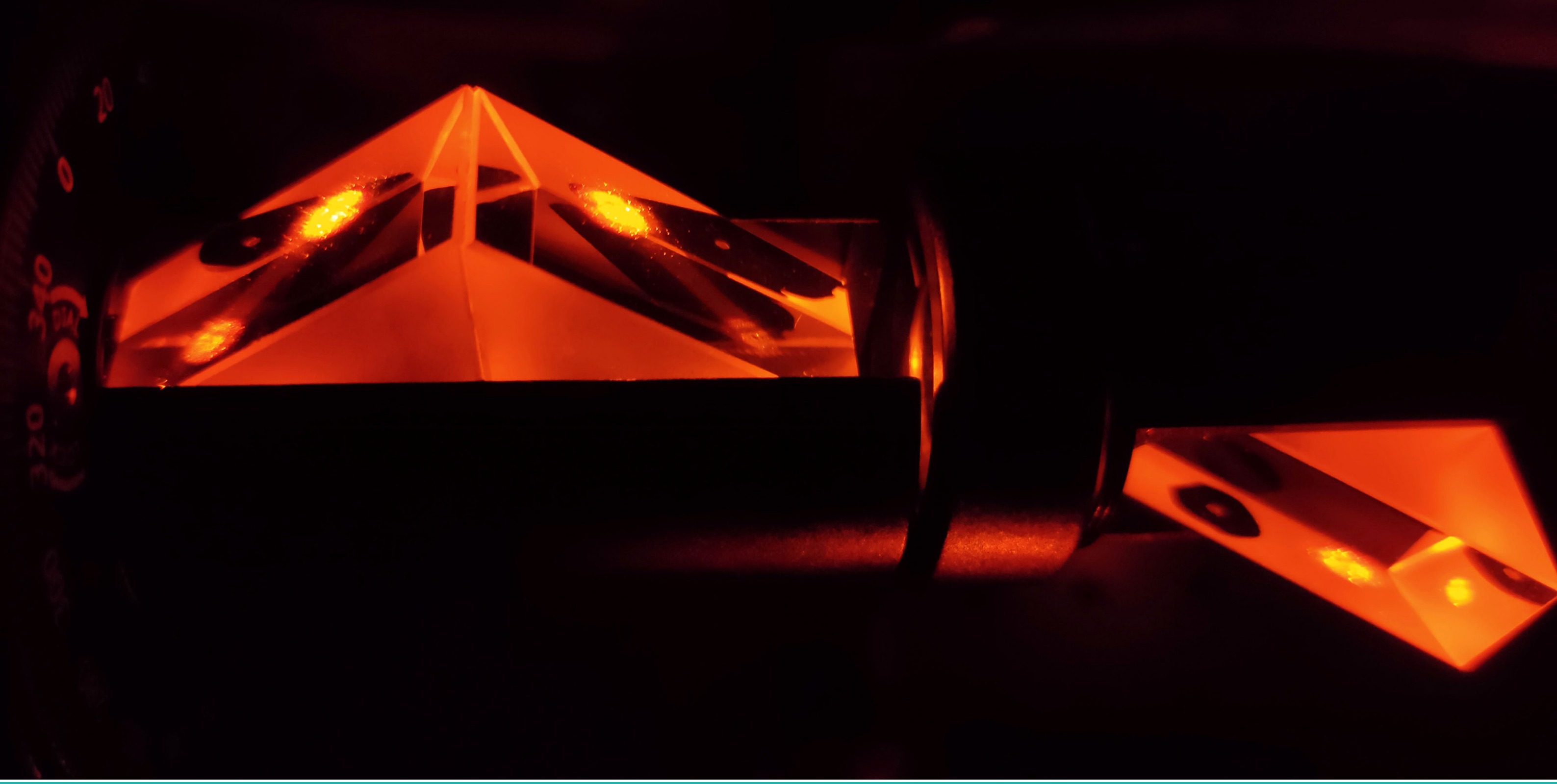


# COURSE HANDBOOK
# MSc, Integrated PhD & PhD Physics.

**School of Physical Sciences,**

**Indian Institute of Technology Mandi.**

**Date:** June 1, 2025 (last updated)

Indian Institute of Technology Mandi

# Contents

# Chapter 1 About Us

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, nineteen bright faculty along with over hundred 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

- 2024 - current: Prof. Bindu Radhamany
- 2022 - 2024: Prof. Suman K. Pal

## 2.2 Faculty advisors

- Batch 2015-16: Dr. Pradyumna Pathak
- Batch 2016-17: Prof. Bindu Radhamany
- Batch 2017-18: Prof. C. S. Yadav
- Batch 2018-19: Prof. Kaustav Mukherjee
- Batch 2019-20: Prof. Ajay Soni
- Batch 2020-21: Prof. Suman K. Pal
- Batch 2021-22: Dr. Gargee Sharma
- Batch 2022-23: Dr. Pradyumna Pathak
- Batch 2023-24: Prof. Bindu Radhamany
- Batch 2024-25: Dr. Amal Sarkar
- Batch 2025-26: Prof. Hari Varma

## 2.3 Laboratory staff

Ms. Aditi Thakur
Mr. Vinod Kumar

## 2.4 Office Staff

Mr. Anugrah Rawat
Mr. Sunil Thakur
Mr. Devesh Sharma

## 2.5 Faculty

At present there are 19 faculties working in the department. Their field of specialization falls into the following categories.

- Soft Matter Physics
- Condensed Matter Physics
- Atomic, Molecular and Optical Physics (including Quantum Information and Communication)
- High Energy Physics (including Cosmology, Nuclear and Particle Physics, String theory)

**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 | 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 | Professor | Experimental Condensed Matter Physics |  |
| Arko Roy | Assistant Professor | Theoretical Atomic, Molecular and Optical Physics |  |
| Tanushree Roy | Assistant Professor | Active Matter, Nonlinear Dynamics |  |
| Amal Sarkar | Assistant Professor | Experimental High Energy Physics |  |
| Ajay Soni | Professor | Experimental Condensed Matter Physics |  |
| Harsh Soni | Assistant Professor | Theoretical Soft Matter Physics |  |
| Hari Varma | Professor | Theoretical Atomic, Molecular and Optical Physics |  |
| C. S. Yadav | 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.

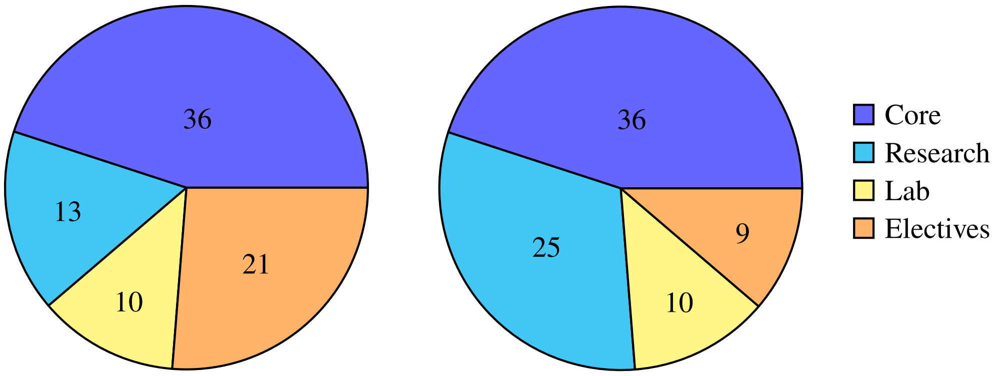



**Figure 4.1:** Course distribution for MSc (left) and IPhD (right)

## Course Content for MSc. Physics

| 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.*

## Course Content for Integrated PhD Physics

| 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-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.

## 9.2 PH-504 Organic Optoelectronics

**Credits:** 3-0-0-3
**Course Preamble:** This course will help to acquire knowledge in the field of organic electronics and optoelectronics: basic theory, applications, recent developments, etc. It will help to study and understand scientific literature in this field by knowing relevant terminology. The course contains an overview of organic electronic and optoelectronic devices. Various relevant phenomena of organic materials and their applications in light emitting devices, solar cells and thin film transistors, etc. are discussed. Aspects related to device fabrication may also be addressed.
**Course Contents:**
**PART I**

- **Organic Molecules:** Electronic structure of atoms, Atomic and Molecular Orbitals, LCAO, Bonding and antibondig orbitals, Covalent Bond, Sigma and Pi Bonds, Energy Levels, Spectroscopic properties [4 Lectures]
- **Photophysics of Molecules and Aggregates:** Excited states: Absorption and emission, Singlet and triplet states, Radiative and non-radiative transitions, Aggregates, Van der Waals Bonding, Hydrogen Bonding, Dimer, Eximers. [2 Lectures]
- **Excitons**: Wannier Exciton, Charge-transfer Exciton Frenkel Exciton, Exciton Diffusion, Excitonic Energy Transfer. [2 Lectures]
- **Conduction in Organic Solids:** Conductivity: carrier concentration versus mobility, Carrier generation, Hopping transport, Mobility measurements, Traps. [2 Lectures]
- **Photovoltaics and Photodetectors:** Photovoltaic Devices: Organic Heterojunction Photovoltaic Cells, Organic/Nanorod hybrid Photovoltaics, Gratzel Cells (Dye sensitized solar cells),Photodetector Devices [5 Lectures]
- **Organic Light Emitting Devices:** Basic OLED Properties, Charged Carrier Transport, Organic LEDs, Quantum Dot LEDs. [8 Lectures]
- **Lasing Action in Organic Semiconductors:** Lasing Process, Optically Pumped Organic Lasers, Electrical Pumping of Organic Lasers. [2 Lectures]
- **Organic Thin Film Transistors: OFETs:** Materials, Contacts, Applications, Nanotube Transistors. [2 Lectures]
- **Device Fabrication Technology:** Growth Techniques: Evaporation, Langmuir-Blodget, Chemical Vapor Phase Deposition, Ink-Jet Printing, Self Assembly.
  **PART II.**
- **Project:** Literature review on a certain relevant topic. [10 Lectures]

**TEXTBOOK**
No textbook required. Lecture notes and handouts will be provided
**GENERAL REFERNCES**
1. "Essentials of Molecular Photochemistry", Gilbert Baggott, CRC Press, 1991.
2. "Fundamentals of Photochemistry" K. K. Rohatgi-Mukherjee, NewAge International, 1978.
3. "Electronic Processes of Organic Crystals and Polymers" , Pope Swenberg, Oxford University press, 2nd edition (1999).
4. "Organic Semiconductors" H. Meier, VerlagChemie GmbH, 1974
5. "Physics of Organic Semiconductors" Wolfgang Brütting, John Wiley  Sons Canada; 1 edition (2005)

6. “Organic Electronics: Materials, Manufacturing, and Applications”, Hagen Klauk, John Wiley Sons; 1st edition (2006)
7. “Electrical transport in solids: with particular reference to organic semiconductors”, Kao, Pergamon Press; 1st edition (1981).

## 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-521 Electromagnetic Theory

**Credit Distribution:** 4-0-0-4

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

**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 covariant formulation of classical electrodynamics.

**Modules:** 1. Overview of Electrostatics Magnetostatics: Differential equation for electric field, Poisson and Laplace equations, Boundary value problems, Dielectrics, Polarization of a medium, Electrostatic energy, Differential equation for magnetic field, Vector potential, Magnetic field from localized current distributions [10]

2. Maxwell's Equations: Maxwell's equations, Gauge symmetry, Coulomb and Lorentz gauges, Electromagnetic energy and momentum, Conservation laws. [8]

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 wave guides. [12]

4. Electromagnetic Radiation: Electric dipole radiation, Magnetic dipole radiation, Radiation from a localized charge, The Lienard-Wiechert potentials [10]

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 contravariant 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)

## 9.6 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.

## 9.7 PH 530: Cosmology-I

**Credits:** 3-0-0-3

**Course Contents**

- **Introduction:** What is Cosmology? A brief history of the Universe a Cosmological erasination, reheating, recombination,etc. Time and length scales involved in Cosmology What is our beloved universe made of? (1 Hour)
- **Homogeneous Universe:** The Cosmological Principle Geometry of the Universe a The FLRW Metric Kinematics a The Hubble Law a Geodesics a Redshift Distances a Luminosity a Angular Diameter Dynamics a Energy Budget of the Universe a Friedmann Equations Some Exact solutions Our Universe. (14 hours)
- **Hot Big Bang:** Thermal Equilibrium a Some aspects of Statistical Mechanics a Primordial Plasma a Entropy and Expansion History a Cosmic Microwave Background a Cosmic Background Beyond Equilibrium a The Boltzmann Equation a Dark Matter Freeze Out a Big Bang Nucleosynthesis More on recombination. (15 hours)
- **Cosmological Inflationary Theory:** Problems faced by the Big Bang Theory a The Horizon Problem a The Flatness Problem a Superhorizon Correlations Before the Hot Big Bang The Physics of Inflation a How in inflation solves these problems? a Slow Roll Inflation. (12 hours)

**Textbooks:**

1. Daniel Baumann, **Cosmology**, Cambridge University Press, 2021
2. Scott Dodelson & Fabian Schmidt, **Modern Cosmology**, Academic Press, Elsevier, 2021.

**References:**

1. Steven Weinberg, **Cosmology**, Cambridge University Press, 2008
2. Valery Rubakov and Dmitry Gorbunov, **Introduction to the theory of Early Universe**, Volume1&2, World Scientic, 2011
3. Luca Amendola, **Cosmology Lecture Notes**, University of Heidelberg, 2023
4. Viatcheslav Mukhanov, **Physical Foundations of Cosmology**, Cambridge University Press, 2005.
5. Andrew Liddle, David Lyth, **Cosmological Ination and Large Scale Structure**, Cambridge University Press, 2000.

## 9.8 PH 550: Introduction to Quantum Optics

**Credits:** 3-0-0-3
**Prerequisites:** Basics of Quantum Mechanics, Classical Electrodynamics, Mathematical Methods for Physics
**Course Contents**

- **Module 1: Two-Level Atom System** (8 lectures)
  - Oscillating dipoles and Bloch sphere representation
  - Density Operator and Density Matrix formalism
  - Optical Bloch Equations
  - Rabi Frequency and Spontaneous Decay
  - Lineshape in Fluorescence and Saturation Broadening
- **Module 2: Quantization of the Electromagnetic Field** (14 lectures)
  - uantized Modes and Operators
  - Ladder Operators, Number Operator, and Quadrature Operators
  - Quantization of the Electromagnetic Field
  - Hamiltonian of Radiation Field and Vacuum State Energy
  - Fock States, Coherent States, and Squeezed States
  - Thermal States and Planck's Black Body Radiation Formula
- **Module 3: Photon Statistics and Measurement** (10 lectures)
  - Photon Statistics
    - Poissonian, Sub-Poissonian, and Super-Poissonian light
    - Intensity interferometer and Hanbury Brown–Twiss experiments
    - Second-order correlation function, g2(t)
    - Photon bunching and antibunching phenomena
    - Coherent, Bunched, and Antibunched light
  - Experimental Demonstrations
    - Photon antibunching experiments
    - Single-photon sources and their application in quantum technologies
- **Module 4: Atoms in Cavities** (10 lectures)
  - Optical and Microwave Cavities
    - Fundamentals of Optical Cavities
    - Microwave Cavities and Rydberg Atoms
  - Atom-Cavity Coupling
    - Weak coupling regime and the Purcell Effect
    - perimental observations of the Purcell Effect
    - Strong coupling regime and Cavity QED
    - Experimental observation of strong coupling in cavities

**Text books:**

1. Scully, M. O., & Zubairy, M. S., Quantum optics.
2. Christopher Gerry and Peter Knight, Introductory Quantum Optics.
3. Mark Fox, Quantum Optics.
4. Leonard Mandel and Emil Wolf, **Optical Coherence and Quantum Optics**.

## 9.9 PH 579: Quantum Computation and Information

**Credits:** 3-0-0-3

**Course Contents**

- **Foundations of Quantum Computing**: Introduction to Quantum Computing, Review of linear vector spaces, Review of Quantum postulates, Qubits and Bloch Sphere, Basic Quantum Gates, Quantum Circuits, Quantum No-Cloning Theorem and Teleportation, Quantum Teleportation Protocol, Quantum Dense Coding, Density Matrix I. (Lectures 1–10)
- **Advanced Quantum Concepts**: Density Matrix II, Projective Measurement, Positive Operator-Valued Measure (POVM), EPR Paradox and Bell's Inequalities I, Bell's Inequalities II, Deutsch Algorithm, Deutsch-Jozsa Algorithm, Simon's Problem, Grover's Search Algorithm I, Grover's Search Algorithm II. (Lectures 11–20)
- **Quantum Algorithms and Applications**: Grover's Search Algorithm III, Grover's Search Algorithm IV, Quantum Fourier Transform I, Quantum Fourier Transform II, Period Finding Problem, Method of Continued Fractions, Shor's Factorization Algorithm I, Shor's Factorization Algorithm II, Quantum Error Correction Codes I, Quantum Error Correction Codes II. (Lectures 21–30)
- **Quantum Information Theory and Cryptography**: Classical Information Theory, Shannon Entropy I, Shannon Entropy II, Von Neumann Entropy I, Von Neumann Entropy II, Classical Cryptography, RSA Algorithm, Quantum Cryptography: BB84 Protocol, Quantum Cryptography: B92 and Eckert Protocol. (Lectures 31–39)
- **Advanced Topics in Quantum Computing**: Practical Realization of Quantum Computers, Future of Quantum Computing, Introduction to Quantum Simulators (QISKIT, etc.). (Lectures 40–42)

**Text books:**

1. Michael A. Nielsen and Issac L. Chuang, Quantum Computation and Information, Cambridge, 2002)
2. Mikio Nakahara and Tetsuo Ohmi, Quantum Computing, CRC Press, 2008.
3. N. David Mermin, Quantum Computer Science, Cambridge, 2007.

## 9.10 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.

## 9.11 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).

## 9.12 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).

## 9.13 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).

## 9.14 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).

**Course outline:**

**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]

**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

## 9.15 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:**

1. **The ideal Bose gas [6 h] :** The Bose-Einstein condensation in ideal Bose gases, Off-diagonal long-range order, Transition temperature and condensate fraction, velocity distribution, thermodynamic quantities.
2. **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.
3. **Atom-atom interaction [4 hrs]:** Contact interaction, scattering length, Feshbach resonances, Dipolar long-range interactions.
4. **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.
5. **Atomic mixtures [7 hrs] :** Coupled GPE, spin waves, phase diagram, Josephson effect and magnetism, Quantum droplets.
6. **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).

## 9.16 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).

## 9.17 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)

**Module 4:** 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).

## 9.18 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).

## 9.19 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
**Course Contents:**

1. Basic introduction to operating system fundamentals . (4 lectures)
2. Introduction to C: Program Organization and Control Structures loops, arrays, and function, Error, Accuracy, and Stability. (8 lectures)
3. Interpolation and Extrapolation - Curve Fitting: Polynomial Interpolation and Extrapolation Cubic Spline Interpolation Fitting Data to a Straight Line, examples from experimental data fitting (8 lectures)
4. Integration and differentiation:Numerical Derivatives Romberg Integration Gaussian Quadratures and Orthogonal Polynomials, (8 lectures)
5. Root Finding:Newton-Raphson Method Using Derivative - Roots of a Polynomial (8 lectures)
6. Ordinary Differential Equations: Runge-Kutta Method, Adaptive Stepsize Control for Runge-Kutta, Examples from electrodynamics and quantum mechanics (8 lectures)
7. Matrices and algebraic equations: Gauss-Jordan Elimination Gaussian Elimination with Backsubstitution, LU Decomposition (8 lectures)
8. Concept of simulation, random number generator (2 lectures)

**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).

## 9.20 PH-625:Data Analysis in Particle Physics

**Credits:** 2-0-4-4

**Preamble:** The objective of the proposed course is to introduce students to one of the most advanced computing methods for data analysis. This course will begin with the basic ideas of numerical computing using C++, followed by various numerical techniques in the ROOT framework. ROOT is a data-processing and mining framework born at CERN in the heart of high-energy physics research, but it can be applied in any field—including astrophysics, neuroscience, and beyond. In ROOT, powerful mathematical and statistical tools are provided to operate on your data. The full power of a C++ application and of parallel processing is available for all kinds of data manipulation. Data can also be generated following any statistical distributions and models, making it possible to simulate complex systems.

Through this course, students will learn how to connect real-world physics experiments with data-driven interpretation of physical phenomena. They will gain hands-on experience with the latest studies from the Large Hadron Collider at CERN, including the discovery of Standard Model particles and searches beyond the Standard Model.

**Course Contents:**

The course will cover the fundamental ideas of data processing, handling, and mining using various numerical techniques for physics analysis within the ROOT framework developed at CERN. Beginning with basic C and C++ computing, students will develop the skills to apply ROOT's powerful mathematical and statistical tools to real data. Topics include Monte Carlo simulation, complex systems modeling using statistical distributions, and parallelized data workflows.

**Data in Experiments, Particle Physics [4 Lectures]**

1. Brief overview of experiments in High Energy Physics. RHIC CERN experiments.
2. Data from Experiments: Pulse processing, Timing and energy resolu- tion, Tracking, Particle Identification (PTD).
3. Analysis Methods: Acceptance, Efficiency, Error Calculations, Observ- able quantities.
4. Data Stmcture/Type/Fonnat and algorithms from experiments and handling.

**Recalls [10 Lectures]**

1. Brief Overview of c++: Program Organization and Control Stmctures loops, arrays, and fimction, Error, Accuracy, and Stability. Transition from C to c++.
2. Brief Overview of numerical analysis in c++: Curve Fitting, ROOT finding, Integration and differentiation, Interpolation and Extrapola- tion

**ROOT Framework and Familiarities [in root/pyroot/rootpy] [15 Lectures]**

1. Introduction to ROOT: Is an object-oriented programming framework based on c++ developed by CERN. Originally designed for particle physics, but it is used in other applications such as astronomy and data mining. ROOT has capability to work in any field and potential to scale globally.
2. ROOT installation: ROOT is available on Linux, Mac. and (as a beta release) on Windows. The latest stable ROOT re lease is updated.
3. ROOT preliminaries:
4. Mathematical foundation, input, output, functions
5. Histograms handling: Writing and reading: Basic, Binning, Statistical analysis: lD, 20,30
6. Tree handling: Writing and reading of the key feature of root
7. Libraries and useful tools

8. Fitting data: Formulas, Reading data, Writing data, TFI functions, Fittings.

**Visualization in ROOT [in root/pyroot/rootpy] (10 Lectures)**

1. Histograms: 1D, 2D, 3D and asymmetric binning
2. Trees, TProfiles, TBrower
3. Graph Plotting, TCanvas, TGraph, TGraphError, Graphs with asym- metric error.
4. Markers and legends
5. Histograms fitting with function

**Statistical Analysis and Error Methods (7 Lectures)**

1. Statistical Analysis
2. Statistical Error: Gaussian Method, Delta Theorem, Bootstrap method
3. systematic error Estimation

**Data Gneration and Models (5 Lectures)**

1. Concept of Simulation
2. Random Generators
3. Monte Carlo Simulation and Data Generation

**Data Analysis: Class Project (5 Lectures)**

1. Astro Physics data analysis High Energy Physics data Analysis

**Textbooks:**

1. Yashavant Kanetkar, Let Us C: Authentic guide to C programming.
2. Yashavant Kanetkar, Let Us C++.
3. https:/IROOT.cem/manual/
4. David J. Griffiths, Introduction to Elementary Particles
5. William R. Leo, Techniques for Nuclear and Particle Physics Experiments
6. Fred James, Statistical Methods in Experimental Physics

**References:**

1. Yashavant Kanetkar, Let Us C++ Solutions
2. ROOT.cern.ch
3. cern.ch
4. rhic.bnl.gov

## 9.21 PH-626: Elementary Theoretical Particle Physics

**Credits:** 3-0-0-3
**Intended for:** UG/PG/I-PhD/PhD
**Prerequisite:** PH612 (Nuclear and Particle Physics), PH301/PH513 (Quantum Mechanics)
**Course Contents:**

- **Feynman Calculus:** Decays, scattering and cross-sections, Mandelstem variables, Fermi Golden rule, Golden rule for two particle decays and scattering of particles, two-body scattering in the COM frame. Feynman rules and diagrams for a toy theory. (6 Lectures)
- **Quantum Electrodynamics:** Dirac equation, solutions to the Dirac equation, and bilinear covariants, photon, Feynman rules for QED and examples, Casimir's Trick, cross-sections and lifetimes, and renormalization, hadron production in e+e- collisions, elastic electron-proton scattering. (10 Lectures)
- **Quantum Chromodynamics:** Feynman rules for Chromodynamics, Color factors, quark and antiquark, Pair annihilation in QCD, asymptotic freedom. (8 Lectures)
- **Weak Interactions:** Charged leptonic weak Interactions, decay of muon, neutron, and pion, charged weak interactions of quarks, neutral weak interactions, Electroweak unification and chiral fermion states, Weak isospin and hypercharge, Electroweak mixing. (10 Lectures)
- **Gauge Theories:** Lagrangian formulation of classical particle mechanics and Lagrangians in relativistic field theory, Local gauge invariance and Yang-Mills Theory, Chromodynamics, Feynman rules and Mass term Spontaneous symmetry-breaking, Higgs Mechanism. (8 Lectures)

**Textbooks:**

1. David Griffiths, **Introduction to Elementary Particles**, 2nd edition, Wiley, 2008.
2. F. Halzen and A. D. Martin, **Quarks and Leptons**, John Wiley, 2016.

**References:**

1. M. Thomson, **Modern Particle Physics**, Cambridge University Press India, 2016.
2. M. E. Peskin, **An Introduction to Quantum Field Theory**, Westview Press, 1995.
3. D. H. Perkins, **Introduction to High Energy Physics**, 4th Edition, Cambridge, 2000.

## 9.22 PH 627: Topological Quantum Matter

**Credits:** 3-0-0-3
**Intended for:** UG/PG/I-PhD/PhD
**Prerequisite:** PH513, PH523
**Course Contents**

- The basics: Potentials in quantum mechanics, Aharanov-Bohm effect, Monopoles in physics, Berry phase. [4 Lectures]
- Symmetries: Time-reversal symmetry (TRS) in classical and quantum mechanics, TRS operator, Kramer's degeneracy, Symmetries in momentum space, Inversion symmetry, particle-hole symmetry, ten-fold classification. [6 Lectures]
- 1D Lattice models: Lattice models and band in momentum space, Peierl's instability, Su-Schrieffer-Heeger model, Berry phase effect on dynamics, topological index, charge fractionalization. [6 Lectures]
- Quantum Hall Effect: Kubo formula and TKNN invariant, quantization of Hall conductance, QHE in 2DEG, Landau levels, QHE in graphene. [6 Lectures]
- Topological insulators: Graphene, Dirac points, topological insulators, , Anomalous Hall Effect, BHZ model, edge states of BHZ model. Kane-Mele model, Z2 invariant, 3D topological insulators, strong and weak TI. [6 Lectures]
- Topological metals: Accidental degeneracies, Weyl and Dirac fermions, symmetry analysis, chiral anomaly, anomalous Hall effect, Fermi arcs, Weyl semimetals, Dirac semimetals. [5 Lectures]
- Majorana fermions: Topological superconductivity, Majorana fermions, Majorana modes in chiral p-wave superconductors, Majorana modes in Rashba spin-orbit coupled semiconductors, detection of Majorana fermions. [5 Lectures]
- Miscellaneous Topics: Quantum Spin Liquid, RVB, Kitaev model, spin fractionalization. Materials research, experimental realization of several topological phases in TIs and topological metals. Electronic structure theory aspect of topological phases. [4 Lectures]

**Textbooks:**

1. B. Andrei Bernevig, Taylor L. Hughes, Topological Insulators and Topological Superconductors, Princeton Universtiy Press, 2013
2. Shun-Qing Shen, Topological Insulators: Dirac Equation in Condensed Matter, Spinger, 2012

**References:**

1. R. Shankar, **Topological Insulators - A review**, https://arxiv.org/pdf/1804.06471.pdf
2. M. Z. Hasan, C. L. Kane, **Topological Insulators**, https://arxiv.org/pdf/1002.3895.pdf
3. Xiao-Liang Qi and Shou-Cheng Zhang, **Topological insulators and superconductors**, https://arxiv.org/pdf/1008.2026
4. N.P. Armitage, E. J. Mele, Ashvin Vishwanath, **Weyl and Dirac Semimetals in Three-Dimensional Solids**, https://arxiv.org/pdf/1705.01111.pdf
5. David Vanderbilt, **Berry Phases in Electronic Structure Theory**, Cambridge University Press, 2018

## 9.23 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.

## 9.24 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.

## 9.25 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.

## 9.26 MA-511 Real Analysis

**credit :** 3-1-0-4

**Preamble:** The objective of this course is to introduce real analysis. Real analysis is a backbone of mathematics (pure and applied both) for example we need to have a profound knowledge of real analysis to study partial differential equation, functional analysis, probability theory etc.

**Course Content:**

1. Introduction to real numbers, Construction, Dedekind cuts, Completeness property, Archimedean property, Countable and uncountable set.

2. Open balls and open sets in Euclidean space, Definition of interior points, Closed sets, Adherent points, Accumulation points, Closure, Bolzano-Weirstrass Theorem, Cantor intersection theorem, Heine-Borel Theorem, Compactness. [6hours]

3. Metric spaces, Open sets, Closed sets, Dense sets, Metric subspaces, Compact subsets of a metric space, Boundary of a set, Totally boundedness, Completeness.

4. Convergent sequences in a metric space, Cauchy sequences, Complete metric space, Limit of a function, Continuous functions, Continuity of composite functions, Continuity and inverse image of open and closed sets, Functions continuous on compact sets, Connectedness. [8hours]

5. Review of Riemann Integration, Riemann-Stieltjes integral: definition and examples, Properties of the integral. [4hours]

6. Uniform continuity, Fixed point theorem for contractions, Sequences of functions, Point wise convergence of sequences of functions, Uniform convergence of sequences of functions, Uniform convergence and continuity, Cauchy condition for uniform convergence, Uniform convergence of infinite series of functions, Cauchy condition for uniform convergence of series, Weirstrass M-test, Dirichlet's test for uniform convergence, Uniform convergence and differentiation, Uniform convergence and integration [10hours]

7. Metric space C[a,b], Characterize compact subsets, i.e., Arzela-Ascoli theorem. [3 hrs]

**Text Books**

1. W. Rudin, Principles of Mathematical Analysis, 3rd ed., McGraw-Hill, 2013.

2. T. Apostol, Mathematical Analysis, 2nd ed., Narosa Publishers, 2002.

**Reference Books** 1. Elias M. Stein and Rami Shakarchi, Real Analysis, Princeton Lectures, 2010.

2. Terrance Tao, Analysis I and II, Trim, Hindustan book agency, 2006.

## 9.27 MA-512 Linear Algebra

**credit:** 3-1-0-4

**Preamble:** Problems in linear algebra arise in a wide variety of scientific and engineering applications including the design of structures, the analysis of electrical networks, and the modeling of chemical processes. This course will cover the analysis and implementation of algorithms used to solve linear algebra problems in practice. This course will enable students to acquire further skills in the techniques of linear algebra, as well as understanding of the principles underlying the subject. This course will prepare students for further courses in mathematics and/or related disciplines (e.g. engineering, economics, actuarial science, etc.). At the end of this course, and having completed the Essential reading and activities, students should have used the concepts, terminology, methods and conventions covered in this course to solve the mathematical problems in this subject. Student will also develop the ability to demonstrate an understanding of the underlying principles of the subject and the ability to solve unseen mathematical problems involving an understanding of the concepts and applications of these methods.

**Course Outline:** Unit 1: Matrices, vectors, and systems of linear equations—Introduction to Matrix and Determinant. [Lecture hours: 3]

Unit 2: Vector spaces, basis, dimension – Vector spaces, Subspaces, Subspaces connected with matrices, Linear span, Linear independence, Bases and dimension, Basis and dimension of range and null space. [Lecture hours: 10]

Unit 3: Linear transformations, change of basis - Linear transformations and matrices, Coordinate change, Change of basis and similarity. [Lecture hours: 6]

Unit 4: Diagonalisation - Eigenvalues and eigenvectors, Diagonalisation of a square matrix, Inner products, orthogonality, orthogonal diagonalisation, Applications of diagonalisation, . [Lecture hours: 7]

Unit 5: Direct sums and projections - The direct sum of two subspaces, Orthogonal complements, Projections, Characterising projections and orthogonal projections, Minimising the distance to a subspace. [Lecture hours: 7]

Unit 6: Complex matrices, vector spaces - Complex vector spaces, Complex inner product spaces, The adjoint. Hermitian and unitary matrices, Unitary diagonalisation. Normal matrices, Spectral decomposition. [Lecture hours: 9]

**Text Books:**

1. G.Strang, "Linear Algebra and its Applications",4th Edition, Thomson, (2006).

2. K. Hoffman and R. Kunze, "Linear Algebra", Prentice Hall, (2008).

3. H.Anton, "Elementary Linear Algebra with Applications",9th Edition, John Wiley (2004).

**Reference Books:**

1. Loehr, Nicholas, Advanced Linear Algebra, Taylor Francis Inc, ISBN13: 9781466559011.

2. Iuliana Iatan, Advanced Lectures on Linear Algebra with Applications, LAP Lambert Academic Publishing, ISBN13 : 9783844324105.

3. Sohail A. Dianat, Eli Saber, Advanced Linear Algebra for Engineers with MATLAB, Taylor Francis Inc, ISBN13 : 9781420095234.

## 9.28 MA-513 Ordinary Differential Equations

**Credit:** 3-1-0-4

**Preamble:** Differential equations are very important field in terms of applications as well as theory. This course introduces techniques for solving ordinary differential equations. First unit is basically on methods of solving. The next section "existence and uniqueness" is important especially when there is no way to solve a given differential equations. Other two units are focused on systems of differential equation and second order differential equations, which arises while modeling several physical and natural processes.

The intended outcomes are:

Revising the basic methods of solving an ordinary differential equation

Check if the given system is well defined

Expressing system in matrix form and express solution in the form of matrix

**General Overview:** Solutions methods: General solution methods, Power Series methods with properties of Bessel functions and Legendre polynomials. [8 Hours]

Existence and Uniqueness: Existence and Uniqueness of Initial Value Problems: Picard's and Peano's Theorems, Gronwall's inequality, continuation of solutions and maximal interval of existence, continuous dependence. [11 Hours]

**Systems of Differential Equations:** Algebraic properties of solutions of linear systems, The eigenvalue-eigenvector method of finding solutions, Complex eigenvalues, Equal eigenvalues, Fundamental matrix solutions, Wronskian, Matrix exponential, Nonhomogeneous equations, Variation of parameters, Stability theory for linear and nonlinear systems, Lyapunov function. [16 Hours]

**Boundary value problems:** Green's function, Sturm comparison theorems and oscillations, eigenvalue problems. [7 hours]

**Texts Books:**

1. G.F. Simmons and S.G. Krantz, Differential Equations: Theory, technique and practice, Tata McGraw-Hill, 2007.

2. V. Arnold, Ordinary Differential Equations, MIT Press, 1978. 3. Coddington, E. A. and Levinson, N., Theory of Ordinary Differential Equations, Krieger Publishing Co, 1984.

**Reference Books:**

1. Ahmad, S. Rao, M.R.M., Theory of ordinary differential equations with applications in biology and engineering, EWP publication, 1999.

2. L. Perko, Differential Equations and Dynamical Systems, Texts in Applied Mathematics, Vol. 7, 2nd ed., Springer Verlag, New York, 1998.

3. Devaney, R., Hirsch, M. W. and Smale, S., Differential Equations, Dynamical Systems, and an Introduction to Chaos (2nd Edition), Academic Press, 2003.

4. Birkhoff, G. and Rota, G.-C., Ordinary Differential Equations, wiley, 1989

5. R.P. Agarwal and D. O'Regan, An Introduction to Ordinary Differential Equations, Springer- Verlag, 2008 .

## 9.29 MA-516 Topology

**Credit Distribution :** 3-1-0-4

**Preamble:** This is a basic course on Topology. The main objective of this course is to introduce the basic concepts of Topology. It is a field that has great importance in mathematics and has tremendous applications in various fields of Science and Technology, like applications to Biology, Robotics, Engineering, Computer Sciences, etc. This course will provide the students an opportunity to learn the fundamental concepts of topology, which will be useful for them to learn advanced courses like Algebraic Topology, Algebraic Geometry, etc.

**Content:**

Module 1 : Topological Spaces: open sets, closed sets, neighbourhoods, bases, subbases, limit points, closures, interiors, continuous functions, homeomorphisms. [7Hours]

Module 2: Examples of topological spaces: subspace topology, product topology, metric topology, order topology. [5 Hours]

Module 3: Compactness: compact spaces and its properties, locally compact spaces, one point compactification, paracompactness, Tychonoff theorem. [7 Hours]

Module 4: Countability Axioms: first countable spaces, second countable spaces, separable spaces, Lindeloff spaces. [4 Hours]

Module 5: Separation Axioms: Hausdorff, regular and normal spaces, Urysohn's lemma, Uryohn's Metrization theorem, Tietze extension theorem, partition of unity. [6 Hours]

Module 6: Connectedness: connectedness, path connectedness, connected subspaces of the real line, components and local connectedness. [5 Hours]

Module 7: Quotient topology: examples of quotient topology: construction of cylinder, cone, suspension, Mobius band, torus, topological groups, orbit spaces. [5 Hours]

Module 8: Algebraic Topology: homotopy, deformation retract, contractible spaces, path homotopy, fundamental group. [3 Hours]

**Text Book**

1. G. F. Simmons, Topology and Modern Analysis, Tata McGraw-Hill, 2004. 2. A. Hatcher, Algebraic Topology, Cambridge University Press, 2002.

**References:**

1. J. Dugundji, Topology, McGraw-Hill Inc., 1988. J. R. Munkres, Topology:A First Course, Prentice-Hall, 1975.

2. M. A. Armstrong, Basic topology, McGraw-Hill Book Co. (UK), Ltd., London-New York, 1979

## 9.30 MA-521 Functional Analysis

**Credit :** 3-1-0-4

**Preamble :**

he objective of this course is to introduce fundamental topics in Functional Analysis. The contents are designed in such a way that it will give foundation of Functional Analysis at a level and depth appropriate for someone aspiring to study higher level mathematics. Many of the concepts and results like Hahn Banach, open mapping, closed graph theorems etc are very useful in proving many results in fields like Differential Equations, Numerical Analysis etc.

**Content :**

Module 1: Normed spaces, Examples of Normed Spaces, Subspaces of Normed Spaces, Quotient Normed Spaces, Riesz Lemma, Finite-Dimensional Normed Spaces, Convex Subsets of Normed Spaces, Stronger and Equivalent Norms, Strictly Convex Normed Spaces. [5 hours]

Module 2: Linear Maps Between Normed Spaces, Continuity of linear maps, Examples of Discontinuous Linear Maps on Infinite Dimensional Normed Spaces, Various Criterion for Continuity of Linear Maps, Linear Functionals, Examples of Continuous Linear Maps, Necessary Conditions for the Continuity of Transformations defined by Infinite Matrices, Operator Norm of Bounded Linear Maps, Operator Norm of Transformations defined by Finite Matrices. [5 hours]

Module 3: Hahn-Banach Separation Theorem, Hahn-Banach Extension Theorem, Consequences of Hahn-Banach Extension Theorem, Uniqueness of the Hahn-Banach Extension, Banach Limits.[5 hrs]

Module 4: Banach Spaces, Subspaces of Banach Spaces, Quotient Banach Spaces, Product of Banach Spaces, Canonical Embedding of Normed Spaces, Schauder Basis, Uniform Bounded Principle and its Applications, Banach-Steinhaus Theorem. [8hours]

Module 5: Closed Maps, Closed graph theorem, Linear Projections, Open Maps, Quotient Maps, Open Mapping Theorem and its Applications, Bounded Inverse Theorem. [6hours]

Module 6: Spectrum of Bounded Operators, Resolvent Set, Eigen-spectrum, Approximate Eigen- spectrum, Spectrum of the Right Shift Operator, Compact Operators on Normed Spaces, Spectrum of Compact Operators. [5 hours]

Module 7: Inner Product Spaces, Orthonormal Sets, Bessel's Inequality, Riesz-Fischer Theorem, Fourier Expansion, Parseval Formula, Projection and Riesz Representation Theorems, Bounded Operators and Adjoints, Normal, Unitary and Self-Adjoint Operators. [8 hours]

**Text Books:**

1. B.V. Limaye, Functional Analysis, New Age International Private Limited, Revised Third Edition, New Delhi, x + 612 pp., 2017.

2. B.V. Limaye, Linear Functional Analysis for Scientists and Engineers, Springer, Singapore, xiv + 254 pp., 2016.

3. J.B. Conway, A Course in Functional Analysis, Springer, 2nd Edition, 1990.

**Reference Books:**

1. E. Kreyzig, Introductory Functional Analysis with Applications, John Wiley  Sons, New York, 1989.

2. K. Yoshida, Functional Analysis, Springer, 6th Edition, 1995.

3. C. Goffman and G. Pedrick, A First Course in Functional Analysis, Prentice-Hall, 1974.

4. A. Taylor and D. Lay, Introduction to Functional Analysis, Wiley, New York, 1980.

## 9.31 MA-522 Partial Differential Equations

**Credit :** 3-1-0-4

**Course Outline:**

Introduction to PDE, First order PDEs, Solution methods for first order PDE. (5L)

Classification of Partial Differential Equations, Cauchy Problem, Cauchy Kowalevski Theorem, Classification of Second Order Partial Differential Equations: normal forms and characteristics. Initial and Boundary Value Problems: Lagrange-Green's identity and uniqueness by energy methods. (8L)

Methods of Solution, Methods of separation of variables, Characteristic method, Green's function, Fourier transform (6L)

Stability theory, energy conservation and dispersion. (4L)

Laplace equation: mean value property, weak and strong maximum principle, Green's function, Poisson's formula, Dirichlet's principle, existence of solution using Perron's method (without proof). (5L)

Heat equation: initial value problem, fundamental solution, weak and strong maximum principle and uniqueness results. (5L)

Wave equation: uniqueness, D'Alembert's method, method of spherical means and Duhamel's principle. (5L)

Introduction to Hilbert Spaces of Functions, Sobolev spaces, Weak solution (4L)

**Textbooks:**

1. G. B. Folland, "Introduction to Partial Differential Equations", Princeton University Press, 1995

2. L.C. Evans, Partial Differrential Equations, Graduate Studies in Mathematics, Vol. 19, AMS, Providence, 1998.

**References:**

1. F. John, Partial Differential Equations, 3rd ed., Narosa Publ. Co., New Delhi,1979.

2. E. Zauderer, Partial Differential Equations of Applied Mathematics, 2nd ed., John Wiley and Sons, New York, 1989.

3. M. Renardy and R.C. Rogers, An Introduction to Partial Differential Equations, Texts in Appl. Math. 13, Springer, 1993

4. M.H. Protter and H. F. Weinberger, Maximum Principles in Differential Equations, Prentice Hall, 1967

## 9.32 MA-560 Nonlinear Dynamics and Chaos

**Credit :** 3-0-0-3

**Preamble :**

It is an applied mathematics course designed to provide an introduction to the theory and basic concepts of Nonlinear Dynamics and Chaos. This course will concentrate on simple models of dynamical systems, their relevance to natural phenomena. The main goal of this course is to introduce and describe nonlinear phenomena in physical systems by only using a minimum background in physics and mathematics. The emphasis will be on nonlinear phenomena that may be described by few variables that evolve with time. There will be problem sets that will require use of computer. The computer exercises will be mainly based on the use of MATLAB, but students will be free to use different software tools as desired.

**Course Contents:**

- Module 1: Introduction to Nonlinear Dynamics and Chaos, Recent applications of Chaos, Computer and Chaos, Dynamical view of the world (3hours)
- Module 2: Basics of nonlinear science: Dynamics, Representations of Dynamical Systems, Types of Dynamical Systems, Nonlinearity, Vector Fields of Nonlinear Systems, Nonlinear systems and their classification, Dissipative Systems, Deter- ministic vs. Stochastic Systems, Degree of Freedom, State Space, Phase Space, Attractor (5 hours)
- Module 3: Existence and uniqueness of solutions, Fixed points and Lineariza- tion, Flows on line, Fixed Points and its Stability, Analytical Approach, Graphical approach, Simulation of Equations (5 hours)
- Module 4: Elementary Bifurcation Theory: Saddle Node, Transcritical, Pitchfork, Imperfect, Hopf bifurcation (4 hours)
- Module 5: Two dimensional Flows, Simple Harmonic Mass-Spring Oscillator (4 hours)
- Module 6: Limit Cycle, Ruling out closed orbits, Poincare Benedixson theorem (4 hours)
- Module 7: Chaos and tools for its Detection: Chaos and Butterfly effect (SDIC), Center manifold theory and Poincare maps, Lyapunov Exponents, Power spectrum, phase, Stable and Unstable Manifolds, Frequency Spectra of Orbits, Dynamics on a Torus, analysis of Chaotic Time Series. Examples of chaotic systems: Lorenz Equations, Application of Chaos in sending secret messages, Rossler Equations, Chua's Circuit, Introduction to Fractals, Dimensions of fractals, Cantor Set and Koch curve (6 hours)
- Module 8: One dimensional map, Logistic Map, Henon map, Period doubling Route to chaos, Feigenbaum constants (5 hours)
- Module 9: Statistical description of Chaotic Systems: The concepts of invari- ant measure, Sinai-Ruelle-Bowen measures, ergodicity and mixing, Lyapunov expo- nents, and the dynamical (Kolmogorov-Sinai) entropy, and connecting them to the fractal dimension of invariant sets, and to the escape rate from a chaotic repeller. (6 hours)

**Text books :**

1. H.G. Solari, M.A. Natiello and G.B. Mindlin, Nonlinear Dynamics: a two-way trip from Physics to Maths, Overseas publication, 2019.

2. Jordan, D. W., and P. Smith., Nonlinear Ordinary Differential Equations, Oxford University Press 2007

**References:**

1. K. Allgood, T.Sauer, J.A.Yorke, Chaos: An Introduction to Dynamical sys- tems, Springer Verlag 1998.

2. Ian Stewart, Does God Play a Dice? The Mathematics of Chaos, Blackwell.

3. Laksmanan M Rajsekhar, Nonlinear Dynamics Integrability Chaos and Pat- tern, Springer.

4. F.C. Moon, Chaotic and Fractal Dynamics, Wiley

5. M W Hirsch, S Smale, R L Devaney, Differential Equations, Dynamical Sys- tems, and an Introduction to Chaos

6. Anatole Katok et Boris Hasselblatt, Introduction to the modern theory of dynamical systems, Cambridge University Press, 1995

7. Peter Walters, An introduction to ergodic theory, Springer, 1982

## 9.33 ME-210 Fluid Mechanics

**Credit:** 2.5-0.5-0-3

**Course Objective:** This course is an introductory course in fluid mechanics. It begins by asking the question what constitutes a fluid. In the first part the continuum concept, various classifications of fluids are discussed. The second part introduces concepts of statics, kinematics and dynamics of fluids and underlying governing equations. Finally, solutions to various problem involving internal pipe flows and external flows are treated in the third part. Concepts of compressible flow and computational fluid dynamics are introduced at the end of the course. The course also gives an opportunity to learn various methods in EXCEL and MATLAB to solve simple flow problems.

**Course Content:**

1. Introduction: definition of fluid, liquids and gases, continuum hypothesis, compressible and incompressible fluid/flow, viscosity, stress field, Newtonian and non-Newtonian fluids 6 hrs

2. Fluid Statics: Pascal's law, hydrostatic pressure, standard atmosphere, manometry, center of pressure, forces on partially and fully submerged bodies, buoyancy, metacentric height, stability, rigid body motion. 6 hrs

3. Fluid Kinematics: Lagrangian and Eulerian description of fluid motion, elementary flows, vorticity and circulation, flow lines, stream lines, stream functions, rotational and ir-rotational flows, flow visualization.6 hrs

4. Fluid Dynamics: Newton's second law, fundamental equations of mass, momentum and energy, Reynolds transport theorem, Integral formulation of governing equations, differential formulation, Euler's equation, Bernoulli's equation, Navier-Stokes equation. 8 hrs

5. Internal Flows: fully developed flow, Couette Flow, Hagen-Poiseuille flow, flow through ducts, channels, Venturi, Orifice, flow measurements, friction factor and head loss calculations, Moody's chart, open-channel flow 8 hrs

6. Dimensional Analysis: scaling and similarity, similitude and dimensional analysis, Buckingham – theorem, non-dimensional parameters, model testing. 4 hrs

7. External Flows: Boundary layer flows, flow over an aerofoil, flow over a cylinder and sphere, laminar and turbulent flows, flow separation, lift and drag, D'Alembert paradox, von Karman integral equation, displacement and momentum thickness. 4 hrs

**Text Books:**

1. Fox and Mc Donald, Introduction to Fluid Mechanics, 7th Edition, John Wiley, 2009.
2. White FM, Fluid Mechanics, 6th Edition, Tata McGraw Hill, 2007.

**Reference Books:**

1. Yuan SW, Foundations of Fluid Mechanics, 2nd Edition, Printice Hall, 1988.
2. Streeter VL, Wylie EB and Bedford KW, Fluid Mechanics, 9th Edition, McGraw Hill, 1998

## 9.34 ME-307 Energy Conversion Devices

**Credit:** 4-0-0-0

**Preamble:**

The course is designed to give undergraduate students in Mechanical Engineering experience in applying principles of basic engineering science to the design and analysis of various types of turbomachinery.

**Course content:** Thermodynamics, Thermal power plants: Gas and steam power cycles, Regenerative and reheat cycles, Turbo Machinery: Classification Similitude and specific speeds, Euler turbine equation, Velocity triangles. Turbine and compressor cascades. Axial-flow turbines and compressors: Stage efficiency and characteristics, Radial equilibrium, Governing. Fans, blowers and compressors: Slip factor, performance characteristics. Hydraulic Machines; Pelton wheel, Francis and Kaplan turbines, Draft tubes, Pumps, Cavitation, Fluid coupling and torque converter, Introduction to IC engine. Use of Computer Aided Engineering (CAE) in Turbomachinary Design

**Suggested Books**

S.L. Dixon, Fluid Mechanics, Thermodynamics of Turbomachinery, Third Edition, Pergamon Press, 1998.

Turbines Compressors And Fans 4th edition, S M. Yahya, 2010

Fundamentals Of Turbomachinery, B. K. Venkannna, 200

## 9.35 ME-503 Heat Transfer

**Credit:**

**Preamble:**

**This course is One time approved Course.**

## 9.36 ME-510 Nanomanufacturing

**Credit:** 3-0-0-0

**Preamble:**

The research on nanotechnology is taking a rapid path towards nonmanufacturing to make the breakthroughs of nanoscience/technology in to practical reality. The economic and scientific promise of nanotechnology will not be realized, if wefail to move forward and show commercial viability. The main objective of the courser is to prepare the students to latest advances in both "top down" and "bottom up" approaches and to address the fundamental challenges in nonmanufacturing. Also the course will be motivated to understand the size reduction in the electronic, memory and energy devices and related progress in industry. This new elective course on nanomanufacturing will be complementary to the existing conventional courses in nanoscience and nanotechnology that focuses on underlying science. The designed course will also bridge the gap between the engineering (mechanical and electrical), industrial developments and underlying basic science research.

**Course Outline:** Nanomanufacturing involves large scale, reliable, economic and controlled production of nano scale materials, structures, devices and products. This course will cover various aspects of nanomanufacturing with major emphasis on the growth of 1D (CNT, Si nanowire) and 2D nanostructures (Graphene and other 2D materials) from chemical vapor deposition, thin film deposition techniques, self-assembly, nanopatterning along with several lithography and microfabrication techniques. This course also will include techniques involved in nanoscale characterization and fabrication.

**Module-1:** Introduction to Nanosceience and Nanotechnology [6 Lectures]

Historical developments in size reduction, fundamentals of nanoscale materials and their interactions, properties of nanocrystalline materials, size effects and quantum confinement in semiconductors, different types of nanostructures (zero, one and two dimensional) with specific examples, nanoscience in electronics, mechanics, photonics, biomedical and energy, nanomanufacturing objectives and opportunities, nanomanufacturing challenges.

**Module-2:** Characterizations/fabrication techniques for nanostructures [4 Lectures]

Basic concepts in microscopy, evolution of microscopes, electron microscopy and scanning probe microscopy for structural, microstructural, topological analysis, atomic order and compositional analysis. Application of microscopes in nanoscale characterizations. In- situ microscopy for the growth and fabrications of various nanostructures. Interface of microscopy with nanofabrication techniques.

**Module-3:** Top down approaches for nanomanufacturing (subtractive) [6 Lectures]

Concepts in top down nanomanufacturing, Mechanosynthesis-ball milling, Focused ion beam milling, thin film fabrication, thermal evaporation, E beam evaporation, Sputtering (DC, RF, reactive), thin film growth mechanism and stress evolution, Essentials of photolithography, Ebeam lithography, nanoimprint lithography, Etching methods for fabrication, dry etching and wet etching.

**Module-4:**Bottom up approaches for nanomanufacturing (additive) [8 Lectures]

Solution synthesis of nanostructures, basics of size and shape control, growth by aggregation and oriented attachment, growth from vapor phase, Atomic layer deposition, Chemical vapor deposition, Growth of carbon nanotubes, graphene and 2D materials, Vapor-liquid-solid method, Vapor phase epitaxy, Molecular beam epitaxy, Growth of important semiconductor materials; Si, GaN nanowires.

**Module-5:** Advanced nanomanufacturing techniques and assembly [4 Lectures])

Non lithographic techniques for nanomanufacturing, Template assisted methods, Template less nanopatterning, self-assembly, electric field assisted assembly.

**Module-6:** Selected Topics in Nanomanufacturing and Microfabrication [7 Lectures]
Introduction to VLSI technology, Electrochemical Processing and MEMS/NEMS technology, Challenges and Applications of nanomanufacturing in electronics, display, nanomedicine, green energy building and smart surfaces. Issues of yield and rate of production. High rate and scalable nanomanufacturing; roll to roll manufacturing for nanomaterials. Industrial R D activities, economics and environmental concerns.

**Text Books:**

1. Nanomanufacturing Handbook,Ahemed Busnaina, CRC press, 2006
2. Fundamentals of Microfabrication and Nanotechnology, Marc J.Madou, CRC Press, 2011
3. Emerging nanotechnologies for manufacturing by Waqar Ahmed M.J Jackson William Andrew Publishing, 2009
4. Open course materials (MIT University of Michigan) and Journal articles

## 9.37 ME-603 Advanced Fluid Mechanics

**Credit:** 3-0-0-3

**Introduction:** Eulerian and Lagrangian description of flow; Motion of fluid element translation, rotation and deformation; vorticity and strain-rate tensors; Continuity equation, Cauchy's equations of motion, Derivation of Navier-Stokes equations for compressible flow.

**Exact solutions of Navier-Stokes equations:** Plane Poiseuille flow and Couette flow, Hagen-Poiseuille flow, flow between two concentric rotating cylinders, Stokes first and second problems, flow near a rotating disk, flow in convergent-divergent channels.

**Slow viscous flow:** Stokes and Oseen's approximation, theory of hydrodynamic lubrication.

**Boundary layer Analysis:** Derivation of boundary layer equations; Exact solutions; Approximate methods; Momentum integral method.

**Stability:** Introduction to hydrodynamic stability, Orr-Sommerfeld equation.

**Introduction to Turbulence:** Description of turbulent flow, averaging, RANS, Introduction to turbulent models, Empirical laws.

Text Reference Books:

1.White F M, Viscous Fluid Flow, 3rd Ed, Tata McGrawhill, 2011.

2.Cebeci T and Bradshaw P, Momentum Transfer in Boundary Layers, McGrawHill, 1977.

3.Schlichting H and Gersten K, Boundary Layer theory, 8th Ed, Springer, 2000.

4.Kundu P K and Cohen I M, Fluid Machanics, 4th Ed, Elsevier, 2005.

## 9.38 EE-203 Network Theory

**Credit:** 3-0-0-3

**Preamble:**

The basic objective of this course is to introduce the fundamental theory and mathematics for the analysis of electrical circuits, frequency response and transfer function of circuits. The students will be able extend these fundamental principles into a way of thinking for problem solving in mathematics, science, and engineering

**Course Outline:**

Overview of network analysis techniques, Transient and steady state sinusoidal response. Network graphs and their applications in network analysis. Two-port networks, combination of two ports, Analysis of common two ports, Resonance, Coupled circuits, Scattering matrix and its application in network analysis. Network functions, parts of network functions, obtaining a network function from a given part. Network transmission criteria; delay and rise time, Elmore's and other definitions. Elements of network synthesis techniques. Introduction to filters and frequency response.

**Course Contents**

**Transient Network Analysis:** Transient and steady state sinusoidal re- sponse. Response of RL, RC and RLC networks using Laplace Transforms for unit step, impulse and ramp inputs. [6 Lectures]

**Two Port Networks and their Characterization:** Open circuit, short circuit, hybrid and transmission parameters; Series, parallel and tandem con- nections of two-port networks, multi-port networks, multi-terminal networks; Resonant and band pass circuits, magnetically coupled circuits, analysis of coupled circuits. Network transmission criteria; delay and rise time, Elmores and other definitions. [10 lectures]

**Network Functions:** Concept of complex frequency, Driving point impedances; Transfer functions of networks, Poles and zeros, Stability analysis. [4 Lec- tures]

**Network Synthesis:** Positive real functions and their properties, tests for positive real functions, Hurwitz polynomials; Driving-point synthesis of LC, RC and RL networks, Foster forms and Cauer forms. [8 lectures]

**Network graphs and their applications in network analysis:** [3 lectures]

**Three-Phase A.C. Circuit Analysis:** Analysis of balanced and unbal- anced three-phase networks; Symmetrical components and their application in analysis of unbalanced networks. [3 Lectures]

**Analysis of A.C. circuits with non-sinusoidal inputs:** Filters: Intro- duction to filters, various types of filters - LP, HP, BP and BS. Transforma- tion of LP to other types. Butterworth, Chebyshev and Elliptic approximations to LPF. [2 Lectures]

**Frequency response:** Polar plots, magnitude and phase plots, Bode plot. [6 lectures]

**Text Reference Books:**

1. Franklin Fa-Kun Kuo, Network Analysis and Synthesis, John Wiley Sons, 1996.

2. Van Valkenburg, Network Analysis, PHI Learning, 2014.

## 9.39 EE-211 Analog Curcuit Design

**Credit:** 2-0-2-3
**Preamble:**
**Course Contents:**

BJT/MOS single stage amplifiers, cascade and cascodes [6 hrs]

1. Large signal and small-signal model, biasing, input and output impedance, operating point calculations and design, single ended BIT/CMOS am- plifiers, cascade and cascade amplifiers

BJT/MOS Current mirrors [3 hrs]

1. PVT independent normal current mirror, cascade current mirror, reg- ulated current mirror and Wilson current mirror

Differential Amplifiers [3 hrs]

1. MOS/BJT Differential Pair, qualitative large/small signal analyses, dif- ferential pairs with active loads and common-mode rejection

BJT/MOS Frequency Response

1. High frequency model of single ended and differential amplifiers, Fre- quency response: magnitude and phase plot calculations [3 hrs]

Feedback theory [3 hrs]

1. Properties of negative and positive feedback, loop gain calculations, types of amplifiers, voltage controlled current source (VCCS), current controlled current source (CCCS), current controlled voltage source (CCVS), voltage current voltage source (VCVS), stability analyses un- der negative feedback topology.

Output stages and power amplifiers [3 hrs]

1. Emitter follower as power amplifier, push-pull amplifier, cross-over dis- tortions, large signal considera- tions, heat dissipation, efficiency, Classes of amplifiers

Oscillators and phase locked loop [4 hrs]

1. Barkhausen criteria of oscillation, bistable, monostable and astable multi vibrators, LC, relaxation, phase shift and Colpit oscillators, phase locked loop concept and its understanding, signal generation and wave shaping circuits.

Data converters [3 hrs]

1. Digital-to-analog converters (DAC): R-2R, current scaling and voltage scaling
2. Analog-to-digital converter (ADC): flash, SAR, single slope, dual slope, pipeline and sigma-delta modu- lator.

**Experiment modules:**

1. Introduction to laboratory: DSO and its advance features, XY-mode (Lis- sajous pattern), LTspice and required software.
2. Understanding ofI-V characteristics ofBJT/MOS transistor using net-listing in SPICE simulations.
3. Common emitter amplifier design.
4. Understanding ofMOS class-AB pull-pull amplifier using CD4007 IC.
5. Oscillator: design of ring, LC and phase shift oscillators.
6. Operation ofPLL understanding using 565 IC.
7. Operation of SAR understanding using 0808/0809 I C.

8. Project on analog circuit application.

**Textbook:**

1. Behzad Razavi, Fundamentals of microelectronics, Wiley, 2013.

**Reference book:**

1. A.S. Sedra and K.C. Smith, Microelectronic Circuits-Theory  Ap- plications, 7th Edition, Oxford University Press, 2017.

## 9.40 EE-307 Theory of Measurement

**Credit:** 3-0-0-3

**Preamble:**

Course Contents **Module 1: Characterization of Measurement Systems:** Significanceof Measurements, Units and Standards, Instruments and Measurements,Examples of Measurement System, Instrument Characteristics (Accuracy,Range, Linearity, Sensitivity, Calibration), Dynamic Characteristics (Zero,First and Second Order Systems).

**Module 2: Error and Noise Analysis:** Errors, Classification of Errors, Re-view of Probability and Statistics, Statistical Treatment of Data, RegressionAnalysis (Least Squares), Uncertainty Analysis.

**Module 3: Primary Sensing Elements:** Strain Gauges, Load Cells, LinearVariable Displacement Transformers (LVDT), Potentiometers, CapacitiveTransducers, Thermistors, Thermocouple, Pressure Sensors, Flow Sensors,Piezoelectric transducers.

**Module 4: Signal Conditioning Circuits:** Analog Signal Conditioning:Amplifiers, Voltage Comparator and Filters. Sampling, Quantization, A/DConverter, D/A Converter, Digital Voltmeter, Data Acquisition, Smart Sen-sors.

Text Books:

1. Ernest Doebelin,Measurement System: Application and Design, 5thEdition, McGraw.
2. Richard S. Figliola and Donald E. Beasley,Theory and Design for Me-chanical Measurements, WileySons.
3. D. Patranabis,Principal of Industrial Instrumentation, 3rd Edition,McGraw-Hill.

## 9.41 EE-511 Computer Vision

**Credit:** 3-0-2-4

**Preamble:** Computer vision is an important applied research area encompassing aspects from geometry, machine learning, probabilistic models, optimization etc. The course consists of various important aspects of computer vision namely geometry, motion, image features, and low-level and high-level image labeling. The course is designed such that some fundamental frameworks as well as some contemporary methods are covered. The course also has a lab component, which includes programming assignments related to many of the topics mentioned below.

**Course Contents:**

**Essential mathematical tools:** Lea st squares, RANSAC, Eigen-analysis,PCA, SVD, clustering,gradient-based optimization methods. (4 Lectures)

**Geometry, Camera models, Epipolar geometry, Stratified recon-struction, Applications:** large scale reconstruction, single-view metrology(8 Lectures)

**Probabilistic graphical models:** MRF, CRF, Combinatorial optimization methods (5 Lectures)

**Module IV:** Stereo disparity estimation, Optical flow (Lucas Kanade andHorn Schunk approaches, contemporary energy minimization methods) (5Lectures)

**Features detection and tracking:** Harris corner detector, KL track-ing,SIFT, Overview of other contemporary descriptors. (5 Lectures)

**Segmentation:** Low-level segmentation,energy minimization and clusteringbased methods, semantic segmentation (5 Lectures)

**High level vision:** CNN overview, single image depth estimation, Flow-net,3D scene understanding and segmentation. (6 Lectures)

**Synthesis:** GAN overview, 3D shape synthesis, integrating viewpoint andtexture, semantic image synthesis (4 Lectures)

**Textbooks:** 1. D. Forsyth and J. Ponce,Computer vision- A modern approach, 2ndedition, Pearson, 2012.

**References:**

1. R. Hartley and A. Zisserman,Multiple view geometry in computervision, 2nd edition, Cambridge university press, 2003

2. S. Prince,Computer vision- Models, learning and inference, Cam-bridge university press, 2012.

3. C. Bishop,Pattern Recognition and Machine learning, Springer, 2006.

## 9.42 EE-519P CMOS Digital IC design Practicum

**Credit:** 1-0-2-2
**Preamble:**
The practicum course will cover the analysis and the design of CMOS digital integrated circuits considering the applications such as memories (DRAM, SRAM, DDR), processor design. The experiments include models of wires, capacitive coupling, inverter design, the design of combinational gates, sequential circuits using CMOS technology. The objective will cover the concept of the understanding of signal integrity. The course deals with extensive usage of Cadence Spectre, MentorGraphics Eldo for the schematic, the simulations and the layout design including parasitic extracted capacitors and inductors at various frequencies, PCB design using Cadence's Allegro and Xilinx FPGA boads.
**Course Content**
All the experiments will be performed using a standard 180 nm CMOS technology, provided by SCL Chandigarh or a smaller technology node.
**Module: 1** ( Physics and modeling of MOS transistor) hours]

MOS Device understanding, NGSPICE and PSPICE modeling [2 lectures + 2 laboratory

Introduction to industry standard tools such as Cadence's Virtuoso schematic, Spectre/Eldo simulator, **Module: 2** (Digital design and simulations) [2 lectures + 4 laboratory hours]

MOSFET device characteristics using NGSPICE and Cadence's Virtuoso schematic and Spectre/Eldo simulators.

Design of CMOS inverter for a given load and generation of I/O characteristics, gain and bandwidth measurement.
**Module: 3** (Layout design techniques and methodologies) [2 lectures + 2 laboratory hours]

Design rule, antenna effects, multi-finger transistor, passive device layout and inter connects

Layout of CMOS inverter – design rule check(DRC) and layout v/s schematic (LVS). Post layout simulation (PLS) using Calibre of MentorGraphics of CMOS inverter using understanding of parasitics R, L and C.
**Module: 4** (Design, layout and PLS of combinational logic circuits) [2 lectures + 6 laboratory hours]

Design, layout and PLS of CMOS digital functions using Complementary CMOS, Pass transistor, Pseudo NMOS logic, Complementary Pass Transistor Logic.

Design, layout and PLS of multiplexer and demultiplexer.
**Module: 3** (Design, layout and PLS of sequential logic circuits)

Design, layout and PLS of sequential logic circuits.

Finite state machine implementation (FSM)
**Module: 4** (Memory design) [2 lectures + 6 laboratory hours]

Design, layout and PLS of memory unit cell, and the complete memory. Learning of GDS generation generation.

The students will submit the project on memory using industry standard tools. The students will follow all the steps from schematic entry to GDS file generation.
**Module: 5** (FPGA) [2 lectures + 4 laboratory hours]

Introduction to FPGA. Hand-on sessions on XILINX FPGA kits.

**Reference books:**

1. "CMOS VLSI Design A Circuits and Systems Perspective" by Neil H. E. Weste and D. Harris.
2. "Digital Integrated Circuits" by J. Rabaey.

## 9.43 EE-524 Digital MOS LSI Circuits

**Credit:** 3-0-0-3
**Preamble:**
The main objective of this course is to teach the students to analyze and synthesize digital logic CMOS circuits of LSI complexity. The students will learn the theory for designing digital logic circuits and logic system designs. The course would help the student to formulate and use the computational models to solve problems of physical design types which includes the development of geometric floor plan for the physical layout for the architecture of the circuit design. The course aims to give exercise and IC project design by which the students learn to manage a computer based graphic editor for physical circuit layouts and to verify the design behavior specification using a simulator. **Course Modules with Quantitative Lecture Hours:**
1. Introduction: An overview of IC development and trends. A review of basic properties of MOS transistors and device physics relevant for digital logic design. CMOS process technology, layout and design rules. (5 hours)
2. CMOS Inverter: Static CMOS inverter, static behavior – switching threshold, noise margin, robustness. Dynamic behavior capacitance computation, propagation delay- first order analysis, power, energy and energy delay. (3 hours)
3. Combination logic gates in CMOS: Static CMOS design – complementary CMOS, Ratioed Logic, Pass transistor logic- dynamic CMOS Design – dynamic logic principles, speed and power dissipation, issues in dynamic design, cascading dynamic gates, designing logic for reduced supply voltage, simulation and layout techniques for complex gates. (5 hours)
4. Sequential logic circuits in CMOS: Timing metrics for sequential circuits, memory element classifications, static latches and Registers, dynamic latches and Registers, Alternative register styles – pulse and sense amplifier based registers, pipelining, Non Bi stable sequential Circuits, Choosing clock strategy. (5 Hours)
5. Design Criteria: Introduction – Custom, semi custom and structured array design approaches, cell based Design methodology, Array based implementations – pre-diffused – pre-wired arrays, characterizing logic and sequential cells (5 Hours)
6. Interconnect: Coping with interconnect , capactiveparasitics – cross talk, resistive parasitics – Ohmic voltage drop- electromigration-RC delay, inductive parasitics – voltage drop – transmission line effects, advanced interconnect techniques – reduced Swing Circuits – Current – mode transmission Techniques. (4 hours)
7. Timing issues: Timing classification of digital systems, synchronous interconnect, Synchronous timing basics, source of skew and jitter, clock distribution techniques and latch based clocking, self timed circuit design- clock synthesis and synchronization using a phase Locked loop (5 hours)
8. Design verification:Datapaths in digital Processor architectures, the adder, multiplier, shifter, power and speed tradeoffs in datapath structures -memory architecture and buliding blocks, memory core, peripheral cicuit, reliability and yield, power dissipation. (5 hours)
9. Design for Testability: issues in design for testability, ad hoc testing, scan based testing, boundary scan design, Built in self Test, test pattern generation, fault models. (5 hours)
**Text Books:**
1. Neil H.E. Weste and Harris D M, "CMOS VLSI Design: A circuit and Systems Perspective " Fourth Edition, Addison Wesley (2011).ISBN 10: 0-321-54774-8 / ISBN 13:978-0-321-54774-3
**References:**

1. Jan M. Rabaye, Digital Integrated Circuits: A Design Perspective (2nd Edition) Prentice-Hall 2003, ISBN 0-13-120764-4

2. Ken Martin, “Digital Integrated Circuit Design”, Oxford University Press (2000).

3. Sung-Mo Kang,YusufLeblebici, “Digital Integrated Circuits: Analysis and Design”, McGraw-Hill, 2002, ISBN:0071196447

4. A. Chandrakasan, W. Bowhill, F. Fox, “Design of High Performance Microprocessor Circuits”, IEEE Press, 2000, ISBN 078036001-X

5. John P. Uyemura, Thomson, “Chip Design for Submicron VLSI: CMOS Layout and Simulation”, 1st Edition, 2005, ISBN:053446629X

## 9.44 EE-534 Probability and Random Processes

**Credits :** 3-0-0-3

**Preamble**

Knowledge of random variables and random processes is essential in the following fields – signal processing, communications and machine learning. Starting with a review of basic concepts in probability the course aims to prepare a student to think in terms of random variables and processes. By the end of the course the student should be able to identify the type of process or variable involved and analyze a problem accordingly and obtain reasonable conclusions from the analysis. The course is oriented towards engineering applications rather than a mathematical one based on measure theory.

**Course modules with Quantitative lecture hours:**

Sigma field. Review of - axiomatic probability, conditional probability and independence. (2 lectures)

Recap of random variables and functions of random variables. (3 lectures)

Probability generating function, moment generating function and characteristic functions – properties and applications. (3 lectures)

Markov chains, classification of states and chains, stationary distribution and limit theorem, Poisson process. (5 lectures)

Convergence of random variables – basic results, inequalities (Markov and Chebyshev), law of large numbers (weak and strong), central limit theorem. (5 lectures)

Concentration inequalities – Chernoff's bound, Hoeffding's inequality, Bennett's inequality, Bernstien's inequality and Efron-Stein inequality. (8 lectures)

Random vectors and covariance matrix. Random processes – stationarity, WSS. Autocorrelation, cross correlation, power spectral density. Filtering of WSS processes. Basic notion of ergodicity. Wiener processes, Markov processes. (10 lectures)

Queueing models - Little's law, M/M/1, M/M/m, M/M/m/m, M/G/1 queuing systems, priority queuing (6 lectures)

**Textbook:**

1. Probability and Random Processes, Grimmett and Stirzaker, Oxford University Press, 2001.

**Reference books:**

(1) Erhan Cinlar, Introduction to Stochastic Processes, Dover Books on Mathematics, 2013

(2) R. G. Gallager, Stochastic Processes: Theory for applications, Cambridge University Press; 1 edition (February 17, 2014)

(3) S. M. Ross, Stochastic processes, 2nd Edition, 1996, John Wiley, New York

(4) J. R. Norris, Markov chains, 1999, Cambridge University Press, Cambridge

(5) Papoulis and Pillai, Probability, Random variables and Stochastic processes, McGraw Hill Europe; 4th edition (January 1, 2002).

## 9.45 EE-551 Applied Photonics for Scientists and Engineers

**Credit:** 2-1-0-3

**Preamble:**

Photonics is a powerful enabling technology that offers unique tools and solutions for innovation. But beyond this, photonics can be also viewed as a gateway discipline – as it can be used to bridge the gap between disciplines towards making valuable long-standing contributions. This course aims to equip the students with the conceptual foundations of the principles of photonics, and requisite skills for enabling them to apply it in their own disciplines. The course topics will include essential principles of photonics, but with a focus on their applications. It is expected that at the end of the module, students will be able use core principles and applied techniques of photonics in their respective disciplines. Pre-requisites for this course are a working knowledge of calculus, vector and matrix algebra. A basic understanding of vector calculus and Fourier transforms are desirable, though not necessary. Upon completion of this module, it is expected that students will be able to

describe light propagation and its interaction with diverse media using wave and ray models.

use basic photonic components and devices in their own disciplinary areas.

analyze and evaluate the use of photonic-based technologies in real-world interdisciplinary applications.

**Course Modules with quantitative lecture hours:**

**Fundamentals of the Electromagnetic theory of light** – complex representation of electromagnetic field disturbances, Maxwell's equations, Fresnel equations, limitations of the electromagnetic description. (2 hours)

**Optical systems** – Fermat's principle, basic optical elements, matrix methods for optics, thick lens and their systems, determination of cardinal points, basic optical systems. (3 hours)

**Polarization** – fundamentals, special devices – crystals, compensators, spatial light modulators, mathematical representations of polarized light. (3 hours)

**Gaussian Beam Optics** – beam propagation equation, beam properties and their characterization, matrix approach for Gaussian beam optics. (2 hours)

**Interferometry** – principles and applications – fundamental concepts – conditions for interference, coherence theory elements, Young's double slit experiment, multiple-beam interference. Systems - Michelson, Twyman Green, Fizeau and other select configurations.

**Selected applications** – e.g. metrology, sensors. (4 hours) Fourier Transforms in Optics – Foundational concepts and theorems, Fourier methods in diffraction theory, Abbe Porter's experiment, applications – e.g. optical wave-shapers. (3 hours)

**Fiber optic systems** – principles of guided wave propagation, basics of single mode and multimode, passive components, active components, fiber-optics based system design considerations, select applications – e.g. Dispersive Fourier Transformer, fiber optic sensors, imaging configurations. (4 hours)

**Nonlinear optics**- Light-matter interaction and the nonlinear wave equation, second order nonlinearity - second harmonic generation, three-wave mixing, third order nonlinearity - third harmonic generation, four-wave mixing, Kerr nonlinearity and its applications. (4 hours)

**Detection of Optical Radiation** – Time-domain methods: High speed detectors, Photomultipliers, Time of flight detectors, Cameras, characterization of ultrashort pulses.

**Spectral-domain methods** – Essential components, resolving power of dispersive devices, the optical spectrum analyzer. Basics of quantum light – single photon generation and detection,

**applications** – e.g., qubits. Full-field measurement techniques. (4 hours)

Tutorial sessions – 10.

**Text books:**

Hecht, E., Optics, 4/e, Pearson. Ghatak, A. K., Thyagarajan, K., Optical Electronics, Cambridge University Press 2018.

**References:**

Saleh, B. E. A, Teich, M. C., Fundamentals of Photonics, 2/e, Wiley Interscience 2007.

## 9.46 EE-593 Low power VLSI Design

**Credit :**

**Preamble :** The everlasting demand for delivering low power circuits and systems has motivated the need for a focused study on low power VLSI design. With the proliferating growth in terms of complexity of integrated circuits, power consumption has emerged as a prerogative and vital metric in the design of integrated circuits and systems. The course aims at design and development of low power integrated circuits, with the challenge of power reduction being aimed at various levels including algorithmic, architectural, logic and transistor levels.

**Course objective:** The course aims to provide understanding of theoretical and practical aspects of power and energy in digital VLSI systems. The course fulfills a basic need of today's industrial design environment. Specific topics include power components of digital CMOS circuits, power analysis, glitch elimination for reducing dynamic power, dual-threshold design for reduced static power, voltage and frequency scaling, power management in memories and microprocessors, parallelism for power saving, battery management, test power, and ultra-low voltage (subthreshold) logic circuits.

**Learning outcomes:** After pursuing the course, a student shall be able to:

Understand the challenges of reduction of power of VLSI circuits at architectural, logic and transistor levels.

Analyze the power dissipation of VLSI circuits.

Design low power VLSI circuits at architectural, logic and transistor levels.

**Course content:**

**Introduction to low power design:** Components of power dissipation of VLSI circuits. 2 hours **Circuit techniques for Low Power Design:** Standby leakage control using transistor stacks, multi-threshold and dynamic threshold techniques, supply voltage scaling technique. 4 hours

**Low power low voltage arithmetic circuits:** Low power adder architectures - ripple carry adder, carry look ahead adder, carry select adder, carry save adder, carry skip adder, current mode adder using multi-valued logic, residue adders, low power multiplier architectures- serial multiplier, parallel multiplier, serial-parallel multiplier, Braun multiplier, Baugh Wooley multiplier, Booth multiplier, Wallace tree multiplier. 10 hours

**Low power low voltage memories:** Read only and random access memories. Power reduction of read only and random access memories at architectural, logic and transistor levels. 8 hours

**Transforms for low power VLSI circuits:** Behavioral level transform, algorithm and architecture level transform, negative differences, sorted recursive differences, shared multiplier based voltage scaling operation, architecture driven voltage scaling, power reduction using operation reduction and operation substitution. 9 hours

**Multiple and Dynamic supply voltage design:** Multiple supply voltage design, dynamic supply voltage design, rate of change of supply voltages, power supply network, variation of the clock speed. 5 hours

**Low power multi-core architectures:** Notion of multi-cores, hardware and software techniques for power reduction in multi-core architectures. 3 hours

**Books:**

K.S. Yeo, K. Roy, "Low Voltage Low Power VLSI Systems", McGraw Hill, 2013. A. Pal, "Low power VLSI design", McGraw Hill, 2014.

## 9.47 EE-611 VLSI Technology

**Credit :** 3-0-0-3

**Preamble**

VLSI Technology course is designed to build up the in-depth understanding among the B.Tech students and MS/Ph.D. scholars about the VLSI state-of-the-art technology. This course consists of class lectures based on advanced device fabrication technology, which also includes hands-on assignments of future device structures in the Nanoelectronics and VLSI Technology Lab.

The major goal of this course is to make the students familiarized with device fabrication and demonstrate the basic concepts such as Clean room, Vacuum technology, thin film deposition (both physical and chemical methods), etc. Additionally, the course aims to illustrate classroom concepts through lab-based demonstrations, giving students the opportunity to build, feel, and test real systems.

Topics include advanced lithography, MOS, MOSFET, CMOS device fabrication and characterization. Application-oriented devices such as MEMS and biosensors will also be fabricated by students and scholars in the nanoelectronics and VLSI technology lab.

In summary, the objective of this course is to provide an understanding of microelectronics fabrication processing technologies.

**Course Outline**

**Unit 1: Vacuum Technology** **No. of Lectures: 5**

Principles of vacuum pumps in the range of $10^{-2}$ torr to $10^{-11}$ torr, principle of different vacuum pumps: roots pump, rotary, diffusion, turbo molecular pump, cryogenic pump, ion pump, Ti sublimation pump. Importance of vacuum measurement; concept of different gauges: Bayard-Alpert gauge, Pirani, Penning; pressure control.

**Unit 2: Conditions for the Formation of Thin Films** **No. of Lectures: 5**

Environment for thin film deposition, deposition parameters and their effects on film growth. Formation of thin films (sticking coefficient, formation of thermodynamically stable clusters – theory of nucleation), capillarity theory, microstructure in thin films, adhesion. Properties of thin films: mechanical, electrical, and optical. Applications of thin films in various fields. Quartz crystal thickness monitor for film thickness measurement.

**Unit 3: Physical Vapor Deposition and Electrical Discharges for Thin Film Deposition** **No. of Lectures: 8**

Thermal evaporation, resistive evaporation, electron beam evaporation, laser ablation, flash and cathodic arc deposition. Sputtering methods: glow discharge sputtering, magnetron sputtering, ion beam sputtering, ion plating. Oxidizing and nitriding. Atomic Layer Deposition (ALD): importance, atomic layer growth, physics and technology.

**Unit 4: Chemical Vapor Deposition Techniques** **No. of Lectures: 8**

Advantages and disadvantages of CVD over PVD. Reaction types, boundaries and flow. Types of CVD: Metalorganic CVD (MOCVD), thermally activated CVD, spray pyrolysis.

**Unit 5: Lithography and Pattern Transfer** **No. of Lectures: 8**

Overview of lithography. Optics of lithography: metrics, optics of micro-lithography, aligners. Photomasks and photoresists: components, processing, multi-layer resist. Types: positive, negative, and image reversal. Advanced lithography: e-beam lithography, soft lithography. Pattern transfer: etch vs. lift-off. Concepts of etching: wet etching (silicon, $SiO_2$, aluminum), dry (plasma) etching.

**Unit 6: MEMS and CMOS Manufacturing Technologies** **No. of Lectures: 8**

Anisotropic etching, process description and testing. Bulk micromachining: DRIE-based and wet processes. Surface micromachining, wafer bonding: fusion bonding (front-end), anodic bonding (back-end). Plastic processes: molding, embossing, LIGA. Interconnects and CMOS process.

**Mini-project:**

Students will carry out a mini-project involving lab exposure. The aim is to understand, solve, and implement solutions to real-world problems.

**Reference Books**

1. S. Franssila, *Introduction to Microfabrication*, Wiley, 2010 (2nd ed.), ISBN 978-0-470-74983-8.
2. James D. Plummer, Michael D. Deal, Peter B. Griffin, *Silicon VLSI Technology: Fundamentals, Practice and Modeling*, Prentice Hall, 2000, ISBN 0-13-0850037-3.
3. Richard C. Jaeger, *Introduction to Microelectronic Fabrication*, Prentice Hall, 2002 (2nd ed.), ISBN 0-201-44494-1.
4. Gary S. May, Simon M. Sze, *Fundamentals of Semiconductor Fabrication*, Wiley, 2004.
5. G.L. Weissler and R.W. Carlson, *Methods of Experimental Physics (Vol 14)*, Vacuum Physics and Technology.
6. T.A. Delchar, *Vacuum Physics and Techniques*, Chapman and Hall.
7. J.P. Hirth and G.M. Pound, *Evaporation: Nucleation and Growth Kinetics*; MEMS Manufacturing Technologies, Pergamon Press.

## 9.48 EE-614 Optical Communication Systems

**Credit :** 3-0-0-3
**Preamble:**
**Course Contents**
**INTRODUCTION TO OPTICAL COMMUNICATION AND FIBER CHARACTERISTICS:**

Evolution of Light wave systems, System components, Optical fibers, StepIndex Graded index Mode theory, Fiber modes, Dispersion in fibers, Lim-itations due to dispersion, Dispersion shifted and dispersion-flattened fibers,Fiber Losses and Non-linear effects. [8 Lectures]

**OPTICAL TRANSMITTERS:**

Basic concepts, LED's structures, Spectral Distribution, Semiconductor lasers,Structures, Threshold Conditions, and Transmitter design. [4 Lectures]

**OPTICAL DETECTORS AND AMPLIFIERS:**

Basic Concepts, PIN and APD diodes structures, Photo detector Noise,Signal impairments, Receiver design. Amplifiers: Basic concepts, Semicon-ductor optical amplifiers, Raman, Brillion amplifiers, Erbium doped fiberamplifiers, pumping requirements, cascaded in-line amplifiers. [8 Lectures]

**COHERENT LIGHTWAVE SYSTEMS:**

Basic coherent systems, Coherent detection principles, Homodyne and het-erodyne detection, Modulation formats, BER in synchronous receivers, Equal-ization, carrier phase and frequency synchronization, timing synchroniza-tion. [4 Lectures]

**MULTICHANNEL SYSTEMS:**

WDM Light wave Systems, WDM Components, WDM System PerformanceIssues, Time- Division Multiplexing, Subcarrier Multiplexing, OrthogonalFrequency Division Multiplexing (OFDM) and Code-Division Multiplexing.[6 Lectures]

**OPTICAL TRANSMISSION LINK LIMITS:**

Power budget and bandwidth limited point-to-point light wave system, OSNRevaluation in high speed optical transmission systems, Dispersion Manage-ment, Nonlinearity management. [6 Lectures]

**OPTICAL NETWORKS:**

LANs, MANs, Long-Haul Networks, Design Guidelines. [6 Lectures]

**Reference Books:** 1. John M. Senior,Optical Fiber Communications: Principles and Prac-tice, 2nd Edition, Prentice Hall of India.
2. G. P. Agrawal,Fiber Optic Communication Systems, 3rd Edition, JohnWiley Sons, 2002.
3. G. Keiser,Optical Fiber Communication Systems, McGraw Hill, 2000.
4. M. Cvijetic and Ivan Djordjevic,Advanced Optical Communication Systems and Networks, Artech House, 2013.
5. Ramaswami, Sivarajan, and Sasaki,Optical networks: A practical per-spective, 3rd Edition, Morgan-Kauffman, 2009

## 9.49 EE-621 Radiating Systems

**Credit :** 3-1-0-4

**Preamble**

This course is an advanced course towards antenna design and engineering. It will familiarize students with different practical aspects of antenna design and radiation mechanisms. In addition to conventional antenna engineering, the course introduces many recent advancements such as printed antennas, multilayer antennas, broadband techniques, antennas integrated with EBG and metamaterial structures, diversity antennas for cellular communication, and beam forming mechanisms.

**Course Objectives**

a) To understand antenna radiation mechanisms, field and polarization analysis.
b) To study antenna tuning and optimization.
c) To explore frequency and pattern reconfigurability.
d) To understand antenna array mechanisms.

**Course Contents**

**1. Basic Antenna Theory** **[10 Lectures]**

Basic dipole theory: flared transmission lines, field equations, dipoles, monopoles. Antenna transmission and radiation parameters, polarization, miniaturization, and Chu–Harrington limit.

**2. Standard Antennas** **[10 Lectures]**

Loops, folded dipoles, helical antennas, Yagi-Uda, spiral antennas. Impedance matching and tuning techniques. Aperture theory, equivalence principle, slot antennas, horn antennas, leaky wave antennas, Vivaldi antennas.

**3. Printed and Planar Antennas** **[10 Lectures]**

Microstrip antennas and feeding techniques. Broadband techniques for printed and planar antennas, fractal geometries, printed monopoles and dipoles. Antennas for cellular communication, diversity/MIMO techniques.

**4. Reflector and Dielectric Resonator Antennas** **[7 Lectures]**

Reflector theory, parabolic reflectors and feeding techniques. Dielectric Resonator Antennas (DRA): radiation mechanisms and feeding techniques.

**5. Array Theory** **[11 Lectures]**

Array synthesis of linear elements, linear and planar arrays, active and passive beam scanning. Excitation techniques. Array synthesis using Schelkunoff polynomial method, Fourier-transform method, and Woodward–Lawson method.

**6. Frequency Selective Surfaces and EBG Structures** **[8 Lectures]**

Effects of Electromagnetic Band-Gap (EBG) and Frequency Selective Surface (FSS) structures on planar and non-planar antennas. Metamaterial-inspired antennas. Antenna design and parameter analysis using electromagnetic simulation tools.

**Additional Components**

Each unit will include tutorials. Students will analyze recent research papers corresponding to each unit. Toward the end of the course, students will deliver a presentation on recent developments in antenna engineering. This presentation may be a literature review, simulation-based study, or MATLAB-based programming demonstration.

**Text Book**

1. J.D. Kraus, *Antennas*, 2nd Edition, TMH Publications.
2. C.A. Balanis, *Antenna Theory: Analysis and Design*, 3rd Edition, Wiley Publications.

**References**

1. Ramesh Garg, P. Bhartia, I. Bahl, A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House.
2. Girish Kumar, K.P. Ray, *Broadband Microstrip Antennas*, Artech House.
3. Ben A. Munk, *Frequency Selective Surface Theory and Design*, Wiley Publications.
4. Fan Yang, Y. Rahmat-Samii, *Electromagnetic Band-Gap Structures in Antenna Engineering*, Cambridge University Press, 2009.

## 9.50 CS202 Data Structures and Algorithms

**Credit :** 3-1-0-4

**Preamble:** The proposed new curriculum for CSE includes six discipline core courses: 1. Mathematical Foundations of Computer Science 2. Advanced Data Structures and Algorithms 3. Paradigms of Programming 4. Computer Organization 5. Information Systems 6. Communicating Distributed Processes

The proposed course follows the new CS curriculum design approach that strives to cover in the above-mentioned six core courses all the fundamental concepts that a CS undergraduate student must know of. The course proposal attempts to include the fundamental topics in data structures and algorithms. The topics form the essential core of this course that must be covered comprehensively, with lots of examples, and practice exercises, and weekly tutorials. Advanced topics in algorithm design and analysis are going to be covered in discipline electives.

**Objective:** After the students have gone through a course on discrete structures, where they learn the formal and abstract representations of data and its manipulation, a course on data structures and algorithms should teach the students concrete implementations and manipulation of such discrete structures and their use in design and analysis of non-trivial algorithms for a given computational task. On completion of such a course, students should be able to:

1. analyse the asymptotic performance of algorithms,
2. demonstrate their familiarity with major data structures, rules to manipulate those, and their canonical applications,
3. construct efficient algorithms for some common computer engineering design problems.

Further, as programming is an integral part of the CS education, in this course students should implement the data structures and algorithms they learn, compute the corresponding achievable performance (computation time, memory requirement, etc), and if possible compare the achievable performance with alternative designs.

**Syllabus:**

**1. Complexity Analysis:** Time and space complexity of algorithms, asymptotic analysis, average and worst case analysis, asymptotic notation, importance of efficient algorithms, program performance measurement, data structures and algorithms. (2 hours)

**2. Stacks and Queues:** Abstract data types, sequential and linked implementations, representative applications such as towers of Hanoi, parenthesis matching, finding path in a maze. (4 hours)

**3. Lists:** Abstract data type, sequential and linked representations, comparison of insertion, deletion and search operations for sequential and linked lists, list and chain classes, doubly linked lists, circular lists, skip lists, applications of lists in bin sort, radix sort, sparse tables. (6 hours)

**4. Dictionary:** Abstract data type, array and tree based implementations. (1 hour)

**5. Hashing:** Search efficiency in lists and skip lists, hashing as a search structure, hash table, collision resolution, universal hashing, linear open addressing, chains, hash tables in data-compression, LZW algorithm. (4 hours)

**6. Trees:** Abstract data type, sequential and linked implementations, tree traversal methods and algorithms, binary trees and their properties, threaded binary trees - differentiation, leftist trees, tournament trees, use of winner trees in mergesort as an external sorting algorithm, bin packing. (8 hours)

**7. Search Trees:** Binary search trees, search efficiency, insertion and deletion operations, importance of balancing, AVL trees, searching, insertion and deletions in AVL trees, tries, 2-3 tree, B-tree. (4 hours)

**8. Heaps:** Heaps as priority queues, heap implementation, insertion and deletion operations, binary heaps, binomial and Fibonacci heaps, heapsort, heaps in Huffman coding. (3 hours)

**9. Graphs:** Definition, terminology, directed and undirected graphs, properties, implementation – adjacency matrix and linked adjacency chains, connectivity in graphs, graph traversal – breadth first and depth first, spanning trees. (4 hours)

**10. Basic Algorithmic Techniques:** Greedy algorithms, divide  conquer, dynamic programming. Search techniques - backtracking, sorting algorithms with analysis, integer sorting, selection sort. Graph algorithms: DFS and BFS with applications, MST and shortest paths. (6 hours)

**Reference Books:**

1. S. Sahni, *Data Structures, Algorithms, and Applications in C++*, Silicon Press, 2/e, 2005.
2. T. H. Cormen, C. E. Leiserson, R. L. Rivest, and C. Stein, *Introduction to Algorithms*, MIT Press, 3/e, 2009.
3. A. M. Tenenbaum, Y. Langsam, and M. J. Augenstein, *Data Structures Using C and C++*, Prentice Hall, 2/e, 1995.

## 9.51 CS-208 Mathematical Foundations of Computer Science

**Credit:** 3-1-0-4

**Preamble:** The proposed new curriculum for CSE includes six discipline core courses: 1. Mathematical Foundations of Computer Science 2. Advanced Data Structures and Algorithms 3. Paradigms of Programming 4. Computer Organization 5. Information Systems 6. Communicating Distributed Processes

The proposed course follows the new CS curriculum design approach that requires covering all the mathematical concepts that are fundamental for entire CS in one basic course. For example, it includes some basic concepts about Finite State Machines (FSM), which are usually covered in a course on Formal Languages and Automata Theory (FLAT). However, as FLAT is an elective course as per the new CSE curriculum, a student who does not take FLAT may not be exposed to a topic as fundamental as FSM. The proposed course replaces erstwhile CS-203 Discrete Structures that was not in complete agreement with the new curriculum design approach.

The proposed course is developed in consultation with the faculty members of the SCEE, especially Prof. Timothy Gonsalves, Dr. Sukumar Bhattacharya, Dr. Arti Kashyap, and Dr. Anil Sao, and Dr. N. S. Narayanaswamy from IIT Madras.

In the proposed contents, there are some topics that are marked "advanced" and/or "optional" ... these topics can be introduced depending on background and interests of the class and if the time permits. Rest of the topics form the essential core of this course that must be covered comprehensively, with lots of examples, and practice exercises, and weekly tutorials.

**Objective:** During the last two decades, there has been a major paradigm shift in processing, communication, and storage of information from predominantly analog domain to digital domain for reasons such as ease of implementation, better efficiency, greater robustness against noise, and enhanced performance and security. This shift has not only resulted in generation of ever increasing volumes of digital data but also an acute need to efficiently process, store, and communicate it.

To address this need the focus of CS curriculum must shift from introducing the traditional elementary discrete structures to represent and process the data to more abstract structures provided by abstract algebra and graph theory. This will enable the students to better understand and appreciate the current developments at the frontiers of CS, both in theory and application, and prepare them to contribute to further advancement of such frontiers. On completion of this course, students should be able to demonstrate their understanding of and apply methods of discrete mathematics in CS to subsequent courses in algorithm design and analysis, automata theory and computability, information systems, computer networks. In particular, students should be able to:

- use logical notation to define fundamental mathematical concepts such as sets, relations, functions and various algebraic structures, reason mathematically using such structures, and evaluate arguments that use such structures.
- model and analyze a computation or communication process and construct elementary proofs based on such structures.

**Syllabus:**

**1. Fundamental Structures:** Functions - surjections, injections, inverses, composition. (2 contact hours) Relations - reflexivity, symmetry, transitivity, equivalence relations. (2 contact hours) Sets - Venn diagrams, complements, Cartesian products, power sets, finite and infinite sets, introduction to lattices. (4 contact hours) Abstract orders: quasi-order, partial order, well-order, (Advanced, optional topics: Zorn's lemma, Koenig's theorem.) (2 contact hours)

**2. Combinatorics:** Counting arguments/techniques; pigeonhole principle; cardinality and countability, the inclusion-exclusion principle, recurrence relations, generating functions. (5 contact hours) Basics of graph theory: graph as a discrete structure, graph coloring and connectivity, traversal problems, and spanning trees. (5 contact hours) Advanced, optional topic: Probabilistic method in combinatorics.

**3. Logic:** Propositional and predicate logic: syntax, semantics, soundness, completeness, unification, inferencing, resolution principle, proof system. (6 contact hours) Proof techniques (negation, contradiction, contraposition, mathematical induction) and the structure of formal proofs; efficiency of proof-systems. (4 contact hours)

**4. State Machines:** Introduction, minimization, grammars, languages. (4 contact hours)

**5. Algebra:** Motivation for algebraic structures, the theory of some algebras such as monoids, groups (finite, cyclic, permutation, matrix), cosets, subgroups, Lagrange's theorem, discrete logarithm. (8 contact hours)

**Optional Topic - 6. Number Theory:** Elementary number theory, fundamental theorem of arithmetic, gcd, unique factorization, Euler's function, modular arithmetic, Fermat's little theorem, Chinese remainder theorem, modular exponentiation, RSA public key encryption.

**Suggested Reference Books:**

1. E. Lehman, F. T. Leighton, and A. R. Meyer, *Mathematics for Computer Science*, 2013. Available online at: http://courses.csail.mit.edu/6.042/spring13/mcs.pdf
2. R. L. Graham, D. E. Knuth, and O. Patashnik, *Concrete Mathematics*, Pearson, 1994. Also available online at: www.maths.ed.ac.uk/~aar/papers/knuthore.pdf
3. A. Aho and J. Ullman, *Foundations of Computer Science*, W. H. Freeman, 1992. Available online at: http://infolab.stanford.edu/~ullman/focs.html
4. I. N. Herstein, *Topics in Algebra*, 2/e, Wiley, 1975.
5. A. Tucker, *Applied Combinatorics*, 6/e, Wiley, 2012.
6. C. Liu and D. P. Mohapatra, *Elements of Discrete Mathematics*, 3/e, Tata-McGraw Hill, 2008.
7. T. Koshy, *Discrete Mathematics with Applications*, Academic Press, 2003.
8. J. Hein, *Discrete Structures, Logic, and Computability*, 3/e, Jones and Barlett, 2009.

## 9.52 CS-241 Introduction to Cryptography

**Credit :** 3-0-0-3
**Preamble:**
**Course Content**
**Overview of Cryptography**

Introduction, Information Security and Cryptography, Background on Func- tions, Basic Terminology and Concepts, Symmetric Key Encryption, Digi- tal Signatures, Authentication and Identification, Public Key Cryptography, Hash Functions, Protocols and Mechanisms, Classes of Attacks and Security Models **Classical Cryptography**

Introduction to Some Simple Cryptosystems, The Shift Cipher, The Substitution Cipher, The Affine Cipher ,The Vigenere Cipher, The Hill Cipher, The Permutation Cipher, Stream Ciphers

Cryptanalysis, Cryptanalysis of the Affine Cipher, Cryptanalysis of the Substitution Cipher, Cryptanalysis of the Vigenere Cipher, A Known Plaintext Attack on the Hill Cipher

Public Key Cryptography, Introduction to public key cryptography, Number theory, Algebra, RSA, DHP and Discrete Log assumptions, Diffie Hellman key exchange, RSA public key system, ElGamal encryp- tion, Pseudo-random bit generators

Digital Signatures, Digital signatures: definitions and applications, How to sign using RSA, Overview of signatures based on discrete-log

**Basic Symmetric Key Encryption**

One time pad and stream ciphers, Shannons Theory, Block Ciphers, Case studies: Feistel networks, DES, 3DES, and AES, Basic modes of operation: CBC and counter mode

Attacks on Block Ciphers, exhaustive search, time-space tradeoffs, dif- ferential linear cryptanalysis, meet in the middle, side channels

Message Integrity, Message integrity: definition and applications, Col- lision resistant hashing, Merkle-Damgard and Davies-Meyer. MACs from collision resistance, Case studies: SHA and HMAC

**Text Books**

1. Abhijit Das and C. E. VeniMadhavan, *Public-Key Cryptography: Theory and Practice*, Pearson Education.
2. Ivan Niven, Herbert S. Zuckerman and Hugh L. Montgomery, *An Introduction to the Theory of Numbers*, Wiley-India.
3. I. N. Herstein, *Topics in Algebra*, 2nd Edition, Wiley India.

## 9.53 CS-304 Formal Language and Automata Theory

**Credits:** 3-0-0-3

**Preamble:** The proposed new curriculum for CS includes six discipline core courses:

1. Mathematical Foundations of Computer Science
2. Advanced Data Structures and Algorithms
3. Paradigms of Programming
4. Computer Organization
5. Information Systems
6. Communicating Distributed Processes

The proposed course follows the new CS curriculum design approach that strives to cover in the above-mentioned six core courses all the fundamental concepts that a CS undergraduate student must know of and provide an exposure to more specialized topics in various discipline electives.

This course proposal attempts to include the fundamental computation models and abstractions. The topics form the essential core of this course that must be covered comprehensively, with lots of examples and practice exercises, with emphasis on clarifying concepts and being able to reason on them. In the proposed contents, there are some topics that are marked ”advanced”. These topics can be introduced depending on background and interests of the class and if the time permits. These and some other advanced topics should be covered in greater detail in advanced discipline electives.

**Objective:** After the students have gone through a course on discrete structures, such as CS-208, where they learn the formal and abstract representations of data and its manipulation, and a course on data structures and algorithms, such as CS-202, where they learn concrete implementations and manipulations of such discrete structures and their use in design and analysis of non-trivial algorithms for a given computational task, this introductory course on formal languages and automata theory familiarizes the students to formal models and abstractions of computation that have been developed over the last few decades and helps them to develop an ability to form abstractions of their own and reason in terms of them.

On completion of such a course, the students should be able to:

**Knowledge and Understanding:**

- Demonstrate familiarity with and manipulate the different concepts in automata theory and formal languages such as formal proofs, (non-)deterministic automata, regular expressions, regular languages, context-free grammars, context-free languages, Turing machines, and notions of computability and undecidability.
- Explain the power and the limitations of various models of computation.

**Skills and Abilities:**

- Prove properties of languages, grammars and automata with rigorously formal mathematical methods.
- Design automata, regular expressions and context-free grammars accepting or generating a certain language.
- Describe the language accepted by an automata or generated by a regular expression or a context-free grammar.
- Transform between equivalent deterministic and non-deterministic finite automata, and regular expressions.
- Simplify automata and context-free grammars.
- Determine if a certain word belongs to a language.

- Define Turing machines performing simple tasks and classify problems as decidable or undecidable.

**Judgement and Approach:**

- Differentiate and manipulate formal descriptions of languages, automata and grammars with focus on regular and context-free languages, finite automata and regular expressions.
- Differentiate among different models of computation based on their computation power.

**Syllabus:**

1. **Regular Languages:** DFA, NFA, Subset construction, Regular expressions, Pumping Lemma, DFA state minimization, Myhill-Nerode relations and theorem. (12 lectures)
2. **Grammars:** Production systems, Right linear grammar and Finite state automata, Context-free grammars, Normal forms, Pumping Lemma for CFLs, Subfamilies of CFL, Derivation trees and ambiguity. (10 lectures)
3. **Pushdown Automata:** Acceptance by final state and empty stack, Equivalence between pushdown automata and context-free grammars, Closure properties of CFLs, Deterministic pushdown automata, the CKY algorithm. (10 lectures)
   *Advanced topics:* the Chomsky-Schützenberger theorem, Parikh's theorem.
4. **Turing Machines:** Techniques for Turing machine construction, Generalized and restricted versions equivalent to the basic model, Universal Turing machine, Recursively enumerable sets and recursive sets. (10 lectures)
5. **Decidability:** Decidable and undecidable problems, Reduction, Post's correspondence problem, Rice's theorem, decidability of membership, emptiness and equivalence problems of languages. (10 lectures)
   *Advanced topics:* Gödel's incompleteness theorem, Gödel's proof.

**Reference Books:**


1. D. C. Kozen, *Automata and Computability*, Springer, 1997.
2. J. E. Hopcroft, R. Motwani and J. D. Ullman, *Introduction to Automata Theory, Languages and Computation*, Pearson, 3/e, 2006.
3. E. A. Rich, *Automata, Computability and Complexity: Theory and Applications*, Pearson, 2007.
4. M. Sipser, *Introduction to the Theory of Computation*, Cengage Learning, 3/e, 2012.
5. Peter Linz, *An Introduction to Formal Language and Automata*, 3rd edition, Narosa Publishing House, 2002.

## 9.54 CS-309 Information and Database Systems

**Credit :** 3-0-2-4

**Preamble:** In line with the philosophy of IIT Mandi curriculum where experiments are done before formal theory is introduced, this course comes after Applied DB practicum. While in Applied DB practicum emphasis is on hands-on practice of SQL, this course provides an in-depth view of modern databases, mainly relational databases.

The course also introduces the concepts related to information systems in organisational usage and considers the different models of information modeling. Further, in recent times, popular relational database systems like DB2, SQLServer, Oracle, and Sybase are struggling to handle the massive scale of data introduced by the Web. For example, Facebook absorbs 15 TeraBytes of data each day while eBay maintains a 6.5 PetaByte of data. A new class of database systems is therefore emerging to handle data at this scale. The course offers exposure to the emerging technologies to handle Big Data and lays the foundation for advanced courses on database technologies.

**Course Outline:** The students will be exposed to the core concepts in information and database systems. The focus will be on building the skills of identifying organizational information requirements, modeling them using conceptual data modeling techniques, converting the conceptual data models into relational data models and verifying its structural characteristics with normalization techniques, and implementing and utilizing a relational database.

Students will also learn transaction management, ACID properties of transactions, online transaction processing and use of stored procedures and triggers as well as query processing in database management systems. Emerging technologies to handle Big Data like Hadoop will be introduced briefly.

Two mini-projects and one final project in the course will exercise students' knowledge of database design, web programming, and information integration, to build real-world applications.

**Modules:**

1. **Introduction (6 hours)**
   (a). Information Modeling: background, approaches, information system lifecycle.
   (b). Four information levels: conceptual, logical, physical, external
   (c). Conceptual Schema Design Procedure: facts, constraints, roles, value, set comparison, final checks
2. **Relational Database Design (6 hours)**
   (a). Overview of ER, Barker notation, mapping from ORM to ER
   (b). Overview of UML, mapping from ORM to UML
   (c). Relational schemas, functional dependencies, Normal forms
3. **Data Manipulation with SQL (9 hours)**
   (a). Relational Algebra
   (b). SQL: Basic operations, Joins, Nested and correlated queries, views, Triggers
   (c). Embedded SQL and database application development
4. **Transactions (9 hours)**
   (a). ACID properties
   (b). Concurrency Control Techniques
   (c). Recovery Techniques
5. **Principles of Query Processing (3 hours)**
   (a). Indexes

   (b). Query plans and operators
   (c). Cost-based query optimization
6. **Data Storage (3 hours)**
   (a). Databases vs. FileSystems (Google FileSystem, Hadoop Distributed FileSystem)
7. **Scalable Data Processing (6 hours)**
   (a). MapReduce and introduction to systems based on MapReduce (Hadoop)
   (b). Introduction to scalable key-value stores (Amazon Dynamo, Google BigTable, HBase)

**Textbooks:**

1. *Information Modeling and Relational Databases*, Second Edition (The Morgan Kaufmann Series in Data Management Systems) by Terry Halpin and Tony Morgan

**References:**

1. *Fundamentals of Database Systems*, 6th edition by Elmasri, Ramez and Navathe, Shamkant
2. Raghu Ramakrishnan and Johannes Gehrke, *Database Management Systems*, 3rd edition, McGraw-Hill
3. Assorted readings from web resources like Yahoo's Hadoop Tutorial, Google's Big Table, etc.

## 9.55 CS-403 Algorithm Design and Analysis

**Credit :** 3-0-2-4

**Preamble:** The proposed elective course, building on top of discipline core course on Advanced Data Structures and Algorithms (ADSA), offers a first formal introduction to various common algorithm design techniques, methods for analyzing the performance of corresponding algorithms and improving their efficiency, and providing performance guarantees. The theoretical aspects of this course are going to be supplemented by comprehensive practice exercises and weekly programming labs worth one lab credit.

**Objective:** After the students have gone through a course on discrete structures, where they learn formal and abstract representations of data and its manipulation, and another course on data structures, where they learn concrete implementations and usage of such discrete structures, a first course on algorithm design and analysis should teach the students how to design an efficient algorithm for a given computational task using one or more of such data structures, analyze performance of a given algorithm, and provide performance guarantees. On completion of such a course, students should be able to:

1. Analyze the asymptotic performance of algorithms and write formal correctness proofs for algorithms.
2. Demonstrate their familiarity with major algorithm design paradigms and methods of analysis.
3. Demonstrate their knowledge of major algorithms and data structures corresponding to each algorithm design paradigm.
4. Construct efficient algorithms for common computer engineering design problems.
5. Classify a problem as computationally tractable or intractable, and discuss strategies to address intractability.

Further, as programming is an integral part of CS education, in this course students should implement the algorithms they learn and compare the corresponding achievable performance (computation time, memory requirement, etc.) with the corresponding asymptotic performance bounds they learn to compute in this course.

**Syllabus:**

1. **Review of Data Structures.** (3 lectures)
2. **Program Performance:** Time and space complexity, average and worst-case analysis, asymptotic notation, recurrence equations and their solution. (3 lectures)
3. **Algorithmic Techniques:** (15 lectures)
   (a). Search techniques (backtracking and bounding)
   (b). Sorting algorithms – lower bound, sorting in linear time
   (c). Greedy algorithms (Huffman coding, knapsack)
   (d). Divide and conquer – Master theorem
   (e). Dynamic programming (0/1 knapsack, Traveling salesman problem, matrix multiplication, all-pairs shortest paths)
   (f). Randomization
   (g). Randomized data structures: Skip Lists, Universal and perfect Hash functions
   (h). Backtracking, Branch and bound

   For each algorithm technique: description of the technique, explanation when an algorithm design situation requires it, examples of algorithms based on this technique, analysis of performance of these algorithms.
4. **Graph Algorithms:** (6 lectures)
   (a). DFS and BFS, biconnectivity, spanning trees

(b). Minimum cost spanning trees: Kruskal's, Prim's, and Sollin's algorithms
(c). Path finding and shortest path algorithms
(d). Topological sorting
(e). Matching, Network Flows, Bipartite graphs

5. **Computational Complexity:** (6 lectures)
   (a). Problem classes: P, NP, NP-complete, NP-hard
   (b). Reduction, Cook's theorem
   (c). Examples of NP-complete problems
6. **Competitive Analysis** (3 lectures)
7. **Amortized Analysis:** (3 lectures)
   (a). Aggregate analysis
   (b). Accounting method
   (c). Potential method
8. **Other Topics:** (3 lectures)
   (a). Number theoretic algorithms (GCD, modulo arithmetic, Chinese remainder theorem)
   (b). String matching algorithms (Rabin-Karp, FSM-based matching, KMP, Boyer-Moore)
   (c). Strassen's matrix multiplication, FFT, integer and polynomial arithmetic
9. **Advanced Topics:** Lower-bound techniques: adversary arguments, information-theoretic bounds.

**Reference Books:**

1. T. H. Cormen, C. E. Leiserson, R. L. Rivest, and C. Stein, *Introduction to Algorithms*, MIT Press, 3/e, 2009.
2. J. Kleinberg and E. Tardos, *Algorithm Design*, Pearson, 2006.
3. S. Dasgupta, C. H. Papadimitriou, U. V. Vazirani, *Algorithms*, McGraw-Hill, 2006.
4. S. S. Skiena, *The Algorithm Design Manual*, Springer, 2/e, 2008.

## 9.56 CS-511 : Applied Probability

**Credit :** 2-0-0-2

**1. Preamble:**

The main objective of this course is to provide students a basic foundation in probabilistic and statistical methods. Upon completion of this course, students should have the necessary prerequisite background in the topics related to probability and statistics to pursue courses in Machine Learning and Data Science.

**2. Course Modules with Quantitative Lecture Hours:**

1. Sigma field. Review of axiomatic probability, conditional probability, and independence, Bayes' rule and applications. (3 hours)
2. Recap of random variables, discrete and continuous random variables, and functions of random variables. (2 hours)
3. Joint, marginal, and conditional distribution, Covariance and correlation, Multinomial, Multivariate Normal, Conditional Expectations. (2 hours)
4. Probability generating function, moment generating function and characteristic functions – properties and applications. (3 hours)
5. Markov chains, classification of states and chains, stationary distribution and limit theorem, Poisson process. Application of Markov Chain in Page Rank, text summarization etc. (4 hours)
6. The convergence of random variables – basic results, inequalities (Markov and Chebyshev), the law of large numbers (weak and strong), central limit theorem, hypothesis testing. (5 hours)
7. Concentration inequalities – Chernoff's bound, Hoeffding's inequality and their applications in parameter estimation and confidence interval of parameters. (3 hours)
8. Random vectors and covariance matrix. Random processes. Autocorrelation, cross correlation, power spectral density. Basic notion of ergodicity. (6 hours)

**Laboratory/Practical/Tutorial Modules:** NA

**3. Textbooks:**

1. Grimmett and Stirzaker, *Probability and Random Processes*, 4/e, Oxford University Press, 2020.
2. Papoulis and Pillai, *Probability, Random Variables and Stochastic Processes*, 4/e, McGrawHill Europe, 2002.

**4. References:**

1. Erhan Cinlar, *Introduction to Stochastic Processes*, Dover Books on Mathematics, 2013.
2. R. G. Gallager, *Stochastic Processes: Theory for Applications*, 1/e, Cambridge University Press, 2014.
3. S. M. Ross, *Stochastic Processes*, 2/e, John Wiley, New York, 1996.
4. J. R. Norris, *Markov Chains*, Cambridge University Press, Cambridge, 1999.
5. Joseph K. Blitzstein and Jessica Hwang, *Introduction to Probability*, CRC Press.
6. Kishor S. Trivedi, *Probability & Statistics with Reliability, Queuing, and Computer Science Applications*, Prentice Hall.

## 9.57 CS-671 Deep Learning and Applications

**Credit :** 3-1-0-4
**Preamble:**
**Course Contents**

Basics of artificial neural networks (ANN): Artificial neurons, Compu- tational models of neurons, Structure of neural networks, Functional units of ANN for pattern recognition tasks. [4 Lectures]

Feedforward neural networks: Pattern classification using perceprton, Multilayer feedforward neural networks (MLFFNNs), Backpropagation learn- ing, Empirical risk minimization, Regularization, Autoencoders. [6 Lectures]

Deep neural networks (DNNs): Difficulty of training DNNs, Greedy layerwise training, Optimization for training DNNs, Newer optimization methods for neural networks (AdaGrad, RMSProp, Adam), Second order methods for training, Regularization methods (dropout, drop connect, batch normalization). [12 Lectures]

Convolution neural networks (CNNs): Introduction to CNNs con- volution, pooling, Deep CNNs, Different deep CNN architectures LeNet, AlexNet, VGG, PlacesNet, Training a CNNs: weights initialization, batch normalization, hyperparameter optimization, Understanding and visualizing CNNs. [12 Lectures]

Recurrent neural networks (RNNs): Sequence modeling using RNNs, Back propagation through time, Long Short Term Memory (LSTM), Bidirec- tional LSTMs, Bidirectional RNNs, Gated RNN Architecture. [8 Lectures]

Generative models: Restrictive Boltzmann Machines (RBMs), Stacking RBMs, Belief nets, Learning sigmoid belief nets, Deep belief nets. [8 Lec- tures]

Applications: Applications in vision, speech and natural language process- ing. [6 Lectures]

**Textbooks:**

1. Ian Goodfellow, Yoshua Bengio and Aaron Courville, Deep learning, In preparation for MIT Press, Available online: http://www.deeplearningbook.org, 2016

**References:**

1. S. Haykin, Neural Networks and Learning Machines, Prentice Hall of India, 2010
2. Satish Kumar, Neural Networks - A Class Room Approach, 2nd Edi- tion, Tata McGraw-Hill, 2013
3. B. Yegnanarayana, Artificial Neural Networks, Prentice- Hall of India, 1999
4. C.M. Bishop, Pattern Recognition and Machine Learning, Springer, 2006

## 9.58 CS-672 Advanced Topics in Deep Learning

**Credit :** 3-0-2-4
**Preamble:**
**Course Contents**

GAN series: Deep Convolutional GAN (DCGAN), Conditional GAN (eGAN), Wasserstein GAN (WGAN), Stacked GAN (StackGAN), Attention GAN, Picture to Picture GAN (Pi x2Pix), Cyclic GAN (Cycle GAN), Discover Cross-Domain R-elations (DiscoGAN), Super Resolution GAN (SRGAN), Texture GAN, Self Attention GAN (SAGAN). [8 Lectures]

Transformer Networks: Drawbacks of Recurrent Neural Networks, Self Attention, Transformers, Bidirectional Encoder Representation from Trans- former (BERT), Generative pre-trained Transformer (GPT). [6 Lectures]

Deep Reinforcement Learning: Basic of reinforcement learning, Markov decision process, Value and Q-val ue functions, Deep Q-learning, Deep Policy Gradient iteration (Reinforce Algo). [10 Lectures]

Graph-based Deep Learning: Basics of Graph Convolutional Neural Network (GCN), Graph Embeddings, Spectral and Spatial GCNs, Graph Autoencoders. [5 Lectures]

Some latest miscellaneous deep learning paradigms and concepts: [10 Lectures]

1. Capsule Network
2. Teacher-student network
3. Attention and Self-attention mechanism
4. Multi-task learning
5. Novel loss functions
6. Model compression/Network Pruning: redundant filter removal, filter ranking, and filter attention.
7. Explainable AI

Advance deep learning application (optional/cover in above topics/related to projects): [3 Lectures]

1. CV related: Object detection, Tracking with Re-id, Flow networks,
2. NLP related: Summarization, text generation,
3. Mise: Domain Adaptation etc.

**Reference Material:**

1. Most of the material will be covered from the recently published research papers at prestigious venues like NIPS, CVPR, ECCV, ICCV, ICLR, etc. [Lecture Material]
2. Aston Zhang et.al., Dive into Deep Learning, (Book website: ms://d21.aiL) (Book PDF: https://d2l.ai/d2l-en.ruti)
3. Ian Goodfellow and Yoshua Bengio and Aaron Courville, Deep Learning, (Book website: https://www.deeglearningbook.org/) [Reference Books]

## 9.59 DS-201 Data Handling and Visualization

**Credit :** 2-0-2-3
**Preamble:**
**Course Contents**

Data sources and collection: This module walks you through the pro- cess of data collection. Starting with a review of existing structured and unstructured data sources, we cover data collection techniques using sen- sors, surveys, and different instruments. This includes data collection and storing for different domains such as IoT, Audio and Video, Web and Social Networks etc. Concepts of Population, Sampling and Experiment Design. [6 Lectures]

Data Pre-processing: Highlight the importance of data correction and discuss some basic features that can affect your data analysis when dealing with sample data. Issues of data access and resources for access are intro- duced in this module. Issues related to data distribution, outlier detection, data skewing. Descriptive data summarization, data cleaning, normaliza- tion, data integration and transformation, data reduction. [7 Lectures]

Data representation: Importance of data representations, Extracting salient features from data, Examples include MFCC from audio signals, histogram representation for text, feature representations for images, encoded representations, Spatial data representation: cartography, GIS paper maps to ArcGIS ArcMap symbolizing, Time-series data representations and curve fit- ting. Importance of representation in latency of retrieval, storage efficiency, computation, classification / regression performance etc. [9 Lectures]

Basic charting and data visualization: Basic charting, examples with real world weather data, extract and manipulate the data to display the maximum information, various types of graphs like pie chart, bar graphs, 3-D plots using Matlab and R. Examples with Mapbox and GoogleMap APIs. Procedure of composite charts by overlaying a scatter plot of record breaking data for a given year, Visualization of high dimensional data e.g. TSNE plot, histogram etc. Also, data representations and visualization of data using tools such as D3.j, PowerBI, Tableau. [6 Lectures]

**Lab Exercises**

Lab to be conducted on a 2-hour slot. It will be conducted in tandem with the theory course so the topics for problems given in the lab are already initiated in the theory class. The topics taught in the theory course should be appropriately be sequenced for synchronization with the laboratory.

**Textbooks:**

1. Yau, Nathan, Visualize this: the Flowing Data guide to design, vi- sualization, and statistics, John Wiley Sons, 2011.

2. 2. Tufte, Edward R., The visual display of quantitative information, Vol. 2, CT: Graphics press, 2001.

**Reference books:**

1. Janert, Philipp K., Data analysis with open source tools: a hands-on guide for programmers and data scientists, O'Reilly Media, 2010.

2. Zhu, Xuan., GIS for environmental applications: a practical ap- proach, Routledge, 2016.

## 9.60 DS-301 Mathematical Foundations of Data Science

**Credit :** 3-1-0-4

**Preamble:**

A large amount of work done in the area of data science and engineering span through range of very simple to mathematically elegant methods. A number of topics in mathematical analysis are of key interests to data science researchers. The mathematical analysis components offered in a typical mathematics program are often scattered in many specialised and dense courses. On the other hand mathematics courses offered in a typical computer science curriculum generally do not cover these important concepts that are very crucial for understanding of the core of many areas of machine learning. This introductory course aims to provide a graspable introduction to mathematical analysis required for data science and engineering practitioner.

On completion of this course, students should be able to demonstrate their understanding of and apply various concepts of mathematical analysis in DSE and serves as the input to many concepts in other courses on numerical linear algebra, optimization, and machine learning. In particular, students should be able to

acquire the adequate depth in relevant topics in mathematical analysis that adjoins to the knowledge of a data science practitioner.

understand concepts related to notion of convergence in norm which is important ingredient in many of the techniques such as regression, classification and clustering requiring approximation different kind of functions.

understand concepts of projection, orthogonality and their properties that are essential ideas for many machine learning techniques.

**Course modules with Quantitative lecture hours:**

Module 1: Definition of metric spaces, Examples, Open sets, Closed sets, Dense sets, Compact sets, Connectedness, Closure and interior of the sets, Metric subspace. (10 lectures)

Module 2: Cauchy sequences, Convergent sequences, Complete metric space, , Continuous functions, Continuity of composite functions, Continuity and inverse image of open and closed sets.

(10 lectures) Module 3: Normed linear spaces, Linear subspaces of normed linear spaces, Banach spaces, Riesz lemma, Continuity of linear maps, Bounded linear maps, Norm equivalence.

(10 lectures) Module 4: Hilbert spaces, Cauchy -Schwarz inequality, Parallelogram law, Orthogonality, Pythagorean Theorem, Orthogonal projection, orthogonal complement and projection theorem, Orthonormal sets, Orthonormal basis, Gram-Schmidt process, Examples of orthonormal basis.

(12 lectures)

**Text Books:**

1. Apostol, T., Mathematical Analysis, 2nd ed., Narosa Publishers, 2002.
2. Limaye, B. V., Functional Analysis, 2nd ed., New age international Publishers, 2009.
3. Dan Simovici Mathematical Analysis for Machine Learning and Data Mining, World Scientific, 2018
4. Rudin, W., Principles of Mathematical Analysis, 3rd ed., McGraw-Hill, 2013.

**Reference Books:**

1. Stein, E. M. and Shakarchi, M., Real Analysis, Princeton Lectures.
2. Tao, T, Analysis I and II, Trim, Hindustan book agency.
3. Kreyszig, E., Introductory Functional Analysis with Applications, Reprint 2017
4. Naylor, A. C. and Sell, G. R., Linear Operator Theory in Engineering and Science.

## 9.61 DS-401 Optimization for Data Science

**Credit :** 3-0-0-3
**Preamble:**
**Course Contents**

Module I: Affine sets, convex sets, cone, examples – hyperplanes, halfs- paces, polyhedra, simplexes, positive semidefinite cones. Operations that preserve convexity. Separating and supporting hyperplanes. Dual cones. [6 Lectures]

Module II: Convex function, first and second order conditions, epigraph, operations that preserve convexity, conjugate function. [5 Lectures]

Module III: Convex optimization – Linear, quadratic, geometric, conic. Formulation of - unconstrained, equality constrained, inequality constrained and both – problems. [5 Lectures]

Module IV: Duality – Lagrange dual function, bounds on the optimal value. Lagrange dual problem, weak and strong duality, optimality conditions. [8 Lectures]

Module V: Gradient methods – Gradient descent, conjugate gradient, ac- celerated gradient descent, Newton methods, proximal and projected gra- dient descent, conditional gradient and Frank-Wolfe algorithm, barrier and interior point methods, Dual gradient ascent, ADMM, Stochastic gradient method. [18 Lectures]
**Textbooks:**
1. Boyd, Stephen, and Lieven Vandenberghe, Convex optimization, Cam- bridge university press, 2004.
**Reference books:**
1. Yurii, Nesterov, Introductory lectures on convex optimization: a ba- sic course, Kluwer Academic Publishers, 2004.

2. Bertsekas, Dimitri P., Nonlinear programming, Journal of the Opera- tional Research Society 48.3 (1997): 334-334.

3. Luenberger, D. G., and Y. Ye, Linear and nonlinear programming, Springer, 2008.

4. Nocedal, Jorge, and Stephen Wright, Numerical optimization, Springer Science  Business Media, 2006.

## 9.62 DS-403 Introduction to Statistical Learning

**Credit :** 3-1-0-4

**Preamble:**

Data science involves using the scientific methods to process the data to extract knowledge and insights from data in various forms, both structured and unstructured. Vast amounts of data are being generated in many fields, and the data analyst's job is to make sense of it all: to extract important patterns and trends. This involves learning from data. This course intends to provide fundamental ideas and techniques in learning from data in the statistical framework.

**Course Contents**

1. Introduction to learning from data: Introduction to supervised learning and unsupervised learning. [2 Lectures]
2. Supervised learning: Regression: Linear regression models and least squares, Shrinkage methods: ridge regression and the LASSO. [6 Lectures]
3. Supervised learning: Classification: Logistic regression, nearest neigh- bour's method, Bayes classifier with unimodal and multimodal density - maximum likelihood estimation, expectation-maximization (EM) algorithm; decision trees, support vector machines (SVMs), basics of neural networks. [8 Lectures]
4. Model Assessment and Selection: Bias, variance and model complexity, The Bayesian approach, AIC and BIC, cross-validation, bootstrap methods, hypothesis testing, confidence intervals, significance testing. [6 Lectures]
5. Unsupervised learning: Introduction to association rules, clustering, and dimension reduction. [6 Lectures]

**Lab Exercises:**

Lab to be conducted on a 2-hour slot. It will be conducted in tandem with the theory course so the topics for problems given in the lab are already initiated in the theory class. The topics taught in the theory course should be appropriately be sequenced for synchronization with the laboratory.

**Textbooks:**

1. Hastie, T., Tibshirani, R. and Friedman, J., The Elements of Statistical Learning: Data Mining, Inference, and Prediction, 2nd Edition, Springer, 2017.

**Reference books:**

1. Duda, R. O., Hart, P. E. and Stork, D. G., Pattern Classification, John Wiley, 2001.
2. Bishop, C. M., Pattern Recognition and Machine Learning, Springer, 2006.
3. Theodoridis, S. and Koutroumbas, K., Pattern Recognition, Academic Press, 2009.

## 9.63 DS-404 Information Security and Privacy

**Credit :**
**Preamble:**
**Course Contents**
**Introduction to information security:**

1. Information security models; attacks, threats, vulnerabilities, and risks. Operations security: Haas' Laws. Identification and authentication: identity verification, falsifying identification, multifactor and mutual authentication, passwords, biometrics, hardware tokens, performance evaluation.
2. Authorization and access control: principle of least privilege, access control lists, and access control methodologies, physical security and access controls. Auditing and accountability: non-repudiation, deter- rence, intrusion detection and prevention, logging, monitoring, assess- ments. [8 Lectures]
3. Authorization and access control: principle of least privilege, access control lists, and access control methodologies, physical security and access controls. Auditing and accountability: non-repudiation, deter- rence, intrusion detection and prevention, logging, monitoring, assess- ments. [8 Lectures]

**Cryptography:** Protocols (key exchange, public key cryptography, secret sharing), techniques (key length, key management, etc), cryptographic al- gorithms (mathematical background, data encryption standard, block and stream ciphers, public-key, digital signatures). [8 Lectures]
**Network security:** Protecting networks and network traffic, mobile device security, network security tools. [6 Lectures]
**Operating system security:** OS hardening, protecting against malware, firewalls and host intrusion detection, OS security tools. [4 Lectures]
**Application security:** Software development vulnerabilities, web security, database security, and application security tools. [6 Lectures] **Information privacy:** Static and dynamic data anonymization and threats to anonymization, privacy in synthetic and test data, privacy regulations. [6 Lectures]
**Information Ethics:** Ownership, privacy, anonymity, validity, algorithmic fairness, societal consequences, code of ethics, attributions. [4 Lectures]

**Text Books:**

1. Andress, J. and Winterfeld, S., The Basics of Information Security, 2nd Edition, Syngress, 2014.
2. Venkataraman, N. and Shriram, A., Data Privacy: Principles and Prac- tice, Chapman and Hall/CRC, 2016.

**Reference Books:**

1. Guise, P. D., Data Protection, Routledge, 2017.
2. Katz, J. and Lindell, Y., Introduction to Modern Cryptography, Chap- man and Hall/CRC, 2015.
3. Torra, V., Data Privacy: Foundations and the Big data Challenge, Springer, 2017.

## 9.64 EN-502 Emerging energy sources

**Credit :** 3-0-0-3
**Preamble:**
**Course contents:**
**Introduction**
Different types of emerging energy sources, potential and installed capacities of these new generation energy sources, Conversion technologies for different primary energy sources, sustainability benefits, and challenges related with reliability, policy dependence, socio-economic advantages and disadvantages. [6 Lectures]
**Biomass Energy**
Organic matters available on renewable basis like forests, agricultural, mill and industrial wastes etc., direct fired plants, co fired power plants, gasification, fixed bed gasifiers, small version of gasification or directly fired plants for modular bio power. [8 Lectures]
**Wind power**
Wind energy availability and basic working principle of wind turbines, wind turbine- rotor blades, tower, nacelle house- electrical generator, power control and other me- chanical equipment, resource assessment overview, modern wind turbines, installa- tions and wind farms, advantages and limitations of wind farms . [8 Lectures]
**Module IV**
Solar power–potential of solar energy reaching earth surface, collecting sunlight, solar photovoltaic and solar thermal techniques, solar cell efficiencies and theoretical limits, solar power plants, future challenges. [8 Lectures]
**Ocean Energy**
Availability in Indian context, Ocean Thermal Energy Conversion, wave energy conversion, Tidal power basic conversion principle, and challenges related with ma- terial corrosion, intermittent primary energy supply, sustainability assessment and improvement. [4 Lectures]
**Module VI**
Hybrid renewable syste [4 Lectures]
**Fuel cell**
Proton exchange membrane, PEM chemical reactions, alkaline fuel cells, molten carbonate fuel cell their working reactions and advantages, solid oxide fuel cells- their working reactions and advantages [6 Lectures]
**Text Books:**
1. K. R. Rao, Energy and Power Generation Handbook: Established and Emerging Technologies, American Society of Mechanical Engineers, U.S., 2011.
2. Aldo V.da Rosa, Fundamental of Renewable Energy Processes, Elsevier Press, 2009.
3. Jahangir Hossain, Mahmud Apel, Large Scale Renewable Power Generation: Advances in Technologies for Generation, Transmission and Storage (Green Energy and Technology), Springer, 2014.
4. Y. Goswami, Principles of Solar Engineering, CRC Press, 2013.
5. R. Ehrlich, Renewable Energy: A First Course, CRC Press, 2013.
6. D. Spera, Wind Turbine Technology, ASME, 2009.
7. S. Srinivasan, Fuel Cells: From Fundamentals to Applications, Springer, 2006.
8. D. A. J. Rand and R. M. Dell, Hydrogen Energy: Challenges and Prospects, RSC Publishing, 2008.

# Chapter 10 Labs/Facilities

## 10.1 General Physics lab experiments

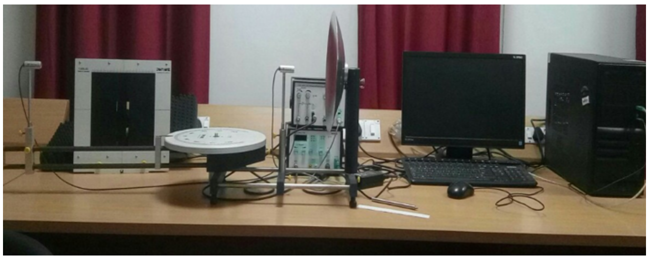
Please also see Figure 10.1a to Figure 10.1f.

- Hall Effect
- Four Probe
- Ultrasonic diffraction
- Frank-Hertz
- Dispersion and resolving power of prism
- GM counter
- Gamma Ray Spectrometer
- Millikan's Oil Drop Method
- Fourier optics
- Michelson Interferometer
- Fabry-Perot interferometer
- Zeeman Effect with Electromagnet

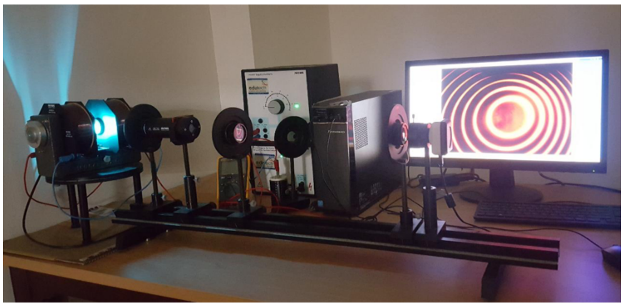
## 10.2 Electronics lab experiments

- Characteristics of BJT
- OPAMP as Inverting-Non-Inverting Amplifier, Adder, Subtractor
- OPAMP as Differentiator, Integrator
- Multiplexer and Demultiplexer
- Shift Register using Flip Flop
- 555 Timer as Multivibrator
- Logic Gates
- Analog to Digital and Digital to Analog Converter using OPAMP

(a) Dispersion and Resolving Power



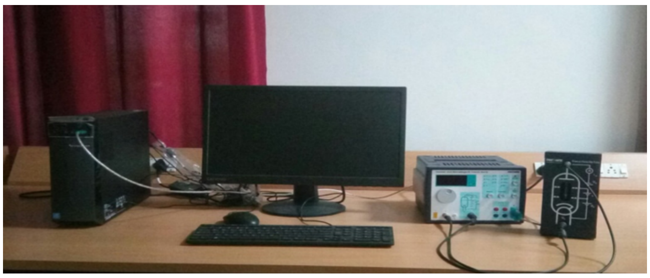
(b) Ultrasonic Diffraction



(c) Zeeman Effect with Electromagnet

(d) Fabry–Pérot Interferometer

(e) Fourier Optics



(f) Frank–Hertz Setup

**Figure 10.1:** All the experiment in the General Physics Lab.

## 10.3 Research Laboratory [Central facilities]

Please also visit Advanced Material Research Center (AMRC) at (LINK)

- 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
- 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