td><td>4</td><td>60</td></tr>
<tr><td>PHY-505</td><td colspan="3">Statistical Mechanics</td><td>4</td><td>60</td></tr>
<tr><td>PHY-506</td><td colspan="3">Nuclear and Elementary Particle Physics</td><td>4</td><td>60</td></tr>
<tr><td>PHY-507</td><td colspan="3">Atomic Physics</td><td>4</td><td>60</td></tr>
<tr><td>PHY-525</td><td colspan="3">General Physics Practical#</td><td>4</td><td>120</td></tr>
<tr><td>PHY-526</td><td colspan="3">Methods of Experimental Physics#</td><td>4</td><td>105</td></tr>
<tr><td colspan="6">#Any one course</td></tr>
<tr><td colspan="6">Semester III</td></tr>
<tr><td>PHS-601
PHC-601
PHB-601</td><td>Solid State Physics I</td><td>Advanced Quantum Mechanics</td><td>Molecular Biophysics</td><td>4</td><td>60</td></tr>
<tr><td>PHS-602
PHC-602
PHB-602</td><td>Solid State Physics II</td><td>Advanced Statistical Mechanics</td><td>Methods of Biophysics</td><td>4</td><td>60</td></tr>
</table>

PHS-621 PHC-621 PHB-621	Solid State Physics Practical	Numerical Techniques Practical	Biophysics Practical	4	120
PHS-62x PHC-62x PHB-62x	Generic Optional Courses (to be chosen from Set I or from any other disciplines or from SWAYAM)			8	120
Semester IV					
PHS-60x PHC-60x PHB-60x	Courses worth 4 credits to be chosen from Set II or from SWAYAM in consultation with Dissertation Guide			4	60
PHY-651	Dissertation			16	

Suggested Optional Courses

Set I – Generic Electives (Sem III)		Credits
PHS-622	Nuclear Reactor Physics	2
PHS-623	Advanced Optics	2
PHS-624	Physics of Energy Materials	2
PHS-625	Physics of Ferroic Materials	2
PHS-626	Nanoscience and Technology	2
PHS-627	Laser Physics and Applications	2
PHS-628	Experimental Techniques in Physics	2
PHS-629	Documentation using Latex (Skill)	2
PHS-630	Astronomy and Astrophysics	2
PHC-622	BEC and Superfluidity	2
PHC-623	Introduction to Quantum information and computing	2
PHC-624	Introduction to Particle Physics	2
PHB-622	Solid State and Biomaterials	4

Set II – Research Electives (Sem IV)		Credits
PHS-603	X-ray Spectroscopy for Condensed Matter	2
PHS-604	Optical Spectroscopy for Condensed Matter	2
PHS-605	Nuclear Spectroscopy for Condensed Matter	2
PHS-606	Introduction to Crystallography and X-ray Diffraction	2
PHS-607	Magnetism in Condensed Matter Physics	2
PHS-608	Microscopy Techniques for Condensed Matter	2
PHS-609	Thin film Physics	2
PHS-610	Physics of Glasses	2
PHC-603	Simulation Techniques	2
PHC-604	Physics of Quantum Materials	2
PHC-605	Superconductivity	2
PHC-606	Advanced Particle Physics	4
PHC-607	Numerical methods and Fortran parallel programming using openMP	2

Programme: M. Sc. (Physics)
Course Code: PHY-001 **Title of the Course:** Bridge Course in Mathematical Methods
Number of Credits: 2
Effective from AY: 2022-23

Prerequisites for the course:	NIL	
Course Objectives:	This course develops problem solving capabilities of students. It also helps to revise and understand the concepts based on Integration, differentiation and such other basic topics of mathematics, which are useful in solving problems based on Physics.	
Content:	**1. Preliminary Calculus** Differentiation from first principles; products; the chain rule; quotients; implicit differentiation; logarithmic differentiation; Leibnitz' theorem; special points of a function; theorems of differentiation, Integration from first principles; the inverse of differentiation; integration by inspection; sinusoidal functions; logarithmic integration; integration using partial fractions; substitution method; integration by parts; reduction formulae; infinite improper integrals; plane polar coordinates; integral inequalities; applications of integration **2. Partial Differentiation** Definition of partial derivative; the total differential and total derivative; Exact and inexact differentials; Useful theorems of partial differentiation; the chain rule; Change of variables; Taylor's theorem for many variable functions; Stationary values of many variable functions; Stationary variables under constraints; Thermodynamic relations; Differentiation of integrals **3. Series and Limits** Series; Summation of series (arithmetic, geometric); convergence of infinite series; Operations with series; Power series; Taylor series; Evaluation of limits. **4. Vector Algebra** Scalars and vectors; Addition and subtraction of vectors; Multiplication by a scalar; Basis vectors and components; Magnitude of a vector; Multiplication of vectors; Equation of lines and planes; Using vectors to find distances; Reciprocal vectors. **5. Ordinary differential equations**	10 hours 5 hours 5 hours 5 hours 5 hours

	Linear equations with constant coefficients; Linear equations with variable coefficients; General ordinary differential equations.	
Pedagogy:	Online lectures along with assignments	
References/Readings	1. K.F. Riley, M.P. Hobson and S.J. Bence, Mathematical Methods for Physics and engineering, Cambridge University Press, Cambridge UK (Reprint 2002). 2. George B. Arfken and Hans J. Weber, Mathematical methods for Physicists, 7/e Elsevier Inc., 2012. 3. Mathematics text books of XI and XII Science prescribed by NTSE/CBSE/Goa Board.	
Course Outcomes:	Student will be able to 1. Understand differentiation, partial differentiation, integration and ODE (Ordinary differential equations) 2. Apply the above techniques to solve the problems in physics. 3. Understand concepts of vector algebra, limits and series. 4. Apply these techniques for solving the problems in physics and day to day life.	

Programme: M. Sc. (Physics)

Course Code: PHY-002 **Title of the Course:** Bridge Course in Thermal Physics

Number of Credits: 2

Effective from AY: 2022-2023

Prerequisites for the Course:	B. Sc. Levels courses on mechanics and mathematics	
Course Objectives:	This course aims to introduce basic concepts of thermodynamics, laws of thermodynamics, entropy its applications.	
Content:	1. **Zeroth and First Law of Thermodynamics:** Extensive and intensive Thermodynamic Variables, Thermodynamic Equilibrium, Zeroth Law of Thermodynamics & Concept of Temperature, Concept of Work & Heat, State Functions, First Law of Thermodynamics and its differential form, Internal Energy, First Law & various processes, Applications of First Law: General Relation between C_P and C_V, Work Done during Isothermal and Adiabatic Processes, Compressibility and Expansion Co-efficient. 2. **Second Law of Thermodynamics:** Reversible and Irreversible process with examples. Conversion of Work into Heat and Heat into Work. Heat Engines. Carnot's Cycle, Carnot engine & efficiency. Refrigerator & coefficient of performance, 2nd Law of Thermodynamics: Kelvin-Planck and Clausius Statements and their Equivalence. Carnot's Theorem. Applications of Second Law of Thermodynamics: Thermodynamic Scale of Temperature and its Equivalence to Perfect Gas Scale. 3. **Entropy:** Concept of Entropy, Clausius Theorem. Clausius Inequality, Second Law of Thermodynamics in terms of Entropy. The entropy of a perfect gas. Principle of Increase of Entropy. Entropy Changes in Reversible and Irreversible processes with examples. Entropy of the Universe. Entropy Changes in Reversible and Irreversible Processes. Principle of Increase of Entropy. Temperature–Entropy diagrams for Carnot's Cycle. Third Law of Thermodynamics. The unattainability of Absolute Zero.	6 hours 8 hours 6 hours 5hours

	4. **Thermodynamic Potentials:** Extensive and Intensive Thermodynamic Variables. Thermodynamic Potentials: Internal Energy, Enthalpy, Helmholtz Free Energy, Gibb's Free Energy. Their Definitions, Properties, and Applications. Surface Films and Variation of Surface Tension with Temperature. Magnetic Work, Cooling due to adiabatic demagnetization, First and second order Phase Transitions with examples, Clausius Clapeyron Equation and Ehrenfest equations. 5. **Maxwell's Thermodynamic Relations:** Derivations and applications of Maxwell's Relations, Maxwell's Relations:(1) Clausius Clapeyron equation, (2) Values of Cp-Cv, (3) TdS Equations, (4) Joule-Kelvin coefficient for Ideal and Van der Waal Gases, (5) Energy equations, (6) Change of Temperature during Adiabatic Process	5 hours
Pedagogy:	Online lectures and assignments	
References/Readings	1. M.W. Zemansky, Richard Dittman, Heat and Thermodynamics, 1981, McGraw-Hill. 2. Meghnad Saha, and B.N.Srivastava, A Treatise on Heat, 1958, Indian Press 3. S. Garg, R. Bansal and Ghosh, Thermal Physics, 2nd Edition, 1993, Tata McGraw-Hill 4. Carl S. Helrich, Modern Thermodynamics with Statistical Mechanics, 2009, Springer. 5. Sears & Salinger, Thermodynamics, Kinetic Theory & Statistical Thermodynamics, 1988, Narosa. 6. S.J. Blundell and K.M. Blundell, Concepts in Thermal Physics, 2nd Ed., 2012, Oxford University Press	
Course Outcomes:	Student will be able to 1. Understand basic concepts of thermodynamics 2. Understand thermodynamic properties of pure substances 3. Formulate and apply the first and second laws of thermodynamics 4. Understand concepts of entropy and the third law of thermodynamics. 5. Understand thermodynamic potentials and their relations.	

Programme: M. Sc. (Physics)

Course Code: PHY-003 **Title of the Course:** Bridge Course in Optics

Number of Credits: 2

Effective from AY: 2022-2023

Prerequisites for the Course:	B. Sc. Levels courses on mechanics and mathematics	
Course Objectives:	This course aims to understand the various concepts of geometric and wave optics	
Content:	**1. Geometric Optics** Brief history, Propagation of light, Scattering, Reflection and Refraction of light, Fermat's principle, Ray equations, Refraction and reflection by spherical surfaces, Paraxial optics, lenses, mirrors, prisms, optical systems, Total internal reflection, thick lenses, Aberrations. Introduction to eyepieces, Ramsden and Huygens eyepieces. **2. Wave Optics** Simple harmonic motion, vibrations, origin of refractive index, sinusoidal waves, one-dimensional wave equation, transverse and longitudinal vibrations, Huygen's principle, plane waves, spherical and cylindrical waves. **3. Interference** Superposition of Waves, Division of wavefront & division of amplitude, Formation of colors in thin film- reflected system, transmitted system, wedge shaped film, Newton's Rings and its application to determine refractive index of liquid (Normal Incidence only), Interferometry: Michelson interferometer-its principle, working and its application to determine wavelength and difference between two wavelengths, Coherence. **4. Diffraction** Fraunhofer diffraction, Single slit and Double slit patterns, Limit of resolution, Diffraction grating, Fresnel diffraction, zone-plates, Diffraction by circular discs and apertures, Holography. **5. Polarization of light** Nature of polarized light, Dichroism, Birefringence, Scattering and Polarization, Polarization by reflection, Brewster angle, Circular polarizers, Wave plates.	6 hours 6 hours 6 hours 6 hours 6 hours
Pedagogy:	Online lectures and assignments	
References/Readings	1. Ajoy Ghatak, Optics, 7th Edition, Tata-McGraw-Hill (2020).	

	2. Eugene Hecht, Optics, Pearson, 5th Edition, (2019). 3. Brij Lal, M N Avadhanulu & N Subrahmanyam, A Textbook of Optics, 25th edition, S. Chand & Company (2012). 4. F.A. Jenkins and H.E. White, Fundamental of Optics, Tata McGraw-Hill (1981).	
Course Outcomes:	Students will be able to 1. Understand geometrical and wave optics 2. Understand phenomena of interference and diffraction 3. Apply these phenomena to problems in Physics 4. Understand concept of polarization of light.	

Programme: M. Sc. (Physics)

Course Code: PHY-004 **Title of the Course:** Bridge Course in Quantum Mechanics

Number of Credits: 2

Effective from AY: 2022-2023

Prerequisites for the Course:	B. Sc. Levels courses on mechanics and mathematics	
Course Objectives:	This course aims to understand the various phenomena of early quantum physics and develop the essential ideas of the old quantum theory.	
Content:	1. THERMAL RADIATION AND PLANCK'S POSTULATE Thermal Radiation, Classical Theory of Cavity Radiation, Planck's Theory of Cavity Radiation, Planck's Postulate and Its Implications. 2. PHOTONS—PARTICLE-LIKE PROPERTIES OF RADIATION Introduction, The Photoelectric Effect, Einstein's Quantum Theory of the Photoelectric Effect, The Compton Effect, The Dual Nature of Electromagnetic Radiation. 3. DE BROGLIE'S POSTULATE—WAVE-LIKE PROPERTIES OF PARTICLES Matter Waves, The Wave-Particle Duality, The Uncertainty Principle, Properties of Matter Waves, Some Consequences of the Uncertainty Principle, The Philosophy of Quantum Theory 4. BOHR'S MODEL OF THE ATOM Thomson's Model, Rutherford's Model, The Stability of the Nuclear Atom, Atomic Spectra, Bohr's Postulates, Bohr's Model, Atomic Energy States. 5. SCHROEDINGER'S THEORY OF QUANTUM MECHANICS Introduction, Plausibility Argument Leading to Schrödinger's Equation, Born's Interpretation of Wave Functions, Expectation Values, the time-independent Schrödinger Equation, Required Properties of Eigen functions, Energy Quantization in the Schrodinger Theory. 6. SOLUTIONS OF TIME-INDEPENDENT SCHROEDINGER EQUATIONS Introduction, The Zero Potential, The Step Potential (Energy Less Than Step Height), The Step Potential (Energy Greater Than Step Height), The Barrier	3 hours 2 hours 2 hours 3hours 5 hours 15 hours

	Potential, Examples of Barrier Penetration by Particles, The Square Well Potential, The Infinite Square Well Potential, The Simple Harmonic Oscillator Potential	
Pedagogy:	Online lectures along with assignments	
References/Readings	1. Robert Eisberg and Robert Resnick, Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles, John Wiley & Sons (2006) 2. A. Ghatak and S. Lokanathan, Quantum Mechanics, Theory and Applications, Mc Millan (2004). 3. P. M. Mathews, and K. Venkatesan, A Textbook of Quantum Mechanics, 2nd Ed., McGraw Hill (2010) 4. Leonard I. Schiff, Quantum Mechanics, 3rd Edn. Tata McGraw Hill, (2010)	
Course Outcomes:	Student will be able to 1. Understand the concept of the wave-particle duality of radiation and particles. 2. Understand energy quantization. 3. Understand wave mechanics in one dimension. 4. Describe the structure of the hydrogen atom. 5. Understand quantization of angular momentum.	

Programme: M. Sc. (Physics)

Course Code: PHY-005 **Title of the Course:** Bridge Course in Electrostatics and Magnetostatics

Number of Credits: 2

Effective from AY: 2022-2023

Prerequisites for the Course:	B. Sc. Levels courses on mechanics, mathematics, and vector algebra	
Course Objectives:	This course is aimed at revising the electrostatics and magnetostatics	
Content:	**1. Electrostatics** Coulomb's law, Electric field and potential, Gauss's law, Application of Gauss's law, the electric field in various circumstances, Electrostatic energy, dielectrics. **2. Magnetostatics** Electric current, the magnetic field, the magnetic force of a current, Ampere's law, magnetic field of a straight wire and of a solenoid, atomic currents, the relativity of magnetic and electric fields, the magnetic field in various situations, the vector potential, induced currents, the Maxwell equations.	15 hours 15 hours
Pedagogy:	Lectures/tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning	
References/Readings	1. The Feynman lectures on Physics, Vol-2, Pearson (2013) 2. Young and Freedman, University Physics with modern Physics, Pearson (2016) 3. H. C. Verma, Concepts of Physics, vol-2, Bharati Bhawan Publishers & Distributors (2019).	
Course Outcomes:	Students will be able to 1. Understand concepts like electric field, potential, electrostatic energy, dielectrics. 2. Learn applications of Gauss Law 3. Understand generation of magnetic field 4. Apply Maxwell equations	

Programme: M.Sc (Physics)(Biophysics)

Course Code: PHY-010 **Title of the Course:** Introduction to Biology and Biophysics

Number of Credits: 3

Effective from AY: 2022-23

Prerequisites for the course:	Understanding of basic concepts in biology, chemistry and physics	
Course Objectives:	This is a bridge course for the students for introducing them to the concepts in biology and biophysics.	
Content:	**Introduction to Biology** Origin and evolution of life, prokaryotic cells, photosynthesis, eukaryotic cells, elementary building blocks of life **Biochemistry I** Chemical components of the cell, energy, catalysis and biosynthesis, cellular membranes, transport across membranes, energy generation in cells, cytoskeletons, cell division, **Biochemistry II** Proteins-structure and function, DNA, RNA and chromosomes, Genes, genetics, carbohydrates, lipids and enzymes **Biophysics** Biological motion, free energy transduction, chemochemical machines, pumps and motors as chemochemcial machines, flux force dependence, molecular motors, mechanochemistry of molecular motors, biomolecular forces, biomechanics of muscle contraction and cardiovascular system.	5 hours 15 hours 15 hours 10 hours
Pedagogy:	Online Lectures/Assignments/Self Study Interactive sessions will be conducted to enable peer group learning.	
References/Readings	1. Geoffrey M. Cooper and Robert E. Hausman, The Cell: A Molecular Approach, Seventh Edition, Oxford University Press (2018). 2. Dennis Bray, Karen Hopkin, Alexander D. Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter, Essential Cell Biology, Bruce Alberts, Fourth Edition Garland Science (2013). 3. David Clark Nanette Pazdernik Michelle McGehee, Molecular Biology, Third Edition, Elsevier (2019). 4. Jack A Tuszynski and Michal Kurzynski, Introduction to Molecular Biophysics, First Edition, CRC Press, (2003).	

	5. Rodney Cotterill, Biophysics: An Introduction, Wiley (2002). 6. Thomas A Weigh, Applied Biophysics, A Molecular Approach for Physical Scientist, First Edition, Wiley, (2007). 7. Mayer & Jackson, Molecular & Cellular Biophysics, Cambridge Press (2006).	
Course Outcomes:	Student will be able to 1. Learn about biology and biochemistry 2. Understand the basic concepts of molecular biophysics 3. Gain knowledge in the structure and functioning of molecular processes 4. Get exposed to the recent developments in biomechanics and molecular motion.	

Programme: M.Sc. (Physics)
Course Code: PHY – 500 **Title of the Course:** Mathematical Physics
Number of Credits: 4
Effective from AY: 2022-23

Prerequisites for the course:	Should have studied the courses in Physics at graduation level.	
Course Objectives:	Students will get exposed to necessary mathematical skills that are essential to understand different phenomena in physics. The course also helps students to understand the theoretical background of other core courses in physics.	
Content:	**1. Ordinary Differential Equations** Second order homogeneous and inhomogeneous equation, Wronskian, General Solutions, Ordinary and Singular points, Series Solutions. Polynomial solutions, Legendre's equation, Bessel's equation, Gamma function	14 hours
	2. Functions of Complex Variable Limits, Continuity, Analyticity of Functions of a Complex Variable, Taylor and Laurent Series, Isolated and Essential Singularities, Branch Cuts, Cauchy Formula, Contour Integration, Application of Residue Theorem.	15 hours
	3. Linear Vector Spaces Linear Operators, Matrices, Coordinate Transformations, Eigenvalue Problems, Diagonalization of Matrices, Infinite Dimensional Spaces, Elements of Group Theory.	9 hours
	4. Integral Transforms Fourier Series, Fourier Transforms, Laplace Transforms, Applications of Integral Transforms.	12 hours
	5. Boundary Value and Initial Value Problems Vibrating String in one Dimension, Heat Conduction, and Wave Equation.	10 hours
Pedagogy:	Lectures/ tutorials or a combination of these. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings:	1. George B. Arfken and Hans J. Weber, Mathematical methods for Physicists, 7/e Elsevier Inc., 2012. 2. K.F. Riley, M.P. Hobson and S.J. Bence, Mathematical Methods for Physics and engineering, Cambridge University Press, Cambridge UK (Reprint 2002) 3. J. Mathew and R. L. Walker, Mathematical Methods for Physics, Benjamin Publishers (1973). 4. James W. Brown and R. V. Churchill Complex	

	Variables and Applications, 6th Edition (international), McGraw - Hill (1996**).** 5. L. A. Pipes, Applied Mathematics for Engineers and Physicists, 3rd Edition, McGraw-Hill (1971). 6. W. W. Bell, Special Functions for Scientists and Engineers, D. Van Nostrand Company Ltd (2004). 7. Charlie Harper, Introduction to Mathematical Physics, PHI. 8. Murray R. Spiegel, Theory and problems in Complex Variables by (Schaum' series) (2009). 9. Murray R. Spiegel, Theory and problems of advanced Mathematics for Engineers and Scientists by (Schaum's series) (1980).	
<u>Course Outcomes:</u>	Students will be able to 1. Analyze the necessary mathematical concepts. 2. Demonstrate proficiency in mathematical skills required for a master's in Physics. 3. Apply the mathematical skills in other courses of Physics. 4. Evaluate the mathematical background of various concepts in physics.	

Programme: M. Sc. (Physics)
Course Code: PHY-501 **Title of the Course:** Classical Mechanics
Number of Credits: 4
Effective from AY: 2022-23

Prerequisites for the course:	Should have studied basic courses in mechanics in B.Sc. and Mathematics.	
Course Objectives:	This course is aimed at understanding intermediate to advanced classical mechanics and to build the necessary framework for other topics that requires classical mechanics such as quantum mechanics, statistical mechanics and electromagnetism.	
Content:	**1. Newton's Laws of Motion** Mechanics of a single particle, Mechanics of a system particles, Constraints and their classification, Principle of virtual work, D'Alembert's principle. **2. Lagrangian Formulation** Degrees of Freedom, Generalized Coordinates, Calculus of variations, Hamilton's principle, Euler-Lagrange's equations of motion, Application to non-holonomic systems, Advantages of a variational principle formulation, Conservation theorems and symmetry properties. **3. Rigid Body Dynamics** Eulerian angles, Inertia tensor, Angular momentum of rigid body. Free motion of rigid body, Motion of symmetric top. **4. Hamilton's equation of motion** Legendre transformation and the Hamilton equations of motion, cyclic coordinates and conservation theorems, Routh's procedure and oscillation about steady motion, Derivation of Hamilton's equations from a variational principle, Principle of least action. **5. Canonical Transformations** Equations of canonical transformations, Examples of canonical transformations, Poisson brackets and other canonical invariants, Equations of motion, Infinitesimal canonical transformation theorems in Poisson bracket formulation, Angular momentum, Poisson brackets relations, Lagrange brackets. **6. Hamilton - Jacobi Theory** H-J equation for Hamilton's principal function, Harmonic oscillator problems, H -J equation for characteristic	6 hours 10 hours 8 hours 10 hours 8 hours 6 hours 7 hours

	function, Action angle, Kepler's problem. **7. Two-body Central Force Problem** Equations of motion and first integrals, Classification of orbits, virial theorem, Differential equation and integrable power law potentials, Kepler's problem. **8. Small Oscillations** Simple Harmonic Oscillations, Damped Oscillations, Forced Oscillations without and with damping, Coupled Oscillations.	5 hours
Pedagogy:	Lectures/ tutorials/ assignments. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. H. Goldstein, Classical Mechanics. McMillan, Bombay, 1998. 2. J. C. Upadhyaya, Classical Mechanics. Himalaya, Publishing House, Mumbai, 1991. 3. M. G. Calkin, Lagrangian and Hamiltonian Mechanics. World Scientific, 1996. 4. N. C. Rana, and P. S. Joag, Classical Mechanics. Tata Mcgraw-Hill, 1991. 5. P. V. Panat, Classical Mechanics. Alpha Science International Ltd, 2004.	
Course Outcomes:	Students will be able to 1. Apply the principles of Lagrange-Hamilton formalism to classify and explain the motion of a mechanical system. 2. Create equations of motion for complex mechanical systems in classical mechanics by applying the formalism of Lagrangian and Hamiltonian. 3. Analyze the differential equations of orbit and determine the stability of the orbit under central force. 4. Evaluate and contrast the differences between Lagrangian and Hamiltonian formalism, Galilean and Lorentz transformation, and various reference frames.	

Programme: M. Sc. (Physics)

Course Code: PHY-502 **Title of the Course:** Electromagnetic Theory

Number of Credits: 4

Effective from AY: 2022-23

Prerequisites for the course:	Should have studied electrostatics and magnetostatics at the graduation level.	
Course Objectives:	The aim of this course is to develop understanding of time varying scalar and vector electromagnetic fields and relativity. To inculcate fundamental concepts related to electromagnetic waves, their transmission via wave guides, radiation and plasma.	
Content:	**1. Maxwells Equations:** Displacement current, Maxwell's equations, Vector and Scalar potentials, Gauge transformation, Lorentz and Coulomb gauge, Poynting's theorem, Conservation of energy and momentum for charged particles and fields. **2. Electromagnetic Waves** Plane electromagnetic waves and their propagation in non- conducting and conducting media, Frequency dispersion in conductors 3. **Electromagnetic Radiation** Retarded Potentials, Fields and radiation by localized dipole, Lienerd Weichert potentials, Power radiated by an accelerated charge. **4. Physics of Plasmas** Electrical neutrality in a plasma, Particle orbits and drift motion in a plasma, Magnetic mirrors, The hydro-magnetic equations, The pinch effect, Plasma oscillations and wave motion, Reflection from a plasma (ionosphere). **5. Wave Guides** Propagation of Waves between conduction planes, Wave guides in arbitrary cross-section, Wave -guides in Rectangular Cross-section, Coaxial Wave guide, Resonant Cavities, Dielectric wave guides. **6. Relativistic Electrodynamics** Lorentz transformation as four dimensional orthogonal transformation, Lorentz matrix, four vectors in mechanics and electrodynamics, Lorentz covariance of Maxwell equations, field tensor, transformation of	10 hours 9 hours 10 hours 9 hours 10 hours 12 hours

	fields, field due to a point charge in uniform motion.	
Pedagogy:	Lectures/ tutorials/ assignments. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	**Text Books / References:** 1. J. B. Marion, Classical Electromagnetic Radiation, Academic Press, New York (1980). 2. J. R. Reitz and F. J. Milford, Foundations of Electromagnetic theory, Addison – Welsey, Reading (1960). 3. B. B. Laud, Electromagneties, Wiley Eastern Ltd., New Delhi (1983). 4. S. P. Puri, Classical Electrodynamics, Tata McGraw-FEII Publishing Co. Ltd. New Delhi (1997). 5. David J. Griffiths, Introduction to Electrodynamics, Prentice - Hall of India Pvt. Ltd., New Delhi (1995). 6. J. D. Jackson, Classical Electrodynamics, Wiley, New York (1995). 7. W. H. Panofsky and M. Philips, Classical Electricity	

	and Magnetism, Addison-Wesley Publication, 1962.	
Course Outcomes:	Student will be able to 1. Analyse the nature of electromagnetic fields due to time varying charge and current distribution using Maxwell's equations. 2. Describe the properties of plane waves in unbounded space, and understand such concepts as wavelength, phase velocity, and attenuation. 3. Develop fundamental concepts of plasma systems using the concepts of electromagnetic theory. 4. Apply equations of electromagnetism to the analysis of waveguides. 5. Develop an understanding of the principles of relativistic electrodynamics.	

Programme: M. Sc. (Physics)

Course Code: PHY-503 **Title of the Course:** Electronics

Number of Credits: 4

Effective from AY: 2022-23

Prerequisites for the course:	Should have studied the Electronics courses in Physics at graduation level.	
Course Objectives:	The aim of the course is to introduce students to wide range of electronic circuits and their applications in Physics such as OP-AMPs. They also get basic understanding of opto-electronic devices, modulation, signals, microprocessor and memories.	
Content:	1. **OP-AMP Applications** OP-AMPS with negative feedback, Voltage controlled voltage source (VCVS), Current controlled voltage source (ICVS), Voltage controlled current source (VCIS), Current controlled current source (ICIS), Inverting and noninverting amplifier circuits, Open-loop frequency and phase response, Closed-loop frequency response, Differential amplifier, Instrumentation amplifier, DC and AC amplifiers, Summing, scaling and averaging amplifier, Voltage to current converter, Current to voltage converter.	15 hours
	2. **Opto-electronic devices** Radiative and non-radiative transitions, Characteristics of LED, Photoconductor, Photo diode, Photo transistor, Photo detector, Solar cell, Semiconductor laser; Optical fiber, Optical fiber waveguides, Fundamentals of optical communication	15 hours
	3. **Communication Electronics** Analog and digital signals, Modulation, Types of modulation, Basic principles of amplitude, frequency and phase modulation, Simple circuits for amplitude modulation and demodulation, Digital modulation and demodulation, Microwave Oscillators, Cavity resonators, Standing wave detector.	15 hours
	4. **Digital Electronics** Types of signals, Digital signal processing (DSP) basics, A/D and D/A conversion methods, DSP applications; Introduction to Microprocessors, Elements of 8-bit Microprocessors (INTEL 8085); Memory and storage, RAM, ROM, PROM and EPROM, Flash memories, Magnetic and optical storage.	15 hours

Pedagogy:	Lectures/tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. Millman, J. and Halkias, C. C., Integrated Electronics, Analog and Digital Circuits and Systems, McGraw – Hill Book Co. Tokyo (1997) 2. Boylestad, R. L. and Nashelsky L., Electronic Devices & Circuit Theory, XI Edn. Prentice-Hall of India (2015). 3. Floyd, T. L., Electronic Devices, V Edn. Pearson Education Asia (2001). 4. Gayakwad, R, A., Op-Amps and Linear Integrated Circuits, IV Edn. Prentice-Hall of India (2002). 5. Chen, Chin-Lin, Elements of Optoelectronics and Fiber Optics, McGraw-Hill Book Co. New Delhi (2014). 6. Kennedy, G., Electronics Communication Systems, IV Edn, Tata McGraw-Hill Book Co. New Delhi (2003). 7. Shrader, R., Electronic Communication, Glencoe Division of MacMillan (1993). 8. Kasap, S. O., Optoelectronics and Photonics: Principles and Practices, Dorling Kindersley India (2009) 9. Floyd, T. L., Digital Fundamentals, VII Edn. Pearson Education (2002). 10. Smith, S. W., Digital Signal Processing, Elsevier India (2006).	
Course Outcomes:	Student will 1. Understand the principles and circuits in electronics and use them in various applications. 2. acquire knowledge about working principles of opto-electronic devices and communication electronics. 3. get exposure to microprocessor and memory devices. 4. Be able to analyse process of AM and FM communication.	

Programme: M. Sc. (Physics)
Course Code: PHY-521 **Title of the Course:** Electronics Practical
Number of Credits: 2
Effective from AY: 2022-23

Prerequisites for the course:	Nil	
Course Objectives:	This course provides laboratory training in designing, and constructing electronics circuits commonly used in a Physics laboratory.	
Content:	Experiments are to be performed on following topics (minimum 8) with emphasis on designing and constructing the circuit on a bread board. 1. Operational Amplifier parameters 2. Design and Construction of Wien Bridge Oscillator 3. Design and Construction of phase shift oscillator 4. Design and Construction of Astable Multivibrator 5. Design and Construction of Monostable Multivibrator 6. Schmitt Trigger circuit and its use as a zero crossing detector and squaring circuit 7. Voltage Regulator 8. Constant Current Source 9. Design and Construction of DC differential amplifier using op-amps 10. Design and Construction of Function generator 11. Design and construction of Negative nonlinear resistor 12. J. K. flip-flop counter: Scale of 16 and 10 using IC 13. Adder and Subtractor Circuits	60 hours
Pedagogy:	Laboratory Experiments	
References/Readings	1. D. P. Leach, A. P. Malvino and G. Saha, Digital Principles and Applications. Tata Mc Graw Hill 7e, 2011. 2. J. Millman and C. C. Halkias, Integrated Electronics: Analog and Digital Circuits and Systems. McGraw Hill International Student Ed., 1972. 3. LM317 – 3 Terminal Adjustable Voltage regulator datasheet Rev. X, Texas Instruments 4. Wikibooks – Negative resistance, Negative differential resistance. https://en.wikibooks.org/wiki/Circuit_Idea	

Course Outcome:	Student will be able to 1. Prepare for laboratory work, by reading from books / laboratory manual / datasheet. 2. Design and construct electronic circuits by identifying and fetching different components. 3. Record observations from different measuring instruments and record them neatly. 4. Plot graphs and analyze the results. 5. Demonstrate the ability to maintain a laboratory notebook. 6. Prepare lab reports in standard scientific format.	

Programme: M. Sc. (Physics)

Course Code: PHY-522 **Title of the Course**: Computer Programming in Fortran 95

Number of Credits: 2

Effective from AY: 2022-23

Prerequisites for the course:	Nil	
Course Objectives:	This course develops concepts of computer programming in general and introduces programming language FORTRAN 95.	
Content:	**1. Fundamentals of Computer Programing** Programming Languages, Fortran Evolution, Character Set, Intrinsic Types, Numeric Storage, Literal Constants, Names, Significance of Blanks, Implicit Typing, Numeric and Logical Type Declarations, Character Declarations, Initialisation, Constants (Parameters), Comments, Continuation lines, Expressions, Assignment, Intrinsic Numeric Operations, Relational and Intrinsic Logical Operators, Intrinsic Character Operations, Operator Precedence, Mixed Type Numeric Expressions, Mixed Type Assignment, Integer Division, Formatting input and output, WRITE Statement, READ Statement, Prompting for Input, Reading and writing to a file, How to Write a Computer Program, Statement Ordering, Compiling and Running the Program, Practical Exercise 1 **2. Logical Operations and Control Constructs** Relational Operators, Intrinsic Logical Operations, Operator Precedence, Control Flow, IF Statement, IF ... THEN ... ELSE Construct, IF ... THEN ELSEIF Construct, Nested and Named IF Constructs, SELECT CASE Construct, The DO construct, Conditional Exit Loop, Conditional Cycle Loops, Named and Nested Loops, Indexed DO Loops, Practical Exercise 2 **3. Arrays** Declarations, Array Element Ordering, Array Sections, Array Conformance, Array Syntax, Whole Array Expressions, WHERE statement and construct, COUNT, SUM, MOD, MINVAL, MAXVAL, MINLOC and MAXLOC functions, Array I/O, The TRANSPOSE Intrinsic Function, Array Constructors, The RESHAPE Intrinsic Function, Named Array Constants,	15 hours 15 hours 15 hours 15 hours

	Allocatable Arrays, Deallocating Arrays, Vector and Matrix Multiplication, Practical Exercise 3. **4. Procedures** Program Units, Introduction to Procedures, Intrinsic Procedures, Intrinsic statement Mathematical Intrinsic Function Summary, Numeric Intrinsic Function Summary, Character Intrinsic Function Summary, Main Program Syntax, Functions, Subroutine and Functions, Practical Exercise 4	
Pedagogy:	Lectures/ Laboratory work/self-study	
References/Readings	1. V. Rajaraman, Computer Programming in FORTRAN 90 and 95, Prentice-Hall of India, New Delhi 1999. 2. Martin Counihan, Fortran 95, UCL Press Limited University College London (1996). 3. Stephen Chapman, Fortran 95/2003: for Scientists and Engineers, McGraw-Hill (2007).	
Course Outcomes:	Student will be able to 1. Understand programming in general; 2. Understand FORTRAN programming language; 3. Write and run simple programs. 4. Compose programs for regression analysis and error analysis	

Programme: M. Sc. (Physics)
Course Code: PHY-523 **Title of the Course:** Computer programming with C
Number of Credits: 2
Effective from AY: 2022-23

Prerequisites for the course:	Nil	
Course Objectives:	This course develops concepts of computer programming in general and introduces programming language C.	
Content:	**1. Introductory Concepts** Introduction to computers, Introduction to Linux OS, Linux basics, Introduction to C, writing a C Program, Compiling and Executing the Program, Error Diagnostics, Some simple C Programs, Desirable Program Characteristics.	7 hours
	2. C Fundamentals The C character set, Identifiers and Keywords, Data types, Constants, variable and Arrays, Declarations, Expressions, Statements, Symbolic Constants	10 hours
	3. Operators and Expressions Arithmetic Operators, Unary Operators, Relational Logical Operators, Assignment Operators, the Conditional Operators, Library Functions.	10 hours
	4. Data Input and Output Preliminaries, Single character input and output, entering Input data, writing output data, Opening and closing data file, format statements.	7 hours
	5. Control Statements Preliminaries, Branching statements, Looping statements, nested control structure, switch, break, continue, go to statements. Practical Exercise	10 hours
	6. Functions Defining functions, accessing functions, Passing arguments to a function. Practical Exercise	8 hours
	7. Arrays Defining an array, processing an array, passing arrays to functions, multidimensional arrays. Practical Exercise	8 hours
Pedagogy:	Lectures/ Laboratory work/self-study	
References/Readings	1. Byron Gottfried, Programming with C, Tata McGraw-Hill (1996).	

Course Outcomes:	Student will be able to 1. Understand programming in general; 2. Understand C programming language; 3. Write and run simple programs. 4. Compose programs for regression analysis and error analysis	

Programme: M. Sc. (Physics)

Course Code: PHY-524 **Title of the Course:** Computer programming with Python

Number of Credits: 2

Effective from AY: 2022-23

Prerequisites for the course:	Nil	
Course Objectives:	This course develops concepts of computer programming in general and introduces programming language Python.	
Content:	1. **Fundamentals of Python**: Introduction to programming in Python, installation and writing, and running Python programs on Windows and Linux	8 hours
	2. **Handling data**: Data types and variables, user input and output, mathematical operators	8 hours
	3. **Decision making and looping**: Logical expressions and operators, conditional operators, lists, for loop, while loop	12 hours
	4. **Arrays and Functions**: Lists, tuples, sets, special arrays, writing and calling user-defined functions,	12 hours
	5. **Data plotting and fitting**: scattered plots, bar plots, histograms, reading data and plotting, linear or quadratic least square fitting	10 hours
	6. **Error analyses**: Propagation of errors, significant figures, Gaussian distribution, mean, median, standard deviation, variance, weighted average.	10 hours
Pedagogy:	Lectures/ Laboratory work/self-study	
References/Readings	1. "Python Cookbook: Recipes for Mastering Python 3" by by David Beazley and Brian K. Jone, O'Reilly	

	Media (2013) 2. "Python: The Complete Reference" by Martin C. Brown, McGraw Hill (2018)	
Course Outcomes:	Student will be able to 1. Understand programming in general; 2. Understand Python programming language; 3. Write and run simple programs. 4. Compose programs for plotting, regression analysis and error analysis	

Programme: M. Sc. (Physics)

Course Code: PHY-504 **Title of the Course:** Quantum Mechanics

Number of Credits: 4

Effective from AY: 2022-23

Prerequisites for the course:	Studied Physics, including an introductory course on Quantum Mechanics at graduate level	
Course Objectives:	1. To develop basic formalisms of non-relativistic Quantum Mechanics. 2. To illustrate the concepts for analyzation of simple quantum mechanical systems	
Content:	**1. Schrodinger's Equation and Hermitian operators** (a) Time-dependent Schrodinger equation, continuity equation, expectation values, Ehrenfest's theorems, time-independent Schrodinger equation and stationary states. (b) Hermitian operators, eigenvalues and eigenstates of Hermitian operators, momentum eigenfunctions, orthogonality and completeness of wave functions, Computability and compatibility of observables, parity operation. **2. The Schrodinger equation in three dimensions** Separation of the Schrodinger equation in Cartesian coordinates, Central potential, separation of the Schrodinger equation in spherical polar coordinates, The free particle, The three-dimensional square well potential, The hydrogen atom, The three-dimensional isotropic oscillator. **3. Vector space formulation of quantum mechanics** Dirac Notation, representation of states and observables, bra and ket vectors, linear operators, relation with wave mechanics, algebra of Hermitian operators, matrix representation, unitary operators, Schrodinger and Heisenberg representations, linear harmonic oscillator problem by operator method. **4. Angular Momentum theory** Angular Rotations in Classical and Quantum Mechanics, Rotational Symmetry and conservation of angular momentum, Treatment of general angular momentum by operator method, eigenvalues and eigenvectors, Eigen values and eigenfunctions of L^2 and Lz operators, ladder operators L^+ and L^-, spin angular momentum, algebra of Pauli matrices, Pauli representation of angular momentum operators. Addition of two angular momenta,	8 hours 12 hours 5 hours 10 hours

	spin-orbit interaction, Clebsch Gordon coefficients. **5. Approximation methods for stationary problems** Time-independent perturbation theory for a non-degenerate energy level, Time-independent perturbation theory for a degenerate energy level, The variational method, The WKB approximation. **6. Approximation methods for time-dependent problems** Time-dependent perturbation theory, General features, Time-independent perturbation, periodic perturbation, The adiabatic approximation, The sudden approximation **7. Quantum Collision Theory** Scattering experiments and cross-sections, potential scattering and general features, the method of partial waves, Application of the partial-wave method, the integral equation of potential scattering, The Born approximation, Collision between identical particles, Collision involving composite systems.	8 hours 7 hours 10 hours
Pedagogy:	lectures/ tutorials/ assignments. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	**Text Books / References** 1. A. K. Ghatak and S. Lokanathan, Quantum Mechanics: Theory and Applications, Springer (2004) 2. P. M. Mathew and K. Venkatesan, A Text Book of Quantum Mechanics, 2/e, Tata McGraw Hill (2017) 3. L. I. Schiff and Jayendra Bandhyopadhyay, Quantum Mechanics, 4/e, McGraw-Hill (2017). 4. V. K. Thankappan, New Age International Publishers (2012)). 5. V. Devanathan, Quantum Mechanics, 2/e Narosa Publishing House (2015). 6. David J. Griffiths, Introduction to Quantum Mechanics 2/e, Cambridge India, (2016). 7. J. J. Sakurai Modern Quantum mechanics, Addition-Wesley Publishing Company, (1994). 8. R. Eisberg and R. Resnick, Quantum Physics of atoms, molecules, solids, nuclear and particles, 2/e, John Wiley and Sons, (1985). 9. W. Greiner, Introductory Quantum mechanics, Springer Publication, (2001).	

	10. R. L. Liboff, Introductory Quantum Mechanics, 4e, Pearson Education Ltd (2003). 11. Nouredine Zettili, Quantum Mechanics: Concepts and Applications 2/e, Wiley India (2016)	
Course Outcomes:	Students will be able to 1. solve wave equations for simple three-dimensional systems. 2. Acquire knowledge and skills to describe the structure of the hydrogen atom and show an understanding of quantisation of angular momentum and spin as well as the rules for quantisation and addition of these. 3. understand the concepts of approximation methods for solving Schrodinger equations 4. gain the knowledge about fundamental scattering of quantum particles.	

Programme: M. Sc. (Physics)
Course Code: PHY-505 **Title of the Course:** Statistical Mechanics
Number of Credits: 4
Effective from AY: 2022-23

Prerequisites for the course:	Should have studied Physics or Mathematics at graduation level. It is assumed that students have a basic working knowledge of classical and quantum mechanics, including Hamiltonian formulation and density matrices.	
Course Objectives:	This course develops concepts in classical laws of thermodynamics and their application, postulates of statistical mechanics, statistical interpretation of thermodynamics, microcanonical, canonical and grant canonical ensembles; the methods of statistical mechanics are used to develop the statistics for Bose-Einstein, Fermi-Dirac and photon gases.	
Content:	**1. Kinetic Theory and Equilibrium state of Dilute Gas** Formulation of problem, binary collisions, Boltzmann transport equation, Boltzmann's H theorem, Maxwell-Boltzmann distribution, Method of the most probable distribution, analysis of the H theorem, recurrence and reversal paradoxes, Validity of the Boltzmann transport equation.	12 hours
	2. Classical Statistical Mechanics Review of laws of thermodynamics, Entropy, Thermodynamic Potentials, Postulate of Classical Statistical Mechanics, Microcanonical ensemble, derivation of thermodynamics, equipartition theorem, Classical ideal gas, Gibbs paradox.	12 hours
	3. Canonical and Grand Canonical Ensembles Canonical ensemble, energy fluctuations in canonical ensemble, grand canonical ensemble, density fluctuations in grand canonical ensembles, equivalence of canonical and grand canonical ensembles, behaviour of W(N), meaning of Maxwell construction.	12 hours
	4. Quantum Statistical Mechanics Postulates of quantum statistical mechanics, density matrix, ensembles in quantum mechanics, third law of thermodynamics, ideal gases in microcanonical and grand canonical ensembles, foundations of statistical mechanics.	8 hours
	5. Ideal Fermi Gas	8 hours

	Equation of state of Ideal Fermi Gas, theory of white dwarfs, Landau diamagnetism, de Hass-Van Alphen effect, Pauli paramagnetism. **6. Ideal Bose Gas** Photons, phonons, Bose-Einstein condensation.	8 hours
Pedagogy:	Lectures/ tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. Kerson Huang, Statistical Mechanics, 2/e, Wiley India 2008. 2. B. B. Laud, Fundamentals of Statistical Mechanics, New Age International Ltd. New Delhi 1998. 3. F. Reif, Fundamentals of Statistical and Thermal Physics, Waveland Press 2009. 4. L. D. Landau and E. M. Lifshitz, Statistical Mechanics, Pergamon Press 1969. 5. R. P. Feynmann, Statistical Physics, The Benjamin Cummings Publishing Co 1981. 6. S. K. Sinha, Introduction to Statistical Physics, Narosa Publishing House, New Delhi 2007. 7. Tony Guenault, Statistical Physics, New Age International Ltd. New Delhi 2007.	

	8. Francis W. Sears and Gerhard Salinger, Thermodynamics, Kinetic Theory, and Statistical Thermodynamics, Addison- Wesley Principles of Physics Series, 1975.	
Course Outcomes:	Students will be able to: 1. Connect between statistics and thermodynamics. 2. differentiate between different ensemble theories used to explain the behaviour of the systems. 3. differentiate between classical statistics and quantum statistics. 4. explain the statistical behaviour of ideal Bose and Fermi systems. 5. Apply techniques from statistical mechanics to a range of situations.	

Programme: M. Sc. (Physics)

Course Code: PHY-506 **Title of the Course:** Nuclear and Elementary Particle Physics

Number of Credits: 4

Effective from AY: 2022-23

Prerequisites for the course:	Concepts like Radioactivity, Nuclear fission, and knowledge of solution of 1 dimensional Schrodinger Equation	
Course Objectives:	To introduce students to the fundamental principles and concepts governing nuclear and particle physics and have a working knowledge of their application to real-life problems.	
Content:	**1. Basic Properties of Nuclei:** a. Nuclear mass, charge, radius, binding energy, nuclear spin, and parity. b. Magnetic moments and electric quadrupole moments.	8 hours
	2. Two-Body Problem: a. Brief review of quantum mechanics tools, properties of deuteron, theory of the ground state of deuteron, magnetic moment, and electric quadrupole moment of deuteron. b. Theory of nucleon-nucleon scattering at low energy, phase shift and scattering length, effective range theory, experimental determination of low energy parameters. c. Nature of nuclear forces and Meson theory of nuclear force.	12 hours
	3. Nuclear Models: a. Liquid drop model, Weizsacker's mass formula, stable and unstable nuclei, mass parabolas. b. Nuclear shell model, energy levels in a three-dimensional harmonic oscillator well potential, spin orbit interaction, prediction of magic numbers, ground state spins and parities, c. Magnetic moments, Schmidt lines, nuclear quadrupole moments, and collective model.	10 hours
	4. Nuclear Transformations: a. Alpha decay, barrier penetration problem, Gamow's theory of alpha decay, Geiger-Nuttal law, alpha spectra and nuclear energy levels. b. Beta decay, experiments in beta spectra, neutrino hypothesis, Fermi's theory of beta decay, Kurie plots, ft values, allowed and forbidden transitions, selection rules, electron capture, parity violation in beta decay, experimental verification, measurement of neutrino helicity. c. Gamma transitions, multipole radiations, quantum	10 hours

	theory of the transition probability, selection rules, angular correlation, calculations of transition rates and comparison with experiments, internal conversion. **5. Nuclear Reactions:** d. Rutherford scattering, cross-sections, decay rates, resonances, Breit-Wigner formula, nuclear fission and fusion processes. **6. Elementary Particles:** a. Classification of elementary particles; properties of quarks and leptons, properties of mesons and baryons. Classification of fundamental forces; Strong, Weak and Electromagnetic interactions. b. Introduction to Feynman diagrams, relativistic kinematics, quark model and eightfold way. c. Particle quantum numbers; charge, isospin, strangeness and parity, Gell-Mann Nishijima formula, conservation laws and symmetries. **7. Particle accelerators and detectors:** a. Introduction to modern accelerators, event rates and luminosity. Large detector systems at electron-positron, electron-proton and hadron colliders. b. Interaction of particles with matter, principle of gas chambers, silicon detectors, scintillators, time-of-flight detectors, and calorimetry.	4 hours 10 hours 6 hours
Pedagogy:	Lectures / tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. H. Enge, Introduction to Nuclear Physics, Addison-Wesley (1974). 2. E. Segre, Experimental Nuclear Physics, John Wiley (1960). 3. V. Devanathan, Nuclear Physics, Alpha Science International Ltd, (2011). 4. S. N. Ghoshal, Nuclear Physics, S. Chand and Co. (2019)	
Course Outcomes:	Student will be able to 1. Apply the models describing the basic nucleon and nuclear properties. 2. Describe the properties of strong and weak interaction. 3. Explain the different forms of radioactivity and account for their occurrence. 4. Classify elementary particles and nuclear states in terms of their quantum numbers.	

Programme: M. Sc. (Physics)

Course Code: PHY-507 **Title of the Course:** Atomic Physics

Number of Credits: 4

Effective from AY: 2022-2023

Prerequisites for the Course:	Knowledge of concepts like Bohr model of atom, Electronic transition in atoms and atomic spectra.	
Course Objectives:	This course is aimed at understanding the atomic structure and atomic spectra	
Content:	**1. Early Atomic Physics** Atomic spectra of hydrogen, The Bohr's theory, Relativistic effects, Moseley and atomic number, Radiative decay, Einstein A and B coefficients, The Zeeman effect. **2. One-electron atoms**: The Schrödinger equation for one-electron atoms, energy levels, the Eigen functions of the bound states, expectation values. Transitions, selection rules, parity, spin of the electron, the spin-orbit interaction, Fine structure of hydrogenic atoms, The Lamb shift, transitions between fine-structure levels. **3. Two-electron atoms:** The Schrödinger equation for two-electron atoms, The ground state of two-electron atoms, Excited states of two-electron atoms. Doubly excited states of two electron atoms. **4. Many-electron atoms**: Shell structure and the periodic table, The central field approximation, The Hartree-Fock method and the self-consistent field, Corrections to the central field approximation. Correction effects, *L-S* coupling and *j-j* coupling. Fine structure in the alkalis. **5. Interaction of atoms with electromagnetic radiation and with static and magnetic field:** Many electron atoms in an electromagnetic field, selection rules for electric dipole transitions, Oscillator and line strengths, Retardation effects, Magnetic dipole and electric quadrupole transitions, The spectra of the alkalis, Helium and the alkaline earths, Atoms with several optically active electrons, Multiplet structure, X-ray spectra, The stark effect, The Zeeman effect.	6 hours 12 hours 12 hours 15 hours 15 hours
Pedagogy:	Lectures/tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning	

References/Readings	1. C. J. Foot, Atomic Physics, Oxford Master Series in Physics (2005) 2. B. H. Bransden, C. J. Joachain, Physics of Atoms and Molecules, Pearson (2004) 3. D. C. Jones, Atomic Physics, CRC Press/Sarat Book House (2018) 4. S. N. Ghoshal, Atomic Physics, S. Chand Publishing (2007)	
Course Outcomes:	Students will be able to 1. understand electronic structure of single electron and multielectron atoms 2. calculate fine structure of atoms 3. deduce the atomic spectra of simple atoms 4. understand the interaction of atoms with electric and magnetic fields.	

Programme: M. Sc. (Physics)
Course Code: PHY-525 **Title of the Course:** General Physics Practical
Number of Credits: 4
Effective from AY: 2022-23

Prerequisites for the course:	Nil	
Course Objectives:	This course provides laboratory training in performing experiments that verify important physical laws and using modern and novel techniques of measurements.	
Content:	Short Lecture Course on – Theory of errors, Treatment of Errors of observation, linear least squares fitting and Data analysis. The experiments on the following topics (any 12) are to be performed with emphasis on the estimation and calculation of errors. 1. Types of Statistical Distributions 2. Analysis of Sodium Spectrum – Quantum defect and Effective quantum number 3. Michelson Interferometer/Fabry-Perot Interferometer 4. Diffraction experiments using laser– single slit, double slit, grating 5. Polarization experiments using laser –linearly and elliptically polarized light 6. Statistical Distribution of radioactive decay 7. Verification of Inverse Square Law using GM counter 8. Linear Absorption Coefficient of Aluminium using GM counter 9. Verification of Debye Relaxation Law and measurement of thermal relaxation of serial light bulb 10. Thermal diffusivity of Brass 11. Thermometry – measurement of thermoemf of Iron-Copper (Fe-Cu) thermocouple as a function of temperature and verification of law of intermediate metals 12. Calibration of Lock-in Amplifier 13. Measurement of mutual inductance of a coil using lock-in amplifier 14. Measurement of low resistance using lock-in amplifier 15. X-ray Emission – characteristics lines of a W target	120 hours

	16. Experiments using Strain Gauge 17. Ultrasonic Interferometer 18. Nonlinear dynamics – Feigenbaum circuit 19. Nonlinear dynamics – Chua's circuit 20. Verification of Percolation phenomena 21. Measurement of electrical resistance of Ni wire to verify para to ferromagnetic phase transition 22. Measurement of electrical resistance of NiTi based shape memory alloy 23. Measurement of Young's modulus of Brass by Flexural vibrations	
Pedagogy:	Lectures and Laboratory Experiments.	
References/Readings	1. P. R. Bevington and D. K. Robinson, Data Reduction and Error Analysis for the Physical Sciences. McGraw Hill (Indian Edition), 2015. 2. R. Srinivasan, K. R. Priolkar, and T. G. Ramesh, A Manual on Experiments in Physics. Indian Academy of Sciences, 2018.	
Course Outcomes:	Student will be able to 1. Employ proper techniques when making scientific measurements. 2. Demonstrate the ability to use selected pieces of measuring devices including the multimeter, oscilloscope, and AC and DC power supplies, Lock-in Amplifier. 3. Apply the appropriate physics to the physical situation presented. 4. Estimate and translate errors and report quantities up to last significant digit. 5. Formulate and report scientific conclusions based on data analysis.	

Programme: M. Sc. (Physics)
Course Code: PHY-526 **Title of the Course:** Methods of Experimental Physics
Number of Credits: 4(1L+3P)
Effective from AY: 2022-23

Prerequisites for the course:	Nil	
Course Objectives:	This course seeks to develop understanding of principles of measurement of various fundamental quantities in a Physics laboratory.	
Content:	**1. Measurement of temperature** Thermocouple, diode and semiconductor sensors, RTD, pyrometer, Langmuir probes, **2. Measurement of resistance** Two probe measurement and four probe measurement using constant current source and constant voltage source, Lock-in amp, discharge of capacitance **3. Measurement of capacitance** RC circuit, DC bridges, AC Bridges **4. Measurement of radiation** GM counter, ionization chambers, scintillation detector, solid state detectors, CCD detectors **5. Measurement of magnetic flux** Force methods, induction methods (including SQUID), Hall probe, indirect methods (MOKE) **6. Measurement of frequency** Resonance methods 7. **Estimation of errors in measurement.** Precision and accuracy, estimation of errors, propagation of errors, general formula, least square fitting, non-linear least square	1 hours + 15 hours 1 hours + 15 hours 1 hours + 15 hours 1 hours + 15 hours 1 hours + 15 hours 1 hours + 15 hours 9 hours
Pedagogy:	Lectures and Laboratory Experiments.	
References/Readings	1. P. R. Bevington and D. K. Robinson, Data Reduction and Error Analysis for the Physical Sciences, McGraw Hill (Indian Edition) 2015. 2. R. Srinivasan, K. R. Priolkar and T. G. Ramesh, A Manual on Experiments in Physics, Indian Academy of Sciences, 2018.	
Course Outcomes:	Student will be able to 1. Understand the advantages and disadvantages of using a technique or probe for making scientific measurements. 2. Demonstrate the ability to use selected pieces of	

	measuring devices. 3. Estimate and translate errors and report quantities up to last significant digit 4. Construct scientific apparatus for measurement of physical quantities.	

Programme: M. Sc. (Physics) (Solid State Physics)
Course Code: PHS-601 **Title of the Course:** Solid State Physics I
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites for the course:	Should have basic knowledge of Quantum Mechanics and Statistical Mechanics	
Course Objectives:	1. To introduce fundamental concepts of solids like crystalline order, symmetry in solids, simple crystal structures and their properties. 2. To acquaint with the concept of reciprocal lattice and its importance in structure determination using x-rays. 3. To introduce different types of crystal bindings and elastic properties of solids. 4. To familiarize the concept of lattice vibration and their role in thermal and optical properties of solids.	
Content:	**Crystal Structure** Crystals - Lattice, Bravais lattice, primitive unit cell, symmetry of molecules and crystals, symmetry operations and symmetry elements, Lattices in one, two and three dimensions, Space groups, definitions of directions, coordinates and planes. Simple crystal structures: NaCl, CsCl, diamond, hexagonal close-packed structure, cubic ZnS structure and their properties, Non ideal crystal structures – random stacking and polytypism Reciprocal Lattice - Diffraction of waves by crystals, Bragg law, Scattered wave amplitude - Fourier analysis, reciprocal lattice vectors, diffraction conditions, Laue equations, Brillouin zones, Geometric structure factor, Atomic Structure factor Point Defects General Thermodynamic Features, Color centres, Line Defects: Dislocations	20 hours
	Crystal Binding and Elastic Constants Crystals of inert gases - Van der Waals - London interaction, repulsive interaction, equilibrium lattice constants, cohesive energy, Ionic Crystals - Electrostatic or Madelung Energy, evaluation of Madelung constant, covalent crystals, bonding in metals and Hydrogen bonds, Atomic Radii, Analysis of elastic strains, elastic compliance and stiffness constants, elastic waves in cubic crystals	13 hours
	Thermal Properties Vibrations of a one -dimensional monatomic lattice, first Brillouin zone, group velocity, long wavelength limit,	15 hours

	derivation of force constant from experiment. Vibrations of a one-dimensional diatomic lattice. Quantization of elastic waves, phonon momentum, Inelastic scattering by Phonons, Phonon Heat capacity, Planck distribution, normal mode enumeration, density of states in one dimension, density of states in three dimensions Debye model for density of states, Debye T^3 law, Einstein model of the density of states, Thermal conductivity - Thermal resistivity of phonon gas, Umklapp process **Optical and Dielectric Properties** Macroscopic electric field, local electric field at atom, dielectric constant and polarizability, Complex dielectric constant, Classical theory of electronic polarization and optical absorption, Structural Phase transitions, Ferroelectric Crystals and Displacive transitions Optical reflectance, Excitons, Raman effect in crystals. Luminescence and Luminescence centres	12 hours
Pedagogy:	Lectures/ tutorials/ assignments. Sessions will be interactive in nature to enable peer group learning.	
References/Readings	1. C. Kittel, Introduction to Solid State Physics, Wiley India (2019) 2. M. A. Omar, Elementary Solid State Physics; Principles and Applications, Addison Wesley (2000) 3. Niel W. Ashcroft, N. David Mermin, Solid State Physics, Harcourt Asia Pte Ltd. (2001) 4. G. Bums, Solid State Physics, Academic press, Inc. London (1985) 5. A. J. Dekker, Solid State Physics, McMillan, India (1985) 6. J. S. Blakemore, W. B. Sauders, Solid State Physics, Philadelphia (1969)	
Course Outcomes::	Student will be able to 1. Understand the fundamental aspects related to structure of solids and lattice symmetry. 2. Determine crystal structure of simple systems using x-ray diffraction. 3. Differentiate between different types of crystal binding and the elastic properties of solids 4. Formulate the idea of vibrating lattice, its quantization and the role of phonons in thermal and optical properties of solids.	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-602 **Title of the Course:** Solid State Physics II

Number of Credits: 4

Effective from AY: 2023-24

Prerequisites for the course:	Should have basic knowledge of Quantum mechanics and statistical mechanics	
Course Objectives:	1. To introduce electronic properties of solids 2. To introduce the concept of formation of bands in solids. 3. To acquaint with techniques associated with measurement of band structure and transport phenomena in solids. 4. To introduce students to different types of magnetic order and superconductivity in solids	
Content:	**Metals: Drude and Sommerfeld models** Free electron theory – Drude model - assumptions, failures of Drude model, Sommerfeld model, Successes and failures of the Sommerfeld model, Electrical conductivity, Experimental electrical resistivity of metals, Heat capacity of electron gas, Experimental heat capacity.	7 hours
	Nearly Free electron model Periodic potential, born – von Karman boundary conditions, Schrodinger equation in a periodic potential, Bloch's theorem, electronic band structure, single electron energy state, degenerate electron levels, Consequences of the nearly free electron model, Fermi surface.	7 hours
	Tight binding model Band arising from a single electronic level, electronic wavefunctions, General points about the formation of tight binding bands, Group I and II metals, Group IV elements, transition metals, comparison of tight binding and nearly free electron band structure, crystal momentum, effective mass, holes.	7 hours
	Semiconductors and Insulators Band structure of Si and Ge, Band structure of direct gap III-V and II-VI semiconductors, Optical absorption and excitons, Thermal population of bands in semiconductors, Intrinsic carrier density, Impurities and extrinsic carrier density, degenerate semiconductors.	7 hours
	Measurement of Band structure Lorentz force and orbits, Landau levels, electronic density of states in a magnetic field, quantum oscillatory phenomena, de Hass – van Alphen effect, Cyclotron resonance, interband magneto optics, electron spectroscopy – angle resolved photoelectron spectroscopy, Some case studies – Copper, Sr_2RuO_4.	7 hours
	Transport Properties	7 hours

	Thermal and electrical conductivity of metals, electron-electron scattering – Fermi liquid behaviour, Electrical conductivity of semiconductors, Disordered systems and hopping conduction, Hall effect, magnetoresistance in metals, magnetophonon effect, magnetoresistance in two dimensional systems, quantum Hall effect, fractional quantum Hall effect. **Magnetic Properties** Magnetic moments, Quantum mechanics of spin, Atom in mangetic field, Magnetic susceptibility, Diamagnetism, Paramagnetism, Semiclassical treatment, Quantum Theory of Paramagnetism, Hund's Rules, Crystal field, Paramagnetic Susceptibility of Conduction electrons, Van Vleck paramagnetism, Adiabatic demagnetization Ferromagnetism, The Weiss model of a ferromagnet, Origin of molecular field, Magnons, Domains, Antiferromagnetism, Neel's theory, Ferrimagnetism **Superconductivity** Experimental survey- Occurrence of Superconductivity, Destruction of superconductivity by magnetic fields, Meissner effect, Heat capacity, Energy gap, microwave and infrared properties, Isotope Effect Theoretical Survey - Thermodynamics of the transition, London equation, Coherence length, BCS theory, Flux quantization, Type II superconductors, Tunnelling, Josephson effects, High Tc superconductivity (introduction)	 12 hours 6 hours
Pedagogy:	Lectures/ tutorials /assignments. Sessions will be interactive in nature to enable peer group learning.	
References/Readings	1. J. Singleton, Band theory and Electronic Properties of Solids, Oxford University Press, (2014) 2. C. Kittel, Introduction to Solid State Physics, Wiley India (2019) 3. Niel W. Ashcroft, N. David Mermin, Solid State Physics, Harcourt Asia Pte Ltd. (2001) 4. M. A. Omar, Elementary Solid State Physics; Principles and Applications, Addison Wesley (2000)	
Course Outcomes::	Student will be able to 1. learn about electronic properties of solids 2. understand formation of bands, their importance in classification of solids and theoretical models of calculation of band structure. 3. get familiarized with some the techniques of band structure measurement and comprehend the effect of band structure on electronic transport properties of solids. 4. recognize diverse types of magnetic orders in solids and phenomenon of superconductivity.	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-621 **Title of the Course:** Solid State Physics Practical

Number of Credits: 4

Effective from AY: 2023-24

Prerequisites for the course:	None	
Course Objectives:	This course aims at developing advanced level experimental skills and competence in the analysis of experimental data on structural, magnetic, transport and optical properties of solids and relate them to different physical concepts studied in the theory courses, PHS-601 and PHS-602.	
Content:	1. X-ray diffraction: Analysis of diffraction patterns of cubic crystal structures to determine their lattice constant, intensity ratios, and lattice type 2. Measurement of dispersion relation of monoatomic and diatomic lattices using electrical equivalent circuits. 3. Measurement of Resistivity of a metal and a Semiconductor by Four Probe Method 4. Measurement of Thermoelectric Power of a metal 5. Determination of Magnetic Susceptibility and Magnetic Moment of a Paramagnetic Material by Gouy's Method. 6. Determination of Magnetic Susceptibility and Magnetic Moment of a Paramagnetic Liquid by Quinke's Method. 7. Study of Hysteresis loop of magnetic materials. 8. Determination of Lande's Splitting Factor, g, in an organic radical. 9. Study of Elastic behaviour of solids using a composite piezoelectric oscillator 10. Measurement as well as determination of Transition Temperature of a Ferroelectric Material Dielectric Constant and understanding failure of mean field theory 11. Measurement of Activation Energy of F-Centres in Alkali Halide Crystals Thermoluminescence 12. Determination of a Hall Coefficient and Nature of a Semiconductor and Mobility of Charge Carriers 13. Analysis of frequency dependence of Dielectric constant of a material. 14. Study of optical properties of a material - absorption, excitation and emission spectra. 15. Measurement of thermal conductivity of a good and poor thermal conductor. 16. Raman effect – demonstration applied to a particular	120 hours

	material. A minimum of 12 experiments are expected to be done by the students.	
Pedagogy:	Laboratory experiments, self-study	
References/Readings	1. Experimental Manuals assigned to each experiment. 2. C. Kittel, Introduction to Solid State Physics, 7th Edition, John Wiley & Son, Inc. New York (1997). 3. B.L. Worsnop & H.T. Flint, Advanced Practical Physics for Students, (1927). 4. A. J. Dekker, Solid State Physics, McMillan, India (1985). 5. Jerry D. Wilson, Physics Lab. Experiments 7/e, D. C. Heath and Company (2009).	
Course Outcomes:	Student will be able to 1. Perform quantitative measurements and evaluation of various properties and constants introduced in the theory courses of Physics. 2. Verify different laws and concepts learned in the theory courses of Physics 3. Develop fine and intensive experimental skills. 4. Interpret results, perform error analysis, analyze data and write reports.	

Programme: M. Sc. (Physics) (Computational Physics)

Course Code: PHC-601 **Title of the Course:** Advanced Quantum Mechanics

Number of Credits: 4

Effective from AY: 2023-24

Prerequisites for thecourse:	Should have knowledge of Quantum Mechanics	
Course Objectives:	To introduce advanced topics in the field of quantum mechanics such as many-body systems, relativistic wave equations and relativistic fields	
Content:	**Second Quantization** Identical Particles, Many-Particle States, and Permutation Symmetry, Completely Symmetric and Antisymmetric States, Bosons: States, Fock Space, Creation and Annihilation Operators, The Particle-Number Operator, General Single- and Many-Particle Operators, Fermions: States, Fock Space, Creation and Annihilation Operators, Single- and Many-Particle Operators, Field Operators: Transformations Between Different Basis Systems, Field Operators, Field Equations, Momentum Representation: Momentum Eigen functions and the Hamiltonian, Fourier Transformation of the Density, The Inclusion of Spin. **Spin-1/2 Fermions** Noninteracting Fermions, The Fermi Sphere, Excitations, Single-Particle Correlation Function, Pair Distribution Function, Density Correlation Functions, and Structure Factor, Ground State Energy and Elementary Theory of the Electron Gas, Hamiltonian, Ground State Energy, in the Hartree–Fock Approximation, Modification of Electron Energy Levels due to the Coulomb Interaction, Hartree–Fock Equations for Atoms. **Bosons** Free Bosons, Pair Distribution Function for Free Bosons, Two-Particle States of Bosons, Weakly Interacting, Dilute Bose Gas, Quantum Fluids and Bose–Einstein Condensation, Bogoliubov Theory of the Weakly Interacting Bose Gas, Superfluidity. **Green's Function** Interaction representation, driven harmonic oscillators, Wick's theorem and generating functionals. Green's functions, Green's function for free fermions, Green's function for free bosons. Adiabatic concept, Gell-Mann Low theorem, generating functions for free fermions, spectral representation. Many particle Green's function **Relativistic Wave Equations** Klein-Gordon equation, Plane wave solution, charge and current densities, hydrogen atom. Dirac equation, algebra of Dirac matrices, covariance of Dirac equation, plane	8 hours 10 hours 10 hours 10 hours 10 hours

	wave solutions, equation in an electromagnetic field. Properties of Dirac electron. The spin of the Dirac particle, Magnetic dipole moment of electron, Velocity operator, Expectation value of the velocity. Parity, Charge conjugation and time reversal operations, Parity operation, Charge conjugation, and Time reversal operation. Dirac's hole theory, Feynman's theory of Positrons. **Quantization of Fields and Radiation Theory** Wave equation for a field, Conjugate field momentum, Hamiltonian, density conservation laws, quantum condition and quantization of scalar field, quantization of complex scalar and Schrodinger fields, Quantization of electromagnetic fields, Interaction of radiation with matter spontaneous and induced emission, Thomson scattering, cross-section for photoelectric effect, Heisenberg-Kramer formula, Rayleigh and Raman scattering. Quantization of Schrodinger field by anticommutator, Atomic level shift, Lamb shift.	12 hours
Pedagogy:	Lectures/ tutorials/assignments. Sessions will be interactive in nature to enable peer group learning.	
References/Readings	1. Franz Schwabl, Advanced Quantum mechanics, Springer (2005) 2. J. J. Sakurai, Advanced Quantum mechanics, Addison-Wesley (1967). 3. B. H. Bransden and C. J. Joachain, Quantum Mechanics, Pearson (2004) 4. S. N. Biswas, Quantum Mechanics, Books and Allied Pvt. Ltd. (2015) 5. A. K. Ghatak and S. Lokanathan, Quantum Mechanics: Theory and Applications, Springer (2004) 6. P. Coleman, Introduction to Many Body Physics, Cambridge University Press (2015)	
Course Outcomes:	Student will be able to 1. learn second quantization. 2. Apply second quantization to weakly interacting electron gas and Bose gases. 3. Interpret the Klein-Gordon and Dirac equation. 4. Develop relativistic equations for electrons and radiation fields.	

Programme: M. Sc. (Physics) (Computational Physics)

Course Code: PHC-602 **Title of the Course:** Advanced Statistical Mechanics

Number of Credits: 4

Effective from AY: 2023-24

Prerequisites for the course:	Should have attended Quantum Mechanics and Statistical Mechanics courses.	
Course Objectives:	To introduce advanced statistical methods to study phase transition and critical phenomena.	
Content:	**Phase Transition and Critical Phenomena** First and second-order transitions, critical phenomena, morphology, fluctuation and correlation and response, Critical exponents, scaling inequalities, how to study critical phenomena. **Models and Universality** Ising models and its ground state, Ising models and its applications, other models and their ground states, Universality in different models. **Mean Field theory** Mean field theory for fluids, critical exponent of a fluid system, Mean field theory for magnetic systems, Mean field equation of state and its solution, Mean field critical exponents, correlation length and correlation function, Bethe approximation, Bethe approximation for 2D Ising model, Landau theory of Phase transition, Critical exponents from Landau theory. **Transfer Matrix method** Transfer matrix and 1D Ising model, Determination of magnetization, susceptibility, specific heat, and correlation length. Spin-1 Ising model and potts model, 2D Ising model. **Series expansion method (Perturbation method**) High-temperature expansion and 1-D Ising model, High and low-temperature expansions for 2D Ising model, Duality and critical temperature, approximation techniques **Monte Carlo method (Numerical method)** Ensemble average in Monte Carlo method, Ergodicity, Detailed balance, and Metropolis algorithm, Monte Carlo Simulation for 2D Ising model, Measurements and errors. **Scaling and renormalization** Homogeneous function, Homogeneity of free energy and scaling, Renormalization group, Renormalization Group, Renormalization operation, Free energy function, correlation length, Critical exponents, fixed point, and universality.	8 hours 6 hours 12 hours 6 hours 6 hours 8 hours 14 hours
Pedagogy:	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	

References/Readings	1. R. K. Pathria and P. D. Beale, Statistical Mechanics, Elsevier, London, 2011. 2. L. D. Landau and E. M. Lifshitz, Statistical Physics, Third Edition, Part 1: Volume 5 (Course of Theoretical Physics, Volume 5), Butterworth-Heinemann, 1980. 3. J. M. Yeomans, Statistical Mechanics of Phase Transitions, Oxford University Press, New York, 1994. 4. H. E. Stanley, Introduction to Phase Transitions and Critical Phenomena, Oxford University Press, New York, 1987. 5. P. M. Chaikin and T. C. Lubensky, Principles of Condensed Matter Physics, Cambridge University Press, Cambridge 2013. 6. S. B. Santra and P. Ray, Statistical Mechanics and Critical Phenomena: A brief overview, in Computational Statistical Physics, edited by S. B. Santra and P. Ray, Hindustan Book Agency, New Delhi, 2011.	
Course Outcomes:	Students will be able to 1. Acquire insights into various types of phase transitions, 2. Understand different models to describe these phase transitions. 3. Describe phase transition theoretically using analytical and numerical methods. 4. Get insight into scaling laws in phase transition. 5. understand the scaling behaviour using renormalization group theory.	

Programme: M. Sc. (Physics) (Computational Physics)

Course Code: PHC-621 **Title of the Course:** Numerical Techniques Practicals

Number of Credits: 4

Effective from AY: 2023-24

Prerequisites for the course:	Basic knowledge of Computer programming	
Course Objectives:	To introduce the methods of solving mathematical problems that occur in physics using numerical techniques.	
Content:	1. Finding Errors: its sources, propagation and analysis 2. Find Roots of functions: bisection, Newton-Raphson,secant method, fixed-point iteration. 3. Solution of Linear equations: Gauss and Gauss-Jordan elimination, Gauss-Seidel, LU decomposition. 4. Eigenvalue Problems. 5. Least square fitting of functions. 6. Interpolation. 7. Numerical differentiation. 8. Numerical integration. 9. Solutions of ODE by initial value problems, Euler's method, second and fourth order Runge-Kutta methods. 10. Boundary value problems by finite difference method. 11. Random number generation and Monte Carlo simulation. 12. Optimization techniques.	120 hours
Pedagogy:	Lectures/Laboratory practicals. Sessions shall be interactive in nature to enable peer grouplearning.	
References/Readings	1. W. H. Press, S. A. Teukolsky, W. T. Vetterling and B. P. Flannery, Numerical Recipes: The Art of Scientific Computing, Cambridge University Press, 1986. 2. W. Cheney and D. Kincaid, Numerical Mathematics and Computing. Thomson Higher Education, USA, 2012 3. A. L. Gercia, Numerical methods for Physics, Create Space Independent Publishing, 2015. 4. S. E. Koonin, and D. C. Meredith, Computational Physics, Westview Press, 1998. 5. S. Chapra, R. Canale, Numerical Methods for Engineers, McGraw Hill Education, 7th edition, 2016.	
Course Outcomes:	Students will be able to 1. Understand efficient numerical techniques. 2. Develop algorithms and implement them using computer programming. 3. Apply the algorithms to solve physical problems. 4. Analyze the accuracy and stability of the techniques.	

Programme: MSc (Physics) (Biophysics)

Course Code: PHB-601 **Title of the Course:** Molecular Biophysics

Number of Credits: 4

Effective from AY: 2023-24

Prerequisites for the course:	PHY-010	
Course Objectives:	This course is intended to enrich the students with the basics of molecular biophysics. The students will learn about the different physical process occurring in biological systems.	
Content:	**Cellular Biophysics** General organization of the cell, Structure of biomolecules, cellular mechanics and transport, Chemical bonding, ionization energy, electron affinity, electron negativity, strong bonds and weak, bond energies in biomolecules, Interatomic potentials for strong and weak bonds, cellular mechanics, transport mechanism **Structure of Proteins, DNA and Enzymes Kinetics** Basics aspects of protein structure, Polypeptide chain geometrics, estimates of potential energy, results of potential energy calculations, hydrogen bonding, hydrophobic & hydrophilic interactions and water as universal solvent in biological systems, Primary structure sequencing of polypeptide, haemoglobin, homologies in proteins, Secondary structure alpha and beta conformation, collagen structure, stability of alpha helix, Ramchandran plot, Tertiary structure, structure of myoglobin and hemoglobin, Quaternary structure, symmetry consideration, Analysis of subunits and chain arrangement of subunits, stability of globular quaternary structure. Protein folding rules, pathways and kinetics Nucleic acids, purines and pyrimides, double helical structure of DNA, polymorphism of DNA, RNA structure, thermodynamics of DNA supercoiling, chromosome structure Enzymes, enzyme kinetics, Michaelis-Menten equation, Inhibitors, kinetics of competitive, non-competitive and uncompetitive inhibitors **Membrane Biophysics** Fundamental aspects of biological membrane, Various membrane models, Carbohydrate, Lipids & Proteins, Components of cell membrane, Composition of biological membranes- lipid molecules, proteins, glycoprotein, membrane, skeletons, forms of lipids and proteins, electrical properties of lipids and proteins, principles of membrane organization & stability, Biogenesis of cell membrane, Molecular motion in membrane & membrane	8 hours 20 hours 20 hours

	fluidity, Protein lipid interactions, Electric properties of membranes: electric double layer, Poisson-Boltzmann theory of electric double layer, Gouy-Chapman model of electric double layer, free energy of electric double layer, bonds and adhesion of electrified molecules on the surface of a membrane, Hodgkin Huxley equation, membrane impedance, Zeta, Stern & total electrochemical potential, Helmholtz-Smoluchowski equation; it's correction by Debye-Huckle theory, transmembrane potential & it's measurement by microelectrodes. Neurobiophysics Transport across membranes: diffusion and osmosis, Selectivity & ion specificity of biomembrane, Ion channel structure and gating function, Ion channel types and characterization, transport of macromolecules with & without vesiculation & by intermediate mechanism, Transport and communication between cells and organelles. **Molecular biomechanics** Biological motion, free energy transduction, chemochemical machines, pumps and motors as chemochemcial machines, flux force dependence, molecular motors, mechanochemistry of molecular motors, biomolecular forces, biomechanics of muscle contraction and cardiovascular system.	12 hours
Pedagogy:	Lectures/ Tutorials/Assignments. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. Jack A Tuszynski and Michal Kurzynski, Introduction to Molecular Biophysics, First Edition, CRC Press (2003). 2. Rodney Cotterill, Biophysics: An Introduction, Wiley (2002). 3. Applied Biophysics, A Molecular Approach for Physical Scientist, Thomas A Weigh Wiley (2007). 4. Mayer B. Jackson, Molecular & Cellular Biophysics, Cambridge University Press (2006). 5. Vasantha Pattabhi and N. Goutham Biophysics, First Edition, Narosa (2002). 6. D. Chapman, Eds, Biomembrane structure and Function, Macmillan, (1983). 7. R. K. Jain, Introduction to Biological Membrane, John Wiley& Sons (1988). 8. J. E. Hall and M. E. Hall, Guyton & Hall Text Book of Medical Physiology, 12th Edition, Elsevier (2010). 9. M. Schliwa, Molecular motors, Wiley-VCH Verlag GmbH & Co (2003).	
Course Outcomes:	Student will 1. Get familiarized with the basic concepts of molecular	

	biophysics. 2. Gain sufficient knowledge in the structure and functioning of molecular processes. 3. Understand physics of membranes, membrane structure and functions. 4. Get exposed to the recent developments in biomechanics and molecular motion.	

Programme: M.Sc (Physics) (Biophysics)

Course Code: PHB-602 **Title of the Course:** Methods in Biophysics

Number of Credits: 4

Effective from AY: 2023-24

Prerequisites for the course:	PHY-010	
Course Objectives:	The aim of course is to introduce various experimental techniques used in biophysical systems.	
Content:	**Separation techniques I** Electrokinetics methods: electrophoresis, electrophoretic mobility (EPM), factors affecting EPM, Paper, PAGE, SDS-PAGE, Disc gel, gradient gel, electrophoresis of nucleic acid and its application, Pulse field electrophoresis, single cell gel electrophoresis, Isolectrophoresis, preparative electrophoresis, 2-D gel electrophoresis, Capillary, Iso-Electric focusing, applications in biology and medicine. Chromatography, TLC, adsorption, partition, ion exchange, gel filtration, affinity and FPLC, GLC, **Separation techniques II** HPLC: mobile phase systems, modes of operations, application, Hydrodynamics method: fundamental principles' Centrifugation: principle, preparative centrifuge, analytical, ultracentrifuge, sedimentation and diffusion, Ultracentrifugation and their applications in molecular weight, size determination. Viscosity and its application, dialysis, solvent fractionation, isoelectric precipitation, **Spectroscopic methods** Principles of spectroscopic techniques, Ultraviolet-visible spectroscopy, circular dichroism and optical rotatory dispersion, fluorescence spectroscopy, infrared spectroscopy, Raman spectroscopy, Atomic Absorption spectroscopy- Inductively coupled plasma atomic emission spectrophotometry. Electron spin resonance, Nuclear Spin resonance, X-ray spectroscopy **Microscopic Techniques** Principle, instrumentation and application of optical microscopy, image formation, magnification, resolving power. optimum resolution, image defects, different types of Microscopy: Dark field, Phase contrast, polarization microscopy, Interference microscopy, Fluorescence microscopy, Electron microscopy: Electron guns, Electron lens, electrostatic focusing, magnetic focusing, SEM, STEM, Atomic force microscopy.	15 hours 15 hours 15 hours 15 hours
Pedagogy:	Lectures/Tutorials/Assignments. Sessions shall be interactive in nature to enable peer group learning.	

References/Readings	1. Igor N S, N Zaccai & J Zaccai, Methods in Molecular Biophysics, First Edition, Cambridge (2007). 2. D Voet, J Voet and CW Pratt, Principle of Biochemistry, Third Edition, John Wiley and Sons, (2008). 3. D. M. Glover DNA Cloning, Vol. I, II, III, First Edition, Oxford (1987). 4. Vasantha Pattabhi and N. Goutham, Biophysics First Edition, Narosa (2002). 5. Brigitte Wittmann-Liebold, Johann Salnikow, Volker A. Erdmann, Eds, Advanced Methods in Protein Microsequence Analysis, First Edition, Springer (1986). 6. C. J. Banwell, Fundamentals of Molecular Spectroscopy, Fourth Edition, McGraw Hill (1994). 7. P.Narayanan Essential Biophysics, First Edition, New Age Publications (2000). 8. Henrik G Bohr, Handbook of Molecular Biophysics (Methods & Application) First Edition, Wiley (2009).	
Course Outcomes:	Students will be able to 1. Familiarize with the basic experimental techniques used in biophysics. 2. Expand their knowledge on various spectroscopic and microscopic methods in characterization. 3. Understand different concepts in biophysics and relate them to experiments. 4. Demonstrate knowledge in separation and microscopic methods.	

Programme: M.Sc (Physics)

Course Code: PHB-621 **Title of the Course:** Biophysics Practical

Number of Credits: 4

Effective from AY: 2023-24

Prerequisites for the course:	PHY-010, basic knowledge in experimental techniques in chemistry and biology	
Course Objectives:	This laboratory course is intended to provide basic laboratory training in the experiments in biophysics. Important biophysical phenomena will be tested and studied. The experiments will start from familiarization of basic characterization tools and protocols followed by advanced experiments.	
Content:	Short lectures on general protocols of biophysics experiments. The following experiments are to be performed/demonstrated: Experiments to be performed 1. Microscopic techniques: The study of biological samples/cells using fluorescence /DIC microscopy 2. Protein-protein interactions using spectroscopy (fluorescence/UV visible) techniques 3. Study of DNA-Protein interaction using fluourimetry 4. Study of fluorescence sensitivity and quenching, fluorescence recovery after photobleaching (FRAP) 5. PAGE and SDS PAGE Demonstrations 6. Classification of gram –ve & +ve organisms, observe cell growth/ survival by colony forming assay, estimation of cell viability by dye exclusion and colony formation assay, observe cell death by physical and chemical agents 7. Preparation of buffers and pH analysis 8. Determination of the titration curve of Proteins, amino acids & calculation of the pKa values 9. Isolation of Proteins- Casein from milk, Hb from RBC. 10. Study of interaction of acridine orange with DNA 11. Enzyme Assays (LKH, beta galactosidase, acid phosphatase, arginase, Succinic De –hydrogenase): Time, Temp, enzyme concentration, cofactors. LKH: Km & Vmax Demonstrations via online videos 12. Gel filtrations chromatography 13. DEAE cellulose chromatography of DNA 14. Study of phase transition of membrane	120 hours

	phospholipids and Study of the membrane potential using fluorescence spectroscopy. 15. To study the charge characteristics of cells through micro Electrophoresis 16. Osmolarity: Determination of osmotic pressure of salts. 17. Study of diffusion of biomolecules/ions (Fick's Law)	
Pedagogy:	Laboratory work, Presentations, demonstrations.	
References/Readings	1. Jay Nadeau, Introduction to Experimental Biophysics: Biological Methods for Physical Scientists, CRC Press (2012). 2. D. T. Plummer, Introduction to Practical Biochemistry, 3rd edition. McGraw-Hill Publishing Co. (1987). 3. M. Holtzhauer, Basic Methods for the Biochemical Lab, 1st English edition. Springer (2006). 4. Stanley R. Maloy, Experimental techniques in bacterial genetics, John and Bartlett (1989).	
Course Outcomes::	Students will be able to 1. Perform basic experimental methods in biophysics. 2. Gain sufficient knowledge in the various characterization and spectroscopic tools. 3. Understand some of the advanced techniques in experimental biophysics. 4. Interpret results, perform error analysis, analyse data and write reports.	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-622 **Title of the Course:** Nuclear Reactor Physics

Number of Credits: 2

Effective from: 2023-24

Prerequisites for the course:	Should have basic knowledge of nuclear physics, thermodynamics, quantum mechanics, and solid state physics	
Course Objectives:	To introduce students to the fundamental principles of neutron and their interaction with matter. To understand the phenomenon of diffusion and slowing down of neutron and waste disposal.	
Content:	**Introduction**: Discovery of neutron, Fundamental properties of neutron, decay of neutron, moment of the neutron, Classification of neutron energy: slow neutrons, thermal neutrons, Epithermal neutrons, Resonance neutron, Intermediate neutrons, Fast neutrons.	2 hours
	Interaction of Neutrons with Matter: Interaction of neutrons with matter, cross-section, variation of cross section with neutron energy. Neutron flux, Maxwellian distribution, Fissile and fertile materials, Neutron life cycle, Fermi four factor formula k_{eff}.	4 hours
	Neutron Diffusion: Diffusion theory approximation, neutron leakage, diffusion equation. Thermal diffusion length, One group critical equation for bare reactor. Boundary conditions and extrapolation distance, measurement of diffusion length	5 hours
	Slowing down of Neutrons: Slowing down length, lethargy, slowing down in a mixture. Moderations.	5 hours
	Calculation of Critical Size of Reactors: Critical equation, One group model, four factor formula and calculation of parameters. Critical size of sphere. Effect of reflector.	5 hours
	Power Operation: Reactor kinetics, prompt neutron lifetime, stable reactor period, the Inhour equation, Fission product poisoning. Fuel burn-up. Measurement or reactor power and period.	5 hours
	Radiological Protection: Units of radiation and radioactivity, Radiation protection standards, Radiation monitoring instruments.	2 hours
	Reactor Fuels and Materials: Uranium resources and requirements. Isotope separation. (one method), reprocessing of spent fuel, Nuclear fuel management.	2 hours

Pedagogy:	Lectures / tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. S. Glasstone and A. Sesonske, Nuclear Reactor Engineering, Van Nostrand Reinhold Co., (1963). 2. E. E. Lewis, Fundamentals of Nuclear Reactor Physics, Elsevier (2008). 3. L.F. Curtiss, Introduction to neutron Physics, D. Van Nostrand Co., (1969). 4. G. L. Squires, Introduction to the theory of Thermal Neutron scattering, Dover Publication, Inc. (1996). 5. Safe Handling of Radioisotopes (Safety Series no.1) (1958).	
Course Outcomes:	Students will be able to 1. Understand neutron interaction with matter 2. Familiarise with the main features of a nuclear reactor and conditions that determine its criticality. 3. Understand neutron diffusion and slowing down 4. Gain insight on the management of nuclear waste	

Programme: M. Sc. (Physics) (Solid State Physics**)**

Course Code: PHS-623 **Title of the Course:** Advanced Optics

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	PHY-003	
Course Objectives:	This course is aimed at understanding intermediate to advanced optics. This course includes fundamental theoretical optics to applied optics and a brief introduction to quantum optics.	
Content:	**1. Light Waves** Eikonal equations, laws of reflection and refraction, guided optics, Lagrange and Hamiltonian formulation of optics, ABCD matrix, thin lens formula, Gaussian optics, Aberrations.	7 hours
	2. Coherence of light and Fourier Optics Fourier transforms in one and two dimensions, convolution operations, spatial frequency filtering, phase contrast microscopy, Correlation function, The Wiener–Khinchin Theorem, Linewidth, Spatial coherence, Interference spectroscopy, Temporal coherence, Stellar intereferometers, Fourier transform properties of lenses.	8 hours
	3. **Optical Modulation and nonlinear optics** Electro-optical effects, acousto-optical effect, Raman-Nath diffraction, Magneto-optics. Nonlinear optical media, second-order and third order optical effects**,** Kerr optical effect, self-focussing, optical bistability, second and third harmonic generation, coupled mode equations, Ultrafast optics.	8 hours
	4. Introduction to Quantum Optics Quantum states of electromagnetic fields, coherent and squeezed states, Operators, ordering procedures and star products, *Q*, *P* and Wigner functions of a density operator, Correlation functions and quantum coherence, Nonclassical light, Quantum entanglement, Bell's inequalities, Cavity QED, Quantum cryptography.	7 hours
Pedagogy:	Lectures/ tutorials/ term papers/assignments/. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. B. D. Guenther, Modern Optics, Oxford University Press, 2015 2. Ajoy Ghatak and K. Thyagarajan, Optical Electronics, Cambridge University Press, 2017. 3. Sharma K. K., Optics- Principles and Applications, Academic Press, Elsevier 2006 4. Yariv and Yeh, Photonics-Optical Electronics in Modern Communications, Oxford University Press, 2007	

	5. B.E.A. Saleh and M. C. Teich, Fundamentals of Photonics, John Wiley and Sons, 2019 6. J. Goodman, Introduction to Fourier Optics, Roberts and Company Publishers; 3rd edition (December 10, 2004) 7. R. W. Boyd, Nonlinear Optics, Elsevier 4th Edition, 2020 8. Marc Fox, Quantum optics: an introduction, Oxford University Press, 2009	
Course Outcomes:	Students will be able to 1. understand advanced theoretical concepts in optical physics. 2. gain knowledge in the phenomenon of coherence Fourier optics. 3. familiarize with methods in optical modulation and nonlinear optics. 4. learn recent progress in quantum optics.	

Programme: M. Sc. (Physics) (Solid State Physics)
Course Code: PHS-624 **Title of the Course:** Physics of Energy Materials
Number of Credits: 2
Effective from AY: 2023-24

Prerequisites for the course:	Student should have basic understanding of the physics concepts related to thermodynamics and electrodynamics.	
Course Objectives:	1. To develop the understanding of different energy materials, their properties and how to make use of them for energy extraction 2. To understand the basic principle of different energy extraction phenomenon.	
Content:	**Photovoltaic Energy materials** Sources of energy: renewable and non-renewable sources, solar power and photovoltaic materials, photovoltaic devices	7 hours
	Energy Storage materials Electrochemical energy conversion and storage, Battery materials, fuel cells, supercapacitors, metal-organic framework for hydrogen storage, materials for water splitting.	8 hours
	Thermoelectric Materials Introduction, The Seebeck and Peltier effects, thermoelectric figure of merit, Measuring the thermoelectric properties, Heat conduction by the crystal lattice, Materials for Peltier cooling, Generator materials, Thermoelectric refrigerators and generators.	8 hours
	Magnetocaloric materials Magnetocaloric effect in the phase transition region, Methods of investigation of magnetocaloric properties, Magnetocaloric effect in different types of materials, Magnetocaloric effect in nanosized materials, Magnetic refrigeration	7 hours
Pedagogy:	lectures/ tutorials /viva/ seminars/ term papers/assignments/ presentations	
References/Readings	1. Ram Gupta Eds, Handbook of Energy Materials, Springer Singapore, 2022 2. Duncan W. Bruce, Dermot O'Hare, Richard I. Walton, Energy Materials, Wiley, 2011 3. Stephen J Fonash, Solar Cell Device Physics, 2nd Edition, Academy Press, 2010. 4. R. Rajasekar, C. Moganapriya, A. Mohankumar, Eds, Materials for Solar Energy Conversion: Materials, Methods and Applications, Wiley, 2022. 5. H Julian Goldsmid, The Physics of Thermoelectric Energy Conversion, Morgan & Claypool Publishers,	

	2017. 6. A.M. Tishin, Y.I. Spichkin, The Magnetocaloric Effect and its Applications, CRC press (Taylor and Francis group), 2016.	
Course Outcomes:	Students will be able to 5. Understand different properties of energy materials 6. Understand basic principles of energy extraction devices such as solar cells. 7. Understand the physics of thermoelectric and magnetocaloric effects for energy applications. 8. Apply concepts of electrochemistry for energy storage applications.	

Programme: M. Sc. (Physics)(Solid State Physics)

Course Code: PHS-625 **Title of the Course: Physics of Ferroic Materials**

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Basic knowledge of Solid State Physics/Chemistry	
Course Objectives:	To introduce various types of ferroic materials and its applications to the students.	
Content:	**Phase Transition** Landau Theory of phase transition – first order and second order. **Ferroelectrics** *P–E* Loop, Relationships Between Dielectric, Piezoelectric, Pyroelectric, and Ferroelectric, Origin of Ferroelectrics, Structure-Induced Phase Change from Paraelectric to Ferroelectric, Soft Phonon Mode, Ferroelectric Domains and Domain Switching, Domain Structure, Ferroelectric Switching, Ferroelectric Materials – $BaTiO_3$, $PbTiO_3$, Antiferroelectric $PbZrO_3$, $Pb(Zr_xTi_{1-x})O_3$ (PZT), Relaxor Ferroelectrics. **Ferromagnetics** General Introduction to Ferromagnetics, Domain and Domain Wall, Magnetoresistance Effect and Device, Anisotropic Magnetoresistance (AMR), Giant Magnetoresistance (GMR), Colossal Magnetoresistance (CMR), Tunnelling Magnetoresistance (TMR), Spin-Transfer Torque Random-Access Memory (STT-RAM), Magnetostrictive Effect and Device Applications, Magnetostrictive Properties of Terfenol-D, Magnetostrictive Ultrasonic Transducer, Magnetoelastic Effect, Magnetomechanical Strain Gauge, Multiferroics, Magnetoelectric Effect, Why Are There so Few Magnetic Ferroelectrics? Single Phase Multiferroic Materials, ME Composite Materials, Multilayered Heterostructures. **Ferroelastics** Shape Memory Alloy, SMA Phase Change Mechanism, Nonlinearity in SMA, One-Way and Two-Way Shape Memory Effect, Superelastic Effect (SE), Application Examples of SMAs, Ferromagnetic Shape Memory Alloys, Formation of Twin Variants, Challenges for Ni–Mn–Ga SMA, Device Application of MSMA.	4 hours 9 hours 9 hours 8 hours
Pedagogy:	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
References/Readings	1. Jian Dai, Ferroic Materials for Smart Systems: From fundamentals to device applications, Wiley VCH (2020) 2. V. K. Wadhavan, Introduction to Ferroic Materials,	

	Taylor & Francis (2000) 3. Jörg Schröder, Doru C. Lupascu, Ferroic Functional Materials: Experiment, Modeling and Simulation, Springer (2018)	
<u>Course Outcomes:</u>	Students will be able to 1. learn about different Ferroic phase transitions. 2. gain knowledge about characteristics of ferroic materials 3. develop an understanding of different applications of ferroelectric, ferromagnetic and ferroelastic materials. 4. Understand about concepts of multiferroicity, glassy behaviour in different ferroic materials.	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-626 **Title of the Course:** Nanoscience and Technology

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Basic knowledge of Solid-State Physics / Solid State Chemistry	
Course Objectives:	This course is aimed at introducing different concepts of nanoscience and technology. It aims at presenting the recent developments in the field of nanomaterials including synthesis and characterization methods.	
Content:	**Introduction to Nanomaterials** Introduction to Nanoscience, Physics and Chemistry of solid surfaces, Size effect on thermal, electrical, electronic, mechanical, optical and magnetic properties of nanomaterials- surface area and aspect ratio- band gap energy- quantum confinement size. Classifications of nanomaterials - Zero dimensional, one-dimensional and two-dimensional nanostructures- Kinetics in nanostructured materials- multilayer thin films and superlattice clusters of metals, semiconductors and nanocomposites. Nanoparticles through homogeneous and heterogeneous nucleation- Oswald ripening process	7 hours
	Synthesis of nanostructures Top down and bottom-up approaches–Mechanical alloying and mechanical ball milling Mechanical and chemical process, Inert gas condensation technique – Arc plasma and laser ablation. Sol gel processing-Solvothermal, hydrothermal, precipitation, Spray pyrolysis, Electro spraying and spin coating routes, Self-assembly, self-assembled monolayers (SAMs). Langmuir-Blodgett (LB) films, micro emulsion polymerization-templated synthesis, pulsed electrochemical deposition Vapor deposition and different types of epitaxial growth techniques (CVD, MOCVD, MBE, ALD)- pulsed laser deposition, Magnetron sputtering - lithography: Photo/UV/EB/FIB techniques, Dip pen nanolithography, Etching process: Dry and Wet etching, micro contact printing	8 hours
	Characterization tools in Nanoscience Optical microscopy: Use of polarized light microscopy – Phase contrast microscopy –Interference Microscopy – hot stage microscopy - surface morphology – Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), HRTEM use in nanostructures. Atomic Force Microscopy (AFM) Scanning Force Microscopy-Shear force Microscopy-Lateral Force Microscopy-Magnetic Force microscopy.	8 hours

	Scanning Tunnelling Microscopy: Principle-Instrumentation- importance of STM for nanostructures – surface and molecular manipulation using STM -3D map of electronic structure. **Applications of Nanoscience** Nanomaterials for energy applications, Nanoelectronics, Nanomagnetism and devices, Nanophotonics, Surface plasmons, Nanobio applications, Environmental issues.	7 hours
Pedagogy:	Lectures/ tutorials/ term papers/assignments/. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. G. Cao, Nanostructures & Nanomaterials: Synthesis, Properties & Applications, Imperial College Press, 2004. 2. Murthy. B.S. Murty, P. Shankar, James Murday and Baldev Raj, Textbook of Nanoscience and Nanotechnology, University Press, Springer Berlin (2013) 3. L. Novotny and B. Hecht, Principles of nano-optics, Cambridge University Press, 2009. 4. M. Baker et al., Lithographic pattern formation via metastable state rare gas atomic beam, Nanotechnology, 15, 1356, 2004. 5. Helmut Schift, Sunggook Park, Bokyung Jung, Choon-Gi Choi, Chul-Sik Kee, Sang-Pil Han, Keun-Byoung Yoon and Jens Gobrecht, Fabrication of polymer photonic crystals using nanoimprint lithography, Nanotechnology 16, 261, 2005. 6. R.D. Piner, Nanolithography- Dip-Pen, Science 283, 661, 1999. 7. Barnes, W., Dereux, A. & Ebbesen, T.,Surface plasmon subwavelength optics, Nature 424, 825, (2003) 8. Heinz Raether, Surface Plasmons on Smooth and Rough Surfaces and on Gratings Springer Tracts in Modern Physics, Vol. 111, Springer Berlin 1988. 9. Stefan Maier, Plasmonics: Fundamentals and Applications, Springer 2007.	
Course Outcomes:	Student will be able to 1. Gain knowledge in Nanoscience and Nanotechnology. 2. Understand various techniques in cutting-edge nanoscience. 3. develop awareness of recent advances in nanotechnology and its applications. 4. demonstrate knowledge in application of nanoscience in different areas.	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-627 **Title of the Course:** Laser physics and applications

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Student should have basic knowledge of Atomic Physics.	
Course Objectives:	1. To develop understanding of construction and operation of different Laser systems. 2. To understand advances in laser physics and its Applications	
Content:	**Introduction to lasers:** Definition, brief history of Lasers, unique Properties of laser, coherence, fundamental wave and quantum properties of light, Laser Safety: Various hazards due to laser radiation-eye, skin, chemical etc., safety measures and standard ANSI	6 hours
	Laser Amplifiers and Resonators: Conditions for producing a laser – population inversions, Gain and gain saturation, Development and growth of laser beam, Requirements for obtaining population inversion, laser pumping requirements and techniques. laser cavity modes: longitudinal and Transverse, Q switching, mode- locking, pulse shortening techniques, ultrashort - pulsed laser and amplifier system, Ring lasers, Cavities for producing spectral narrowing of laser output.	8 hours
	Laser systems and their applications He -Ne laser, Ar ion laser, Molecular Gas lasers: CO_2 laser, Excimer lasers, Laser systems involving high-density gain media: Organic dye lasers, solid state lasers: Ruby laser, Nd-YAG and glass lasers. Applications of lasers in materials engineering (cutting, welding, cladding, peening, surface engineering), communication, LIDAR, Medical Applications (dentistry, LASIK, laser lithotripsy, dermatology etc), Laser Cooling and Trapping of Atoms, Spectroscopic applications (RAMAN, LIBS).	16 hours
Pedagogy:	Lectures/ tutorials/laboratory work/project work/ vocational training/viva/ seminars/ term papers/assignments/ presentations/ self-study/ Case Studies etc. or a combination of some of these. Sessions will be interactive in nature to enable peer group learning.	
References/Readings	1. William T. Silfvast, Laser Fundamentals, second edition Cambridge publication, 2004 2. Joseph T. Verdeyen, Laser Electronics, third edition,	

	Prentice Hall series, 1994. 3. Karl F. Renk, Basics of laser physics, second edition, Springer, 2012. 4. Tarasov. L, Laser Physics and application, Mir Publication, 1987. 5. Bakefi, George, Principles of Laser Plasmas, John Wiley & Sons Inc., 1977. 6. William V. Smith, Laser application, Artech House Publishers, 1970. 7. K. Thyagarajan, Ajoy Ghatak, Lasers: Fundamentals and Applications (Graduate Texts in Physics), second edition, Springer publication, 2012. 8. Ross Monte, Laser application, Academic press New York, 1974.	
Course Outcomes:	Students will be able to 1. understand the basic principle and operation of different types of Lasers. 2. get exposure to applications of Lasers in different fields. 3. Gain insights of intricacies involved in laser construction and design. 4. Develop understanding of laser pulsing techniques.	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-628 **Title of the Course:** Experimental Techniques in Physics

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Students enrolling for this course should have knowledge in basic mathematical concepts	
Course Objectives:	This course introduces the concepts in experimental physics, instrumentation and error analysis	
Content:	**Data Interpretation and Error Analysis** Data interpretation and analysis. Uncertainties, Statistical analysis of uncertainties, Precision and accuracy, Parent and Sample Distributions, Mean and Standard Deviation of Distributions, Binomial Distributions, Poisson Distribution, Gaussian or Normal Error Distribution, Lorentzian Distribution; Approximation and Errors in Computing: Significant Digits, Numerical Errors, Modelling errors, Conditioning and Stability, Convergence of Iterative Processes. Error analysis, propagation of errors. Least squares fitting, Linear and nonlinear curve fitting, chi-square test	15 hours
	Measurements and Instrumentation Transducers (temperature, pressure/vacuum, magnetic fields, vibration, optical, and particle detectors), low current and voltage measurements, High and low temperature measurements, thermocouples, photoresistors, thermal and electronic conduction measurements, optical measurements, photon counting techniques, low and high magnetic field measurements, Measurement and control. Signal conditioning and recovery. Impedance matching, amplification (Op-amp based, instrumentation amp, feedback), filtering and noise reduction, shielding and grounding. Fourier transforms, lock-in detector, box-car integrator, modulation techniques. High frequency devices (including generators and detectors)	15 hours
Pedagogy:	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
References/Readings	1. Philip R Bevington and D Keith Robinson, Data Reduction and Error Analysis for the Physical Sciences 3rd Ed. McGraw – Hill (2003) 2. John R. Taylor,An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements, 2nd Ed. University Science Books (1997) 3. M. I. Pergament, Methods of Experimental Physics, CRC Press (2019) 4. R. Srinivasan, K. R. Priolkar and T. G. Ramesh, Experiments in Physics, Indian Academy of Sciences	

	(2018) 5. G. L. Squires, Practical Physics, 4th Edition, Cambridge University Press, (2015) 6. A. K. Ghosh, Introduction to Measurements and Instrumentation, PHI Learning Pvt. Ltd., (2012)	
Course Outcomes:	Students will be able to 1. understand the basics concepts in measurement techniques. 2. Understand about different types of sensors and detectors used to measure different physical quantities. 3. Estimate and translate errors and report quantities up to last significant digit 4. Apply statistical tools in data interpretation and analysis	

Programme: M. Sc. (Physics)
Course Code: PHS-629 **Title of the Course:** Documentation using Latex
Number of Credits: 1T + 1P
Effective from AY: 2023-24

Prerequisites for the course:	Nil	
Course Objectives:	This course provides an introduction to technical writing with Latex.	
Content:	**Introduction** Introduction and Installation of the software LaTeX. Understanding Latex compilation. **Module 1.** Basic Syntax of Latex, Writing equations, Matrix, Tables **Module 2.** Page Layout – Titles, Abstract, Chapters, Sections, References, Equation references, citation. List-making environments, Table of contents, generating new commands, Figure handling, numbering, List of figures, List of tables, Generating index. **Module 3.** Packages: Geometry, Hyperref, amsmath, amssymb, algorithms, algorithmic graphic, color, tiles listing **Model 4.** Classes: article, book, report, beamer, slides. **Module 5.** Applications to: Writing Resume Writing question paper Writing articles/ research papers Presentation using beamer. Preparing Poster.	5 hours 6 hours 7 hours 6 hours 3 hours 18 hours
Pedagogy:	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
References/Readings:	1. Dilip Datta, LaTeX in 24 Hours: A Practical Guide for Scientific Writing, Springer, (2017). 2. Leslie Lamport, LaTeX: A Document Preparation System, Addison-Wesley Professional (1994). 3. Frank Mittelbach, Michel Goossens, Johannes Braams, David Carlisle and Chris Rowley, The LaTeX Companion, 2nd edition (TTCT series), Addison-Wesley Professional, 2004	
Course Outcomes:	Student will be able to 1. Create basic types of LaTeX documents (article, report, letter, book). 2. Format words, lines, and paragraphs, design pages, create lists, tables, references, and figures in LaTeX.	

	3. Create tables, typeset mathematical equations, import graphics, etc. 4. Develop large documents like books and thesis and professional presentations using LaTeX.	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-630 **Title of the Course:** Astronomy and Astrophysics

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Should have basic knowledge of electromagnetic theory, classical mechanics, thermodynamics	
Course Objectives:	The objective of this course is to develop an understanding of the scale, constituents, radiative process and stellar astronomy. A descriptive course includes the methods astronomy in different bands of electromagnetic radiation.	
Content:	**Fundamentals of Astrophysics** Major contents of universe, Black body radiation, specific intensity, flux density, luminosity, Magnitudes, Color index, Color temperature, effective temperature, Brightness temperature, Excitation temperature, kinetic temperature, stellar atmospheres	4 hours
	Astronomical Scales and techniques Units of measurement, celestial coordinates, precession, Mass, length and time scales in Astrophysics, Parallax method. Standard Candle method. Cepheid variable method. RedShift.	5 hours
	Astronomy in different bands of electromagnetic radiation Electromagnetic radiation, Optical astronomy , Radio astronomy , Infrared, UV and X-ray astronomy.	5 hours
	Radiative Processes Basics of theory of radiation field, radiation transfer equation, thermal radiation, radiative diffusion, basics of radiative transfer, elementary stellar atmospheres, relativistic electrodynamics, emission of electromagnetic radiation, scattering, Brehmstrahlung, synchrotron radiation, inverse-Compton process, plasma effects.	6 hours
	Stellar Physics Electromagnetic spectrum, spectral classification of stars, HR diagram, stellar opacities, Energy Generation in Stars: Calculation of thermonuclear reaction rates, the various reaction chains: PP chain and CNO cycle, He-burning, C-burning, Si-burning, photo-dissociation, neutrino emission from stars, Chandrashekhar limit.	5 hours
	Physics of Compact Objects Properties of black holes, white dwarfs, and neutron stars, formation of compact objects, equilibrium configurations, equations of state, stability criteria, and mass limits, the influence of rotation and magnetic fields, pulsar phenomena, black hole spacetimes, Hawking radiation,	5 hours

	mass flow in binary systems, spherical and disk accretion, high-temperature radiation processes, pulsar spin-up, compact x-ray sources and x-ray bursts, supermassive black holes in star clusters and galactic nuclei, gravitational and neutrino radiation from supernova collapse and binary coalescence.	
Pedagogy:	Lectures / tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. G. B. Rybicki & A. P. Lightman, Radiative Processes in Astrophysics, John Wiley, 1985. 2. A. E. Roy and D. Clarke, Astronomy Principles and Practice, 4th ed., Institute of Physics, 2003. 3. A R Choudhuri, Astrophysics for Physicist, Cambridge press,2010 4. J.V. Narlikar, The Structure of the Universe, Oxford University Press, 1977	
Course Outcomes:	Student will be able to 1. Recognize the content of the universe, distances, mass, colour and temperature of stars. 2. Understand the astronomical measurement units and techniques. 3. Gain knowledge about light emitted by stars in the electromagnetic spectrum. 4. Gain awareness of different radiative processes. 5. Gain knowledge about compact objects and their formations.	

Programme: M. Sc. (Physics) (Computational Physics)

Course Code: PHC-622 **Title of the Course:** BEC and Superfluidity

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Should have basic knowledge of electrodynamics, thermodynamics and quantum mechanics, and solid-state physics	
Course Objectives:	To introduce up-to-date experimental and theoretical progress in BEC and superfluidity.	
Content:	**Superfluid Helium-4** Introduction, Classical and quantum fluids, the macroscopic wave function, Superfluid properties of He II, Flow quantization and vortices, the momentum distribution, quasiparticle excitations. **Superfluid Helium-3** Introduction, The Fermi liquid normal state of He-3, the pairing interaction in liquid He-3, Superfluid phases of He-3. **Bose-Einstein Condensates-Theory** Ultracold atomic gases. Bose-Einstein condensation in an ideal gas. Interacting Bose-Einstein condensates. Dynamics of Bose-Einstein condensates. Elementary excitations. Bose-Einstein condensates at finite temperatures. Two-dimensional Bose gases. Quantum vortices in Bose-condensed gases. True and quasi condensates in one-dimensional trapped gases. Solitons in 1D Bose-condensed gases. Strongly interacting 1D Bose gases. Rapidly rotating Bose gases. **Bose-Einstein Condensate-: Experiment** Ultracold quantum gases: What? Why? How? Atom-laser interaction, Bloch sphere Dressed state picture, Optical Bloch equations Light forces, Molasses cooling, Sisyphus cooling Atomic beam oven, Zeeman slower, Magneto-optical trap Optical dipole trap, Magnetic trap, Technology, Evaporative cooling, Characterizing a BEC.	8 hours 5 hours 10 hours 7 hours
Pedagogy:	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
References/Readings	1. James F. Annett, Superconductivity, Superfluids and Condensates Oxford Series in Condensed Matter Physics (2004). 2. R.P. Feynman, Statistical Mechanics, Westview Press, (1972). 3. K. Huang, Statistical Mechanics, Wiley Eastern Limited, (1988). 4. Ph. Nozieres and D. Pines, Theory of quantum liquids, Vol II, CRC. (2019).	

	5. S. Stringari and L. Pitaevskii, Bose-Einstein condensation, Clarendon Press, (2003). 6. C.J. Pethick and H. Smith, Bose-Einstein condensation in dilute gases, Cambridge University Press, (2011). 7. H. J. Metcalf and P. van der Straten, Laser Cooling and Trapping, Springer (1999). 8. D. Jervis and J. H. Thywissen, Making an ultracold gas, arXiv:1401.7659, (2014).	
Course Outcomes:	Students will be able to 1. understand the basics of superfluidity. 2. Understand the different process of laser cooling and trapping techniques. 3. Differentiate between BEC and superfluid state. 4. characterize ultracold quantum gases.	

Programme: M. Sc. (Physics) (Computational Physics)

Course Code: PHC-623 **Title of the Course:** Introduction to Quantum Information and Computing

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Basic knowledge of Quantum mechanics.	
Course Objectives:	This course provides an introduction to the theory and practice of quantum computation.	
Content:	**Introduction** Need of Quantum Computing, Postulates of Quantum Mechanics, Qubits, Bloch sphere representation, Multiple Qubit States, Quantum Gates, and Quantum Circuits.	8 hours
	Quantum measurement and communication protocols No-Cloning Theorem and Quantum Teleportation, Super Dense Coding, Density Matrix, Bloch Sphere, Measurement Postulates.	5 hours
	Quantum Algorithms Deutsch Algorithm, Simon Problem. Grover's Search Algorithm, Grover's Search Algorithm, Quantum Fourier Transform, Shor's Factorization Algorithm.	7 hours
	Quantum Information theory Classical Information Theory, Shannon Entropy, Shannon's Noiseless Coding Theorem, Von Neumann Entropy, EPR and Bell's Inequalities, Cryptography and RSA Algorithm, Quantum Cryptography	7 hours
	Quantum error correction and experimental aspects Quantum error correction, Experimental Aspects of Quantum Computing.	3 hours
Pedagogy:	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
References/Readings:	1. Michael A. Nielsen and Issac L. Chuang, Quantum Computation and Information, Cambridge University Press (2002). 2. Mikio Nakahara and Tetsuo Ohmi, Quantum Computing, CRC Press (2008). 3. N. David Mermin, Quantum Computer Science, Cambridge University Press (2007) 4. Mark M. Wilde, Quantum Information theory, Cambridge University Press (2017) 5. H.-K. Lo, T. Spiller and S. Popescu, Introduction to Quantum Computation and Information, World Scientific, (1998). 6. G. Benenti, G. Casati and G. Strini, Principles of	

	Quantum Computation and Information., World Scientific (2004).	
Course Outcomes:	Students will be able to 1. Differentiate between classical and quantum computer. 2. Identify key quantum mechanical properties as computational resource. 3. understand basic quantum gates, circuits, and algorithms. 4. understand the basics of Quantum Information Theory and the importance of Quantum error correction.	

Programme: M. Sc. (Physics)

Course Code: PHC-624 **Title of the Course:** Introduction to Particle Physics

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Basic knowledge of Quantum Mechanics	
Course Objectives:	To introduce students the fundamental principles and concepts in particle physics and particle accelerators	
Content:	**Introduction to Elementary Particles:** Historical introduction, Mesons, Baryons, antiparticles, neutrinos, strange particles, The eightfold way and the quark model	4 hours
	Cross-section and decay rates: Cross-sections, decay rates, resonances, Breit-Wigner formula	3 hours
	Relativistics Kinematics: Lorentz Transformations and Four-vectors Energy and Momentum conservations Classical and Relativistic Collisions, examples and applications	5 hours
	Elementary Particle Dynamics: Introduction to Feynman diagrams and four forces Quantum Electrodynamics (QED), Quantum Chromodynamics (QCD), and Weak interactions Weak and Electromagnetic couplings of W and Z Decays and conservation law, and unification schemes.	7 hours
	Symmetries Symmetries, groups, and conservation Laws Angular momentum and addition of angular momenta Flavor Symmetries, Discrete Symmetries, Parity, Charge Conjugation and CP symmetries Neutral Kaons, CP Violation and Time Reversal and the TCP Theorem	7 hours
	Particle accelerators: Introduction to modern accelerators LHC at CERN and and RHIC and BNL, event rates and luminosity. Large detector systems at electron-positron, electron-proton and hadron colliders.	4 hours
Pedagogy:	Lectures/tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning.	

References/Readings	1. David Griffiths, Introduction to Elementary Particles, Wiley (2008) 2. M. Thomson, Modern Particle Physics, Cambridge University Press India (2016) 3. F. Halzen and A. D. Martin, Quarks and Leptons, John Wiley (1984)	
Course Outcomes:	Student will be able to 1. Classify elementary particles and fundamental forces, 2. Construct Feynman diagrams for reactions. 3. Learn particle states and their quantum numbers, conservation laws, and symmetries in nature. 4. Learn modern particle accelerators and its working	

Programme: M.Sc (Physics)(Biophysics)

Course Code: PHB-622 **Title of the Course:** Solid state and Biomaterials

Number of Credits: 4

Effective from AY: 2023-24

Prerequisites for the course:	None	
Course Objectives:	This course is intended to introduce the concepts in biomaterials. The students will have a good understanding of the different bio materials and their properties. A brief introduction to new and advanced materials for biological applications will also be covered in the course.	
Content:	**Introduction to Solid State** Crystal structure, Crystal Binding, Phase changes, crystal imperfections, defects and dislocations, non-crystalline solids, surface energy, contact angle, surface tension, Types of materials-ceramics, metals, semiconductors, polymers, composites, Impact of biomaterials	15 hours
	Properties of Materials Mechanical properties-elasticity, stress, strain, tensile strength, plastic deformation, hardness, thermal properties, optical properties,	15 hours
	Biomaterials I Introduction to biomaterials, property requirements for biomaterials, concept of biocompatibility, structure of cells and biological tissues, cell material interaction and response to foreign bodies, histocompatibility, genotoxicity.	15 hours
	Biomaterials II Important biometallic alloys: Ti-based, stainless steels, Co-Cr-Mo alloys, Nitinol, Tantalum and magnesium, Bioinert, Bioactive and bioresorbable ceramics, Processing and properties of different bioceramic materials silicates, aluminates, Zirconia, hydroxyapatite tricalcium phosphatecalcium sulfate, bioactive glasses, Synthesis of biocompatible coatings on structural implant materials, Microstructure and properties of glass-ceramics, common biocompatible polymers and their properties, biodegradable polymers, Natural biomaterials, design concept of developing new materials for bioimplant applications, Nanobiomaterials	15 hours
Pedagogy:	Lectures/Tutorials/Assignments Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. Ratner, Hoffman, Schoet and Lemons Eds, Biomaterials Science: An introduction to Materials in	

	Medicine, Third Edition, Elsevier Academic Press (2012). 2. Mauli Agrawal, Ong, Appleford and G. Mani, Introduction to Biomaterials: Basic Theory with Engineering Applications, First Edition, Cambridge Press, (2013). 3. Fredrick H. Silver and David L. Christiansen, Biomaterials Science and Biocompatability, Piscataway, First Edition, Springer (1999). 4. John B Park and Roderik S Lakes, Biomaterials: An Introduction, Third Edition, Springer, (2007). 5. Wang, M. Ramalingam, X. Kong L. Zhao, Eds., Nanobiomaterials: Classification, Fabrication and Biomedical Applications, First Edition, Wiley (2018). 6. Roger Narayan, Nanobiomaterials, First Edition, Elsevier (2017).	
Course Outcomes:	Student will be able to 1. Get familiarized with the basic types of biomaterials and their properties. 2. Gain sufficient knowledge in the biomaterials and their applications. 3. Acquire knowledge of recent developments in biomaterial engineering and nanobiomaterials. 4. Develop an understanding of biocompatible materials.	

Programme: M. Sc. (Physics)(Solid State Physics)

Course Code: PHS-603 **Title of the Course:** X-ray Spectroscopy

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Basic knowledge of Solid State Physics/Chemistry and Electromagnetic waves	
Course Objectives:	To introduce students to various techniques in x-ray spectroscopy and their applications to condensed matter physics, chemistry and material science.	
Content:	**X-rays: Sources and Interaction with matter** X-rays: Waves and photons, Scattering, Absorption, Refraction and Reflection. X-ray tubes, Synchrotron radiation, Bending magnet sources, Undulator radiation, Wiggler radiation. X-ray detection	6 hours
	Scattering of X-Rays Scattering from an electron, scattering from an atom, scattering from a molecule, scattering from liquids and glasses, small angle x-ray scattering, scattering from a crystal, Debye-Waller factor, measured intensity from a crystallite.	8 hours
	X-ray Absorption Absorption coefficient, absorption edge, Definition: x- ray absorption fine structure (XAFS), x-ray absorption near edge structure (XANES), extended x-ray absorption fine structure (EXAFS), History, Theory of XAFS, XAFS Experiment, Beamline and optics, Data acquisition, treatment and modelling, XANES as fingerprint technique, x-ray magnetic circular dichroism.	8 hours
	Photoelectron Spectroscopy Photoelectric Effect, history of x-ray photoelectron spectroscopy (XPS), theoretical model – three step model, instrumentation, the electron mean free path, Auger electrons, core level binding energies in atoms, molecules and solids, final state effects, valence band in solids, band structure, angle resolved photoelectron spectroscopy (ARPES).	8 hours
Pedagogy:	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
References/Readings	1. Jens Als-Nielsen and Des Mc Morrow, Elements of Modern X-ray Physics, 2^{nd} Edition, Wiley 2011. 2. B.D.Cullity and S. R. Stock, Elements of X-ray Diffraction, 3rd edition, Pearson Education, 2014. 3. Grant Bunker, Introduction to XAFS, Cambridge University Press, 2010.	

	4. Stefan Hufner, Photoelectron Spectroscopy, Principles and Applications, Springer 2003.	
Course Outcomes:	Students will be able to 1. gain knowledge about characteristics of different X-ray sources, especially synchrotron radiation sources. 2. understand the principles, experimental equipment, basic data analysis methods with respect to X-ray diffraction (XRD), X-ray photoemission and X-ray absorption spectroscopy, 3. understand the kind of structural information obtained from the three x-ray spectroscopic methods. 4. Analyse the spectroscopic data to extract physical information.	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-604 **Title of the Course:** Optical Spectroscopy

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Should have studied courses in classical mechanics, electromagnetism, elementary quantum mechanics and nuclear physics.	
Course Objectives:	To introduce different optical spectroscopic techniques that can be used for characterization of materials, especially in condensed matter.	
Content:	**Electronic Spectroscopy** One-electron and two-electron atoms: spectrum of hydrogen, helium and alkali atoms; Many electron atoms: Hund's rule, L-S and j-j coupling, Spectroscopic terms, Lande interval rule; Interaction with Electromagnetic fields: Zeeman, Paschen Back and Stark effects, electron spin resonance spectroscopy, Hyperfine structure and isotope shift, selection rules; Lamb shift, Electromagnetic radiation, Absorption and Emission of radiation, Line width and its broadening mechanisms, Spontaneous and stimulated emissions, Einstein coefficients, Introduction to lasers and laser spectroscopy	15 hours
	Molecular Spectroscopy Microwave spectroscopy, Infrared spectroscopy, the vibrating diatomic molecule – simple harmonic oscillator, the anharmonic oscillator, the diatomic vibrating rotator, Interaction of rotation and vibrations, the vibrations of polyatomic molecules, Raman spectroscopy– Electronic spectra of diatomic molecules – Born-Oppenheimer approximation, vibrational coarse structure – progressions. Intensity of vibrational transitions – the Franck-Condon principle. Optical absorption: Free carrier absorption-optical transition between bands-direct, and indirect-excitons, Luminescence in crystal - excitation and emission - decay mechanism, Fluorescence, Phosphorescence, Crystal Field Theory, Spectroscopy of transition metals complexes, Fluorescence spectroscopy, Introduction to time-resolved spectroscopy	15 hours
Pedagogy:	Lectures/ tutorials/seminars/ term papers/assignments/ presentations/ self-study. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. B. H. Bransden and C. J. Joachain, Physics of Atoms	

	and Molecules, 2nd Edition, Pearson; 2008. 2. C. N. Banwell and E. M. McCash, Fundamentals of Molecular Spectroscopy, 4th Edition, Tata McGraw, 2004 3. H. E. White, Introduction to Atomic Spectra, Tata McGraw Hill, 1934. 4. K. Thayagarajan and A.K Ghatak, Lasers Theory and Applications, Macmillan (Tata McGraw Hill) 1995. 5. D. Satyanarayana Handbook of Molecular Spectroscopy, International Publishing House, 2015, 1st edition 6. A. H. Kitai, Solid State Luminescence, Chapman and Hall London; 1993. 7. D. R. Vij, Eds, Luminescence of Solids, Plenum Press, New York, 1998.	
Course Outcomes:	1. Understand different optical spectroscopic techniques 2. Learn concepts of atomic and molecular physics 3. Apply the techniques for the experimental characterisation of materials. 4. Demonstrate knowledge in recent developments in optical spectroscopy.	

Programme: M. Sc. (Physics) (Solid State Physics)
Course Code: PHS-605
Title of the Course: Nuclear Spectroscopy for Condensed Matter
Number of Credits: 2
Effective from AY: 2023-24

Prerequisites for the course	Should have studied classical mechanics, electromagnetism, elementary quantum mechanics and nuclear physics.	
Objectives	To introduce the concept of methods that uses properties of a nucleus to probe material properties	
Content	**Properties of a nucleus:** Nuclear magnetic dipole moment, nuclear electric dipole moment, nuclear decays, magnetic and electric hyperfine interactions	4 hours
	Nuclear Magnetic Resonance (NMR) Spectroscopy: Principles, classical treatment of NMR (Bloch equations), quantum theory of NMR, experimental methods, Chemical shift, Knight shift in metals, spin-lattice relaxation, spin-spin relaxation, applications.	6 hours
	Mossbauer Spectroscopy: Principles, The Debye-Waller Factor, Mossbauer Sources and Experimental Apparatus, Isomer Shifts, Electric quadrupole interaction, Magnetic Dipole Interaction, Quadratic Doppler effect, Results from Mossbauer spectroscopy.	6 hours
	Neutron Scattering: Neutrons and Neutron Sources, neutron spectrometer and detectors, the process of neutron scattering, response function and correlation function for inelastic neutron scattering, results from neutron scattering.	6 hours
	muon spin rotation (μSR) spectroscopy: Muons and muon spin rotation, influence of internal fields, results from μSR	4 hours
	Positron annihilation spectroscopy (PAS): Positrons in solids, positron sources and spectrometers, results from PAS	4 hours
Pedagogy	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
Reference/Readings	**Text Books/References:** 1. G. Schatz and A. Weidinger, Nuclear condensed matter physics: nuclear methods and applications, John Wiley; 1997. 2. H. Kuzmany, Solid-state spectroscopy, Springer, 1998. 3. A. Beiser, Concepts of Modern Physics, McGraw Hill Education, 6^{th} Edition, 2003 4. R. Schafer and P. C. Schmidt, Methods in Physical Chemistry, Wiley-VCH Verlag GmbH & Co. 2012	

Course Outcomes:	Student will be able to 1. Learn NMR, Mossbauer, neutron scattering, µSR, and PAS spectroscopic techniques 2. Apply the techniques in experimental characterization of materials. 3. Know applications of these techniques in different fields 4. gain knowledge about hyperfine interactions.	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-606 **Title of the Course:** Introduction to Crystallography and X-ray Diffraction

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Basic knowledge of Solid State Physics / Solid State Chemistry	
Course Objectives:	This course is designed to familiarize students with general aspects of symmetry, crystal structure and X-ray diffraction and use the basic understanding in the characterization of materials.	
Content:	**Introduction to Symmetry and Crystal Structures** Symmetry elements and their operations, Unit cell and crystal systems, Bravais lattice, Point groups and space groups and their stereographic representations, Herrmann-Mauguin and Schoenflies notations, Group-subgroup-supergroup relationships, Equivalent points, General and special positions, Deriving general positions of space groups, Wyckoff notations and site symmetry, Shifting of origin in lattice, Crystal directions and planes, Miller indices, Real space vs reciprocal lattice, Close packed structures, Octahedral and tetrahedral sites, Asymmetric unit, Concept of Z and Z′, Metric matrix, Deriving bond length and bond angles, Introduction to quasicrystals and their importance	7 hours
	X-ray Scattering and Structure Factors White and Characteristic X-rays, Laboratory and synchrotron X-ray sources and their properties, Coherent and incoherent scattering, Scattering of X-rays by an electron, atom and crystal, Atomic scattering factor, Structure factor, Fourier transform, Electron density, Laue’s equations, Bragg’s law, Ewald’s sphere, Limiting sphere and reflecting sphere, Bragg’s law in reciprocal space, Systematic absences, Deriving conditions for systematic absences, Phase problem in crystallography, Solution to the phase problem, Direct method, Patterson method, ∇F synthesis, L-P corrections, Temperature factors, Absorption and extinction of X-rays, Friedel’s law and Absolute configuration determination, Anomalous scattering, Laue method, X-ray detectors	8 hours
	Single Crystal X-ray Diffraction (SCXRD) Pros and cons of single crystal and powder X-ray diffraction, Single crystal growth and selection, Indexing of crystals, Data collection, Data reduction, Space group determination, Structure solution and refinement, Parameters/constraints/restraints, Anisotropic	5 hours

	displacement parameters (ADPs), Reliable (R) factor, Twining, Treatment of disordered structures, Introduction structure refinement software: OLEX2 and WinGX, Crystal structure analysis, CIF preparation, Validation of structures, Examples: X-ray data of aspirin and $KHSO_4$ **Powder X-ray Diffraction (PXRD)** Importance of PXRD method, Background of methodology, Geometrical basis of PXRD, Sample preparation, background noise determination, Indexing powder pattern, Le-bail profile fitting, Rietveld refinement, phase identification and quantification, Crystallite size and strain determination, Example: PXRD of CeO_2 **Total X-ray Scattering and Pair Distribution Function (PDF)** Short- and long-range order, Bragg and diffuse scattering concepts, atomic scattering amplitude, Debye's scattering intensity, Total scattering structure function, atomic PDF, Structure and reaction mechanism, Examples: Ni and WO_3 nanoparticles	 5 hours 5 hours
Pedagogy:	Lectures/tutorials/term papers/assignments/presentations/self-study	
References/Readings	1. C. Giacovazzo, Fundamentals of Crystallography, Oxford Science Publications, 2011. 2. G. H. Stout and L. H. Jensen, X-ray Structure Determination: A Practical Guide, John Wiley and Sons, New York, 1989. 3. B. D. Cullity and S. R. Stock, Elements of X-ray Diffraction, 3rd edition, Pearson Education, 2014. 4. C. Hammond, The Basics of Crystallography and Diffraction, Oxford Science Publications, 2015. 5. Jens Als-Nielsen and Des Mc Morrow, Elements of Modern X-ray Physics, 2nd Edition, Wiley 2011. 6. W. Massa, Crystal Structure Determination, Springer, 2000. 7. R. A. Young, The Rietveld Method, Oxford University Press, 1993. 8. T. Egami and S. J. L. Billinge, Underneath the Bragg Peaks: Structural Analysis of Complex Materials, Pergamon Materials Series, Volume 16, 2012	
Course Outcomes:	Student will be able to 1. acquire basic understanding of crystallography and X-ray diffraction in the solid state. 2. Gain knowledge of single crystal, powder X-ray diffraction and PDF methods. 3. apply X-ray scattering methods as an experimental	

	tool for materials characterization. 4. Evaluate the structural details from x-ray data.	

Programme: M. Sc. (Physics) (Solid State Physics)
Course Code: PHS-607 **Title of the Course:** Magnetism in Condensed Matter Physics
Number of Credits: 2
Effective from AY: 2023-24

Prerequisites for the course:	Basic knowledge of Solid-State Physics / Solid State Chemistry	
Course Objectives:	This course is designed to familiarize students with general and specific aspects of magnetic interaction in condensed matter and methods of magnetic measurements.	
Content:	**Magnetic structures and interactions** Diamagnetism, Paramagnetism, Ferromagnetism, Antiferromagnetism, Effect of magnetic field, Ferrimagnetism, Dipolar interactions, Exchange interactions – origin, direct and indirect exchange, Indirect exchange in ionic solids, indirect exchange in metals, Double exchange, Anisotropic exchange	11 hours
	Measurement of magnetic order Magnetic fields, Atomic scale magnetism, Domain scale measurements, Bulk magnetism measurements – magnetization and magnetic susceptibility, Neutron scattering, other techniques	4 hours
	Order and broken symmetry Broken symmetry, Landau theory of ferromagnetism, Heisenber and Ising models (1D and 2D), Consequences of broken symmetry, Phase transitions, Rigidity, Excitations – magnons, Domains, Domain walls, Magnetocrystalline anisotropy, Domain wall width, Magnetization process, Observation of domain wall, small magnetic particles, Stoner-Wohlfarth model, Soft and hard materials	8 hours
	Magnetism in metals Pauli paramagnetism, spontaneously spin-split bands, spin- density functional theory, Landau levels, Landau diamagnetism	3 hours
	Competing interactions and low dimensionality Frustration, Spin glasses, Superparamagnetism, One dimensional and two-dimensional magnets – spin chains, Spinons Haldane chains, Spin-Peierls transitions, spin ladders, Magnetoresistance, Magneto-optics	4 hours
Pedagogy:	Lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
References/Readings	1. D. C. Mattis, Theory of Magnetism. Springer Verlag, 1981. 2. J. M. D. Coey, Magnetism and magnetic materials. Cambridge University Press, 2010. 3. Stephen Blundell, Magnetism in Condensed Matter. Oxford University Press, 2001.	

Course Outcomes:	Students will be able to 1. acquire basic understanding of Magnetism and magnetic interactions in solids. 2. Distinguish between different types of magnetic order and magnetically frustrated states. 3. Gain knowledge of different experimental methods of measuring magnetization at bulk, domain size and atomic level. 4. Understand magnetic order in low dimensional systems.	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-608 **Title of the Course:** Microscopy Techniques for Condensed Matter

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course	Basic knowledge of Solid State Physics	
Objectives	Student will be able to gain knowledge about working principle, instrumentation, material imaging and data analysis using imaging techniques such as Transmission electron microscopy, scanning electron microscopy and scanning probe microscopy.	
Content	**Transmission Electron Microscopy (TEM)** Interaction of electrons with matter, elastic and inelastic scattering, secondary effects, Instrumentation: Electron sources, pumps and holders, lenses, apertures, and resolution, Diffraction in TEM: Selected area diffraction, specimen preparation, Imaging and interpretation.	10 Hours
	Scanning Electron Microscopy (SEM) Electron beam -specimen interaction, Backscattered electrons, Secondary electrons, SEM instrumentation, specimen preparation, Image formation and interpretation, Image defects, data analysis using Image J, Energy Dispersive Spectroscopy (EDS).	10 Hours
	Scanning Probe Microscopy (SPM) Introduction, principle, Atomic Force Microscope instrumentation (AFM), Forces Between Tip and Sample, Technical Aspects of Atomic Force Microscopy, Calibration of AFM Measurements, Static Atomic Force Microscopy, Amplitude Modulation (AM) Mode in Dynamic Atomic Force Microscopy, Intermittent Contact Mode/Tapping Mode, Frequency Modulation (FM) Mode in Dynamic Atomic Force Microscopy—Non-contact Atomic Force Microscopy, AFM image artefacts, Applications of AFM, Scanning Tunnelling Microscopy (STM): Overview, Experimental Realization of Spectroscopy with STM, Normalized Differential Conductance, Relation Between Differential Conductance and the Density of States, Asymmetry in the Tunnelling Spectra, Energy Resolution in Scanning Tunneling Spectroscopy, Barrier Height Spectroscopy, Spectroscopic Imaging with examples, Vibrational Spectroscopy with the STM, Principles of Inelastic Tunneling Spectroscopy with the STM, Examples of Vibrational Spectra Obtained with the STM	10 Hours

<u>References/Readings</u>	1. David B. Williams and C. Barry Carter, Transmission Electron Microscopy-A Textbook for Materials Science, Springer US, 2nd edition, 2009. 2. Joseph I. Goldstein, Dale E. Newbury, Joseph R. Michael, Nicholas W.M. Ritchie, John Henry J. Scott, David C. Joy, Scanning Electron Microscopy and X-Ray Microanalysis, Fourth Edition, Springer 3. Peter Eaton, Atomic Force Microscopy, Oxford University Press, 2010 4. Bert Voigtlander, Scanning Probe Microscopy: Atomic Force Microscopy and Scanning Tunneling Microscopy, Nano Science and Technology, Springer, 2015, 5. C. Julian Chan, Introduction to Scanning Tunnelling Microscopy, Second Edition, Oxford Science Publication, 2007 6. Thomas G., Transmission electron microscopy of metals, John Wiley, 1996.	
Course Outcomes:	Student will be able to 1. understand basic principle of electron microscopic techniques 2. learn concepts of force microscopy. 3. Gain knowledge of working, data capturing and data analysis using TEM, SEM and SPM. 4. Apply microscopic techniques to different physical systems.	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-609 **Title of the Course:** Thin film Physics

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Basic knowledge of concepts in physics, chemistry, electrochemistry and experimental techniques.	
Course Objectives:	To introduce various types of thin films techniques, growth mechanisms and their applications.	
Content:	**Introduction to Thin Films** Definition of thin films, Comparison of thin and thick films, Theory of growth of thin films: Nucleation, condensation, Capillarity model, Atomistic model, comparison of models, various stages of film growth.	4 hours
	Physical, Electrochemical, Chemical Deposition Techniques Overview of vacuum techniques, physical vapour deposition, chemical vapour deposition, molecular beam epitaxy, sputtering, electron –beam deposition, pulsed laser ablation. Electrodeposition: deposition mechanism and preparation of compound thin film, anodization, chemical bath deposition, successive ionic layer adsorption reaction method (SILAR) method Spray pyrolysis: deposition mechanism and preparation of compound thin films, sol-gel method, hydrothermal method.	8 hours
	Characterization of Thin Films Thickness measurement - Tolansky technique, Talystep (styles) method, Quartz crystal microbalance, Stress measurement by optical method, Gravimetric method. Influence of thickness on the resistivity of thin films, Hall Effect & Magneto-resistance in thin films, Fuch-Sondhemir theory, TCR and its effects. Mechanical properties: Contact angle (hydrophobicity and hydrophillicity), Adhesion and its measurement with mechanical and nucleation methods, stress measurement by using optical method. Structural characterization: X-ray diffraction (GI-XRD)	10 hours
	Emerging Thin Film Materials and Applications Patterning techniques (Photolithography), Diamond Films, Thin film resistors, capacitors, Junction devices (Diodes, Transistors, Solar cells), ICs, Thin film sensors (gas and humidity), Thin films for information storage (Magnetic and optical recording), Metallurgical applications, Photo thermal converters, Optical coatings, Electro acoustics and telecommunication	8 hours

Pedagogy:	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
References/Readings	1. Maissel and Glang, Hand book of Thin Film Technology, Mc Graw Hill 1970. 2. K. L. Chopra Thin Film Phenomena, Mc Graw Hill, 1969. 3. M. Ohring, Material Science of Thin Films, Academic Press, 2nd edition, 2001. 4. J. L. Vossen and W Kern, Thin Film Process, Academic Press 1st edition, 1991. 5. A. Roth, Vacuum Technology, 3rd updated and revised edition, Elsevier, North Holland, 1990 6. Joy George Properties of Thin Films, , 1st edition Marcel and Decker, 1992 7. R.K. Pandey, S.N. Sahu, S. Chandra, Handbook of semiconductor electrodeposition, Marcel Dekker, 1996.	
Course Outcomes:	Students will be able to 1. Learn about different techniques and growth mechanism of thin films. 2. Gain knowledge about characteristics of thin film materials. 3. Understand structural and mechanical properties of thin films 4. Comprehend applications of thin film in various fields	

Programme: M. Sc. (Physics) (Solid State Physics)

Course Code: PHS-610 **Title of the Course:** Physics of Glasses

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Should have basic knowledge of Solid-state Physics, Thermodynamic and statistical mechanics	
Course Objectives:	To introduce students to the Physics governing amorphous materials. The course includes the preparation of amorphous materials, kinetics and their characterization methods.	
Content:	**Amorphous materials** Introduction, Definition, difference between crystalline and amorphous materials, properties of amorphous materials, Examples of amorphous materials, Methods of preparation of amorphous materials.	5 hours
	Glasses Historical perspective of glass, Types of glasses. Refractive index, color, density, porosity, transparency, viscosity	3 hours
	The Glass transition The glass transition-change in volume with temperature, glass formation vs crystallization, Thermodynamic phase transition, Entropy, Relaxation, Factors determining glass transition temperature, Theory of glass transition, kinetics of glass formation,	8 Hours
	Structure of glass Network former, network modifier, Intermediates, Structure and topology, Zachariasen random Network theory, coordination number, radial distribution function, structural modelling	9 hours
	Experimental techniques Microscopy, X-ray diffraction, small angle scattering, vibrational spectroscopy, Raman spectroscopy, Thermal analysis.	5 hours
Pedagogy:	Lectures / tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. S R Elliott, Physics of Amorphous materials, Longman, Harlow, 1990 2. Richard Zallen, The Physics of Amorphous materials, Wiley VCH, 2004. 3. B. D. Cullity and S. R. Stock, Elements of X-ray Diffraction, 3rd edition, Pearson Education, 2014. 4. G. L. Squires, Introduction to the theory of Thermal Neutron Scattering, Cambridge University Press (1978) 5. J D Richard Tilley, Understanding solids: the science of	

	materials, Wiley publication, 2004 6. K Nakamoto, Infrared and Raman spectra of Inorganic and coordination compounds, 6th Edition Wiley Publication,2009	
<u>**Course Outcomes:**</u>	Students will be able to 1. Distinguish between crystalline and amorphous materials. 2. Acquire knowledge of glass history and important properties of glass. 3. Understand kinetics and thermodynamic of glass formation 4. Aware of basic rules of glass formation and structure 5. Understand different methods of characterization of glasses.	

Programme: M. Sc. (Physics) (Computational Physics)
Course Code: PHC-603 **Title of the Course:** Simulation Techniques
Number of Credits: 2 (1T+1P)
Effective from AY: 2023-24

Prerequisites for the course:	Basic knowledge of Computer programming, Quantum mechanics and Statistical mechanics.	
Course Objectives:	To introduce computational methods for simulating many-body systems in condensed matter physics.	
Content:	Monte Carlo methods for classical spin systems Exact diagonalization of quantum lattice models The density matrix renormalization group and tensor network methods	7T+4P=19 hours 1T+2P=7 hours 7T+4P=19 hours
Pedagogy:	Lectures/Laboratory practicals. Sessions shall be interactive in nature to enable peer grouplearning.	
References/Readings	1. J. Thijssen, Computational Physics, Second Edition, Cambridge University Press, 2012. 2. Tao Pang, An Introduction to Computational Physics, Second Edition, Cambridge University Press, 2006 3. U. Schollwock, The density-matrix renormalization group in the age of matrix product states, Annals of Physics **326**, 96192 (2011)	
Course Outcomes:	Student will be able to 1. Understand the need for numerical simulations to study lattice models 2. Acquire knowledge of various numerical techniques like exact diagonalization, DMRG and Monte Carlo method. 3. Develop computer programs for the same 4. Apply these methods to study many-body condensed matter systems. 5. Infer the advantages and limitations of these methods.	

Programme: M. Sc. (Physics)
Course Code: PHC-604 **Title of the Course:** Physics of Quantum Materials
Number of Credits: 2
Effective from AY: 2023-24

Prerequisites for the course	Should have studied modern physics	
Objectives	The aim of this course is to give a background relevant to research in the physics of topological materials and low dimensional structures and quantum devices.	
Content	**Physics of topological materials:** Berry phase, Dirac fermions, Hall conductance and its link to topology, and the Hofstadter problem of lattice electrons in a magnetic field, Linear response theory, Topological phases of matter such as Chern insulators and two- and three-dimensional topological insulators. Angle, Spin, and Depth Resolved Photoelectron Spectroscopy on Quantum Materials, Results of topological insulators, HgTe, Bi_2Se_3 family (Bi_2Te_3, Sbi_2Te_3) topological semimetal Na_3Bi, quantum spin Hall insulator WTe_2	11 hours
	Physics of low dimensional systems: Concepts about heterostructures and resulting low dimensional systems such as quantum wells, nanowires and quantum dots. Quantum physics applied to such systems. Optical properties of low dimensional systems (transition rules, polarisation etc). Electron transport properties of 2D and 1D system. Quantised conductance with Landauer-formalism. Scattering phenomena in 1D. Devices based on quantum phenomena and Coulomb blockade.	11 hours
	Low dimensional quantum magnetism: Dimers, Shastry-Sutherland network, Dimers, Bose-Einstein condensation, Chains, spin liquids, phase transitions, spin gap, long-range order, Ladders, Nersesyan-Tsvelik network, Layers, triangular, Kagome and honeycomb lattices, Examples.	8 hours
Pedagogy	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
Reference/Readings	**Text Books/References:** 1. N. W. Ashcroft and N. D. Mermin, Solid State Physics, Cengage Learning Publishers, 1976 1st Edition. 2. John Singleton, Band Theory and Electronic	

	Properties of Solids, Oxford University Press, (2012) 3. B. Yan and S-C. Zhang, Topological Materials, Rep.Prog. Phys. **75** (2012) 096501 4. Kane C L and Mele E J, Quantum Spin Hall Effect in Graphene, *Phys. Rev. Lett.* **95** (2005) 226801 5. B. A. Bernevig and S. C. Zhang, Simple Quantum Spin Hall Effect, 2006 *Phys. Rev. Lett.* **96** 106802. 6. N. Kumar, S. N. Guin, K. Manna, C. Shekhar, C. Felser, Topological Quantum Materials from the viewpoint of Chemistry, Chemical Reviews **121** (2021) 2780-2815. 7. P. D. C. King et al., Angle, Spin and Depth resolved photoelectron spectroscopy on Quantum Materials, Chemical Reviews **121** (2021) 2816-2856. 8. A. Vasiliev et al, Milestones of low-d quantum magnetism npj Quantum Materials 3 (2018) 8368	
Course Outcomes:	Students will be able to 1. Develop a broad understanding of low dimensional physics. 2. gain perspective on recently developed low dimensional materials. 3. understand topological interactions and its influence on properties of materials. 4. gain knowledge of key applications in quantum technologies.	

Programme: M. Sc. (Physics)

Course Code: PHC-605 **Title of the Course:** Superconductivity

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course	Should have basic knowledge of electrodynamics, thermodynamics and quantum mechanics, and solid state physics	
Objectives	To introduce an up-to-date experimental progresses and theories of superconductivity	
Content	**Basic Experimental Aspects** Introduction, Conduction in metals, Zero-resistivity, Meissner- Ochsenfeld effect, Perfect diamagnetism, Type-I and type-II superconductors, Application of low and high temperature superconductors.	2 hours
	Superconducting Materials Classical Superconductors: Elemental superconductors, superconducting compounds and alloys, A15 compounds, Chevrel phase compounds and their crystal structure, experimental studies on these materials, Phase diagrams. High-temperature Superconductors: La-Ba/Sr-Cu-O systems, Y-Ba- Cu-O systems, Bi-Sr-Ca-Cu-O systems, Ti-Sr-Ca-Cu-O systems, superconductivity in rare-earth and actinide compounds, organic superconductors, MgB_2 and Iron Arsenide systems, their crystal structure, phase diagrams experimental studies on these materials, Phase diagrams.	10 hours
	Theoretical Aspects Phenomenological theories: Thermodynamics of superconducting transition, expressions for critical temperature T_C, critical field H_C, London's theory, Pippard non-local theory, Ginzburg-Landau Theory. Microscopic theory: BCS theory, the electron-phonon interaction, the Cooper pair formation, BCS ground state, Consequences of the BCS theory and comparison with experimental results, Coherence of the BCS ground state and the Meissner-Ochsenfeld effect. Possible Mechanisms of high TC Superconductors	18 hours
Pedagogy	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
Reference/Readings	1. James F. Annett, Superconductivity, Superfluids and Condensates, Oxford Series in Condensed Matter Physics (2004).	

	2. J.B. Ketterson and S.N. Song, Superconductivity, Cambridge Univ. Press (1999). 3. M. Tinkham, Introduction to Superconductivity, McGraw Hill (1996). 4. C. Kittel, Introduction to Solid State Physics, Wiley, Eight Ed. (1997). 5. H. Ibach and H. Luth, Solid State Physics, Springer (2012).	
<u>Course Outcomes:</u>	Student will be able to 1. gain knowledge of different families of superconducting materials. 2. Understand phase diagrams of different superconductor families. 3. Understand theories on conventional superconductors. 4. Develop understanding of mechanisms of unconventional superconductivity.	

Programme: M. Sc. (Physics)
Course Code: PHC-606 **Title of the Course:** Advanced Particle Physics
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites for the course:	Introduction to Particle Physics (PHC-654) and Nuclear and Elementary Particle Physics (PHY-507), Quantum Mechanics (PHY-505)	
Course Objectives:	To introduce students the core principles in particle physics	
Content:	**Feynman Calculus:** Decays, scattering and cross-sections Fermi Golden rule, Golden rule for two particle decays and scattering of particles Two-body scattering in the COM frame Feynman rules for a toy theory and higher-order Feynman diagrams	10 hours
	Quantum Electrodynamics: Dirac equation, solutions to the Dirac equation, and bilinear covariants Photon, Feynman rules for QED and examples Casimir's Trick, cross-sections and lifetimes, and renormalization Hadron production in e+e- collisions Elastic electron-proton scattering	12 hours
	Quantum Chromodynamics: Feynman rules for Chromodynamics Color factors, quark and antiquark Pair annihilation in QCD Asymptotic Freedom	10 hours
	Weak Interactions: Charged leptonic weak Interactions Decay of muon, neutron, and pion Charged weak interactions of quarks Neutral weak interactions Electroweak unification and chiral fermion states Weak isospin and hypercharge, electroweak mixing	12 hours
	Gauge Theories: Lagrangian formulation of classical particle mechanics and Lagrangians in relativistic field theory Local gauge invariance and Yang-Mills Theory Chromodynamics, Feynman rules and Mass term Spontaneous symmetry-breaking Higgs Mechanism	12 hours
	Neutrino Oscillations: Solar neutrino problem and neutrino oscillations	4 hours

	Neutrino mixing and neutrino mixing matrix	
Pedagogy:	Lectures/tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning.	
References/Readings	1. David Griffiths, Introduction to Elementary Particles, 2nd edition, Wiley (2008) 2. F. Halzen and A. D. Martin, Quarks and Leptons, John Wiley (1984) 3. D. H. Perkins, Introduction to High Energy Physics, 4th edition, Cambridge (2000) 4. M. Thomson, Modern Particle Physics by Cambridge University Press India (2016)	
Course Outcomes:	Student will be able to 1. Learn Feynman diagrams, rules and calculate cross-section for QED, QCD and Weak processes. Classify particles and fundamental forces. 2. Learn about QED, QCD and Weak interactions in details 3. Gain understanding of Lagrangian formulation and local gauge invariance, spontaneous symmetry-breaking and Higgs mechanics. 4. Understand neutrino oscillations and mixing.	

Programme: M. Sc. (Physics) (Computational Physics)

Course Code: PHC-607 **Title of the Course: Introduction to** Parallel Programing using openMP

Number of Credits: 2

Effective from AY: 2023-24

Prerequisites for the course:	Students enrolling for this course should be comfortable with programming in FORTRAN	
Course Objectives:	This is an introductory course in shared memory parallel programming suitable for students working on parallel/HPC applications and interested in parallel programming.	
Content:	**Parallel Programming with OpenMP** What is Parallel Computing? Why would one make codes parallel? Shared and Distributed Memory OpenMP Who would use OpenMP?	8 hours
	How do you make your existing codes parallel? How does one make existing codes parallel? How does one compile code to run OpenMP? How does one decide if a loop is parallel or not? What are Private and Shared variables? How can one do Summations? Summary	8 hours
	Basic Linear Algebra using OpenMP and OpenMP tasks Numerical Integration Matrix Multiplication Solution of linear equations Solution of Ordinary differential equations	14 hours
Pedagogy:	lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these.	
References/Readings:	1. Ananth Grama, Anshul Gupta, George Karypis, Vipin Kumar, Introduction to Parallel Computing, Second Edition, Addison Wesley, (2003). 2. OpenMP Tutorial from LLNL https://computing.llnl.gov/tutorials/openMP 3. V. Rajaraman, Computer Programming in FORTRAN 90 and 95, Prentice-Hall of India, New Delhi (1999). 4. Martin Counihan, Fortran 95, UCL Press Limited University College London (1996). 5. Stephen Chapman, Fortran 95/2003: for Scientists and Engineers, McGraw-Hill (2007).	
Course Outcomes:	1. understand the basics of parallel programming using OpenMP, 2. gain knowledge on techniques in numerical methods	

	3. solve linear and non-linear algebraic equations using OpenMP 4. use parallel programming OpenMP to solve eigenvalue problems.	