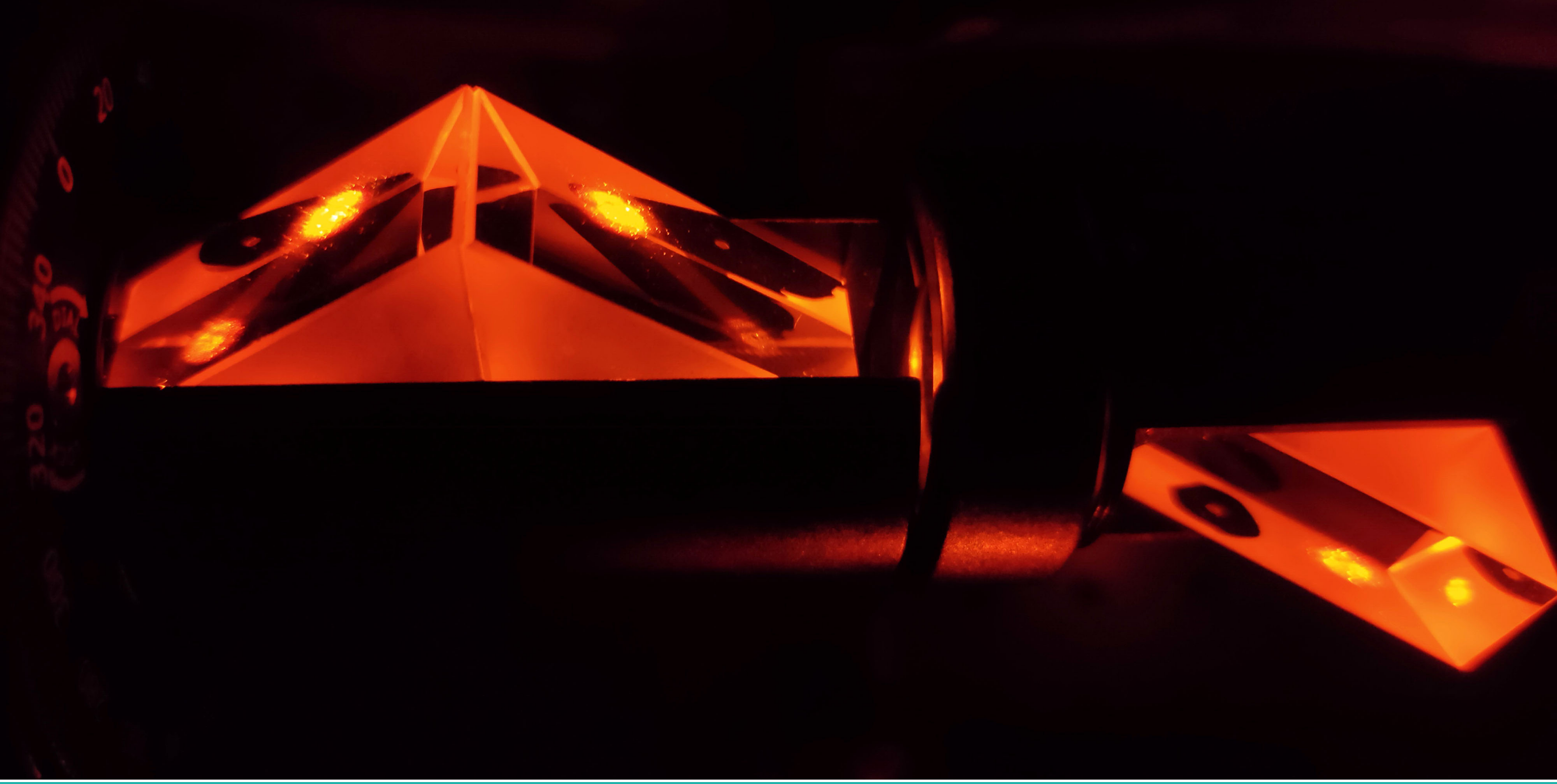

COURSE HANDBOOK – Masters in Physics, Integrated PhD in Physics, PhD Physics.

School of Physical Sciences,

Indian Institute of Technology Mandi.

Date: May 30, 2023 (last updated)

Contents

Chapter 1 About

Welcome to the School of Physical Sciences (SPS), IIT Mandi. Formed in 2022 after the dissolution of the School of Basic Sciences (SBS), the mission of SPS is to establish itself as an internationally recognised fraternity of academics contributing to knowledge creation in cutting-edge themes of the physical sciences; training future scientists and engineers via rigorous academic programs.

Currently, eighteen bright faculty along with over fifty research scholars, conduct research in cutting-edge themes of physics ranging from the physics of atoms, molecules, and quarks to the dynamics of black holes and the early universe, from exploring exotic states of matter to the physics of polymers and glasses. We offer a vibrant research ambience with state-of-the-art experimental and high-performance computing facilities.

We also conduct teaching programs at the undergraduate, postgraduate, and research levels. Students engage in research at both undergraduate and postgraduate levels, often serving as authors in research publications and frequently presenting their research at national and international conferences. Many of our alums have made us proud with their outstanding academic and research achievements. We aim to foster a friendly and diverse environment in our school, striving for excellence, equity, and inclusiveness.

This handbook is intended for the faculty and students of the School of Physical Sciences and provides a comprehensive details of the courses offered by the School at postgraduate level and above.

Chapter 2 Faculty & Staff

2.1 Chairperson

- 2022 - current: Prof. Suman K. Pal

2.2 Faculty advisors

- Batch 2015-16: Dr. Pradyumna Pathak
- Batch 2016-17: Dr. Bindu Radhamany
- Batch 2017-18: Dr. C. S. Yadav
- Batch 2018-19: Dr. Kaustav Mukherjee
- Batch 2019-20: Dr. Ajay Soni
- Batch 2020-21: Dr. Suman K. Pal
- Batch 2021-22: Dr. Gargee Sharma
- Batch 2022-23: Dr. Pradyumna Pathak

2.3 Laboratory staff

Ms. Aditi Thakur.

2.4 Faculty

Table 2.1: List of SPS faculty

Prasanth Jose	Associate Professor	Theoretical Soft Matter Physics	
Nirmalya Kajuri	Assistant Professor	Theoretical High Energy Physics	
Arti Kashyap	Professor	Computational Condensed Matter	
Rahuk Kothari	Assistant Professor	Cosmology	
Pradeep Kumar	Associate Professor	Experimental Condensed Matter	
Kaustav Mukherjee	Associate Professor	Experimental Condensed Matter	
Suman K. Pal	Professor	Experimental Atomic, Molecular and Optical Physics	
Prabhakar Palni	Assistant Professor	Experimental Nuclear and Particle Physics	
Krishnamohan Parattu	Assistant Professor	Gravitation and cosmology	
Pradyuman Pathak	Associate Professor	Theoretical Quantum Optics	

Table 2.2: List of SPS faculty (cont.)

Bindu Radhamany	Associate Professor	Experimental Condensed Matter Physics	
Arko Roy	Assistant Professor	Theoretical Atomic, Molecular and Optical Physics	
Amal Sarkar	Assistant Professor	Experimental High Energy Physics	
Gargee Sharma	Assistant Professor	Theoretical Condensed Matter Physics	
Ajay Soni	Associate Professor	Experimental Condensed Matter Physics	
Harsh Soni	Assistant Professor	Theoretical Soft Matter Physics	
Hari Varma	Associate Professor	Theoretical Atomic, Molecular and Optical Physics	
C. S. Yadav	Associate Professor	Experimental Condensed Matter Physics	

Table 2.3: Other faculty currently involved in SPS teaching

Sudhir K. Pandey	Assistant Professor	School of Materials and Mechanical Engineering	

Chapter 3 Overview of Academic Programs

3.1 M.Sc. Physics

This course is open to students with a Bachelor's Degree in Science or Engineering. Admission to this program is through the national-level exam JAM examination. A variety of discipline core and elective courses provide a rigorous training in the fundamentals of physics. A vital laboratory component allows students to explore a range of experiments, from the basic to the more recent and advanced ones. Project courses allow the student to explore cutting-edge research areas of their interest. Students have to complete a minimum of eighty credits by the end of the program.

3.2 I-PhD (Integrated Ph. D.) in Physics

The Integrated Ph.D. in Physics program is designed to attract bright and young minds at an early age to the frontiers of physics research. Students enrolled in the Integrated Ph.D.(I-Ph.D) program, on successful completion, are awarded two degrees: a Master of Science (M.Sc.) in Physics and a Doctor of Philosophy (Ph.D.). Entry to the I-Ph.D. program is Bachelor's Degree in Physical/Mathematical sciences with a JAM score and an interview. Students must complete at least eighty-nine credits along with an original thesis.

3.3 Dual Degree M.Sc. + Ph.D. in Physics

The school offers this program that allows students admitted as part of the M.Sc. program to upgrade to a dual-degree PG + Ph.D. program. A minimum CGPA of 8/10 is necessary to apply for this program. Students obtain M.Sc. and Ph.D. degrees at the end of their Ph.D. program.

3.4 Ph.D. in Physics

The school offers the Ph.D. program to students with M.Sc. Physics/B.Tech degree. Entry to this program requires qualification of a national-level examination. Please check the IIT Mandi website occasionally for applications and other details. Students must complete a minimum of thirteen credits of coursework along with an original thesis. Coursework is decided in consultation with the doctoral committee of the student.

Chapter 4 Summary of Course Content

4.1 Course content for MSc Physics

Refer to Table. 4.1 below.

4.2 Course content for Integrated Ph.D. Physics

Refer to Table. 4.2 below.

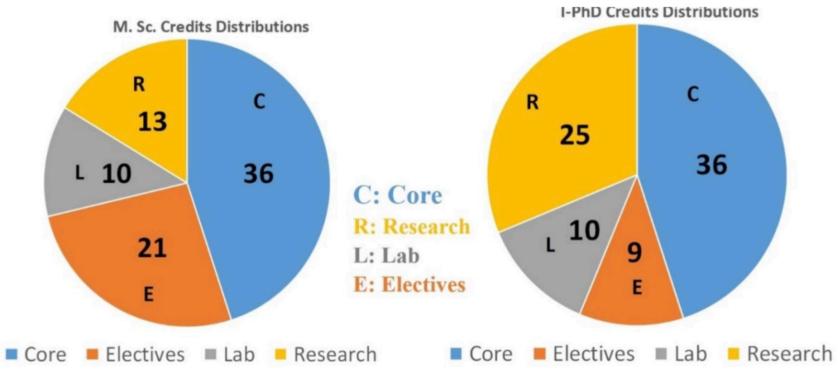

Figure 4.1: Course distribution for MSc and IPhD

Sem	Course	L-T-P-C	
I	PH-511 Mathematical Physics	4-0-0-4	Core
I	PH-512 Classical Mechanics	4-0-0-4	Core
I	PH-513 Quantum Mechanics	3-0-0-3	Core
I	PH-514 Electronics	3-0-0-3	Core
I	PH-515P Physics Lab.	0-0-5-3	Core
I	HS-241 Technical Comm.	1-0-0-1	Core
I	Discipline/Free Elective	3-0-0-3	Elective
	cumulative credits	21	
II	PH-521 Electromagnetic Theory	4-0-0-4	Core
II	PH-522 Statistical Mechanics	4-0-0-4	Core
II	PH-523 Cond. Matter Physics	3-0-0-3	Core
II	PH-524 Atom. Mol. Physics	3-0-0-3	Core
II	PH-621 Comput. Meth. Physics	2-0-4-4	Core
II	Discipline/Free Elective	3-0-0-3	Elective
	cumulative credits	42	
III	PH-614 Seminar and Report	0-0-4-2	Core
III	PH-613 Spe. Topics. in QM	3-0-0-3	Core
III	PH-518P PG Project-I	0-0-6-3	Core
III	PH-525P Electronics Lab. Pract.	0-0-6-3	Core
III	Discipline Elective	3-0-0-3	Elective
III	Discipline Elective	3-0-0-3	Elective
III	Discipline/Free Elective	3-0-0-3	Elective
	cumulative credits	62	
IV	PH-519P PG Project-II	0-0-16-8	Core
IV	PH-611P Exp. Res. Techniques	0-0-8-4	Core
IV	Discipline Elective	3-0-0-3	Elective
IV	Discipline/Free Elective	3-0-0-3	Elective
	cumulative credits	80	

Table 4.1: Course Content for MSc. Physics. *A total of two free electives must be completed before the end of the program.*

Sem	Course	L-T-P-C	
I	PH-511 Mathematical Physics	4-0-0-4	Core
I	PH-512 Classical Mechanics	4-0-0-4	Core
I	PH-513 Quantum Mechanics	3-0-0-3	Core
I	PH-514 Electronics	3-0-0-3	Core
I	PH-515P Physics Lab.	0-0-5-3	Core
I	Technical Communications	1-0-0-1	Core
I	PH-516 Research Project I	0-0-4-2	Core
I	PH-517 Research Project II (Winter)	0-0-8-4	Core
	cumulative credits	24	
II	PH-521 Electromagnetic Theory	4-0-0-4	Core
II	PH-522 Statistical Mechanics	4-0-0-4	Core
II	PH-523 Cond. Matter Physics	3-0-0-3	Core
II	PH-524 Atom. Mol. Physics	3-0-0-3	Core
II	PH-621 Comput. Meth. Physics	2-0-4-4	Core
II	Discipline Elective	3-0-0-3	Elective
II	PH-526 Research Project III	0-0-6-3	Core
II	PH-527 Research Project IV (Summer)	0-0-6-3	Core
	cumulative credits	51	
III	PH-614 Seminar and Report	0-0-4-2	Core
III	PH-613 Spe. Topics. in QM	3-0-0-3	Core
III	PH-615P Mini Thesis I	0-0-6-3	Core
III	PH-525P Electronics Lab. Pract.	0-0-6-3	Core
III	Discipline Elective	3-0-0-3	Elective
III	Discipline Elective	3-0-0-3	Elective
III	Discipline/Free Elective	3-0-0-3	Elective
	cumulative credits	71	
IV	PH-622 Mini Thesis II	0-0-16-8	Core
IV	PH-611P Exp. Res. Techniques	0-0-8-4	Core
IV	Discipline Elective	3-0-0-3	Elective
IV	Discipline Elective	3-0-0-3	Elective
	cumulative credits	89	

Table 4.2: Course Content for Integrated PhD Physics. *Note that students can finish a minimum of 80 credits by the end of Sem IV, but should finish 89 credits by the end of Sem VI. One free elective can be completed in any semester.*

Chapter 5 Core Courses – First Semester

5.1 PH-511 Mathematical Physics

Credits: 4-0-0-4

Preamble: Mathematical physics provides a firm foundation in various mathematical methods Developed and used for understanding different physical phenomena. This course provides mathematical tools to address formalisms used in the core course of a masters-level physics program. Course Outline: The course starts with vector calculus, followed by an introduction to tensor analysis and the concept of linear vector space. The course continues to introduce differential equations and special functions that are used to understand physical phenomena in different geometries. This is followed by complex analysis and finally, Fourier analysis and integral transforms are discussed.

Modules:

Coordinate system, Vector calculus in Cartesian and Curvilinear coordinates, Introduction to Tensor analysis. Linear vector spaces, Gram-Schmidt orthogonalization, Self -adjoint, Unitary, Hermitian Operators, transformation of operators, eigenvalue equation, Hermitian matrix diagonalization.

Ordinary differential equation (ODE) with constant coefficients, second order Linear ODE, Series Solution-Frobenius Method, Inhomogeneous linear ODE. Sturm Liouville equation Hermitian operators - eigenvalue problem.

Special functions: Bessel, Neumann, Henkel, Hermite, Legendre, Spherical Harmonics, Laguerre, Gamma, Beta, Delta functions.

Complex analysis, Cauchy- Riemann conditions, Cauchy's Integral theorem, Laurent expansion, Singularities,

Calculus of residues, evaluation of definite integrals, Method of steepest descent, saddle point.

Fourier series general properties and application, Integral transform, Properties of Fourier transform, Discrete Fourier transform, Laplace transform, Convolution theorem.

Text books:

1. Mathematical methods for physicists by Arfken and Weber (Elsevier Academic Press, 6th edition, 2005).

2. Mathematical Methods in Physical Sciences by Mary L Boas (Willey 3rd edition, 2005).

References:

1. Mathematical Methods for Physics and Engineering: A Comprehensive Guide by K. F. Riley, M. P. Hobson (Cambridge India South Asian Edition, 2009).

2. Mathematical Methods for Physicists by Mathews, J., and Walker, R.L. (Imprint, New edition 1973).

3. Mathematics of Classical and Quantum Physics by F W Byron and R W Fuller (Dover Publication, New edition, 1992).

4. Methods of Theoretical Physics Vol. I and II by P M Morse, H. Freshbach (Mc-GrawHill, 1953).

5. Advanced Engineering Mathematics by E Kreyszing (Wiley India Private Limited, 10th edition, 2003).

6. Mathematics for Physicists by Philippe Dennery and Andre Krzywicki (Dover Publications Inc. 1996).

5.2 PH-512 Classical Mechanics

Credits: 4-0-0-4

Preamble: Classical mechanics is one of the backbones of physics which deals with understanding the motion of particles. The present course covers topics beyond Newtonian mechanics for a proper base for many other branches of physics.

Course Outline: The course discusses an abstraction of the mechanics with an introduction to Lagrangian mechanics starting from Newtonian mechanics, variational principles of mechanics, Hamilton's equations of motion, canonical transformations, Poisson brackets and Hamilton-Jacobi equations. The concepts are illustrated using examples such as a harmonic oscillator, two-body problem, rigid body dynamics, and small oscillations.

Modules:

Introduction: Mechanics of a system of particles, Constraints, D'Alembert's Principle and Lagrange Equations, Simple Applications of the Lagrangian Formulation, Hamilton's principle, Some techniques of the calculus of variations, Derivation of Lagrange's equations from Hamilton's principle, Conservation theorems, and Symmetry properties.

The Central Force Problem: The Equivalent one-dimensional problem, and classification of orbits, The virial theorem, The Kepler problem.

The Kinematics of Rigid Body motion: Orthogonal transformations, Euler's theorem on the motion of a rigid body, Finite rotations, Infinitesimal rotations, Rate of change of a vector, Angular momentum and kinetic energy of motion, the inertia tensor and the moment of inertia. Euler equation of motion of the rigid body.

Oscillations: Formulation of the problem, the eigenvalue equation and the principal axis transformation, Small oscillations, Frequencies of free vibration, Normal coordinates, Non-linear oscillations, and Chaos.

The Hamilton Equations of Motion: Legendre Transformations and the Hamilton Equations of Motion, Cyclic Coordinates and Conservation Theorems, The Principle of Least action.

Canonical Transformations: The examples of canonical transformation Poisson Bracket and Canonical invariants, Liouvilles theorem. Hamilton-Jacobi theory and Action-Angle Variables the Hamilton-Jacobi equation for Hamilton's characteristic function.

Textbooks:

1. Classical Mechanics by H. Goldstein, (Pearson Education; 3 edition (2011)).
2. The Variational Principles of Mechanics by Cornelius Lanczos (Dover Publications Inc. 1986).
3. Classical Mechanics by N.C. Rana and P.S. Joag, McGraw Hill Education (India) Private Limited; 1 edition (16 February 2001).

References:

1. Classical Dynamics: A Contemporary Approach by J.V.Jose and E.J. Saletan, (Cambridge University Press 2002).
2. Mechanics by L.D. Landau and E.M. Lifshitz, (Butterworth-Heinemann Ltd; 3rd Revised edition edition (29 January 1982)).
3. Classical dynamics D T Greenwood (Dover Publications Inc.; New edition edition (21 October 1997)).
4. Introduction to Dynamics by I.C. Percival and D. Richards (Cambridge University Press (2 December 1982)).
5. A treatise on the analytical dynamics of particles and rigid bodies by E.T. Whittaker, (Forgotten Books (27 September 2015)).

6. Classical mechanics by John R Taylor (University Science Books (15 September 2004)).

7. Classical Dynamics of particles and systems by Thorton and Marion (Cengage; 05 edition (17 December 2012)).

8. Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry and Engineering, Steven H Strogatz (Perseus Books; First Edition edition (1 February 1994)).

5.3 PH-513 Quantum Mechanics

Credits: 3-0-0-3

Preamble: This course is an introductory level course on quantum mechanics covering its basic principles. Several applications of quantum mechanics will be discussed to train students to apply these ideas to model systems in both one-dimension and three-dimensions. Course outline: The course begins with a discussion on the origins of quantum theory and will introduce the basic postulates. Applications of quantum mechanics on various one-dimensional cases will be discussed. Further Dirac notation will be introduced. Applications of quantum mechanics in three dimensions will be discussed. Approximation techniques such as perturbation theory (both time-dependent and time-independent) and variational methods will be also discussed in this course.

Modules:

Origins of quantum theory, Postulates of quantum mechanics, observables and operators, theory of measurement in quantum mechanics, state of the system and expectation values, time-evolution of the state, wave-packets, uncertainty principle, probability current, the transition from quantum mechanics to classical mechanics-Ehrenfest theorem.

Application of Schrodinger equation: scattering, tunneling, bound states, harmonic oscillator, electrons in a magnetic field in 2D, comparison of classical and quantum results.

The basic mathematical formalism of quantum mechanics, Dirac notation, linear vector operators, matrix representation of states and operators, commutator relations in quantum mechanics, commutator and uncertainty relations, complete set of commuting observables.

Theory of angular momentum in quantum mechanics, commutator relations in angular momentum, Eigen values and Eigen states of angular momentum, spin-angular momentum.

Application of Schrodinger equation in 3-D models, symmetry and degeneracy, central potentials, Schrodinger equation in spherical coordinates, the solution to hydrogen atom problem.

Time-independent non-degenerate and degenerate perturbation theory, fine-structure of hydrogen, Zeeman Effect, and hyperfine splitting.

Text books:

1. Introduction to quantum mechanics-D J Griffith (Pearson, Second edition, 2004).

2. Quantum Mechanics -Vol.1, Claude Cohen-Tannoudji, B Diu, F Laloe (Wiley, First edition.

3. Modern Quantum Mechanics - J J Sakurai (Addison Wesley, revised edition, 1993).

References:

1. Introductory Quantum Mechanics, R Liboff (Pearson, Fourth edition, 2002).

2. Quantum physics of atoms and molecules-R Eisberg and R Resnick (Wiley, 2nd edition, 1985).

3. Quantum Mechanics B. H. Bransden and C. J. Joachain (Pearson, Second edition, 2000).

4. Principles of Quantum Mechanics - R Shankar (Plenum Press, Second edition, 2011) Student Section.

5. The Feynman Lectures in Physics, Vol. 3, R.P. Feynman, R.B. Leighton, and M. Sands (Narosa Publishing House, 1992).

6. Practical Quantum Mechanics - Siegefried Flügge (Springer 1994).

5.4 PH-514 Electronics

Credits: 3-0-0-3

Preamble: To understand the principle of analog and digital electronics.

Course Outline: The course begins with analog electronics involving the study of amplifiers, oscillators, field effect transistors, and operational amplifiers. Then the concept of Boolean algebra and digital electronics is introduced. Consecutively various digital circuits like combinational, clock and timing, sequential, and digitally integrated circuits are studied. Further, the course will introduce microprocessors.

Modules:

Amplifiers: BJT, Classification of Amplifiers, Cascading of amplifiers, Types of power amplifiers, Amplifier characteristics, Feedback in amplifiers, Feedback amplifier topologies, Effects of negative feedback.

Oscillators and Multivibrators: Classification and basic principle of an oscillator, Feedback oscillator's concepts, Types of oscillators, Classes of multivibrator.

Field effect transistors: JFET, MOSFET. Operational amplifiers: OPAMPs, OPAMP applications.

Boolean algebra and Digital circuit: Number systems, Boolean algebra, De Morgan's theorem, Logic Gates, Karnaugh Maps, Combinational circuits: Adder, Multiplexer, DE multiplexer, Encoder, and Decoder.

Clock and timing circuit: Clock waveform, Schmitt Trigger, 555 Timer-A stable, Monostable, Sequential circuits: Filp-Flops, Registers, Counters, and Memories, D/A and A/D conversions

Microprocessor Basics: Introduction, Outline of 8085/8086 processor, Data analysis.

Text Books:

1) Integrated electronics by Millman and Halkias (McGraw-Hill, 2001).

2) Electronic Principles: A. P. Malvino and D. P. Bates (7th Edn) McGraw-Hill (2006).

3) Digital Principles and Applications: D. P. Leach, A. P. Malvino and G. Saha, (6th Edn), Tata McGraw Hill (2007).

4) Digital Electronics-Principles, Devices and Applications: A. K. Maini John Wiley & Sons (2007).

5) R. S. Gaonkar, Microprocessor Architecture: Programming and Applications with the 8085, Penram India (1999).

6) Microelectronic circuits, Sedra and Smith, Oxford publications, sixth edition 2013.

5.5 PH-515P Physics Laboratory Practicum

Credits: 0-0-5-3

Preamble: This experimental course is expected to develop the art of experimentation and analysis skills, understanding of the basis of knowledge in physics, and collaborative learning skills among students. Course Outline: The course content includes standard physics experiments from various modules of physics, the theory of which students have learned during their final year of B. Sc.

Experiments:

1. Hall Effect in Semiconductor Objective: To measure a semiconductor sample's resistivity and Hall voltage as a function of temperature and magnetic field. The band gap, the specific conductivity, the type of charge carrier, and the mobility of the charge carriers can be determined from the measurements.

2. Michelson Interferometer Objective: To determine the wavelength of the light source by producing an interference pattern.

3. Fabry-Perot Interferometer Objective: To investigate the multibeam interference of laser light. Also, the determination of the wavelength of the light source and thickness of a transparent foil.

4. Zeeman Effect Objective: To observe the splitting up of the spectral lines of atoms within a magnetic field (normal and anomalous Zeeman effect) and find the value of Bohr's magnetron.

5. Diffraction of ultrasonic waves Objective: To observe Fraunhofer and Fresnel diffraction and determine the wavelength of the ultrasound wave.

6. Frank-Hertz Experiment Objective: To demonstrate the quantization of atomic energy states and determine the first excitation energy of neon.

7. Fourier optics Objective: To observe Fourier transformation of the electric field distribution of light in a specific plan.

8. Dispersion and resolving power Objective: Determination of the grating constant of a Rowland grating based on the diffraction angle (up to the third order) of the high-intensity spectral lines. Determination of the angular dispersion and resolving power of a grating.

9. Geiger-Müller-Counter Objective: To study random events, determination of the half-life, and radioactive equilibrium. Verification of the inverse-square law for beta and gamma radiation.

10. Scintillation counter Objective: Energy dependence of the gamma absorption coefficient / Gamma spectroscopy.

Books:

1. R. A. Dunlop, Experimental Physics, Oxford University Press (1988).
2. A. C. Melissinos, Experiments in Modern Physics, Academic Press (1996).
3. E. Hecht, Optics, Addison-Wesley; 4 edition (2001).
4. J Varma, Nuclear Physics Experiments, New Age Publishers (2001).
5. E. Hecht, Optics, Addison-Wesley; 4 edition (2001).
6. Worsnop and Flint, Advanced Practical Physics for Students Methusen & Go. (1950).
7. E.V. Smith, Manual for Experiments in Applied Physics. Butterworths (1970).
8. D. Malacara (ed), Methods of Experimental Physics, Series of Volumes, Academic Press Inc. (1988).

5.6 HS-541 Technical Communication

Credit: 1-0–0-1

Preamble: Students in general and graduate students, in particular, are required to share and communicate their academic activities both in written and oral form to their peers and reviewers for their comments and review. The duration of these presentations may vary from a few minutes to a few hours. The audience may be homogeneous or heterogeneous. This course intends to help students to learn the art of communication in these areas.

Objectives : The course objectives include facilitating learning of the skill of preparing poster presentations, slides, abstracts, reports, papers, and thesis and their oral presentations through lectures, examples, and practices in class. Students are expected to learn the structuring of these academic activities and time allotment for each sub-element of the structure of oral presentations.

Major topics:

1) Review of appropriate and correct use of articles, adjectives and adverbs, active and passive voices, affirmative sentences, sentences with positive and negative connotations, and presentation styles. Examples and class exercises.

2) Poster preparation and presentation at conferences.

3) Research articles for conferences and journals and slides for their presentations.

4) Thesis and/or book.

5) Job interviews.

Reference:

Perelman, Leslie C., and Edward Barrett.The Mayfield Handbook of Scientific and Technical Writing. New York, NY: McGraw-Hill, 2003. ISBN: 9781559346474.

General Resources:

Carson, Rachel. ”The Obligation to endure,” chapter 2 in Silent spring. 104th-anniversary ed. New York, NY: Mariner Books, 2002. ISBN: 9780618249060. (Originally published in 1962. Any edition will do.)Day, Robert A., and Barbara Gastel.How to Write and Publish a Scientific Paper. 6th ed. Westport, CT: Greenwood Press, 2006. ISBN: 9780313330407.—.Scientific English: A Guide for Scientists and Other Professionals. 2nd ed. Phoenix, AZ: Oryx Press, 1995. ISBN: 978-0897749893.Hacker, Diana.A Pocket Style Manual.4th spiral ed. New York, NY: Bedford/St. Martin's, 1999. ISBN: 9780312406844. Jackson, Ian C.Honor in Science.Sigma Xi, The Scientific Research Society, Research Triangle Park, N. C., 1992.Klotz, Irving M.Diamond Dealers and Feather Merchants: Tales from the Sciences.Boston: Birkhauser, 1986

5.7 PH-516 Research Project I [I-PhD only]

Credits: 0-0-4-2

Preamble: This course is aimed at giving research exposure to students by giving small projects to them in physics-related areas.

Course outline: Each student will be given a project which they have to complete during their first semester.

Modules:

Faculty members of physics and related areas can offer this project course. Toward the end of the vacation, they must submit their report and give a seminar based on their work. Evaluation will be based on student's performance during the period and their report and talk. The evaluation will be carried out by the faculty members involved in the program.

Textbooks:

As advised by the faculty member.

References:

As advised by the faculty member.

5.8 PH-517 Research project II [I-PhD only]

Credits: 0-0-8-4

Preamble: This course is aimed at giving research exposure to students by giving small projects to them in physics-related areas.

Course outline: Each student will be given a project which they have to complete during their first-year winter vacation.

Modules:

Faculty members of physics and related areas can offer this project course. Toward the end of the vacation, they must submit their report and give a seminar based on their work. Evaluation will be based on students' performance during the period and their reports and talk. The evaluation will be carried out by the faculty members involved in the program.

Textbooks:

As advised by the faculty member.

References:

As advised by the faculty member.

Chapter 6 Core Courses – Second Semester

6.1 PH-521 Electromagnetic Theory

Credits: 4-0-0-4

Preamble: The course is intended for physics students at the advanced undergraduate level or beginning graduate level. It is designed to introduce the theory of electrodynamics, mainly from a classical field theoretical point of the field.

Course outline: The course content includes electrostatics and magnetostatics and their unification into electrodynamics, gauge symmetry, and electromagnetic radiation. The special theory of relativity has been included with four vector fields and the covariant formulation of classical electrodynamics.

Modules:

1) Overview of Electrostatics & Magneto statics: Differential equation for the electric field, Poisson and Laplace equations, Boundary value problems, Dielectrics, Polarization of a medium, Electrostatic energy, Differential equation for the magnetic field, Vector potential, Magnetic field from localized current distributions.

2) Maxwell's Equations: Maxwell's equations, Gauge symmetry, Coulomb and Lorentz gauges, Electromagnetic energy and momentum, and Conservation laws.

3) Electromagnetic Waves: Plane waves in a dielectric medium, Reflection, and Refraction at dielectric interfaces, Frequency dispersion in dielectrics and metals, Dielectric constant and anomalous dispersion, Wave propagation in one dimension, Group velocity, and Metallic waveguides.

4) Electromagnetic Radiation: Electric dipole radiation, Magnetic dipole radiation, Radiation from a localized charge, The Lienard-Wiechert potentials.

5) Relativistic Electrodynamics: Michelson–Morley experiment, Special theory of relativity, Relativistic kinematics, Lorentz transformation and its consequences, Covariance of Maxwell equations, Radius four-vector in contra variant and covariant form, Four-vector fields, Minkowski space, covariant classical electrodynamics.

Textbooks:

1) Classical Electrodynamics by J.D. Jackson (John Wiley & Sons Inc, 1999).

2) Introduction to Electrodynamics by D.J. Griffiths (Prentice Hall, 1999).

References:

1) Classical theory of fields, by L.D. Landau, E.M. Lifshitz and L.P. Pitaevskii (Elsevier,2010).

2) The Feynman Lectures on Physics, by Feynman, Leighton, Sands (CALTECH, 2013).

3) Classical Electrodynamics by W. Greiner (Spinger, 1998).

4) Foundations of Electromagnetic Theory by J.R. Reitz, F.J. Milford and R.W. Christy (Addition- Wesley, 2008).

6.2 PH-522 Statistical Mechanics

Credits: 4-0-0-4

Preamble: Statistical mechanics use methods of probability to extend the mechanics to many-body systems to make statistical predictions about their collective behavior. It also acts as a bridge between thermodynamics and the mechanics of constituent particles. Statistical mechanics of ideal gas systems provide the basic functioning of the formalisms of statical mechanics. Methods of statistical mechanics serve as essential pre-requisite to many advanced topics in various branches of physics where many body systems are dealt with. Course Outline: This course starts by introducing the concepts of basic probability theory. The next modules explain the connection between the many-body mechanics and phase space to probability theory. This course gives an introduction to different statistical ensembles. Also introduces studies of the statistical behavior of classical and quantum systems.

Modules:

1) Review of Thermodynamics: Laws of Thermodynamics, Specific heat, Maxwell relations, Thermodynamic potentials, Ideal gas, Equation of state, van der Waal's equations.

2) Probability concepts and examples - random walk problem in one dimension mean values probability distribution for large N. Probability distribution of many variables.

3) Liouvellie equation-Boltzman ergodic hypothesis, Gibbsian ensemble. Phase space and connection between mechanics and statistical mechanics- Microcanonical ensemble. Classical ideal gas. Gibb's paradox.

4) Canonical ensemble partition function. Helmholtz free energy, Thermodynamics from the partition function. Classical ideal gas- equipartition and virial theorem. Examples: harmonic oscillator and spin systems, Grand canonical ensemble- density, and energy fluctuations- Gibbs free energy.

5) Formulation of quantum statistical mechanics density matrix- micro-canonical, canonical, and grand canonical ensembles- Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics - comparison.

6)Ideal gas in classical and quantum ensembles Ideal Bose and Fermi systems Examples of ideal quantum gases, Landau diamagnetism, Pauli paramagnetism, Phonons in solids, Bose-Einstein condensation in Harmonic Trap, White dwarf Star, Phase transformation.

Textbooks:

1. Statistical Mechanics, R K Pathria (Academic Press Inc; 3rd Revised edition edition (25 February 2011)).

2. Statistical Physics by K Huang (Wiley; Second edition (24 September 2008).

3. Concepts in Thermal Physics, Stephen Blundell (OUP UK; 2 editions, 24 September 2009).

References:

1. Fundamentals of statistical and thermal physics, F. Reif (Waveland Press (1 January 2010)).

2. Statistical Physics Part I by L D Landau and E M Lifshitz (Butterworth-Heinemann; 3 edition (22 October 2013)).

3. Statistical physics of particles by Mehran Kardar (Cambridge University Press; 1 edition (7 June 2007)).

4. The principles of Statistical Mechanics R. C Tolman (Dover Publications Inc.; New edition edition (1 June 1980)).

6.3 PH-523 Condensed Matter Physics

Credits: 3-0-0-3

Preamble: A basic understanding of solids is important for practicing physicists as well as for many other related disciplines. The course is an introduction to the physics of solid-state matter. Course Outline: The course emphasizes the large-scale properties of solid materials resulting from their atomic-scale properties. This course provides a basic understanding of what makes solids behave the way they do, how they are studied, and the basic interactions which are important.

Modules:

Introduction: Crystal Structures, Reciprocal Lattice, Brillioun Zones, X-ray diffraction and Structure factor, Defects in Crystal structures Lattice Vibrations and Phonons: Monoatomic and Diatomic basis, Quantization of elastic waves, Phonon momentum and Phonon density of states, Einstein and Debye model of heat capacity, Thermal properties of solids.

Electrons in Solids: Drude and Somerfield theories, Fermi momentum and energy, Fermi surface, Density of states, Electrical conductivity, Ohm's law, Motion in a magnetic field, Hall Effect, Bloch Theorem and crystal momentum, Electron motion in Solids, Kroning-Pening Model, Formation of band, Effective mass

Semiconductors: Intrinsic and extrinsic semiconductors, Acceptor and donor level, Bound State and optical transitions in semiconductors. Degenerate and non-degenerate semiconductor, Optical properties of solids.

Magnetism: Introduction, Origin of magnetism, Bohr-Van Leeuwen theorem, Types of magnetism: Diamagnetism, Paramagnetism, Ferro and Anti-ferro magnetism.

Superconductivity: Basic phenomena, Meissner effect, Types of superconductors, London equation, Idea of Cooper pair, Flux quantization, Josephson's tunneling.

Textbooks:

1. Introduction to Solid State Physics by C. Kittel, 8th Edition, John Wiley & Sons, Inc, 2005.

2. Solid State Physics by N. W. Ashcroft and N. D. Mermin. 3. Condensed Matter Physics by M. P. Marder, (John Wiley & Sons, 2010).

References:

1) Advanced Solid State Physics by Phillips. (Cambridge University Press, 2012).

2) Solid State Physics, Hook and Hall, Wiley Science.

3) Physics of Semiconductor Devices, S. M. Sze.

6.4 PH-524 Atomic and Molecular Physics

Credits: 3-0-0-3

Preamble: This course introduces the basic ideas of atomic and molecular physics. It teaches students how to apply quantum mechanics and extract information from many-electrons atoms and molecules. An introduction to group theory is also provided.

Course outline: The course begins with a review of some of the basic concepts in quantum mechanics and then discusses the time-dependent perturbation theory and its applications. It will then proceed to many-electron atomic systems and then to molecules. Further, the course discusses the ideas and concepts associated with various spectroscopy techniques and will also introduce the elementary concepts of group theory.

Modules:

1) Time-independent perturbation theory, Time-dependent perturbation theory and application Fermi-Golden rule. Interaction of electromagnetic radiation with single electron atoms, Rabi flopping, Dipole approximation and dipole selection rules, Transition rates, Line broadening mechanisms, spontaneous and stimulated emissions and Einstein coefficients.

2) Review of atomic structure of H, Atomic structure of two-electron system-variational method, alkali system, central field approximation, Slater determinant, Introduction to self-consistent field method, L- S coupling, J-J coupling. General nature of molecular structure, molecular binding, LCAO, BornOppenheimer approximation.

3) General nature of molecular structure, molecular binding, LCAO, Born-Oppenheimer approximation.

4) Introduction to microwave, infra-red and Raman spectroscopy, NMR and ESR, Symmetry and Spectroscopy.

Textbooks:

1. Quantum Mechanics, Leonard Schiff, Mc Graw Hill Education; 3 edition (9 April 2010).
2. Physics of atoms and molecules - Bransden and Joachain (Pearson, second edition, 2011).
3. Fundamentals of molecular spectroscopy- C. Banwell and E. Maccash (Mc Graw Hill, 2013).
4. Introductory Quantum Mechanics, R.L. Liboff, Addison-Wesley (2002).

References:

1. Atoms, Molecules and Photons - Wolfgang Demtroder (Springer, Second edition, 2006).
2. Atomic Physics, C. J. Foot (Oxford, First edition 2005).
3. Group theory and Quantum Mechanics-M. Tinkham (Dover Publications, First edition, 2003).
4. Chemical applications of group theory-F Albert Cotton (Willey, Third edition, 2015).

6.5 PH-526 Research project III [I-PhD only]

Credits: (0-0-6-3)

Preamble: This course is aimed at giving research exposure to students by giving small projects to them in physics-related areas.

Course outline: Each student will be given a project which they have to complete during their Second semester.

Modules:

Faculty members of physics and related areas can offer this project course. Toward the end of the vacation, they have to submit their report and must give a seminar based on their work. Evaluation will be based on student's performance during the period and their report and talk. The evaluation will be carried out by the faculty members involved in the program.

Textbooks:

As advised by the faculty member.

References:

As advised by the faculty member

6.6 PH-527 Research project IV [I-PhD only]

Credits: (0-0-6-3)

Preamble: This course is aimed at giving research exposure to students by giving small projects to them in physics-related areas.

Course outline: Each student will be given a project which they have to complete during their first-year summer vacation.

Modules: Faculty members of physics and related areas can offer this project course. Toward the end of the vacation, they have to submit their report and must give a seminar based on their work. Evaluation will be based on student's performance during the period and their report and talk. The evaluation will be carried out by the faculty members involved in the program.

Textbooks:

As advised by the faculty member.

References:

As advised by the faculty member.

6.7 PH-621 Computational Methods for Physicists

Credits: 2-0-4-4

Preamble: The objective of the proposed course is to introduce students to the basic ideas of numerical methods and programming Course Outline: The course will cover the basic ideas of various numerical techniques for interpolation, extrapolation, integration, differentiation, solving differential equations, matrices, and algebraic equations.

Modules:

1) Basic introduction to operating system fundamentals.

2) Introduction to C: Program Organization and Control Structures loops, arrays, and function, Error, Accuracy, and Stability.

3) Interpolation and Extrapolation - Curve Fitting: Polynomial Interpolation and Extrapolation Cubic Spline Interpolation Fitting Data to a Straight Line, examples from experimental data fitting.

4) Integration and differentiation: Numerical Derivatives Romberg Integration Gaussian Quadrature and Orthogonal Polynomials.

5) Root Finding: Newton-Raphson Method Using Derivative - Roots of a Polynomial.

6) Ordinary Differential Equations: Runge-Kutta Method, Adaptive Step size Control for Runge- Kutta, Examples from electrodynamics and quantum mechanics.

7) Matrices and algebraic equations: Gauss-Jordan Elimination Gaussian Elimination with Back substitution, LU Decomposition.

8) Concept of simulation, random number generator.

Textbooks:

1. The C Programming Language by B W Kernighan and D M Richie (PHI Learning Pvt. Ltd, 2011)

2. Elementary numerical analysis: algorithmic approach by S D Conte and C de Boor (McGraw- Hill International, 1980).

References:

1. Computer Programming in C by V. Rajaraman, (PHI Learning Pvt. Ltd, 2011).

2. Numerical Methods by Germund Dalquist and Ake Bjork (Dover Publications, 1974).

3. Numerical Recipes by William H. Press, Saul A. Teukolsky, William T. Vetterling, and Brian P. Flannery, (Cambridge University Press, 1992).

Chapter 7 Core Courses – Third Semester

7.1 PH-525P Electronics Laboratory Practicum

Credits: 0-0-5-3

Preamble: To provide instruction and acquaintance with electronic devices and instrumentation techniques important in the modern physics laboratory. This course will serve as an introduction to practical laboratory electronics by way of covering the application of analog, digital, frequency and mixed-signal electronics to experiments in the physical sciences.

Course Outline: The course is a laboratory support to the electronics course PH 414.

List of Experiments

1. To design and use bipolar junction transistor (BJT) as an amplifier and switch, based on common emitter (CE), common collector (CC) and common base (CB) configurations.

2. Design of Integrator, Differentiator, low pass and high pass filter using operational amplifier (Op Amp) IC 741.

3. Design of Wein Bridge and Colpitts oscillator.

4. Verify mathematical expression of the De-morgans theorem using electronic circuits.

5. Design of 4-bit Multiplexer and DE multiplexer using flip flops.

6. Design of 4-bit Shift registers and Counters using flip flops.

7. Design and verify A/D and D/A converters using OpAmp.

8. Design of A stable and Mono stable Multivibrator using IC 555. 9. Study of 8085 Microprocessor.

References:

1. Basic Electronics, B.L. Thareja.

2. Principles of Electronics, V.K. Mehta and Rohit Mehta.

7.2 PH-614 Seminar and report

Credits: 0-0-4-2

Preamble: This course is aimed at developing students' self-study and presentation skills which are very much important to build a successful research career.

Course outline: Each student will choose a particular topic for their seminar. The student will be continually preparing in a self-study mode in consultation with faculty members working on physics-related topics. Students are also required to write a report.

Modules:

Students will be continually preparing during the semester in consultation with faculty members. At the end of the semester, students have to give a seminar and a report. Faculty members who are involved in the program will evaluate based on the performance of students during the period and their seminar and report.

Textbooks:

As advised by the faculty member.

References:

As advised by the faculty member.

7.3 PH-613 Special Topics in Quantum Mechanics

Credits: 3-0-0-3

Preamble: This course introduces some of the advanced-level topics on quantum mechanics. Course outline: The course begins with a review of some of the basic concepts in quantum mechanics and then discusses angular momentum algebra. It will then proceed to discuss the concepts in scattering theory, symmetry principles, and second quantization. Relativistic quantum mechanics will be introduced toward the end of the course.

Modules:

1. Review of basic concepts in quantum mechanics, measurements, observables, and generalized uncertainty relations, change of basis, generator of translation

2. Angular Momentum: General theory of angular momentum, Angular momentum algebra, Addition of angular momenta, Clebsch-Gordon coefficients, Tensor operators, matrix elements of tensor operators, Wigner-Eckart theorem

3. Scattering Theory: Non-relativistic scattering theory. Scattering amplitude and cross-section. The integral equation for scattering. Born approximation. Partial wave analysis, optical theorem

4. Symmetries in Quantum Mechanics: Symmetry principles in quantum mechanics, conservation laws and degeneracies, discrete symmetries, parity and time reversal

5. Second Quantization: Systems of identical particles, Symmetric, and anti-symmetric wave functions. Bosons and Fermions. Pauli's exclusion principle, occupation number representation, commutation relations, applications of second quantization. Instructors may choose any one of the modules given below:

6. Elements of relativistic quantum mechanics. The Klein-Gordon equation. The Dirac equation. Dirac matrices, spinors. Positive and negative energy solutions, physical interpretation. Nonrelativistic limit of the Dirac equation.

Textbooks:

1. Modern Quantum Mechanics - J J Sakurai(Addison Wisley, revised edition, 1993).

2. Advanced Quantum Mechanics, J J Sakurai (Pearson, First edition, 2002).

3. Quantum Mechanics, Cohen-Tannoudji, B Diu, F Laloe (Vol. II) (Wiley, second edition 1977).

References:

1. Quantum Mechanics-Vol. I and II-Messiah (Dover Publications Inc., 2014).

2. Practical Quantum Mechanics - Siegefried Flügge (Springer 1994).

3. Many-electron theory-S. Raimes (North-Holland Pub. Co.1972).

4. Relativistic Quantum Mechanics-W. Greiner and D. A. Bromley (Springer, 3rd edition , 2000).

5. Quantum theory of many-particle systems- Fetter and Walecka (Dover Publications Inc2003).

6. Quantum Mechanics-Merzbacher (Third edition, Wiley, 2011).

7. Quantum mechanics-Landau and Lifshitz (Butterworth-Heinemann Ltd; 3rd Revised edition (18 December 1981).

7.4 PH-518P Post-Graduate Project-1 [M Sc only]

Credits: 0-0-6-3

Preamble: The course is aimed at giving research exposure to students by giving small projects to them in physics-related areas.

Course outline: Each student will be given a project which they have to complete during their 1st semester.

Modules:

Faculty members of physics and related areas can offer this project course. Toward the end of the vacation, they have to submit their reports and must give a semester based on their work. Evaluation will be based on student performance during the period and their report and talk. The evaluation will be carried out by the faculty members involved in the program.

Textbooks: As advised by the faculty member.

References: As advised by the faculty member.

7.5 PH-615 Mini-thesis I [I-PhD only]

Credits: 0-0-6-3

Preamble: The course is aimed at equipping students with the necessary knowledge and skills to take up their Ph.D. work.

Course outline: Each student can work with their supervisor where they are expected to do research at an advanced level.

Modules:

At the end of the semester, they have to submit their report and must give a seminar based on their work. A committee shall be formed to evaluate the student's performance during the period and their report and seminar.

Textbooks: As advised by the faculty member.

References: As advised by the faculty member.

Chapter 8 Core Courses – Fourth Semester

8.1 PH-622 Mini-thesis II [I-PhD only]

Credits: 0-0-16-8

Preamble: The course is aimed at equipping students with the necessary knowledge and skills to take up their Ph.D. work.

Course outline: Each student can work with their supervisor where they are expected to do research at an advanced level.

Modules:

At the end of the semester, they have to submit their report and must give a seminar based on their work. A committee shall be formed to evaluate the student's performance during the period and their report and seminar.

Textbooks: As advised by the faculty member.

References: As advised by the faculty member.

8.2 PH-611P Experimental Research Techniques

Credits: (0-0-7-4)

Preamble: According to Newton's third law, we can just move the earth up and down by just throwing the ball up and down. But why don't we feel it? It's simply because it is immeasurable within the uncertainty of the measuring setup. Performing an experiment without the knowledge of uncertainty has no meaning. The students will be given a flavor of what it really means by (a) performing an experiment; (b) developing a mini experiment (c) assembling and engineering tools.

Course Outline: The aim of the proposed course is to amalgamate the concepts in Physics through assembling, developing mini-experiments, and building components.

Modules:

Temperature dependence of Electrical resistivity of materials: This experiment involves measuring the temperature-dependent resistivity of any material using the four probe method and Vander Pauw methods. The skills that one will develop are to make fine contacts on the sample and learn the intricacies involved in making this setup. Electronic properties of a material using the photoemission technique: Photoemission experiments will be done on any material and its electronic properties will be studied. The skills that one will develop are the intricacies involved in conducting experiments in ultra-high vacuum conditions. Seebeck coefficient measurement: Develop a mini Seebeck coefficient experiment to distinguish n-type and p-type semiconductors from a mixture of them. Structural properties of a material using powder X-ray diffraction (XRD) technique.

8.3 PH-519P Post-Graduate Project-II [M Sc only]

Credits: 0-0-16-8

Preamble: The course is aimed at giving research exposure to students by giving small projects to them in physics-related areas.

Course outline: Each student will be given a project which they have to complete during their 1st semester.

Modules:

Faculty members of physics and related areas can offer this project course. Toward the end of the semester, they have to submit their reports and must give a semester based on their work. Evaluation will be based on student performance during the period and their report and talk. The evaluation will be carried out by the faculty members involved in the program.

Textbooks:

As advised by the faculty member.

References:

As advised by the faculty member.

Chapter 9 Elective Courses

9.1 PH-502 Optics/Photonics

Credit: 3-0-0-3

Course objective: In this course, applications of light in modern technologies will be introduced. The main focus will be on the wave and particle nature of light, transmission, detection and interaction of light, optical information propagation and different applications of photonic technologies. The main topics covered in the course include optical fibres, wave guides, polarization of light, interference and diffraction of light, lasers, detectors, photonic crystals, metamaterials, light emitting diodes, quantum dots and solar cells. The concepts of modulation of light through the electro-optic and acousto-optic effects will also be included.

Course content:

Electromagnetic Optics: electromagnetic theory of light, electromagnetic waves in vacuum & dielectric media, absorption and dispersion, pulse propagation in dispersive media, Metamaterials [6 lectures].

Polarization Optics: polarization of light, reflection and refraction, optics of anisotropic media, Optics of liquid crystals, polarization devices. [5 lectures].

Guided wave Optics: electromagnetic waves in dielectric layered media, photonic crystals, waveguides, resonators, plasmonics. [5 lectures].

Fiber Optics: electromagnetic waves in fiber, Attenuation and dispersion, photonic crystal fibers. [5 lectures].

Semiconductor Optics: quantization of electromagnetic field, quantum states of light, photon statistics, interaction of photons with charge carriers, light emitting diodes, laser diodes, microcavity lasers. [6 lectures].

Detection of light: theory of photo detection, photodetectors, photodiodes, avalanche photodiodes, noise in photodetectors. [5 lectures].

Acousto and Electro Optics: interaction of light and sound, acousto-optic devices, Principles of electro optics, electro optics of anisotropic media, electro optics of liquid crystals. [5 lectures]

Optical fiber communication: fiber Optic components, optical fiber communication system, modulation and multiplexing, fiber optic networks. [5 lectures].

Textbooks:

Optical Electronics by A.K. Ghatak, K. Thyagarajan (Cambridge University Press).

References:

1. Principles of Optics by Max Born, Emil Wolf (Cambridge University Press).
2. Fundamentals of Photonics by Saleh&Teich (Wiley-Interscience).

9.2 PH-503 Laser and Applications

Credit Distribution: 3-0-0-3

Modules:

1. Radiation: energy density and pressure of radiation, cavity radiation, modes of oscillation. [1 Lectures]

2. Interaction of radiation with matter: absorption, spontaneous and stimulated emission, Einstein coefficients, photoexcitation cross-section, amplification of radiation, laser pumping systems: optical pumping, electrical pumping other methods of pumping, spectral lines shapes, different types of broadening mechanism, gain calculation, threshold condition. [7 Lectures]

3. Cavity resonator: time constant and quality factor of optical cavity, stability of resonators, g parameters, various types of resonators. [6 Lectures]

4. Various Lasers: (i) Solid state lasers: Ruby Laser and Nd: YAG laser (ii) Gas lasers: He-Ne laser, CO2 laser and Nitrogen laser (iii) Liquid lasers: Dye lasers (iv) Semiconductor lasers (v) Free electron lasers [8 Lectures]

5. Laser pulse generation: Q-switching: theory and various methods; mode locking: methods of mode locking, the efficiency of mode locking, ultrashort (nanosecond, picosecond and femtosecond) laser pulse generation. [6 Lectures]

6. Applications in time-resolved spectroscopy: fluorescence lifetime, various measurement techniques-oscilloscope method, time-correlated single photon counting, Streak Camera, fluorescence upconversion. [4 Lectures]

7. Application in optical communication: optical fibre, fibre laser. [2 Lectures] 8. Higher harmonic generation: white light continuum generation, optical parametric amplifier, pump- probe spectroscopy. [3 Lectures]

9. Holography: Theory, classification and application. [3 Lectures]

Textbooks:

1. O. Svelto - Principles of lasers.

2. W. Koechner - Solid State Laser Engineering.

References:

1. W. T. Silfvast, Laser and Fundamentals.

2. A. E. Seigman, Lasers.

3. A. Yariv - Quantum Electronics.

4. D.R.Hall and P.E.Jackson (ed by) - The Physics and Technology of Laser Resonators.

5. M.Young. - Optics and Lasers.

6. D. Meschede - Optics, Lights and Lasers.

7. B.A.Lengyel - Lasers.

9.3 PH-507 X-rays as a probe to study material properties

Credits: 3-0-0-3

Course Preamble: This course deals with understanding the basic interaction of x-rays with matter and the kind of information one can draw to understand material properties using some of the state-of-the-art techniques installed on laboratory and synchrotron radiation sources. The application of x-rays has not only revolutionized our knowledge of matter at the fundamental level of atoms, electrons and spins but also redefined entire fields of science like physics, chemistry, biology, and medicine. There are about 19 Nobel prizes awarded for x-ray-related works.

Course Outline: You will get the experimental flavor of quantum mechanics and solid-state physics using the state of the art techniques. The techniques we study here are currently used in understanding the emergent phenomena which form the basis for making a magnetoelectric, spintronic, superconducting, ferroelectric, dielectric, magnetic, thermoelectric, fuel cell, and battery applications etc. The focus will be made to understanding the basic theory, experimental and the extraction of information from the experimentally collected data.

Modules:

1. The discovery of x-rays [1 Lecture].

2. Interaction of radiation with matter [5 Lectures]. Time-independent perturbation theory. Time-dependent perturbation theory. Fermi Golden rule.

3. State-of-the-art Techniques.

(a) X-ray sources. Conventional laboratory sources. Synchrotron radiation sources.

(b) X-ray Diffraction [10 Lectures + lab visit]. Theory. Scattering by electrons. Scattering by atoms. Scattering by unit cell. Crystal axes and Reciprocal lattice. Structure factors. Diffraction Intensity calculations. Diffractometer measurements: Various diffraction geometries – This includes geometries used for (a) ambient conditions, (b) extreme (high pressure using diamond anvil cell) conditions. The basic idea behind the generation of high-pressure conditions in the laboratory. Detection systems. Applications- understanding the order-disorder transformation.

(c) X-ray absorption Spectroscopy [7 Lectures] Basic theory. Experimental Importance of local structural measurements. Local structural links with the physical properties of different materials. X-ray magnetic circular dichroism.

(d) Photoemission spectroscopy [12 Lectures] Electron Spectroscopy- Basic Concepts. Electron spectrometer Design. Electron spectrum- Qualitative and Quantitative. Different Photoemission spectroscopic techniques. Angle-integrated photoemission spectroscopy. Angle-resolved photoemission spectroscopy. Spin resolved photoemission spectroscopy. Inverse photoemission spectroscopy. Application of spectroscopy in Material Science.

Textbooks:

1. X-rays in Theory and Experiment Arthur Holly Compton, Samuel King Allison, 1935.

2. Elements of x-ray diffraction B.D. Cullity, Prentice Hall; 3 edition (February 15, 2001).

3. X-ray absorption: Principles, Applications, Techniques of EXAFS, SEXAFS and XANES Edited by D.C. Konningsberger and R.Prins , Wiley, 1988.

4. Photoelectron Spectroscopy Stephan Hüfner, Springer, 2003.

9.4 PH-508 Magnetism and Magnetic Materials

Credits: 3-0-0-3

Course Preamble: Magnetism is an open field where engineers, material scientists, physicists, and others work together. This course is proposed for undergraduate/postgraduate level students. It starts with the fundamentals of magnetism and proceeds to explain magnetic materials and their applications. Course Outline: The course will cover a thorough study of different types of magnetism along with the types of magnetic interactions. Also, various types of glassy magnetism and magnetism in low dimensions will be covered. A detailed study of novel magnetic materials which are used for technological applications will be carried out. Further, the course will introduce various measurement techniques used for measuring magnetization.

Modules:

Introduction History of magnetism, Magnetic units, Classical and quantum mechanical model of the magnetic moment of electrons, magnetic properties of free atoms. Types of magnetism Classification of magnetic materials, Theories of Diamagnetism, Para magnetism, Theories of ordered magnetism, Quantum theory of magnetism: electron-electron interactions, localized electron theory, itinerant electron theory. Magnetic interactions Origin of crystal field, Jahn Teller effect, Magnetic dipolar interaction, Origin of exchange interaction, Direct exchange interactions, Indirect exchange interactions in ionic solid and metals, double and anisotropic exchange interaction.

Magnetic domains Development of domain theory, Block and Neel Wall, Domain wall pinning, Magnons, Bloch's law, Magnetic anisotropy, magneto restriction.

Competing interactions and low dimensionality Frustration, Spin glass, superparamagnetism, one and two-dimensional magnets, thin film and multilayers, Heisenberg and Ising models.

Novel magnetic materials Colossal and giant magnetoresistive materials, magnetic refrigerant materials, Shape memory alloys, multiferroics, spintronics devices and their application in magnetic storage.

Measurements techniques Production and measurement of field, magnetic shielding, Faraday balance, AC susceptometer, Vibration sample magnetometer, torque magnetometer, SQUID magnetometer, Experimental method in low temperature.

Textbooks: 1. B. D. Cullity and C. D. Graham, Introduction to magnetic materials. John Wily & Sons, Inc, 20112. D. Jiles, Introduction to magnetism and magnetic materials. Taylor and Francis, CRC Press 1998.

Reference books: 1. K. H. J. Buschow and F. R. de Boer, Physics of Magnetism and Magnetic Materials. Kluwer Academic Publishers, 2003.

2. Stephen Blundell, Magnetism in Condensed Matter. Oxford University Press (2001).

3. Mathias Getzlaff, Fundamentals of Magnetism, Springer, 2008.

9.5 PH-528 Introduction to General Relativity

Credit Distribution: 3-0-0-3

Preamble: General Relativity is one of the main pillars of modern physics. Einstein's discovery of General Relativity revolutionized our understanding of gravity and the universe. Since then, there has been enormous progress on both theoretical and observational fronts. General Relativity is foundational to fields such as cosmology, astrophysics, black hole physics, and the physics of gravitational waves. In this course, we introduce students to the theory and applications of General Relativity.

Course Modules with quantitative lecture hours:

Special Relativity: Principles of special relativity – Lorentz transformations, Covariant and contravariant vectors, Relativistic Mechanics. (4 Hours).

Tensor Algebra and Tensor Calculus: Manifolds and metric, Introduction to tensors – Transformation of coordinates, Lie derivatives – covariant differentiation – Christoffel symbols, The Riemann and Ricci tensors – The Bianchi identities, Geodesics, Isometries – The Killing equation and conserved quantities. (9 Hours).

General Relativity: The equivalence principle – The principle of general covariance, The stress-energy tensor, Einstein equations, The equation of geodesic deviation, linearized gravity, and the idea of gravitational waves. (9 Hours).

Schwarzschild solution and Black holes: The Schwarzchild solution, Motion of particles in the Schwarzschild metric – Precession of the perihelion – Bending of light, Black holes – event horizon and singularity, The Kruskal extension – Penrose diagrams. (10 hours).

Cosmology: Homogeneity and isotropy – The FRW metric, Friedmann equations – Solutions with different types of matter, Cosmological redshift – standard candles, Dark matter and dark energy, Thermal history of the universe, Horizon problem, and Inflation. (10 hours).

Text books:

1. J. B. Hartle, Gravity: An Introduction to Einstein's General Relativity, Pearson Education, India, 2003.

2. B. F. Schutz, A First Course in General Relativity, 2nd Edition, Cambridge University Press, United Kingdom, 2009.

References:

1. S. Carroll, Spacetime and Geometry, Addison Wesley, USA, 2004).

2. Barbara Ryden, Introduction to Cosmology, 2nd Edition, Addison-Wesley, USA, 2016.

9.6 PH-601 Mesoscopic Physics and Quantum Transport

Credits: 3-0-0-3

Course Preamble: Rather a young branch of science, mesoscopic physics already has several exciting and instructive achievements in fundamental understanding and technological applications. This course highlights the mechanisms of electronic transport at the mesoscopic scales where novel concepts of quantum mechanics are necessary. The course deals with the understanding of how physics and quantum rules are operative in electronic transport in low-dimensional structures.

Course Outline: The course is planned to get a broad overview of the world of mesoscopic physics and various approaches to studying quantum transport and related phenomena in nanostructures. Among the topics covered are the length scaling in physics, conductance from the transmission, scattering approaches, semi-classical transport, interference, and decoherence effects, and concludes by emphasizing the application of mesoscopic physics with the rapid evolution of novel materials and experimental techniques.

Modules:

1. Introduction Drude and Somerfield model for electrons in solids, Quantum mechanics of particles in a box, Bloch states, Density of states, and Dimensionality.

2. Mesoscopic physics Mesoscopic phenomena and length scaling in physics, Quantum structures, Tunneling through the potential barrier, Coulomb blockade.

3. Quantum transport and Localization Influence of reduced dimensionality on electron transport: Ballistic and Diffusive Transport, Single channel Landauer formula, Landauer-Buttiker formalism, Localization, Thermally activated conduction, Thouless picture, General and special cases of localization, Weak localization regime.

4. Quantum Hall effect Origin of zero resistance, Two Dimensional Electron Gas, Transport in Graphene and two-dimensional systems, Localizations in weak and strong magnetic fields, Quantum Hall effect, Spin Hall Effect.

5. Quantum interference effects in electronic transport Conductance in mesoscopic systems, Shubnikov de Haas-Van and Aharonov-BohmOscillations, Conductance fluctuations.

6. Mesoscopic Physics with Superconductivity Superconducting ring and thin wires, weakly coupled superconductors, Josephson effects, Andreev Reflections, Superconductor-Normal, and Superconductor-Normal-Superconductorjunctions.

7. Application of Mesoscopic physics Optoelectronics, Spintronics and Nanoelectronic Devices.

Text Books:

1.Y. Imri, Introduction to Mesoscopic Physics, Oxford University Press, 2008.

2. S. Datta, Electronic Transport in Mesoscopic Systems, Cambridge University Press, 1997.

Reference Books:

1. S. Datta, Quantum Transport: Atom to transistor, Cambridge University Press, 2005.

2. B.L. Altshuler (Editor), P.A. Lee (Editor), R.A. Webb (Editor), Mesoscopic Phenomena in Solids (Modern Problems in Condensed Matter Sciences), North Holland (July 26, 1991).

3. D. K. Ferry, S. M. Goodnick, Transport in Nanostructures, Cambridge University Press, 2009.

4. N. W. Ashcroft and N. D. Mermin, Solid State Physics, Cengage Learning, 1976.5.P. Harrison, Quantum Wells, Wires & Dots: Theoretical and Computational Physics of Semiconductor Nanostructures, Second Edition, WileyScience, 2009.

9.7 PH-603 Advanced Condensed Matter Physics

Credits: 3-0-0-3

Course Preamble: The aim of the proposed course is to introduce the basic notion of condensed matter physics and to familiarize the students with the various aspects of the interaction effects. This course will bridge the gap between basic solid-state physics and the quantum theory of solids. The course is proposed for postgraduate as well as undergrad students. Course Outline: The course begins with a review of some of the basic concepts of introductory condensed matter physics and then sequentially explores the interaction effects of electron-electron/phonon, optical properties of solids, the interaction of light with matter, and finally, the superconductivity.

Course Modules: 1. Second quantization for Fermions and Bosons. Review of Bloch's theorem, tight binding Model, Wannier orbitals, and density of states.

2. Born-Oppenheimer approximation. Effects of electron-electron interactions -Hartree-Fock approximation, exchange and correlation effects. Fermi liquid theory, elementary excitations, quasiparticles.

3. Dielectric function of electron systems, screening, random phase approximation, plasma oscillations, optical properties of metals and insulators, excitons, polarons, fluctuation-dissipation theorem.

4. Review of harmonic theory of lattice vibrations, harmonic effects, electron-phonon interaction -mass renormalization, effective interaction between electrons, polarons.

5. Metal-Insulator transition, Mott insulators, Hubbard model, spin and charge density waves, electrons in a magnetic field, Landau levels, integer quantum Hall effect.

6. Superconductivity: phenomenology, Cooper instability, BCS theory, Ginzburg-Landau theory.

Text books:

1. Solid State Physics by N. W. Ashcroft and N. D. Mermin. (Publisher -Holt, Rinehart and Winston, 1976).

2. Quantum Theory of Solids by C. Kittel. (Wiley, 1987).

3. Condensed Matter Physics by M. P. Marder. (John Wiley & Sons, 2010).

4. Solid State Physics by H. Ibach and H. Luth. (Springer Science & Business Media, 2009).

References:

1. Theoretical Solid State Physics by W. Jones and N. H. March.(Courier Corporation, 1985).

2. Advanced Solid State Physics by Phillips. (Cambridge University Press, 2012).

3. Many-Particle Physics by G. D. Mahan. (Springer Science & Business Media, 2000).

4. Elementary Excitations in Solids by D. Pines. (Advanced Book Program, Perseus Books, 1999).

5. Lecture Notes on Electron Correlation and Magnetism by Patrik Fazekas. (World Scientific, 1999).

6. Quantum Theory of the Electron Liquid by Giuliani and Vignale. (Cambridge Uni. Press, 2005).

9.8 PH-604 Optical Properties of Solids

Credits: 3-0-0-3

Preamble: The study of the optical properties of solids is very important to understand optoelectronics technology in the 21st century. The objective of this course is to know about the classical and the quantum theory of light-matter interactions, the optical properties of low dimensional materials, and the nonlinear optical effects in solids.

Course Outline: The course is focused on the optical properties of several classes of materials. It starts with the classical description of optical processes taking place in solids. Subsequently, it covers the treatment of absorption and luminescence by quantum theory and the excitonic effects. The optical phenomena of semiconductors and metals are covered with an emphasis on quantum structures. The course also includes a discussion about the effect of phonons on optical properties. Finally, a brief introduction to nonlinear optical properties is introduced.

Modules:

Introduction: Optical processes, the complex refractive index, and dielectric constant, quantum theory of radiative transition. [3]

Propagation of light in solid: Phenomenological models-Drude and Lorentz models. quantum mechanical description, linear response functions and Kramers–Kronig relations, dispersion, birefringence, optical anisotropy. [4]

Absorption of light: Interband transitions, transition rate, absorption in direct and indirect semiconductors, spin-orbit coupling, indirect gaps, Urbach tails, Landau levels, Franz-Keldysh the effect, and absorption spectra. [3]

Excitons: Frenkel vs. Wannier excitons, optical selection rules, the effect of Coulomb interaction on interband absorption, Franck-Condon approximation, Huang-Rhys model, Wannier exciton – LO phonon bound states. [3]

Luminescence: Emission from solids, Interband luminescence, photo and electroluminescence, photoluminescence spectroscopy. [3]

Quantum structures: Low dimensional materials and their electronic structures, absorption of quantum well, quantum confined Stark-effect, photoluminescence, optical properties of quantum dots, recent advancement in confined optical materials like zero and two-dimensional materials. [6]

Plasmonic systems: Metals, doped semiconductors, free carrier absorption and plasmons, surface and slab plasmons, plasmons in metallic particles, negative refraction. [3]

Light-phonon interactions: Infrared and Raman active phonons, Phonon absorption and reflectivity, polaritons, polarons, inelastic light scattering (Raman and Brillouin scattering), Feynman diagrams for light scattering. [4]

Impurity centers in semiconductors: Electronic spectrum of shallow donors, multiple valleys, valley-orbit coupling and acceptors, pseudospin-orbit coupling, impurity bands and metal-insulator transition, localized vibrational modes, LO modes bound to neutral impurities, lattice dynamics of isoelectronic impurities, and mixed crystals. [5]

Nonlinear optics: optical nonlinearities, second-order nonlinearities, third-order nonlinearities, optical Kerr effect, stimulated Raman scattering, generation and detection of terahertz radiation, and recent advancement in this field. [6]

Textbooks: 1. Optical Properties of Solids by Mark Fox, Oxford University Press (2010).

References: 1. Optical Processes of Solids by Yutaka Toyozawa, Oxford University Press (2010).

2. Optical Properties of Solids by Frederick Wooten, Academic Press (2013).

3. Solid State Physics Part II Optical Properties of Solids by M. S. Dresselhaus (2001).

9.9 PH-605 Superconductivity

Credits: 3-0-0-3

Preamble: The course is intended for physics students at the advanced undergraduate level or beginning graduate level. It is designed to familiarize students with the phenomenon of superconductivity, its basic theory, and the various experimental techniques employed to understand its exotic physics.

Course Modules:

Module-1 Introduction: Historical perspective, Resistivity, Specific heat, Thermal conductivity, Magnetic Susceptibility and Hall Effect of normal metal; Zero resistance, persistent current, Meissner effect, London-London equations, Penetration depth and critical field. [9]

Module-2 Phenomenological theory of Superconductivity: Free energy, First order, and second order transition, specific heat, thermal conductivity, Superconducting order parameter, Ginzburg-Landau equations and their predictions, Coherence length, Type-I, and Type-II superconductors, The vortex lattice. Phase coherence, Flux quantization. [9]

Module-3 Microscopic Theory of Superconductivity: Isotope effect and its significance. The Cooper problem, Formation of Cooper pairs, BCS wave function, Existence of energy gap, Finite temperature properties of BCS ground state. [9]

Module-4 Tunneling and energy gap: Tunnelling phenomenon, DC Josephson Effect. AC Josephson Effect. Inverse AC Josephson Effect and Shapiro jump, Superconducting quantum interference device (SQUID). [7]

Module-5 Unconventional Superconductors: Alternate pairing mechanisms (e.g. spin-triplet, d-wave etc.), Symmetry of the gap function, Experimental methods for probing Nodal structure, Parity, spin state, Lattice symmetry and internal structure, Heavy Fermion, High-temperature superconductivity, Cuprates, and Fe-based Superconductors. [8]

Textbooks:

Superconductivity by J.B. Ketterson and S.N. Song (Cambridge University Press 1999)

References:

1. Introduction to Superconductivity by M. Tinkham (McGraw-Hill, Inc, 1996).

2. Unconventional Superconductors by Grenet Goll (Springer-Verlag Berlin Heidelberg 2006).

3. Superconductivity by Charles p. Poole Jr., H.A. Farach, R.J. Creswick, R. Prozorov (Elsevier, The Netherlands 2007).

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

9.10 PH-606 Quantum Field Theory

Credits: 3-0-0-3

Preamble: Quantum field theory forms one of the central pillars of modern theoretical physics. The objective of the proposed course is to introduce students to some key ideas and methods in quantum field theory and also discuss relevant applications. Course Outline: The course will start with a review of second quantization and some mathematical tools, such as functional analysis. Then the course will move on to the more formal and rigorous treatment of quantum fields. Important ideas of quantization of fields, symmetries, Feynman diagrams, and propagators will be introduced with several examples in the first five modules (canonical quantization formulation). The instructor can choose either of Module 6 (each of which is aimed at specific applications).

Modules:

Module 1: Mathematical preliminaries, Lagrangian and Hamiltonian density, second quantization, functionals, path integrals, functional field integrals, coherent states for bosons and fermions. [7 hours]

Module 2: Classical fields, Klein-Gordon field, massless scalar field theory, massive scalar fields, Phi-4 theory, complex scalar fields. [5 hours]

Module 3: Schrodinger, Heisenberg, and interaction pictures, time-evolution operator, translations and rotations in space-time, transformations of quantum fields, symmetries, and conservation laws, Noether's theorem. [8 hours]

Module 4: Canonical quantization of fields with examples, normal ordering, internal symmetries, massive vector fields, polarizations, gauge fields, and gauge theory. [7 hours]

Module 5: Propagators and Green's functions, Dyson equation, field and Feynman propagator, S-matrix, perturbation expansion, Wick's theorem, Feynman diagrams. [7 hours]

Module 6 (some applications of field theory in condensed matter physics): Superfluids and fields, Fermi liquid theory, field theory formulation of the many-body problem in metals and superconductors, Hartree-Fock energy, random phase approximation, fractional quantum Hall effect. [8 hours]

Module 6 (some applications of field theory in particle physics): Dirac and Weyl equation, spinors, the transformation of spinors, quantizing the Dirac field, fermion propagator, quantum electrodynamics (QED), Feynman rules, QED scattering cross sections. [8 hours]

Textbooks:

1. Quantum field theory for gifted amateur, by Lancaster and Blundell, Oxford (2014).
2. Quantum field theory, by Mandl and Shaw, John Wiley, and Sons (2010).
3. An introduction to quantum field theory, by Peskin and Schroeder, CRC Press (2018).

References:

1. Quantum theory of Fields, Vol.1, by S. Weinberg, Cambridge (1995).
2. Quantum field theory, by M. Srednicki, Cambridge (2007).
3. Quantum field theory by M. H. Ryder, Cambridge (1996).

Online resources:

1. David Tong: Lectures on QFT http://www.damtp.cam.ac.uk/user/tong/qft.html
2. Lectures on advanced quantum mechanics by Freeman Dyson. https://arxiv.org/pdf/quant-ph/0608140.pdf

9.11 PH-607 Physics of Ultracold Quantum Gases

Credit Distribution: 3-0-0-3

Preamble: With the expanding interest in harnessing quantum science and technology, the main goal of this course is to introduce the basic concepts and fundamentals related to the recent research directions in the field of ultracold atoms, including the ones that investigate fundamental physical problems and those in which highly controllable superfluids are used as quantum simulators of other complex systems. Students will learn the basic tools and acquire competence to be able to read and understand scientific papers dealing with these topics and, in general, with the physics of quantum gases and liquids. At the end of the lectures, students are expected to have a broad knowledge of many topics currently studied worldwide using quantum gases. They will have hands-on experience in numerically solving the Gross-Pitaevskii equation to obtain equilibrium and non-equilibrium solutions and interpret the results.

Course Modules with quantitative lecture hours:

(a) The ideal Bose gas [6 hrs] The Bose-Einstein condensation in ideal Bose gases, Off-diagonal long-range order, Transition temperature and condensate fraction, velocity distribution, Thermodynamic quantities.

(b) Manipulation of atomic internal and external degrees of freedom [6 hrs] Level structure and atomic transitions of alkali-metal atoms, Atom-field interaction, Cooling, trapping, and imaging ultracold gases.

(c) Atom-atom interaction [4 hrs] Contact interaction, scattering length, Feshbach resonances, Dipolar long-range interactions.

(d) Bose-Einstein condensates (BEC) [12 hrs] Condensation and Gross-Pitaevskii equation (GPE) for the macroscopic wave function, BEC dynamics in uniform and trapped configurations; Thomas-Fermi approximation, Hydrodynamic equations, Elementary excitations, BEC as a simulator of the quantum vacuum effects(Hawking radiation and Casimir effect), collapse and supersolidity with dipolar quantum gases.

(e) Atomic mixtures [7 hrs] Coupled GPE, spin waves, phase diagram, Josephson effect and magnetism, Quantum droplets.

(f) Lower dimensional systems as solid-state quantum simulators [7 hrs] Phase fluctuations, Mermin-Wagner-Hohenberg theorem, optical lattices, Bose-Hubbard model, Entanglement, and correlations.

Text books:

1. Atomic Physics; C.J. Foot (Oxford University Press, 2005).

2. Bose-Einstein condensation in dilute gases; C.J. Pethick and H. Smith (Cambridge University Press, 2008).

References:

1. M. Ueda, Fundamentals and New Frontiers of Bose-Einstein Condensation, World Scientific Publishing Company 2010.

2. Lev Pitaevskii and Sandro Stringari, Bose-Einstein Condensation and Superfluidity, Oxford Science Publication, 2016.

3. F. Dalfovo, S. Giorgini, Lev P. Pitaevskii, and S. Stringari, Theory of Bose-Einstein condensation in trapped gases, Rev. Mod. Phys. 71, 463 (1999).

9.12 PH-608 Computer assisted quantum mechanics

Credit Distribution: 2-0-3-3

Preamble:

The objective of this course is to provide an introduction to some of the basic computational techniques used in quantum mechanics. It mainly teaches how to numerically solve Schrodinger equations (both time-independent and time-dependent). It starts with single-particle systems and later deals with many-electron systems. Students have to implement all the methods during the lab sessions using Fortran/C/Python for the specific quantum mechanical problems given. These exercises provide deep insights into some of the computational aspects used in quantum mechanics, particularly in the field of atomic/molecular/condensed matter physics. The hours mentioned below include lectures and lab sessions.

Course Modules with quantitative lecture hours:

Module1: The single-particle problem- Time-independent Schrodinger equation and its solution with the Numerovs method, Bound state solutions for one-dimensional (1D) case such as the Harmonic oscillator, Schrodinger equation for central potentials, solutions of the hydrogen atom, scattering from different types of central potentials, and Response of atoms to external fields.

Module 2: Variational method-The variational principle, Numerical solutions to quantum mechanical problems using variational methods, Plane-wave basis set, and Non- orthonormal basis set.

Module 3: Multi-electron systems-Basics of Hartree-Fock (HF) methods and its numerical implementation to a few selected problems, going beyond HF methods, density functional theory and its implementation with some specific examples for simple atomic systems.

Module 4: Time propagation- Spectral methods, direct numerical integration, split operator, and Crank-Nicolson methods. Implementation of these methods to a few quantum mechanical systems (20 hours)

Text books:

1) Computational Physics by J. M. Thijssen (Cambridge University Press, 2007).

2) Computational Quantum Mechanics by J. Izaac and J. Wang (Springer, 2018).

References:

1) Numerical methods in quantum mechanics by Paolo Giannozzi
(Online lecture notes, http://www.fisica.uniud.it/giannozz/Corsi/MQ/LectureNotes/mq.pdf).

2) Computational physics, R. H. Landau, M. J. Paez and C. C. Bordeianu (2015 WILEY-VCH Verlag).

9.13 PH-609 Theory of quantum collision and spectroscopy

Credit Distribution: 3-0-0-3

Preamble:

The objective of this course is primarily to provide a detailed understanding of the field of collision theory and also to provide an introduction to some advanced topics in many-body theory. It introduces the basic formalism in scattering theory and its applications to a number of cases that are of current research interest. Further, it introduces some of the many-body theoretical techniques that play a very crucial role in order to understand the electronic and photonic collision processes.

Course Modules with quantitative lecture hours:

Module 1: Scattering theory-Quantum collisions: Review of Method of Partial wave analysis, and Integral equation of potential scattering; Lippman-Schwinger equation, Born series and approximations, Applications of scattering: Coulomb scattering, Scattering by complex potential Scattering of identical particles, Pseudo-potential and Bethe–Peierls collision theory, Levinson's and Seaton's theorems. (12 hours)

Module 2: Resonant Scattering-Scattering of the partial wave, Resonances in quantum collisions, Breit-Wigner formalism, Fano parameterization of the Breit-Wigner formula, correlations induced resonances and shape resonances Broad vs. narrow resonances, Resonance lifetime, Eisenbud-Wigner-Smith formalism of time-delay in scattering, recent experiments. (8 hours)

Module 3: Many-body formalism Many-body theory, electron correlations, Second quantization, Many-particle Hamiltonian in occupation number representation, Density fluctuations of the electron gas in the Hartree-Fock method, introduction to density functional theory, Bohm-Pines approach to random phase approximation. (12 hours)

Module4: Relativistic formulation-Foldy-Woutheysen transformations and separation of radial and angular parts of the Dirac equation, introduction to relativistic many-body theory.

Module 5: Feynman diagrammatic methods- Schrodinger, Heisenberg, and Dirac pictures, Dyson's chronological operator, Gell-Mann- Low Theorem, Rayleigh-Schrodinger perturbation methods, and adiabatic switching, Feynman Diagrams, I Order Feynman Diagrams, II and higher order Feynman Diagrams, Linear response of electron correlations. (4 hours)

Textbooks:

1) Physics of Atoms and Molecules, B. H. Bransden & C. J. Joachain (Pearson, 2003).

2) Quantum Theory of Many-Particle Systems by A.L.Fetter and J.D.Walecka (Dover, 2003).

References:

1) Theory of electron-atom collisions, P. G. Burke and C. J. Joachain (Plenum Press, 1995). 2) Many Electron Theory by Stanley Raimes (Elsevier, 1972).

9.14 PH-612 Nuclear and Particle Physics

Credits: 3-0-0-3

Preamble: The objective of the proposed course is to introduce students to the fundamental principles and concepts of nuclear and particle physics. Students will be able to know the fundamentals of the interaction of high-energy particles. This course is expected to provide a working knowledge of real-life problems.

Course Outline: The course begins with basic nuclear phenomenology, including stability. Eventually, it will explore nuclear models and reactions; experimental methods: accelerators, detectors, and detector systems; particle phenomenology: leptons, hadrons, quarks; elements of the quark model: spectroscopy, magnetic moments, and masses.

Modules:

1. Properties of Nuclei: Nuclear size, nuclear radius, charge distribution, mass and binding energy, semi-empirical mass formula, angular momentum, parity and isospin, magnetic dipole moment, electric quadrupole moment, and nuclear shape.

2. Two-body problems: Deuteron ground state, excited states, spin dependence of nuclear forces, two nucleon scattering, charge symmetry and charge independence of nuclear forces, exchange nature of nuclear forces, Yukawa's theory.

3. Nuclear decay: Alpha, Beta, and Gamma decay, Gamow theory, Fermi theory, direct evidence for the neutrino.

4. Nuclear models: Liquid drop model, shell model, magic numbers, ground state spin, and collective model.

5. Nuclear Reactions: Different reactions, Breit-Wigner dispersion relation, Compound nucleus formation and break-up, nuclear fission, neutron physics, fusion reaction, nuclear reactor.

6. Elementary particles: Fundamental interactions. Particle Zoo: Leptons, Hadrons. Organizing principle: Baryon and Lepton Numbers, Strangeness, Isospin, The eightfold way. Quarks: Colour charge and strong interactions, confinement, Gell-Mann – Okubo mass relation, magnetic moments of Hadrons. Field Bosons: charge carrier. The Standard Model: party non-conservation of weak interaction, Wu's experiment, an elementary idea about electroweak unification, Higgs boson and origin of mass, quark model, the concept of color charge, discrete symmetries, properties of quarks and leptons, gauge symmetry in electrodynamics, particle interactions and Feynman diagrams.

Text Books:

1. K.S. Krane, Introductory Nuclear Physics, John Wiley (2008).
2. D. J. Griffiths, Introduction to Elementary Particles, John Wiley & Sons Inc. (2008).

References:

1. W. E. Burcham and M. Jobes, Nuclear and particle Physics, John Wiley & Sons Inc.R. R. (1979).
2. W. L. Cottingham and D. A Greenwood, an Introduction to Nuclear Physics, Cambridge University Press (2001).
3. A. Das and T. Ferbel, Introduction to nuclear and particle physics, John Wiley (2003).
4. M. A. Preston and R. K. Bhaduri, Structure of the nucleus, Addison-Wesley (2008).
5. S. N. Ghoshal, Atomic and Nuclear Physics (Vol. 2) (S. Chand, 2010).
6. Roy and B. P. Nigam, Nuclear Physics: Theory and Experiment, New Age.
7. D. Perkins, Introduction to High Energy Physics, Cambridge University Press; 4th edition (2000).
8. G. L. Kane, Modern Elementary Particle Physics, Westview Press.

9. B. R. Martin, Nuclear and Particle Physics: An Introduction, Wiley (2013).

9.15 PH-701 Introduction to Molecular Simulations

Credits: 2-2-0-4

Course content:

Classical statistical mechanics 1) Ensembles: microcanonical, canonical, grand canonical ensembles ideal gas- harmonic oscillator – Spin Systems. Introduction to Stochastic process, Brownian Motion, Langevin equation, Fokker-Planck equation, Introduction to liquid state theory- pair distribution functions- structure factor- coherent and in-coherent scattering- Ornstein-Zernike correlation function Diffusion in a liquid-mean square displacement- self and collective van Hovecorrelation function – Intermediate scattering function and dynamic structure factor.

2) Programming in C and FORTRAN 95 - essential for programming in this course.

3) Introduction of Monte Carlo methods: Value of using MC method, Gaussian distribution from 1d random walk, Metropolis algorithm for construction NVT ensemble, Implementation of ensemble using MC methods.

4) Proj 1. Write a Monte Carlo simulation to simulate the model liquid.

5) Introduction to Molecular dynamic simulations: Molecular dynamics simulations, Numerical integration of linear differential equations, Leap-Frog algorithm, Velocity Varlet algorithm, Periodic boundary condition one, two, and three dimensions.

6) Proj. 2 Write an MD simulation code for simple liquids and a polymer chain connected by a harmonic spring.

7) Introduction to Brownian and Langevin dynamics simulations: Simple Brownian dynamics algorithm without hydrodynamic interactions. Langevin dynamics simulations.

8) Proj. 3: Write a Brownian dynamics code to simulate colloids in a solution and the motion of a single polymer chain.

9) Analysis data from simulations: Computation of radial distribution function, Structure factor, Time series analysis, and Mean square displacement.

10) Proj 4: Using trajectories produced from the earlier simulation to compute: Radial distribution functions. Mean square displacement of the center of mass and monomers for a polymer chain. Computation of stress, stress correlation function, and viscosity.

Text & Reference Books:

1. Statistical Mechanics R. K. Pathria Introduction stochastic process in physics and astronomy.
2. Rev. Mod. Phys. 1 15(1943) what is liquid?
3. Understanding the state of matter, J. A. Barker and D. Henderson, Rev. Mod.Phys. 587 48 (1976).
4. Theory of simple liquids by J. P. Hansen and I. R. McDonald.
5. Statistical Mechanics by D. A. McQuarrie.
6. Computer simulation of liquids by M. P. Allen and D. J. Tildesey.
7. Understanding molecular simulation by Daan Frenkel.
8. The art of molecular dynamics simulations by D. C. Rappaport.
9. A guide to Monte Carlo simulations in statistical Physics by D. P. Landau and Kurt Binder.

9.16 PH-706 Introduction to Stochastic Problems in Physics

Credit: 3-0-0-3

Course Outline:

Introduction to random walk in 1D, Mean values of random walk problem, Probability distribution for large N, Binomial, and Gaussian distributions, the Probability distribution of many variables, continuous probability distributions, General calculation of mean values for the random walk, Example of random walk problem, freely joined model for polymers, Gaussian chains.

Historical introduction to stochastic process, Einstein's formulation of the random walk, Comparison between ordinary and stochastic differential equations, Differential equation of probability – the diffusion equation from – random walk – kinetic arguments, Definition of the diffusion coefficient.

Langevin equation for a Brownian particle, average velocity and mean square displacement. Formal solution, Probabilistic approach to stochastic process, Birth and death process– master equation. Noise in the electronic system – short noise and Johnson noise.Poisson distribution – formulation of the differential equation, Limitation of ordinary calculus. Definition of a stochastic variable, probability distribution, probability density distribution. Transformation between stochastic variables. Characteristic function, moments and cumulants, Stochastic process of many variables, Conditional probability density, cross-correlations.Multivariate Gaussian distribution.

Time-dependent random variables, stationary processes. Classification or stochastic process, purely random, Markov process, and non-Markovian process.Chapman Kolmogorov equation- Weiner Khinchine theorem.

Langevin equation revisited – velocity autocorrelation function- mean square displacement. Maxwell Boltzmann distribution from moments of velocity. Ornstein Uhlenbeck process, Green's function solution, correlation function, moments, solution by Fourier transformation. Non-linear Langevin equation- Kubo oscillator.Drift and diffusion coefficients – Kramer's Moyal expansion coefficients- Ito and Stratonovich's definitions of stochastic calculus.

Fokker-Planck equation- KramersMoyal Forward and backward expansion and equivalence. The Fokker-Planck equation for one variable. Application of truncated Kramer's Moyal expansion.FP equation of many variables with examples.Methods of solution of FP equation of one variable.

Discussion of Kramer's problem of escape over the barrier. Master equations. Probabilistic approaches molecular systems. BBGKY hierarchy, Boltzmann equation, Quantum stochastic processes. Master equation approaches to density matrix, Linear response theory – fluctuation-dissipation theory.

Text & Reference Books:

1. The Fokker-Planck Equation Methods of solution and applications by H Risken, Springer.
2. Stochastic Methods: A Handbook for the Natural and social science by C Gardiner, Springer.
3. Synergetics: An introduction by Herman Haaken, Springer.
4. An introduction to statistical Communication theory by D Middleton, Peninsula Publishing.
5. Collected papers in noise and stochastic process by Nelson Wax, Dover.
6. Fundamentals of Statistical and thermal physics by F Reif, McGrew Hill.
7. Theory of polymer dynamics by M Doi and S F Edwards by Oxford University Press.
8. An introduction to probability theory and its applications I & II by W Feller, John Wiley & Sons.
9. An introduction to stochastic processes and non-equilibrium statistical physics by H S Wio, World Scientific.

9.17 EN-511 Computational Methods in Material Science

Credit Distribution: 1-0-6-4

Preamble: This course is designed keeping students coming from diverse fields in mind. It assumes an initial knowledge of physics, chemistry, and mathematics at the undergraduate level. It will provide a solid conceptual background necessary for calculating the various physical properties of (especially energy-based) materials mentioned below using standard first principle-based codes. Finally, the students will use ABINIT, AFLOW, and JARVIS codes to calculate these properties with reasonable accuracy.

Course Modules with quantitative lecture hours:

Theory: Density functional theory, Pseudo potentials, Plane wave, and Projector augmented wave methods, Exchange-correlation functionals, Self-consistent solutions, Density of states, Band structures, Optical properties, Electrical and thermal conductivities, Seebeck coefficient, Polarization, Piezoelectric tensor, Specific heat, Entropy, Free energy, Elastic tensors, Moduli of elasticity, phonon dispersion, and Machine learning. [14 Hours]

Laboratory/practical/tutorial Modules: [42 Hours]

Part-1: Introduction to the various features of ABINIT code. Calculations of properties related to (i) Photovoltaic materials: Density of states, Band structures and Optical properties; (ii) Thermoelectric materials: Electrical conductivity, thermal conductivity, Seebeck coefficient, Specific heat, Entropy, Free energy; and (iii) Piezoelectric materials: Polarization, Piezoelectric tensor, Elastic tensors and Moduli of elasticity. [24 Hours]

Part-2: Introduction to the various features of AFLOW and JARVIS codes. Search for new materials with better (i) Electronic, (ii) Optical, (iii) Thermoelectric, and (iv) Piezoelectric properties. [10 Hours] Project: Proposing and demonstrating various scenarios for improving the properties of the existing state-of-the-art Photovoltaic, Thermoelectric, and Piezoelectric materials. [8Hours]

Textbooks:

1. Electronic Structure: Basic Theory and Practical Method, Volume 2 by Richard M. Martin, Cambridge University Press, 2020.

2. Machine Learning in Materials Science: Recent Progress and Emerging Applications by Tim Mueller, Aaron Gilad Kusne and Rampi Ramprasad; A Chapter in Reviews in Computational Chemistry, Volume 29, Editors: Abby L. Parrill and Kenny B. Lipkowitz, John Wiley & Sons, Inc., 2016.

References:

1. The ABC of DFT by Kieron Burke of Department of Chemistry, University of California.

9.18 EP-502 Informatics for Materials Design

Credit Distribution: 2-0-2-3

Preamble: The rapid growth of computational technology and information science has led to a new era of advancement in materials science. In the past decade, many materials databases have emerged where theoretical as well as experimental data is collected. But it is not easy to use these databases without a huge amount of pre-processing, data integration, and deeper domain knowledge. Few efforts using the data-driven approach have shown that machine learning models that enable rapid predictions based on past data are promising approaches for material design. But the field of material design using informatics is still in its infancy. The objective of this course is to introduce students to the fast-growing field of material informatics.

Course Modules with quantitative lecture hours (2 Credits):

Unit/Topic 1: (4 Hours) Computational material science: Crystal Structure and symmetry, Material properties, Property-based classification of materials (mechanical, electrical, thermal, magnetic, optical), Performance of materials, Metamaterials, Need for new materials.

Unit/Topic 2: (9 Hours) State of art techniques: Concept of multiscale modeling, First-principles approach, Density Functional Theory (electronic level), A brief introduction to Schrodinger's equation, Overview of most commonly used approximations (Born Oppenheimer, Local Density Approximations), Kohn-Sham equations, Pseudopotentials, Description of the self-consistent field iterations, Total energy minimization, and Overview of major algorithms in DFT calculations.

Unit/Topic 3: (6 Hours) Databases and Python Scripting: DBMS fundamentals, Design, Workflows, Query writing, python libraries: Numpy, Panda, Pymatgen, Materials database repositories, Materials open database integration APIs.

Unit/Topic 4: (9 Hours) Introduction to Machine learning for material design The philosophy behind machine learning, Basic vocabulary terms, and Algorithms based on learning: supervised and unsupervised, Regression vs. classification, Regression algorithms, Clustering algorithms, Decision tree algorithms, Interpretability analysis using Lyme/Shap. Model-independent Descriptors for material data analytics.

Laboratory/practical/tutorial Modules:

Lab work (1 Credit)

1. Hands on with Quantum Espresso (QE)- 3 Labs
2. Hands on with MySQL- 1 Lab
3. Working with python scripts, use of APIs etc – 2 Labs
4. Creating databases using APIs to fetch material data – 1 Lab
5. Machine learning with Scikit/Weka – 2 Labs

Research project (1 Credit): Based on the use of machine learning/Quantum Espresso for understanding material design and its properties for particular applications like magnetic storage, photovoltaic response, electrical conductivity, magnetism, and spintronic application.

Textbooks: (Relevant and Latest, Only 2)

1. June Gunn Lee, Computational Materials science, CRC press, USA 2012.

2. Aurélien Géron, Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow, 2nd Edition, O'Reilly Media, Inc. 2019.

References:

Online resources for learning SQL, python

Research papers.

Chapter 10 Labs/Facilities

10.1 Special Experiments in the Physics Laboratory

Please also see Figure 10.1 to Figure 10.6.

- Ultrasonic diffraction
- Frank-Hertz
- Dispersion and resolving power
- Fourier optics
- Fabry-Perot interferometer
- Zeeman Effect with Electromagnet
- Research Laboratory
- Scanning tunnelling microscopy
- Vibration sample magnetometer

10.2 Research Laboratory [Central facilities]

Please also visit Advanced Material Research Center (AMRC) at https://www.iitmandi.ac.in/research/amrc/

- Powder X ray diffractometer
- Nuclear Magnetic Resonance Spectrometer
- Transmission Electron Microscope
- Confocal microscope
- Single crystal x-ray diffractometer
- High resolution mass spectrometer
- Field emission scanning electron microscopy
- Gas Chromatography
- Pump probe system
- Physical property measurement system

Figure 10.1: Dispersion and Resolving Power

Figure 10.2: Ultrasonic Diffraction

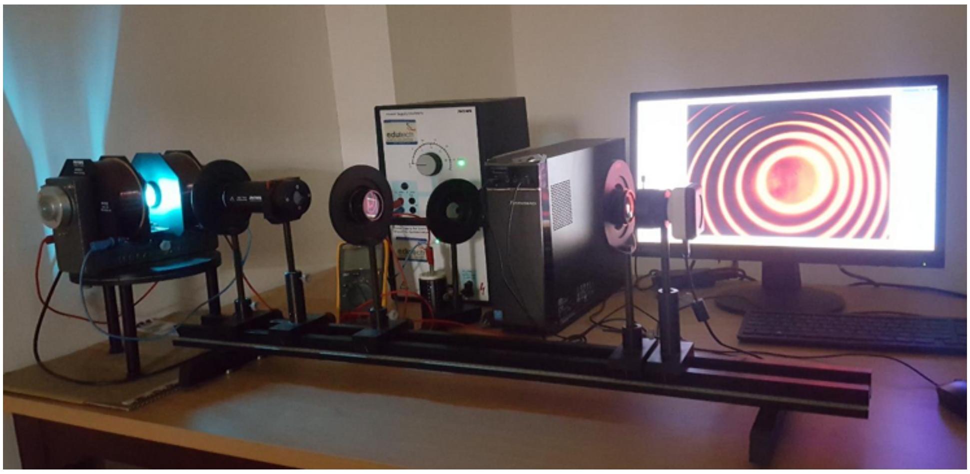

Figure 10.3: Zeeman Effect with Electromagnet

Figure 10.4: Fabry Perot Interferometer

Figure 10.5: Fourier Optics

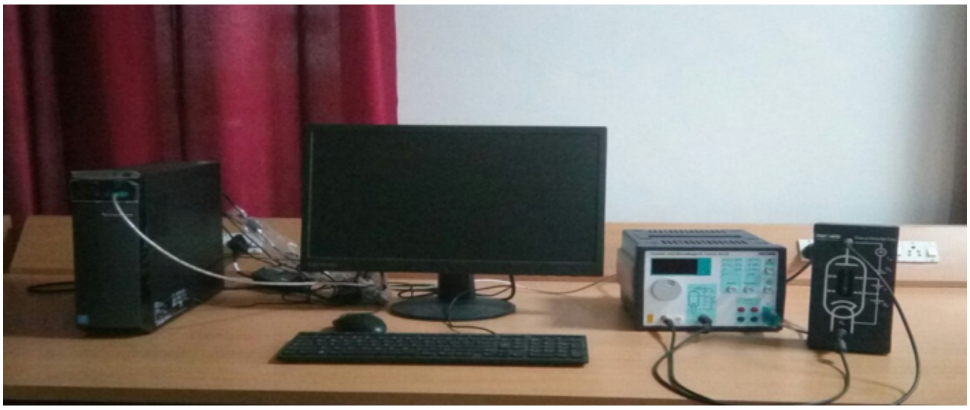

Figure 10.6: Frank-Hertz setup

- Magnetic property measurement system
- Fluorescence spectrophotometer
- Photo emission spectroscopy
- Get permeation chromatography
- Fluorescence lifetime measuring system
- Raman Spectrometer
- High performance liquid chromatography
- Thermo gravimetric analysis with differential scanning calorimetry
- Atomic absorption analysis
- Dynamic light scattering
- Fourier-transform infrared spectroscopy
- UV-vis Spectrophotometer
- Fluorescence spectrophotometer
- Fluorescence lifetime measuring system
- Optical cum polarising microscope
- Circular dichroism spectrometer
- Cyclic Voltammetry (2)
- Photo emission spectroscopy
- Liquid N2 Plant
- Stereo optical microscope
- UV-VIS-NIR Spectrophotometer
- Thermo gravimetric analysis
- Differential scanning calorimetry
- Fluorescence spectrophotometer