Manipal Academy of Higher Education
Department of Sciences
Department of Physics, MIT-Manipal
M.Sc. (Physics)
Choice Based Credit System (2024)

L - Lecture Hours, **T** - Tutorial Hours, **P** - Practical Hours, **C** - Credits

I Semester

Subject Code	Subject	L	T	P	C
PHY 5111	Mathematical Methods of Physics	4	0	0	4
PHY 5112	Classical Mechanics	4	0	0	4
PHY 5113	Quantum Mechanics	4	0	0	4
PHY 5114	Nuclear and Particle Physics	3	0	2	4
PHY 5115	Computational Physics	3	0	2	4
	TOTAL CREDITS				**20**

II SEMESTER

Subject Code	Subject	L	T	P	C
PHY 5211	Thermodynamics and Statistical Physics	4	0	0	4
PHY 5212	Atomic and Molecular Spectroscopy	4	0	0	4
PHY 5213	Electromagnetic Theory	4	0	0	4
PHY 5214	Condensed Matter Physics	3	0	2	4
PHY 5215	Solid State Electronics	3	0	2	4
	TOTAL CREDITS				**20**

III SEMESTER

Subject code	Subject	L	T	P	C
PHY 6111	Astrophysics and Relativity (MOOC)	4	0	0	4

PHY 6112	**Project Course Work 1:** Research Methodology and Technical Communication (MOOC)	3	0	0	3
PHY 6113	**Project Course Work 2:** Experimental methods in Physics (MOOC)	3	0	0	3
PHY 6114*	**Project Course Work 3:** Course related to the project topic (MOOC)*	3	0	0	3
PHY 6115*	**Project Course Work 4:** Course related to the project topic (MOOC)*	3	0	0	3
	TOTAL CREDITS				**16**

* SWAYAM/NPTEL/Coursera courses identified by the department.

IV SEMESTER

Subject code	**Subject**	**L**	**T**	**P**	**C**
PHY 6091	Project**	-	-	-	22
PHY 6092	Internship***	-	-	-	02
	TOTAL CREDITS				**24**

** Spread over 3rd and 4th semester

***To be done at the end of 1st or 2nd Semester

Total Credits for M.Sc. = 80

PHY 5111: MATHEMATICAL METHODS OF PHYSICS [4 0 0 4]

Course Outcomes:

At the end of this course, students will be able to

1. Apply special functions and functions of complex variables to solve physics problems effectively.
2. Analyze and apply curvilinear coordinates and matrices in quantum mechanics.
3. Apply integral transforms and group theory in wave mechanics, relativity and crystallography contexts.

Functions of Complex Variable: Review of functions of a complex variable: Cauchy Riemann conditions (without proof), Analytic functions. Contour integrals. Cauchy integral theorem, Cauchy integral formula. Laurent's series. Singular points, simple pole, m^{TH} order pole. Evaluation of residues. The Cauchy's residue theorem. Evaluation of definite integrals using residues. **10 hours**

Special Functions: Bessel functions of the first kind-derivation of the series form- Recurrence relations, differential equation, Fraunhofer diffraction at a circular aperture. Legendre and Associated Legendre functions - Recurrence relations and differential equations, potential due to a dipole. Laguerre functions – differential equations. Hermite functions - Recurrence relations – differential equation, simple harmonic oscillator. **10 hours**

General Curvilinear Coordinates: Elements of curvilinear coordinates - transformation of coordinates - orthogonal curvilinear coordinates – expression for arc length, elemental area, and volume element. Special cases. The gradient, Laplacian, divergence and curl in orthogonal curvilinear coordinates: special cases – spherical polar coordinates, cylindrical coordinates. **8 hours**

Matrices: Matrices as operators. Simultaneous equations – Solving simultaneous equations using matrices, Cramer's rule. Symmetric, orthogonal, Hermitian and unitary matrices. Eigen values and eigen vectors of a matrix - examples. Similarity, orthogonal, unitary and congruence transformations. Diagonalization of a matrix using similarity and congruence transformation, examples. **6 hours**

Group theory: Basic concepts of Group Theory - multiplication tables - subgroups - direct product. Properties of groups. Representations of finite group - reducible and irreducible representations and example of C4v , SU(2), O(3) groups. **5 hours**

Integral Transform: Fourier series – Review. Mean convergence of Fourier series, change of interval, complex form of Fourier series, Fourier integral and Fourier transform, applications. Laplace transforms and applications in physics z-transforms, wavelet transforms (qualitative discussion)

9 hours

References:

[1] G. B. Arfken, H. J. Weber and F. E. Harris for the 7th edition, Academic Press, 2012.

[2] Charlie Harper, *Introduction to Mathematical Physics*, 1st Edition, India: Prentice Hall India Private Limited,1995.

[3] I.N. Sneddon, *Special Functions of Mathematical Physics and Chemistry*, 1st Edition, United States: Addison-Wesley Longman Ltd, 1980.

[4] P.K. Chattopadhyay, *Mathematical Physics*, 3rd Revised Edition, United Kingdom: New Academic Science Ltd, 2008.

[5] E. Kreyszig, *Advanced Engineering Mathematics*, 9th Edition, New York: Wiley, 2011

[6] M.R. Spiegel, *Complex Variables* : *Schaum's outline series*, 2nd Edition, New York: McGraw Hill Education, 2017.

[7] H.Cohen, *Mathematics for Scientists and Engineers*, 1st Edition, United States: Prentice Hall, 1992.

[8] A.W. Joshi, *Matrices and Tensors in Physics*, 3rd Edition, India: New Age International,1995

[9] Mathews J and Walker R L, *Mathematical Methods of Physics*, 2nd Edition, United States: W A Benjamin Inc.,1979.

[10] Sokolnikoff and Redheffer, *Mathematics of Physics and Modern Engineering*, 2nd Edition, New York: McGraw Hill,1966

[11] A W Joshi, *Elements of Group Theory for Physicists*, 5th Edition, India: New Age International, 2018.

PHY 5112: CLASSICAL MECHANICS [4 0 0 4]

Course Outcomes:

At the end of this course, students will learn:

1. Non inertial frames of References , Central Force and Constrained Motion
2. Variational Principle and Hamilton's formulation and Lagrangian formulation
3. Canonical Transformations and Poisson Brackets

Unit-I-Mechanics of a System of Particles: Center of mass, total angular momentum and total kinetic energies of a system of particles, conservation of linear momentum, energy and angular momentum.

Reduction of two particle equations of motion to the equivalent one-body problem, reduced mass of the system, equations of motion for the orbit, classification of orbits, conditions for closed orbits, the Kepler problem (inverse square law force).

Scattering in a central force field: general description of scattering, cross-section, impact parameter, Rutherford scattering, the Coriolis force, deviation due east of a falling body, the Foucault pendulum. **(12 hours)**

Unit II Lagrangian Formulation: Constraints and their classification, degrees of freedom, generalized co-ordinates, virtual displacement, D'Alembert's principle, Lagrange's equations of motion of the second kind, uniqueness of the Lagrangian, Simple applications of the Lagrangian formulation: 1. Single free particle in (a) Cartesian co-ordinates, (b) plane polar co-ordinates; 2. Atwood's machine; 3.bead sliding on a uniformly rotating wire in a force free space; 4. Motion of block attached to a spring ; 5. Simple pendulum. Symmetries of space time: Cyclic coordinate, Conservation of linear momentum, angular momentum and energy.

(12 hours)

Unit -III Rigid body dynamics: Degrees of freedom of a free rigid body, angular momentum and kinetic energy of a rigid body, moment of inertia tensor, principal moments of inertia, classification of rigid bodies as spherical, symmetric and asymmetric, Euler's equations of motion for a rigid body, Torque free motion of a rigid body, precession of earth's axis of rotation, Euler angles, angular velocity of a rigid body, notions of spin, precession and nutation of a rigid body. **(8 hours)**

Unit- IV Hamiltonian formulation: Generalized momenta, canonical variables, Legendre transformation and the Hamilton's equations of motion, Examples of (a) the Hamiltonian of a particle in a central force field, (b) the simple harmonic oscillator, cyclic co-ordinates and conservation theorems, derivation of Hamilton's equations from variational principle. Canonical transformation: Generating functions (four basic types), examples of canonical transformations, the harmonic oscillator in one dimension, Poisson brackets, Poisson brackets of angular momentum, The Hamilton-Jacobi equation, Linear harmonic oscillator using Hamilton-Jacobi method **(12 hours)**

Unit V: Small Oscillations: Formulation of the problem, Eigen value equation, Eigenvectors and Eigenvalues, Orthogonality, Principal axis transformation, Frequencies of free vibrations, Normal coordinates, Free vibrations of a linear tri atomic molecule.

(4 hours)

References:

1. H. Goldstein, C. P. Poole, and J. L. Safko, Classical Mechanics, 3rd Ed., Pearson (2011).
2. N. C. Rana and P. S. Joag, Classical Mechanics, McGraw Hill, (2013).

3. L. D. Landau and E.M. Lifshitz, Mechanics, 3rd Ed., Butterworth-Heinemann (1976).
4. G. Aruldhas, Classical Mechanics, Prentice Hall India (2008).
5. R. G. Takwale and P. S. Puranik, Introduction to Classical Mechanics, McGraw Hill, (2017).

PHY 5113: QUANTUM MECHANICS [4 0 0 4]

Course Outcomes:

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

1. Describe the mathematical formalism of quantum mechanics
2. Explain the basic postulates of quantum mechanics and apply it to investigate simple quantum systems
3. Apply time independent Schrodinger equation to various one-dimensional problems and Solve the three dimensional Schrodinger equation for some simple potentials including the hydrogen atom and describe the structure of the hydrogen atom.
4. Explain the quantisation of angular momentum and spin, and combine spin and angular momenta
5. Evaluate approximate solutions to the Schrodinger equation

Mathematical Formalism: Basic probability theory; Linear vector space; Inner product; Hilbert Space; Dimension and Basis; Orthogonality; Orthonormality; Completeness; Dirac notation; Operators; Hermitian adjoint; Hermitian operators; Commutator algebra; Uncertainty relation between two operators; Inverse and Unitary operators; Eigenvalues and eigenvectors of an operator; Representation in discrete bases; Matrix representation of kets, bras, and operators; Representation in continuous bases; Position and momentum representation; Connecting the position and momentum representations

14 Hours

Postulates of Quantum Mechanics and the Schrodinger Equation: State of a system; Probability density; Superposition Principle; Observables and operators; Measurement and the Uncertainty relations; Expectation values; Schrodinger equation for Time-independent potentials; Stationary states; Conservation of probability; Ehrenfest Theorem

8 Hours

Applications of Schrodinger Equation: Problems in one dimensions - Infinite square well, Harmonic oscillator, etc.; Potential barrier; Tunneling; Schrodinger equation in spherical coordinates; Central potentials; Separation of variables; Angular and radial equations; Hydrogen atom

10 Hours

Angular Momentum: Orbital angular momentum; Eigen functions and eigenvalues L_z and L^2; Stern-Gerlach Experiment; Spin angular momentum; Matrix representation of spin operators; Pauli spin matrices; Addition of two angular momenta; Clebsch-Gordan coefficients

9 Hours

Approximate Methods: Time independent perturbation theory; Non-degenerate perturbation theory; Degenerate perturbation theory; Applications; Variational method; Applications

7 Hours

References:

1) Nouredine Zettili, *Quantum Mechanics: Concepts and Applications*, 2nd Edition, New Delhi: Wiley, 2016.
2) D. J. Griffiths and D. F. Schroeter, *Introduction to Quantum Mechanics*, 3rd Edition, Cambridge: Cambridge University Press, 2018.
3) R. Shankar, *Principles of Quantum Mechanics*, 2nd Edition, New York: Springer, 1994.

PHY [5114] NUCLEAR AND PARTICLE PHYSICS [PHY XXXX] [3 0 2 4]

Course Outcomes:

At the end of this course, the student should be able to,

1. Apply the concepts of properties of nuclei to study nuclear decay processes.
2. Make use of the concepts of nuclear force to examine the nuclear models and nuclear reactions.
3. Apply the principles of particle physics to study elementary particle interactions.
4. Apply the radiation-matter interaction to construct the radiation detectors.

General properties of the nucleus: Constituents of nucleus and their properties. Mass of the nucleus-binding energy. Charge and charge distribution. Size - estimation and determination of the nuclear radius. Nuclear radius from mirror nuclei - spin statistics and parity. Electric and Magnetic moment of the nucleus. **4 hours**

Nuclear decay - Alpha decay - quantum mechanical tunnelling - wave mechanical theory. Beta decay - continuous beta ray spectrum - neutrino hypothesis. Detection of neutrino - non-conservation of parity in beta decay. Gamma decay - selection rules – multipolarity.
6 hours

Nuclear reactions and Nuclear force: Cross section for a nuclear reaction. ‘Q’ equation of a reaction in laboratory system - threshold energy for a reaction. Compound nucleus and direct reactions (Qualitative). General features of nuclear forces. Two nucleon problem, Meson theory of nuclear forces- Yukawa's theory. **8 hours**

Nuclear Models: Liquid drop model-Weissacker's formula and its applications. Shell model-single particle potentials, spin-orbit coupling and level scheme. Magic numbers. Fermi gas model. Rotational Model. **4 hours**

Elementary particle interactions and families: Classification of fundamental forces and elementary particles. Photons, gluons, baryons, mesons and leptons; quark model, Gellmann-Nishijima scheme. Properties of elementary particles -charge, isospin, mass, time reversal, spin and parity, strangeness. Conservation laws, CPT invariance. Relativistic kinematics.
6 hours

Interaction of radiation with matter, radiation: Energy loss of charged particles in matter. Interaction of gamma rays with matter - photoelectric effect, Compton scattering, and pair production processes. Ionization chamber, proportional counter, and GM counter. Scintillation detector. **8 hours**

References:

[1] K. S. Krane, *Introductory Nuclear Physics*, 1st edition, New Delhi: Wiley India Pvt. Ltd., 2008.

[2] S. N. Ghoshal, *Nuclear Physics*, 1st edition, New Delhi: S Chand & Co. Ltd., 2009.

[3] G. F. Knoll, *Radiation Detection and Measurement*, 4th Edition, New York: Wiley, 2010.

[4] R. D. Evans, *The Atomic Nucleus*, 1st edition, New Delhi: Tata McGraw Hill Publishing Co. Ltd., 1972.

[5] S. L. Kakani and S. Kakani, *Nuclear and Particle Physics*, 2nd Edition, New Delhi: Viva Books Pvt. Ltd., 2013.
[6] D. Griffiths, *Introduction to Elementary Particles*, 2nd Edition, Weinheim: Wiley-VCH, 2008.
[7] H. A. Enge, *Introduction to Nuclear Physics*, 1st edition, Boston: Addison Wesley Pub. Co., 1966.

Experiments:

1. Geiger-Muller (GM) tube characteristics and dead time of GM counter.
2. Half-life of radioactive isotope K-40 using GM Counter
3. Random nature of radioactive decay
4. Absorption of beta rays
5. Energy calibration of gamma ray spectrometer (study of linearity)

* *Additional experiments may be included.*

PHY 5115: COMPUTATIONAL PHYSICS [3 0 2 4]

Course Outcomes:

1. To apply computational techniques to solve some problems in physics.
2. To implement computational methods using Python programming.

Introduction to Python language: Inputs and Output methods, Variables, operators, expressions and statements, Strings, Lists, list functions and methods (len, append, insert, del, remove, reverse, sort, +, *, max, min, count, in, not in, sum), sets, set functions and methods(set, add, remove, in, not in, union, intersection, symmetric difference)-Tuples and Dictionaries, Conditionals, Iteration and looping - Functions and Modules - File input and file output, Exercises. 6 hours

Numpy module-Arrays and Matrices: Creation of arrays and matrices (arrange, linspace, zeros, ones, random, reshape, copying arrays), Arithmetic Operations, cross product, dot product , Saving and Restoring, Matrix inversion, solution of simultaneous equations(use functions in linalg module),Exercises. 6 hours

Data visualization-The Matplotlib, Module: Methods defined in matplotlib, Plotting graphs, Multiple plots, Polar plots-, Pie Charts, Plotting Sine, Log, Exponential, Bessel, Legendre, Gaussian and Gamma functions. Parametric plots, Exercises. 4 hours

Least Square curve fitting: Linear and nonlinear curve fitting, Weighted Least Square, Least Square for continuous functions. **Numerical differentiation and integration:** Divided difference method for differentiation. Newton-Cotes formula. Trapezoidal rule, Simpson's 1/3 and 3/8 rules. 6 hours

Ordinary differential equations: Taylor’s series method, Euler's method and its modifications, Runge-Kutta method (II order), Predictor-Corrector Methods (Adams – Moulton and Milne's methods), Applications- Free, Damped and Forced oscillators, LCR

Electrical Circuits. Boundary value problems by finite difference method – application in Schrödinger wave equation. 6 hours

Partial differential equations: Finite difference equations, Laplace's equation – steady state system, Poisson’s Equation – electrostatics and torsion in a rod examples, Parabolic equations – diffusion equation and application, Hyperbolic Equations-wave equation.

4 hours

Monte Carlo methods: Random numbers, Monte-Carlo crude integration, PI value, Particles in a box, and Radioactive Decay, Generation of random variables having specified distribution, Central Limit Theorem, Importance Sampling, Acceptance-Rejection method.

4 hours

Computer Programming Lab (Using Python):

Any eight programs from the following,

1. Linear least square fit of given data points.
2. Integrating given function by trapezoidal method.
3. Integrating given function by Simpson’s 1/3 rule.
4. Capacitor charging/discharging by Euler’s method.
5. Oscillation of driven oscillator by Euler’s method.
6. Solving Schrödinger wave equation (time independent) by finite difference method.
7. Estimation of PI value by Monte-Carlo method.
8. Integration of given function by Monte-Carlo crude integration.
9. Radioactive decay of one type of nucleus by Monte-Carlo simulation.
10. Solving particles in a box problem by Monte-Carlo method.

* *Additional programs may be included*.

Reference books:

[1] Python Essential Reference, David M Beazley, Addison-Wesley
[2] Ajith Kumar B.P. Python for Education
[3] Travis E. Oliphant, Guide to NumPy
[4] Sandro Tosi, Matplotlib for python developers, Packt Publishing (2009).
[5] S.S. Sastry, *Introductory Methods of Numerical Analysis*, 4^{th} Edition, New Delhi: Prentice Hall of India Pvt Ltd, 2010.
[6] Verma, R C, Ahluwalia, P K, Sharma, K C, *Computational Physics – An Introduction*, 1^{st} Edition, New delhi: New Age International (P) Limited Publishers, 2005.
[7] M.K. Jain, S.R.K. Iyengar and R.K. Jain, *Numerical Methods for Scientific and Engineering Computation*, 6^{th} Edition, New Delhi: New Age International (P) Limited Publishers, 2012.
[8] E Balagurusamy, *Numerical Methods*, 1^{st} Edition, New Delhi: Tata McGraw-Hill Publishing Company Ltd, 1999.

PHY 5211: THERMODYNAMICS AND STATISTICAL PHYSICS [4 0 0 4]

Course outcomes:

At the end of this course students will be able to:

1. Describe the laws of thermodynamics and their consequences; discuss thermodynamic potentials and Maxwell relations; Understand the statistical basis of thermodynamics and relate thermodynamic quantities to statistical quantities
2. Describe different ensembles in statistical mechanics, their distribution functions, ranges of applicability and the corresponding thermodynamic potentials
3. Understand quantum mechanical ensemble theory and their applications
4. Discuss the thermodynamics of ideal Bose and ideal Fermi gas and their physical applications.
5. Understand the theory of phase transitions

Statistical Basis of Thermodynamics: Review of thermodynamics; Laws of thermodynamics and their consequences; Thermodynamic potentials; Maxwell relations; Macrostates and microstates; Contact between statistics and Thermodynamics: Expressing T, P and μ in terms of Ω; The classical Ideal gas; Entropy of mixing and the Gibbs paradox; Sackur-Tetrode equation; Phase space of a classical system; Liouville's theorem **9 Hours**

Ensemble Theory: Microcanonical ensemble; Examples: Classical Ideal gas, harmonic oscillator; Canonical ensemble; Equilibrium between a system and a heat reservoir; Physical significance of the various statistical quantities in the canonical ensemble; Alternative expressions for the partition function; Examples: Classical Ideal gas, harmonic oscillators; Statistics of paramagnetism; Energy fluctuations in the canonical ensemble; Equipartition theorem; Virial theorem; Grand canonical ensemble; Equilibrium between a system and a particle-energy reservoir; Physical significance of the various statistical quantities in the grand canonical ensemble; Example: Classical Ideal gas; Density and energy fluctuations in the grand canonical ensemble **12 Hours**

Quantum Statistics: Quantum mechanical ensemble theory: Density matrix; Statistics of the various ensembles; Examples; Systems composed of indistinguishable particles; An ideal gas in a quantum-mechanical microcanonical ensemble; An ideal gas in other quantum-mechanical ensembles; Statistics of the occupation numbers; Gaseous systems composed of molecules with internal motion; monoatomic and diatomic molecules **10 Hours**

Ideal Bose and Fermi Systems: Thermodynamic behavior of ideal Bose gas; Bose-Einstein condensation; Thermodynamics of black body radiation and Planck's law; Specific heats of solids; Thermodynamic behavior of an ideal Fermi gas; Magnetic behavior of an ideal Fermi gas; Electron gas in metals **11 Hours**

Phase Transitions: First and second order phase transitions; Phase equilibrium; Clausius-Clapeyron equation; Critical point; Ising model **06 Hours**

References:

[1] R. K. Pathria and Paul D. Beale, *Statistical Mechanics*, 3rd Edition, Cambridge: Academic Press, 2011.

[2] Kerson Huang, *Statistical Mechanics*, 2nd Edition, New York: Wiley, 1987.

[3] Avijit Lahiri, *Statistical Mechanics*, 1st Edition, India: Universities Press, 2008.

[4] Palash B. Pal, *An Introductory Course of Statistical Mechanics*, 1st Edition, India: Narosa, 2009.

[5] Roger Bowley and Mariana Sanchez, *Introductory Statistical Mechanics*, 2nd Edition, United Kingdom: Oxford University Press, 2000.

[6] F. Reif, *Fundamentals of Statistical and Thermal Physics*, 1st Edition, New York: McGraw Hill, 2008.
[7] F. Mandl, *Statistical Physics*, 2nd edition, New York: Wiley, 1991.
[8] Linda E Reichl, *A Modern Course in Statistical Physics*, 4th Edition, New York: Wiley, 2016.
[9] Mehran Kardar, *Statistical Physics of Particles*, 1st Edition, Cambridge University Press, 2007.
[10] L. D. Landau and E. M. Lifshitz, *Statistical Physics*, 3rd Edition, United Kingdom: Butterworth-Heinemann, 1980.
[11] Daniel V. Schroeder, *An Introduction to Thermal Physics*, 1st Edition, London: Pearson, 1999.
[12] Herbert B. Callen, *Thermodynamics and An Introduction to Thermostatistics*, 2nd Edition, New York: Wiley, 2006

PHY 521**2:ATOMIC AND MOLECULAR SPECTROSCOPY [4 0 0 4]**

Course Outcomes:

At the end of this course, the student should be able to,

1. Make use of spectra obtained from atoms to explore the properties of atomic systems.
2. Apply the concepts of interaction EM radiation with atoms and molecules and in different spectroscopic techniques.
3. Apply the concepts of spectroscopy techniques like Resonance spectroscopy, Microwave spectra, infra-red spectra for the study and quantitative analysis of molecular properties.
4. Apply the principles of Raman spectroscopy to study the molecular structure and properties.
5. Make use of electronic spectroscopy to investigate the structural properties materials.

Spectra of Atoms: Atomic models. Total angular momentum, quantum numbers, energy levels, transition rates, selections rules. Simple spectra of hydrogen and hydrogen like ions. Ground state of multi electron atoms. LS and jj coupling, doublet structure, triplet structure, transition and intensity rules. Quantum mechanical treatment of fine and hyperfine structure. Zeeman Effect, Paschen-Bach & Stark effects. **6 hours**

Interaction of EM-radiation with Atoms and Molecules: Regions of spectrum, Absorption and emission of radiation, representation of spectra, basic elements of practical spectroscopy, line width, broadening mechanisms, removal of line broadening. signal to noise-resolving power, Fourier transform spectroscopy. **4 hours**

Resonance Spectroscopy: Magnetic properties of nuclei, Resonance condition, nuclear magnetic resonance spectroscopy (both hydrogen nuclei and other than hydrogen) techniques & instrumentation, Relaxation Processes, Bloch Equations, Chemical shift, structural study. Electron spin resonance spectroscopy: Principle of ESR, Hyperfine structure, ESR spectrum.

8 hours

Microwave Spectra, Infrared Spectra: Theory of rotational spectra of diatomic molecules - Experimental technique - structural information. Theory of vibrating rotator, vibration - rotation spectra, IR spectrometer. Application in chemical analysis. **8 hours**

Raman Spectroscopy: Introduction, Theory of-Raman Scattering, Rotational and vibrational Raman spectra - correlation with IR spectra - polarization of Raman lines - laser Raman studies. FT Raman spectroscopy, Raman Spectrometer, Structure determination form Raman and infra-red spectroscopy. **4 hours**

Electronic Spectroscopy: Electronic spectra of diatomic molecules - coarse structure - Frank-Condon principle - rotational fine structure - formation of band head and shading of bands. Fluorescence and phosphorescence: mirror image symmetry of absorption and fluorescence bands. Basic principles of photoelectron spectra, X-ray photo electron spectroscopy (XPS), determination of ionization potential. **12 hours**

Other Spectroscopic Techniques: Mossbauer spectroscopy. Principles of Mossbauer spectroscopy. Applications. UV-Vis Spectroscopy, Thermoluminescence (TL) spectroscopy, Deep-level transient spectroscopy (DLTS). **6 hours**

References:

[1] H E White, *Introduction to Atomic Spectroscopy*, Mc Graw Hill Book Company Inc., 1934.
[2] G. Aruldhas, *Molecular structure and Spectroscopy,* 2nd Edition, Prentice Hall of India, 2001.
[3] J.M.Hollas, *Modern Spectroscopy,* 4th Edition. John Wiley, 2004.
[4] Robert Eisberg and R Resnick, *Quantum Physics of Atoms, Molecules, Solids, Nuclei & Particles*, 2nd Edition, John Wiley & Sons, 2006.
[5] Beiser A, *Concept of Modern Physics*, 5th Edition, Tata McGraw Hill, 1997.
[6] Lakowicz J R, *Principles of fluorescence spectroscopy*, 2nd Edition, Springer, 2006.
[7] Banwell C N and E M McCash, *Fundamentals of Molecular Spectroscopy*, 4th Edition, Tata McGraw Hill, 1994.
[8] Chatwall Gurdeep, *Spectroscopy*, 3rd Edition. Himalayas, 1994.
[9] Herzberg, *Molecular Spectra and Molecular Structure*, Van Nostrand Co., 1966.
[10] Ghatak & Thyagarajan, Optical Electronics, Cambridge University Press, 1991.

PHY 5213: ELECTROMAGNETIC THEORY [4 0 0 4]

Course Outcomes:

1. Understanding basics and applications of electrostatics and magnetostatics
2. Comprehending the concepts and applications of electrodynamics
3. Understanding basics of electromagnetic theory and EM radiations

Electrostatics and Magnetostatics: Laplace and Poisson equations, Boundary-Value problems in electrostatics, method of images. Multipole expansion, Field due to the polarized object, Gauss law in the presence of dielectric.
Biot-Savart law, Ampere's theorem, Vector Potential, magnetostatic boundary condition, multipole expansion of the vector potential. Magnetic properties of matter. Magnetisation, Field due to magnetized object, Ampere’s law in magnetized objects.
12 hours

Classical Electrodynamics: Electromagnetic induction; Maxwell's equations in free space and linear isotropic media; boundary conditions; Energy and momentum in electrodynamics; Scalar and vector potentials; Gauge Transformations: Lorentz Gauge and Coulomb Gauge, fields of a moving point charge. **12 hours**

Electromagnetic wave propagation: Electromagnetic waves in vacuum and matter, Propagation in linear media, Reflection and transmission in normal and oblique incidence. Absorption and dispersion, Reflection at a conducting surface, wave guides. **8 hours**

Plasma; Dynamics of charged particles in static and uniform electromagnetic field, Debye shielding distance, pinch effect **4 hours**

Radiation: Electric dipole radiation, Magnetic dipole radiation, Retarded potential, Lienard-Wiechert potential, radiation from arbitrary source, power radiated by point charge, Radiation reaction. **6 hours**

Relativistic Electrodynamics: Magnetism as a relativistic phenomenon, Field transform, Field tensor, electrodynamics in tensor notation, potential formulation of relativistic electrodynamics. **6 Hours**

References:

[1] David J. Griffiths, Introduction to Electrodynamics, 4th Edition, Essex: Pearson New International Ed, 2013.
[2] J. D. Jackson, Classical Electrodynamics, 3rd Edition, USA: Wiley Eastern, 1998.
[3] J.R. Reitz, F.J. Milford and R. W. Christy, Foundations of Electromagnetic Theory, 4th Edition, India ; Narosa Pub. House, 2008.
[4] Francis F Chen, Introduction to plasma physics and controlled fusion, 2nd Edition, New York: Springer, 2006

PHY 5214: CONDENSED MATTER PHYSICS [3 0 2 4]

Course Outcomes:

At the end of this course, students will be able to

1. Analyze crystal structure concepts, applying experimental techniques for structural quantification.
2. Analyze the elastic and thermal properties of solids.
3. Evaluate the electrical properties of solids.
4. Understand the fundamentals of semiconductor.
5. Conduct experiments exploring condensed matter physics principles effectively.

Crystal structure: Bonding in Solids, Lattice energy of ionic crystals, Madelung constant. Overview of crystal Structure (Symmetry, Space lattice, Unit cell, Crystal systems, Bravais lattices, Close packing of spheres, Miller indices, Indices of a direction), Crystal projections, Point groups and crystal classes, Glide plane, Screw axes, Space groups, Reciprocal lattice, Ewald sphere, Brillouin zone, Wigner Seitz cell, Bragg-Laue formulation of X-ray diffraction by a crystal, Atomic scattering factor, geometric structure factor, Experimental methods of X-ray diffraction, Electron and neutron diffraction by crystals. **12 hours**

Elastic and thermal properties of solids: Elastic vibrations of one-dimensional homogeneous line, Normal modes of vibration in a finite length of the lattice, Linear diatomic lattice – dispersion relation, optical and acoustical mode, normal modes, Phonons, Phonon momentum. Overview of theories on Specific heat: Classical theory, Einstein theory, Debye theory. Thermal conductivity, Phonon-phonon scattering, Normal and Umklapp processes, Thermal expansion. **9 hours**

Electrical properties of metals: Classical free electron theory (Overview) - Drude model, Drawbacks of classical theory, Sommerfeld theory of electrical conductivity, Fermi-Dirac statistics and electron distribution in solids, Density of energy states and Fermi energy, Heat capacity of the electron gas, Variation of resistivity with temperature – Matthiessen's rule, Thermal conductivity in metals, Wiedemann-Franz law, Thermoelectric effects, Failure of Sommerfeld's free electron theory, Band theory of solids, Electron in a periodic field of a crystal – Kronig Penney model, Brillouin zones, Effective mass, Distinction between metals, semiconductors and insulators. **10 hours**

Semiconductors: Energy band gap, Equations of motion, Effective masses in semiconductors, Intrinsic carrier concentration, Intrinsic mobility, Impurity conductivity, Donor and acceptor states, Intrinsic and extrinsic semiconductors and their Fermi level, Hall Effect in metals and semiconductors. **5 hours**

Experiments: Perform any ten experiments**.** **24 hours**

1. Study of dispersion relations for monoatomic and diatomic lattice.
2. Transition temperature of ferroelectrics.
3. Hall Effect in Semiconductors.
4. Fermi Energy of a Metal.
5. Hysteresis Loop Tracer.
6. Paramagnetic Susceptibility.
7. Energy gap of a semiconductor by four probe method.
8. Electron Spin Resonance (ESR).
9. Determination of Planck's constant by photoelectric effect and verification of inverse square law.
10. Measurement of magnetoresistance.
11. Thermal conductivity of a metal bar.
12. Frank Hertz Experiment.
13. Study of thermoluminescence of F-Centers.
14. Transition temperature of ferrites.
15. Thermal and electrical conductivity of Copper.
16. Thermal diffusivity of Brass.

* *Additional experiments may be added.*

References:

1. A. R. Verma and O. N. Srivastava, *Crystallography applied to Solid State Physics*, 2nd Ed. New Delhi: New Age International Pvt. Ltd., 2005.
2. B. D. Cullity and S. R. Stock, *Elements of X-Ray Diffraction*, 3rd Edn. UK: Pearson Education Ltd., 2014.
3. Charles Kittel, *Introduction to Solid State Physics*, 7th Edn. New York: John Wiley & Sons Inc., 1996.
4. N. W. Ashcroft and N. D. Mermin, *Solid State Physics*, New York: Harcourt College Publishers, 1976.
5. L. Azaroff, *Introduction to Solids*, UK: McGraw Hill Education, 2017.
6. H. Ibach and H. Luth, *Solid State Physics*: *An Introduction to Principles of Materials Science*, 4th Edn., Berlin: Springer-Verlag, 2009.
7. M. Ali Omar, *Elementary Solid State Physics*, USA: Addison Wesley Pub. Co., 1975.

8. R. L. Singhal, *Solid State Physics*, Meerut: Kedar Nath Ram Nath & Co., 1998
9. J. P. McKelvey, *Solid State and Semiconductor Physics*, Florida: Krieger Pub. Co., 1982.
10. J. S. Blakemore, *Solid State Physics*, 2nd Edn., UK: Cambridge University Press, 2008.

S. O. Pillai, *Solid State Electronic Engineering Materials*, New Delhi: Wiley Eastern Ltd.,

PHY 5215: SOLID STATE ELECTRONICS [3 0 2 4]

Course Outcomes:

At the end of this course, students will be able to

6. Analyze and evaluate the operational characteristics of various semiconductor devices.
7. Construct various analog circuits.
8. Analyze the functionality and design principles of operational amplifiers and integrated circuits.
9. Demonstrate proficiency in analyzing logic functions and designing various digital circuits.
10. Perform some experiments on semiconductor devices and electronics circuits.

Semiconductor Devices: Formation of p-n junction: built-in potential barrier, space charge width, junction capacitance. p-n junction current, generation and recombination current, Bipolar Junction Transistors (BJT), non-ideal effects, Metal-Semiconductor Junctions: Schottky and Ohmic contacts, Heterojunctions. Unipolar devices: Field-Effect Transistors (FET): Junction FET and Metal Oxide Semiconductor FET (MOSFET), charge coupled device. Optoelectronic Devices: Light-Emitting Diodes, Semiconductor lasers: Radiative and non-radiative transitions, diode laser, population inversion, laser operating characteristics, quantum and overall efficiency, Photodiode and Phototransistor, p-n junction solar cells: solar radiation and ideal conversion efficiency. **12 hours**

Analysis of Analog Circuits: Clipping and clamping circuits. BJT and FET - Voltage divider bias. BJT ac analysis – transistor modelling – r_e model, hybrid equivalent model and hybrid π model. Small signal analysis of BJT and FET amplifiers in CE/CS configuration. Comparison of CE/CS configuration with CB/CG and CC/CD configurations. Frequency response of BJT amplifier. UJT in a relaxation oscillator. SCR in ac power control. **9 hours**

Operational Amplifiers and Integrated Circuits: BJT differential amplifier. Operational amplifier - voltage/current feedback concepts (series & parallel). Inverting and noninverting configurations. Basic applications of opamps - comparator and Schmitt trigger, differentiator, integrator, Wein bridge oscillator, active filters- first order low pass and high pass butter worth filters. IC555 timer - monostable and astable multivibrators. Crystal oscillator using opamp. Instrument amplifier. **9 hours**

Digital Electronics: Simplification of logic functions by Karnaugh maps. Decoders and encoders. Multiplexers and demultiplexers with applications. Parallel and series shift registers, Synchronous and asynchronous counter design. Digital to analog conversion with R/2R network. Analog to digital conversion using flash technique. **6 hours**

Experiments: Perform any ten experiments**.** **24 hours**

1. UJT characteristics and Relaxation Oscillator.
2. Wein-Bridge oscillator using OP-AMP.
3. Integrator and Differentiator using OP-AMP.
4. Monostable and astable multivibrator using IC555 Timer.
5. Active filters - high pass, low pass, band pass and band stop using OP-AMP.
6. Analog to Digital & Digital to Analog converter.
7. Study of p-n junction.
8. JFET characteristics.
9. Solar cell characteristics.
10. I-V Characteristics of Photodiode/phototransistor.
11. Verification of Gaussian nature of laser beam.
12. Determination of divergence angle of diode laser.

* *Additional experiments may be added.*

References:

1. Boylestad R L, Nashelsky L, *Electronic Devices & Circuit Theory*, Tenth edition, India, Prentice Hall of India Pvt. Ltd, 2009.
2. Floyd T L, *Electronic Devices*, Ninth edition, India, Pearson Education Asia, 2015.
3. Ben G. Streetman, Sanjay Kumar Banerjee, *Solid State Electronic Devices*, 7^{th} Edition, Pearson Education Limited, Harlow, England, 2016.
4. Gayakwad R A, *Opamps and Linear Integrated Circuits*, Fourth edition, India, Prentice Hall of India Pvt. Ltd, 2012.
5. Floyd T L, *Digital Fundamentals*, Tenth edition, India, Pearson Education Asia, 2011.

PHY XXXX: ASTROPHYSICS AND RELATIVITY [4 0 0 4]

Course Outcomes:

1. The students will be able to understand the structure and life cycle of stars
2. The students will be able to understand the large scale structure of our universe
3. The students will be equipped with the necessary mathematical foundation to understand the concepts of general theory of relativity.
4. The students will be able to differentiate between the Newtonian concept of gravity and relativistic concept of gravity
5. The students will be able to understand the modern cosmological models based on general theory of relativity

Stellar distances – Astronomical Unit, Light year, PARSEC, measuring stellar distances using parallax (direct method) and cepheid variables (indirect method); Stellar Brightness – Apparent Magnitude, Absolute Magnitude, Luminosity; Stellar temperature and power – Blackbody radiation spectra; Stellar spectra – Spectral classes; Hertzsprung-Russel diagram; Stellar Energy- proton-proton chain, CNO cycle, triple alpha process **- 10 hrs**

1. **Stellar Evolution**
   Birth of stars-nebulae, protostar, Jeans mass and Jeans length, hydrostatic equilibrium; Evolution off the main sequence-High mass and low mass stars-Red giants, supergiant, white dwarf, Chandrashekhar limit, supernovae, neutron star, PULSARs, stellar black holes **- 9 hrs**

2. **Galaxies and Cosmological models**
   Types of galaxies-Elliptical, Spiral, irregular galaxies, Hubble's classification, Dark matter; Cosmological models – Cosmological principle, Expansion of universe-Hubble's law, Closed, open and flat models, Big bang, big bang nucleosynthesis, cosmic background radiation **– 5 hrs**

3. **Special Relativity**
   Lorentz transformation equations, postulates of special theory of relativity, Minkowski space time diagram, simultaneity, length contraction and time dilation using Minkowski spacetime diagram, relativistic doppler shift, relativistic energy and momentum, four vectors **– 10 hrs**

4. **General Relativity**
   Equivalence principle, curved spacetime, tensors - contravariant, covariant and mixed tensors, contaction, outer product, inner product, covariant derivative, symmetric tensors, metric tensor. Geodesics, Reimann curvature tensor, Energy momentum tensor, Einstein's field equation-Schwarzschild solution, Schwarzschild radius, photon, and particle trajectories in Schwarzschild spacetime, bending of light in gravitational field-radar echo delay, precession of Mercury orbit **– 14 hrs**

References

1. Marc L Kutner, Astronomy: A physical Perspective, Cambridge University Press, 2003
2. Baidyanath Basu, An Introduction to Astrophysics, II Edn, PHI Learning Pvt. Ltd, 2011.
3. L. Ryder, Introduction to General Relativiy, 1st edition, Cambridge: Cambridge University Press, 2009.
4. K. D. Krori, Fundamentals of Special and General Relativity, 1st edition, New Delhi: PHI Learning Pvt. Ltd., 2010.
5. J. V. Narlikar, An Introduction to Relativity, 1st edition, New Delhi: Cambridge University Press, 2010.

Project Course Work 1:

PHY 6111: RESEARCH METHODOLOGY AND TECHNICAL COMMUNICATION

Course Outcomes:

1. Students are introduced to research field.
2. Students will be able to do literature review and identify the research gaps
3. Students will be able to write objectives, methodology.
4. Students will be aware of research ethics, plagiarism, journal publication procedures.

Introduction to Research Methodology: Types of research, Significance of research, Research framework, Case study method, Experimental method, Sources of data, Data collection using questionnaire, interviewing, and experimentation. Components, selection and formulation of a research problem, Objectives of formulation, and Criteria of a good research problem. Criterion for hypothesis construction, Nature of hypothesis, Need for having a working hypothesis, Characteristics and Types of hypothesis, Procedure for hypothesis testing. Applications in Physics **12 hours**

Sampling Methods and Data Analysis: Measurement and Scaling Techniques, Methods of Data Collection, Processing & Analysis of Data, Measures of Central Tendency, Dispersion, Skewness Regression Analysis and Correlation, Sampling Fundamentals, Central Limit Theorem, Estimation Testing of Hypotheses, Chi-Square Test. Applications in Physics

12 hours

Literature Review and Journal Communications: Importance of literature review. Performance of literature review and identification of research gap, Defining scope and objectives of the research problem, IEEE and Harvard styles of referencing. Preparation of conference presentations (Oral and Poster) through case study, Effective Presentation. Journal communication, Copyrights, and avoiding plagiarism. Preparation of dissertation.

12 hours

References:

[1] Ranjit Kumar, *Research Methodology; A Step-by-Step Guide for Beginners*, 2nd Edition, Chennai: Pearson, 2005.

[2] Geoffrey R. Marczyk, David De Matteo & David Festinger, *Essentials of Research Design and Methodology*, New Jersey: John Wiley &Sons, 2004

[3] John W. Creswel, *Research Design: Qualitative, Quantitative, and Mixed Methods approaches*, Singapore: SAGE, 2004.

[4] C. R. Kothari, *Research Methodology; Methods & Techniques*, New Delhi: New age international publishers, 2008.

[5] Michael P Marder, *Research Methods for science*, London: Cambridge University Press, 2014.

Project Course Work 2:

PHY 6112: EXPERIMENTAL METHODS IN PHYSICS [3 0 0 3]

Course outcomes:

At the end of the course, student should be able to

1. learn about the data interpretation and error analysis
2. get an insight into various electronic instrumentation techniques
3. explain the construction, working principle and applications of vacuum production, measurement, temperature measurements, transducers, thin films
4. explain the construction, working principle and applications of different experimental techniques used in modern day research

Data interpretation and analysis: Precision and accuracy, types of errors, error analysis, propagation of errors, Gaussian or Normal Distribution, significance of standard deviation in measurements, basic ideas about data acquisition using a PC. **5 hours**

Instrumentation: Voltmeter, ammeter, frequency generator, CRO, measurements using CRO, storage type CRO, capacitance bridge, Impedance meter, production of vacuum (rotary, diffusion, turbo and cryogenic pumps), measurement of vacuum, thin film deposition techniques (Physical and Chemical methods), thickness measurements for thin films, pressure gauge, cryogenics, measurement of temperature, types of thermocouples, resistive strain gauge. **10 hours**

Material analysis techniques I: Four probe method, Hall Effect, thermal conductivity, thermoelectric power, specific heat, Thermal analysis, thermal expansion, powder X-Ray diffraction; Static and dielectric measurements for para and ferroelectric materials. **9 hours**

Material analysis techniques II: Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Atomic Force Microscopy (AFM), Raman spectroscopy, X-ray photoelectric spectroscopy (XPS), Ultraviolet photoelectric spectroscopy (UPS), elemental analysis, Energy dispersive X-ray spectroscopy (EDAX), Secondary Ion Mass Spectrometry (SIMS), Auger electron spectroscopy (AES), vibrating sample magnetometer (VSM) and superconducting quantum interference infrared detectors (SQUID). **12 hours**

References:

[1] Albert D. Helfrick and William D. Cooper, *Modern Electronic Instrumentation and Measurement Techniques*, Prentice Hall of India Private Limited, New Delhi, Original edition, 1990.

[2] A Pipko, Boris Kuznetsov, *Fundamentals of Vacuum Techniques*, MIR, Original edition,1984.

[3] K.L. Chopra , *Thin film phenomena*, McGraw-Hill Inc , Ist edition, 1969.

[4] V.V.Rao, T.B. Ghosh, K.L.Chopra , *Vacuum science and technology*, Allied Publishers Pvt. Ltd. 3rd edition, 2008.

[5] A.R.West, *Solid State Chemistry and its applications*, John Wiley Publications, 2nd edition,1987.

[6] V. A. Phillips, *Modern Metallographic Techniques and Their Applications*, John Wiley & Sons Inc, Ist edition, 1972.

[7] C. E. Hall, *Introduction to electron microscopy*, McGraw-Hill, 2nd edition,1966.

[8] D. B. Williams, C. B. Carter, *Transmission Electron Microscopy-A text book of materials science*, Springer, 2nd edition, 2009.
[9] B. D. Cullity, S.R. Stock, *Elements of X ray diffraction*, Addison-Wesley, 3rd edition, 2014.
[10] G. Haugstad, *Atomic Force Microscopy: Understanding Basic Modes and Advanced Applications*, Wiley, Ist edition, 2012.