SRI SATHYA SAI INSTITUTE OF HIGHER LEARNING
(Deemed to be University)

Syllabus for
M.Sc. (Physics)

(w.e.f. 2018-2019)

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Program Objective and Outcome

The 5-year Integrated M.Sc. Physics program is designed to provide a strong foundation in fundamental physics as Physics is the basis for advanced scientific research and technological inventions. The curriculum provides a blend of science and technology, with appropriate theoretical and applied physics courses. The courses are complimented by adequately equipped laboratory experiments. Additional hands-on training in electronics, microcontrollers, computer programming and computational techniques makes the program unique.

The first three years of the integrated program is an advanced B.Sc. (Hons.) program that also permits lateral exit by empowering the students to pursue higher studies in premier institutions through competitive exams. During the last two years, the rigor of theoretical physics coupled with advanced courses in photonics, materials science and nuclear physics gives the students a clear edge for entry into research as well technology oriented programs.

Above all healthy teacher-student interactions ensure that students develop into individually competent, collectively compatible and socially responsible citizens.

SCHEME OF INSTRUCTION AND EVALUATION
M.Sc. (Physics) PROGRAMME
(Effective from A.Y. 2018-2019 onwards)

Paper Code	Title of the Paper	Credits	Hours	Modes of Evaluation	Types of Papers	Maximum Marks
SEMESTER – I:						
PPHY-101	Classical Mechanics	3	3	IE2	T	100
PPHY-102	Classical Electrodynamics	3	3	IE2	T	100
PPHY-103	Quantum Mechanics – I	3	3	IE2	T	100
PPHY-104	Solid State Physics – I	3	3	IE2	T	100
PPHY-105	Mathematical Physics – I	2	2	IE2	T	50
PPHY-106	Experimental Methods in Physics - I	3	6	I	P	100
PPHY-107	Electronics and Microcontroller Lab	3	6	I	P	100
PPHY-108	Semester End Viva voce	1	-	E1	SEV	50
PAWR-100	Awareness Course-I: Education for Life	1	2	I	T	50
		22 credits	28 hours			750 marks
SEMESTER – II:						
PPHY-201	Nuclear and Particle Physics	3	3	IE2	T	100
PPHY-202	Modern Optics	3	3	IE2	T	100
PPHY-203	Quantum Mechanics – II	3	3	IE2	T	100
PPHY-204	Solid State Physics – II	3	3	IE2	T	100
PPHY-205	Mathematical Physics – II	2	2	IE2	T	50
PPHY-206	Experimental Methods in Physics - II	3	6	I	P	100
PPHY-207	Software Lab	3	6	I	P	100
PPHY-208	Semester End Viva voce	1	-	E1	SEV	50
PAWR-200	Awareness Course-II: God, Society and Man	1	2	I	T	50
		22 credits	28 hours			750 marks
SEMESTER – III:						
PPHY-301	Advanced Spectroscopy	4	4	IE2	T	100
PPHY-302	Statistical Mechanics	4	4	IE2	T	100
PPHY-303	Semiconductor Device Physics	4	4	IE2	T	100
PPHY-304	Elective – I	3	3	IE2	T	100
PPHY-305	Advanced Physics Lab	3	6	I	P	100
PPHY-404**	Project work	-	9	I	PW	50**
PPHY-306	Semester End Viva voce	1	-	E1	SEV	50
PAWR-300	Awareness Course-III: Guidelines for Morality	1	2	I	T	50
		20 credits	32 hours			650 marks
SEMESTER – IV:						
PPHY-401	Elective – II	3	3	IE2	T	100
PPHY-402	Elective – III	3	3	IE2	T	100
PPHY-403	Elective – IV	3	3	IE2	T	100
PPHY-404**	Project Work	6	18	E2	PW	150**
PAWR-400	Awareness Course-IV: Wisdom for Life	1	2	I	T	50
		16 credits	29 hours			500 marks
	TOTAL	80 Credits	117 hours			2650 marks

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Modes of Evaluation

Indicator	Legend
IE1	CIE and ESE ; ESE single evaluation
IE2	CIE and ESE ; ESE double evaluation
I	Continuous Internal Evaluation **(CIE)** only Note: 'I' does not connote 'Internal Examiner'
E	End Semester Examination **(ESE)** only Note: 'E' does not connote 'External Examiner'
E1	ESE single evaluation
E2	ESE double evaluation

Continuous Internal Evaluation (CIE) & End Semester Examination (ESE)

Types of Papers

Indicator	Legend
T	Theory
P	Practical
SEV	Semester End Viva voce
PW	Project Work
D	Dissertation

Contact Hours distribution

L	Lecture
P	Practical
T	Tutorial

PS: Please refer to guidelines for 'Modes of Evaluation for various types of papers', and Viva voce nomenclature & scope and constitution of the Viva-voce Boards.

** Total marks for the Project Work would be **200 marks**, which consists of **50 marks** for the Project Work Review at the end of semester III, **50 Marks** for the Project presentation & Viva-voce conducted at the end of the semester IV and **100 marks** for the double evaluation of the Project Report submitted at the end of the semester IV.

List of Electives:

EL 1: Principles of Laser Physics
EL 2: Concepts in Materials Science
EL 3: Nuclear Spectroscopy
EL 4: Fiber Optics
EL 5: Functional Ceramics and Devices
EL 6: Nuclear Reactions
EL 7: Ultrafast Nonlinear Optics
EL 8: Photovoltaics for Energy Conversion
EL 9: Accelerators, Reactors & Detectors
EL 10: Femtosecond Laser Material processing
EL 11: Materials Characterization Techniques
EL 12: Biomaterials
EL 13: Materials for Photonics
EL 14: Introduction to Microfluidics: Devices and Applications
EL 15: Physics and Technology of Thin Films
EL 16: Computational Materials Science
EL 17: Microelectronics
EL 18: Superconductivity
EL 19: Fundamentals of Nanoelectronics
EL 20: Nanoscale Physics
EL 21: Graphene and 2-dimensional Materials
EL 22: Foundations of Quantum Optics
EL 23: Quantum Computing

PPHY-101: Classical Mechanics 3 Cr

Course Objectives:
Classical Mechanics remains an indispensable part of the physicist's education. It has a twofold role in preparing the student for the study of modern physics. First, classical mechanics, in one or another of its advanced formulations, serves as the springboard for the various branches of modern physics. Thus, the technique of action-angle variables is needed for the older quantum mechanics; the Hamilton-Jacobi equation and the principle of least action provide the transition to wave mechanics, while Poisson brackets and canonical transformations are invaluable in formulating the newer quantum mechanics. Secondly, classical mechanics affords the student and opportunity to master many of the mathematical techniques necessary for quantum mechanics while still working in terms of the familiar concepts of classical physics

Course Outcomes:
After completing the course the student will:

Be familiar with some of the advanced formulations of classical mechanics, namely, Lagrangian and Hamiltonian formulation

Be able to apply these in the detailed study of rigid body dynamics, small oscillations, and central force motion.

Syllabus:

1. **Variational Principles and Lagrange's Equations:** Hamilton's principle, derivation of Lagrange's equations from Hamilton's principle, extension of Hamilton's principle to Nonholonomic systems, Conservation theorems and symmetry properties, Energy function and the conservation of energy. *5 hrs*

2. **The Central Force Problem:** Reduction to the Equivalent one-body problem, Equations of motion and first integrals, equivalent one-dimensional problem, Virial theorem, The Kepler-problem, The Laplace-Runge-Lenz vector. *5 hrs*

3. **Kinematics and equations of motion of rigid body:** Euler angles, finite and infinitesimal rotations, Coriolis Effect; Angular momentum and kinetic energy of motion about a point, moment of inertia tensor: eigenvalues and the principal axis transformation, Euler equations of motion, torque-free motion of a rigid body. *6 hrs*

4. **Oscillations:** Formulation of the problem, eigenvalue equation and the principal axis transformation, frequencies of free vibrations and normal coordinates, free vibrations of a linear triatomic molecule. *6 hrs*

5. **Hamilton Equations of Motion:** Legendre transformations and Hamilton Equations of motion, cyclic coordinates and conservation theorems, derivation of Hamilton's equations from a variational principle. *6 hrs*

6. **Canonical Transformations:** Equations of canonical transformation, harmonic oscillator, symplectic approach, Poisson brackets, equations of motion, infinitesimal canonical

transformations, and conservation theorems in the Poisson bracket formulation, Liouville's theorem. *8 hrs*

7. **Hamilton-Jacobi Theory:** Hamilton-Jacobi equation for Hamilton's principal function, harmonic oscillator, Hamilton-Jacobi equation for Hamilton's characteristic function, Kepler problem. *6 hrs*

References:

1. Herbert Goldstein, Charles Poole, John Safko, Classical Mechanics, 3rd edition, Addison Wesley Professional, 2001.

2. L. D. Landau, E.M. Lifshitz, Mechanics, 3rd Edition, Butterworth-Heinemann, 1976.

3. Narayan Rana, Pramod Joag, Classical Mechanics, Tata McGraw-Hill Education, 2001.

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PPHY-102: Classical Electrodynamics 3 Cr

Course Objectives:
Application of Maxwell's equations and boundary conditions to solve electrostatic and magnetostatic problems and also understand electromagnetic wave propagation in linear isotropic media, hollow metallic waveguides and radiations from different types of sources.

Course Outcomes:
On completion of this course the student will

Be able to use Maxwel's equations to solve electrostatic and magnetostatic problems in different coordinate systems using special functions and vector calculus,

Be able to perform multipole exapansion of charge sources

Be able to use Maxwell's Stress tensor and understand the Poynting's theorem.

Be able to solve problems and understand EM wave propagation in linear isotropic dielectric and conducting media, hollow metallic waveguides

Be able to predict radiation from arbitrary charge distributions including oscillating electric dipoles, oscillating magnetic dipoles, and accelerating point charges

Be able to understand the need for gauge transformations in electrodynamics,

Syllabus:

1. **Boundary value problems in electrostatics:**
   Laplace equations: Laplace equations in 1-D, 2-D and 3-D; boundary conditions and uniqueness theorems; conductors and second uniqueness theorem *2 hrs*

The method of images: Induced surface charge; force and energy *1 hr*
Separation of variables: Laplace equation in cartesian, spherical and cylindrical coordinates. *2 hrs*

2. **Multipole expansion of electrostatic potential:** Approximate potentials at large distance; multipole expansion; monopole and dipole terms; origin of coordinates in multipole expansion; electric field of a dipole; multipole expansion of energy of a charge distribution in an external field. *4 hrs*

3. **Conservation laws in electrodynamics:** Continuity equation; Poynting's theorem; Newton's third law in electrodynamics; Maxwell's stress tensor; conservation of momentum; angular momentum. *5 hrs*

4. **Electromagnetic waves:** Waves in 1-D**:** wave equation; sinusoidal waves; boundary condition-reflection and transmission; EM waves in vacuum**:** wave equation for E and B; monochromatic plane waves; energy and momentum in EM waves; EM waves in matter: propagation in linear media; reflection and transmission at normal incidence and oblique incidence. *6 hrs*
   Absorption and Dispersion**:** EM waves in conductors; reflection at a conducting surface; frequency dependence of permittivity. *2 hrs*

5. **Wave guides and resonant cavities:** Fields at the surface of and within a conductor; cylindrical cavities and wave-guides; the modes in a rectangular wave-guide; TE waves in a rectangular wave guides; the coaxial transmission line; energy flow and attenuation in wave guides; resonant cavities; power losses in a cavity- Q of a cavity; *8 hrs*

6. **Potentials and fields:** Scalar and vector potentials; gauge transformations; Coulomb and Lorentz gauge; retarded potentials; Jefimenko's equations; Lienard –Wiechart potentials; field of a moving point charge. *7 hrs*

7. **Radiation:** Electric dipole radiation; magnetic dipole radiation; radiation from an arbitrary source; power radiated by a point charge; *7 hrs*

References:

1. Griffiths, D. J.: Introduction to Classical Electrodynamics, Prentice Hall, Ed III, (1999).

2. Jackson, J.D: Classical Electrodynamics, (II Edition) Wiley Eastern (1975).

3. Heald, M.A., and Marion, J.B.: Classical Electromagnetic Radiation, (III Edition) Saunders (1995).

4. Jordan E.C., and Balmain, K.G, Electromagnetic Waves and Radiating Systems, (II Edition), Prentice Hall India (1987).

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PPHY-103: Quantum Mechanics – I 3 Cr

Course Objectives:
Provide a strong foundation to the quantum mechanical principles, understand the different formalism of quantum mechanics and solve Schrodinger equations for different systems.

Course Outcomes:
On completion of this course the student will

Acquire a tool set for understanding how the microscopic world works. Mathematical tools essential in understanding Quantum mechanics.

Understand the theoretical foundations of Quantum mechanics. Postulates and their implications.

Be able to use Matrix and wave formulations of quantum mechanics to find the energy spectrum and the states of quantum systems.

Be able to solve the Schrodinger wave equation (for few idealized systems) to obtain the various energy levels of the particle and their corresponding wave functions.

Understand the formalism of angular momentum.

Be able to use approximate methods for stationary states: to solve time-independent potentials (of real systems which may not be solved exactly), such as the variational method, and the WKB method

Syllabus:

1. **Mathematical Tools of Quantum Mechanics:** Hilbert Space and Wave Functions, Dirac Notation, Operators, Representation in Discrete Bases, Representation in Continuous Bases, Matrix and Wave Mechanics. 6 *hrs*

2. **Postulates of Quantum Mechanics:** Basic Postulates of Quantum Mechanics, State of a System, Observables and Operators, Measurement in Quantum Mechanics, Time Evolution of the System's State, Symmetries and Conservation Laws, Connecting Quantum to Classical Mechanics. 8 *hrs*

3. **One-Dimensional Problems:** Properties of One-Dimensional Motion, Free Particle: Continuous States, Potential Step, Barrier and Well, Infinite and Finite Square Well Potential, Harmonic Oscillator. 7 *hrs*

4. **Angular Momentum**: Orbital Angular Momentum, General Formalism of Angular Momentum, Matrix Representation of Angular Momentum, Geometrical Representation of Angular Momentum, Spin Angular Momentum, Eigen functions of Orbital Angular Momentum. 7 *hrs*

5. **Three-Dimensional Problems:** 3D Problems in Cartesian Coordinates: Free particle, Box potential, harmonic oscillator, 3D Problems in Spherical Coordinates: central potential, free particle, spherical square well potential, isotropic harmonic oscillator, hydrogen atom, effect of magnetic fields on central potentials. 7 *hrs*

6. **Approximation Methods for Stationary States:** Time-independent perturbation theory; variational method, Wentzel–Kramers–Brillouin Method. 7 *hrs*

References:

1. Nouredine Zettili, **Quantum Mechanics: Concepts and Applications**, 2nd edition, John Wiley and Sons Ltd., 2009.

2. L. I. Schiff, **Quantum Mechanics**, McGraw Hill Higher Education; 3rd revised edition, 1968.

3. R. Shankar, **Principles of Quantum Mechanics**, 2nd Edition, Plenum Press, 2011.

4. David J. Griffiths, **Introduction to Quantum Mechanics**, Prentice Hall, 1995.

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PPHY-104: Solid State Physics - I 3 Cr

Course Objectives:
This is the first part of Solid State Physics course and it will deal with the fundamentals of electrical transport and optical properties of crystalline solids.

Course Outcomes:
On completion of this course the student will
Understand the origin of formation of energy bands in solids
Understand two extreme models - the nearly free electron approximation and the tight binding approximation.
Be able to understand electrical transport using Boltzmann transport theory,
Understand optical properties of semiconductors from the band theory point of view.

Syllabus:

1. **Theory of metals**: Drude Theory: Basic assumptions, DC & AC conductivity, Hall Effect and magnetoresistance, thermal conductivity; Sommerfeld theory**:** Ground state properties, Fermi-Dirac distribution, thermal properties. 8 *hrs*

2. **Electron levels in a periodic potential:** Bloch's theorem, Born-von Karman boundary conditions, crystal momentum, Fermi surface, density of levels; electrons in a weak periodic potential**:** weak periodic potential, Energy levels near a single Bragg plane, energy gap, various zone schemes. 11 *hrs*

3. **The tight-binding method:** Linear combination of atomic orbitals, Applications to bands from *s* – levels. 3 *hrs*

4. **Semiclassical model of electron dynamics:** wave packets of Bloch electrons, semiclassical model and its consequences, concept of hole, semiclassical motion in uniform electric and magnetic field. 5 *hrs*

5. **Semiclassical theory of conduction in metals:** relaxation time approximation, nonequilibrium distribution function, DC and AC electrical conductivity, thermal conductivity, thermoelectric effects. 8 *hrs*

6. **Optical properties:** Dipole oscillator model, Kramers-Kronig relationships, Interband absorption: interband transitions, transition rate for direct absorption, band edge absorption in direct gap and indirect gap semiconductors, interband absorption above the band edge, Free excitons, Free excitons in external electric and magnetic fields. 10 *hrs*

Special topics: de Haas–van Alphen effect.

References:

1. Neil W. Ashcroft, N. David Mermin, Solid State Physics, Saunders College Publishing, Philadelphia, 1976.

2. Mark Fox, Optical Properties of Solids, Edition II, Oxford University Press, 2010.

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PPHY-105: Mathematical Physics – I 2 Cr

Course Objectives:
This is the first part of the course in Mathematical Physics which deals with tensor algebra along with applications related to physics problems, introduces the techniques of calculus of variations with applications in classical and quantum mechanics. The course also reviews special functions and theory of Fourier transforms emphasizing their applications in physical sciences.

Course Outcomes:
On completion of this course the student will

Be familiar with the algebra of tensors; understand how some physical properties' like conductivity, polarizability, stress, moment of inertia etc. are tensorial in nature and be able to work with these tensors; be able to apply the theory of Fourier transforms in to Quantum Mechanics, Optics and Image processing.

Syllabus:

1. **Cartesian Tensors:** Tensor notation and summation convention; change of basis; Cartesian tensors – first and zero-order Cartesian tensors; second and higher-order Cartesian tensors; contravariant and covariant components of tensor; tensor algebra; quotient law; Kronecker delta and the Levi-Cevita tensor; isotropic tensors; inner and cross product of vectors. Gradient, divergence and curl in tensor notation and few vector identities; 6 *hrs*

2. **Non-Cartesian Tensors and tensor calculus:** Non-Cartesian coordinates and the metric tensor; general coordinate transformation and tensors; index raising and lowering using metric tensor, definition of the line element using metric tensor; derivatives of basis vectors and Christoffel symbols; Covariant derivatives of metric and non-metric types; vector operators in tensor form; the four-vectors of position-time, momentum-energy and vector-scalar potentials; the electromagnetic field tensor; 8 *hrs*

3. **Fourier transforms;** Fourier transforms – basic concept; Fourier transform of a Gaussian function; example of Fourier transforms in optics - Fraunhofer diffraction; the Dirac delta function and its relation to Fourier transforms; Convolution and de-convolution; Correlation functions and energy spectra; 5 *hrs*

4. **Special functions:** Legendre polynomials, Bessel functions; the gamma, beta and error function; 4 *hrs*

5. **Calculus of variation:** Euler-Lagrange equation; constrained variation; physical variational principles; general eigenvalue problems, adjustment of parameters; 5 *hrs*

References:

1. K.F. Riley, M.P. Hobson and S.J. Bence, Mathematical Methods for Physics and Engineering, Cambridge University Press, III Ed, (2006).

2. Young, E. C.: Vector and Tensor Analysis, Marcel Dekker (1978).

3. Lawden, D. F.: An Introduction to Tensor Calculus and Relativity, Chapman and Hall (1975).

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PPHY-106 Experimental Methods in Physics – I 3 Cr

Course Objectives:
This is a laboratory course to provide hands on knowledge of some basic experiments in optics, material science and nuclear physics.

Course Outcomes:
At the end of this course, the students would have performed the following experiments

1. X-ray diffraction analysis of standard crystalline samples and interpretation
2. UV-Vis spectra of liquid and powder samples
3. Heat Capacity Vs Temperature
4. Temperature coefficient of resistance
5. Mach-Zehnder Interfermeter
6. Production and analysis of polarized light
7. Emission characteristics of a LED
8. Characteristics of a Photodetector
9. Energy resolution of Scintillation detector
10. Determination of internal conversion coefficient using XPG method
11. determination of linear attenuation coefficient of absorber materials

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PPHY-107 Electronics and Microcontroller Lab 3 Cr

Course Objectives:
This laboratory course provides hands on training on some basic experiments in power electronics, microprocessor interfacing control and programming, as well as some basic electrical essentials.

Course Outcomes:
On completion of this course the student will be able to do get hands-on experience pertaining to the following:

A. Power Electronics Lab:
   1. Characteristics of a power diode.
   2. Characteristics of a transistor.
   3. Characteristics of a MOSFET.
   4. Characteristics of an IGBT.
   5. 1 phase half wave controlled rectifier with R and RL load.
   6. Full wave controlled rectifier with R and RL load.
   7. Speed control of universal motor using SCR.
   8. Bridge inverter.

B. Arduino Lab:
   1. Blinking LED.
   2. Stepper motor control.
   3. UART, SPI (LIFI)
   4. Calculate 'g' using lasers.
   5. Closed loop.

C. Electrical Workshop Lab:
   1. Study of electrical materials.
   2. Stair case wiring.
   3. Fluorescent tube light.
   4. MC MI Electrodynamic & Induction type Meters - Theory.
   5. UPS - simulation.
   6. Fuses & MCB's - Theory.

D. Simulation Lab:
   1. Design of oscillators.
   2. Power quality.

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PPHY-201: Nuclear and Particle Physics 3 Cr

Course Objectives:

This course aims to introduce students to the fundamental concepts of nuclear and sub-nuclear physics. Starting with an overview of the development of nuclear and particle physics, the course builds on previous learning in quantum mechanics and electromagnetism. To develop students' understanding of the properties of the strong and weak forces. To perform basic calculations using nuclear models to derive the observed stable nuclei.

Course Outcomes:

On completion of this course the student will

Have a basic understanding of nuclear properties and models that describe the quantum structure, decay, and reactions of nuclei.

Be able to describe the role of spin-orbit coupling in the shell structure of atomic nuclei, and predict the properties of nuclear ground and excited states based on the shell model.

Be able to apply quark mixing models to analyse weak interaction physics such as beta decay.

Be able to read, understand and explain scholarly journal articles in nuclear and particle physics.

Be able to make relevant measurements of energy and decay spectra using basic experimental facilities and apply Poisson statistics to evaluate the uncertainties in the data.

Syllabus:

1. **Nuclear Models:**
   The shell model: Evidence for shell structure; Magic numbers, the shell model potential, spin-orbit potential, shell structure obtained with infinite well and harmonic oscillator potentials, filling of the shells, ground state spins and parities of nuclei, magnetic dipole moments, electric quadrupole moments, excited states and shell model , valence nucleons Even-Z, Even-N nuclei and collective model: Nuclear vibrations, nuclear rotations.
   10 hrs
2. **Beta decay:**
   Basic beta decay process, energy release in beta decay, Fermi's theory of beta decay, shape of the beta spectrum, comparative half-life, Fermi-Kurie plot, angular momentum and parity selection rules; non-conservation of parity in beta decay; beta spectroscopy.
   8 hrs
3. **Gamma decay:**
   Energetics of gamma decay, angular momentum and parity selection rules, life times for gamma emission, measurements of gamma ray energies; measurement of lifetimes of excited states; multipole moments; theoretical predictions of decay constants; Estimation of transition rates and comparison with experiment; Internal conversion; Gamma ray spectroscopy. *8 hrs*

4. **Nuclear reactions:**
   Introduction; types of nuclear reactions, observables, conservation laws, energetics of nuclear reactions; The Q-equation; Isospin, reaction cross sections; experimental

techniques, compound nucleus reactions, direct reactions, Resonance reactions; Breit-Wigner Formula, heavy ion reactions. *8 hrs*

5. **Detecting Nuclear Radiations:**
   Interaction of radiation with matter: heavy charged particles, electrons, electromagnetic radiation, scintillation detectors, semiconductor detectors, counting statistics, energy measurements, magnetic spectrometers. *5 hrs*

6. **Elementary particles:** Particle interactions and families, symmetries and conservation laws: angular momentum; parity; baryon number lepton number, isospin, strangeness and charm, the quark model; colored quarks and gluons, charm, beauty and truth quarks dynamics; grand unified theories. *5 hrs*

References:

1. Kenneth S. Krane: Introductory Nuclear Physics, John Wiley & Sons (1988).

2. Enge, H.A.: Introduction to Nuclear Physics, Addison-Wesley (1971).

3. Griffiths, D: Introduction to Elementary particles, John Wiley & Sons, (1987).

4. Segre, E**.:** Nuclei and Particles, (II Edition) Benjamin (1977).

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PPHY-202: Modern Optics 3 Cr

Course Objectives:
This is designed to supplement the basics of Physical optics which an undergraduate student has learnt. This course will act a bridge course for lateral entry students to revisit the fundamentals of geometrical and wave optics which will act as a foundation for specializing in Photonics.

Course Outcomes:
Outcomes: Coupled with the Optics Laboratory course work (PPHY 206) , the student will be empowered to standalone to design & develop his/her own Photonics experiments with sufficient exposure to both theory and practicals.

Syllabus:

1. **Multiple Beam Interferometry and coherence:** Multiple beam interference with a plane parallel plate; Interference filters; Fabry-Perot Resonator and Resolving power; Concepts of spatial and temporal coherence, coherence time and line width. 5 *hrs*

2. **Diffraction:** Diffraction Grating: the Grating equation, FSR & Resolution of Grating, Types of Grating: Blazed & Interference Gratings; Grating Instruments; Fresnel Kirchhoff's diffraction integral, diffraction of a Gaussian beam, diffraction from straight edge, circular aperture, cornu's spiral. 5 *hrs*

3. **Matrix treatment of Polarization:** Review of Jones calculus, Cartesian complex plane representation of polarized light; Poincare sphere representation: Stokes parameters; Coherency matrix. Applications based on Polarization. 5 *hrs*

4. **Fourier Optics and Holography:** Concept of spatial frequencies**;** Thin lens as a phase transformation; Fourier transformation with a lens; Optical data imaging and processing; Fourier–Transform spectroscopy; Gabor hologram; Leith-Upatnieks hologram; Application of Holography to microscopy and interferometry. 7 *hrs*

6. **Optical Instrumentation:** Measurement of Light: Sources & Detectors of optical radiation, Radiometry & Photometry; Optical Microscopes: Bright Field, Dark Field, Phase contrast, Fluorescence & Confocal microscopes; Telescopes, Ellipsometer, Refractometer. 4 *hrs*

7. **Lasers:** Spontaneous and stimulated emission; absorption; Einstein's A and B coefficients; the Laser idea - Amplification by an atomic system; Broadening of Spectral Lines: Line-shape; homogeneous and inhomogeneous broadening; Rate equations for two, three and four-level lasers. 6 *hrs*

8. **Optics of Anisotropic media:** introduction; permittivity tensor; principal axes and principal refractive indices; uniaxial, biaxial and isotropic crystals; index ellipsoid; propagation along a principal axis and in an arbitrary direction; Magneto optics and optics of liquid crystals. 5 *hrs*

9. **Fiber Optics:** ray propagation in an optical fiber; single mode and multimode fibers; attenuation and dispersion effects in fibers. 3 *hrs*

10. **Scattering:** Overview of Scattering Processes; Rayleigh & Rayleigh Wing Scattering; Mie Scattering; Brillouin & Raman Scattering. 2 *hrs*

References:

1. E. Hecht., **Optics,** Ed IV, Pearson Education, (2002).

2. Pedrotti F L and Pedrotti L S., **Introduction to Optics**, II Edition, Prentice Hall.

3. Born, M. and Wolf, E.: **Principles of Optics**, (VI Edition), Pergamon (1989).

4. Goodman, J.W.: **Introduction to Fourier Optics**, McGraw Hill (1968).

5. Azzam, R. M. A. and Bashara, N. M.: **Ellipsometry and Polarized light**, (II Edition), North Holland (1987).

6. S. Bradbury and P.J. Evennett, **Contrast Techniques in Light Microscopy**, Royal Microscopical Society-Microscopy handbooks-34 , Bios Scientific Publishers

7. P. Hariharan, **Basics of Holography,** Cambridge University Press, (2002).

8. B.E.A. Saleh and M.C. Teich, **Fundamentals of Photonics**, Ed II, Wiley series in Pure and applied Optics, 2007; section 6.3 – 6.5.

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PPHY-203: Quantum Mechanics – II 3 Cr

Course Objectives:

This course is a continuation of PPHY-103 (Quantum Mechanics I). It deals with more complicated / composite systems, time dependent perturbed systems and scattering formalism. That there is a fundamental issue of objective reality in quantum mechanics is brought out through the Einstein-Podolsky-Rosen paradox. Modern developments leading to new devices and new technologies as applications of quantum mechanics are brought into focus. Relativistic quantum mechanics is also covered.

Course Outcomes:

After completing the course the student will:

Learn how angular momenta are combined and how the state of the compound system depends on the states of the component systems.
Learn how identical particles are to be described consistent with the Pauli Exclusion Principle.
Know how an atom interacts with electromagnetic radiation.
Be able to develop interest in fundamental issues of quantum mechanics like the paradoxes of Einstein-Podolsky-Rosen and that of the Schrodinger's cat.
Learn about recent developments in quantum theory. What was thought to be a bug has resulted in novel applications in quantum information science. The concepts of qubits, quantum gates, teleportation of a quantum state, quantum entanglement will develop awareness and kindle interest in the present state of the subject.

Syllabus:

1. **Rotations and Addition of Angular Momenta:** Rotations in classical physics, rotations in quantum mechanics, addition of angular momenta. *5 hrs*

2. **Identical Particles:** Many-particle systems, systems of identical particles, Pauli exclusion principle. *4 hrs*

3. **Time-dependent Perturbation Theory:** pictures of quantum mechanics, time-dependent perturbation theory, adiabatic and sudden approximations, interaction of atoms with radiation. *9 hrs*

4. **Scattering Theory:** Scattering and cross section, scattering amplitude of spin-less particles, Born approximation, partial wave analysis, scattering of identical particles. *8 hrs*

5. **Elements of relativistic quantum mechanics:** Klein-Gordon equation, Dirac equation, Dirac matrices, spinors, Positive and negative energy solutions, physical interpretation, Nonrelativistic limit of the Dirac equation. *8 hrs*

6. **Quantum Spookiness:** Einstein-Podolsky-Rosen Paradox, Schrödinger Cat Paradox. *3 hrs*

7. **Modern Applications of Quantum Mechanics:** Manipulating Atoms with Quantum Mechanical Forces, Magnetic Trapping, Laser Cooling, Quantum Information Processing, Quantum Bits—Qubits, Quantum Gates, Quantum Teleportation, Quantum Entanglement. *6 hrs*

References:

1. Nouredine Zettili, **Quantum Mechanics: Concepts and Applications**, 2nd edition, John Wiley and Sons Ltd., 2009.

2. L. I. Schiff, **Quantum Mechanics**, McGraw Hill Higher Education; 3rd revised edition, 1968.

3. R. Shankar, **Principles of Quantum Mechanics**, 2nd edition, Plenum Press, 2011.

4. David J. Griffiths, **Introduction to Quantum Mechanics**, Prentice Hall, 1995.

5. David McIntyre, Corinne A Manogue, Janet Tate, **Quantum Mechanics - A Paradigms Approach,** Addison-Wesley (2012)

6. Ballentine L., **Quantum mechanics - a modern development,** World Scientific publishing (2000)

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PPHY-204: Solid State Physics – II 3 Cr

Course Objectives:
This is the second part of Solid State Physics course which deals with the fundamentals of dielectric, piezoelectric, pyroelectric, ferroelectric, magnetic and superconducting properties of solids. Emphasis is given on basics as well as on the various theoretical models used to understand these properties.

Course Outcomes:
On completion of this course the student will

Be familiar with the theories of various types of magnetic order;
Understand the behavior of dielectrics in static and alternating fields,
Learn the basics principles of superconductors,
Be familiar with the fundamentals of piezo, pyro and ferroelectricity.

Syllabus:

1. **Diamagnetism and Paramagnetism:** interaction of solids with magnetic fields, Larmor diamagnetism, Hund's rules, Van-Vleck paramagnetism, Curie's law for free ions and solids, adiabatic demagnetization, Pauli paramagnetism, conduction electron diamagnetism. *6 hrs*

2. **Electron interactions and magnetic structure:** electrostatic origins of magnetic interactions, magnetic properties of a two-electron system, failures of the independent electron approximation, Spin Hamiltonians, Direct Exchange. *4 hrs*

3. **Magnetic ordering:** types of magnetic structure, thermodynamic properties at the onset of magnetic ordering, ground state of the Heisenberg ferro- and antiferro-magnet, Spin waves, high temperature susceptibility, Mean field theory, domains and demagnetization factors. *10 hrs*

4. **Superconductivity:** critical temperature, persistent currents, thermoelectric properties, magnetic properties, type-I, type-II superconductors, specific heat, London equations, qualitative features of microscopic BCS theory. *5 hrs*

5. **Dielectric properties of insulators in static fields:** static dielectric constant, polarization, atomic interpretation of the dielectric constant of monatomic gases, dielectric constant of polyatomic molecules, internal field in solids and liquids, dielectric constant of solids. *4 hrs*

6. **Dielectrics in alternating fields:** frequency dependence of the electronic polarizability, ionic polarization as a function of frequency, complex dielectric constant, dipolar relaxation, dielectric losses. *5 hrs*

7. **Piezoelectricity and pyroelectricity:** theory, Parameters for Piezoelectric materials and their Measurement, concept of pyroelectricity. *3 hrs*

8. **Ferroelectrics:** Crystal structure and Ferroelectricity, spontaneous polarization, examples of ferroelectrics, Landau theory of ferroelectric phase transition. *5 hrs*

9. **Special topics:** Negative refractive index materials; Ising Model in one dimension.

References:

1. Neil W. Ashcroft, N. David Mermin, Solid State Physics, Saunders College Publishing, Philadelphia, 1976.

2. J. M. D. Coey, Magnetism and Magnetic Materials, Cambridge University Press, 2010.

3. Dekker A. J., Electrical Engineering Materials, Prentice-Hall Inc, 1959.

4. Leonid V. Azároff and James John Brophy, Electronic processes in materials, McGraw-Hill, New York 1963.

5. Arthur R. van Hippel, Dielectrics and Waves, The MIT Press, Cambridge, Massachusetts, 1954.

6. Arthur R. van Hippel, Dielectrics Materials and Applications, The MIT Press, Cambridge, Massachusetts, 1954.

7. A. J. Moulson and J. M. Herbert, Electroceramics: Materials, Properties, Applications. 2nd Edition, John Wiley & Sons Ltd, 2003.

8. Kenji Uchino, Ferroelectric Devices, 2nd edition, CRC Press, 2010.

9. S Anantha Ramakrishna 2005 *Rep. Prog. Phys.* **68** 449.

10. Stephen Blundell, Magnetism in Condensed Matter, Oxford University Press, 2001.

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PPHY-205: Mathematical Physics – II 2 Cr

Course Objectives:
This second part of the Mathematical Physics course deals majorly with the theory of groups and representations, along with brief review of random variables and their distributions and applications of Green's functions in solving linear differential equations

Course Outcomes:
On completion of this course the student will

Become familiar with the fundamentals of groups and representation theory and be able to apply point and space groups to electronic and vibrational states along with some applications in solid state physics; Be able to understand symmetry properties of Schroedinger wave function in some quantum mechanical problems

Syllabus:

1. **Group Theory fundamentals:** Finite and continuous (Lie groups) types; permutation groups, cyclic groups, subdividing a group-congruence and coset decompositions; representation theory; dipole moments of molecules; irreducible representations; physical applications to bonding in molecules, matrix elements in quantum mechanics; degeneracy of normal modes. *10 hrs*

2. **Continuous groups:** Continuous Lie groups and Lie algebras; translational and rotational symmetry; Unitary groups and canonical groups of transformations in quantum and classical mechanics; Galilean and Lorenz groups of transformations-illustrations from classical and quantum mechanics and electromagnetism. *10 hrs*

3. **Probability theory:** Random variables and their distributions--binomial, Gaussian, Poissonian distributions, Properties of distributions: Mean, Mode and median, Moments, central moments. *5 hrs*

4. **Green's Functions:** Green's functions for solving ordinary differential equations (Relevant sections from Ch. 15 of Ref 1); *4 hrs*

References:

1. K.F. Riley, M.P. Hobson and S.J. Bence, Mathematical Methods for Physics and Engineering, Cambridge University Press, III Ed, 2006.

2. Michael Tinkham, Group Theory and Quantum Mechanics, Dover Publications, 2003.

3. A. W. Joshi, Elements of Group Theory for Physicists, New Age Publishers, 2008.

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PPHY-206 Experimental Methods in Physics – II 3 Cr

Course Objectives:
This is a second laboratory course that provides hands on knowledge of experiments in laser- and fiber-optics, material science, and nuclear physics.

Course Outcomes:
On completion of this course students would have performed experiments pertaining to the following:

1. Obtaining gamma spectra using HPGe detector

2. Obtaining electron spectra using Si(Li) detector

3. Study of dielectric properties of standard samples using impedance analyser

4. Determining the PE loop of a ferroelectric sample

5. Profile of a Laser beam

6. Fabry Perot interferometer

7. Experiments in fiber optics

8. Determination of d33 coefficient of piezoelectric material

9. Study of hysteresis of a ferromagnetic magnetic material

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PPHY-207 Software Lab 3 Cr

Course Objectives:
After a first course in Python programming at the undergraduate level, this course enhances programming skills in python, and Java along with some specific numerical techniques relevant to the theory papers.

Course Outcomes:

Students will learn

Advanced Python programming

Implementation of advanced numerical techniques using Python

Introductory Java programming

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PPHY-301: Advanced Spectroscopy 4 Cr

Course Objectives:
Spectroscopy is an inevitable tool for any Physicist. After having introduced to the basics of various spectroscopic techniques at undergraduate level, this advanced course is designed with the objective of teaching in detail the theory and applications of range of spectroscopic techniques like rotational, vibrational, electronic, Raman, NMR and X-ray Spectroscopy.

Course Outcomes:
The learning outcomes of this course are

Have a thorough understanding of the rotational, vibrational and electronic transitions that occur in any molecule

Apply symmetry operations to molecules and classify molecules under different point groups

Develop an understanding on Raman spectroscopy and its applications

Understand the theory and applications of NMR, ESR and XRF

Syllabus:

1. **Group theory:** Symmetry elements, Algebra of symmetry operations; Point groups, Matrix representation of symmetry operations, Reducible and Irreducible Representations; Character Table for Point groups- C_{2v} and C_{3v}; Symmetry and dipole moments. 8 *hrs*

2. **Rotational spectroscopy:** Linear, symmetric rotor, spherical rotator and asymmetric rotor molecules; Diatomic & Polyatomic molecules; Symmetric rotor molecules; Stark effect in diatomic, linear and symmetric rotor molecules; Asymmetric rotor molecules; Rotational Raman spectroscopy- symmetric and asymmetric rotor; Selection rules. 10 *hrs*

3. **Vibrational spectroscopy:** Infrared & Raman spectroscopy of (i) Diatomic molecules; (ii) Polyatomic molecules; Anharmonicity; Vibration–rotation spectroscopy of different molecules; Selection rules. 8 *hrs*

4. **Electronic spectroscopy of diatomic and polyatomic molecules:** Vector coupling of angular momenta. Russell- Saunders and J-J coupling; Molecular term symbols; the vibrational structure of electronic bands; rotational structure of electronic bands; the Franck - Condon principle, Deslanders tables and dissociation energies; Symmetry of diatomic levels and parity (Gerade / Ungerade). Jahn-Teller and Renner-Teller effects; Fluorescence spectroscopy: Non - radiative transitions and Jablonski diagram. 12 *hrs*

5. **Magnetic resonance spectroscopy:**
Nuclear Magnetic Resonance (NMR): Introduction; Nuclear magneton; Larmor precession; Boltzmann distribution in NMR; Mechanisms of spin-lattice and spin-spin relaxations; Bloch equations; Chemical shifts; FT-NMR as Analytical tool; Application of NMR: Magnetic Resonance Imaging. 6 *hrs*
Electron Spin resonance (ESR): Principle of ESR, ESR spectrometer, hyperfine structure, ESR spectrum of hydrogen atom. 3 *hrs*

6. **X-ray spectroscopy:** X-ray Photoelectron Spectroscopy; X-Ray Fluorescence spectroscopy. 3 *hrs*

References:

1. J. Micheal Hollas, **Modern Spectroscopy**, Edition IV, John Wiley & Sons, Ltd.
2. Herzberg, G: **Molecular spectra and Molecular Structure: Vol. 1**, (II Edition), Van Nostrand (1950).
3. Barrow, G. M.: **Introduction to Molecular Spectroscopy**, McGraw Hill (1962).
4. Aruldhas, **Molecular Structure and Spectroscopy**, Ed II, PHI, India.
5. J. R. Lakowicz, **Principles of Fluorescence Spectroscopy**, Kluwer Academic, NY.
6. Chang, R: **Basic Principles of Spectroscopy**, McGraw Hill (1971).
7. Breitmaier, E., and Voelter, W.: **Carbon-13 NMR Spectroscopy**, (III Edition), VCH (1987)

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PPHY-302: Statistical Mechanics 4 Cr

Course Objectives:
Provide an introduction to the microscopic formulation of the thermal physics by exploring the general principles of the statistical interpretation of entropy and the ensemble formalism; learn the basic principles and applications of equilibrium statistical mechanics.

Course Outcomes:
Understand the connection between thermodynamics and statistical mechanics through microstates and macrostates; develop the ensemble formalism and phase space to study different types of ensembles; determine the thermodynamic properties of systems like ideal gas using statistical mechanics approach; applications of canonical ensemble to study magnetic systems; learn the basics of quantum statistical mechanics and its applications to boson and fermion systems;

Syllabus:

1. **Microstates and Entropy:** Phase space; statistical definition of entropy; statistical calculation of entropy of ideal gas; Gibbs' paradox. *5 hrs*

2. **Ensemble theory and Microcanonical Ensemble**: phase space density; ergodic hypothesis; Liouville's theorem; the microcanonical ensemble; entropy as an ensemble average. *5 hrs*

3. **Canonical ensemble**: System in a canonical ensemble; canonical phase space density; canonical partition functions; ideal gas in Canonical ensemble; System of harmonic oscillators; calculation of observables as ensemble average; connection between microcanonical and canonical ensemble and fluctuations; Equipartition and virial theorems. *10 hrs*

4. **Applications of Boltzmann statistics:** Quantum system in Boltzmann statistics; statistics of paramagnetism; Negative temperature. *5 hrs*

5. **Grand Canonical Ensemble**: phase space density and grand canonical partition function. *3 hrs*

6. **Formulation of Quantum Statistics**:
   Density Operators: Density matrix fundamentals; pure and mixed states; properties of density matrix; Statistics of various ensembles; Examples. *5 hrs*

   Ideal Bose and Fermi systems: Thermodynamics of an ideal Bose gas; Bose-Einstein condensation. Thermodynamic behaviour of an ideal Fermi gas. 8 *hrs*

7. **Examples of Bose and Fermi systems:** Planck's radiation formula; lattice oscillations in solid; Richardson effect and thermionic emission. *8 hrs*

8. **Molecular partition function and nuclear spin statistics**:
   Translational, rotational and vibrational partition functions; Electronic and nuclear partition functions; symmetry and nuclear spin; Ortho and para nuclear states; Ortho and para hydrogen. 6 *hrs*

References:

1. Greiner,W., Neise, L., and Stoecker, H.: Thermodynamics and Statistical Mechanics Springer Verlag (1995).

2. Pathria, R.K.: Statistical Mechanics, Pergamon (1972).

3. Gupta, M.C.: Statistical Thermodynamics, Wiley Eastern (1990).

4. Huang, K.: Statistical Mechanics, (II edition), John Wiley (1987).

5. Reif, F.: Statistical Physics, (Berkeley Physics Course), Vol. 5, McGraw Hill (1967).

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PPHY-303: Semiconductor Device Physics 4 Cr

Course Objectives:
The objective of this course is to provide the theoretical basis and the physics behind the operations of semiconductor devices like diodes, transistors, MOSFETs and optoelectronic devices.

Course Outcomes:
At the end of the course students will be able to appreciate the physics of semiconductors and the various aspects of semiconductor devices such as

- Fermi Levels in a semiconductor
- Current carrying mechanisms
- Concept of holes
- PN junction formation
- Diode equations and I-V characteristics

- Junction capacitances and junction breakdown
- Transistor current equations and ambipolar transports
- MOSFETs and their uses
- Physics of Photovoltaic devices and semiconductor materials for different applications.

Syllabus:

1. **Physics and Properties of Semiconductors:** Semiconductor materials; Crystal structure; Valence bonds; Energy bands; Density of states; Intrinsic carrier concentration; Donors and acceptors; Carrier drift; mobility effects; Carrier diffusion; diffusion current density; Carrier injection; Generation and recombination processes. *10 hrs*

2. ***pn* Junction:** Basic structure of the pn junction; thermal equilibrium condition; built-in potential barrier; depletion region; the space charge width and electric field; forward and reverse bias operation; depletion capacitance and storage capacitance; current–voltage characteristics; Junction breakdown mechanisms; one-sided junctions; linearly graded junctions; *pn* junction current – minority carrier distribution, ideal *pn* junction current equation. *10 hrs*

3. **Metal-Semiconductor and semiconductor heterojunctions:** Schottky barrier diode – junction properties; heterojunctions – energy band diagram, current voltage characteristics. *6 hrs*

4. **Bipolar Devices:** The transistor action; current gain; charge distribution in each region; different modes of operation; current-voltage characteristics of common-base and common-emitter configurations; base width modulation, high injection and emitter band gap narrowing effects; Frequency response and switching of bipolar transistors; Heterojunction bipolar transistors. *8 hrs*

5. **Fundamentals of MOSFETs:** Introduction; the two terminal MOS structure – energy band diagram; depletion layer thickness; work function differences; MOSFET basic characteristics and the operating principle; types of MOSFETS – depletion and enhancement type; NMOS and CMOS. *6 hrs*

6. **Physics of Photonic devices and photovoltaics:** optical devices – solar cells; *pn* junction solar cell, conversion efficiency and solar concentration, heterojunctions solar cells; photo detectors, principle and operation of LEDs and Laser diodes. *10 hrs*

7. **Semiconductor materials:** elemental semiconductor; binary compound semiconductors; oxide semiconductors; organic semiconductors; wide band gap semiconductors. *3 hrs*

References:

1. Sze S. M., Semiconductor Devices: Physics and Technology; John Wiley and Sons (2000).
2. Streetman and Banerjee; Semiconductor Electronic Devices, Pearson Eastern Education (2000).
3. Neamen D, Semiconductor Devices, Ed III, Tata McGraw Hill, (2003).
4. Sedra A. S. and Smith K. C.; Microelectronic Circuits, 2e, Holt, Rinehart and Winston (1987).

5. Kasap S. O., Optoelectronics and Photonics, Pearson International edition, (2012).
6. Gerd Keiser, Optical Fiber Communications, Tata McGraw Hill, (2008).
7. Yacobi, B.G., Semiconductor Materials, Springer (2003).

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PPHY-305 Advanced Physics Lab 3 Cr

Couse Objective:
The objective of this laboratory course is to expose students to some advanced experimental techniques and familiarize them with the working of a few sophisticated instruments.

Couse Outcomes:
Students will perform experiments and get an exposure to the following experimental techniques and advanced research grade Instruments.

1. Spectroscopy A: Raman Spectroscopy- Vibrational modes of Perovskite/CNT/Graphene

2. Spectroscopy B: FTIR- Polymer/Organic molecules characterization

3. Spectroscopy C: XRF –Elemental Analysis

4. Spectroscopy D: ESR

5. Thin films optical properties measurements-n, k determination

6. Materials Synthesis: by any one of the methods

7. Advanced Low Signal Measurement: Lock-in Amplifier

8. Familiarization with NMR

9. Familiarization with Mass Spectrometry

10. Familiarization with electron microscopy – SEM and TEM

11. Study of Electro-optic and magneto optic effects

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Elective Courses
(PPHY-304/401/402/403)
3 Cr

The following electives are offered either in the III or the IV semester of the M.Sc. program. Each elective course is a 3 credit course.

EL 1: Principles of Laser Physics

Course Objectives:
Learn the underlying physics of Lasers and laser systems by combining the knowledge of gain media together with the aspects of design, configuration and operation of lasers.

Course Outcomes:
By the end of the course, students will understand basic light matter interaction, characteristics of atomic transitions and line broadening mechanisms, the necessary and sufficient conditions for laser operation, basic laser beam characteristics and its relation to cavity parameters, steady-state and transient operations, threshold requirements, different types of lasers and laser applications.

Syllabus:

1. **Atomic Radiation:** Review of basic concepts; Broadening of Spectral Lines: Line-shape; Homogenous and inhomogeneous broadening mechanisms; expressions for line shape functions due to different broadening mechanisms. 8 *hrs*

2. **Ray tracing in Optical Cavities:** Ray tracing in an optical system; Application of Ray tracing in optical cavities; the stability diagram. *4 hrs*

3. **Gaussian Beams:** TEM waves; $TEM_{0,0}$ mode and its physical description; Higher order modes. 5 *hrs*

4. **Laser Resonance and cavity modes:** ABCD law for Gaussian Beams; Gaussian beams in stable resonators; ABCD law applied to cavities; Mode volume, Resonance; Q- factor & finesse; Photon lifetime; Resonance of Hermite – Gaussian modes. *8 hrs*

5. **Laser oscillation:** Threshold condition; Oscillation frequency, Oscillation and amplification in a homogeneously broadened transition; Gain saturation; Oscillations in an inhomogeneous system; Hole burning & Lamb dip. *4 hrs*

6. **Generation of laser pulses:** Q- Switching; Mode – locking; generation of ultrashort pulses. 8 *hrs*

7. **Semiconductor lasers**: Principle of semiconductor laser operation; Homojunction lasers; Double heterostructure lasers, Quantum well lasers. *5 hrs*

References:

1. Verdeyen,J.T.: Laser Electronics, (III Edition) Prentice Hall, 1995.

2. Svelto O.: Principles of Lasers, (V Edition), Springer 2010.

3. William Silfvast, Laser Fundamentals, Cambridge press, 2004.

4. Ghatak and K. Thyagarajan; Optical Electronics, Cambridge University Press, 1996.

5. A E Siegman, Lasers, University Science Books, California, 1986.

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EL 2: Concepts in Materials Science

Course Objectives:
The objective of this course is to expose the students to the fundamental aspects of materials science and teach the methods of synthesis of materials.

Course Outcomes:
The learning outcomes of this course are

Understanding classification of materials

Different synthesis methods to make materials at different length scales

Knowledge of crystallographic interpretation of material structures

Defects in materials and their effect on material properties

Syllabus:

1. Classification of materials: States of Matter – Solids, Liquids, Gases and Plasma; Structural & Functional Materials; Amorphous/Glasses, Polycrystalline and Single Crystalline Materials; Materials Classification Based on their Physical Properties - Metals, Semiconductors, Insulators, Polymers, Composites. *3 hrs*

2. Basics of crystallography: Crystal Systems, Bravais Lattices, Point Groups, Space Groups, Generation of Point Groups, Symmetry Dependent Physical Properties. *7 hrs*

3. Preparation of Functional Materials in Different Configurations: Bulk-Polycrystalline powders, Ceramics, Thin films, Single Crystals, Glasses and Glass-Ceramics preparation.

Synthesis of polycrystalline materials at different length scales: Solid-State Reaction Route, Kinetics of Solid-State Reactions; Mechanochemical Synthesis (Mechanical Alloying). *3 hrs*

Soft Chemistry Routes: Solvothermal/Hydrothermal Method, Sol-Gel Method, Co-precipitation method. *4 hrs*

Fabrication of Ceramics: consolidation of polycrystalline powders, calcination, sintering. *3 hrs*

Thin film preparation: Physical and Chemical vapour deposition, RF/DC sputtering, laser ablation techniques. *6 hrs*

Crystal growth techniques: Solid-Solid, Liquid-Solid, Gas-Solid Equilibria: Czochralski method, Bridgman and Stockbarger method, zone melting, flux method. *8 hrs*

4. Defects in solids: different types of defects; Linear, planar and volume defects: Edge dislocations, screw dislocations, partial and mixed dislocations, planar defects (external surfaces, grain boundaries, phase boundaries, twin boundaries, antiphase boundaries), volume defects (precipitates); influence of defects on physical properties. *8 hrs*

References:

1. W. D. Callister, Materials Science and Engineering, Wiley, 2010.
2. C. Barry Carter, M. Grant Norton, Ceramic Materials: Science and Engineering, Springer 2013.
3. Anthony R West, Solid State Chemistry and its Applications, Wiley, 2014
4. W. F. Hosford, Materials Science: An Intermediate Text, Cambridge Univ. Press, 2011.
5. James F. Shackelford, Introduction to Materials Science for Engineers, Prentice Hall, 2015.
6. R. J. D. Tilley, Understanding Solids: The Science of Materials, Wiley, 2013.
7. H. L. Bhat, Introduction to Crystal Growth: Principles and Practice, CRC Press, 2014.

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EL 3: Nuclear Spectroscopy

Course Objectives:
Understand basic properties of nuclei, various phenomenological models of nuclei, practical aspects of alpha, beta and gamma spectroscopy and their interpretations.

Course Outcomes:
Students can interpret nuclear rotational and vibrational spectra in the context of the collective model; will be able to calculate quadrupole moments and predict ground state properties (spin and parity) of nuclei; Detailed knowledge of alpha, beta and gamma spectroscopy of nuclei and interpretation of nuclear structure from these.

Syllabus:

1. **The Two-body Problem and Nuclear Forces:** Ground state and excited states of deuteron; Low energy n-p scattering; scattering length; spin dependence of n-p scattering; singlet state in n-p scattering; Effective range theory and Zero-range theory in n-p scattering; Charge dependence of Nuclear forces – isotopic spin. *8 hrs*

2. **Nuclear Models:** Introduction; single particle orbits; extreme single particle model and spin; single particle model; configuration mixing. *5 hrs*

3. **Collective Nuclear Motion:** Introduction; Collective modes of motion; coupling of particles in collective motion; weak coupling; strong coupling; particle states in distorted nuclei; calculation of equilibrium shape; levels of distorted odd-A nuclei; values of inertial parameters; comparison of nuclear models. *10 hrs*

4. **Static Electromagnetic moments:** Shell model with interactions; collective model; electric quadrupole moments. *3 hrs*

5. **Gamma Transitions and Nuclear Models:** Single particle transition rates; electric dipole, magnetic dipole and electric quadrupole transitions. *4 hrs*

6. **Experimental Techniques:** Spin parity determination; lifetime measurements; in-beam spectroscopy; physics with radioactive ion beams; nuclear structure with radioactive ion beams; production and acceleration of radioactive ion beams. *7 hrs*

7. **Instrumentation:**
   Compton suppression systems; BGOs, Crystal balls; multiplicity detectors; Gamma detection array; multiwire proportioinal counters; Multi Channel analysers; CAMAC systems; electron transporters. *5 hrs*

References:

1. Cerny J. Nuclear Spectroscopy and Reactions, Academic Press (1974)
2. Roy, R. R., and Nigam, B. P.: Nuclear Physics, Wiley Eastern,(1979).
3. Emilio Segre: Nuclei and Particles, II edition, The Benjamin/Cummings Publishing Company, Reading, Massachusetts, (1977)
4. M. A. Preston: Physics of the Nucleus, Addison Wesley (1962).
5. K. N. Mukhin: Experimental Nuclear Physics – Vol 1: Physics of Atomic Nucleus, Mir Publishers (1987)
6. H. Ejiri: Electron Gamma Spectroscopy, Oxford (1990).

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EL 4: Fiber Optics

Course Objectives:
Optical Fibers are now the work horse of many technologies, including its major application in optical communications. This course is designed to give an exposure to the fundamentals of Fiber Optics and Optical Fiber Technology to a Masters student.

Course Outcomes:
Knowledge of the physics behind the light guiding mechanism and physical characteristics of light propagation in optical fibers, understand different mechanisms that causes signal

attenuation and dispersion, modes and mode propagation in an optical fiber, working principles of fiber based components like coupler and FBGs.

Syllabus:

1. **Ray paths and pulse dispersion in planar optical waveguides:** Review of basic fiber optics concepts; The one dimensional ray equation; Ray paths in a homogeneous medium; Ray paths in square law media; Transit time calculations; Pulse dispersion in a parabolic index medium. *6 hrs*

2. **Dispersion:** Pulse dispersion in graded index optical fibers; Material dispersion and its calculation; Material dispersion in pure and doped silica; Material dispersion in fluoride glasses. *5 hrs*

3. **Step Index Fiber:** Scalar modes in the weakly guiding approximation; Modal analysis for a step index fiber; Fractional modal power in the core; Single mode fibers; The Gaussian approximation; Splice loss. *6 hrs*

4. **Measurement methods in Optical Fibers:** Measurement of attenuation; Measurement of refractive index profile; The transmitted near field (TNF) method; The refracted near field (RNF) method; Measurement of NA. *6 hrs*

5. **Special Fibers and FBGs (overview):** Photonic crystal fibers, photonic band-gap fibers, hollow fibers, doped fibers, large-mode area fibers, highly nonlinear fibers, dispersion compensating fibers, Basic Concepts, Fabrication techniques, grating characteristics, types of FBG's, applications. *6 hrs*

6. **Optical Fiber Sensors:** Optical fiber directional coupler; Principle; Power exchange; Coupling coefficient of identical fiber directional couplers; Practical parameters of a coupler; Mach Zehnder interferometric sensor; Fiber optic rotation sensor (Gyroscope); Intensity sensors. *7 hrs*

7. **Fiber Lasers (FLs):** CW Erbium doped fiber lasers; pulsed fiber lasers: active mode-locked FLs, passive mode-locked FLs; super-continuum fiber lasers; cavity design. *6 hrs*

References:

1. Ghatak, A. and Thyagarajan, K.: Introduction to Fiber Optics, 3rd Ed, Cambridge University Press(2007)

2. R. Kahsyap, Fiber Bragg Gratings, (2nd Edition), Academic Press, Imprint of Elsevier, Amsterdam, (2010).

3. Culshaw B., Optical Fiber Sensors, Academic Press (2000)

4. Agarwal G. P., Applications of Nonlinear Fiber optics, Ed II, Academic Press, (2008).

5. Keiser, Gerd: Optical Fiber Communications, 3rd Ed, McGraw Hill (2000).

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EL 5: Functional Ceramics and Devices

Course Objectives:
This course is designed to provide a detailed study on Ceramic materials and their applications in devices. The prerequisite for this would be to do a fist course on concepts of materials science.

Course Outcomes:
At the end of this course, students will
Have a thorough knowledge of functional ceramic materials.
Know the methods of synthesis of functional ceramics.
Acquire knowledge of how to choose ceramic materials for specific applications.

Syllabus:

1. **Introduction:** Functional ceramics; High-Permittivity Dielectrics: Ceramic capacitors, Multilayer capacitors, Relaxor ferroelectrics. *6 hrs*
2. **Piezoelectricity:** Piezoceramics, Ultrasonic transducers, Ultrasonic imaging, Piezoelectric Transformers, energy harvesting applications. *5 hrs*
3. **Pyroelectricity:** Figure of merit and applications: Temperature/Infrared Sensors. 4 hrs
4. **Ferroelectricity:** Material Designing and Dopant effects, Ferroelectric Memory Devices: DRAM, FeRAM, MFSFET. *6 hrs*
5. **Electro-Optic Devices**: Review, Transparent Electro-Optic Ceramics, Bulk Electro-Optic Devices, Waveguide Modulators. *7 hrs*
6. **Magnetic Ceramics**: Soft & Hard Ferrites, Information storage and optical signal processing, Microwave devices. *7 hrs*
7. **Ceramic Conductors**: Ohmic and Voltage-dependent resistors (varistors), Temperature-sensitive resistors, High transition temperature superconductors, NTC & PTC materials as thermistors. *7 hrs*

References:

1. Kenji Uchino, Ferroelectric devices, CRC Press, 2010.

2. A. J. Moulson, J. M. Herbert, Electroceramics: Materials, Properties, Applications, John Wiley & Sons, Ltd, 2003.

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EL 6: Nuclear Reactions

Course Objectives:
Provide an advanced knowledge and the theory of different kinds of nuclear reactions

Course Outcomes:

Students will learn the

Properties of N-N scattering,
Basic properties of alpha, beta, and gamma emission from nuclei,
Spectra and spin and parities of daughters in alpha, beta, and gamma emission,
Theory of various nuclear reactions and their possible outcomes.

Syllabus:

1. **Introduction to nuclear reactions:** Center of mass co-ordinate system, types of reactions, energy and mass balance, conserved quantities, cross sections, attenuation of beam, a typical accelerator experiment, coulomb scattering, coulomb excitation, polarization, angular correlations. *8 hrs*

2. **Qualitative features of nuclear reactions:** Compound nucleus formation and direct reactions, compound resonances, reaction times, energy spectra, branching ratios, Giant resonances and strength functions, importance of direct reactions, characteristic angular distributions, coulomb effects. *8 hrs*

3. **Compound nucleus, Resonance and Optical Model:** Introduction, General features of cross-sections; Inverse reaction – detailed balance; Reaction mechanisms – Qualitative description of Compound nucleus; Formal description – scattering matrix; Resonances; Optical model; Compound nucleus – Level density. *9 hrs*

4. **Direct Reactions:** Introduction and General Properties of direct reactions; Partial penetration of Deuteron into a nucleus; stripping reactions; Butler's semi classical theory; Fission processes *8 hrs*

5. **Heavy-ion Reactions:** Introduction and general features; Techniques of operation with heavy ions; Review of reactions by heavy ions; Heavy ion interactions with nuclei at $T_{ion} < B_C$; Heavy ion interactions with nuclei at $T_{ion} > B_C$. *9 hrs*

References:

1. Satchler G.R. Introduction to Nuclear Reactions, Macmillan Education Ltd., II Ed. 1990.

2. Cerny J. Nuclear Spectroscopy and Reactions, Academic Press (1974).

3. M.A. Preston: Physics of the Nucleus, Addison Wesley (1962).

4. Mukhin K.N. Experimental Nuclear Physics, MIR Publishers (1987).

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EL 7: Ultrafast Nonlinear Optics

Course Objectives:
Provide fundamental understanding and working knowledge of various aspects of ultrafast optical experiments including effects of dispersion and nonlinearity on ultrashort pulse propagation and the methods to characterize such pulses.

Course Outcomes:
At the end of the course the students will be able to get an understanding and fair working knowledge of various ultrafast optical processes and be able to understand how to completely characterize ultrashort optical pulses using SHG autocorrelation, FROG and SPIDER techniques Understand the limitations imposed by material and angular dispersion and be able to make the right choice of lenses, mirrors, prisms in an optical system design using femtosecond pulses. Understand various processes affecting ultrashort pulse propagation in nonlinear media including SPM,XPM, delayed Raman, Self steepening, FWM, diffraction and dispersion, Soliton formation. Understand how to set up and analyze the results of ultrashort pump-probe experiments including nonlinear absorption and polarization gating spectroscopy.

Syllabus:

1. **Introduction:** Description of Nonlinear interactions, Nonlinear optical susceptibility tensor, Classical anharmonic oscillator model; Properties of nonlinear susceptibility; Ultra short pulse propagation equation and interpretation. *7 hrs*

2. **Dispersion and Dispersion Compensation:** Group Velocity Dispersion; temporal Dispersion Based on Angular Dispersion; Dispersion of Grating Pairs; Dispersion of Prism Pairs; dispersive Properties of Lenses; dispersion of Mirror Structures. *7 hrs*

3. **Second order effects:** Coupled wave equation for sum frequency generation, Manley-Rowe relations, sum frequency generation, Second Harmonic Generation, coupled-wave analysis of SHG, Type I and Type II phase matching, Optical parametric oscillators, Quasi phase matching. *7 hrs*

4. **Intensity dependent Refractive Index:** Description of intensity dependent refractive index, Tensor nature of third order susceptibility, Optical phase conjugation, self-focusing of light, optical switching, Z scan and four-wave mixing for measurement of nonlinear susceptibility. *7 hrs*

5. **Selected Topics:** Basics of Stimulated Raman Scattering and Basics of Stimulated Brilloiun Scattering, Basics of Electro-optic and Acousto-Optic effects, Solitons, Femtosecond frequency combs, Ultrafast Spectroscopy, nonlinear microscopy. *7 hrs*

6. **Ultrashort Pulse Characterization:** Basics of Autocorrelation, Frequency resolved optical gating (FROG) and spectral phase interferometry for direct electric field reconstruction (SPIDER); Characterization of Noise and Jitter. *7 hrs*

**Introduction to Optical Damage and Multiphoton Absorption. Thermal nonlinear optical effects, High harmonic generation, Attosecond pulses.
(**Not for Testing)

References:

1. Boyd, Nonlinear Optics, Ed III, Elsevier, (2008).

2. Andrew Weiner, Ultrafast Optics

3. A. Yariv, Optical Electronics, Holt McDougal; 3rd edition (1984).

4. Butcher and Cotter, Elements of Nonlinear Optics, Cambridge University press, (1990).

5. Geofrey New, Basics of Nonlinear optics

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EL 8: Photovoltaics for Energy Conversion

Course Objectives:
Gain a fundamental understanding of solar cell physics. Understand basic solar cell operation, design and limitations. Understand the physical concepts and operation of advanced photovoltaics. Gain appreciation of competing solar cell technologies and their applications

Course Outcomes:
Student will know some general facts on energy and the current status of PV in the world; basic explanation on how solar cells work, concepts of semiconductor physics. They will be able to elaborate on generation and recombination mechanisms, and introduce different types of semiconductor junctions. They will learn the most important parameters for characterizing solar cells, the efficiency limits of photovoltaic devices, some general design rules. Also they will gain understanding of different PV technologies, crystalline silicon technology, different thin-film technologies, some processing technologies and how to fabricate PV modules from solar cells.

Syllabus:

1. **Solar radiation:** Radiometric properties, Blackbody radiation, Solar spectra. *2 hrs*

2. **Generation and recombination of electron-hole pairs:** Bandgap-to-bandgap processes, Shockley–Read–Hall recombination, Auger recombination, Surface recombination, Carrier concentration in non-equilibrium; Semiconductor junctions: *p-n* homojunctions, Heterojunctions, Metal-semiconductor junctions *6 hrs*

3. **Solar cell parameters and equivalent circuit:** External solar cell parameters, external quantum efficiency, the equivalent circuit. *4 hrs*

4. **Losses and efficiency limits:** The thermodynamic limit, The Shockley-Queisser limit, additional losses, Design rules for solar cells. *4 hrs*

5. **Crystalline silicon solar cells:** Crystalline silicon, Production of silicon wafers, Designing c-Si solar cells, fabricating c-Si solar cells, High-efficiency concepts; *4 hrs*

6. **Thin-film solar cells:** Transparent conducting oxides, The III-V PV technology, Thin-film silicon technology; Chalcogenide solar cells, Organic photovoltaics, Hybrid organic-

inorganic solar cells; Plasma-enhanced chemical vapour deposition, Physical vapour deposition, Screen printing technology, Electroplating technology; *8 hrs*

7. **PV modules:** Series and parallel connections in PV modules, PV module parameters, Bypass diodes, Fabrication of PV modules, PV module lifetime testing, Thin-film modules, Concentrator photovoltaics (CPV). *4 hrs*

8. **Third generation concepts:** Multi-junction solar cells, Spectral conversion, Multi-exciton generation, Intermediate band solar cells, Hot carrier solar cells. *6 hrs*

9. **Hybrid Solar Cells: Materials, Interfaces, and Devices:** Background on Hybrid Photovoltaics, Materials development, Types of Hybrid solar cells, Efficient Hybrid Photovoltaics Based on Ordered Structures, Interface manipulation. *4 hrs*

References:

1. Arno Smets, Klaus Jäger, Olindo Isabella, Miro Zeman, René van Swaaij, "Solar Energy: The Physics and Engineering of Photovoltaic Conversion, Technologies and Systems", UIT Cambridge, 2016.

2. Xiaodong Wang, Zhiming M. Wang (Editors), Springer Series in Materials Science-Volume 190, "High-Efficiency Solar Cells: Physics, Materials, and Devices".

3. Jenny Nelson, "The Physics of Solar Cells" Imperial College Press, 2003.

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EL 9: Accelerators, Reactors & Detectors

Course Objectives:
This advanced level course is meant to cover the theory and practical aspects of different types of particle accelerators, the physics of nuclear reactors and design aspects and principles of radiation detection.

Course Outcomes:
At the end of the course the students will learn

Physical principles behind the operations of particle accelerators
Different types of particle accelerators
Practical aspects involved in reactor designs
Interaction of radiation with matter and different types of radiation detectors
Aspects of radiation safety

Syllabus:

1. **Accelerators:** Particle motion in electric and magnetic fields, concept of emittance; relativistic equations of motion; Basic principles of operation, typical parameters of different types of accelerators; different types of magnets, magnet design, quadrupoles and sextupoles, lens action of quadrupoles, quadrupole doublets and triplets. *10 hrs*

2. **Reactor Types:**
   Based on fuel elements – Enriched Uranium and Natural Uranium reactors;
   Based on moderator used – Light water reactors, Heavy water reactors, and Graphite moderated reactors;
   Based on fuel consumption – Thermal breeder reactors and Fast breeder reactors. *6 hrs*

3. **Design of Reactors:** Thermal Reactors: Fuel element fabrication; Moderator design; Coolant selection, primary and secondary coolant cycle; Design of control rods; Start up and Shut down of the reactor; Reprocessing of spent fuel; Fast Reactor: Fissionable and Fertile materials; Utilization of fission neutrons for sustaining chain reaction and breeding; Coolant design for fast reactors; Control of fast reactors. *10 hrs*

4. **Reactor Safety and Safeguards:** Assessment of reactor accident risk; Regulatory process; Nuclear safeguards: Domestic and International; Waste disposal problems. *4 hrs*

5. **Radiations and detectors:** Interaction of gamma rays , electrons, heavy charged particles and neutrons with matter; production of radio nuclides and measurement of strength of radioactive sources, radiation exposure, absorbed doses, biological effects, radiation protection, shielding, safety aspects; *7 hrs*

6. **Pulse processing and Life time:** Charge sensitive and voltage sensitive pre-amplifiers, pulse amplifiers, pulse shaping techniques, base line restoration, pulse height discriminators *5 hrs*

References:

1. Thomas J. Connolby: Foundations of Nuclear Engineering, John Wiley & Sons.

2. Ronald Allen Knief: Nuclear Energy Technology– Theory and practice of commercial Nuclear Power, McGraw Hill Book Co.

3. C.V.Sundaram, L.V.Krishnan and T.S.Iyengar: Atomic Energy in India – 50 years, DAE, Govt. of India, 1998.

4. Wiedemann H,: Particle Accelerator Physics I, Springer, 1999.

5. Staneley H,: Principles of Charged Particle Acceleration, John Wiley & Sons.

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EL 10: Femtosecond Laser Material processing

Course Objectives:
To teach the fundamentals of laser materials processing and femtosecond laser micromachining.

Course Outcomes:
Learn the fundamentals of laser-matter interaction
Understand the physical principles of femotsecond laser micromachining
Learn about various applications of femtosecond laser micromachining
Introduce to optofluidics

Syllabus:

1. **Review of Laser:** Principle of working of a laser, different types of lasers: based on gain medium, based on emission wavelength, continuous wave and pulsed lasers. Basic characteristics of a laser light; coherence, polarization, monochromaticity. *6 hrs*

2. **Fundamentals of laser-matter interaction**: basic physics of light matter interaction; laser processing and parameters; laser wavelength, power, dose, temporal profile and pattern generation. *12 hrs*

3. **Femtosecond laser micromachining Overview of applications:**
   Advantages of Femtosecond laser micromachining *2 hrs*
   Applications of laser for surface processing
   – Ablation and surface patterning e.g. Black silicon. *3 hrs*

4. **Medical applications**: laser direct surgery. *3 hrs*

5. **Laser polymerization:** fabrication of scaffolds for regenerative medicine. *4 hrs*

6. **Femtosecond laser micro-machining**
   for Lab-on-Chip devices *4 hrs*
   for integrated optics
   (Waveguide fabrication, splitters, Waveguide Bragg grating) *4 hrs*

7. **Optofluidic devices** (FLICE technique) *4 hrs*

References:

1. Koji Sugioka, Michel Meunier and Alberto Pique (Eds.), Laser Precision Microfabrication, Springer, 2010.

2. Roberto Osellame, Giulio Cerullo, Roberta Ramponi, Femtosecond Laser Micromachining: Photonic and Microfluidic Devices in Transparent Materials, Springer Publications, 2012.

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EL 11: Materials Characterization Techniques

Course Objectives:
Learn basics in analytical techniques. Characterize the structures and chemistries of materials. Select the proper characterization technique to solve problems in research and/or industry.

Course Outcomes:
The students will learn materials characterization techniques and use this knowledge to choose appropriate technique: Surface, interfaces and thin films characterization; Metals, ceramics, polymers, semiconductors and composite characterization.

Syllabus:

1. **Diffraction methods:** X-ray Powder diffraction – compound identification, lattice parameter, crystallite size, lattice strain measurements; Electron diffraction. *8 hrs*
2. **Electron Microscopy:** Scanning electron microscopy, Transmission electron microscopy; Energy-dispersive X-ray spectroscopy. *8 hrs*
3. **Electron Spectroscopy**: X-ray Photoelectron spectroscopy and Auger electron spectroscopy. *4 hrs*
4. **Scanning Probe Microscopy:** Scanning Tunnelling Microscopy; Atomic Force microscopy (AFM) and overview of different modes of operation in AFM. *8 hrs*
5. **Thermal Analysis:** thermo-gravimetric analysis, differential scanning calorimetry, differential thermal analysis; Dilatometry. *7 hrs*
6. **Optical methods to characterize materials**: Transmission and reflection spectra, band-gap, n, α, k for thin films, n for bulk materials. *7 hrs*

References:

1. Yang Leng, Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, Wiley, 2013.
2. Sam Zhang, Lin Li, Ashok Kumar, Materials Characterization Techniques, CRC Press, 2008.
3. Robert Speyer, Thermal Analysis of Materials, CRC Press, 1993.

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EL 12: Biomaterials

Course Objectives:
The objective of the course is to introduce various types of biomaterials, their properties and medical applications.

Course Outcomes:
Students will be learn about different types of biomaterials, their mechanical properties, selection of biomaterials for different applications, toxicity and corrosion related issues.

Syllabus:

1. **Definitions:** Biomaterials, Biomedical materials and Biological materials, Biocompatibility. *2 hrs*

2. **Toxicity and corrosion:** Elements in the body, Biological roles and Toxicities of trace elements, Selection of metallic elements in Medical-Grade alloys, Corrosion of Metals, Environment inside the Body, Minimization of Toxicity of Metal Implants, Biological Roles of Alloying Elements. *9 hrs*

3. **Mechanical Properties of Biomaterials:** Role of Implant Biomaterials, Mechanical Properties of General Importance - Hardness, Resilience and Strechability, Failure, Essential Mechanical Properties of Orthopedic Implant Biomaterials. *9 hrs*

4. **Metallic Biomaterials:** Development of Metallic Biomaterials, Stainless Steels, Cobalt-Based Alloys, Titanium Alloys, Comparison of Stainless Steels, Cobalt, and Titanium Alloys, Dental Materials, Ni-Ti Shape-Memory Alloys; Other Clinically Applied Metallic Materials, New Metallic Materials: Magnesium Alloys. *8 hrs*

5. **Bioinert Ceramics:** Overview of Bioceramics, Inert Bioceramics: Al_2O_3, ZrO_2, Types of Joints, Total Joint Replacement. *7 hrs*

6. Biomaterials for dental applications; Polymeric Biomaterials and Bioinert Polymers. *7 hrs*

References:

1. Larry L Hench, An Introduction to Bioceramics: Second Edition, Imperial College Press, (2013)
2. Qizhi Chen, George Thouas, Biomaterials: A Basic Introduction, CRC Press (2014)
3. David Williams, Essential Biomaterials Science, Cambridge University Press (2014)
4. Joon Park, Bioceramics: Properties, characterizations, and applications, Springer (2008)

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EL 13: Materials for Photonics

Course Objectives:
This course deals with varieties of materials used for photonic applications. Having learnt the basics of materials science, synthesis and materials characterization techniques, students can opt for this course to learn specifically about materials that are useful for photonic applications.

Course Outcomes:
After completion of the course students would have gained in-depth knowledge of III-V, II-VI semiconductors, Group - III nitride materials for LEDs, LDs, photovoltaic and photodetector applications along with knowedge of liquid crystals for display applications.

Syllabus:

1. **III-V ternary and quaternary compounds**: Introduction to III–V ternary and quaternary compounds; structural parameters; energy band parameters; optical properties; carrier transport properties. *7 hrs*

2. **Group III Nitrides:** crystal structures of nitrides; lattice parameters; electrical and optical properties; nitride alloys. *6 hrs*

3. **II–IV Semiconductors for optoelectronics:** CdS, CdSe, CdTe; solar cells and radiation detector applications. *6 hrs*

4. **II–VI Narrow-band-gap semiconductors for optoelectronics:** applications and sensor design; photoconductive detectors in HgCdTe and related alloys; photovoltaic devices in HgCdTe; emission devices in II–VI semiconductors. *8 hrs*

5. **Liquid crystals:** introduction to liquid crystals; basic physics of liquid crystals; liquid-crystal devices; materials for displays. *7 hrs*

6. **Luminescent materials:** luminescent centres; interaction with the lattice; thermally stimulated luminescence; optically (photo-) stimulated luminescence; experimental techniques – photoluminescence; applications. *8 hrs*

References:

1. Safa Kasap and Peter Capper (Eds.), Springer Handbook of Electronic and Photonic Materials, 2006.

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EL 14: Introduction to Microfluidics: Devices and Applications

Course Objectives:
An introductory course on microfluidics to introduce the basic principles of microfluidics and microfluidics devices,

Course Outcomes:
The students will learn about the fundamentals of microfluidics devices, their classifications, principles of microfluidics, various methods of fabrication of microfluidics devices and different areas of applications.

Syllabus:

1. **Introduction and General overview of Applications:** Microfluidics classification; Glass, Polymer and Paper based microfluidics their advantages and limitations. *8 hrs*

2. **Basic principles in microfluidics:** General principles of microfluidic flow, Design principles for microfluidic devices. *8 hrs*

3. **Device fabrication:** Soft lithography, femtosecond laser processing, printing technologies. *12 hrs*

4. **Optofluidic Device Applications:** Biological, chemical and optical sensing applications, point-of-care diagnostics. *12 hrs*

References:

1. Patric Tabeling, Introduction to Microfluidics, Oxford, 2005.

2. Frank A. Gomez (Editor), Biological Applications of Microfluidics, Wiley,2008

3. Roberto Osellame, Giulio Cerullo, Roberta Ramponi (Editors), Femtosecond laser micromachining, First Edition, Springer, 2012.

4. Sang-Joon John Lee, Narayan Sundararajan, Microfabrication for Microfluidics, Artech House, 2010.

5. Trung Nguyen and Stev, Fundamentals and Applications of Micro- fluidics, 2nd Ed.Artech House; 2006.

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EL 15: Physics and Technology of Thin Films

Course Objectives:
This course deals with the principles underlying the growth of materials in thin film configuration along with their characterization and some physical properties.

Course Outcomes:
After completing the course, students would gain deeper knowledge in the synthesis of thin films using methods like chemical vapour deposition, electrolytic deposition, thermal evaporation, cathodic sputtering, molecular beam epitaxy and laser ablation methods; techniques to characterize thin films like electron and X-ray diffraction; evaluation of optical constants of thin films; magnetic proerpties of thin films.

Syllabus:

1. Preparation methods: electrolytic deposition, cathodic and anodic films, Physical vapour deposition- thermal evaporation, cathodic sputtering; chemical vapour deposition; Molecular beam epitaxy and laser ablation methods, Atomic layer deposition. *7 hrs*

2. Thickness measurement and monitoring: electrical, mechanical, optical interference, microbalance quartz crystal methods. *3 hrs*

3. Analytical techniques of characterization: X-ray diffraction, electron microscopy, high and low energy electron diffraction, Auger emission spectroscopy. *5 hrs*

4. 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. *6 hrs*

5. Mechanical properties of films: elastic and plastic behavior. *2 hrs*

6. Optical properties: Reflectance and transmittance spectra. Absorbing films. Optical constants of film material. Multilayer films. Anisotropic and gyrotropic films. *5 hrs*

7. Electric properties to films: Conductivity in metal, semiconductor and insulating films. Discontinuous films. Superconducting films. Dielectric properties. *6 hrs*

8. Magnetism of films: Molecular field theory. Spin wave theory. Anisotropy in magnetic films. Domains in films. Applications of magnetic films. *6 hrs*

References:

1. Donald Smith, Thin Film Deposition, McGraw Hill, (1995)

2. Milton Ohring, Materials Science of Thin Films, Academic Press, (2001)

3. K.L. Chopra, Thin Film Phenomena, McGraw-Hill (1983)

4. K.L. Chopra and I.J. Kaur, Thin Film Solar Cells, Plenum Press (1983)

5. L.I. Maissel and Glang (Eds.), Handbook of Thin film Technology, McGraw-Hill, (1970)

6. J.C. Anderson, The Use of Thin Films in Physical Investigation, Academic Press, (1966)

7. J.J. Coutts, Active and Passive Thin Film Devices, Academic Press, (1978)

8. R.W. Berry, P.M. Hall and M.T. Harris, Thin Film Technology, Van Nostrand, (1968)

9. George Hass, Physics of Thin Films: Volumes 1 to 2, Academic Press, (1963)

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EL 16: Computational Materials Science

Course Objectives:
To introduce the field of computational materials science and teach the fundamental theory and methods of computing material properties.

Course Outcomes:
At the end of the course the student would be familiar with classical and quantum mechanical simulation techniques - namely, Molecular Dynamics, Monte Carlo methods, and density functional theory based simulations. Students also will learn to apply these methods in the field of materials science to determine physical properties like melting point, band structure, electrical transport, etc.

Syllabus:

1. **Molecular dynamics (MD):** Interaction potentials - pair potential, empirical potential. *6 hrs*

2. MD under different constraints like NVE, NVT and NPT; MD simulation of thin film growth; Non-equilibrium molecular dynamics; MD simulation of phonon mean free path and thermal conductivity. *10 hrs*

3. **Monte Carlo (MC) methods**: Introduction to MC methods; Monte Carlo simulation of surface adsorption; Monte Carlo simulation of grain growth. *10 hrs*

4. **Quantum-Mechanical calculations:** Tight binding model and simple band structure calculations; Density functional based tight binding (DFTB) method; Applications: band structure of metal, insulator and semiconductor; Applications: geometry optimization and transport calculations. *14 hrs*

References:

1. Allen and Tildesley, Computer simulation of liquids, Oxford, 1989.

2. June Gunn Lee, Computational materials science: an introduction, CRC Press, 2017.

3. Richard Martin, Electronic structure: basic theory and practical methods, Cambridge University Press, 2004.

4. Dierk Raabe, Computational Materials Science: The simulation of materials microstructures and properties, Wiley-VCH, 1998.

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EL 17: Microelectronics

Course Objectives:
To introduce students to the field of digital integrated circuits and fundamentals of CMOS circuits.

Course Outcomes:
Learning outcomes are as follows: basic introduction to integrated circuits and their performance metrics, MOS transistor operation and functionality, design of logic gates using CMOS, CMOS fabrication technology and CMOS circuit layouts.

Syllabus:

1. **Introduction to Digital Integrated Circuits** – Quality metrics– functionality, performance, power and cost perspective. 4 *hrs*
2. **The Device**– MOS transistor operation & current models – CMOS inverter functionality, static and dynamic behavior & power. 4 *hrs*
3. **Combinational Gates**– Design of basic and compound gates.in Static CMOS. 4 *hrs*
4. **Introduction to CMOS fabrication** – Basic masking steps and design rules. 4 *hrs*
5. **Layout of CMOS Circuits** – Introduction to physical layout of inverter and basic gates. 4 *hrs*
6. **Sequential Logic Circuits** – Design of static Latche, Flip flops and registers. 4 *hrs*
7. **Design implementation options** – Introduction to gate arrays, standard cells and programmable logic arrays. 4 *hrs*
8. **Datapath -** Design of basic adders, counters, shifters and multipliers in CMOS technology. 4 *hrs*
9. **Memories** - Introduction to SRAM, DRAM, FLASH, OTP memory arrays. 4 *hrs*
10. **HDL** - Introduction to design abstraction and Verilog HDL. 4 *hrs*

References:

1. Jan M. Rabaey, Anantha Chandrakasan, Borivoje Nicolic :Digital Integrated Circuits – A Design Perspective, II Edition; PHI Learning (2009)
2. Sameer Palnitkar:Verilog HDL – A Guide to Digital Design and Synthesis, II Edition, Pearson India, (2003).

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EL 18: Superconductivity

Course Objectives:
This is a course which deals in detail with the theory of superconductivity and also describes some of the experimental methods for probing the superconducting state.

Course Outcomes:
After completing the course the students will understand the thermodynamics of the normal metal to superconducting phase transition; the phenomenological Ginzburg-Landau approach; the microscopic theory of superconductivity due to Bardeen, Cooper and Schrieffer (BCS).The theoretical understanding will be helpful to explain tunneling and quantum interference phenomena in superconductors. Students will also learn some of the experimental methods for probing the superconducting state and obtain some knowledge of high-Tc superconductors

Syllabus:

1. **A historical overview:** Superconductivity in Hg, cuprates, MgB_2 and Fe pnictides. *3 hrs*

2. **Basic properties of metals in normal state:** Resistivity, electronic and phonon specific heats, thermal conductivity, magnetic susceptibility and Hall effect. *2 hrs*

3. **Phenomenon of superconductivity:** Zero resistance, persistent currents, superconducting transition temperature T_c, isotope effect, perfect diamagnetism and Meissner effect, penetration depth and critical field. *5 hrs*

4. **Thermodynamics of superconducting transition:** First-order and second-order transition, specific heat above and below Tc, thermal conductivity. *5 hrs*

5. **Phenomenological theory of superconductivity:** Free energy, order parameter, Ginzburg-Landau equations, predictions of Ginzburg-Landau equations, flux-quantization, penetration depth. *8 hrs*

6. **Microscopic theory of superconductivity:** Electron-phonon interaction, Cooper pairs, Bardeen-Cooper-Schrieffer (BCS) Hamiltonian, variational approach, canonical transformation, finite temperatures, properties of the BCS ground state, macroscopic properties of superconductors. *9 hrs*

7. **Tunneling and the energy gap:** Tunneling phenomenon, energy-level diagram, Josephson effect, quantum interference. *5 hrs*

8. **Type-I and Type-II superconductivity:** Type-I and type-II superconductors, intermediate states, mixed states. *5 hrs*

References:

1. James F Annett, Superconductivity, Superfluids and Condensates, Oxford University Press, (2004).

2. M. Tinkham, Introduction to Superconductivity, 2nd Edition, Dover Publications, Inc., New York (1996).

3. C.P. Poole Jr., H.A. Farach, R.J. Creswick, and R. Prozorov, Superconductivity, 2nd Edition, Academic Press (2007).

4. A.C. Rose-Innes and E.H. Rhoderick, Introduction to Superconductivity, 2nd Edition, Pergamon, Oxford (1978).

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EL 19: Fundamentals of Nanoelectronics

Course Objectives:
To convey key concepts of nanoelectronics and quantum transport phenomena.

Course Outcomes:
After completing the course, students will understand the size and surface effects on electrical ressitance; current flow in quantum systems; distinguish between diffusive and ballistic transport; apply Landauer-Büttiker formalism to nanoscale transport phenomena

Syllabus:

1. **Macroscopic current flow:** Origin of electrical resistance, size effects on electrical resistance, surface effects. *3 hrs*

2. **Quantum current flow:** Point contacts - from mesoscopic to atomic, conductance, quantum transmission, conductance quantum, Transmission probability and current flow in quantum systems - single potential step, single potential barrier, double potential barrier, techniques for the fabrication of quantum nanostructures. *10 hrs*

3. **Mesoscopic transport:** Boltzmann transport equation, resistivity of thin films and wires, surface scattering, grain boundary scattering, measurement of resistance of thin film. 9 hrs

4. **Electromigration:** fundamentals of electromigration, diffusion of material, importance of surfaces, failure of wires, current induced heating in a nanowire device, electromigration in micron-scale devices, consequences for nanoelectronics *8 hrs*

5. **Elements of single-electron and molecular electronics:** single electron transport and Coulomb blockade, mechanism of electron transport through molecules, visualizing transport through molecules, the contact resistance problem, contacting molecules - nanogaps formed by electron-beam lithography, formed by electromigration, mechanically controlled break junctions, molecular sandwiches, STM probing of molecules *10 hrs*

6. **Scanning probe multimeters:** quick review of STM, AFM, and various modes of operation. *2 hrs*

References:

1. Colm Durkan, Current at the Nanoscale, 2nd edition, World Scientific, 2013.

2. Supriyo Datta, Lessons from Nanoelectronics, 2nd edition, World Scientific, 2017.

3. Supriyo Datta, Quantum Transport, Cambridge University Press, 2005.

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EL 20: Nanoscale Physics

Course Objectives:
This course gives the students a comprehensive description of the phenomena and changes that can be expected when macroscopically sized materials are reduced down to the nanometer level.

Course Outcomes:
At the end of the course students will gain a deeper understanding of why and how electrical, optical and magnetic properties of materials change when the dimensionality of materials comes down to the level of few nanometers.

Syllabus:

1. **Low dimensionality and energy spectrum:** Electron DOS of 3D materials with macroscopic dimensions, Electron DOS in 2D materials (nanosheets), Electron DOS in 1D materials (nanowires), Quantized conductance in 1D nanowire systems, Electron DOS in 0D materials (nanodots); *8 hrs*
2. **Quantization**: 2D square wells, 2D cylindrical wells, Shape effect on the quantized states, Finite potential wells, Edge (surface)-localized states, Charging effect, Tunneling phenomena, *8 hrs*

3. **Size-dependent optical properties**: Absorption and emission, Wannier excitons, Size effects in high-dielectric-constant materials, Molecular Frenkel exciton, Size effects in molecular excitons: Coherence length and cooperative phenomena, Size-dependent scattering from dielectric spheres: Mie solutions, Optical properties of metal nanoparticles: Plasmonics, Local feld enhancement and surface-enhanced Raman scattering. *12 hrs*

4. **Magnetic and magnetotransport properties of Nanoscale materials:** Quantization of electronic structures and the Kubo effect, Surface magnetism of transition noble metals, Single-domain structures and superparamagnetism, Macroscopic quantum tunneling in magnetic nanostructures. *12 hrs*

References:

Takaaki Tsurumi, Hiroyuki Hirayama, Martin Vacha, Tomoyasu Taniyama, Nanoscale Physics for Materials Science, CRC Press, 2009.

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EL 21: Graphene and 2-dimensional Materials

Course Objectives:
This course deals with physics and applications of devices based on graphene and other two dimensional materials such as MoS_2.

Course Outcomes:
After completing the course, the student will acquire knowledge of various synthesis routes for making graphene and some other 2D materials; understand Raman spectral signatures of these 2D materials; understand some mechanical and chemical properties; and their applications.

Syllabus:

1. **Introduction:** History of graphene, Atomic structure and graphene, Imaging the structure of graphene, Properties of graphene overview *2 hrs*

2. **Production of graphene and 2-d materials:** Comparison of production methods, Scotch-tape method (micromechanical cleavage), Chemical vapour deposition, Solution-exfoliation – graphene and other 2-d materials, graphene oxide, Decomposition of silicon carbide, Production of graphene nano-ribbons . *4 hrs*

3. **Electronic properties and devices:** Electronic structure of graphene, First graphene device, Further graphene devices and evidence of 2-dimensional nature, Electronic properties of bilayer graphene, Switching graphene OFF. *8 hrs*

4. **Raman spectroscopy:** Principles of Raman spectroscopy, Raman spectrum of graphene, Analysis of graphene Raman spectra, Raman spectra of other 2-D materials. *5 hrs*

5. **Chemical properties and sensors:** X-ray photoemission spectroscopy, Optical absorption spectroscopy, Functionalizing graphene, Hydrogels and aerogels, Liquid cystals, Gas and chemical sensors. *6 hrs*

6. **Mechanical properties and applications:** Measuring mechanical properties, Graphene resonators, Electromechanical devices, Graphene bubbles, Graphene composites. *5 hrs*

7. **Graphene membranes:** GO and rGO membranes, Membranes for separation, Membranes as barriers, Porous membranes, Supercapacitor electrodes. *6 hrs*

8. **Biomedical devices and 2-d heterostructures:** Biocompatibility and biodistribution, Scaffolds for tissue engineering, Drug and gene delivery, Cancer therapy, Introduction to 2-d heterostructures, 2D heterostructure devices *6 hrs*

References:

1. Mikhail I. Katsnelson, Graphene: Carbon in Two Dimensions, Cambridge University Press, 2012.

2. Dragoman, Mircea, Dragoman, Daniela, 2D Nanoelectronics: Physics and Devices of Atomically Thin Materials, Springer, 2017.

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EL 22: Foundations of Quantum Optics

Course Objectives:
This foundation course explains the quantum nature of light and some of its consequences.

Course Outcomes:
After completing the course, the student will - understand the statistical nature of light; apply the formalism of creation and annihilation operators for the electromagnetic field to describe quantum states of light; calculate and explain the fluctuations and correlations of different quantum states of light; describe and calculate the properties of squeezed states; understand a few applications like laser cooling and trapping.

Syllabus:

1. **Photon statistics:** Photon-counting statistics, Coherent light, Classification of light by photon statistics, Super-Poissonian light, Sub-Poissonian light, Semi-classical theory of photodetection, Quantum theory of photodetection, Shot noise in photodiodes. *6 hrs*

2. **Photon antibunching:** the intensity interferometer, Hanbury Brown–Twiss experiments and classical intensity fluctuations, Hanbury Brown–Twiss experiments with photons, Photon bunching and antibunching, Single-photon sources. *6 hrs*

3. **Coherent states and squeezed light:** Light waves as classical harmonic oscillators, Light as a quantum harmonic oscillator, The vacuum field, Coherent states, Shot noise and number–phase uncertainty, Squeezed states. *6 hrs*

4. **Photon number states:** Operator solution of the harmonic oscillator, The number state representation, Photon number states, Coherent states, Quantum theory of Hanbury Brown–Twiss experiments. *6 hrs*

5. **Resonant light–atom interactions: T**wo-level atom approximation, Coherent superposition states, density matrix, time-dependent Schrodinger equation, the weak-field and strong field limit, The Bloch sphere. *6 hrs*

6. **Atoms in cavities:** Optical cavities, Atom–cavity coupling, Weak coupling - Free-space spontaneous emission, Spontaneous emission in a single-mode cavity, Strong coupling - Cavity quantum electrodynamics, Applications of cavity effects. *6 hrs*

7. **Cold atoms:** Laser cooling - Basic principles of Doppler cooling, Magneto-optic atom traps, Cooling and trapping of ions, Atom lasers. *6 hrs*

References:

1. Mark Fox, Quantum Optics - An Introduction, Oxford University Press, 2006.

2. Harry Paul, Introduction to Quantum Optics, Cambridge University Press, 2004.

3. Vlatko Vedral, Modern Foundations of Quantum Optics, Imperial College Press, 2005.

4. Marlan O. Scully, M. Suhail Zubairy, Quantum Optics, Cambridge University Press, 1997.

5. Gilbert Grynberg, Alain Aspect, Claude Fabre, Introduction to Quantum Optics: From the Semi-classical Approach to Quantized Light, Cambridge University Press, 2010.

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EL 23: Quantum Computing

Course Objectives:
Quantum computing exploits the quantum mechanical nature of matter to simultaneously exist in multiple possible states. Building up on the digital binary logic of bits, quantum computing is built on the basis of interacting two-level quantum systems or 'qubits' that follow the laws of quantum mechanics. Addressability of the quantum system and its fragility to fidelity are the major issues of concern, which if addressed appropriately, will enable this new approach to revolutionize the present form of computing. After developing the basics, this course delves on various implementation aspects of quantum computing and quantum information processing.

Course Outcomes:
After completing the course, the students will gain a good understanding of basics of quantum measurement, quantum cryptography; understand some basic quantum algorithms; gain knowledge of some aspects of quantum computing based on NMR, linear optics, lasers, ion traps and spintronics.

Syllabus:

1. Computational tools, Quantum measurement and teleportation, Quantum teleportation and cryptography. *7 hrs*

2. DJ algorithm and implementation aspects, Grover's algorithm, Basics of Shor's algorithm and Quantum Fourier Transform. 7 *hrs*

3. Basic concepts of NMR Quantum Computing; *6 hrs*

4. Linear optical approaches towards Quantum Computing, laser experimental implementation for Grover's algorithm. *8 hrs*

5. Implementing Quantum Computing using Ion traps; *7 hrs*

6. Qubits used in commercial quantum computing, Spintronics quantum computing. *7 hrs*

References:

1. Michael A. Nielsen and Issac L. Chuang, "Quantum Computation and Information", Cambridge (2002).

2. Riley Tipton Perry, "Quantum Computing from the Ground Up", World Scientific Publishing Ltd (2012).

3. Scott Aaronson, "Quantum Computing since Democritus", Cambridge (2013).

4. P. Kok, B. Lovett, "Introduction to Optical Quantum Information Processing", Cambridge (2010).

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