Master of Science (M.Sc.)

in

Physics

Department of Physics

Motilal Nehru National Institute of Technology Allahabad

INDIA

Contents

1 Unique features of the program

The Masters of Science (M.Sc.) in Physics is a two-year (four-semester) program with following unique features:

1. This two-year program is intended to provide basics of physics in the first year and applied aspects of physics in various fields in the second year through electives, projects and core courses.

2. In addition to employability of the students in different industries, the program is designed in such a way so that students can qualify various international and national level competitive exams including GRE, TOEFL, GATE, CSIR-JRF, JEST and other higher-educational entrance exams.

3. The students shall learn in-depth in their area of interest through projects of one-year duration.

2 Objective of the program

The program shall develop basic understanding of physics and prepare students for the challenges in the field of research and development, academia, and industry by providing them in-depth knowledge through projects and electives in their field of interest.

3 Technical details

- **Degree on offer:** The department of physics shall offer the degree "`Master of Science (M.Sc.) in Physics`".

- **Total intake:** 29 Students. The seat matrix is given in Table 1.

- **Eligibility:**

  1. B.Sc. with physics as one of the subject in the final year.
  2. Candidates should have minimum 60% marks (or CGPA 6.5/10) in aggregate of all semesters/years and for SC/ST/PwD candidates 55% marks (or CGPA 6.0/10) in aggregate of all semesters/years.

Table 1: Seat Matrix.

Open	Open-Pwd	EWS	EWS-Pwd	SC	SC-Pwd	ST	ST-Pwd	OBC-NCL	OBC-Pwd	Total
11	1	3	0	4	0	2	0	8	0	29

4 Program requirements and course structure

The list of core and elective courses of the program is given in Table 2. The distribution of lecture (L), tutorial (T), and practical (P) hours for each course is given in Table 3.

Table 2: Semester wise credit distribution.

Semester	Core Courses	Electives	Project	Total Credits
I	20	0	0	**20**
II	22	0	0	**22**
III	10	9	3	**22**
IV	2	6	8	**16**
Total	**54**	**15**	**11**	**80**

Table 3: Course details along with distribution of lectures, tutorials and practicals.

Semester	Course Name	Course Code	L-T-P	Credits
I	Mathematical Physics	PH51101	3-1-0	4
	Classical Mechanics	PH51102	3-1-0	4
	Quantum Mechanics	PH51103	3-1-0	4
	Condensed Matter Physics - I	PH51104	3-1-0	4
	Computational Physics	PH51105	1-0-2	2
	General Physics Laboratory	PH51201	0-0-4	2
II	Electromagnetic Theory	PH52101	3-1-0	4
	Thermodynamics and Statistical Physics	PH52102	3-1-0	4
	Nuclear and Particle Physics	PH52103	3-1-0	4
	Atomic, Molecular, and Laser Physics	PH52104	3-1-0	4
	Physics of semiconductor devices	PH52105	3-1-0	4
	Electronics Laboratory	PH52201	0-0-4	2
III	Advanced Quantum Mechanics	PH53101	3-1-0	4
	Numerical methods and programming	PH53102	3-0-2	4
	Elective 1(a): Condensed Matter Physics - II	PH53301	3-0-0	3
	Elective 1(b): Molecular Spectroscopy	PH53302	3-0-0	3
	Elective 1(c): Advanced Materials Characterization	PH54304	3-0-0	3
	Elective 1(d): Plasma Physics	PH54305	3-0-0	3
	Elective 2(a): Nanostructured Materials	PH53304	3-0-0	3
	Elective 2(b): Physics of biological systems	PH53305	3-0-0	3
	Elective 2(c): Nonlinear Dynamics and Chaos	PH53306	3-0-0	3
	Elective 2(d): Introduction to quantum computing	PH53307	3-0-0	3
	Open Elective - I	PH54501	3-0-0	3
	Project Part - I	PH53601	0-0-6	3
	Advanced Physics Laboratory	PH53201	0-0-4	2
IV	Project Part - II	PH54601	0-0-16	8
	Research Seminar	PH54651	0-0-4	2
	Elective 3(a): Molecular orbital theory and electronic spectra of molecules	PH54301	3-0-0	3
	Elective 3(b): X-ray and electron diffraction	PH54302	3-0-0	3
	Elective 3(c): Thin Film Technology	PH54303	3-0-0	3
	Elective 3(d): Virtual Instrumentation: Labview	PH54305	3-0-0	3
	Elective 3(e): Energy storage systems	PH54306	3-0-0	3
	Open Elective - II	PH54502	3-0-0	3

5 Syllabi

The detailed syllabi of courses mentioned above is as follows.

5.1 Semester - I

5.1.1 Mathematical Physics (3-1-0)

CO: Mathematics is the tool to deal with physical problems. The purpose of this course is to introduce the basic techniques of mathematical physics to solve physical problems.

Course Contents:
Vector algebra and vector calculus. Linear algebra. Vector spaces. Matrices, Eigenvalues and eigenvectors. Cayley-Hamilton Theorem, Diagonalization. Orthogonal, Hermitian, and unitary matrices. Gram-Schmidt ortho-normalization process. Similarity transforms. Double and triple integrals. Dirac delta function and its representations. [7 Lectures]

Fourier series and Fourier coefficients. Half range expansion, Fourier integral and Transform, Integral transforms: Laplace transforms and Fourier transforms. Convolution theorem. Inverse Laplace Transform. Introduction to tensors. [7 Lectures]

Ordinary differential equations of first and second order. Series solutions and singular points of second-order differential equations. Special functions: Hermite, Legendre, Laguerre, and Bessel functions. Recurrence relations and generating functions. Spherical harmonics. Gamma, beta, and error functions. Partial differential equations. [10 Lectures]

Complex Variables. Analytic functions of a complex variable. Cauchy-Riemann conditions. Power series, Taylor and Laurent series. Cauchy's integral theorem. Conformal transformations. Complex integral. Cauchy's theorem. Singularities: poles, essential singularities. Residue theorem. Analytic continuation. Multiple-valued functions, branch points, and branch cut integration. [10 Lectures]

Probability theory and Random variables. Probability distributions and probability densities. Standard discrete and continuous probability distributions. Moments and generating functions. Binomial, Poisson and normal distribution. Central limit theorem. [6 Lectures]

References

[1] G. Arfken, and H.J. Weber, *Mathematical Methods for Physicists* (Elsevier Academic Press, 2005).

[2] K.F. Riley, M.P. Hobson, and S.J. Bence, *Mathematical Methods for Physics and Engineering* (Cambridge University Press, 2006).

[3] *Schaum's outline series : (i) Vector and tensor analysis, (ii) Linear Algebra, (iii) Differential Equations, (iv) Probability, (v) Statistics* (McGraw-Hill).

[4] M.L. Boas, *Mathematical Methods in the Physical Sciences* (John Wiley & Sons, 1983).

[5] P.R. Halmos, *Finite-Dimensional Vector Spaces* (Springer, 1987).

[6] P. Dennerey, and A. Krzywicki, *Mathematics for Physicists* (Dover, 1995).

[7] V. Balakrishnan, *Mathematical Physics with Applications, Problems, and Solutions* (Ane Books 2020).

[8] J. W. Brown, and R. V. Churchill, *Complex Variables and Applications*, (McGraw-Hill International, 2004).

[9] H.K. Dass, and R. Verma, *Mathematical Physics* (S. Chand, 2019).

5.1.2 Classical Mechanics (3-1-0)

CO: To introduce the basic concepts and laws that governs the equilibrium and motion of the objects.

Course Contents:
Degrees of freedom. Generalised coordinates and velocities. Lagrangian. Action principle and Euler-Lagrange equations, Constraints, Applications of Lagrangian formalism. [4 lectures]

Hamilton's principle, Generalised momenta, Hamiltonian, Hamilton's equations of motion, Relation to Lagrangian formalism. [4 lectures]

Phase space, Phase space trajectories. Stability analysis, Applications to systems with one and two degrees of freedom, Legendre transformation, Cyclic coordinates and conservation theorems. principle of least action. [7 lectures]

Canonical transformations. Poisson brackets, Hamilton-Jacobi theory, Action-angle variables. Symmetry, invariance and Noether's theorem, Non-integrable systems and elements of chaotic motion. [7 lectures]

Central force problem, Kepler problem. Bound and scattering motions, Scattering in a central potential, Rutherford formula, Scattering cross section. [6 lectures]

Elements of rigid-body dynamics, Euler angles, Non-inertial frames of reference and pseudo-forces: centrifugal Coriolis and Euler forces. Inertial tensor and moment of inertia, The symmetric top, Small oscillations, Normal mode analysis. [8 lectures]

Special theory of relativity - Lorentz transformations, relativistic kinematics and mass–energy equivalence. [4 lectures]

References

[1] H. Goldstein, *Classical Mechanics* (Pearson Education, 2011).

[2] D. Morin, *Introduction to Classical Mechanics* (Cambridge University Press, 2009).

[3] J. R. Taylor, *Classical Mechanics* (University Science Books, 2004).

[4] N. C. Rana and P. S. Joag, *Classical Mechanics* (Tata McGraw-Hill, 1991).

[5] I. Percival and D. Richards, *Introduction to Dynamics* (Cambridge University Press, 1987).

[6] S. N. Biswas, *Classical Mechanics* (Books & Allied Ltd, 1998).

[7] L. D. Landau and E. M. Lifshitz, *Mechanics* (Pergamon Press, 1960).

[8] V. I. Arnold, *Mathematical Methods of Classical Mechanics* (Springer Verlag, 1981).

[9] S. Thornton,*Classical Dynamics of Particles and Systems* (Brooks/Cole, 2003).

5.1.3 Quantum Mechanics (3-1-0)

CO: To introduce to students the fundamental nature of things around us and the laws that govern their behaviour.

Course Contents:
Wave-particle duality. Schrödinger equation. Eigenvalues and eigenstates problems (particle in a box, harmonic oscillator, etc.). Tunneling through a barrier. Hydrogen atom problem. [13 lectures]

Dirac Bra-Ket notations, Matrix representation of observables and states. Determination of eigenvalues and eigenstates for observables using matrix representations. Change of representation and unitary transformations, Coordinate and momentum representations. [14 lectures]

Theory of Angular Momentum, Symmetry, invariance and conservation laws, relation between rotation and angular momentum, commutation rules, Matrix representations. Spins. Addition of angular momenta. [13 lectures]

References

[1] L. I. Schiff, *Quantum Mechanics* (McGraw-Hill, 1949).

[2] J. J. Sakurai, and J. Napolitano, *Modern Quantum Mechanics* (Pearson Education India, 2013).

[3] B. H. Bransden, and C. J. Joachain, *Introduction to quantum mechanics* (Wiley, 1989).

[4] D.J. Griffiths, *Introduction of Quantum Mechanics* (Cambridge University Press, 2016).

[5] P. A. M. Dirac, *The Principles of Quantum Mechanics* (Clarendon Press, 1981).

5.1.4 Condensed Matter Physics - I (3-1-0)

CO: To introduce to students the basics of physics useful to understand solid state materials and their application in various research and development areas.

Course Contents:
Crystal Structure: Crystal structures, Bravais lattices, Reciprocal lattice, Directions, Planes and Miller indices, X-ray diffraction and the structure factor, Bragg's X-ray diffractometer, Powder crystal method. [6 lectures]

Defects and dislocations: Point Defects (Vacancies-Schottky defect, Interstitialcies-Frenkel defect, Compositional defects, Electronic Defects), Line defects (Edge dislocation, Screw dislocation), surface defects (grain boundaries, twin boundaries, tilt boundaries, stacking fault), Burger Vectors. [6 lectures]

Crystal Binding and elastic constants: Forces between atoms, Cohesion of atoms and Cohesive Energy, and Bonding of solids. [6 lectures]

Elastic, Thermal and Electrical Properties of Solids: Analysis of elastic strain, Elastic Compliance and stiffness Constants. Elastic waves in cubic crystals, phonons, lattice specific heat. Classic and Einstein's theory of specific heat, Debye's theory, Free electron theory and electronic specific heat, Temperature dependence of electrical resistivity, Wiedemann-Franz Law, Density of Energy state and Fermi energy, Matthiessen's rule, Response and relaxation phenomena. Hall effect and thermoelectric power. [12 lectures]

Superconductivity: Type-I and Type II superconductors, Meissner effect, London equation, BCS Theory, Josephson junctions, flux quantization. [10 lectures]

References

[1] C. Kittel, *Introduction to Solid State Physics* (Wiley Eastern, 2012).

[2] S. O. Pillai, *Solid State Physics* (New Age International, 2006).

[3] N. W. Ashcroft, and N.D. Mermin, *Solid State Physics* (Cengage Learning, 2010).

[4] B. D. Cullity, and S. R. Stock, *Elements of X-ray Diffraction* (Pearson, 2014).

[5] A. J. Dekker, *Solid State Physics* (Prentice Hall of India, 1971).

[6] B. D. Cullity, and C. D. Graham, *Introduction to Magnetic Materials* (Wiley, 2009).

[7] N. A. Spaldin, *Magnetic Materials: Fundamentals and Applications* (Cambridge University Press, 2003).

5.1.5 Computational Physics (1-0-2)

CO: To introduce basic computer programming used to solve various problems computationally.

Course Contents:

Introduction to GNU/Linux environment [1 Lecture]

Elementary numerical programming using either FORTRAN or C Language, and MATLAB software. [11 Lectures]

Monte-Carlo methods and random numbers, Discrete Fourier transform, and their applications. [2 Lecture]

References

[1] B. Davis and T.R. Hoffmann, Fortran-77-A Structured Disciplined style, McGraw Hill, Singapore, 1988.

[2] S. J. Chapman, *Introduction to Fortran 90/95* (McGraw-Hill, 1998).

[3] W.H. Press, B.P. Flannery, S.A. Teukolsky, and W.T. Vetterling *Numerical Recipies: The Art of Scientific Computing* (Cambridge University Press, 1988).

[4] S. B. Lippmann, J. Lajoie, and B. Moo, *C++ Primer* (Addison-Wesley, 2012).

[5] H. Schildt, *C++: The Complete Reference* (McGraw-Hill, 2017).

[6] K. H. Hoffmann, and M. Schreiber, *Computational Physics* (Springer, 1996).

[7] S. E. Koonin, and D. C. Meredith, *Computational Physics* (Westview Press, 1998).

[8] T. Pang, *An Introduction to Computationl Physics* (Cambridge Univ Press, 2006).

5.1.6 General Physics Laboratory (0-0-4)

CO: To provide hands on training of various phenomena students learned in theory classes.

Course Contents:

1. Michelson Interferometer: thickness of mica sheet.
2. Dielectric constant.
3. Thermal conductivity by Forbes' Method.
4. Magnetic Susceptibility Gouy's Method.
5. M-H curve.
6. Determination of band-gap using four probe method.
7. Hall Effect: determination of Hall coefficient, charge carrier's type, mobility of charge carriers and their concentration.
8. Determination of the specific heat.

References

[1] Laboratory manual.

5.2 Semester-II

5.2.1 Electromagnetic Theory (3-1-0)

CO: To introduce to students concepts of electromagnetic fields which are essential to understand several electromagnetic instrumentation and their applications.

Course Contents:
Electrostatics: Coulomb's law, Scalar potential, Electrostatic potential energy, Conductors, field of an electric dipole, Laplace and Poisson equations. Boundary value problems. Dirichlet and Neumann boundary conditions. Method of images. Electrostatic field in matter, Polarization, bound charges, Electric Displacement. [10 Lectures]

Magnetostatics: Steady currents, Ampere's law and Biot-Savart's law. Concept of a vector potential. Multipole expansion, magnetic field in matter, bound charges, magnetic susceptibility and permeability, Boundary conditions. [10 Lectures]

Electrodynamics: Dynamic and Quasi-static fields, Faraday's Law and induced emf. Maxwell's equations, Displacement current, Poynting theorem, Electromagnetic waves in vacuum and dielectric media. Reflection and refraction, polarization, Fresnel's law, interference, coherence, and diffraction. Gauge transformation: Lorentz and coulomb, reflection and refraction of electromagnetic waves. [12 Lectures]

Lorentz invariance of Maxwell's equation. Transmission lines and wave guides. Radiation- from-moving charges and dipoles and retarded potentials. [8 Lectures]

References

[1] D. J. Griffiths, *Introduction to Electrodynamics* (Cambridge University Press, 2020).

[2] J. D. Jackson, *Classical Electrodynamics* (Wiley, 2007).

[3] A. Zangwill, *Modern Electrodynamics* (Cambridge university press, 2012).

[4] S. P. Puri, *Classical Electrodynamics* (Narosa Publishing, 2016).

[5] J.R. Reitz, F.J. Milford, and R. W. Christy, *Foundations of Electromagnetic Theory* (Pearson, 2008).

[6] P. Lorrain, and D. Corson, *Electromagnetic Fields and Waves* (W.H Freeman and Company, 1988).

[7] B.H. Chirgwin, C. Plumpton, and C. W. Kilmister, *Elementary Electromagnetic Theory, Vols. 1, 2 and 3* (Pergamon Press, 1972).

5.2.2 Thermodynamics and Statistical Physics (3-1-0)

CO: To explore techniques which deal with many-particle systems statistically averaged and relevant properties of the system.

Course Contents:
Laws of thermodynamics and their consequences. Thermodynamic potentials, Maxwell relations, chemical potential, phase equilibria. [8 lectures]

Phase space, micro- and macro-states. Micro-canonical, canonical and grand-canonical ensembles and partition functions. Free energy and its connection with thermodynamic quantities. Classical and quantum statistics: Maxwell-Boltzmann, Bose-Einstein, Fermi-Dirac statistics. [20 lectures]

Ideal Bose and Fermi gases. Bose-Einstein condensation, Principle of detailed balance. Black body radiation and Planck's distribution law. 1st and 2nd order phase transition. [12 lectures]

References

[1] D. J. Amit, Y. Verbin, *Statistical Physics: An Introductory Course* (World Scientific Publishing, 1999).

[2] D. Chandler, *Introduction to Modern Statistical Mechanics* (Oxford University Press, 1987).

[3] C.J. Thompson, *Classical Equilibrium Statistical Mechanics* (Clarendon Press, 1988).

[4] F. Reif, *Fundamentals of Statistical and Thermal Physics* (McGraw-Hill, 1988).

[5] K. Huand, *Statistical Mechanics* (Wiley, 1987).

[6] L.D. Landau and E.M. Lifshitz, *Statistical Physics* (Pergamon Press, 1989).

[7] F. Mandl, *Statistical Physics* (Wiley, 1988)

[8] E.S.R. Gopal, *Statistical Mechanics and Properties of Matter* (MacMillan India, 1988).

[9] R. Kubo. *Thermodynamics: An advance course with problems and solutions* (North Holland, 1968).

5.2.3 Nuclear and Particle Physics (3-1-0)

CO: To provide the basic understandings of the constituents and the interactions of the atomic nuclei.

Course Contents:
Basic nuclear properties: size, shape and charge distribution, spin and parity. Binding energy, semi-empirical mass formula, liquid drop model. [4 lectures]

Nature of the nuclear force, form of nucleon-nucleon potential, charge-independence and charge-symmetry of nuclear forces. Deuteron problem. [6 lectures]

Evidence of shell structure, single-particle shell model, its validity and limitations. Rotational spectra. Elementary ideas of alpha, beta and gamma decays and their selection rules. [7 lectures]

Fission and fusion. Nuclear reactions, reaction mechanism, compound nuclei and direct reactions. [4 lectures]

Linear Accelerator (LINAC), Cyclotron, Betatron, Synchrotron, Collider Physics, Geiger-Muller counter, Scintillation counter, NMR, Nuclear Reactors. [8 lectures]

Classification of fundamental forces, Elementary particles and their quantum numbers (charge, spin, parity, isospin, strangeness, etc.), Conservation Laws, Gell-Mann–Nishijima formula. [5 lectures]

Quark model, baryons and mesons. C, P, and T invariance. Application of symmetry arguments to particle reactions. Parity non-conservation in weak interaction. Relativistic kinematics. [6 lectures]

References

[1] K. S. Krane, *Introductory Nuclear Physics* (Wiley, 2008).

[2] I. Kaplan, *Nuclear Physics* (Narosa, 2002).

[3] S. N. Ghoshal, *Nuclear Physics* (S. Chand Publishing, 2019).

[4] M. A. Preston, and R. K. Bhaduri, *Structure of the Nucleus* (Westview Press, 1993).

[5] M. K. Pal, *Theory of Nuclear Structure* (Scientific and Academic Editions, 1983).

[6] S. S. M. Wong, *Introductory Nuclear Physics* (Wiley-VCH, 1998).

[7] S. DeBenedetti, *Nuclear Interactions* (John Wiley & Sons, 1964).

[8] B. R. Martin, and G. Shaw, *Nuclear and Particle Physics: An Introduction* (Wiley, 2019).

[9] D. J. Griffiths, *Introduction to Elementary Particles* (Wiley-VCH, 2008).

5.2.4 Atomic, Molecular, and Laser Physics (3-1-0)

CO: To provide a basic understanding of laws that governs transitions at the atomic and molecular level.

Course Contents:
Atomic Physics: Quantum mechanical treatment of one electron atom: Atomic spectra and Hydrogen atom, Dipole selection rules, magnetic dipole moment, vector model of an atom, Stern-Gerlach experiment, Spin-orbit coupling, fine structure of hydrogen atom, Lamb shift, Pauli's exclusion

principle, spectra of alkali elements. [8 lectures]

Multi-electron atoms: Hartree field, spectroscopic terms: L-S and j-j couplings for many electrons atom, Normal and Anomalous Zeeman effect, Paschen-Back and Stark Effect, fine and hyperfine structure of spectral lines, Natural and Doppler Broadening, Normal and specific mass shifts [6 lectures]

Molecular Physics: Types of molecular spectra and molecular energy states, pure rotational spectra of a diatomic molecule as a: rigid and non-rigid rotator, isotopes effect. Vibrational-Rotational spectra of a diatomic molecule as a: harmonic, anharmonic oscillator, and vibrating rotator, thermal distribution of vibrational and rotational levels, Raman Effect: vibrational and rotational Raman spectra of diatomic molecules. [9 lectures]

Electronic spectra: vibrational and rotational (fine) structure of electronic bands, Franck-Condon Principle, isotopes effect, , classification of molecular electronic spectra, Nuclear spin and intensity alternation, missing lines in rotational spectra, coupling of rotational and electronic motions: Hund's coupling, dissociation energy. [9 lectures]

Lasers: Requisites for producing laser light, spontaneous and stimulated emission, Einstein A & B coefficients. Optical pumping, population inversion, rate equation. Modes of resonators and coherence length. Line broadening, q-switching and laser systems. [9 lectures]

References

[1] B.H. Bransden, and C.J. Joachain, *Physics of Atoms and Molecules* (John Wiley & Sons, 1983).

[2] H.E. White, *Introduction to Atomic Spectra* (McGraw-Hill, 1934).

[3] H.G. Kuhn, *Introduction to Atomic Spectra* (Prentice Hall Press, 1970).

[4] G. Herzberg, *Molecular Spectra & Molecular Structure: Spectra of diatomic molecules, Vol I* (Van Nostrand Reinhold Company, 1979).

[5] C.N. Banwell, *Fundamental of molecular spectroscopy*, (McGraw-Hill, 1983).

[6] G.M. Barrow, *Introduction to molecular spectroscopy* (McGraw-Hill, 1962).

[7] J.M. Hollas, *Basic Atomic and Molecular spectroscopy*, (Royal Society of Chemistry, 2002).

[8] J.C. Slater, *Quantum theory of molecules and solids* (McGraw Hill, 1963).

[9] K. Thyagarajan, and A. Ghatak, *Lasers: Theory and Applications*, (Springer, 2010).

5.2.5 Physics of semiconductor devices (3-1-0)

CO: To familiarize the students with the basics of analog and digital electronics applied in electronics and allied industries.

Course Contents:
Electronic Properties of Solids: Free electron theory, band theory of solids, Kronig-Penney Model, nearly free electron and tight binding models, Brillouin Zones, Motion of electron in one-dimensional periodic potential - Effective mass, metals, semiconductors and insulators, conductivity, mobility. [10 lectures]

Intrinsic and extrinsic semiconductors, diodes, transistors, transistor models, transistor biasing and characteristics. [4 lectures]

Amplifiers (CE, CC), Darlington pairs, difference amplifiers, operational amplifiers, feedback, two stage feedback amplifier. [7 lectures]

Filters, FETs, JFETs and MOSFETs, MOS (PMOS, NMOS, CMOS), Opto-electronic devices (solar cells, photo-detectors-photodiode, phototransistor, LDR, LEDs, and laser diodes). [7 lectures]

Digital electronics: Logic gates, Boolean algebra, Karnaugh maps, Implementation using universal gates, flip flops, shift registers, adders, counters, ADC and DAC. [11 lectures]

References

[1] S. M. Sze, K. K. Ng, *Physics of Semiconductor Devices* (Wiley, 2008).

[2] B. G. Streetman and S. K. Banerjee, *Solid State Electronic Devices* (Pearson, 2018).

[3] J. Millman, and C. Halkias, *Integrated Electronics: Analog and Digital Systems* (McGraw-Hill, 1972).

[4] R. L. Boylestad, and L. Nashelsky, *Electronic Devices and Circuit Theory* (Pearson Education India, 2015).

[5] A. P. Malvino, *Electronic Principles* (Tata McGraw-Hill Publishing, 1993).

[6] P. Horowitz, and W. Hill, *The Art of Electronics* (Cambridge University Press, 2015).

[7] J. Millman, and H. Taub, *Pulse, Digital and Switching Waveforms* (McGraw-Hill, 2017).

[8] A. Paul Malvino, and D. P. Leach, *Digital Principles and Applications* (Tata McGraw-Hill Publishing, 1994).

[9] T. L. Floyd, *Digital Fundamentals* (Prentice Hall, 2005).

[10] M. M. Mano, and M. D. Ciletti, *Digital Design* (Pearson Education, 2018).

[11] R. P. Jain, *Modern Digital Electronics* (McGraw-Hill, 2009).

5.2.6 Electronics Laboratory (0-0-4)

CO: To provide hands on training of various phenomena students learned in theory classes.
Course Contents:

1. LED characteristics.
2. Zener breakdown: I-V characteristics, Set up a power supply using a Zener diode as a voltage regulator, To calculate percentage of regulation.
3. To study the input and output characteristics of an NPN transistor in Common Emitter mode and determine transistor parameters.
4. To determine the 'h' parameters of bi-junction transistor.
5. Design and study of common emitter amplifier, two stage feeddback amplifier.
6. FET characteristics: The drain and transfer characteristics, drain resistance ($\mathrm{r_d}$), amplification factor (μ) and trans conductance ($\mathrm{g_m}$).
7. MOSFET characteristics: Frequency response of MOSFET amplifier in common source configuration, I-V characteristics, MOSFET as a variable resistor and as a switch.
8. Use of IC741: basic configuration of OPAMP, simple mathematical operations and its use as comparator and Schmitt trigger, inverting amplifier, Integrator, Multivibrator, and Weinbridge oscillator, Phase shift Oscillator.
9. RC Coupled amplifiers: construct a two stage R-C Coupled amplifier, study the frequency response of the amplifier and to determine the bandwidth.
10. A/D and D/A converter.
11. Logic gate circuits: all six gates and truth table verification
12. R-S and J-K flips flops, adder and subtractor circuits, counter circuits.

References

[1] Laboratory manuals.

5.3 Semester-III

5.3.1 Advanced Quantum Mechanics (3-1-0)

CO: To introduce to students the fundamental nature of things around us and the laws that govern their behaviour.

Course Contents:
Approximation Methods: Time-independent Perturbation theory (non-degenerate and degenerate) and applications. [7 Lectures]

Variational method and applications to helium atom and simple cases, WKB approximation. Time dependent Perturbation theory, Fermi's Golden rule. Selection rules. [9 Lectures]

Identical particles. Pauli exclusion principle, spin-statistics connection. Spin-orbit coupling, fine structure. [7 Lectures]

Elementary theory of scattering: phase shifts, partial waves, Born approximation. [6 Lectures]

Relativistic quantum mechanics: Klein-Gordon and Dirac equations. Dirac Matrices, Semi-classical theory of radiation. [11 Lectures]

References

[1] R. Shankar, *Principles of Quantum Mechanics* (Springer, 2014).

[2] J. J. Sakurai, *Modern Quantum Mechanics* (Cambridge University Press, 2020).

[3] D. J. Griffiths, *Introduction to Quantum Mechanics* (Cambridge India, 2016).

[4] J. J. Sakurai, *Advanced Quantum Mechanics* (Pearson Education India, 2002).

[5] N. Zettili, *Quantum Mechanics: Concepts and Applications* (Wiley Publication, 2009).

[6] E. Merzbacher, *Quantum Mechanics* (Wiley Publication, 2011).

[7] J. D. Bjorken, and S. D. Drell, *Relativistic Quantum Mechanics* (Primis, 2008).

[8] B. R. Desai, *Quantum Mechanics with Basic Field Theory* (Cambridge University Press, 2009).

[9] A. Lahiri, and P.B. Pal, *A First Book on Quantum Field Theory* (Narosa, 2007).

5.3.2 Numerical Methods and Programming (3-0-2)

CO: To deliver computational tools and techniques required to solve various problems in physics.

Course Contents:
Approximation Methods and Errors: Truncation and round-off errors. Accuracy and precision. Roots of Equations: bisection method, false position method, iteration Methods, Newton- Raphson and secant methods. Systems of linear algebraic equations, inversion and LU decomposition methods. [9 lectures]

Interpolation: polynomial interpolation. Finite differences, Newton's interpolation formulae, Lagrange's interpolation formulae for unevenly spaced points. [5 lectures]

Curve fitting: Least squares regression. Linear, multiple-linear and nonlinear regressions. Method of least squares for Continuous Functions: Orthogonal Polynomials, Gram-Schmidt Orthogonalization Process. Fourier Approximation: Fourier Transform, Discrete Fourier Transform, Fast Fourier Transform (FFT). Cubic spline. [9 lectures]

Numerical differentiation: Divided difference method. Numerical integration: Trapezoidal, Simpson's, Boole's and Weddle's rules. [4 lectures]

Ordinary differential equations: Euler's and modified Euler's method. Runge-Kutta methods. Partial differential equations: Finite difference equations. Application in physical problems: Laplace's equation and solutions. Solution of the heat conduction equation. Introductory finite element method. [9 lectures]

Chaotic behaviour in dynamical systems. Simple one-dimensional maps. Period doubling. [4 lectures]

References

[1] S.S. Sastry, *Introductory Methods of Numerical Analysis* (Prentice Hall India, 2012).

[2] S. E. Koonin, and D. C. Meredith, Computational Physics (Westview Press, 1998).

[3] T. Pang, *An Introduction to Computationl Physics* (Cambridge Univ Press, 2006).

[4] J.B. Scarborough, *Numerical Mathematical Analysis* (Oxford University Press, 2005).

[5] S. C. Chapra and R.C. Canale, *Numerical Methods for Engineering* (McGraw-Hill, 2010).

[6] M.K. Jain, S.R.K. Iyengar, and R.K. Jain, *Numerical Methods for Scientific and Engineering Computation* (Wiley, 1992).

[7] W.H. Press, B.P. Flannery, S.A. Teukolsky, and W.T. Vetterling *Numerical Recipies: The Art of Scientific Computing* (Cambridge University Press, 1988).

5.3.3 Elective 1(a): Condensed Matter Physics - II (3-0-0)

CO: To introduce to students the basics of physics useful to understand solid state materials and their application in various research and development areas.

Course Contents:
Optical properties of solids: Drude Theory–Free Carrier Contribution to the Optical Properties, intra- and inter-band transitions, Kramer's-Kronig relation, Impurities and Excitons, Raman Effect in Crystals. [10 lectures]

Dielectric properties of solid: Macroscopic Electric Field, Local Electric Field at an atom, dielectric constant and polarizability: Clasius-Mossotti relation, Electronic Polarizibility, ferroelectric crystals and their classification. [10 lectures]

Magnetic properties of solids: Langevin's classical and quantum theories of dia and para magnetism, Weiss theory of ferromagnetism, Heisenberg model of exchange interaction, Concept of domain and hysteresis, Magnetic anisotropy, Antiferromagentism, Ferri-magnetism (Spinel, Garnet and Hexaferrites). [12 lectures]

Magnetic Resonance: Nuclear Magnetic Resonance, electron paramagnetic resonance, ferromagnetic resonance. [4 lectures]

Ordered phases of matter: translational and orientational order, kinds of liquid crystalline order, Quasi crystals. [4 lectures]

References

[1] C. Kittel, *Introduction to Solid State Physics* (Wiley Eastern, 2012).

[2] S. O. Pillai, *Solid State Physics* (New Age International, 2006).

[3] N.W. Ashcroft, and N.D. Mermin, *Solid State Physics* (Cengage Learning, 2010).

[4] B. D. Cullity, and S. R. Stock, *Elements of X-ray Diffraction* (Pearson, 2014).

[5] F. Wooten, *Optical Properties of Solids* (Academic Press, 1972)

[6] M. S. Dresselhaus, *Solid State Physics Part I (Transport Properties of Solids), II (Optical Properties of Solids), III (Magnetism) and IV (Superconductivity).*

[7] B. D. Cullity, and C. D. Graham, *Introduction to Magnetic Materials* (Wiley, 2009).

[8] B. Lax, and K. J. Button, *Microwave ferrites and ferrimagnetics* (McGraw-Hill, 1962)

[9] N. A. Spaldin, *Magnetic Materials: Fundamentals and Applications* (Cambridge University Press, 2003).

[10] S. Chandrasekhar, *Liquid Crystals* (Cambridge University Press, 1994).

[11] E. Macia-Barber, *Quasicrystals Fundamentals and Applications* (CRC Press, 2021).

5.3.4 Elective 1(b): Molecular Spectroscopy (3-0-0)

Course Contents:
Symmetry and Group Theoretical Treatment: Molecular symmetry and Group Theory. Matrix Representations of symmetry elements of a Point Group. Reducible and irreducible Representations, Character Tables for C_{2v} and C_{3v} point groups. [8 lectures]

Normal modes of vibration and their distribution into symmetry species of the molecule. Infrared and Raman Selection rules, Overtone and Combination Bands, Concept of multiple potential minima and inversion of NH_3. [9 lectures]

Vibration-Rotation Energy Levels and Spectra: Rotational Energy of Spherical, Prolate and Oblate Symmetric Rotors, Rotational Raman and IR Spectra of linear molecules and Determination of their Geometry. [10 lectures]

Influence of Nuclear Spin on Rotational Raman Spectrum, RotationVibration Band of a Diatomic Molecule, Parallel and Perpendicular type Bands in Linear and symmetric Rotor Molecules. Qualitative description of Type A, B and C bands in Asymmetric Rotor Molecules. [10 lectures]

References

[1] F. A. Cotton, *Chemical Applications of Group Theory* (Wiley, 2008).

[2] C. N. Banwell, *Fundamentals of Molecular Spectroscopy* (McGraw-Hill, 2017).

[3] G.M. Barrow, *Introduction to Molecular Spectroscopy* (McGraw-Hill, 1962).

[4] J.M. Hollas, *Modern Spectroscopy* (Wiley, 2004).

5.3.5 Elective 1(c): Advanced Materials Characterization (3-0-0)

CO: In this course, the students will learn the fundamentals, instrumentation, and applications of the various advanced characterization technique.

Course Contents:
Microscopic Technique: Optical Microscopy, Scanning Electron Microscopy (SEM) and Electron Dispersive Spectroscopy (EDS), Tunnelling Electron Microscopy (TEM). [8 lectures]

Diffraction Technique: X-Ray Diffraction, Neutron Scattering, Electron Diffraction. [5 lectures]

Spectroscopic Technique:Fourier Transform Infrared Spectroscopy (FTIR), Ultra-Violet (UV-Vis) Spectroscopy, Photoluminescence (PL) Spectroscopy, Raman Spectroscopy, Electron Spin Resonance (ESR) spectroscopy, Nuclear Magnetic Resonance (NMR) Spectroscopy. [9 lectures]

Other Characterization Technique: Materials Characterization by X-Ray Photoelectron Spectroscopy (XPS), Auger Electron Spectroscopy (AES), BET Measurement for surface area and pore size determination, Atomic Force Microscopy (AFM). [6 Lectures]

Electrical, Magnetic and Thermal Characterization Techniques: Impedance Analyser and its Applications, Piezo-electric, Ferroelectric, and pyroelectric materials and their characterization techniques, SQUID, Hall Effect, Vibrating Sample Magnetometer (VSM), Thermogravimetric Analyser (TGA), Differential Scanning Calorimetry (DSC), Differential Thermal Analysis (DTA), Polarized Optical Microscope (POM), Contact Angle Measurement. [12 lectures]

References

[1] B. D. Cullity, *Elements of X-Ray Diffraction* (Addison-Wesley Publishing, 1956).

[2] S. Svanberg, *Atomic and Molecular Spectroscopy* (Springer, 2004).

[3] J. M. Hollas, *Basic Atomic and Molecular Spectroscopy* (Royal Society of Chemistry, 2002).

[4] C. N. Benwell, *Fundamentals of Molecular Spectroscopy* (McGRAW-Hill Company, 1983)

[5] R. F. Egerton, *Physical Principles of Electron Microscopy* (Springer, 2005)

[6] A. K. Tyagi, M. Roy, S.K. Kulshreshtha, and S. Banerjee, *Advanced Techniques for Materials Characterization* (Trans Tech Publications, 2009)

[7] D. B. Williams, and C.B. Carter, *Transmission Electron Microscopy* (Springer, 2009).

[8] J. F. Watts, and J. Wolstenholme, *An Introduction to Surface Analysis by XPS and AES* (John Wiley & Sons Ltd, 2003)

[9] J. R. Ferraro, K. Nakamoto, and C.W. Brown, *Introductory Raman Spectroscopy* (Elsevier, 2003).

[10] K. Y. Law, and H. Zhao, *Surface Wetting: Characterization, Contact Angle, and Fundamentals* (Springer, 2016)

[11] R. F. Speyer, *Thermal Analysis of the Materials* (Taylor and Francis, 1993).

5.3.6 Elective 1(d): Plasma Physics

Course Contents:
Plasma Physics: Elementary Concepts: Plasma Oscillations, Debye Shielding, Plasma Parameters, Magnetoplasma, Plasma Confinement, First, Second, and Third Adiabatic Invariants (Pinch Effect, Magnetic Mirrors), Formation of Van Allen Belt. Hydrodynamical Description of Plasma: Fundamental equations, Hydromagnetic Waves: Magnetosonic and Alfven Waves, Magnetoconvection and Sun Spots, Bipolar magnetic Regions and Magnetic Buoyancy, Magnetised Winds (Solar Wind). Wave Phenomena in Magnetoplasma: Polarisation, Phase Velocity, Group Velocity, Cut-offs, Resonance for Electromagnetic Wave Propagating Parallel and Perpendicular to the Magnetic Field Propagation at Finite Angle.

References

[1] . Classical Electricity and Magnetism: W.K.H. Panofsky and M. Phillips.

[2] . Plasma Physics: A Bittencourt.

[3] . Plasma Physics and Controlled Fusion: F.F. Chen.

[4] . Classical Electrodynamics: J.D. Jackson.

5.3.7 Elective 2(a): Nanostructured Materials (3-0-0)

Course Contents:

Introduction to nanoscience and nanotechnology, quantum effect, size effect: surface effect and quantum confinement; nanomaterial structure: quantum well, quantum dot, quantum wire; density of state. [10 lectures]

Nanomaterial Synthesis techniques: top-down and bottom-up approach, physical method: sputtering, thermal decomposition, pulsed laser deposition (PLD), ball milling, lithography; chemical method: co-precipitation, sol-gel method, hydrothermal, reflux method. [8 lectures]

Properties of nanomaterial: optical properties: band gap engineering, surface plasmon resonance; magnetic properties: super-paramagnetism; electrical properties: ballistic transport, Coulomb blockade. [10 lectures]

Nano-scale characterisation techniques: XRD, UV-Visible spectroscopy, Transmission electron microscope (TEM), scanning electron microscope (SEM), atomic force microscope (AFM), Raman spectroscopy, photoluminescence (PL), X-ray photoelectron spectroscopy (XPS). [8 lectures]

References

[1] G. Cao, *Nanostructures & Nanomaterials: Synthesis, Properties & Applications* (Imperial College Press, 2004).

[2] Micheal F. Ashby, P.J. Ferreria, and D.L. Schodek, *Nanomaterials, Nanotechnologies and Design: An introduction for engineers and Architects* (Butterworth-Heinemann, 2009).

[3] G. L. Hornyak, H. F. Tibbals, J. Dutta, and J. J. Moore, *Introduction to Nanoscience and Nanotechnology* (CRC Press, 2008)

[4] G. L. Hornyak, J. J. Moore, H. F. Tibbals, and J. Dutta, *Fundamentals of Nanotechnology* (CRC Press, 2009)

[5] D. Vollath, *Nanomaterials: An introduction to synthesis, properties and application* (Wiley VCH, 2008)

[6] B. Cantor, *Novel Nanocrystalline Alloys and Magnetic Nanomaterials* (CRC Press, 2004).

[7] B. D. Cullity, *Elements of X-ray Diffraction* (Addison Wesley, 1977).

[8] D. B. Williams, and C. B. Carter, *Transmission Electron Microscopy: A Textbook for Materials Science* (Plenum Press, 1996).

[9] D. L. Schodek, P. Ferreira, and M. F. Ashby, *Nanomaterials, Nanotechnologies and Design: An Introduction for Engineers* (Elsevier, 2009).

[10] R. E. Newnham, *Properties of materials* (Oxford university press, 2005).

5.3.8 Elective 2(b): Physics of Biological Systems (3-0-0)

Course Contents:
Bonding: Covalent bond, electrostatic interaction, hydrogen bond, Bonded and non-bonded interactions, cooperative phenomena, hydrophobic and hydrophilic interactions. [6 lectures]

Sugars and metabolites: Molecules of biological interest, structures of sugars, ATP and ADP, energetics, photosynthesis,. Lipids and Membranes: Structures of membranes, transport across membranes. [7 lectures]

Nucleic Acids: Double helical structure of DNA, Watson-Crick Model, Conformational parameters of nucleic acids and their constituents, DNA Types: B, A and Z DNA, DNA super coiling, RNA and its Types, Genetic Code. [7 lectures]

Proteins and their structures: Structures and properties of amino acids, primary, secondary, tertiary and quaternary structures of proteins, protein folding. [6 lectures]

Enzymes: Mechanism of enzyme action, enzyme kinetics, effects of temperature and pH, Lock and Key model, Induced-fit model, Conformations. [7 lectures]

The Cell: Introduction to the Cells, cell organelles, cell types and cell functions, structures and functions of neurons, neurotransmitters. [7 lectures]

References

[1] P. Narayanan, *Essentials Of Biophysics* (New Age International, 2000).

[2] P. Nelson, *Biological Physics: Energy, Information, Life* (W.H. Freeman, 2007).

[3] M. B. Jackson, *Molecular and Cellular Biophysics* (Cambridge University Press, 2010).

[4] T. Waigh, *Applied Biophysics: A Molecular Approach for Physical Scientists* (Wiley, 2007).

[5] B. Alberts, A. Johnson, J. Lewis, M. Raff, K. Roberts, and P. Walter, *Molecular Biology of the Cell* (Garland Science, 2002).

5.3.9 Elective 2(c): Nonlinear Dynamics and Chaos (3-0-0)

CO: To provide basic knowledge tools and techniques to deal with non-linear problems.

Course Contents:
Dynamical Systems and their stability: Motion in one, two and three dimensions. Fixed points and stability analysis. Bifurcations: Saddle-Node, Transcritical, and Pitchfork bifurcations. Phase space and trajectories for two and three dimensional systems, fixed point, stability and linearization. Stable, unstable and center manifolds. [12 lectures]

Classical Chaos: Iterative maps and Poincar'e section. One dimensional non-invertible maps, Logistic map, Sensitivity to initial conditions, Lyapunov exponents. Higher dimensional systems, Henon map, Lorenz equations. chaos in Hamiltonian systems, integrability, Liouville's theorem, KAM theorem, area preserving maps. [16 lectures]

Quantum Chaos: Chaos in quantum systems. Chaos signatures in stationary states - Fluctuation statistics and spectrum unfolding, level spacing distribution, variance of number static, spectral rigidity, Introduction to Random Matrix Theory. Phase space dynamics - Husimi and Wigner function. Ehrenfest time. [12 lectures]

References

[1] S. H. Strogatz, *Nonlinear Dynamics and Chaos* (Westview Press, 2014).

[2] I. Percival, and D. Richards, *Introduction to Dynamics* (Cambridge University Press, 1982).

[3] E. Ott, *Chaos in Dynamical Systems* (Cambridge University Press, 2002).

[4] A. J. Lichtenberg, and M. A. Lieberman, *Regular and Chaotic Dynamics* (Springer, 1994).

[5] M. C. Gutzwiller, *Chaos in Classical and Quantum Mechanics* (Springer, 1990).

[6] H.-J. Stöckmann, *Quantum Chaos: An Introduction* (Cambridge University Press, 2009).

[7] M. L. Mehta, *Random Matrices* (Elsevier, 2004).

[8] F. Haake, *Quantum Signatures of Chaos* (Springer, 2010).

5.3.10 Elective 2(d): Introduction to quantum computing

Course Contents:
Elementary quantum mechanics:, linear algebra for quantum mechanics,Quantum states in Hilbert space,The Bloch sphere, Density operators, generalized measurements, no-cloning theorem.
Quantum correlations: Bell inequalities and entanglement, Schmidt decomposition, Quantum cryptography and quantum key distribution, Quantum gates and algorithms: Universal set of gates, quantum circuits, information scrambling.

References

[1] Phillip Kaye, Raymond Laflamme et. al., An introduction to Quantum Computing, Oxford University press, 2007.

[2] Chris Bernhardt, Quantum Computing for Everyone, The MIT Press,Cambridge, 2020

[3] David McMahon-Quantum Computing Explained-Wiley-Interscience , IEEE Computer Society (2008)

[4] Quantum Computation and Quantum Information, M. A. Nielsen &I.Chuang, Cambridge University Press (2013).

[5] Quantum Computing, A Gentle Introduction , Eleanor G. Rieffel and Wolfgang H. Polak MIT press (2014)

5.3.11 Open Elective - I (3-0-0)

The course content will be of the relevant department, offering the elective.

5.3.12 Project Part - I (0-0-6)

The project and its content shall be decided by the concerned faculty of the project.

5.3.13 Advanced Physics Laboratory (0-0-4)

1. Determination of the relaxation time by Electron Spin Resonance for a given sample and find the value of g.
2. Lattice vibration or lattice dynamics: To investigate the interaction of electromagnetic waves with crystalline solids)
3. Solar cell (Study the I-V characteristic of solar cell illuminated by sun light and incandescent bulb at different frequencies.
4. To determine the temperature dependence of total radiation and hence verify the Stefan's law.
5. UV-Vis spectroscopy, and determination of the bandgap of solid sample in disperse form (using Tauc plot).
6. Photoluminescence spectroscopy.
7. G.M Counter: The purpose of this experiment is to determine Plateau Characteristics of GM tube and to determine reasonable operating point for the tube.
8. Study of Zeeman effect
9. Balmer series:
   (a) To measure the wavelengths of visible spectral lines in Balmer series of atomic hydrogen
   (b) To determine the value of Rydberg's constant
10. Study of spectral and spatial properties of the beam of He-Ne laser.
    (a) To determine the wavelength of laser light from single-slit diffraction pattern.
    (b) To determine the thickness of a fine wire from its diffraction pattern.
11. Verification of mutual exclusion principle using IR and Raman spectra of benzene and CCL_4.

References

[1] Laboratory Manuals.

5.4 Semester-IV

5.4.1 Project Part - II (0-0-16)

The project and its content shall be decided by the concerned faculty of the project.

5.4.2 Research Seminar (0-0-4)

The course content of research seminar shall be decided by the concerned faculty such that it will be in line with the interest of the student.

5.4.3 Elective 3(a): Molecular Orbital Theory and Electronic Spectra of Molecules (3-0-0)

Course Contents:
Atomic and Molecular Orbital Theories: Elementary idea of Atomic Orbitals in Hartree-Fock Theory, Qualitative description of ab-initio methods, LCAO treatment of H_2^+ and H_2 molecules. Molecular charge distribution and Dipole moment. Hellman-Feynman Theorem and concept of force. [8 lectures]

Hybrid Atomic Orbitals in H_2O, CH_4, C_2H_2, and C_2H_4. Concept of lone pairs. Huckel method and its application to Ethylene, Butadiene and Benzene. Changes in molecular geometry on electronic excitation. [9 lectures]

Spectroscopy of Diatomic and Polyatomic Molecules: Dissociation Energy of Diatomic Molecules, Coupling of Electronic and Rotational motion in Diatomic Molecules and Rotational structure of $1\pi - 1\Sigma$ and $1\Sigma - 1\Sigma$ transitions. [10 lectures]

Vibronic interaction and Herzberg Teller theory for absorption spectrum of benzene vapour. Single vibronic level spectroscopy and lifetime of vibronic levels in benzene, Quantum yield, Kasha Rule and the concept of non-radiative transitions in molecules. Jablanski diagram. [10 lectures]

References

[1] A. Streitwieser, *Molecular Orbital Theory for Organic Chemists* (John Wiley & Sons, 1962).

[2] C.A. Coulson, *Valence* (Oxford University Press, 1953).

[3] J. M. Hollas, *High Resolution Spectroscopy* (Wiley, 1998).

[4] W. Demtröder, *Laser Spectroscopy: Basic Concepts and Instrumentation* (Springer, 1996).

5.4.4 Elective 3(b): X-ray and Electron Diffraction (3-0-0)

CO: To introduce to students the basics, applications and analysis of data of very useful materials characterization techniques namely X-ray and electron diffraction.

Course Contents:

Properties of X-rays: Production and Properties of X-rays, Continuous and Characteristic spectrum, Absorption, Filters, Production of X-rays and Detection of X-rays. [5 lectures]

Diffraction of X-rays: Diffraction by a crystal. The Bragg's law. X-ray spectroscopy, Diffraction directions, Diffraction Methods (Laue Method, Rotating-crystal method, powder method), Diffraction nonideal condition (Scherrer formula), Scattering by an electron, Scattering by an atom, Scattering by a unit cell, Structure-factor calculation, Application to powder method, Multiplicity factor, Lorentz factor, Absorption factor, Temperature factor, and Intensities of powder pattern lines. [12 lectures]

Determination of crystal structure: Preliminary treatment of data, Indexing of cubic and noncubic crystals, The effect of cell distortion on the powder pattern, Chemical analysis by diffraction, and Stress measurement [15 lectures]

Transmission Electron Microscopy: Fundamentals of Electron Optics and Instrumentation, Fundamentals of image formation, Scattering Mechanism and Contrast Formation, Electron Sources, Lenses, Aperture and Resolution, Specimen preparation, Diffraction in TEM, Indexing diffraction pattern, Kikuchi diffraction, and CBED pattern, and Imaging (Bright and dark field images). [8 lectures]

References

[1] B. D. Cullity, and S. R. Stock, *Elements of X-ray Diffraction* (Pearson, 2014).

[2] D. B. Williams, and C. B. Carter, *Transmission Electron Microscopy A Textbook for Materials Science* (Springer, 2009).

[3] G. H. Michler, *Electron Microscopy of Polymers* (Springer, 2008).

5.4.5 Elective 3(c): Thin Film Technology (3-0-0)

Course Contents:
Introduction to thin film science and technology, vacuum science and technology, Preparation methods: electrolytic deposition, cathodic and anodic films, thermal evaporation, cathodic sputtering, chemical vapor deposition, physical vapor deposition. Molecular beam epitaxy and laser ablation methods. [10 Lectures]

Thickness measurement and monitoring: electrical, mechanical, optical interference, microbalance, quartz crystal methods. [5 Lectures]

Growth and structure of films. General features. Nucleation theories Effect of electron bombardment on film structure. Post-nucleation growth Epitaxial films and growth. Structural defects. [5 Lectures]

Mechanical properties of films: elastic and plastic behavior. Optical properties. Reflectance and transmittance spectra. Absorbing films. Optical constants of film material. Multilayer films. Anisotropic and gyrotropic films. Diffusion in thin films. [7 Lectures]

Electric properties to films: Electrical conduction in thin-film: metal, semiconductor, and insulating films. Discontinuous films. Dielectric properties: Thin-film capacitors. Superconducting films. [5 Lectures]

Magnetism in films: Molecular field theory. Spin wave theory. Anisotropy in magnetic films. Domains in films: wall energy. Applications of magnetic films. [4 Lectures]

Thin-film devices: fabrication and applications: Integrated circuits, thin-film transistors, Photovoltaic cells, Magnetic switching devices. [4 Lectures]

References

[1] K.L. Chopra, *Thin Film Phenomena* (McGraw-Hill, 1969).

[2] A. Wagendristel, and Y. Wang, *An Introduction to Physics and Technology of Thin Films* (World Scientific, 1994).

[3] K.L. Chopra, and S.R Das, *Thin Film Solar Cells* (Springer, 1983).

[4] L.I. Maissel, and R. Glang, *Handbook of Thin film Technology* (McGraw-Hill, 1970).

[5] J.C. Anderson, *The Use of Thin Films in Physical Investigation* (Academic Press, 1966).

[6] J.J. Coutts, *Active and Passive Thin Film Devices* (Academic Press, 1978).

[7] R.W. Berry, P.M. Hall, and M.T. Harris, *Thin Film Technology* (Van Nostrand, 1968).

[8] G. Hass, M.H. Francombe, and J.L. Vossen, *Physics of Thin Films* (Academic Press 1982).

5.4.6 Elective 3(d): Virtual Instrumentation: LabVIEW (3-0-0)

Course Contents:
Theory: Introduction (Virtual Instrumentation Advantages), Graphical programming techniques, Structures, Arrays and Clusters, Data Acquisition methods, Instrumental control, Data Communication Standards, RS-232C, GPIB, Real time operating systems

Laboratory: Familiarization with LabView programming, LabVIEW Functions and Debugging, Advance LabVIEW Functions, Data Aquations, VI Applications.

References

[1] J. Jerome, *Virtual Instrumentation Using LabVIEW* (PHI India New Delhi, lst Edition, 2010).

[2] S. Gupta & J. John, *Virtual Instrumentation Using LabVIEW* (Tata McGraw-Hili, 2005).

[3] R. Bishop, *Labview 7 Express Student Edition* (PHI. CD-ROM - Student Edition, 2003).

[4] *LabVIEW User Manual* (National lnstruments, Texas Instruments, USA, www.ni.com, 2003).

[5] *LabVIEW FPGA Module User Manual* (National Instruments, Texas Instruments, USA, www.ni.corn, 2004).

[6] G. Johnsons, and R. Jennings, *LabVIEW Graphical Programming* (McGraw Hill, 2011).

[7] N. Pradhan, *Let Us LabVIEW* (Notion Press, 2020).

[8] J. Essick, *Advanced LabVIEW Labs* (Pearson, 1998).

[9] Garcia, N. Ertugrul, *LabVIEW For Electrical Circuits, Machine Drives and Labs* (National Instruments, 2002).

[10] L. Sokoloff, *Applications in LabVIEW* (Pearson, 2003).

5.4.7 Elective 3(e): Energy storage systems

CO: The student will be able to cope up with upcoming technologies in the energy storage systems.

Course Contents:
Electrochemical energy storage - Thermodynamics and Kinetics of Electrochemical Reactions. Introduction to Electrochemical Techniques, Electrochemical Energy Storage Systems (a) Advanced Rechargeable Batteries (b) Supercapacitors. Hybrid power systems: Differences/interactions between batteries and supercapacitors.
Hydrogen storage – compressed storage, liquid state storage, solid state storage, different materials for storage – metal hydrides, high surface area materials, complex and chemical hydrides, hydrogen storage system – design and materials aspects.
Solar thermal storage
Pumped hydroelectric energy storage
Flywheel energy storage

References

[1] S. P. Sukhatme, - Principles of thermal collection and storage, Tata McGraw-Hil

[2] Michael Hirscher, Hand Book of Hydrogen Storage, McGraw-Hill Professional

[3] Robert A. Huggins, Advanced Batteries : Materials Science Aspects, Springer US

[4] T. Reddy, Linden‘s Handbook of Batteries, McGraw-Hill Professional

5.4.8 Open Elective - II (3-1-0)

The course content will be of the relevant department, offering the elective.