SRI SATHYA SAI INSTITUTE OF HIGHER LEARNING

(Deemed to be University)

Syllabus for

M.Sc. (Physics)

(w.e.f. Academic Year 2022-2023)

Prasanthi Nilayam – 515 134

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REGISTRAR

Sri Sathya Sai Institute of Higher Learning

(Deemed to be University)

Vidyagiri, Prasanthi Nilayam

Sri Sathya Sai District, A.P. - 515 134

India

17-10-2022

M.Sc. Programme Objectives and Outcomes

Student passing through the Master of Science (M. Sc.) Programmes of the institute would:

1. Receive sound knowledge and understanding of the basic principles of Science.
2. Possess necessary competency to pursue a career in academia, research institutions or industry in basic or applied sciences.
3. Achieve proficiency in use of various scientific instruments and be in a position to design, plan and execute sophisticated experimental protocols.
4. Acquire good oral and written communication skills and be ready to take on competitive examinations both at national and international levels.
5. Grow up into a self-confident individual with innovative ideas and entrepreneurial spirit.
6. Develop into an individual with a right balance of scientific temper and ethics.

Programme Specific Objectives and Outcomes

The Two-year M.Sc. Physics Programme is designed to provide a strong foundation in fundamental physics as Physics is the basis for advanced scientific research and technological inventions.

Specific objectives of the Programme and the curriculum include:

1. Seamlessly integrate the courses as a continuation of the 3 year B.Sc Hons. Programme of the department.
2. Provide a blend of science and technology, with appropriate theoretical and applied physics courses.
3. Complement each course by adequately equipped laboratories.
4. Rigor of theoretical physics coupled with advanced courses in photonics, materials science and nuclear physics.

Specific outcomes of the M.Sc. Physics Programme

1. Students get the required skill to design, set up and perform experiments.
2. The Programme becomes unique because of additional hands-on training in electronics, microcontrollers, computer programming and computational techniques.
3. Comprehensive approach equips the students with the ability to use many techniques to solve Physics problems.
4. Helps the students to develop proficiency in both theory and experiments.
5. Provides a clear edge to students for entry into research as well technology oriented programmes.

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

SCHEME OF INSTRUCTION AND EVALUATION
M.Sc. (Physics) PROGRAMME
(Effective from A.Y. 2022-2023 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	Mathematical Physics	4	4	IE2	T	100
PPHY-105	Experimental Methods in Physics – I	3	6	I	P	100
PPHY-106	Electronics and Microcontroller Lab	3	6	I	P	100
PPHY-107	Self Development *	1	3	I	P	50
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	30 hours			750 marks
	* Offered by DMC					
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	Statistical Mechanics	4	4	IE2	T	100
PPHY-205	Experimental Methods in Physics – II	3	6	I	P	100
PPHY-206	Software Lab	3	9	I	P	100
PPHY-207&	Mini Project	1	2	I	MP	50&
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	32 hours			750 marks
SEMESTER – III:						
PPHY-301	Advanced Spectroscopy	4	4	IE2	T	100
PPHY-302	Solid State Physics	4	4	IE2	T	100
PPHY-303	Elective – I	3	3	IE2	T	100
PPHY-304	Elective – II	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
		19 credits	31 hours			650 marks
SEMESTER – IV:						
PPHY-401	Elective – III	3	3	IE2	T	100
PPHY-402	Elective – IV	3	3	IE2	T	100
PPHY-403	Elective – V	3	3	IE2	T	100
PPHY-404**	Project Work	9	18	E2	PW	150**
PAWR-400	Awareness Course-IV: Wisdom for Life	1	2	I	T	50
		19 credits	29 hours			500 marks
	TOTAL	82 Credits	122 hours			2650 marks

Contd ...

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
MP	Mini Project

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.

& The evaluation of the mini project is completely internal with a maximum of 50 marks.

List of Electives: (3 Cr each)

EL-1: Principles of Laser Physics
EL-2: Concepts in Magnetism and Superconductivity
EL-3: Semiconductor Device Physics
EL-4: Concepts in Materials Science
EL-5: Nuclear Spectroscopy
EL-6: Fiber Optics
EL-7: Functional Ceramics and Devices
EL-8: Nuclear Reactions
EL-9: Photovoltaics for Energy Conversion
EL-10: Ultrafast Nonlinear Optics
EL-11: Accelerators, Reactors & Detectors
EL-12: Biomaterials
EL-13(T): Molecular Simulations (2 Credit Theory)[&&]
EL-13(P): Molecular Simulations (1 Credit Practical)
EL-14: Microelectronics
EL-15: Fundamentals of Nanoelectronics
EL-16: Nanoscale Physics
EL-17: Foundations of Quantum Optics
EL-18: Quantum Computing
EL 19(T): Industry 4.0- IoT, Artificial Intelligence & Additive Manufacturing (2 Credit Theory)[&&]
EL 19(P): Industry 4.0- IoT, Artificial Intelligence & Additive Manufacturing (1 Credit Practical)

[&&] This elective is 2 credits theory (T) + 1 credit practical (P)

PPHY-101: Classical Mechanics 3 Cr

Course Objectives:

Classical Mechanics remains an indispensable part of a physicist's education. It plays a major role in preparing the student for the study of modern physics. The course aims.

1. To familiarize the students with alternative formulations of mechanics, Lagrangian and Hamiltonian, which serve as the springboard for various branches of theoretical physics.
2. To explain generating functions, canonical transformations and Poisson brackets.
3. To introduce the Hamilton-Jacobi equation and the principle of least action which provides a transition to wave mechanics.
4. To apply the Lagrangian formalism to central force problems and small oscillations.

Course Outcomes:

1. Set up the Lagrangian and Lagrange's equations of motion for different physical systems and solve them.
2. Set up the Hamiltonian and Hamilton's equations of motion for different physical systems and solve them.
3. Understand Poisson brackets.
4. Understand the Hamilton-Jacobi formulation and solve simple problems based on action-angle variables.
5. Understand canonical transformations.
6. Apply some of these techniques in the detailed study of 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. 7 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. 7 hrs

3. **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. 7 hrs

4. **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

5. **Canonical Transformations:** Equations of canonical transformation, harmonic oscillator, Poisson brackets, equations of motion, infinitesimal canonical transformations, and conservation theorems in the Poisson bracket formulation, Liouville's theorem. 7 hrs

6. **Hamilton-Jacobi Theory:** Hamilton Jacobi equation for Hamilton's principal function, harmonic oscillator, free particle, particle in uniform gravitational field, Hamilton-Jacobi equation for Hamilton's characteristic function, Kepler problem. 8 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, (1982).
3. Stephen Thornton, Jerry Marion, Classical Dynamics of Particles and Systems, 5th edition, Brooks/Cole, (2004).

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PPHY-102: Classical Electrodynamics 3 Cr

Course Objectives:

This course aims to equip the students to understand and apply Maxwell's equations and boundary conditions to solve problems in electrodynamics that include electro / magneto statics, EM wave propagation in all linear isotropic media, hollow metallic waveguides and radiation from different types of sources.

Course Outcomes:

On completion of this course the students will

1. Be able to use Maxwell's equations to solve electrostatic and magnetostatic problems in different coordinate systems using special functions and vector calculus.
2. Be able to perform multipole expansion of charge sources.
3. Be able to use Maxwell's Stress tensor and understand the Poynting's theorem.
4. Be able to solve problems and understand EM wave propagation in linear isotropic dielectric & conducting media, and hollow metallic waveguides.
5. Be able to predict radiation from arbitrary charge distributions including oscillating electric dipoles, oscillating magnetic dipoles, and accelerating point charges.
6. Be able to understand the need and solve problems on 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. 5 hrs

References:

1. Griffiths, D. J.: Introduction to Classical Electrodynamics, Prentice Hall, 3rd edition, (1999).

2. Jackson, J.D: Classical Electrodynamics, 2nd edition, Wiley Eastern (1975).

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

4. Jordan E.C., and Balmain, K.G, Electromagnetic Waves and Radiating Systems, 2nd edition, Prentice Hall India (1987).

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PPHY-103: Quantum Mechanics - I 3 Cr

Course Objectives:
To Provide a strong foundation to the quantum mechanical principles, understand the different formalisms of quantum mechanics and solve Schrodinger equation for different physical systems.

Course Outcomes:
On completion of this course the student will
1. Acquire a tool set for understanding how the microscopic world works, mathematical tools essential in understanding Quantum mechanics.
2. Understand the theoretical foundations of Quantum mechanics, postulates and their implications.
3. Be able to use matrix and wave formulations of quantum mechanics to find the energy spectrum and the states of quantum systems.
4. Be able to solve the Schrodinger wave equation (for few idealized systems) to obtain the various energy levels of the particle and the corresponding wave functions.
5. Understand the formalism of angular momentum.
6. 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

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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, 2nd edition, Prentice Hall, (1995).

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PPHY-104: Mathematical Physics 4 Cr

Course Objectives:

This course on Mathematical Physics consists of two parts – Tensor Calculus and Group Theory. The course aims:

1. To introduce tensor algebra along with applications related to physics problems.
2. To introduce principles of group theory and the theory of representations along with some applications.

Course Outcomes:

On completion of this course the student will

1. Be familiar with tensor notations and the algebra of Cartesian tensors.
2. Be familiar with non-Cartesian tensor algebra and usage of the metric tensor and Christoffel symbols.
3. 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.
4. Understand different matrix representations of point groups.
5. Understand equivalent, reducible and irreducible representations.
6. Apply the ideas of groups and representation theory in quantum mechanics and molecular vibrations.

Syllabus:

I. Tensor calculus

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. 10 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. 15 hrs

II. Group Theory

1. **Symmetry operations and point groups:** algebra of symmetry operations, dipole moments and optical activity, definition of a group, examples, classification of point groups, determination of molecular point groups. 6 hrs

2. **Matrix representations:** Symmetry operations on a position vector, matrix representations for C_{2h} and C_{2v}, function space, transformation operators, determination of transformation operators for C_{3v} point group using d-orbital function space, determinants as representations. 6 hrs

3. **Reducible, irreducible representations and character tables:** equivalent representations, unitary representations, reducible representations. Great orthogonality theorem, characters, reduction of reducible representation, construction of character tables, notation for irreducible representations.

8 hrs

4. **Representations in quantum mechanics:** Invariance of Hamiltonian operators, direct product representations within a group, vanishing integrals.

4 hrs

5. **Molecular vibrations:** Vibrational equation, Γ^0 representation, reduction of Γ^0, classification of normal coordinates, classification of vibrational levels, infrared and Raman spectra of CH_4 and CH_3D.

7 hrs

References:

1. Young, E. C.: Vector and Tensor Analysis, Marcel Dekker, (1978).
2. Lawden, D. F.: An Introduction to Tensor Calculus and Relativity, Chapman and Hall, (1975).
3. David M Bishop, Group Theory and Chemistry, Dover Publications, (1973).
4. Michael Tinkham, Group Theory and Quantum Mechanics, Dover Publications, (1964).
5. A.W. Joshi, Elements of Group Theory for Physicists, New Age International Publishers, 4th revised edition, (2015).

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PPHY-105 Experimental Methods in Physics – I 3 Cr

Course Objectives:

1. The main aim of this course is to introduce students to various experiments in Physics discipline, while concomitantly imparting essential experimental skills and inducing curiosity for designing new experiments.
2. In this lab, the scope of the experiments performed is restricted to topics in Solid State Physics, Nuclear Physics, Material Science, and Applied Optics & Photonics.

Course Outcomes:

1. *Solid State Physics Experiments*: The student will be able to investigate electrical, magnetic and thermal behavior of materials.
2. *Materials Science:* Complementing the solid state physics experiments, these fundamental experiments are essential for the student to familiarize with structural characterization of various materials.
3. *Nuclear Physics Experiments:* The planned experiments are designed to expose students to Nuclear spectroscopic techniques which involve usage of radiation detectors like Scintillation and semiconductor detectors for studying gamma radiation; Integrating Multichannel spectrum analyzer with the gamma spectrometers to probe the Nuclear structure of radioactive nuclei; Safe handling of Radio-isotopes and sensitive radiation detectors.
4. *Applied Optics & Photonics Experiments:* Students are exposed to experiments which comprehend the concepts of optical phenomena such as Interference, Diffraction, Polarization, Physics of Optical Materials while Photonics experiments include familiarizing with applications & testing of Optical modulators and Opto-electronic components that are essential in modem optical communications.
5. *Hard skill set:* Student after going through this course will gain knowledge of different experimental components: their functioning principles and usage; Ways of setting up experiment/alignment methods for obtaining better results; Rigorous Experimental data analysis which includes Error Analysis, Linear and Nonlinear Curve Fitting & modeling of experimental data using standard numerical and analytical methods.

Syllabus:

Section A

1. X-ray diffraction analysis
2. Magnetoresistance
3. Resistivity and bandgap of semiconductors (using four probe technique)
4. Ionic conductivity of solids
5. Study of dielectric properties of standard samples using LCR meter
6. Thermal expansion coefficient
7. Viscosity of fluids
8. Lattice dynamics

Section B

1. Determining solar constant
2. I-V characteristics of a solar cell
3. I V characteristics of a photodiode
4. Profile of a laser beam
5. Determination of linear attenuation coefficient of absorber materials
6. UV-Vis spectra of powder solid samples
7. Refractive index measurement using camera based lateral shift method
8. Lock-in detection

References:

1. Experiments with GM counter, edited by J. Narender Reddy and M.S.R. Murthy, Published by Nucleonix systems Pvt. Ltd., www.nucleonix.com
2. Glenn F. Knoll, Radiation Detection and Measurement, 2nd Edition, John Wiley & Sons, New York, (1989).
3. Methods in Experimental Physics 6, Part B, K. Lark-Horovitz and Vivian A. Johnson (Eds.) - Solid State Physics Electrical, Magnetic, and Optical Properties-Academic Press, Elsevier (1959).
4. E.C. Subbarao, L.K.Singhal, D.Chakravorty, Marshal.F.Merriam, and V.Raghavan, Experiments in Materials Science, Tata McGraw-Hill (1972).
5. Standard Test Method for Viscosity by Ford Viscosity Cup, ASTM D1200-10(2018), https://www.astm.org/d1200-10r18.html
6. Lattice dynamics - kit with frequency meter, Manual of Mittal Enterprises, Delhi.
7. Adrian Melissinos and Jim Napolitano, Experiments in Modern Physics, 2nd edition, Academic Press, (2003).
8. Experiments with the Lock-In Amplifier, Kit instruction manual, sponsored by Indian Academy of Sciences, Bangalore.
9. J. M. Khosrofian andB. A. Garetz, "Measurement of a Gaussian laser beam diameter through the direct inversion of knife-edge data," Appl. Opt. 22, 3406–3410 (1983).
10. P. P. Bardapurkar et al., Practical physics, 1st edition, Nirali Prakashan (2019).
11. C. Suryanarayana, M. Grant Norton, X-Ray Diffraction - A Practical Approach, Springer (1998).
12. (Unpublished) MSc. Phy.Project Thesis, SSSIHL 2020, by Vaibhav and Malhar Nagar, "Time Resolved Third Order Nonlinear Optical Susceptibility Measurements Using Femtosecond Degenerate Four Wave Mixing: Automation and Analysis"- for refractive index using lateral shift.

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PPHY-106 Electronics and Microcontroller Lab 3 Cr

Course Objectives:

1. To use electronics & microcontrollers as powerful tools to study the concepts in physics and apply them to automate real-life situations for bringing out smarter devices.
2. The lab course aims to understand the power electronics circuit components and the role they play in designing high-power electrical systems. It provides an exposure to the characteristics of high-power fast-switching IGBTs.
3. It aims at an understanding of the working of popular Atmel make Microcontrollers and to design, and process data by implementing interface technology for IoT.
4. It intends to correlate the theoretical and experimental concepts of various analog & digital electronics circuits with simulation packages, thereby students can get an in-depth understanding of their electrical characteristics.

Course Outcomes:

At the end of the course, the student would be able to:

1. Write microcontroller-based programs to interface different I/O components and systems
2. Understand the principles of sensor technology and interface popular IoT sensors with ATmega 328 Microcontroller
3. Capable of designing smart home automation
4. Provide working experience with the power electronics components that include power diode, transistor, and IGBT
5. Impart computational capability to simulate the electronic circuits and study their performance and limits.
6. Provide basic working knowledge about the common electrical appliances like the MCBs, fluorescent bulbs, motors, etc.

Syllabus:

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.

References:

1. Getting Started with Arduino by Massimo Banzi, 3rd edition, Maker Media, Inc., (2015).
2. Power Electronics by D. A. Bradley, 2nd edition, Springer-Science, (1995).
3. Power Electronics by Daniel W. Hart, McGraw-Hill Companies, Inc., (2017).

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PPHY-107: Self-Development 1 Cr

(Offered by Dept. of Management and Commerce under MBAG-104 SELF-DEVELOPMENT)

(1 credit, 3 hours, Practical)

Course Objectives:

Self Development course is designed as a practical course that aims at application of the concepts and tools of personal excellence. Through various self development exercises, reflections and discussions, the course introduces students to insights, tools, skills and attitudes that empower them. The program is based on traditional Indian schools of knowledge and modern western research in psychology, management and coaching tools. Students would be evaluated on the basis of the students' understanding of the self development concepts, and quality of their effort to improve themselves.

Course Outcomes:

At the end of the course, the students would be able to work on their own self development. They would have a raised sense of self-awareness, self-responsibility and self-accountability for developing themselves, by putting the ideas of personal excellence into practice.

Syllabus:

1. 'Self' development
   Self-responsibility (Locus of Control), Self-Concept / identity, Self-Awareness- SWOT, JOHARI Window, 360 degree appraisal, Self-accountability for Self-development (Structure). Overcoming 'Self-imposed limiting traits'. 6 hrs

2. Self-confidence and Developing a Strong Personality
   Overcoming self consciousness and 'need for approval'. Self-satisfaction Overcoming guilt and shame. Self-acceptance. Integrity. Connect with roots for confidence (parents, nation, society and nature). Self-sacrifice. Authenticity - Unity of thought-word-deed. Self discipline. Authentic humility. Assertiveness. Bhagawan Sri Sathya Sai Baba on Self. 6 hrs

3. Integrity and Gravitas
   Importance of Posture and Body Language. Importance of voice modulation in delivery. 4 hrs

4. Positive Attitude
   Overcoming fears. Healing scars of Past. Overcoming Anger and resentment. Forgiveness. Authentic apology. Persevering with patience through setbacks. 3 Gunas. Mindfulness. Self-discipline and will-power (Habits). Importance of Diet. Meditation. 7 hrs

5. Collaboration and Teamwork
   Real Goal of Communication, Building strong relationships, Shifting from improving others to self, Love, Real listening, Responding to here and now, Transactional analysis, Authentic appreciation, Teamwork for creativity, Being open to Points of views. 9 hrs

6. Finding Happiness and Fulfillment - Positive Psychology
   Happiness-wealth disconnect -Daniel Gilbert. Ceiling on desires and Minimalism. Martin Seligman on Happiness. Sharing and Service (Seva). Designing life for

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Fulfillment – IKIGAI and a Balanced Life Inside-out. A life of Purpose. Gratitude. Bhagawan Baba on Purpose of Life. 7 hrs

Evaluation:

Students would be evaluated on the basis of the students' understanding of the self development concepts, and quality of their effort to improve themselves. Evaluation of students in this course is through in class exercises, seminars and individual assigaments that would track the student's work on various aspects of self development covered in the course. Exercises would include self appraisal (introspection, 360 degree feedback and reflection) on various disciplines, action-plans and evaluating of own progress.

Through Assignments, Essays (Concept clarity, quality of introspection, resolve and implementation), Quality of Class discussion (quality of participation in sharing and introspection).

Course Text:

Notes and reading material shared by the teachers.
Self Development by Prof. R. Kumar Bhaskar

Suggested Readings:

1. Dr. Wayne Dyer- *Your Erroneous Zones: Step-by-Step Advice for Escaping the Trap of Negative Thinking and Taking Control of Your Life.* Publisher: William Morrow Paperbacks (1e, 21 August 2001) ISBN-10: 0060919760, ISBN-13: 978-0060919764.
2. Dr. Martin Seligman - *Authentic Happiness: Using the New Positive Psychology to Realize Your Potential for Lasting Fulfillment*, Publisher: Atria Books; Reprint edition (5 January 2004), ISBN-10: 0743222989, ISBN-13: 978-0743222983.
3. Charles Duhigg - *The Power of Habit: Why We Do What We Do in Life and Business* Paperback – 1e, 7 Jan 2014 Publisher: Random House Trade Paperbacks. ISBN-10: 081298160X, ISBN-13: 978-0812981605.
4. Phyllis Krystal - *Taming Our Monkey Mind: Insight, Detachment, Identity,* Paperback – February 1, 1994, Publisher: Weiser Books, ISBN-10: 0877287937, ISBN-13: 978- 0877287933.
5. HBR's 10 Must Reads - *On Managing Yourself* – 3rd Jan 2011, Publisher: Harvard Business Review Press; 1 edition (January 3, 2011), ISBN-10: 1422157997, ISBN-13: 978-1422157992.
6. Dale Carnegie - *'How to Win Friends and Influence People'* Publisher: RHUK; 2004 edition (1 October 2004), ISBN-10: 0091906350, ISBN-13: 978-0091906351.
7. Dale Carnegie *'How to Stop Worrying and Start Living'* - Publisher: RHUK; edition :1 October 2004), ISBN-10: 9780091906412, ISBN-13: 978-0091906412.
8. Thomas A Harris - *'I'm OK, You're OK'* - Publisher: Arrow (4 May 1995 edition), ISBN- 10: 9780099552413, ISBN-13: 978-0099552413.

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PPHY-201: Nuclear and Particle Physics 3 Cr

Course Objectives:

1. Introduce students to the fundamental concepts of nuclear and sub-nuclear physics.
2. Provide an overview of the development of nuclear and particle physics.
3. To develop students' understanding of the properties of the strong and weak forces.
4. To perform basic calculations using nuclear models to derive the observed stable nuclei.
5. Understand the theory of Beta and Gamma decay and apply it to deduce nuclear structure.
6. Learn the basics of nuclear reactions.

Course Outcomes:

On completion of this course the student will

1. Have a basic understanding of nuclear properties and models that describe the quantum structure, decay, and reactions of nuclei.
2. 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.
3. Be able to apply quark mixing models to analyze weak interaction physics such as beta decay.
4. Be able to read, understand and explain scholarly journal articles in nuclear and particle physics.
5. 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.
   8 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

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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. 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, 2nd edition, Benjamin (1977).

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PPHY-202: Modern Optics 3 Cr

Course Objectives:

1. This course is designed to supplement the basics of Physical optics, which an undergraduate student has learnt in our integrated graduate course.
2. This course will also act as a bridge course for lateral entry students to revisit the fundamentals of geometrical and wave-optics.

Course Outcomes:

On completing this course, each student will be able

1. To understand various fundamental optical phenomena and factors affecting them
2. To understand the theory and analyze the working of various optical instruments that they utilize in different experimental optics and photonics laboratories.
3. To appreciate the light matter interaction and optical properties of technologically important optical materials
4. To choose the best optical technique for enabling a given photonics/spectroscopy/Imaging/communication applications.
5. To suitably modify and optimize the performance of various optical components in advanced experiments

Syllabus:

1. **Optical Phenomena**

a. Coherence: 2 hrs

Concepts of spatial and temporal coherence, coherence time and line width.

b. Interferometry: 5 hrs

i. Multiple beam interference
ii. Fabry-Perot resonator and resolving power
iii. Optical thin film based interference filters

c. Holography: 3 hrs

i. Gabor hologram
ii. Leith-Upatnieks hologram
iii. Application of Holography

d. Diffraction: 6 hrs

i. Fraunhofer diffraction -Diffraction Grating: Grating equation, FSR & Resolution of Grating.
ii. Fresnel Kirchhoff's diffraction integral, Cornu's spiral.

e. Polarization & Scattering: 5 hrs

i. Review of Jones calculus, Cartesian complex plane representation of polarized light; Mueller Matrices; Stokes parameters.
ii. Scattering: Overview of scattering processes; Rayleigh & Rayleigh Wing Scattering; Mie Scattering; Brillouin & Raman Scattering.

f. Optics in Anisotropic Crystals 5 hrs

i. Wave propagation in anisotropic media: indicatrix

ii. Electro-optical modulators; Magneto-optical modulators; Acousto- optic Modulators; liquid crystals & Spatial Light Modulators.

2. Applied Optics

a. Measurement Essentials: 2 hrs

i. Radiometry & Photometry

ii. Conventional sources & detectors of optical radiation

b. Optical Microscopy: 4 hrs

i. Bright field, dark field, phase contrast imaging modalities

ii. Fluorescence & confocal microscopes

c. Optical Spectrometers: 2 hrs

i. Dispersion based optical spectrometers

ii. Fourier Transform Spectrometers

d. Fourier Optics & Optical system design: 6 hrs

i. Concept of spatial frequencies

ii. Fourier transformation with a lens

iii. OTF, MTF and PSF

iv. Analysis and synthesis of optical system design- an overview

e. Adaptive Optics (AO): 2 hrs

i. Examples of imaging with large wavefront aberrations

ii. Zernike polynomials for describing aberrations

iii. Wavefront sensing and wavefront correction using AO techniques

References:

1. E. Hecht., Optics, 4th edition, Pearson Education, (2002).
2. Pedrotti F L and Pedrotti L S., Introduction to Optics, 3rd edition, Prentice Hall (2006).
3. Born, M. and Wolf, E.: Principles of Optics, 6th 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, 2nd 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 (1996).
7. P. Hariharan, Basics of Holography, Cambridge University Press, (2002).
8. B.E.A. Saleh and M.C. Teich, Fundamentals of Photonics, 2nd edition, Wiley Series in Pure and Applied Optics, (2007).

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PPHY-203: Quantum Mechanics – II 3 Cr

Course Objectives:

This course is a continuation of PPHY-103 (Quantum Mechanics - I).

1. Deals with more complex / composite systems, time dependent perturbed systems and scattering formalism.
2. The fundamental issue of objective reality in quantum mechanics is brought out through the Einstein-Podolsky-Rosen paradox.
3. To Learn modern developments leading to new devices and new technologies as applications of quantum mechanics.
4. Give the basics of Relativistic quantum mechanics.

Course Outcomes:

After completing the course, the student will:

1. Learn how angular momenta are combined and how the state of the compound system depends on the states of the component systems.
2. Learn how identical particles are to be described consistent with the Pauli exclusion principle.
3. Know how an atom interacts with electromagnetic radiation.
4. 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.
5. 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. 6 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:** Quantum information processing, Quantum bits—Qubits, Quantum gates, Quantum teleportation, Quantum entanglement.
4 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: Statistical Mechanics 4 Cr

Course Objectives: This course introduces students to the fundamental principles of equilibrium statistical mechanics. The focus is on developing a formalism to derive macroscopic properties of various physical systems. The course aims.

1. To provide an introduction to the microscopic formulation of thermal physics by exploring the general principles of the statistical interpretation of entropy and the ensemble formalism.
2. To explain the basic principles of equilibrium statistical mechanics.
3. To apply the principles of equilibrium statistical mechanics to derive macroscopic properties of various physical systems.

Course Outcomes:
On completion of this course the student will

1. Understand the connection between thermodynamics and statistical mechanics through the concepts of microstates and macrostates.
2. Understand the ensemble formalism and different types of ensembles.
3. Apply Boltzmann distribution to study magnetic systems.
4. Apply the Bose-Einstein distribution to thermal properties of solids, blackbody radiation.
5. Apply the Fermi-Dirac distribution to study electrical properties of metals.
6. Understand quantum statistics and derive the macroscopic properties of ideal Fermi and Bose gases.

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 systems 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. 6 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 a 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, Walter, Neise, Ludwig, Stöcker, Horst, Thermodynamics and Statistical Mechanics, Springer Verlag (1995).
2. Pathria, R.K., Paul D Beale, Statistical Mechanics, 3rd edition, Academic Press, (2011).
3. Gupta, M.C., Statistical Thermodynamics, Wiley Eastern (1990).
4. Huang, K., Statistical Mechanics, 2nd edition, John Wiley (1987).
5. Reif, F., Statistical Physics, Berkeley Physics Course, Vol. 5, McGraw Hill (1967).
6. Reif, F., Fundamentals of Statistical and Thermal Physics, McGraw Hill, (1965).
7. Robert H. Swendsen, An Introduction to Statistical Mechanics and Thermodynamics, 2nd edition, Oxford University Press, (2019).
8. S. J. Blundell, K. M. Blundell, Concepts in Thermal Physics, 2nd edition, Oxford University Press, (2009).
9. Franz Mandl, Statistical Physics, 2nd edition, Wiley (1988).
10. Ralph Baierlein, Thermal Physics, Cambridge University Press (2012).

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PPHY-205 Experimental Methods in Physics – II 3 Cr

Course Objectives:

1. The main aim of this course is to introduce students to various experiments in physics discipline, while concomitantly imparting essential experimental skills and inducing curiosity for designing new experiments.
2. In this lab, the scope of the experiments performed is restricted to topics in Solid State Physics, Nuclear Physics, Material Science, and Applied Optics & Photonics.
3. These experiments will supplement the theory courses that run parallel enabling them to enhance their learning.

Course Outcomes:

1. *Solid State Physics Experiments*: The student will be able to investigate electrical, magnetic and thermal behavior of materials.
2. *Materials Science:* Complementing the solid state physics experiments, these fundamental experiments are essential for the student to familiarize with structural characterization of various materials.
3. *Nuclear Physics Experiments:* The planned experiments are designed to expose students to nuclear spectroscopic techniques which involve usage of radiation detectors like scintillation and semiconductor detectors for studying gamma radiation; integrating multichannel spectrum analyzer with the gamma spectrometers to probe the nuclear structure of radioactive nuclei; safe handling of radio-isotopes and sensitive radiation detectors.
4. *Applied Optics & Photonics Experiments:* Students are exposed to experiments which comprehend the concepts of optical phenomena such as Interference, Diffraction, Polarization, Physics of Optical Materials while Photonics experiments include familiarizing with applications & testing of Optical modulators and Opto-electronic components that are essential in modern optical communications.
5. *Hard skill set:* Student after going through this course will gain knowledge of different experimental components: their functioning principles and usage; Ways of setting up experiment/alignment methods for obtaining better results; Rigorous Experimental data analysis which includes Error Analysis, Linear and Nonlinear Curve Fitting & modelling of experimental data using standard numerical and analytical methods.

Syllabus:

Section A

1. Energy resolution of a Scintillation detector
2. Energy linearity calibration and finding the unknown isotope
3. Determination of internal conversion coefficient using XPG method
4. Obtaining Gamma spectra using HPGe detector
5. XCOM calculations
6. Familiarization with NIM modules

Section B

7. Study of dielectric properties of standard samples using impedance analyser/LCR meter
8. Determining the PE loop of a ferroelectric sample
9. Determination of d_{33} coefficient of a piezoelectric material
10. Study of hysteresis of a ferromagnetic material
11. Materials synthesis: synthesis of metallic nanostructure/quantum dots/ bulk ceramics

Section C

12. Production and analysis of all components of polarized light using Stokes parameters
13. Verification of a photodetector performance in photovoltaic & photoconductive mode with the aid of an optical chopper and modulated laser diode
14. Building a dispersive fluorescence spectrometer using a diffraction grating and validating it
15. Demonstrating Kerr effect (electro - optic effect) and measuring half-wave voltage
16. Fourier optics- building 4f system for spatial filtering
17. Optical microscopy - familiarization with different imaging modalities
18. Demonstrating Faraday rotation (Magneto – optic effect) - Verdet Constant

References:

1. Experiments with Multi Channel Analyser System / Experiments with Gamma ray spectrometer, edited by J. Narender Reddy and M.S.R. Murthy, Published by Nucleonix systems Pvt. Ltd., www.nucleonix.com
2. Glenn F. Knoll, Radiation Detection and Measurement, 2nd edition, John Wiley & Sons, New York, (1989).
3. AN34 - ORTEC lab manual, www.ortec-online.com
4. XCOM Database, NIST National Institute of Standards and Technology, http://physics.nist.gov.
5. ENDF Database, Experimental Nuclear Reaction Data, IAEA, http://www-nds.iaea.org/
6. RADlab -- Virtual Radiation Detection Experiment Open Source Software, Dagistan Sahin, http://radlab.sourceforge.net/pages/experiments.htm
7. Techniques for Nuclear and Particle Physics Experiments - A how-to Approach, by William R. Leo, Springer-Verlag, (1987).
8. Impedance Measurement Handbook - A guide to measurement technology and techniques, 4th edition, Agilent technologies.
9. Kenji Uchino, Advanced Piezoelectric Materials: Science and Technology, Woodhead Publishing (2017).
10. Decoding the Fingerprint of Ferroelectric Loops: Comprehension of the Material Properties and Structures, J. Am. Ceram. Soc., 97 [1] 1–27, DOI: 10.1111/jace.12773, (2014).
11. IEEE standards on Piezoelectricity, IEEE society documents on industrial and measurement standards, DOI-https://doi.org/10.1109/IEEESTD.1988.79638 (1988).

12. Experimental manual for BH curve setup customized for teaching and demonstration, Marine India vendor specific operation manual.
13. (a) Nano The Essentials, By T Pradeep, 7McGraw-Hill Education (India) Pvt Limited(2007); (b) Introduction to Nanoscience By Stuart Lindsay, Oxford University Press (2009); (c)Introduction to Nanoscience and Nanotechnology: A Workbook By M. Kuno, Paperback edition, CreateSpace Independent Publishing Platform (2014)
14. Methods in Experimental Physics by K. Lark-Horovitz and Vivian A. Johnson (Eds.) - Solid State Physics - Electrical, Magnetic, and Optical Properties-Academic Press, Elsevier (1959).
15. Experiments in Materials Science, E.C. Subbarao, L.K.Singhal, D.Chkravorty, Marshal. F. Merriam, and V. Raghavan, Tata McGraw-Hill, (1972).
16. Measuring the Stokes polarization parameters, Beth Schaefer, Edward Collett, Robert Smyth, et al. Citation: American Journal of Physics 75, 163 (2007); doi: 10.1119/1.2386162
17. Photodiode Characteristics -UDT pin10D detectors, Source-https://qtwork.tudelft.nl/~schouten/linkload/phdiode.pdf
18. Joseph R. Lakowicz, Principles of fluorescence spectroscopy, 3rd edition, https://doi.org/10.1007/978-0-387-46312-4, Springer-Verlag US (2006).
19. Bahaa E. A. Saleh, Malvin Carl Teich, Fundamentals of Photonics, Wiley-Interscience Publishers, 2nd edition (2007).
20. Joseph W. Goodman, Introduction to Fourier Optics, W. H. Freeman Publisher (2017).
21. Light & Optical Microscopy, virtual labs and simulations for various optical parameters from Nikon Microscopy website: https://www.microscopyu.com/

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PPHY-206 Software Lab 3 Cr

Course Objectives:

After a two-semester course on coding skills in Python, and a theoretical course on computational methods at the undergraduate level, this course aims to further develop coding skills that are specifically useful in scientific research, data mining & analytics, and also provide hands-on experience on a specific software package that is useful either for doing photonics, material science or nuclear physics.

Course Outcomes:

At the end of this course students should be able to

1. Analyze / interpret /visualize / & predict data by using linear / nonlinear regression.
2. Analyze / interpret /visualize / & predict data using Fourier techniques, Lock-in detection, eigen value / singular value decomposition, data mining and simple neural networks.
3. Write GUI based programs in Scilab.
4. Solve time dependent differential equations describing selected physical problems.
5. Get basic hands-on experience in one out of the choice of available software packages for photonics / material Science / nuclear Physics like COMSOL / OptiFDTD / Geant4 /MD or any other similar packages.

Syllabus:

Section A (8-10 weeks) (60% weightage)

1. Nonlinear regression using steepest descent, Newton-Gauss and Lavenberg-Marquardt Algorithms and application to real world data.
2. Two layer neural network using sigmoid function and its application to prediction.
3. Fourier transform for Low-Pass, High-Pass, Band-Pass filtering applied to 1D or 2D data.
4. Application of singular and eigen value decomposition (image compression or other).
5. Data mining & visualization skills using Scilab.
6. GUI programming in SCILAB.
7. Solving the 2D-time dependent Schrodinger equation (circular potential well) / 3D-Heat diffusion (spherical boundary).

Section B (about 4-6 weeks) (40% weightage)

1. Familiarization with Programming, using any one of the selected software packages.
2. Application of the same to one domain specific problem.

References:

1. Steven C. Chapra and Raymond P. Canale, Numerical Methods for Engineers, McGraw-Hill Education (2015).
2. Tao Pang, An Introduction to Computational Physics, Cambridge University Press, (2006).
3. Computational Physics Course by Richard Fitzpatrick at University of Texas, Austin. https://farside.ph.utexas.edu/teaching/329/329.html

PPHY-301 Advanced Spectroscopy 4 Cr

Course Objectives:

1. Spectroscopy is an indispensable tool for a physicist to validate their scientific models and theory. After learning various Modern Physics topics at the undergraduate level and other core physics papers at the Master's level, this advanced spectroscopy course is designed with the objective of learning the theoretical details and applications of a wide range of spectroscopic techniques.
2. The course aims to impart essential knowledge of characterization at the atomic, molecular, and elemental levels through familiarization of various spectroscopic tools.
3. Cumulatively, the student could be able to appreciate the complete theoretical framework of all factors contributing to individual spectroscopy technique and their related applications.

Course Outcomes:

On completing this course the students will

1. be able to understand the fundamental formulations of observed atomic and molecular phenomena.
2. be able to understand the experimental design of each of the spectroscopic technique.
3. be able to appreciate various Atomic spectroscopy techniques
4. be able to understand and analyze the Zeeman and Stark effects arising from contribution from spin of the electrons in the context of Atomic spectroscopy and their unique applications.
5. be able to derive the Atomic spectroscopic terms for any given electronic configuration
6. be able to learn about selection rules governing various electronic transitions
7. be able to employ advanced X-ray spectroscopy techniques and their industrial applications.
8. be able to appreciate various aspects of Molecular spectroscopy techniques
9. be able to differentiate the rotational and vibrational spectroscopic transitions in various molecules
10. be able to learn about selection rules governing various energy transitions
11. be able to learn about very useful nature of molecular spectroscopic techniques that are applied across many industrial (Non-destructive), space research & biomedical domains.
12. be able to appreciate Magnetic Resonance phenomenon, and its application as NMR spectroscopy for Molecular structure elucidation and also understand proton NMR which the basis for MRI scans in biomedical imaging.
13. Over all, each student can gain insights on Analytical applications of each of the spectroscopic tool and integrate them /complementing them effectively for atomic and molecular fingerprinting or detection.

Syllabus:

1. **Atomic Spectroscopy:** 8 hrs
   a. Electronic configuration, vector coupling of angular momenta. Russell- Saunders and J-J coupling;
   b. Atomic term symbols; Hund's rule for ground state determination for Multi-electron atomic system (ex: Alkali atoms);

c. Interaction in external fields

i. Zeeman effect (ZE): Normal ZE, Anomalous & Paschen-Bach ZE; Observation of ZE modes.

ii. Stark Effect & its applications.

2. **Magnetic Resonance Spectroscopy:** 8 hrs

a. Nuclear Magnetic Resonance (NMR):

i. Nuclear magneton; Larmor precession; Boltzmann distribution in NMR; NMR spectrometer

ii. NMR- Bloch equations; Mechanisms of spin-lattice and spin-spin relaxations;

iii. Application of NMR spectroscopy: Chemical shift in NMR spectroscopy; Magnetic Resonance Imaging.

b. Electron Spin resonance (ESR):

i. Principle of ESR, Hyperfine structure, ESR spectrometer

ii. ESR spectrum of hydrogen atom.

3. **X-Ray Spectroscopy** 4 hrs

a. X-Ray Photoelectron Spectroscopy (XPS): XPS Spectrometer, Applications to Materials Characterization.

b. X-Ray Fluorescence spectroscopy (XRF); Types of XRF spectrometers and XRF for Elemental Analysis

4. **Molecular Spectroscopy**

a. Rotational/Microwave spectroscopy: 6 hrs

Rigid rotator model; non-rigid rotator model for diatomic molecules; polyatomic molecules: linear molecules, symmetric rotor, spherical rotator and asymmetric rotor molecules; Stark effect in diatomic, linear and symmetric rotor molecules; Microwave spectroscopy Spectrometer; Microwave spectroscopy Application.

b. Vibrational Spectroscopy: 18 hrs

i. **Infrared Spectroscopy:** IR spectrometer-instrumentation; Harmonic and anharmonic oscillator models for diatomic molecules & selection rules-fundamental, harmonics/overtones & hot bands; diatomic vibrating rotator – selection rules; vibrations of polyatomic molecules & their normal modes of vibrations.

ii. Vibration–rotation spectroscopy of different molecules; selection rules.

iii. **Raman spectroscopy:** Raman spectrometer –instrumentation; Raman spectroscopy of (i) diatomic molecules; (ii) polyatomic molecules;

iv. Rotational Raman spectroscopy- symmetric and asymmetric rotor; selection rules.

5. **Electronic Spectroscopy:** 12 hrs

a. **Vibrational & Rotational coarse structure of electronic bands:** Born-Oppenheimer Approximation; Deslanders tables and dissociation energies;

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Franck - Condon Principle - intensity of vibrational electronic spectra; Rotational structure of electronic bands;

b. **Fluorescence spectroscopy**: Jablonski diagram of representation; Case study of origin of Fluorescence spectrum of rare–earth ions and their photonic & optoelectronic applications based on their photo-physical property.

References:

1. J. Micheal Hollas, Modern Spectroscopy, 4th edition, John Wiley & Sons, Ltd. (2004).
2. Herzberg, G: Molecular spectra and Molecular Structure: Vol. 1, 2nd edition, Van Nostrand (1950).
3. Rita Kakkar, Atomic and Molecular Spectroscopy, Cambridge University Press (2017).
4. Peter Atkins & Ronald S. Friedman, Molecular Quantum Mechanics, Oxford University Press, USA (2010).
5. Bernath, P. F. Spectra of Atoms and Molecules, 3rd edition, Oxford University Press, (2016).
6. Aruldhas, Molecular Structure and Spectroscopy, 2nd edition, PHI, India (2007).
7. J. R. Lakowicz, Principles of Fluorescence Spectroscopy, 3rd edition, Kluwer Academic (2006).

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PPHY-302 Solid State Physics 4 Cr

Course Objectives:

1. Introducing the physics of solids,
2. Imparting knowledge of microscopic structure of solids and structural interpretation,
3. Infer interaction of atoms in solids by studying lattice vibrations and phonons,
4. Interpret electrical, thermal, optical, and magnetic behaviour of solids by studying the electronic structure in solids: metals, semiconductors and insulators.

Course Outcomes:

On completion of this course the students will

1. Understand the shortcomings of the classical picture in predicting the properties of metals.
2. Learn the quantum picture of solids: electrons in a periodic potential, and formation of energy bands using fundamental quantum mechanical models by applying perturbation theory.
3. Be able to infer electron motion in bands and understand the concept of holes.
4. Be able to understand the true physical (electrical, thermal, optical and magnetic) behaviour of solids, after learning the energy band structure of solids.

Syllabus:

1. **Crystal Structure and Reciprocal Lattice: Review** 5 hrs
   Lattices, crystal structures, diffraction of waves by crystals, reciprocal lattice, diffraction condition, Brillouin zones, structure factor of lattice and atomic form factor.
2. **Lattice dynamics: Phonons** 7 hrs
   Diatomic linear chain, density of states, thermal energy of harmonic oscillator, specific heat capacity, anharmonicity, heat conduction by phonons.
3. **Free electron theory of metals** 8 hrs
   Drude model: dc and ac conductivity, thermal conductivity, Hall Effect and magnetoresistance.
   Sommerfeld model: Free electron gas in an infinite square well potential, Fermi gas at T= 0K, Fermi-Dirac distribution at different temperatures, specific heat capacity of electrons, thermionic and field emission.
4. **Band theory of solids** 12 hrs
   Bloch theorem, Kronig-Penney model, nearly free-electron model-zone schemes, tight-binding model-sc, bcc, and fcc, density of states.
5. **Electron Dynamics** 5 hrs
   Motion of electrons in bands, effective mass, currents in bands and holes.
6. **Optical properties** 7 hrs
   Dipole oscillator model, Kramers-Kronig relations, interband absorption: interband transitions, transition rate for direct absorption, band edge absorption in direct gap and indirect gap semiconductors, excitons, free excitons in external electric and magnetic field.

7. **Magnetism and superconductivity** 12 hrs

Diamagnetism and Paramagnetism, exchange interactions, exchange interaction between free electrons, band model of ferromagnetism and temperature behaviour, ferromagnetic coupling, superconductivity, London equations, Josephson junctions.

References:

1. Harald Ibach and Hans Luth, Solid State Physics, 4th edition, Springer (2009).
2. C. Kittel, Introduction to Solid State Physics, 8th edition, Wiley (2004).
3. N. W. Ashcroft and N. D. Mermin, Solid State Physics, Saunders (1976).
4. Mark Fox, Optical Properties of Solids, Oxford (2001).
5. A.J. Dekker, Solid State Physics, Macmillan (1969).

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PPHY-305 Advanced Physics Lab 3 Cr

Course Objectives:

This laboratory course is aimed at training the graduate students performing and familiarizing with experimental techniques which are related to advanced research domains pertaining to various physics sub-disciplines like Photonics, Materials Science (including Nanoscience), Materials Characterization, Molecular & Atomic Spectroscopy, Nonlinear Optics and Fiber optics technologies.

Course Outcomes:

The students based on the core and elective papers opted in their course work will perform a total of NINE experiments from the cohort of listed experiments.

1. *Materials Characterization Techniques*: The student while undertaking Materials Characterization Technique experiments like Electron Microscopy (Scanning & Transmission Electron Microscopy), Scanning Tunneling Microscopy, will attempt to learn the fundamentals physics principles employed in its construction and application for investigating functional and structural materials.
2. *Molecular & Atomic Spectroscopy methods:* Spectroscopy experiments involving molecular fingerprinting techniques like Raman spectroscopy or FT-IR will enable students to understand molecular vibrations in organic molecules predominantly. Extending to nanostructures, they could also appreciate the role of size dependency on vibrational modes. Further, electron spin resonance and X-Ray fluorescence spectroscopy technique will aid them to understand advanced spectroscopy techniques in identification of elemental and molecular moieties.

3. *Linear & Nonlinear Optical Spectroscopy:* Exposure to optical detection techniques widely adapted in industry like Absorption spectroscopy and Light scattering technique will enhance student's skill set. Further, learning intense light (Laser) matter interactions and their applications like Second Harmonic Generation that are widely used in Photonics industry will be beneficial for students.

4. *Photonics & Fiber Optics Technology*: Experiments engineered for understanding & applying optical interferometry techniques like optical coherence tomography, optical vibrometry and a gamut of fiber optics based optical wave guiding complements students to realize know-hows of optical technologies.

5. *Experimental Automation and Interfacing*: Students are encouraged to handle & integrate advanced equipment to design their in-house experiments for attaining higher sensitivity and for critical measurement that are manually impossible. This is achieved by training them in using robust automation software platforms. This promotes their creativity in building efficient experimental setups.

6. *Physics Simulations:* Beyond computational physics techniques, students embark on learning additional simulations rendered to appreciate nanoscale physics to test theoretical models and property predictions.

Syllabus:

1. **Spectroscopy A: Raman Spectroscopy**- Vibrational modes of Perovskite/CNT/Graphene/Organic Molecules in ambient/non-ambient conditions
2. **Spectroscopy B: FTIR**- Molecular finger-printing based characterization of Polymer/Organic molecules
3. **Spectroscopy C: XRF** –Instrumentation & Elemental Analysis of functional materials
4. **Spectroscopy D: ESR**- Demonstration of Electron Spin Resonance
5. **Materials Characterization A:** Familiarization with Electron microscopy techniques – SEM and TEM along with Simulators training
6. **Materials Characterization B:** Optical properties measurements (n, k determination) of thin films fabricated by RF/DC sputtering (deposition) technique
7. **Materials Characterization C:** Photovoltaics-Demonstrating working of a Solar Simulator
8. **Materials Characterization D:** STM- Scanning Tunnelling Microscopy for Demonstration of Quantum Tunnelling effect and obtaining Atomic resolution image of HOPG
9. **Optical Characterization A:** Dynamic Light Scattering for particle size determination
10. **Optical Characterization B:** Determination of SPR peak for Nanoparticle using UV-Visible spectroscopy
11. **Fiber Optics A:** Launching light in a SMF and MMF and Numerical aperture measurements.
12. **Fiber Optics B:** Measuring parameters of a 2x2 single mode optical fiber coupler
13. **Fiber Optics C:** Demonstration and measurement of the laser output parameters of a mode locked / CW / Q-switched fiber laser
14. **Fourier Domain Optical Coherence Tomography A:** Measurement and visualisation of 3D sample features
15. **Fourier Domain Optical Coherence Tomography B:** J_0 Null technique for vibrometry
16. **Nonlinear Optics: (Femtosecond Four Wave Mixing)** –Box car geometry for measurement of third order nonlinear susceptibility
17. **Automation Training:** Using LabVIEW or any equivalent software platform for automating experiments and interfacing
18. **Nanoscale Physics Simulation** for predicting Materials properties at the nanoscale.

References:

1. Ewen Smith, Geoffrey Dent, Modern Raman Spectroscopy, A Practical Approach, Wiley Publishers (2013); Characterizing Carbon Materials with Raman Spectroscopy - Application Notes- 51901 from ThermoDXR microscope on Handbook of Vibrational Spectroscopy,Wiley Publishers, DOI: 10.1002/0470027320 (2006).

2. Douglas Skoog, F. Holler, Stanley Crouch, Principles of Instrumental Analysis, 7th edition, Brooks-Cole Publishers, (2017).
3. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, 2nd Edition, Yang Leng, Wiley-VCH publishers (2013).
4. Molecular Structure and Spectroscopy, by G. Arulhas, PHI Learning Publisher (2007).
5. The materials science of thin films, by Milton Ohring, Academic Press (1992).
6. Online tutorial in AMMRF- Myscope portal Virtual Labs offered by Microscopy Australia.
7. Ajoy Ghatak, K. Thyagarajan, An Introduction to Fiber Optics, Cambridge University Press (1998).
8. A.K. Ghatak & M.R. Shenoy, Fiber Optics through Experiments , World Scientific Publishing Co Pte Ltd (1997).
9. Robert Boyd, Nonlinear Optics, Academic Press (2008).
10. https://notionpress.com/read/optical-coherence-tomography-for-everyone/paperback
11. H. Nandakumar, S.P. Mallick, S. Srivastava, "Sensing high frequency sub-nanometer vibrations using optical coherence tomography with real-time profilometry of multiple inner layers", Optics and Lasers in Engineering,127, 105992, (2020) Elsevier https://doi.org/10.1016/j.optlaseng.2019.105992.
12. Thesis "Developments and applications of four wave mixing spectroscopies in the picosecond and femtosecond time regimes", by Gumy Jeane Claude, Institut de Chimie Physique, de l'Université de Fribourg (Suisse) (2000) https://doc.rero.ch/record/3680/files/GumyJC.pdf

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Elective Courses

(PPHY-303/304/401/402/403) 3 Cr

The following electives are offered either in the III or the IV semester of the M.Sc. Physics programme.

All elective courses are 3 credits.

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:

1. Students will understand basic light-matter interaction
2. Know the characteristics of atomic transitions and line broadening mechanisms
3. Recognize the necessary and sufficient conditions for laser operation
4. Understand basic laser beam characteristics and its relation to cavity parameters
5. Differentiate between steady-state and transient operations
6. Calculate threshold requirements.
7. Know the 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. 6 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. 8 hrs

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

References:

1. Verdeyen, J.T.: Laser Electronics, 3rd edition, Prentice Hall, (1995).
2. Svelto O.: Principles of Lasers, 5th edition, Springer, (2010).
3. William Silfvast, Laser Fundamentals, Cambridge press, (2004).
4. A. 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 Magnetism and Superconductivity

Course Objectives: This course applies the principles of quantum mechanics, electromagnetism and statistical mechanics to understand the physics of solids.

The course aims:

1. To explain the fundamentals of magnetic and superconducting properties of solids.
2. To develop various theoretical models used to understand these properties.

Course Outcomes:

1. Understand that magnetism and superconductivity are purely quantum mechanical phenomena.
2. Understand the theories of various types of magnetic order.
3. Understand different properties of superconductors.
4. Apply Landau's theory of phase transition to understand ferromagnetism and superconductivity.
5. Be familiar with high temperature superconductors.
6. Be familiar with novel applications of magnetic materials and superconductors.

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. 10 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. 8 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:** discovery and phenomena, critical temperature, persistent currents, thermoelectric properties, magnetic properties, Type-I, Type-II superconductors, specific heat, London equations, qualitative features of microscopic BCS theory. 8 hrs

5. **Superconducting Devices:** Quantum interference, Josephson effect, superconducting junctions, SQUID and its applications, qubits and quantum chips. 6 hrs

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. Stephen Blundell, Magnetism in Condensed Matter, Oxford University Press, (2001).
4. James F. Annett, Superconductivity, Superfluids and Condensates, Oxford University Press, (2004).
5. Eoin O'Reilly, Quantum Theory of Solids, CRC Press (2002).

EL -3: Semiconductor Device Physics

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

1. Fermi Levels in a semiconductor
2. Current carrying mechanisms
3. Concept of holes
4. PN junction formation
5. Diode equations and I-V characteristics
6. Junction capacitances and junction breakdown
7. Transistor current equations and ambipolar transports
8. MOSFETs and their uses
9. 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. 9 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. 9 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: Solar cells; pn junction solar cell, conversion efficiency; photo-detectors: PIN and Avalanche photodiode 4 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, 3rd edition, Tata McGraw Hill, (2003).
4. Sedra A. S. and Smith K. C., Microelectronic Circuits, 8th edition, Oxford University Press (2019).
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).

EL-4: 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 various methods to synthesize materials.

Course Outcomes:
The learning outcomes of this course are

1. Understanding materials and their different classifications
2. Knowledge of crystal structure and symmetries: point groups and space groups.
3. Represent symmetry equivalent points of different point groups using stereograms
4. Understand symmetry-property correlations
5. Learn different methods to synthesize materials at different length scales: soft chemistry routes and physical methods
6. Understand the advantageous and uniqueness of different synthesis methods
7. Learning different types of defects in materials and their role 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-5: 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:

1. Students can interpret nuclear rotational and vibrational spectra in the context of the collective model
2. will be able to calculate quadrupole moments and predict ground state properties (spin and parity) of nuclei
3. 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. 9 hrs

2. **Nuclear Models:** Introduction; single particle orbits; extreme single particle model and spin; single particle model; configuration mixing. 6 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 and Instrumentation:** 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; Compton suppression systems; BGOs, Crystal balls; multiplicity detectors; Gamma detection array; Multi Channel analyzers; CAMAC systems; electron transporters. 10 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, 2nd 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-6: 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:

1. Knowledge of the physics behind the light guiding mechanism and physical characteristics of light propagation in optical fibers
2. Understand different mechanisms that cause signal attenuation and dispersion in different types of optical fibers: their minimizing criteria
3. Understanding guided modes in fibers and obtain allowed modes that can propagate in an optical fiber
4. Knowledge of special fibers and their unique applications
5. Ability to explain the working principle of fiber optic coupler and its usage in fiber optic sensors.
6. Understand fiber optic based sensors and their principles
7. Fiber lasers principles and methods to create intense pulsed fiber lasers

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. 4 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. 7 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. 4 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. 8 hrs

References:

1. Ghatak, A. and Thyagarajan, K.: Introduction to Fiber Optics, 3rd edition, Cambridge University Press (2007).
2. R. Kahsyap, Fiber Bragg Gratings, 2nd edition, Academic Press, Amsterdam, (2010).
3. Culshaw B., Optical Fiber Sensors, Academic Press (2000).
4. Agarwal G. P., Applications of Nonlinear Fiber optics, 2nd edition, Academic Press, (2008).
5. Keiser, Gerd: Optical Fiber Communications, 3rd edition, McGraw Hill (2000).

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EL-7: Functional Ceramics and Devices

Course Objectives:

1. This course is designed to provide a detailed understanding of ceramic materials and their applications in devices.
2. This will aid the students to undertake developing and designing sensor using various interesting features of functional materials of technological and strategic importance.

Course Outcomes:

At the end of this course, students will

1. Have a thorough overview of salient features of various functional ceramic materials
2. Be able to understand both micro and macro level of functional properties like Piezoelectricity, Ferroelectricity, Pyroelectricity
3. Acquire knowledge of how to choose ceramic materials for specific applications like
   a. Communication technology
   b. Information technology & Data storage
   c. Biomedical and sensing applications
   d. Be able to appreciate the microstructural and physical properties of various functional materials, thereby leading to deriving their critical important structure-property correlation
   e. To optimize structure-property correlation for enhance device operation built using these functional materials.

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).

EL-8: Nuclear Reactions

Course Objectives:

Provide an advanced knowledge and the theory of different varieties of nuclear reactions.

Course Outcomes:

1. Understand the properties of N-N scattering,
2. Know the basic properties of alpha, beta, and gamma emission from nuclei,
3. Determine the spectra and spin and parities of daughter nuclei in alpha, beta, and gamma emission,
4. Understand the 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., 2nd edition, (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-9: Photovoltaics for Energy Conversion

Course Objectives:

1. Gain a fundamental understanding of solar cell physics
2. Understand basic solar cell operation, design and limitations
3. Understand the physical concepts and operation of advanced photovoltaics
4. Gain appreciation of competing solar cell technologies and their applications

Course Outcomes:

1. Student will know some general facts on energy and the current status of PV in the world
2. Explain the basic working of solar cells
3. Elaborate on generation and recombination mechanisms, and introduce different types of semiconductor junctions
4. Determine the most important parameters for characterizing solar cells, the efficiency limits of photovoltaic devices, some general design rules.
5. Gain knowledge of different PV technologies, crystalline silicon technology, different thin-film technologies, few 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

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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" (2014).
3. Jenny Nelson, The Physics of Solar Cells, Imperial College Press, (2003).

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EL-10: Ultrafast Nonlinear Optics

Course Objectives:
This course provides fundamental understanding and working knowledge of various aspects of 2^{nd} and 3^{rd} order nonlinear optical processes. The course also aims to provide insight into various modern applications of ultrafast nonlinear optics including effects of dispersion and nonlinearity on ultrashort pulse propagation and the methods to characterize ultrashort pulses.

Course Outcomes: At the end of this course, the students should be able to do the following:

1. Understand second / third order nonlinear susceptibility tensors and their properties
2. Be able to understand analyze and calculate details for setting up a Type1&Type11 phase matched SHG experiment for any uniaxial crystal, with known Sellemier coefficients, including the effect of crystal dispersion & thickness on the output pulse.
3. Be able to understand and analyze four-wave mixing (FWM) experiments including optical phase conjugation
4. Use results of FWM and Z-scan to calculate 3^{rd} order susceptibilities of materials.
5. Be able to calculate details for setting up a SHG autocorrelation, FROG and SPIDER device
6. Be able to 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.
7. Gain knowledge of various processes that affect ultrashort pulse propagation in nonlinear media including dispersion, SPM, XPM, delayed Raman, Self-steepening, FWM, diffraction, self-focusing, and Soliton formation.

Syllabus:

1. Introduction: Description of Nonlinear interactions and overview of various 2^{nd} and 3^{rd} order nonlinear effects, Classical anharmonic oscillator model, Nonlinear optical susceptibility tensor, Properties of nonlinear susceptibility

6 hrs

2. 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, Quasi phase matching.

8 hrs

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

8hrs

4. Ultra short pulse propagation equation and interpretation in terms of effect of Self Phase Modulaton, Dispersion, Solitons, Self-Steepening, and Delayed Raman response, Numerical Solution using Split Step Fourier Technique. Time resolved ultrafast nonlinear pump-probe spectroscopy.

6 hrs

5. Dispersion and Dispersion Compensation: Temporal Dispersion Based on Angular Dispersion; Dispersion of Grating Pairs; Dispersion of Prism Pairs; dispersive Properties of Lenses

7 hrs

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

7 hrs

References:

1. Robert Boyd, Nonlinear Optics, 4th edition, Academic Press (2020).
2. Andrew Weiner, Ultrafast Optics, 1st edition, Wiley Series in Pure and Applied Optics, (2009).
3. Geoffrey New, Introduction to Nonlinear Optics, Cambridge University Press, 2nd edition (2011).

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EL-11: 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 know

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

Syllabus:

1. Accelerator Physics:

Ion Sources: Production of charged particles, space charge limitation; extraction & focusing geometries, positive and negative ion sources, radio frequency sources, penning ionization source, Duoplasmatron, sputter ion source, ECR source (room temperature and superconducting). 4 hrs

Accelerators & their Applications: Principle of tandem accelerator, Pelletron accelerator; Pulsed accelerators - cyclotron, synchrotron; Radio frequency linear accelerators; Superconducting linac, Radio frequency quadrupole; Drift tube linac; Storage rings; 8 hrs

Trace element analysis: RBS - measurement of elemental ratios & concentrations, channeling RBS, Nuclear Reaction Analysis (NRA), Particle Induced X-ray emission (PIXE) studies, Medical applications of accelerators. 4 hrs

Beam Optics and Beam Transport: Motion of charged particles in electric and magnetic fields; Phase space - longitudinal and transverse, and Liouville's theorem, Focusing devices: Einzel lens, solenoid magnet, quadrupole; magnetic and electric sector fields; Matrix method, Aberrations, Design of a beam line for beam transport; 4 hrs

2. Reactor Physics

Reactors 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. 4 hrs

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. 8 hrs

Reactor Safety and Safeguards: Assessment of reactor accident risk; Regulatory process; Nuclear safeguards: Domestic and International; Waste disposal problems. 3 hrs

3. **Detectors & Transducers:**
   Review of gas filled counters, scintillation detectors and semiconductor detectors; multi-wire proportional counter; channel electron multipliers and micro-channel plates; position sensitive detectors, magnetic spectrometers; particle identification techniques & time of flight; neutron detectors for fast and slow neutron; 7 hrs

References:

1. Wiedemann H, Particle Accelerator Physics I, Springer, (1999).
2. Stanley H, Principles of Charged Particle Acceleration, John Wiley & Sons, (1986).
3. Klaus Wille, J. McFall, The Physics of Particle Accelerators: An Introduction, Clarendon Press (2001).
4. W. R Leo, Techniques for Nuclear and Particle Physics experiments, Springer – Verlag, (1994).
5. Glenn F. Knoll, Radiation Detection and Measurement, 4th edition, Wiley (2010).
6. S. S. Kapoor and V. S. Ramamurthy, Nuclear Radiation Detectors, New Age International (P) Ltd (2014).
7. John R. Lamarsh, Anthony J. Baratta, Introduction to Nuclear Engineering, 3rd edition, Pearson (2014).
8. Lewis E E, Fundamentals of Nuclear Reactor Physics, Academic Press (2008).
9. Samuel Glasstone, Alexander Sesonske, Nuclear Reactor Engineering- Reactor Design Basics 4th edition, Vol. 1, CBS publishers (2004 reprint).
10. Weston M. Stacey, Nuclear Reactor Physics, 3rd revised edition, Wiley (2018).

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EL-12: Biomaterials

Course Objectives:

The objective of the course is to introduce various types of biomaterials, designing strategies, their properties and medical applications.

Course Outcomes:

Students will gain knowledge of

1. Biomaterials and understanding various forms biomaterials
2. Chemical constituents of human body and skeletal system: concept of biocompatibility materials
3. Toxicity and corrosion related issues in developing biomaterials: strategies to develop medical grade alloys
4. Importance of mechanical properties and their different aspects in the human body system: accordingly designing biomaterials
5. Selection of different biomaterials for different applications

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 Stretchability, 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. 5 hrs

Special Topic: Bioactive Materials 2 hrs

References:

1. Larry L Hench, An Introduction to Bioceramics, 2nd 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: Molecular Simulations (2 Cr Theory + 1 Cr Practical)

Course Objectives:

1. The main aim of this course is to introduce the Molecular Dynamics (MD) and Monte Carlo (MC) simulation methods.
2. Calculation of various structural and dynamical properties of systems using MD and MC simulation methods.

Course Outcomes:

1. Students will understand the introduction to various interaction potentials used in molecular simulations.
2. Students become familiar with concepts like periodic boundary conditions, minimum image conventions, long-range corrections, and different integration schemes and their importance in molecular simulations.
3. Students will be introduced to various thermostats and barostats used in molecular simulations.
4. Students will be familiar with metropolis algorithm and various (NVE, NVT and NPT) ensembles used in molecular simulations.
5. Students understand the calculation of various properties of systems like radial distribution functions, diffusion, and free energy calculations, etc.

EL-13(T) 2 Cr

Syllabus:

1. Molecular dynamics (MD): Interaction potentials, periodic boundary conditions and minimum image convention, long-range corrections, integration schemes: verlet, velocity verlet, leapfrog; constraint dynamics; extended Lagrangian dynamics; thermostats and barostats. 12 hrs

2. Monte Carlo (MC) methods: Introduction to MC methods; Metropolis algorithm; NVE, NVT and NPT simulations. 6 hrs

3. Estimation of pressure, chemical potential, radial distribution function, auto-correlation function, Ewald summation; umbrella sampling. 10 hrs

References:

1. D. J. Tildesley and M.P. Allen, Computer Simulation of Liquids, 2nd edition, Oxford University Press, (2017).
2. Berend Smit and Daan Frenkel, Understanding Molecular Simulation: From Algorithms to Applications, 2nd edition, Academic Press, (1996).

EL-13(P) 1 Cr

Course Objectives:

1. This course is mainly to implement the Molecular Dynamics (MD) and Monte Carlo (MC) simulation techniques.
2. Computing the structural/ dynamical/ thermodynamical using MD & MC simulation trajectories.
3. Apply these simulation methods to realistic/physical systems.

Course Outcomes:

1. At the end of the course, the student will write MD & MC codes for a simple Lennard-Jones system.
2. Student is able to use one out of the choice of available simulation software packages (like LAMMPS, GROMACS, NAMD and AMBER) to perform MD simulations of realistic systems.
3. Compute various properties like radial distribution functions, diffusion etc using MD simulation trajectories.
4. Student performs the potential of mean force calculations using the umbrella sampling method.
5. Compute the free energy calculations using the umbrella sampling trajectories.

Syllabus:

1. Writing the codes for MD and MC simulations of model Lennard-Jones system. 6 hrs
2. MD simulations of realistic systems using LAMMPS/GROMACS/NAMD/AMBER simulation packages 10 hrs
3. Writing the codes for radial distribution function (RDF), mean-square-displacement (MSD) and velocity-velocity auto-correlation function using the MD trajectories. 6 hrs
4. Computation of potential of the mean force (PMF) calculations using the umbrella sampling method 6 hrs

References:

1. D. J. Tildesley and M.P. Allen, Computer Simulation of Liquids, 2nd edition, Oxford University Press, (2017).
2. Berend Smit and Daan Frenkel, Understanding Molecular Simulation: From Algorithms to Applications, 2nd edition, Academic Press, (1996).
3. Online Resources from Computational Biophysics Workshop, NIH Center for Macromolecular Modeling and Bioinformatics Beckman Institute at UIUC, 2021.
4. Gromacs Tutorials by Justin A. Lemkul, Department of Biochemistry at Virginia Tech.

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EL-14: Microelectronics

Course Objectives:

1. Introduce students to the field of digital integrated circuits and fundamentals of CMOS circuits.
2. This will enable the students to earn hard skills related to Microelectronic circuit designing that are crucial to industrial semiconductor fabrication processes and make them highly employable.

Course Outcomes:

The students will be exposed to following focused learning outcomes

1. learning integrated circuits and their performance metrics
2. to know the MOS transistor operation and functionality in depth
3. Design logic gates using CMOS, CMOS fabrication technology and CMOS circuit layouts
4. Familiarize with various electronic memory technologies
5. Learn about Microelectronic Circuit designing using VHDL tools.

Syllabus:

1. **Introduction to Digital Integrated Circuits** – Quality metrics– functionality, performance, power and cost perspective. 5 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. 5 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, 2nd edition; PHI Learning (2009).
2. Sameer Palnitkar, Verilog HDL – A Guide to Digital Design and Synthesis, 2nd edition, Pearson India, (2003).

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EL-15: Fundamentals of Nanoelectronics

Course Objectives: This course applies the principles of quantum mechanics to understand the fundamentals of nanoelectronics.

The course aims:

1. To introduce the students to nanoelectronics, spintronics and molecular electronics.
2. To explain the principle and applications of nanoelectronic devices.

Course Outcomes:

1. Understand the size and surface effects on electrical resistance.
2. Understand that the conductance in quantum systems is quantized.
3. Understand various techniques for fabricating nanostructures.
4. Apply the Boltzmann transport equation to understand quantum transport and understand different scattering mechanisms in quantum devices.
5. Understand the concept of electromigration and heating effects in nanodevices.
6. Understand the basics of single electron transport and molecular electronics.

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-16: 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.

The course aims:

1. To give a theoretical background necessary to understand the effects of size and surface on electrical, optical and magnetic properties.
2. To demonstrate some applications of size dependent physical properties.

Course Outcomes:

1. Understand the variation of density of electron energy states as a function of materials' dimensions.
2. Understand the role of localized states in electrical transport.
3. Understand the concept of excitons and the size effects on excitons.
4. Analyze optical properties using Mie theory.
5. Understand the role of surface and size on magnetic properties of materials.
6. Understand superparamagnetism and its applications.

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. 9 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 field enhancement and surface-enhanced Raman scattering. 13 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-17: Foundations of Quantum Optics

Course Objectives: This is a graduate level course on quantum optics.
The course aims:

1. To provide the basic notions and the analytical methods for the quantum description of the radiation field.
2. To discuss the principal quantum states of radiation and higher-order interferometry.
3. To give knowledge and understanding of state-of-the-art experiments in areas such as nonlinear quantum optics, ultracold atoms etc.

Course Outcomes:

1. Understand the statistical nature of light and its classification.
2. Understand higher-order interference experiments and their applications.
3. Apply the formalism of creation and annihilation operators to describe quantum states of light.
4. Analyze Hanbury Brown–Twiss experiment using quantum theory.
5. Model resonant light-atom interactions using two-level approximation.
6. Gain basic knowledge in cavity quantum electrodynamics and few applications like laser cooling etc.

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:** Two-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

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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-18: Quantum Computing

Course Objectives: Quantum computing is an interdisciplinary field that lies at the intersection of computer science, mathematics, and physics. This is a graduate level course on quantum computing.

The course aims:

1. To provide a self-contained, comprehensive introduction to quantum computing, focusing on the design and analysis of quantum algorithms.
2. To explain the basics of quantum cryptography and quantum computing.
3. To describe some methods to implement quantum algorithms.

Course Outcomes:

1. Understand the basics of quantum measurement.
2. Understand basic quantum algorithms.
3. Gain knowledge of some aspects of quantum computing based on NMR and linear optics.
4. Gain knowledge of some aspects of quantum computing based on spintronics and ion traps.
5. Understand the basics of quantum teleportation and quantum cryptography.
6. Familiarization with some applications of quantum computing in solving physics problems.

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 Quantum Information, Cambridge (2010).
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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EL-19: Industry 4.0- IoT, Artificial Intelligence & Additive Manufacturing

(2 Cr Theory + 1 Cr Practical)

Course Objectives:

1. To introduce Industry 4.0 requirement for technological development that will enable employability of students at postgraduate level.
2. To familiarize students with latest trend in various components that constitute Industry 4.0 revolution globally and nationally.
3. It is imperative to train students in allied areas of applied science and technology, which will enhance them in preparation as a skilled work force for Industrial 4.0 revolution at National level.

Course Outcomes:

1. Students will be familiar with IoT enabled technology and tools required to build applications in different industry.
2. Students will be trained in the theoretical framework of generic Deep learning technique and its application.
3. Students will be able to learn novel skill sets related to Additive manufacturing and prototyping for both academic research and for industrial applications.

EL-19 (T) **2 Cr**

Syllabus:

1. **Industry 4.0:** Overview of factors enabling and constituting Industrial 4.0 revolution 2 hrs

2. **Internet of Things (IoT)**: Components of IoT driving Industry 4.0 - IOT enabled technological Applications in Biomedical, Automotive and Defense domains; Smart Sensors & Actuators for IoT enabled technological applications (Agricultural, Vehicular & Healthcare IoTs); IoT connectivity & communication technologies; IoT enabled Robotics: Introduction to Aerial Robotics/ Drone Technology Building Drones, Design and Development of Unmanned Aerial and Ground Vehicle. 10 hrs

3. **Artificial Intelligence applications in Industry 4.0**: Introduction to Artificial Intelligence, Machine Learning and Deep Learning concepts; Theoretical framework of artificial & convoluted Neural Networks; Implementation of Deep learning techniques in Physics & related domains like Image processing, Signal processing & Data processing with case studies from different Industries. 8 hrs

4. **Industrial Manufacturing Pipeline:** Additive Manufacturing Technology (AMT); Overview of CAD; Rapid Prototyping & Stereolithography processes; AMT vs Conventional Manufacturing; Classification and Types of AM techniques; Application of AMT in various manufacturing Industries 8 hrs

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References:

1. Sudip Misra, Anandarup Mukherjee, Arijit Roy, Introduction to IoT, Cambridge University Press, (2020)
2. Nitin Goyal, Sharad Sharma, Arun Kumar Rana, Suman Lata Tripathi, Internet of Things: Robotic and Drone Technology, CRC Press (2022).
3. Ronald T. Kneusel, Practical Deep Learning, No Starch Press, Inc (2022).
4. Ian Gibson, David Rosen, Brent Stucker, Mahyar Khorasani, Additive Manufacturing Technologies, Third Edition, Springer Nature Switzerland AG (2021).

EL-19 (P): Industry 4.0- IoT, Artificial Intelligence & Additive Manufacturing 1 Cr

Students are expected to complete a minimum of three experiments from the list* below

Syllabus:

1. IoT (a): Industrial Automation: LabVIEW based IoT automation and Computer Interfacing.
   IoT (b): Drone /Autonomous Technology -Build your own Drone and coding the microcontroller using open source programming.
   IoT(c): Raspberry Pi based IoT for Smart Industry applications.
   IoT(d): Smart Control systems (PID) for IoT & Robotics Applications-Design and tuning techniques.
2. AI(a): Implementing Deep learning based models for image, signal and data processing.
   AI(b): Implementing Deep learning based models for signal processing.
   AI(c): Implementing Deep learning based models for data processing and mining.
3. AMT(a): Familiarization with CAD designing tools for Mechatronics/Opto-mechanical/Optoelectronic applications.
   AMT(b): Device designing using Multiscale Physics Simulator-COMSOL / Equivalent Open source FEM/Optical Designing –Zemax software platforms.
   AMT(c): Additive Manufacturing: 3D printing – Hands-on Training in various AM techniques

(*Not limiting to the above listed topics, additional training will be given with concurrent trends from Industry perspective)

References:

1. John Baichtal, Building Your Own Drones: A Beginners' Guide to Drones, UAVs, and ROVs, Que Publishing, (2016).
2. Ahmed Fawzy Gad and Fatima Ezzahra Jarmouni, Introduction to Deep Learning and Neural Networks with Python- A Practical Guide, Academic Press (2021).
3. Lydia Cline, 3D Printing with Autodesk 123D, Tinkercad, and MakerBot, McGraw-Hill/TAB Electronics Publishers (2014).

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