

UNIVERSITY OF DELHI

CNC-II/093/1(28)/2023-24/64

Dated: 07.03.2024

NOTIFICATION

Sub: Amendment to Ordinance V

[E.C Resolution No. 14-1/-(14-1-6/-) dated 09.06.2023]

Following addition be made to Appendix-II-A to the Ordinance V (2-A) of the Ordinances of the University;

Add the following:

Syllabi of Semester-IV/V in respect of the Physics Component of following courses under under Faculty of Science based on Under Graduate Curriculum Framework - 2022 implemented from the Academic Year 2022-23:

- (i) **SEMESTER-IV/V: BSc. (Analytical Chemistry) – DSC/DSE**
(As per Annexure-1)
- (ii) **SEMESTER-IV/V: BSc. (Industrial Chemistry) – DSC/DSE**
(As per Annexure-2)

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14/3/24
REGISTRAR

SEMESTER-IV/V
ANALYTICAL CHEMISTRY

DISCIPLINE SPECIFIC CORE COURSE
THERMAL PHYSICS AND STATISTICAL MECHANICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Thermal Physics and Statistical Mechanics	4	2	0	2	--

LEARNING OBJECTIVES

This course will review the basic concepts of thermodynamics, kinetic theory of gases with a brief introduction to statistical mechanics. The primary goal is to make the student understand the applications of fundamental laws of thermodynamics to various systems and processes. This coursework will enable the students to understand the connection between the macroscopic observations of physical systems and microscopic behaviour of atoms and molecule through a brief knowledge of statistical mechanics. The laboratory course deals with providing the knowledge of the concepts of thermodynamics along with Planck's law and Stefan Boltzmann laws related to black body radiation.

LEARNING OUTCOMES

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

- Get an essence of the basic concepts of thermodynamics, the first and the second law of thermodynamics, the concept of entropy and the associated theorems, the thermodynamic potentials and their physical interpretations along with Maxwell's thermodynamic relations.
- Know the fundamentals of the kinetic theory of gases, Maxwell-Boltzman distribution law, mean free path of molecular collisions, viscosity, thermal conductivity and diffusion.
- Learn about the black body radiations, Stefan- Boltzmann's law, Rayleigh-Jean's law and Planck's law and their significances.
- Gain the basic knowledge about quantum statistics: the Bose-Einstein statistics and the Fermi-Dirac statistics.
- In the laboratory course, the students are expected to: Measure of Planck's constant using black body radiation, determine Stefan's Constant, coefficient of thermal conductivity of a bad conductor and a good conductor, determine the temperature coefficient of resistance, study variation of thermo-emf across two junctions of a thermocouple with temperature etc.

SYLLABUS

THEORY COMPONENT

Unit – I (11 Hours)

Laws of Thermodynamics: Fundamental basics of thermodynamic system and variables, zeroth law of thermodynamics and temperature, first law and internal energy, various thermodynamical processes, applications of first law: general relation between C_P and C_V , work done during various processes, compressibility and expansion coefficient, reversible and irreversible processes, second law: Kelvin-Planck and Clausius statements, Carnot engine, Carnot cycle and theorem, basic concept of entropy, entropy changes in reversible and irreversible processes, Clausius inequality, entropy-temperature diagrams.

Unit – II (5 Hours)

Thermodynamic potentials and Maxwell's relations: Basic concept of thermodynamic potentials, internal energy, enthalpy, Helmholtz free energy, Gibb's free energy, derivation of Maxwell's thermodynamic relations and their applications in Clausius Clapeyron equation, value of $C_P - C_V$, TdS equations, evaluation of C_P/C_V

Unit – III (6 Hours)

Kinetic Theory of Gases and Molecular Collisions: Maxwell-Boltzmann law of distribution of velocities in an ideal gas and its experimental verification, Mean, Root Mean Square and Most Probable Speeds, Mean Free Path (Zeroth order only)

Unit – IV (4 Hours)

Theory of Radiation: Blackbody radiation, spectral distribution, derivation of Planck's law, idea about Wein's law, Rayleigh-Jeans law, Stefan Boltzmann law and Wien's displacement law (derivation not required)

Unit – V (4 Hours)

Statistical Mechanics: Macrostate and Microstate, phase space, entropy and thermodynamic probability, Maxwell-Boltzmann law, qualitative description of quantum statistics – Bose Einstein and Fermi Dirac, comparison of three statistics.

References:

Essential Readings:

- 1) Heat and Thermodynamics, M. W. Zemansky and R. Dittman, 1981, Tata McGraw-Hill.
- 2) Thermal Physics, S. C. Garg, R. M. Bansal and C. K. Ghosh, 2nd edition, Tata McGraw-Hill.
- 3) Thermodynamics, Kinetic Theory and Statistical Thermodynamics, Sears and Salinger, 1988, Narosa.
- 4) Concepts in Thermal Physics, Blundell and Blundell, 2nd edition, 2009, Oxford University Press.
- 5) Thermal Physics, A. Kumar and S. P. Taneja, 2014, R. Chand Publications.
- 6) A Text Book of Heat and Thermodynamics for Degree Students, J. B Rajam, 1981, S. Chand.
- 7) Statistical Physics : Berkley Physics Course, F. Reif, Mc Graw Hill

Additional Readings:

- 1) An Introduction to Thermal Physics, D. Schroeder, 2021, Oxford University Press (earlier

- published by Pearsons).
- 2) Thermal Physics: C. Kittel and H. Kroemer, 1980, 2nd edition
 - 3) Heat, Thermodynamics and Statistical Physics, B. Lal, N. Subrahmanyam and P. S. Hemne, S. Chand and Company

PRACTICAL COMPONENT

(15 Weeks with 4 hours of laboratory session per week)

At least 6 experiments to be performed from the following list

- 1) To determine mechanical equivalent of heat, J, by Callender and Barne's constant flow method.
- 2) To determine the coefficient of thermal conductivity of Cu by Searle's apparatus.
- 3) To determine the coefficient of thermal conductivity of a bad conductor by Lee and Charlton's disc method using steam or electrical heating.
- 4) Measurement of Planck's constant using black body radiation.
- 5) To determine the temperature coefficient of resistance by Platinum Resistance Thermometer by Carey Foster's Bridge
- 6) To study the variation of thermos-emf across two junctions of a thermocouple with temperature.
- 7) To determine Stefan's constant.
- 8) To determine the temperature coefficient of resistance using Platinum Resistance Thermometer using Callender and Griffith Bridge.

References for laboratory work:

- 1) Advanced Practical Physics for students: B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House.
- 2) A Text Book of Practical Physics: I. Prakash and Ramakrishna, 11th edition, Kitab Mahal
- 3) Advanced level Practical Physics, Nelkon and Ogborn, 4th edition, reprinted 1985, Heinemann Educational Publishers.
- 4) An Advanced Course in Practical Physics, D. Chattopadhyay and P. C. Rakshit, 1990, New Central Book Agency.
- 5) Practical Physics, G. L. Squires, 1985, Cambridge University Press.
- 6) B.Sc. Practical Physics, H. Singh and P.S. Hemne, revised edition 2011, S. Chand and Co.
- 7) B.Sc. Practical Physics, C. L. Arora, 2001, S. Chand and Co.
- 8) B.Sc. Practical Physics, G. Sanon, R. Chand and Co.

POOL OF DSEs

DISCIPLINE SPECIFIC ELECTIVE COURSE SOLID STATE PHYSICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Solid State Physics	4	2	0	2	Understanding of basic concepts of Physics

LEARNING OBJECTIVES

This course introduces the basic concepts and principles required to understand the various properties exhibited by condensed matter, especially solids. It enables the students to appreciate how the interesting and wonderful properties exhibited by matter depend upon its atomic and molecular constituents. It also communicates the importance of solid state physics in modern society.

LEARNING OUTCOMES

On successful completion of the module students should be able to,

- Elucidate the concept of lattice, crystals and its planes
- Understand the elementary lattice dynamics and its influence on the properties of materials
- Understanding about origin of energy bands, and their influence on electronic behaviour
- Explain the origin of dia-, para-, and ferro-magnetic properties of solids
- Explain the origin of the dielectric properties exhibited by solids and the concept of polarizability
- In the laboratory students will carry out experiments based on the theory that they have learned to measure the magnetic susceptibility, dielectric constant, trace hysteresis loop. They will also employ to four probe methods to measure electrical conductivity and the hall set up to determine the hall coefficient of a semiconductor.

SYLLABUS

THEORY COMPONENT

Unit – I - Crystal Structure

(10 Hours)

Solids: Amorphous and Crystalline Materials, Lattice Translation Vectors, Lattice with a Basis, Unit Cell, Types of lattices, Miller Indices, Reciprocal Lattice, Ewald's construction (geometrical approach) Brillouin Zones, Diffraction of X-rays by Crystals, Bragg's Law

Unit – II - Elementary Lattice Dynamics

(6 Hours)

Lattice vibrations and phonons: linear monoatomic and diatomic chains, acoustical and

optical phonons, Dulong and Petit's law, qualitative discussion of Einstein and Debye theories, T^3 law.

Unit – III - Elementary Band Theory (5 Hours)

Qualitative understanding of Kronig and Penny model (without derivation) and formation of bands in solids, concept of effective mass, Hall effect in semiconductor, Hall coefficient, application of Hall Effect, basic introduction to superconductivity

Unit – IV - Magnetic Properties of Matter (6 Hours)

dia-, para-, and ferro- magnetic materials, classical Langevin theory of dia- and para-magnetism (no quantum mechanical treatment), qualitative discussion about Weiss's theory of ferromagnetism and formation of ferromagnetic domains, B-H curve hysteresis and energy loss

Unit – V - Dielectric Properties of Materials (3 Hours)

Polarization, local electric field in solids, electric susceptibility, polarizability, Clausius Mossoti equation, qualitative discussion about ferroelectricity and PE hysteresis loop

References:

Essential Readings:

- 1) Introduction to Solid State Physics, C. Kittel, 8th edition, 2004, Wiley India Pvt. Ltd.
- 2) Elements of Solid-State Physics, J. P. Srivastava, 2nd edition, 2006, Prentice-Hall of India
- 3) Introduction to Solids, L. V. Azaroff, 2004, Tata Mc-Graw Hill
- 4) Solid State Physics, N. W. Ashcroft and N. D. Mermin, 1976, Cengage Learning
- 5) Solid State Physics, M. A. Wahab, 2011, Narosa Publications

Additional Readings:

- 1) Elementary Solid State Physics, M. Ali Omar, 2006, Pearson
- 2) Solid State Physics, R. John, 2014, McGraw Hill
- 3) Superconductivity: A Very short Introduction, S. J. Blundell, Audiobook

PRACTICAL COMPONENT

(15 Weeks with 4 hours of laboratory session per week)

At least six experiments to be performed from the following list

- 1) Measurement of susceptibility of paramagnetic solution (Quinck's tube method)
- 2) To measure the magnetic susceptibility of solids
- 3) To determine the coupling coefficient of a piezoelectric crystal
- 4) To study the dielectric response of materials with frequency
- 5) To determine the complex dielectric constant and plasma frequency of a metal using Surface Plasmon Resonance (SPR) technique
- 6) To determine the refractive index of a dielectric layer using SPR technique
- 7) To study the PE Hysteresis loop of a ferroelectric crystal
- 8) To draw the BH curve of iron (Fe) using a solenoid and determine the energy loss from hysteresis loop
- 9) To measure the resistivity of a semiconductor (Ge) crystal with temperature (up to 150° C) by four-probe method and determine its band gap

- 10) To determine the Hall coefficient of a semiconductor sample
- 11) Analysis of X-ray diffraction data in terms of unit cell parameters and estimation of particle size
- 12) Measurement of change in resistance of a semiconductor with magnetic field.

References for laboratory work:

- 1) Advanced Practical Physics for students, B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House
- 2) Advanced level Physics Practicals, M. Nelson and J. M. Ogborn, 4th edition, reprinted 1985, Heinemann Educational Publishers
- 3) Elements of Solid-State Physics, J. P. Srivastava, 2nd edition, 2006, Prentice-Hall of India
- 4) An Advanced Course in Practical Physics, D. Chattopadhyay and P. C. Rakshit, 2013, New Book Agency (P) Ltd.
- 5) Practical Physics, G. L. Squires, 4th edition, 2015
- 6) Practical Physics, C. L. Arora, 19th edition, 2015, S. Chand

DISCIPLINE SPECIFIC ELECTIVE COURSE WAVES AND OPTICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Waves and Optics	4	2	0	2	--

LEARNING OBJECTIVES

This is a core course in Physics curriculum that begins with explaining ideas of superposition of harmonic oscillations leading to physics of travelling and standing waves. The course also provides an in depth understanding of wave phenomena of light, namely, interference and diffraction with emphasis on practical applications of the same.

LEARNING OUTCOMES

On successfully completing the requirements of this course, the students will have the skill and knowledge to,

- Understand simple harmonic oscillation and superposition principle.
- Understand superposition of a range of collinear and mutually perpendicular simple harmonic motions and their applications.
- Understand concept of normal modes in stationary waves: their frequencies and configurations.
- Understand interference as superposition of waves from coherent sources derived from same parent source.
- Demonstrate understanding of interference experiments: Young's Double Slit, Fresnel's biprism, Lloyd's Mirror, Newton's Rings
- Demonstrate basic concepts of diffraction: Superposition of wavelets diffracted from apertures
- Understand Fraunhofer diffraction from apertures: single slit, double Slit, grating
- Demonstrate fundamental understanding of Fresnel diffraction: Half period zones, diffraction of different apertures
- Laboratory course is designed to understand the principles of measurement and skills in experimental designs.

SYLLABUS

THEORY COMPONENT

Unit – I

(11 Hours)

Superposition of collinear harmonic oscillations: Simple harmonic motion (SHM); linearity and superposition principle; superposition of two collinear oscillations having (1) equal frequencies and (2) different frequencies (beats).

Superposition of two perpendicular harmonic oscillations: Graphical and analytical methods. Lissajous figures with equal and unequal frequencies and their uses

Superposition of two harmonic Waves: Standing (stationary) waves in a string; normal modes of stretched strings

Unit – II **(8 Hours)**

Interference: Division of amplitude and division of wavefront; Young's double slit experiment: width and shape of fringes; Fresnel's biprism; Lloyd's mirror; Phase change on reflection: Stokes' treatment; Interference in thin films: parallel and wedge-shaped films. Fringes of equal inclination (Haidinger fringes); Fringes of equal thickness (Fizeau Fringes); Newton's rings: Measurement of wavelength and refractive index

Unit – III **(11 Hours)**

Diffraction:

Fraunhofer diffraction: Single slit, double slit, diffraction grating

Fresnel diffraction: Fresnel's assumptions. Fresnel's half-period zones for plane wave.

Explanation of rectilinear propagation of light; Fresnel's diffraction pattern of a straight edge, a slit and a wire using half-period zone analysis

References:

Essential Readings:

- 1) Vibrations and Waves, A. P. French, 1st edition, 2003, CRC press.
- 2) The Physics of Waves and Oscillations, N. K. Bajaj, 1998, Tata McGraw Hill.
- 3) Waves: Berkeley Physics Course, vol. 3, Francis Crawford, 2007, Tata McGraw-Hill.
- 4) Fundamental of Optics, A. Kumar, H. R. Gulati and D. R. Khanna, 2011, R. Chand Publications.
- 5) Optics, A. Ghatak, 6th edition, 2017, McGraw-Hill Education, New Delhi
- 6) The Physics of Vibrations and Waves, H. J. Pain, 2013, John Wiley and Sons.

Additional Readings:

- 1) Principles of Optics, M. Born and E. Wolf, 7th edition, 1999, Pergamon Press.
- 2) Optics, E. Hecht, 4th edition, 2014, Pearson Education.
- 3) Fundamentals of Optics, F. A. Jenkins and H. E. White, 1981, McGraw-Hill

PRACTICAL COMPONENT

(15 Weeks with 4 hours of laboratory session per week)

At least 7 experiments to be performed from the following list

- 1) To determine the frequency of an electric tuning fork by Melde's experiment and verify λ^2-T law.
- 2) To study Lissajous figures.
- 3) Familiarization with Schuster's focusing and determination of angle of prism.
- 4) To determine refractive index of the material of a prism using sodium light.
- 5) To determine the dispersive power and Cauchy's constants of the material of a prism using mercury light.
- 6) To determine wavelength of sodium light using Fresnel biprism.
- 7) To determine wavelength of sodium light using Newton's rings.
- 8) To determine the thickness of a thin paper by measuring the width of the interference fringes produced by a wedge-shaped Film.
- 9) To determine wavelength of (1) Na source and (2) spectral lines of Hg source using plane diffraction grating.

10) To determine dispersive power and resolving power of a plane diffraction grating.

References for laboratory work:

- 1) Advanced Practical Physics for students, B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House
- 2) A Text Book of Practical Physics, I. Prakash and Ramakrishna, 11th edition, 2011, Kitab Mahal
- 3) Advanced level Physics Practicals, M. Nelson and J. M. Ogborn, 4th edition, reprinted 1985, Heinemann Educational Publishers
- 4) A Laboratory Manual of Physics for undergraduate classes, D. P. Khandelwal, 1985, Vani Pub.
- 5) B.Sc. Practical Physics, G. Sanon, 2019, R.Chand & Co

DISCIPLINE SPECIFIC ELECTIVE COURSE ELEMENTS OF MODERN PHYSICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Elements of Modern Physics	4	2	0	2	--

LEARNING OBJECTIVES

This course introduces modern development in Physics. Starting from Planck's law, it develops the idea of probability interpretation and then discusses the formulation of Schrodinger equation. This paper aims to provide knowledge about atomic physics, hydrogen atoms and X-rays. It also introduces concepts of nuclear physics and accelerators.

LEARNING OUTCOMES

After getting exposure to this course, the following topics would be learnt.

- Main aspects of the inadequacies of classical mechanics as well as understanding of the historical development of quantum mechanics. Heisenberg's Uncertainty principle and its applications, photoelectric effect and Compton scattering
- The Schrodinger equation in 1-d, wave function, probability and probability current densities, Normalization, conditions for physical acceptability of wave functions, position and momentum operators and their expectation values. Commutator of position and momentum operators.
- Time Independent Schrodinger Equation, derivation by separation of variables, wave packets, particle in a box problem, energy levels.
- Modification in Bohr's Quantum Model: Sommerfeld theory of elliptical orbits
- Hydrogen atom energy levels and spectra emission and absorption spectra.
- X-rays: their production and spectra: continuous and characteristic X-rays, Moseley Law.
- Basic Properties of Nuclei, nuclear binding energy, semi-empirical mass formula, nuclear force and meson theory.
- Types of Accelerators, Van-de Graaff generator Linear accelerator, Cyclotron, Synchrotrons

SYLLABUS

THEORY COMPONENT

Unit – I - Origin of Quantum Theory (8 Hours)

Black Body Radiation and failure of classical theory, Planck's Quantum Hypothesis, Planck's Radiation Law, Quantitative treatment of Photo-electric effect and Compton scattering, Wave properties of particles: de Broglie hypothesis, Group and Phase velocities and relation between them. Heisenberg's Uncertainty Principle, Gamma ray microscope thought experiment, Position -Momentum Uncertainty, consequences of uncertainty principle.

Unit – II - The Schrodinger Equation (7 Hours)

The Schrodinger equation in 1-d, statistical interpretation of wave function, probability and probability current densities. Normalization, conditions for physical acceptability of wave functions with examples, position and momentum operators and their expectation values. Commutator of position and momentum operators

Unit – III - Time Independent Schrodinger Equation (5 Hours)

Demonstration of separation of variable method for time independent Schrodinger equation: Free particle wave function, wave packets, application to energy eigen values and stationary states for particle in a box problem, energy levels.

Unit – IV - Atomic Physics (5 Hours)

Beyond the Bohr's Quantum Model: Sommerfeld theory of elliptical orbits
Hydrogen atom energy levels and spectra emission and absorption spectra
Correspondence principle, X-rays: Method of production, X-ray spectra: Continuous and characteristic X-rays, Moseley Law.

Unit – V - Basic Properties of Nuclei (5 Hours)

Introduction (basic idea about nuclear size, mass, angular momentum, spin), semi-empirical mass formula, nuclear force and meson theory
Accelerators: Accelerator facility available in India: Van-de Graaff generator Linear accelerator, Cyclotron, (Principle, construction, working, advantages and disadvantages).
Discovery of new elements of the periodic table

References:

Essential Readings:

- 1) Concepts of Modern Physics, A. Beiser, 2002, McGraw-Hill.
- 2) Modern Physics, R. A. Serway, C. J. Moses and C. A. Moyer, 2012, Thomson Brooks Cole Cengage
- 3) Schaum's Outline of Modern Physics, R. Gautreau and W. Savin, 2020, McGraw Hill LLC
- 4) Modern Physics for Scientists and Engineers, S. T. Thornton Rex, 4th edition, 2013, Cengage Learning
- 5) Introduction to Modern Physics, R. Meyer, Kennard, Coop, 2002, Tata McGraw Hill
- 6) Physics for scientists and Engineers with Modern Physics, Jewett and Serway, 2010.
- 7) Learning Modern Physics, G. Kaur and G.R. Pickrell, 2014, McGraw Hill.
- 8) Modern Physics, R. Murugesan, S Chand & Co. Ltd
- 9) Schaum's Outline of Beginning Physics II | Waves, electromagnetism, Optics and Modern Physics, A. Halpern, E. Erlbach, McGraw Hill.
- 10) Theory and Problems of Modern Physics, Schaum's outline, R. Gautreau and W.Savin, 2nd edition, Tata McGraw-Hill Publishing Co. Ltd.
- 11) Quantum Physics, Berkeley Physics, Vol.4. E. H. Wichman, 1971, Tata McGraw-Hill Co.
- 12) Quantum Mechanics: Theory and Applications, A. Ghatak and S. Lokanathan, 2004, Macmillan Publishers India Limited.
- 13) Introduction to Quantum Mechanics, D. J. Griffith, 2005, Pearson Education.
- 14) Concepts of nuclear physics, B. Cohen, McGraw-Hill Education
- 15) Atomic Physics, Ghoshal, 2007, S. Chand Publishing House.
- 16) Atomic Physics, J. B. Rajam, 1980, Chand Publisher
- 17) Nuclear Physics, S. N. Ghoshal, S. Chand Publishers
- 18) Atomic and Molecular Physics, R. Kumar, RBSA PUBLISHERS.

Additional Readings:

- 1) Six Ideas that Shaped Physics: Particles Behave like Waves, T. A. Moore, 2003, McGraw Hill.
- 2) Thirty years that shook physics: The story of quantum theory, G. Gamow, Garden City, NY: Doubleday, 1966.

PRACTICAL COMPONENT

(15 Weeks with 4 hours of laboratory session per week)

Mandatory activity:

- Sessions on the review of experimental data analysis, sources of error and their estimation in detail, writing of scientific laboratory reports including proper reporting of errors.
- Application to the specific experiments done in the lab
- Familiarization with Schuster's focusing; determination of angle of prism.

At least six experiments to be performed from the following list

- 1) Measurement of Planck's constant using black body radiation and photo-detector.
- 2) Photo-electric effect: photo current versus intensity and wavelength of light, maximum energy of photo-electrons versus frequency of light.
- 3) To determine the work function of material of filament of directly heated vacuum diode.
- 4) To determine the Planck's constant using LEDs of at least 4 different colours.
- 5) To determine the wavelength of the H-alpha emission line of Hydrogen atoms.
- 6) To determine the ionization potential of mercury.
- 7) To determine the value of e/m by (a) Magnetic focusing or (b) Bar magnet.
- 8) To show the tunneling effect in tunnel diodes using I-V characteristics.
- 9) To determine the wavelength of a laser source using diffraction of a single slit.
- 10) To determine the wavelength of a laser source using diffraction of double slits.
- 11) To determine angular spread of He-Ne laser using plane diffraction grating
- 12) One innovative experiment designed by the teacher relevant to the syllabus.

References for laboratory work:

- 1) Advanced Practical Physics for students, B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House.
- 2) A Text Book of Practical Physics, I. Prakash and Ramakrishna, 11th edition, 2011, Kitab Mahal.
- 3) Advanced level Physics Practicals, M. Nelson and J. M. Ogborn, 4th edition, reprinted, 1985, Heinemann Educational Publishers.
- 4) A Laboratory Manual of Physics For Undergraduate Classes, D. P. Khandelwal, 1985, Vani Publisher.
- 5) B. Sc. Practical Physics, H. Singh, S Chand & Co Ltd
- 6) B.Sc. Practical Physics, G. Sanon, R. Chand and Co.

DISCIPLINE SPECIFIC ELECTIVE COURSE QUANTUM MECHANICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Quantum Mechanics	4	2	0	2	Elements of Modern Physics paper of this course or its equivalent

LEARNING OBJECTIVES

The development of quantum mechanics has revolutionized the human life. In this course, the students will be exposed to the probabilistic concepts of basic non-relativistic quantum mechanics and its applications to understand the sub atomic world.

LEARNING OUTCOMES

After completing this course, the students will be able to

- Learn the methods to solve time-dependent and time-independent Schrödinger equation.
- Characteristics of an acceptable wave function for any sub atomic particle in various potentials.
- Applications of the Schrodinger equation to different cases of potentials namely infinite and finite potential well, step potential, rectangular potential barrier, harmonic oscillator potential.
- Learn effect of magnetic field on atom, calculation of magnetic moment, basic theory of Stern Gerlach experiment, splitting of lines and energy levels, and various coupling schemes
- In the laboratory course, the students will be able to use computational methods to
 - Solve Schrödinger equation for ground state energy and wave functions of various simple quantum mechanical one- dimensional potentials
 - Solve Schrödinger equation for ground state energy and radial wave functions of some central potentials.

SYLLABUS

THEORY COMPONENT

Unit – I

(10 Hours)

General discussion of bound states in an arbitrary potential: Review of Schrodinger wave equation, Continuity of wave function, boundary conditions and emergence of discrete energy levels. Application to energy eigen states for a particle in a finite square potential well, reflection and transmission across step potential and rectangular potential barrier.

Unit – II

(10 Hours)

Harmonic oscillator: Energy eigen values and eigen states of a 1-D harmonic oscillator using

algebraic method (ladder operators) and using Hermite polynomials. Zero point energy and uncertainty principle. Applications to various kinds of wavefunctions

Unit – III

(10 Hours)

Atoms in Electric and Magnetic Fields: Electron angular momentum, Angular momentum quantization. Electron Spin and Spin Angular Momentum. Larmor's Theorem. Spin Magnetic Moment. Stern-Gerlach Experiment. Normal Zeeman Effect: Electron Magnetic Moment and Magnetic Energy. Pauli Exclusion Principle. Symmetric and Antisymmetric Wave Functions. Spin orbit coupling. Spectral Notations for Atomic States, Total angular momentum, Spin-orbit coupling in atoms-L-S and J-J couplings.

References:

Essential Readings:

- 1) Quantum Mechanics: Theory and Applications, A. Ghatak and S. Lokanathan, 6th edition, 2019, Laxmi Publications, New Delhi.
- 2) Introduction to Quantum Mechanics, D. J. Griffith, 2nd edition, 2005, Pearson Education.
- 3) A Text book of Quantum Mechanics, P. M. Mathews and K. Venkatesan, 2nd edition, 2010, McGraw Hill.
- 4) Quantum Mechanics, B. H. Bransden and C. J. Joachain, 2nd edition, 2000, Prentice Hall
- 5) Quantum Mechanics: Concepts and Applications, 2nd edition, N. Zettili, A John Wiley and Sons, Ltd., Publication
- 6) Atomic Physics, S. N. Ghoshal, 2010, S. Chand and Company

Additional Readings:

- 1) Quantum Mechanics for Scientists & Engineers, D. A. B. Miller, 2008, Cambridge University Press.
- 2) Introduction to Quantum Mechanics, R. H. Dicke and J. P. Wittke, 1966, Addison-Wesley Publications
- 3) Quantum Mechanics, L. I. Schiff, 3rd edition, 2010, Tata McGraw Hill.
- 4) Quantum Mechanics, R. Eisberg and R. Resnick, 2nd edition, 2002, Wiley.
- 5) Quantum Mechanics, B. C. Reed, 2008, Jones and Bartlett Learning.
- 6) Quantum Mechanics, W. Greiner, 4th edition, 2001, Springer.
- 7) Introductory Quantum Mechanics, R. L. Liboff, 4th edition, 2003, Addison Wesley

PRACTICAL COMPONENT

(15 Weeks with 4 hours of laboratory session per week)

At least 6 programs must be attempted. The implementation may be done in Python/C++/Scilab. Use of available library functions may be encouraged. Similar programs may be added.

Unit 1

- 1) Visualize the spherical harmonics by plotting the probability density for various values of the quantum numbers (l, m).
- 2) Use the analytical solution for a particle in finite potential well. Numerically solve the transcendental equation one gets after putting the continuity and boundary conditions to determine the energy eigenvalues for various values of the potential width and depth. Plot the corresponding normalised eigenfunctions.

Unit 2

Solve the Schrödinger equation using shooting/finite difference or any other method for the following simple 1-D potentials and compare with the analytical solutions:

- 1) Particle in a box
- 2) Particle in a finite potential well
- 3) Harmonic Potential

Unit 3

Solve the s-wave Schrodinger equation

$$\frac{d^2u}{dr^2} = A(r)u(r), A(r) = \frac{2m}{\hbar^2} [V(r) - E],$$

for the following cases:

- 1) Ground state and the first excited state of the hydrogen atom:

$$V(r) = \frac{-e^2}{r}$$

where m is the reduced mass of the electron. Obtain the energy eigenvalues and plot the corresponding wavefunctions. Remember that the ground state energy of the hydrogen atom is ≈ -13.6 eV. Take $e = 3.795$ (eVÅ)^{1/2}, $\hbar c = 1973$ (eVÅ) and $m = 0.511 \times 10^6$ eV/c².

- 2) For an atom in the screened coulomb potential

$$V(r) = \frac{-e^2}{r} e^{-r/a}$$

where m is the reduced mass of the system (which can be chosen to be the mass of an electron). Find the energy (in eV) of the ground state of the atom to an accuracy of three significant digits. Also, plot the corresponding wavefunction. Take $e = 3.795$ (eVÅ)^{1/2}, $m = 0.511 \times 10^6$ eV/c², and $a = 3$ Å, 5 Å, 7 Å. In these units $\hbar c = 1973$ (eVÅ). The ground state energy is expected to be above -12 eV in all three cases.

Unit 4

Solve the s-wave Schrodinger equation $\frac{d^2u}{dr^2} = A(r)u(r), A(r) = \frac{2m}{\hbar^2} [V(r) - E]$, for a particle of mass m for the following cases

- 1) Anharmonic oscillator potential

$$V(r) = \frac{1}{2}kr^2 + \frac{1}{3}br^3$$

for the ground state energy (in MeV) of particle to an accuracy of three significant digits. Also, plot the corresponding wave function. Choose $m = 940$ MeV/c², $k = 100$ MeV fm⁻², $b = 0, 10, 30$ MeV fm⁻³. In these units, $c\hbar = 197.3$ MeV fm. The ground state energy is expected to lie between 90 and 110 MeV for all three cases.

- 2) For the vibrations of hydrogen molecule with Morse potential

$$V(r) = D(e^{-2ar'} - e^{-ar'}), r' = \frac{r - r_0}{r}$$

Here m is the reduced mass of the two-atom system for the Morse potential

Find the lowest vibrational energy (in MeV) of the molecule to an accuracy of three significant digits. Also plot the corresponding wave function.

Take: $m = 940 \times 10^6$ eV/c², $D = 0.755501$ eV, $\alpha = 1.44$, $r_0 = 0.131349$ Å

Solve the hydrogen atom Schrodinger equation for an external electric field of $E = 10^9$ eV/cm. The additional term in the Hamiltonian will be eEz .

Laboratory based experiments (Optional):

- 1) Study of Electron spin resonance- determine magnetic field as a function of the resonance frequency
- 2) Study of Zeeman effect: with external magnetic field; Hyperfine splitting
- 3) Quantum efficiency of CCD

References for laboratory work:

- 1) Schaum's Outline of Programming with C++, J. Hubbard, 2000, McGraw-Hill Education.
- 2) C++ How to Program, P. J. Deitel and H. Deitel, 2016, Pearson
- 3) Scilab (A Free Software to Matlab): H. Ramchandran, A. S. Nair, 2011, S. Chand and Co
- 4) Documentation at the Python home page (<https://docs.python.org/3/>) and the tutorials there (<https://docs.python.org/3/tutorial/>).
- 5) Documentation of NumPy and Matplotlib: <https://numpy.org/doc/stable/user/> and <https://matplotlib.org/stable/tutorials/>
- 6) Computational Physics, Darren Walker, 1st edition, 2015, Scientific International Pvt. Ltd
- 7) An Introduction to Computational Physics, T. Pang, 2010, Cambridge University Press

DISCIPLINE SPECIFIC ELECTIVE COURSE MATHEMATICAL PHYSICS-I

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Mathematical Physics-I	4	3	1	0	--

LEARNING OBJECTIVES

The emphasis of course is to equip students with the mathematical tools required in solving problem of interest to physicists. The mathematical tools learned by students will help them develop critical skills and knowledge that will prepare them not only for doing fundamental and applied research but also for a wide variety of careers.

LEARNING OUTCOMES

After completing this course, students will be able to,

- Apply the concepts of calculus to the functions of more than one variable.
- Understand the concepts of vector calculus and apply them to the physics problems.
- Represent a periodic function by a sum of harmonics using Fourier series.
- Obtain power series solution of differential equation of 2nd order with variable coefficients using Frobenius method.
- Understand special functions.

SYLLABUS

THEORY COMPONENT

Unit – I

(18 Hours)

Calculus of functions of more than one variable: Functions of several variables, Limits and continuity, partial derivatives, chain rule for partial derivatives, exact and inexact differentials. Taylor's series of a function of two variables. Maxima and minima, constrained extrema using Lagrange Multipliers.

Vector Calculus: Scalar and vector fields, directional derivative gradient of a scalar field and its geometrical interpretation. Divergence and curl of a vector field and their physical interpretation. Laplacian operator. Vector identities.

Integrals of vector-valued functions of single scalar variable. Multiple integrals, Jacobian, Notion of infinitesimal line, surface and volume elements. Line, surface and volume integrals of vector fields. Flux of a vector field. Gauss divergence theorem, Green's and Stokes' Theorems (no proofs) and their applications.

Unit – II

(12 Hours)

Fourier series: Periodic functions. Orthogonality of sine and cosine functions, Dirichlet Conditions (Statement only). Expansion of periodic functions in a series of sine and cosine

functions and determination of Fourier coefficients. Even and odd functions and their Fourier expansions. Parseval's Identity. Application: Summing of Infinite Series.

Unit – III

(15 Hours)

Frobenius method and special functions: Singular Points of Second Order Linear Differential Equations and their importance. Frobenius method and its applications to differential equations. Legendre Differential Equation and its solution. Properties of Legendre Polynomials: Rodrigues Formula, Orthogonality. Recurrence relations.

References:

Essential Readings:

- 1) Mathematical methods for Scientists and Engineers, D.A. McQuarrie, 2003, Viva Book.
- 2) Advanced Engineering Mathematics, E. Kreyszig, 2008, Wiley India.
- 3) Fourier analysis: With Applications to Boundary Value Problems, M. Spiegel, 2017, McGraw Hill Education
- 4) Essential mathematical methods, K. F. Riley and M. P. Hobson, 2011, Cambridge Univ. Press.
- 5) Vector Analysis, M. Spiegel, 2nd edition, 2017, Schaum's outlines series.

Additional Readings:

- 1) Mathematical Methods for Physicists, G. B. Arfken, H. J. Weber and F. E. Harris, 7th edition, 2013, Elsevier.
- 2) Introduction to Electrodynamics, Chapter 1, D. J. Griffiths, 4th edition, 2017, Cambridge University Press.
- 3) Advanced Engineering Mathematics, D. G. Zill and W. S. Wright, 5th edition, 2012, Jones and Bartlett Learning.
- 4) Introduction to Vector Analysis, Davis and Snider, 6th edition, 1990, McGraw Hill.
- 5) Differential Equations, G. F. Simmons, 2007, McGraw Hill.
- 6) Mathematical Physics, A. K. Ghatak, I. C. Goyal and S. J. Chua, 2017, Laxmi Publications Private Limited

DISCIPLINE SPECIFIC ELECTIVE COURSE MATHEMATICAL PHYSICS-II

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Mathematical Physics-II	4	3	1	0	Mathematics as Discipline Specific Core paper containing Linear Algebra and Calculus.

LEARNING OBJECTIVES

The emphasis of course is to equip students with the mathematical tools required in solving problem of interest to chemists. The mathematical tools might be building blocks to understand the fundamental computational skills and hence enable them to solve a wide range of physics as well as chemistry problems. Overall, to help students develop critical skills and knowledge that will prepare them not only for doing fundamental and applied research but also prepare them for a wide variety of careers.

LEARNING OUTCOMES

After completing this course, students will be able to,

- Determine continuity, differentiability and analyticity of a complex function, find the derivative of a function and understand the properties of elementary complex functions.
- Evaluate a contour integral, fundamental theorem of calculus and Cauchy's integral formula.
- Find the residues and use the residue theorem to evaluate a contour integral and real integral.
- Learn Fourier Transforms (FTs) and their applications.

SYLLABUS

THEORY COMPONENT

Unit – I

(25 Hours)

Complex Analysis:

Complex functions and mappings. Limits of complex functions. Continuity and differentiability of a complex function, Cauchy-Riemann equations, sufficient conditions for differentiability. Analytic functions, singular points. Elementary functions.

Integration in complex plane: contours and contour integrals, Cauchy-Goursat Theorem (No proof) for simply and multiply connected domains. Cauchy's Inequality. Cauchy's Integral formula. Taylor's and Laurent's theorems (statements only), types of singularities (removable, poles and essential), residues and Cauchy's residue theorem. Evaluation of real integrals by contour integration (excluding integrands with branch points).

Unit – II **(15 Hours)**

Fourier Transforms (FTs): Fourier Integral Theorem. Sine and Cosine Transforms. Properties of FTs: (1) FTs of Derivatives of Functions, (2) Change of Scale Theorem, (3) FTs of Complex Conjugates of Functions, (4) Shifting Theorem, (5) Modulation Theorem, (6) Convolution Theorems, and (7) Parseval's Identity.
Solution of First and Second Order ODEs by using FTs.

Unit – III **(5 Hours)**

Some Special Integrals: Beta and Gamma Functions and Relation between them. Expression of Integrals in terms of Gamma Functions.

References:

Essential Readings:

- 1) Mathematical Methods in the Physical Sciences, M. L. Boas, 3rd edition, 2007, Wiley India
- 2) Advanced Engineering Mathematics, E. Kreyszig, 2008, Wiley India
- 3) Theory and Problems of Linear Algebra, S. Lipschutz, 1987, McGraw-Hill Inc.
- 4) Mathematical Methods for Physicists, H. J. Weber and G. B. Arfken, 2010, Elsevier.
- 5) Introduction to Matrices and Linear Transformations, D. T. Finkbeiner, 1978, Dover Publication.
- 6) Matrices and tensors in Physics: A.W. Joshi, 2017, New Age International Pvt.

Additional Readings:

- 1) Mathematical Tools for Physics, J. Nearing, 2010, Dover Publications.
- 2) Elementary Linear Algebra, Applications Version, H. Anton and C. Rorres, Wiley Student edition.
- 3) Mathematics for Physicists, S. M. Lea, 2004, Thomson Brooks/Cole.
- 4) An Introduction to Linear Algebra and Tensors, M. A. Aklonis, V. V. Goldberg, Richard and Silverman, 2012, Dover Publications

DISCIPLINE SPECIFIC ELECTIVE COURSE ELECTRICITY AND MAGNETISM

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Electricity and Magnetism	4	2	0	2	Physics and Mathematics syllabus of class XII

LEARNING OBJECTIVES

This course reviews the concepts of electricity and magnetism learnt at school from a more advanced perspective and goes on to build new concepts. The course covers static and dynamic electric and magnetic fields, and the principles of electromagnetic induction. It also includes analysis of electrical circuits and introduction of network theorems. The students will be able to apply the concepts learnt to several real world problems.

LEARNING OUTCOMES

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

- Understand Gauss' law, Coulomb's law for the electric field, and apply them to systems of point charges as well as line, surface, and volume distributions of charges. Also to use the knowledge to solve some simple problems
- Express electric current and capacitance in terms of electric field and electric potential.
- Calculate the force experienced by a moving charge in a magnetic field
- To determine the magnetic force generated by a current carrying conductor
- Have brief idea of magnetic materials, understand the concept of electromagnetic induction, solve problems using Faraday's and Lenz's laws
- In the laboratory course, students will be able to measure resistance (high and low), voltage, current, self and mutual inductance, capacitor, strength of magnetic field and its variation, study different electric circuits.

SYLLABUS

THEORY COMPONENT

Unit – I - Electrostatics

(10 Hours)

Electric field, electric flux, Gauss' theorem in electrostatics, applications of Gauss' theorem (linear, plane and spherical charge distribution), divergence and curl of electric field, electric field as negative gradient of the potential, line integral of electric field, electric field of a dipole and charged disc, capacitance due to parallel plates and spherical condenser. Electrostatic energy of system of charge (charged sphere), dielectric medium, dielectric polarization, displacement vector, Gauss' theorem in dielectrics, parallel plate capacitor filled with dielectric.

Unit – II - Magnetostatics

(8 Hours)

Magnetic force between current elements and definition of magnetic field B, Biot-Savart's law and its applications (current carrying straight conductor, current carrying circular coil,

current carrying solenoid), divergence and curl of magnetic field, Ampere's circuital law, magnetic properties of materials (magnetic intensity, magnetic induction, permeability, magnetic susceptibility), brief introduction of dia-, para- and ferro magnetic materials

Unit – III - Electromagnetic Induction (7 Hours)

Faraday's laws of electromagnetic induction, Lenz's law, self-inductance of single coil, mutual inductance of two coils, energy stored in magnetic field. Maxwell's equations and equation of continuity of current, displacement current

Unit – IV - Electrical Circuits (5 Hours)

DC Circuits: Review of Kirchhoff's Voltage and Current Laws, Thevenin theorem, Norton theorem, Superposition theorem, Maximum Power Transfer theorem.

References:

Essential Readings:

- 1) Fundamentals of Electricity and Magnetism, A. F. Kip, 2nd edition, 1981, McGraw-Hill.
- 2) Electricity and Magnetism, J. H. Fewkes and J. Yarwood, Vol. I, 1991, Oxford Univ. Press
- 3) Electricity and Magnetism, D. C. Tayal, 1988, Himalaya Publishing House.
- 4) Fundamentals of Electromagnetics, M. A. W. Miah, 1982, Tata McGraw Hill
- 5) Introduction to Electrodynamics, D.J. Griffiths, 3rd edition, 1998, Benjamin Cummings.

Additional Readings:

- 1) Electricity and Magnetism, Berkeley Physics Course, E. M. Purcell, 1986, McGraw-Hill Education.
- 2) University Physics, R. L. Reese, 2003, Thomson Brooks/Cole.
- 3) Problems and Solutions in Electromagnetics, A. Ghatak, K. Thyagarajan and R. Varshney.
- 4) Schaum's Outline of Electric Circuits, J. Edminister and M. Nahvi, 3rd edition, 1995, McGraw Hill.

PRACTICAL COMPONENT

Mandatory training:

- Measuring resistances, a.c and d.c voltages, d.c. current, capacitance using multimeter.
- Working of various instruments and circuits related to different experiments.
- Knowledge of recording and analyzing experimental data.

At least six experiments to be performed from the following list

- 1) Ballistic Galvanometer:
 - a. Measurement of charge and current sensitivity
 - b. Measurement of critical damping resistance
 - c. Determine a high resistance by leakage method
 - d. Determine self-inductance of a coil by Rayleigh's method.
- 2) To compare capacitances using de Sauty's bridge.
- 3) Measurement of field strength B and its variation in a solenoid
- 4) To study the characteristics of a series RC Circuit.

- 5) To study a series LCR circuit and determine its resonant frequency and quality factor.
- 6) To study a parallel LCR circuit and determine its anti-resonant frequency and quality factor
- 7) To determine a low resistance by Carey Foster bridge.
- 8) To verify the Thevenin, superposition and maximum power transfer theorems
- 9) To verify Norton theorem

References for laboratory work:

- 1) Advanced Practical Physics for Students, B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House.
- 2) Engineering Practical Physics, S. Panigrahi and B. Mallick, 2015, Cengage Learning India Pvt. Ltd.
- 3) A Textbook of Practical Physics, I. Prakash and Ramakrishna, 11th edition, 2011, Kitab Mahal, New Delhi.
- 4) Practical Physics, G. L. Squires, 4th edition, 2015, Cambridge University Press
- 5) Advanced level Physics Practicals, M. Nelson and J. M. Ogborn, 4th edition, reprinted 1985, Heinemann Educational Publishers

SEMESTER-IV/V
INDUSTRIAL CHEMISTRY

DISCIPLINE SPECIFIC CORE COURSE
THERMAL PHYSICS AND STATISTICAL MECHANICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Thermal Physics and Statistical Mechanics	4	2	0	2	--

LEARNING OBJECTIVES

This course will review the basic concepts of thermodynamics, kinetic theory of gases with a brief introduction to statistical mechanics. The primary goal is to make the student understand the applications of fundamental laws of thermodynamics to various systems and processes. This coursework will enable the students to understand the connection between the macroscopic observations of physical systems and microscopic behaviour of atoms and molecule through a brief knowledge of statistical mechanics. The laboratory course deals with providing the knowledge of the concepts of thermodynamics along with Planck's law and Stefan Boltzmann laws related to black body radiation.

LEARNING OUTCOMES

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

- Get an essence of the basic concepts of thermodynamics, the first and the second law of thermodynamics, the concept of entropy and the associated theorems, the thermodynamic potentials and their physical interpretations along with Maxwell's thermodynamic relations.
- Know the fundamentals of the kinetic theory of gases, Maxwell-Boltzman distribution law, mean free path of molecular collisions, viscosity, thermal conductivity and diffusion.
- Learn about the black body radiations, Stefan- Boltzmann's law, Rayleigh-Jean's law and Planck's law and their significances.
- Gain the basic knowledge about quantum statistics: the Bose-Einstein statistics and the Fermi-Dirac statistics.
- In the laboratory course, the students are expected to: Measure of Planck's constant using black body radiation, determine Stefan's Constant, coefficient of thermal conductivity of a bad conductor and a good conductor, determine the temperature coefficient of resistance, study variation of thermo-emf across two junctions of a thermocouple with temperature etc.

SYLLABUS

THEORY COMPONENT

Unit – I (11 Hours)

Laws of Thermodynamics: Fundamental basics of thermodynamic system and variables, zeroth law of thermodynamics and temperature, first law and internal energy, various thermodynamical processes, applications of first law: general relation between C_P and C_V , work done during various processes, compressibility and expansion coefficient, reversible and irreversible processes, second law: Kelvin-Planck and Clausius statements, Carnot engine, Carnot cycle and theorem, basic concept of entropy, entropy changes in reversible and irreversible processes, Clausius inequality, entropy-temperature diagrams.

Unit – II (5 Hours)

Thermodynamic potentials and Maxwell's relations: Basic concept of thermodynamic potentials, internal energy, enthalpy, Helmholtz free energy, Gibb's free energy, derivation of Maxwell's thermodynamic relations and their applications in Clausius Clapeyron equation, value of $C_P - C_V$, TdS equations, evaluation of C_P/C_V

Unit – III (6 Hours)

Kinetic Theory of Gases and Molecular Collisions: Maxwell-Boltzmann law of distribution of velocities in an ideal gas and its experimental verification, Mean, Root Mean Square and Most Probable Speeds, Mean Free Path (Zeroth order only)

Unit – IV (4 Hours)

Theory of Radiation: Blackbody radiation, spectral distribution, derivation of Planck's law, idea about Wein's law, Rayleigh-Jeans law, Stefan Boltzmann law and Wien's displacement law (derivation not required)

Unit – V (4 Hours)

Statistical Mechanics: Macrostate and Microstate, phase space, entropy and thermodynamic probability, Maxwell-Boltzmann law, qualitative description of quantum statistics – Bose Einstein and Fermi Dirac, comparison of three statistics.

References:

Essential Readings:

- 1) Heat and Thermodynamics, M. W. Zemansky and R. Dittman, 1981, Tata McGraw-Hill.
- 2) Thermal Physics, S. C. Garg, R. M. Bansal and C. K. Ghosh, 2nd edition, Tata McGraw-Hill.
- 3) Thermodynamics, Kinetic Theory and Statistical Thermodynamics, Sears and Salinger, 1988, Narosa.
- 4) Concepts in Thermal Physics, Blundell and Blundell, 2nd edition, 2009, Oxford University Press.
- 5) Thermal Physics, A. Kumar and S. P. Taneja, 2014, R. Chand Publications.
- 6) A Text Book of Heat and Thermodynamics for Degree Students, J. B Rajam, 1981, S. Chand.
- 7) Statistical Physics : Berkley Physics Course, F. Reif, Mc Graw Hill

Additional Readings:

- 1) An Introduction to Thermal Physics, D. Schroeder, 2021, Oxford University Press (earlier

- published by Pearsons).
- 2) Thermal Physics: C. Kittel and H. Kroemer, 1980, 2nd edition
 - 3) Heat, Thermodynamics and Statistical Physics, B. Lal, N. Subrahmanyam and P. S. Hemne, S. Chand and Company

PRACTICAL COMPONENT

(15 Weeks with 4 hours of laboratory session per week)

At least 6 experiments to be performed from the following list

- 1) To determine mechanical equivalent of heat, J, by Callender and Barne's constant flow method.
- 2) To determine the coefficient of thermal conductivity of Cu by Searle's apparatus.
- 3) To determine the coefficient of thermal conductivity of a bad conductor by Lee and Charlton's disc method using steam or electrical heating.
- 4) Measurement of Planck's constant using black body radiation.
- 5) To determine the temperature coefficient of resistance by Platinum Resistance Thermometer by Carey Foster's Bridge
- 6) To study the variation of thermos-emf across two junctions of a thermocouple with temperature.
- 7) To determine Stefan's constant.
- 8) To determine the temperature coefficient of resistance using Platinum Resistance Thermometer using Callender and Griffith Bridge.

References for laboratory work:

- 1) Advanced Practical Physics for students: B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House.
- 2) A Text Book of Practical Physics: I. Prakash and Ramakrishna, 11th edition, Kitab Mahal
- 3) Advanced level Practical Physics, Nelkon and Ogborn, 4th edition, reprinted 1985, Heinemann Educational Publishers.
- 4) An Advanced Course in Practical Physics, D. Chattopadhyay and P. C. Rakshit, 1990, New Central Book Agency.
- 5) Practical Physics, G. L. Squires, 1985, Cambridge University Press.
- 6) B.Sc. Practical Physics, H. Singh and P.S. Hemne, revised edition 2011, S. Chand and Co.
- 7) B.Sc. Practical Physics, C. L. Arora, 2001, S. Chand and Co.
- 8) B.Sc. Practical Physics, G. Sanon, R. Chand and Co.

POOL OF DSEs

DISCIPLINE SPECIFIC ELECTIVE COURSE SOLID STATE PHYSICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Solid State Physics	4	2	0	2	Understanding of basic concepts of Physics

LEARNING OBJECTIVES

This course introduces the basic concepts and principles required to understand the various properties exhibited by condensed matter, especially solids. It enables the students to appreciate how the interesting and wonderful properties exhibited by matter depend upon its atomic and molecular constituents. It also communicates the importance of solid state physics in modern society.

LEARNING OUTCOMES

On successful completion of the module students should be able to,

- Elucidate the concept of lattice, crystals and its planes
- Understand the elementary lattice dynamics and its influence on the properties of materials
- Understanding about origin of energy bands, and their influence on electronic behaviour
- Explain the origin of dia-, para-, and ferro-magnetic properties of solids
- Explain the origin of the dielectric properties exhibited by solids and the concept of polarizability
- In the laboratory students will carry out experiments based on the theory that they have learned to measure the magnetic susceptibility, dielectric constant, trace hysteresis loop. They will also employ to four probe methods to measure electrical conductivity and the hall set up to determine the hall coefficient of a semiconductor.

SYLLABUS

THEORY COMPONENT

Unit – I - Crystal Structure

(10 Hours)

Solids: Amorphous and Crystalline Materials, Lattice Translation Vectors, Lattice with a Basis, Unit Cell, Types of lattices, Miller Indices, Reciprocal Lattice, Ewald's construction (geometrical approach) Brillouin Zones, Diffraction of X-rays by Crystals, Bragg's Law

Unit – II - Elementary Lattice Dynamics

(6 Hours)

Lattice vibrations and phonons: linear monoatomic and diatomic chains, acoustical and

optical phonons, Dulong and Petit's law, qualitative discussion of Einstein and Debye theories, T^3 law.

Unit – III - Elementary Band Theory (5 Hours)

Qualitative understanding of Kronig and Penny model (without derivation) and formation of bands in solids, concept of effective mass, Hall effect in semiconductor, Hall coefficient, application of Hall Effect, basic introduction to superconductivity

Unit – IV - Magnetic Properties of Matter (6 Hours)

dia-, para-, and ferro- magnetic materials, classical Langevin theory of dia- and para-magnetism (no quantum mechanical treatment), qualitative discussion about Weiss's theory of ferromagnetism and formation of ferromagnetic domains, B-H curve hysteresis and energy loss

Unit – V - Dielectric Properties of Materials (3 Hours)

Polarization, local electric field in solids, electric susceptibility, polarizability, Clausius Mossoti equation, qualitative discussion about ferroelectricity and PE hysteresis loop

References:

Essential Readings:

- 1) Introduction to Solid State Physics, C. Kittel, 8th edition, 2004, Wiley India Pvt. Ltd.
- 2) Elements of Solid-State Physics, J. P. Srivastava, 2nd edition, 2006, Prentice-Hall of India
- 3) Introduction to Solids, L. V. Azaroff, 2004, Tata Mc-Graw Hill
- 4) Solid State Physics, N. W. Ashcroft and N. D. Mermin, 1976, Cengage Learning
- 5) Solid State Physics, M. A. Wahab, 2011, Narosa Publications

Additional Readings:

- 1) Elementary Solid State Physics, M. Ali Omar, 2006, Pearson
- 2) Solid State Physics, R. John, 2014, McGraw Hill
- 3) Superconductivity: A Very short Introduction, S. J. Blundell, Audiobook

PRACTICAL COMPONENT

(15 Weeks with 4 hours of laboratory session per week)

At least six experiments to be performed from the following list

- 1) Measurement of susceptibility of paramagnetic solution (Quinck's tube method)
- 2) To measure the magnetic susceptibility of solids
- 3) To determine the coupling coefficient of a piezoelectric crystal
- 4) To study the dielectric response of materials with frequency
- 5) To determine the complex dielectric constant and plasma frequency of a metal using Surface Plasmon Resonance (SPR) technique
- 6) To determine the refractive index of a dielectric layer using SPR technique
- 7) To study the PE Hysteresis loop of a ferroelectric crystal
- 8) To draw the BH curve of iron (Fe) using a solenoid and determine the energy loss from hysteresis loop
- 9) To measure the resistivity of a semiconductor (Ge) crystal with temperature (up to 150° C) by four-probe method and determine its band gap

- 10) To determine the Hall coefficient of a semiconductor sample
- 11) Analysis of X-ray diffraction data in terms of unit cell parameters and estimation of particle size
- 12) Measurement of change in resistance of a semiconductor with magnetic field.

References for laboratory work:

- 1) Advanced Practical Physics for students, B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House
- 2) Advanced level Physics Practicals, M. Nelson and J. M. Ogborn, 4th edition, reprinted 1985, Heinemann Educational Publishers
- 3) Elements of Solid-State Physics, J. P. Srivastava, 2nd edition, 2006, Prentice-Hall of India
- 4) An Advanced Course in Practical Physics, D. Chattopadhyay and P. C. Rakshit, 2013, New Book Agency (P) Ltd.
- 5) Practical Physics, G. L. Squires, 4th edition, 2015
- 6) Practical Physics, C. L. Arora, 19th edition, 2015, S. Chand

DISCIPLINE SPECIFIC ELECTIVE COURSE WAVES AND OPTICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Waves and Optics	4	2	0	2	--

LEARNING OBJECTIVES

This is a core course in Physics curriculum that begins with explaining ideas of superposition of harmonic oscillations leading to physics of travelling and standing waves. The course also provides an in depth understanding of wave phenomena of light, namely, interference and diffraction with emphasis on practical applications of the same.

LEARNING OUTCOMES

On successfully completing the requirements of this course, the students will have the skill and knowledge to,

- Understand simple harmonic oscillation and superposition principle.
- Understand superposition of a range of collinear and mutually perpendicular simple harmonic motions and their applications.
- Understand concept of normal modes in stationary waves: their frequencies and configurations.
- Understand interference as superposition of waves from coherent sources derived from same parent source.
- Demonstrate understanding of interference experiments: Young's Double Slit, Fresnel's biprism, Lloyd's Mirror, Newton's Rings
- Demonstrate basic concepts of diffraction: Superposition of wavelets diffracted from apertures
- Understand Fraunhofer diffraction from apertures: single slit, double Slit, grating
- Demonstrate fundamental understanding of Fresnel diffraction: Half period zones, diffraction of different apertures
- Laboratory course is designed to understand the principles of measurement and skills in experimental designs.

SYLLABUS

THEORY COMPONENT

Unit – I

(11 Hours)

Superposition of collinear harmonic oscillations: Simple harmonic motion (SHM); linearity and superposition principle; superposition of two collinear oscillations having (1) equal frequencies and (2) different frequencies (beats).

Superposition of two perpendicular harmonic oscillations: Graphical and analytical methods. Lissajous figures with equal and unequal frequencies and their uses

Superposition of two harmonic Waves: Standing (stationary) waves in a string; normal modes of stretched strings

Unit – II **(8 Hours)**

Interference: Division of amplitude and division of wavefront; Young's double slit experiment: width and shape of fringes; Fresnel's biprism; Lloyd's mirror; Phase change on reflection: Stokes' treatment; Interference in thin films: parallel and wedge-shaped films. Fringes of equal inclination (Haidinger fringes); Fringes of equal thickness (Fizeau Fringes); Newton's rings: Measurement of wavelength and refractive index

Unit – III **(11 Hours)**

Diffraction:

Fraunhofer diffraction: Single slit, double slit, diffraction grating

Fresnel diffraction: Fresnel's assumptions. Fresnel's half-period zones for plane wave.

Explanation of rectilinear propagation of light; Fresnel's diffraction pattern of a straight edge, a slit and a wire using half-period zone analysis

References:

Essential Readings:

- 1) Vibrations and Waves, A. P. French, 1st edition, 2003, CRC press.
- 2) The Physics of Waves and Oscillations, N. K. Bajaj, 1998, Tata McGraw Hill.
- 3) Waves: Berkeley Physics Course, vol. 3, Francis Crawford, 2007, Tata McGraw-Hill.
- 4) Fundamental of Optics, A. Kumar, H. R. Gulati and D. R. Khanna, 2011, R. Chand Publications.
- 5) Optics, A. Ghatak, 6th edition, 2017, McGraw-Hill Education, New Delhi
- 6) The Physics of Vibrations and Waves, H. J. Pain, 2013, John Wiley and Sons.

Additional Readings:

- 1) Principles of Optics, M. Born and E. Wolf, 7th edition, 1999, Pergamon Press.
- 2) Optics, E. Hecht, 4th edition, 2014, Pearson Education.
- 3) Fundamentals of Optics, F. A. Jenkins and H. E. White, 1981, McGraw-Hill

PRACTICAL COMPONENT

(15 Weeks with 4 hours of laboratory session per week)

At least 7 experiments to be performed from the following list

- 1) To determine the frequency of an electric tuning fork by Melde's experiment and verify λ^2-T law.
- 2) To study Lissajous figures.
- 3) Familiarization with Schuster's focusing and determination of angle of prism.
- 4) To determine refractive index of the material of a prism using sodium light.
- 5) To determine the dispersive power and Cauchy's constants of the material of a prism using mercury light.
- 6) To determine wavelength of sodium light using Fresnel biprism.
- 7) To determine wavelength of sodium light using Newton's rings.
- 8) To determine the thickness of a thin paper by measuring the width of the interference fringes produced by a wedge-shaped Film.
- 9) To determine wavelength of (1) Na source and (2) spectral lines of Hg source using plane diffraction grating.

10) To determine dispersive power and resolving power of a plane diffraction grating.

References for laboratory work:

- 1) Advanced Practical Physics for students, B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House
- 2) A Text Book of Practical Physics, I. Prakash and Ramakrishna, 11th edition, 2011, Kitab Mahal
- 3) Advanced level Physics Practicals, M. Nelson and J. M. Ogborn, 4th edition, reprinted 1985, Heinemann Educational Publishers
- 4) A Laboratory Manual of Physics for undergraduate classes, D. P. Khandelwal, 1985, Vani Pub.
- 5) B.Sc. Practical Physics, G. Sanon, 2019, R.Chand & Co

DISCIPLINE SPECIFIC ELECTIVE COURSE ELEMENTS OF MODERN PHYSICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Elements of Modern Physics	4	2	0	2	--

LEARNING OBJECTIVES

This course introduces modern development in Physics. Starting from Planck's law, it develops the idea of probability interpretation and then discusses the formulation of Schrodinger equation. This paper aims to provide knowledge about atomic physics, hydrogen atoms and X-rays. It also introduces concepts of nuclear physics and accelerators.

LEARNING OUTCOMES

After getting exposure to this course, the following topics would be learnt.

- Main aspects of the inadequacies of classical mechanics as well as understanding of the historical development of quantum mechanics. Heisenberg's Uncertainty principle and its applications, photoelectric effect and Compton scattering
- The Schrodinger equation in 1-d, wave function, probability and probability current densities, Normalization, conditions for physical acceptability of wave functions, position and momentum operators and their expectation values. Commutator of position and momentum operators.
- Time Independent Schrodinger Equation, derivation by separation of variables, wave packets, particle in a box problem, energy levels.
- Modification in Bohr's Quantum Model: Sommerfeld theory of elliptical orbits
- Hydrogen atom energy levels and spectra emission and absorption spectra.
- X-rays: their production and spectra: continuous and characteristic X-rays, Moseley Law.
- Basic Properties of Nuclei, nuclear binding energy, semi-empirical mass formula, nuclear force and meson theory.
- Types of Accelerators, Van-de Graaff generator Linear accelerator, Cyclotron, Synchrotrons

SYLLABUS

THEORY COMPONENT

Unit – I - Origin of Quantum Theory (8 Hours)

Black Body Radiation and failure of classical theory, Planck's Quantum Hypothesis, Planck's Radiation Law, Quantitative treatment of Photo-electric effect and Compton scattering, Wave properties of particles: de Broglie hypothesis, Group and Phase velocities and relation between them. Heisenberg's Uncertainty Principle, Gamma ray microscope thought experiment, Position -Momentum Uncertainty, consequences of uncertainty principle.

Unit – II - The Schrodinger Equation (7 Hours)

The Schrodinger equation in 1-d, statistical interpretation of wave function, probability and probability current densities. Normalization, conditions for physical acceptability of wave functions with examples, position and momentum operators and their expectation values. Commutator of position and momentum operators

Unit – III - Time Independent Schrodinger Equation (5 Hours)

Demonstration of separation of variable method for time independent Schrodinger equation: Free particle wave function, wave packets, application to energy eigen values and stationary states for particle in a box problem, energy levels.

Unit – IV - Atomic Physics (5 Hours)

Beyond the Bohr's Quantum Model: Sommerfeld theory of elliptical orbits
Hydrogen atom energy levels and spectra emission and absorption spectra
Correspondence principle, X-rays: Method of production, X-ray spectra: Continuous and characteristic X-rays, Moseley Law.

Unit – V - Basic Properties of Nuclei (5 Hours)

Introduction (basic idea about nuclear size, mass, angular momentum, spin), semi-empirical mass formula, nuclear force and meson theory
Accelerators: Accelerator facility available in India: Van-de Graaff generator Linear accelerator, Cyclotron, (Principle, construction, working, advantages and disadvantages).
Discovery of new elements of the periodic table

References:

Essential Readings:

- 1) Concepts of Modern Physics, A. Beiser, 2002, McGraw-Hill.
- 2) Modern Physics, R. A. Serway, C. J. Moses and C. A. Moyer, 2012, Thomson Brooks Cole Cengage
- 3) Schaum's Outline of Modern Physics, R. Gautreau and W. Savin, 2020, McGraw Hill LLC
- 4) Modern Physics for Scientists and Engineers, S. T. Thornton Rex, 4th edition, 2013, Cengage Learning
- 5) Introduction to Modern Physics, R. Meyer, Kennard, Coop, 2002, Tata McGraw Hill
- 6) Physics for scientists and Engineers with Modern Physics, Jewett and Serway, 2010.
- 7) Learning Modern Physics, G. Kaur and G.R. Pickrell, 2014, McGraw Hill.
- 8) Modern Physics, R. Murugesan, S Chand & Co. Ltd
- 9) Schaum's Outline of Beginning Physics II | Waves, electromagnetism, Optics and Modern Physics, A. Halpern, E. Erlbach, McGraw Hill.
- 10) Theory and Problems of Modern Physics, Schaum's outline, R. Gautreau and W.Savin, 2nd edition, Tata McGraw-Hill Publishing Co. Ltd.
- 11) Quantum Physics, Berkeley Physics, Vol.4. E. H. Wichman, 1971, Tata McGraw-Hill Co.
- 12) Quantum Mechanics: Theory and Applications, A. Ghatak and S. Lokanathan, 2004, Macmillan Publishers India Limited.
- 13) Introduction to Quantum Mechanics, D. J. Griffith, 2005, Pearson Education.
- 14) Concepts of nuclear physics, B. Cohen, McGraw-Hill Education
- 15) Atomic Physics, Ghoshal, 2007, S. Chand Publishing House.
- 16) Atomic Physics, J. B. Rajam, 1980, Chand Publisher
- 17) Nuclear Physics, S. N. Ghoshal, S. Chand Publishers
- 18) Atomic and Molecular Physics, R. Kumar, RBSA PUBLISHERS.

Additional Readings:

- 1) Six Ideas that Shaped Physics: Particles Behave like Waves, T. A. Moore, 2003, McGraw Hill.
- 2) Thirty years that shook physics: The story of quantum theory, G. Gamow, Garden City, NY: Doubleday, 1966.

PRACTICAL COMPONENT

(15 Weeks with 4 hours of laboratory session per week)

Mandatory activity:

- Sessions on the review of experimental data analysis, sources of error and their estimation in detail, writing of scientific laboratory reports including proper reporting of errors.
- Application to the specific experiments done in the lab
- Familiarization with Schuster's focusing; determination of angle of prism.

At least six experiments to be performed from the following list

- 1) Measurement of Planck's constant using black body radiation and photo-detector.
- 2) Photo-electric effect: photo current versus intensity and wavelength of light, maximum energy of photo-electrons versus frequency of light.
- 3) To determine the work function of material of filament of directly heated vacuum diode.
- 4) To determine the Planck's constant using LEDs of at least 4 different colours.
- 5) To determine the wavelength of the H-alpha emission line of Hydrogen atoms.
- 6) To determine the ionization potential of mercury.
- 7) To determine the value of e/m by (a) Magnetic focusing or (b) Bar magnet.
- 8) To show the tunneling effect in tunnel diodes using I-V characteristics.
- 9) To determine the wavelength of a laser source using diffraction of a single slit.
- 10) To determine the wavelength of a laser source using diffraction of double slits.
- 11) To determine angular spread of He-Ne laser using plane diffraction grating
- 12) One innovative experiment designed by the teacher relevant to the syllabus.

References for laboratory work:

- 1) Advanced Practical Physics for students, B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House.
- 2) A Text Book of Practical Physics, I. Prakash and Ramakrishna, 11th edition, 2011, Kitab Mahal.
- 3) Advanced level Physics Practicals, M. Nelson and J. M. Ogborn, 4th edition, reprinted, 1985, Heinemann Educational Publishers.
- 4) A Laboratory Manual of Physics For Undergraduate Classes, D. P. Khandelwal, 1985, Vani Publisher.
- 5) B. Sc. Practical Physics, H. Singh, S Chand & Co Ltd
- 6) B.Sc. Practical Physics, G. Sanon, R. Chand and Co.

DISCIPLINE SPECIFIC ELECTIVE COURSE QUANTUM MECHANICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Quantum Mechanics	4	2	0	2	Elements of Modern Physics paper of this course or its equivalent

LEARNING OBJECTIVES

The development of quantum mechanics has revolutionized the human life. In this course, the students will be exposed to the probabilistic concepts of basic non-relativistic quantum mechanics and its applications to understand the sub atomic world.

LEARNING OUTCOMES

After completing this course, the students will be able to

- Learn the methods to solve time-dependent and time-independent Schrödinger equation.
- Characteristics of an acceptable wave function for any sub atomic particle in various potentials.
- Applications of the Schrodinger equation to different cases of potentials namely infinite and finite potential well, step potential, rectangular potential barrier, harmonic oscillator potential.
- Learn effect of magnetic field on atom, calculation of magnetic moment, basic theory of Stern Gerlach experiment, splitting of lines and energy levels, and various coupling schemes
- In the laboratory course, the students will be able to use computational methods to
 - Solve Schrödinger equation for ground state energy and wave functions of various simple quantum mechanical one- dimensional potentials
 - Solve Schrödinger equation for ground state energy and radial wave functions of some central potentials.

SYLLABUS

THEORY COMPONENT

Unit – I

(10 Hours)

General discussion of bound states in an arbitrary potential: Review of Schrodinger wave equation, Continuity of wave function, boundary conditions and emergence of discrete energy levels. Application to energy eigen states for a particle in a finite square potential well, reflection and transmission across step potential and rectangular potential barrier.

Unit – II

(10 Hours)

Harmonic oscillator: Energy eigen values and eigen states of a 1-D harmonic oscillator using

algebraic method (ladder operators) and using Hermite polynomials. Zero point energy and uncertainty principle. Applications to various kinds of wavefunctions

Unit – III

(10 Hours)

Atoms in Electric and Magnetic Fields: Electron angular momentum, Angular momentum quantization. Electron Spin and Spin Angular Momentum. Larmor's Theorem. Spin Magnetic Moment. Stern-Gerlach Experiment. Normal Zeeman Effect: Electron Magnetic Moment and Magnetic Energy. Pauli Exclusion Principle. Symmetric and Antisymmetric Wave Functions. Spin orbit coupling. Spectral Notations for Atomic States, Total angular momentum, Spin-orbit coupling in atoms-L-S and J-J couplings.

References:

Essential Readings:

- 1) Quantum Mechanics: Theory and Applications, A. Ghatak and S. Lokanathan, 6th edition, 2019, Laxmi Publications, New Delhi.
- 2) Introduction to Quantum Mechanics, D. J. Griffith, 2nd edition, 2005, Pearson Education.
- 3) A Text book of Quantum Mechanics, P. M. Mathews and K. Venkatesan, 2nd edition, 2010, McGraw Hill.
- 4) Quantum Mechanics, B. H. Bransden and C. J. Joachain, 2nd edition, 2000, Prentice Hall
- 5) Quantum Mechanics: Concepts and Applications, 2nd edition, N. Zettili, A John Wiley and Sons, Ltd., Publication
- 6) Atomic Physics, S. N. Ghoshal, 2010, S. Chand and Company

Additional Readings:

- 1) Quantum Mechanics for Scientists & Engineers, D. A. B. Miller, 2008, Cambridge University Press.
- 2) Introduction to Quantum Mechanics, R. H. Dicke and J. P. Wittke, 1966, Addison-Wesley Publications
- 3) Quantum Mechanics, L. I. Schiff, 3rd edition, 2010, Tata McGraw Hill.
- 4) Quantum Mechanics, R. Eisberg and R. Resnick, 2nd edition, 2002, Wiley.
- 5) Quantum Mechanics, B. C. Reed, 2008, Jones and Bartlett Learning.
- 6) Quantum Mechanics, W. Greiner, 4th edition, 2001, Springer.
- 7) Introductory Quantum Mechanics, R. L. Liboff, 4th edition, 2003, Addison Wesley

PRACTICAL COMPONENT

(15 Weeks with 4 hours of laboratory session per week)

At least 6 programs must be attempted. The implementation may be done in Python/C++/Scilab. Use of available library functions may be encouraged. Similar programs may be added.

Unit 1

- 1) Visualize the spherical harmonics by plotting the probability density for various values of the quantum numbers (l, m).
- 2) Use the analytical solution for a particle in finite potential well. Numerically solve the transcendental equation one gets after putting the continuity and boundary conditions to determine the energy eigenvalues for various values of the potential width and depth. Plot the corresponding normalised eigenfunctions.

Unit 2

Solve the Schrödinger equation using shooting/finite difference or any other method for the following simple 1-D potentials and compare with the analytical solutions:

- 1) Particle in a box
- 2) Particle in a finite potential well
- 3) Harmonic Potential

Unit 3

Solve the s-wave Schrodinger equation

$$\frac{d^2u}{dr^2} = A(r)u(r), A(r) = \frac{2m}{\hbar^2} [V(r) - E],$$

for the following cases:

- 1) Ground state and the first excited state of the hydrogen atom:

$$V(r) = \frac{-e^2}{r}$$

where m is the reduced mass of the electron. Obtain the energy eigenvalues and plot the corresponding wavefunctions. Remember that the ground state energy of the hydrogen atom is ≈ -13.6 eV. Take $e = 3.795$ (eVÅ)^{1/2}, $\hbar c = 1973$ (eVÅ) and $m = 0.511 \times 10^6$ eV/c².

- 2) For an atom in the screened coulomb potential

$$V(r) = \frac{-e^2}{r} e^{-r/a}$$

where m is the reduced mass of the system (which can be chosen to be the mass of an electron). Find the energy (in eV) of the ground state of the atom to an accuracy of three significant digits. Also, plot the corresponding wavefunction. Take $e = 3.795$ (eVÅ)^{1/2}, $m = 0.511 \times 10^6$ eV/c², and $a = 3$ Å, 5 Å, 7 Å. In these units $\hbar c = 1973$ (eVÅ). The ground state energy is expected to be above -12 eV in all three cases.

Unit 4

Solve the s-wave Schrodinger equation $\frac{d^2u}{dr^2} = A(r)u(r), A(r) = \frac{2m}{\hbar^2} [V(r) - E]$, for a particle of mass m for the following cases

- 1) Anharmonic oscillator potential

$$V(r) = \frac{1}{2}kr^2 + \frac{1}{3}br^3$$

for the ground state energy (in MeV) of particle to an accuracy of three significant digits. Also, plot the corresponding wave function. Choose $m = 940$ MeV/c², $k = 100$ MeV fm⁻², $b = 0, 10, 30$ MeV fm⁻³. In these units, $c\hbar = 197.3$ MeV fm. The ground state energy is expected to lie between 90 and 110 MeV for all three cases.

- 2) For the vibrations of hydrogen molecule with Morse potential

$$V(r) = D(e^{-2ar'} - e^{-ar'}), r' = \frac{r - r_0}{r}$$

Here m is the reduced mass of the two-atom system for the Morse potential

Find the lowest vibrational energy (in MeV) of the molecule to an accuracy of three significant digits. Also plot the corresponding wave function.

Take: $m = 940 \times 10^6$ eV/c², $D = 0.755501$ eV, $\alpha = 1.44$, $r_0 = 0.131349$ Å

Solve the hydrogen atom Schrodinger equation for an external electric field of $E = 10^9$ eV/cm. The additional term in the Hamiltonian will be eEz .

Laboratory based experiments (Optional):

- 1) Study of Electron spin resonance- determine magnetic field as a function of the resonance frequency
- 2) Study of Zeeman effect: with external magnetic field; Hyperfine splitting
- 3) Quantum efficiency of CCD

References for laboratory work:

- 1) Schaum's Outline of Programming with C++, J. Hubbard, 2000, McGraw-Hill Education.
- 2) C++ How to Program, P. J. Deitel and H. Deitel, 2016, Pearson
- 3) Scilab (A Free Software to Matlab): H. Ramchandran, A. S. Nair, 2011, S. Chand and Co
- 4) Documentation at the Python home page (<https://docs.python.org/3/>) and the tutorials there (<https://docs.python.org/3/tutorial/>).
- 5) Documentation of NumPy and Matplotlib: <https://numpy.org/doc/stable/user/> and <https://matplotlib.org/stable/tutorials/>
- 6) Computational Physics, Darren Walker, 1st edition, 2015, Scientific International Pvt. Ltd
- 7) An Introduction to Computational Physics, T. Pang, 2010, Cambridge University Press

DISCIPLINE SPECIFIC ELECTIVE COURSE MATHEMATICAL PHYSICS-I

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Mathematical Physics-I	4	3	1	0	--

LEARNING OBJECTIVES

The emphasis of course is to equip students with the mathematical tools required in solving problem of interest to physicists. The mathematical tools learned by students will help them develop critical skills and knowledge that will prepare them not only for doing fundamental and applied research but also for a wide variety of careers.

LEARNING OUTCOMES

After completing this course, students will be able to,

- Apply the concepts of calculus to the functions of more than one variable.
- Understand the concepts of vector calculus and apply them to the physics problems.
- Represent a periodic function by a sum of harmonics using Fourier series.
- Obtain power series solution of differential equation of 2nd order with variable coefficients using Frobenius method.
- Understand special functions.

SYLLABUS

THEORY COMPONENT

Unit – I

(18 Hours)

Calculus of functions of more than one variable: Functions of several variables, Limits and continuity, partial derivatives, chain rule for partial derivatives, exact and inexact differentials. Taylor's series of a function of two variables. Maxima and minima, constrained extrema using Lagrange Multipliers.

Vector Calculus: Scalar and vector fields, directional derivative gradient of a scalar field and its geometrical interpretation. Divergence and curl of a vector field and their physical interpretation. Laplacian operator. Vector identities.

Integrals of vector-valued functions of single scalar variable. Multiple integrals, Jacobian, Notion of infinitesimal line, surface and volume elements. Line, surface and volume integrals of vector fields. Flux of a vector field. Gauss divergence theorem, Green's and Stokes' Theorems (no proofs) and their applications.

Unit – II

(12 Hours)

Fourier series: Periodic functions. Orthogonality of sine and cosine functions, Dirichlet Conditions (Statement only). Expansion of periodic functions in a series of sine and cosine

functions and determination of Fourier coefficients. Even and odd functions and their Fourier expansions. Parseval's Identity. Application: Summing of Infinite Series.

Unit – III

(15 Hours)

Frobenius method and special functions: Singular Points of Second Order Linear Differential Equations and their importance. Frobenius method and its applications to differential equations. Legendre Differential Equation and its solution. Properties of Legendre Polynomials: Rodrigues Formula, Orthogonality. Recurrence relations.

References:

Essential Readings:

- 1) Mathematical methods for Scientists and Engineers, D.A. McQuarrie, 2003, Viva Book.
- 2) Advanced Engineering Mathematics, E. Kreyszig, 2008, Wiley India.
- 3) Fourier analysis: With Applications to Boundary Value Problems, M. Spiegel, 2017, McGraw Hill Education
- 4) Essential mathematical methods, K. F. Riley and M. P. Hobson, 2011, Cambridge Univ. Press.
- 5) Vector Analysis, M. Spiegel, 2nd edition, 2017, Schaum's outlines series.

Additional Readings:

- 1) Mathematical Methods for Physicists, G. B. Arfken, H. J. Weber and F. E. Harris, 7th edition, 2013, Elsevier.
- 2) Introduction to Electrodynamics, Chapter 1, D. J. Griffiths, 4th edition, 2017, Cambridge University Press.
- 3) Advanced Engineering Mathematics, D. G. Zill and W. S. Wright, 5th edition, 2012, Jones and Bartlett Learning.
- 4) Introduction to Vector Analysis, Davis and Snider, 6th edition, 1990, McGraw Hill.
- 5) Differential Equations, G. F. Simmons, 2007, McGraw Hill.
- 6) Mathematical Physics, A. K. Ghatak, I. C. Goyal and S. J. Chua, 2017, Laxmi Publications Private Limited

DISCIPLINE SPECIFIC ELECTIVE COURSE MATHEMATICAL PHYSICS-II

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Mathematical Physics-II	4	3	1	0	Mathematics as Discipline Specific Core paper containing Linear Algebra and Calculus.

LEARNING OBJECTIVES

The emphasis of course is to equip students with the mathematical tools required in solving problem of interest to chemists. The mathematical tools might be building blocks to understand the fundamental computational skills and hence enable them to solve a wide range of physics as well as chemistry problems. Overall, to help students develop critical skills and knowledge that will prepare them not only for doing fundamental and applied research but also prepare them for a wide variety of careers.

LEARNING OUTCOMES

After completing this course, students will be able to,

- Determine continuity, differentiability and analyticity of a complex function, find the derivative of a function and understand the properties of elementary complex functions.
- Evaluate a contour integral, fundamental theorem of calculus and Cauchy's integral formula.
- Find the residues and use the residue theorem to evaluate a contour integral and real integral.
- Learn Fourier Transforms (FTs) and their applications.

SYLLABUS

THEORY COMPONENT

Unit – I

(25 Hours)

Complex Analysis:

Complex functions and mappings. Limits of complex functions. Continuity and differentiability of a complex function, Cauchy-Riemann equations, sufficient conditions for differentiability. Analytic functions, singular points. Elementary functions.

Integration in complex plane: contours and contour integrals, Cauchy-Goursat Theorem (No proof) for simply and multiply connected domains. Cauchy's Inequality. Cauchy's Integral formula. Taylor's and Laurent's theorems (statements only), types of singularities (removable, poles and essential), residues and Cauchy's residue theorem. Evaluation of real integrals by contour integration (excluding integrands with branch points).

Unit – II **(15 Hours)**

Fourier Transforms (FTs): Fourier Integral Theorem. Sine and Cosine Transforms. Properties of FTs: (1) FTs of Derivatives of Functions, (2) Change of Scale Theorem, (3) FTs of Complex Conjugates of Functions, (4) Shifting Theorem, (5) Modulation Theorem, (6) Convolution Theorems, and (7) Parseval's Identity.
Solution of First and Second Order ODEs by using FTs.

Unit – III **(5 Hours)**

Some Special Integrals: Beta and Gamma Functions and Relation between them. Expression of Integrals in terms of Gamma Functions.

References:

Essential Readings:

- 1) Mathematical Methods in the Physical Sciences, M. L. Boas, 3rd edition, 2007, Wiley India
- 2) Advanced Engineering Mathematics, E. Kreyszig, 2008, Wiley India
- 3) Theory and Problems of Linear Algebra, S. Lipschutz, 1987, McGraw-Hill Inc.
- 4) Mathematical Methods for Physicists, H. J. Weber and G. B. Arfken, 2010, Elsevier.
- 5) Introduction to Matrices and Linear Transformations, D. T. Finkbeiner, 1978, Dover Publication.
- 6) Matrices and tensors in Physics: A.W. Joshi, 2017, New Age International Pvt.

Additional Readings:

- 1) Mathematical Tools for Physics, J. Nearing, 2010, Dover Publications.
- 2) Elementary Linear Algebra, Applications Version, H. Anton and C. Rorres, Wiley Student edition.
- 3) Mathematics for Physicists, S. M. Lea, 2004, Thomson Brooks/Cole.
- 4) An Introduction to Linear Algebra and Tensors, M. A. Akivis, V. V. Goldberg, Richard and Silverman, 2012, Dover Publications

DISCIPLINE SPECIFIC ELECTIVE COURSE ELECTRICITY AND MAGNETISM

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Electricity and Magnetism	4	2	0	2	Physics and Mathematics syllabus of class XII

LEARNING OBJECTIVES

This course reviews the concepts of electricity and magnetism learnt at school from a more advanced perspective and goes on to build new concepts. The course covers static and dynamic electric and magnetic fields, and the principles of electromagnetic induction. It also includes analysis of electrical circuits and introduction of network theorems. The students will be able to apply the concepts learnt to several real world problems.

LEARNING OUTCOMES

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

- Understand Gauss' law, Coulomb's law for the electric field, and apply them to systems of point charges as well as line, surface, and volume distributions of charges. Also to use the knowledge to solve some simple problems
- Express electric current and capacitance in terms of electric field and electric potential.
- Calculate the force experienced by a moving charge in a magnetic field
- To determine the magnetic force generated by a current carrying conductor
- Have brief idea of magnetic materials, understand the concept of electromagnetic induction, solve problems using Faraday's and Lenz's laws
- In the laboratory course, students will be able to measure resistance (high and low), voltage, current, self and mutual inductance, capacitor, strength of magnetic field and its variation, study different electric circuits.

SYLLABUS

THEORY COMPONENT

Unit – I - Electrostatics

(10 Hours)

Electric field, electric flux, Gauss' theorem in electrostatics, applications of Gauss' theorem (linear, plane and spherical charge distribution), divergence and curl of electric field, electric field as negative gradient of the potential, line integral of electric field, electric field of a dipole and charged disc, capacitance due to parallel plates and spherical condenser. Electrostatic energy of system of charge (charged sphere), dielectric medium, dielectric polarization, displacement vector, Gauss' theorem in dielectrics, parallel plate capacitor filled with dielectric.

Unit – II - Magnetostatics

(8 Hours)

Magnetic force between current elements and definition of magnetic field B, Biot-Savart's law and its applications (current carrying straight conductor, current carrying circular coil,

current carrying solenoid), divergence and curl of magnetic field, Ampere's circuital law, magnetic properties of materials (magnetic intensity, magnetic induction, permeability, magnetic susceptibility), brief introduction of dia-, para- and ferro magnetic materials

Unit – III - Electromagnetic Induction (7 Hours)

Faraday's laws of electromagnetic induction, Lenz's law, self-inductance of single coil, mutual inductance of two coils, energy stored in magnetic field. Maxwell's equations and equation of continuity of current, displacement current

Unit – IV - Electrical Circuits (5 Hours)

DC Circuits: Review of Kirchhoff's Voltage and Current Laws, Thevenin theorem, Norton theorem, Superposition theorem, Maximum Power Transfer theorem.

References:

Essential Readings:

- 1) Fundamentals of Electricity and Magnetism, A. F. Kip, 2nd edition, 1981, McGraw-Hill.
- 2) Electricity and Magnetism, J. H. Fewkes and J. Yarwood, Vol. I, 1991, Oxford Univ. Press
- 3) Electricity and Magnetism, D. C. Tayal, 1988, Himalaya Publishing House.
- 4) Fundamentals of Electromagnetics, M. A. W. Miah, 1982, Tata McGraw Hill
- 5) Introduction to Electrodynamics, D.J. Griffiths, 3rd edition, 1998, Benjamin Cummings.

Additional Readings:

- 1) Electricity and Magnetism, Berkeley Physics Course, E. M. Purcell, 1986, McGraw-Hill Education.
- 2) University Physics, R. L. Reese, 2003, Thomson Brooks/Cole.
- 3) Problems and Solutions in Electromagnetics, A. Ghatak, K. Thyagarajan and R. Varshney.
- 4) Schaum's Outline of Electric Circuits, J. Edminister and M. Nahvi, 3rd edition, 1995, McGraw Hill.

PRACTICAL COMPONENT

Mandatory training:

- Measuring resistances, a.c and d.c voltages, d.c. current, capacitance using multimeter.
- Working of various instruments and circuits related to different experiments.
- Knowledge of recording and analyzing experimental data.

At least six experiments to be performed from the following list

- 1) Ballistic Galvanometer:
 - a. Measurement of charge and current sensitivity
 - b. Measurement of critical damping resistance
 - c. Determine a high resistance by leakage method
 - d. Determine self-inductance of a coil by Rayleigh's method.
- 2) To compare capacitances using de Sauty's bridge.
- 3) Measurement of field strength B and its variation in a solenoid
- 4) To study the characteristics of a series RC Circuit.

- 5) To study a series LCR circuit and determine its resonant frequency and quality factor.
- 6) To study a parallel LCR circuit and determine its anti-resonant frequency and quality factor
- 7) To determine a low resistance by Carey Foster bridge.
- 8) To verify the Thevenin, superposition and maximum power transfer theorems
- 9) To verify Norton theorem

References for laboratory work:

- 1) Advanced Practical Physics for Students, B. L. Flint and H. T. Worsnop, 1971, Asia Publishing House.
- 2) Engineering Practical Physics, S. Panigrahi and B. Mallick, 2015, Cengage Learning India Pvt. Ltd.
- 3) A Textbook of Practical Physics, I. Prakash and Ramakrishna, 11th edition, 2011, Kitab Mahal, New Delhi.
- 4) Practical Physics, G. L. Squires, 4th edition, 2015, Cambridge University Press
- 5) Advanced level Physics Practicals, M. Nelson and J. M. Ogborn, 4th edition, reprinted 1985, Heinemann Educational Publishers