Syllabus

Ph.D. Course Work in Physics

(Effective from the session 2019-2020)

Department of Physics

Aliah University

New Town, Kolkata

This Syllabus for PhD Course Work in Physics (*effective from the session 2019-2020*) is framed as per the Course Work Structure provided in the Aliah University PhD Regulations-2017 and the related amendment by the University in 2020 following the UGC notification for the compulsory course Research and Publication Ethics (RPE) [D.O. No. F.1-1/2018(Journal/CARE) dated December, 2019]. The Structure of the PhD Course Work Syllabus is given by the University Research Programme (URP) cell of Aliah University, approved by the Board of Research Studies (BRS, 28 July, 2020) and Academic Council (7th Meeting on 30th August, 2020) of Aliah University. The structure is given below,

Course Code	Course Title	Credit
PHD/RM-01	Research Methodology	04
PHD/RPE-02	Research and Publication Ethics	02
PHD/LR-03	Literature Review, Report and Seminar Presentation	04
PHD/SP-04	Subject Paper (……..)	04

BOS, Physics Department has approved the same as below,

Course Code	Course Title	Credit	L	T	F.M.*
PHD/RM-01	Research Methodology	04	4	1	50
PHD/RPE-02	Research and Publication Ethics	02	2	1	25
PHD/LR-03	Literature Review, Report and Seminar Presentation	04	4	1	50
PHD/SP-04	Subject Paper (……..)	04	4	1	50

*** F.M. 50 = 40 (Written exam) + 10 (TA)** for PHD/RM-01 and PHD/SP-04

*** F.M. 25 = 20 (Written exam) + 5 (TA)** for PHD/RPE-02

*** F.M. 50 = 20 (Report Writing/ Term Paper and Evaluation) + 20 (Seminar Presentation) + 10 (TA)** for PHD/LR-03

***** As per AU PhD Regulation-2017, Ph.D. Course Work is One Semester Programme. PhD Course work may be completed within One Semester /Two Semesters duration from the date of enrollment.

Signature of the BOS Members:

PHD/RM-01: Research Methodology

(Credit- 4, F.M.-50, 60 Lectures)

1. **Research Aptitude**
   Meaning of research, Objectives of research, Motivation in research, Types of research: Descriptive vs. Analytical, Applied vs. Fundamental, Quantitative vs. Qualitative, Conceptual vs. Empirical, Research process, Criteria of good research, Research formulation, Defining and formulating the research problem, Selecting the problem, Necessity of defining the problem, Importance of literature review in defining a problem, Literature review, Critical literature review, Identifying gap areas from literature review, Proposing and testing hypotheses, Proposing postulates, Establishing a functional relationship. [12 lectures]

2. **Data Interpretation, Data Analysis and Mathematical Modelling**
   Sources, acquisition and interpretation of data, Quantitative and qualitative data, Graphical representation and mapping of data, Statistical data analysis, Sampling, analysis of the sampled data, Distribution of the data, Measurement and confidence intervals, Measurement of a value, Experimental error analysis, the Central limit theorem, Estimating with confidence, Measurement of a proportion, Propagation of errors, Mathematical modelling of physical systems; Models built from first principles, Dimensional consistency, Modeling using dimensional analysis, Phenomenological models, examples. [10 lectures]

3. **Use of Information and Communication Technology (ICT) in Research**
   ICT, meaning, advantages, disadvantages and uses, General abbreviations and terminology, Basics of internet and e-mailing. Use of internet networks in research activities in searching material (paper/thesis/data) downloading from ShodhGanga, Google Scholar, Microsoft Academic Search, Mendeley, SSRN, Researchgate *etc.*, submission of manuscripts in arXiv/different journals, use of SPIRES database, Orchid, Overleaf *etc.* [8 lectures]

4. **Art of Scientific Writing and Presentation**
   Steps to better writing, flow method, organization of material and style; Title, Abstract, The body of the paper, Drawing figures, graphs, tables, footnotes, citing references, Conclusion, Acknowledgement, Revising the manuscript etc. in a research paper or while writing a thesis. Presentation in seminars and conferences; The art of preparing visual presentation material, The art of delivering a talk at a conference, Poster presentation, Preparing the poster, Presenting a poster, Preparation of project proposal: Title, Abstract, Introduction, Rationale, Objectives, Methodology, Time frame and work plan, Budget and justification. [10 lectures]

5. **Introduction to Patent Laws etc.**
   Patent laws, the process of patenting a research finding, Copyright, Cyber laws. [2 lectures]

6. **Computer Applications and Programming**
   Working in a Linux environment, basic Linux commands, Writing scientific documents with Latex/Libre office/MS Office environments, Basic applications of Excel/LibreOffice Calc, Power point/LibreOfficeImpress, Paint/Gimp etc. Graphic and visualization tools *e.g.* Gnuplot,

XmGrace, Labplot, Origin Plot *etc.* Introduction to symbolic computation software tools *e.g.* Mathematica, Matlab, Octave etc., Programming with FORTRAN/C (or C++)/Python/Julia language (s). [18 lectures]

REFERENCES

1. An introduction to Research Methodology, B. L. Garg, R. Karadia, F. Agarwal and U. K. Agarwal
2. Research Methodology: Methods and Techniques, C. R. Kothari
3. Research Methodology, S. C. Sinha, A. K. Dhiman
4. Research Methodology, P. M. Bulakh, P. S. Patki and A. S. Chodhary
5. Research Methodology, Mukul Gupta, Deepa Gupta
6. A Hand-Book of Methodology of Research, Rajammall, P. Devadoss and K. Kulandaivel
7. Practical Research: Planning and Design, P. D. Leedy and J. E. Ormrod
8. Statistical Methods, S. P. Gupta
9. Fundamentals of Mathematical statistics, S.C. Gupta and V.K. Kapoor,
10. Statistical Methods, G.W. Snedecor and W.G. Cochrans
11. Law relating to patents, trademarks, copyright designs and geographical indications, B. L. Wadehra
12. Intellectual property rights and Copyright, S. V. Satarkar
13. Internet for everyone, Leon & Leon (2202)
14. Thesis and Assignment Writing, J. Anderson

PHD/RPE-02: Research and Publication Ethics

(Credit- 2, F.M.-25, 30 Lectures)

This course is offered for the awareness about the publication ethics and publication misconduct to the Ph.D. students and interested faculty members. The course comprises six modules listed in the table below. Each module has 4-5 units. The pedagogy of this course is as follows- classroom teaching, guest lectures, group discussions and practical sessions.

Modules	Unit title	Teaching hours
Theory		
RPE 01	Philosophy and Ethics	04
RPE 02	Scientific Conduct	04
RPE 03	Publication Ethics	07
Practice		
RPE 04	Open Access Publishing	04
RPE 05	Publication Misconduct	04
RPE 06	Databases and Research Metrics	07
	Total	30

THEORY

- **RPE 01: Philosophy and Ethics** [3 lectures]
  1. Introduction to philosophy: definition, nature and scope, concept, branches.
  2. Ethics: definition, moral philosophy, nature of moral judgements and reactions.

- **RPE 02: Scientific Conduct** [5 lectures]
  1. Ethics with respect to science and research
  2. Intellectual honesty and research integrity
  3. Scientific misconducts: Falsification, Fabrication and Plagiarism (FFP)
  4. Redundant publications: duplicate and overlapping publications, salami slicing
  5. Selective reporting and misrepresentation of data

- **RPE 03: Publication Ethics** [7 lectures]
  1. Publication ethics: definition, introduction and importance
  2. Best practices / standards setting initiatives and guidelines: CPOE, WAME, etc.
  3. Conflicts of interest
  4. Publication misconduct: definition, concept, problems that lead to unethical behavior and vice versa, types
  5. Violation of publication ethics, authorship and contributorship
  6. Identification of publication misconduct, complaints and appeals
  7. Predatory publishers and journals

PRACTICES

- **RPE 04: Open Access Publishing** [4 lectures]
  1. Open access publications and initiatives
  2. SHERPA/RoMEO online resource to check publisher copyright & self-archiving policies
  3. Software tool to identify predatory publications developed by SPPU
  4. Journal finder / journal suggestion tools viz. JANE, Elsevier Journal Finder, Springer Journal Suggester, etc.

- **RPE 05: Publication Misconduct** [4 lectures]
  - **A. Group Discussion (2 hrs)**
    1. Subject specific ethical issues, FFP, authorship
    2. Conflicts of interest
    3. Complaints and appeals: examples and fraud from India and abroad
  - **B. Software Tools (2 hrs)**
    1. Use of plagiarism software like Turnitin, Urkund and other open source software tools.

- **RPE 06: Databases and Research Metrics** [7 lectures]
  - **A. Databases (4 hrs)**
    1. Indexing databases
    2. Citation databases: Web of science, Scopus, etc.

B. Research Metrics (3 hrs)

1. Impact Factor of journal as per Journal Citation Report, SNIP, SJR, IPP, Cite Score
2. Metrics: h-index, g index, i10 index, altmetrics

- ***Evaluation Process:*** *Continuous assessment will be done through tutorials, assignments, quizzes, and group discussions. Weightage will be given for active participation. The final written examination will be conducted at the end of the course.*

REFERENCES

[1] Bird, A. (2006*). Philosophy of Science*. Routledge.
[2] MacIntyre, Alasdair (1967) *A Short History of Ethics*. London.
[3] P. Chaddah, (2018) Ethics in Competitive Research: Do not get scooped; do not get plagiarized, ISBN:978-9387480865
[4] National Academy of Sciences, National Academy of Engineering and Institute of Medicine. (2009). *On Being a Scientist: A Guide to Responsible Conduct in Research: Third Edition.* National Academies Press.
[5] Resnik, D. B. (2011). What is ethics in research & why is it important. *National Institute of Environmental Health Sciences*, 1-10.
[6] Beall, J. (2012). Predatory publishers are corrupting open access. Nature, 489(7415) 179-179
[7] Indian National Science Academy (INSA), Ethics in Science Education, Research and Governance (2019), ISBN:978-81-939482-1-7.

PHD/LR-03: Literature Review, Report and Seminar Presentation

(Credit- 4, F.M.-50, 60 Lectures)

1. Literature review/survey on the previous works done on his/her Ph.D. topic

PhD/ Research topic will be provided by the respective PhD Supervisor which will be related to the topic of PhD Registration. The candidate will review or survey previous works done on his/her PhD topic using online/offline primary and secondary sources.

2. Report writing (term paper) and scientific presentation

- The candidate must write a report (Term Paper) on the Literature Review/Survey done on his/her PhD topic. The term paper will be soft binding and within 5000 words (5 copies).
- Seminar presentation /Oral presentation in the form of PowerPoint (PPT) which includes text, graphs, images, tables, references, etc.; The evaluation will be done on the development of communication skills in the presentation of scientific seminars- eye to eye contact, facing to audience, question & answer sessions, etc.

3. The respective Supervisor will assess the candidate's performance on the Literature Review and writing of the Term Paper and based on that TA will be given.

PHD/SP-04: Subject Paper (…….……)

(Credit- 4, F.M.-50, 60 Lectures)

*The candidate will choose **Any One Subject Paper** depending upon his/her PhD topic which will be assigned by his/her Supervisor.*

❖ Advanced Atomic, Molecular and Optical Physics

(Item no. 1 is mandatory** and as per the research interest and scope, scholars have to choose **Either items 2, 3 Or 4, 5 Or 4, 6)

1. **Recapitulation** on *i)* Linear vector space, Fourier transforms, Special orthogonal functions, Group theory, Numerical methods and programming with Fortran and Python language, *ii)* time-independent and time-dependent perturbation theory, Variational method, MacDonald-Hylleraas-Undheim theorem, Quantum theory of angular momentum, Solution of quantum linear harmonic oscillator using operator method and the idea of coherent states, Zeeman and Stark effect (A.C. and D.C.), Schrodinger equation in a parabolic coordinate system, *iii)* Spatial and temporal coherence of light beam, Spectral resolution, Fundamentals of optical polarization, Wave plates and construction of circularly and elliptically polarized light beams. [15 lectures]

2. **Few-body atomic and molecular systems:** Separation of centre-of-mass coordinate from N-body Schrodinger equation; Hatree-Fock method; Explicitly correlated methods; Configuration Interaction method (CI); Perimetric coordinates; Generalized Hylleraas method; Hylleraas-CI method; Symmetric Euler angle decomposition; Symmetrization and Anti-symmetrization of wavefunction; Construction of spin eigenfunctions; Reduced anti-symmetrizer; Generalized eigenvalue equation; Computation of matrix elements; Evaluation of correlated basis integrals; Optimization techniques; Jacobi Coordinates; Hyperspherical method; Hyperspherical harmonics; Feshbach and shape resonances; Idea of Complex coordinate method, Stabilization method; General idea of molecular structure; The Born-Oppenheimer approximation; Electronic, Vibrational and Rotational structure of diatomic molecule; Raman spectroscopy; Molecular symmetry; Photoassociation and Photodissociation; Relativistic and quantum electrodynamical corrections of atomic and molecular energy levels. [30 lectures]

3. **Confined quantum systems:** Different types of Spatial and plasma confinements; model potentials; Dirichlet and von Neumann boundary conditions; Evaluation of structural properties for confined two-body systems; Exotic systems; Idea of Effimov or Borromean systems; Quantum entanglement, Schmidt decomposition, Linear and Von Neumann entropy; Quantum information theoretic measures e.g. Shannon entropy, Fisher entropy etc. [15 lectures]

4. **Semi-classical theory of light-matter interaction**: Interaction of light with one- and many-electron systems; Transition matrix elements and transition rates; The derivation of selection rules for multipolar electric and magnetic transitions; Oscillator strengths; Multipolar polarizabilities; Two-level system, Induced resonant transitions, Decay phenomena; Oscillating dipoles; The Bloch vector and Bloch sphere; Density operator/ matrix; Optical Bloch equations; Vector model of density matrix; Lambert-Beer law; Rotating wave approximation; Exact Rabi solution in the strong field, Rabi flopping, Dressed state picture; A stationary two-level atom in a standing wave; A moving two-level atom in travelling wave; A moving two-level atom in a standing wave; Lamb dip; Saturation phenomena; Hole burning; Perturbative method under density matrix formalism; Linear and non-linear susceptibilities; Three-level Λ, V and Ξ-type systems with two laser fields: pump-probe spectroscopy, concepts and approach; Doppler broadening phenomenon. [25 lectures]

5. **Quantum mechanical theory of light-matter interaction**: Wave equation and energy density of classical radiation field; Quantization of electromagnetic field; Field states of single radiation field mode : Fock states and coherent states; Quadrature operators and phase space of field states; Vacuum fluctuation and the idea of spontaneous emission; Thermal radiation states and Planck's blackbody radiation formula; The classical and quantum beam splitter; Mach-Zehnder interferometer; Balanced homodyne detection; Quantized light-matter interaction; Jaynes-Cummings model; Interaction of a two-level atom with a coherent state; Experimental test of quantized Rabi oscillations; Preliminaries of cavity quantum electrodynamics; Dressed states. [20 lectures]

6. **Instrumentation in pump-probe laser spectroscopy:** Basics of Ruby, He-Ne, Dye and Semiconductor lasers; Optical resonator, Fabry-Perot interferometer; Homo- and hetero-junction diode lasers; External cavity diode laser (ECDL) including current, temperature and frequency scan controllers; Frequency tuning mechanism by diffraction grating (Littrow and Littman-Metcalf configurations); Optical isolator; Alkali (Rb or Cs) vapour cell, Absorption and saturation absorption spectroscopy (SAS)-experiment in Rb vapour cell; Frequency locking of a diode laser by using PID, and Lock-in-amplifier; Different types of photo detector; Experimental data recording, storage and analysis techniques using digital storage oscilloscope (DSO); Acousto-optic modulator (AOM); Electro-optic modulator (EOM), Power/intensity measurement of laser light; Optical Spectrum Analyser (OSA) including wavelength measurement; Fluorescence imaging by a CCD/CMOS camera; Interfacing technique by RS232 and GPIB; Generation of homogenous and inhomogeneous magnetic field; Applications of different types of optical components- mirrors, beam splitters, wave plates, polarizer, neutral density filter, lenses, optical chopper, etc. [20 lectures]

REFERENCES

1. Mathematical Methods for Physics, Arfken & Weber (Elsevier)
2. Fundamentals of Optics, F. A. Jenkins and H. E. White (Mc Graw Hill, Kogakusha)
3. Geometrical and Physical Optics, B. S. Longhurst (Orient Longmans)
4. Optics, Hecht and Zajac (Addison-Wesley)
5. Lectures on Light, Nonlinear and Quantum Optics using the Density Matrix, Stephen C. Rand (Oxford University press)
6. Quantum Optics, M. O, Scully and M. S. Zubairy (Cambridge University press)

7. Quantum Statistical properties of radiation, W. H. Louisell (Wiley)
8. Physics of Atoms and Molecules, B. H. Bransden and C. J. Joachain (Pearson Education)
9. Atomic Spectra and atomic structure, G. Hertzberg (Dover Pub.)
10. Introduction to atomic spectra, H. White (M. G. H)
11. Quantum mechanics of one and two-electron atoms, H. A. Bethe and E. E. Salpeter (Academic Press)
12. Structure and spectra of diatomic molecules, G. Hertzberg
13. Hyperspherical Harmonics Expansion Techniques, Tapan Kumar Das (Springer)
14. Electronic Structure of Quantum Confined Atoms and Molecules, K. D. Sen (Ed.) (Springer)
15. Numerical Recipe, The art of Scientific Computations, W. H. Press, B. P. Flannery, S. A. Teukolsky, W. T. Vetterling (Cambridge University press)
16. Laser Spectroscopy (Vol. 1 & 2), Wolfgang Demtröder, Springer.
17. Laser Physics and Spectroscopy, Pradip N Ghosh, CRC Press
18. Atomic Physics, C J Foot, Oxford
19. Lasers: Fundamentals and Applications, K Thyagrajan and A Ghatak (Springer)
20. Laser Physics, M Sargent III, M O Scully and W E Lamb Jr, CRC Press/ ABP

❖ Electronic Structure of Materials

A. Basics [12 lectures]

1. Electrons in periodic potentials - Bloch's theorem - Kronig-Penney model - concept of energy bands.
2. Density of states - Green's function - Tridiagonal matrices & Continued fractions - Singularities in DOS.
3. Reciprocal lattice & Brillouin zone - Special k-points in BZ sampling.

B. Electron-Ion Problem [8 lectures]

4. Adiabatic approximation (Born-Oppenheimer).
5. Classical nuclei approximation (Ehrenfest Theorem).
6. Hellman-Feynman force on nuclei.

C. Many-Electron Problem [20 lectures]

7. Hartree approximation - LCAO method.
8. Hartree-Fock approx. - Slater-determinantal wavefunction & its properties - Hartree-Fock equation - Fock operator - Energy of the groundstate - Koopman's theorem
9. Going beyond Hartree-Fock (introductory) - absence of correlation in H-F theory - Basics of MCI and Perturbative (Moller-Plesset) methods
10. Density Functional Theory - Energy as a functional of density : basic concepts - Thomas-Fermi theory - Hohenberg-Kohn Theorem - Kohn-Sham Eqn. - LDA for the exchange-correlation function.

D. Electron Correlation [12 lectures]

11. Mott Trasition and Hubbard Model; Mott Insulators; Heisenberg Magnets; Itinerant Electron Magnetism.

REFERENCES

1. Solid State Physics, Ashcroft & Mermin
2. Solid State Theory, Grosso & Pastore-Parravicini
3. Electronic Structure of Solids, Kaxiras
4. Electronic Structure of Materials, Sutton
5. Lecture Notes on Electron Correlation and Magnetism, Patrik Fazekas
6. Electronic Structure, Richard M. Martin
7. Mganetism in Condensed Matter, Stephen Blundell

❖ Nanoscience and Nanotechnology

1. **Background to Nanoscience:** Defination of Nano, Properties of materials & nanomaterials, role of size in nanomaterials,Scientific revolution-Atomic Structure and atomic size, emergence and challenges of nanoscience and nanotechnology, carbon age-new form of carbon (CNT to Graphene), influence of nano over micro/macro, size effects and crystals, large surface to volume ratio,scales in nanophysics. [6 lectures]

2. **Types of Nanostructure and Properties of Nanomaterials:** One dimensional, Two dimensional and Three dimensional nanostructured materials, 3D-Pontential Wells (Spherical & Rectangular Parallelepiped), 2D (Circular & Square, quantum wells, quantum rods, quantum wires, quantum rings, Quantum Corrals), 1D (Quantum Wires), 0D (QuantumDots). [6 lectures]

3. **Nanostructured Materials and their Applications:** Physics of thin film deposition, adsorption, surface deposition, nucleation growth and structure development; surface structure, role of surfaces in nanosciences; Epitaxial growth, lattice mismatch and strain, growth modes, self organization, self aligned nanostructures, heterostructures; Growth of quantum structures, Multilayer superlattice structures, Bulk nanostructured materials, porous silicon, metal nanoclusters, metal oxides, semiconducting chalcogenitde and oxide and sulfide based nanocrystals and nanoparticles, nanowires, applications. [12 lectures]

4. **Design and Synthesis of Nanostructure Materials:** Physics of nanoscale engineering, nanofabrication, nano composites. Nucleation and growth of nanosystems; self- assembly, Common techniques for nano-structure fabrication, Top down and bottom up approach, Chemical process: Sol-gel method, Spin coating , plating, ion exchanged and reduction electro deposition technique, Langmuir-Blodget technique, chemical reduction and oxidation; Physical process: vaporization, DC and RF sputtering, chemical vapour deposition, molecular beam epitaxy and laser ablation

mechanical milling, microwave plasma, Electron beam lithography, UV imprint lithography,focused ion beam (FIB), pulsed laser ablationand related theories and technology for thin film growth, condensation, nucleation, phase stability and basic modes of thin film growth. [16 lectures]

5. **Nano Scale Characterization using Scattering and Imaging Techniques:** Microscopy: Compound microscopes, Electron microscopes, Scanning Electron Microscope (SEM), Secondary electron imaging, backscattered electron imaging, Electron Backscattered diffraction (EBSD), Transmission Electron Microscope (TEM), High resolution Transmission Electron Microscopy (HRTEM),Scanning probe microscopies, such as Atomic Force Microscopy (AFM), Piezeo Force Microscopy, Scanning Tunneling Microscopy (STM), Magnetic Force Microscopy (MFM) etc.. X-ray diffraction (XRD), powder diffraction, lattice parameters, structure analyses, strain analyses, phase identification, particle size analyses using - Scherer`s formula. [12 lectures]

6. **Nano Scale Characterization using Spectroscopy:** Basic concepts of spectroscopy, operational principle and application for analysis of nanomaterials, Various spectroscopic instrument like Ultraviolet-Visible-Infrared (UV-VIS-IR) spectrophotometer, Principle of operation and application for band gap measurement, Fourier Transform Infrared Spectrometer (FTIR) Raman spectrophotometer, X-ray photoelectron spectroscopy. Photoluminescence.. Electroluminescence. Photoconductivity. Auger spectroscopy. Energy Dispersive X-ray (EDX) Spectroscopy. Basic understanding of each technique with special emphasis on characterization at nano scale.
[8 lectures]

REFERENCES

1. J. Arbiol and Q. Xiong, Semiconductor Nanowires: Materials, Synthesis, Characterization and Applications,Woodhead Publishing Series in Kindle Edition(2015).
2. Annelise Alves and Carlos P. Bergmann, Novel Synthesis and Characterization of Nanostructured Materials, EngineeringMaterials,(2013).
3. A. William, Goddard III and Donald Brenner, Handbook of Nanoscience, Engineering, and Technology, Electrical EngineeringHandbook, (2002).
4. G. Cao, Z. Wang, Nanostructures and Nanomaterials : Synthesis, Properties, and Applications, 2nd Ed., World scientific, (2011).
5. C. N. R. Rao, A. Mueller, A. K .Cheetham, Chemistry of nanomaterials : Synthesis, properties and applications, Wiley, (2004).
6. C. N. R. Rao, P. J. Thomas, G. U. Kulkarni, Nanocrystals: Synthesis, properties and applications, Springer, (2007)
7. B. D. Cullity, R. W. Stock Elements of X-Ray Diffraction, 3rd Ed., Pearson, (2014).
8. P. J. Goodhew, J. Humphreys, R. Beanland, Electron Microscopy and Analysis (3rd Ed.), Taylor & Francis, (2000)
9. D. B. Williams and C. B. Carter, Transmission Electron Microscopy: A Textbook for Materials Science, Springer, (2009).
10. B. J. Berne, R. Pecora, Dynamic Light Scattering: With Applications to Chemistry, Biology, and Physics, Courier Dover Publications, (2000).

❖ Emerging Electronic Functional Materials

The 'triple E' mantra - energy efficient, economically inexpensive, and environmentally friendly, is the motivation for the state of art functional materials. Here few of them are intriduced.

Liquid Crystals

1. Thermotropic liquid crystals, Classification, lyotropic liquid crystals, Transition between different mesophases, Landau theory. [10 lectures]
2. Ferroelectricity in chiral and achiral liquid crystals molecules. [3 lectures]
3. Experimental investigation of liquid crystal using polarizing microscopy, Simple models for ionic conduction, dielectric relaxation in materials, polarisation, complex permittivity and loss factor, frequency and temperature dependence of dielectric parameters, scaling of frequency dependent conductivity (Jonschers law). Viscoelastic relaxation. [12 lectures]

Polymer/Organic/Molecular/MOF Ferroelectrics [15 lectures]

Crystallographic groups of ferroelectric materials, crystallographic constraints, metal oxide framework
Technological importance, high dielectric, ferroelectric capacitor.
Dielectric behavior, ferroelectric- paraelectric phase transition.

Exprimentation

Small angle x-ray diffracrtion, Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM), High Resolution Transmission Electron Microscopy (HRTEM), Scanning probe microscopies, such as Atomic Force Microscopy (AFM), Piezeo Force Microscopy, Polarization measurement methods (Sawyer-Tower, Triangle and PUND), Ultraviolet-Visible-Infrared (UV-VIS-IR) spectrophotometer, Principle of operation and application for band gap measurement, Fourier Transform Infrared Spectrometer (FTIR), Raman spectrophotometer, X-ray photoelectron spectroscopy. Photoluminescence. Electroluminescence. Photoconductivity. Auger spectroscopy. Energy Dispersive X-ray (EDX) Spectroscopy. [20 lectures]

REFERENCES

1. P. J. Connilns and M. Hird, Introduction to Liquid Crystals: Chemistry and Physics, CRC Press, London (1997).
2. P. G. dE Gennes and J Prost, The Physics of Liquid Crystals, Clarendon Press, Oxford (1993).
3. Handbooks of Liquid Crystals, Wiley-VCH Verlag GmbH & Co. (2014).
4. M. E. Lines and A. M. Glass, Principles and Applications of Ferroelectrics and Related Materials, Claredon, Oxford, (1977).
5. Ennio Fatuzzo and Walter J. Merz, Ferroelectricity, North-Holland Publishing Company, (1967).
6. B. D. Cullity, R. W. Stock, Elements of X-Ray Diffraction, 3rd Ed., Pearson, (2014).
7. P. J. Goodhew, J. Humphreys, R. Beanland, Electron Microscopy and Analysis, (3rd Ed.), Taylor & Francis, (2000).
8. D. B. Williams and C. B. Carter, Transmission Electron Microscopy: A Textbook for Materials Science, Springer, (2009).

❖ Science and Technology of Organic Thin Films

1. Organic Molecules: Structure, Classification and Nomenclature [12 lectures]

Determining the Structure of Organic Compounds, Carbon, Covalent Bond (Lewis Structure Formalism), Molecular Geometry (Bond Length, Bond Angle). Sigma and Pi Bonds.

Cyclic and Conjugated Molecules; Cyclic Compounds, Aromatic Hydrocarbons (Benzene, Determining the Structure of Organic Compounds (Spectroscopy).

Electronic Structure of Atoms and Molecules, BO approximation, Atomic and Molecular Orbitals, LCAO, Bonding and antibonding orbitals, Orbital hybridization, HOMO and LUMO levels.

2. Basic Photophysics and Spectroscopy of pi-conjugated Materials [8 lectures]

Photophysics of Organic Molecules Excited states: (Absorption and emission, Singlet and triplet states), Rates of electronic transitions, Transition moment, Frank Condon Principle, Radiative and non-radiative transitions, Excited state kinetics.

3. Charge Transport in Disordered/Molecular Materials [5 lectures]

Exciton Processes in Organic Solids, Charge-transfer Exciton, Frenkel Exciton, Exciton Diffusion, Exciton Energy Transfer (Förster, Dexter), Electronic Conduction in Organic Solids Conductivity: (carrier concentration versus mobility), Carrier generation, Hopping transport, Mobility measurements, Traps etc.

4. Growing and Pattering Thin Organic Films [5 lectures]

Purifying Organic Materials, Growth Techniques: Spin-on, Evaporation, Langmuir-Blodget, Chemical Vapor Phase Deposition, Ink-Jet Printing, Self Assembly, Vacuum components and systems : Need for vacuum, ways to achieve vacuum, determination of vacuum, dry and vapour pumps, pressure measurement gauges, conductance and other system design considerations.

5. Characterization of Thin Films: Different Methods of Thickness Measurements, Electrical, Electronic and Structural Property Determination. [15 lectures]

Electronic: Measuring the Energy Structure of Thin Films and interface: Interface formation, And definition, Measuring the Energy Structure using different techniques such as Photoemission Spectroscopy, Inverse Photoemission Spectroscopy, Cyclic Voltametry, Dipoles at the Organic Thin Film Interfaces.

Structural: Experimental techniques and analysis of materials through X-ray scattering techniques: X-ray reflectivity (XRR), crystal structure determination. Phase diagram determination; Morphological characterisation using Scanning techniques (SEM, AFM, STM); Optical microscopy; optical and vibrational spectroscopy.

Electrical: Conductivity measurements; 2 and 4 probe measurements mobility, carrier concentration measurements. AC measurements, impedance and dielectric measurements. Different measurement techniques.

6. Applications of organic thin films in electronics [15 lectures]

Understand the basic concepts behind organic semiconductors and materials and application to different devices such as thin film transistor (OTFT), Organic LED (OLED), Solar cells etc.

OTFT operation mechanism and characteristics, important phenomena, challenges, recent developments. Aspects of OLED Physics and Technology Charge injection from metal contacts, Charge transport and device characteristics, Photovoltaic Devices: General background, device operation mechanism and characteristics, important phenomena, current challenges, recent developments. Thin films resistors, capacitors and active devices, thin fil, solar cells etc.

REFERENCES

1. Photoelectron Spectroscopy, Principles and Applications, Stefan Hüfner, Springer.
2. X-Ray Scattering from Soft Matter Thin Films, Springer Tracts in Modern Physics; M. Tolan, Springer: Berlin, 1999.
3. X-Ray and Neutron Reflectivity: Principles and Applications; J. Daillant, and A. Gibaud, Springer: Berlin, 1999.
4. Peter Stallinga, Electrical Characterization of Organic Electronic Materials and Devices, Wiley, NJ, 2009.
5. Laszlo Solymar, Donald Walsh, Electrical Properties of Materials, Oxford University Press, 8thEd., 2010.
6. Organic Electronics: Materials, Manufacturing, and Applications" , Hagen Klauk, John Wiley & Sons; 1st edition 2006.

❖ Nuclear Physics: Theory, Experiment and Computational Techniques

Nuclear Decays: Nuclear transformations – Radioactive decay – Alpha decay – Gamow's theory – Beta decay – Fermi theory –Selection rules – Interaction of gamma radiation with matter – Photo electric effect – Compton scattering – Pair production. [10 lectures]

Particle Accelerators: Introduction – Linear accelerators – Drift tube and Wave guide accelerators – Low energy circular accelerators – Cyclotron and Betatron. [5 lectures]

Models of Nuclei: Few Body Models of Exotc Atoms & Nuclei, Liquid drop model, Shell Model, Collective Model, Degenerate Gas Model. [10 lectures]

Nuclear Reaction: Compound nucleus hypothesis. Optical model of elastic scattering, average interaction potential for nucleus, energy dependence of the potential, spin orbit coupling, isospin effect. Nuclear reaction using Radioactive ion Beam. [10 lectures]

Nuclear Energy: Nuclear fission: Energy release, mass and energy distribution of fission fragments, cross section for neutron induced fission. Chain reaction. [5 lectures]

Nuclear Astrophysics: Primordeal nucleosynthesis, Nuclear Fusion- Astrophysical S-factor, Reaction rates; PP -chain; CNO Cycle. [8 lectures]

Computational Techniques: Programming language – FORTRAN, Numerical integration (trapezoidal and Simpson's method), numerical differentiation; Diagonalization and inverse of symmetric and non-symmetric matrices, Eigenvalues and eigenvectors.; Root finding (bisection and Newton-Raphson method); Interpolation techniques; Solution of ordinary differential equations (Euler and Runge-Kutta methods). [12 lectures]

REFERENCES

1. Concepts of Nuclear Physics, B. L. Cohen (Tata McGraw Hill)
2. Nuclear Physics - An Introduction, S. B. Patel
3. Nuclear Physics, I. Kaplan
4. Nuclei and Particles, Emilio Segre
5. Nuclear Radiation Detectors, S. S. Kapoor, V. S. Ramamurthy
6. Techniques for Nuclear and Particle Physics Experiments, W R Leo
7. Radiation Detection and Measurement, G F Knoll
8. Nuclear Astrophysics- A Course of Lectures, Md A Khan
9. Computer Oriented Numerical Methods, V. Raiaraman

❖ General Relativity and Astrophysics

1. Recapitulation of General Relativity: Introduction to general relativity (GR), equivalence principle, gravitation as a manifestation of the curvature of spacetime. Tensor algebra, covariant derivatives and parallel transport, Curvature - Riemann tensor, Bianchi identities, Energy momentum tensors, Einstein's field equations. Spherical symmetry, derivation of the Schwarzschild solution. Precession of the perihelion of Mercury, Schwarzschild Embedding Diagram. Deflection of light, Gravitational Lensing, Lens equation, Einstein ring, Image brightness. Gravitational redshift. [8 lectures]

2. Black holes: Schwarzschild Black hole, Motion of test particles around Schwarzschild black hole. Tortoise coordinate, Eddington-Finkelstein coordinate, Kruskal-Szekeres coordinate, event horizon - one way membranes. Reissner-Nordstrom solution, charged black hole. Kerr metric and Kerr black holes (without deduction of solution), Kerr-Newmann black hole (no derivation of the metric required). Particle orbit in Kerr spacetime, ZAMO, Ergoregion and horizon, Penrose process. Laws of Black hole thermodynamics, Hawking radiation. [20 lectures]

3. Advanced Topics: [20 lectures]

Relativistic Astrophysics: Interior solution for a spherical star; Birkhoff's theorem, Oppenheimer–Volkoff and Tolman equation; Metric for uniform density stars. Polytropic Stars, their potential and kinetic energies and stability. Radial oscillations and maximum rotational frequency. Lane-Emden Equation, Chandrashekhar Mass limit, Neutron stars, pulsars and stiff and soft Equation of State.

Wormhole Physics: The Einstein-Rosen bridge, wormhole geometry, Macroscopic vs. Microscopic wormhole, Lorentzian wormholes, Euclidean wormholes; Traversable wormhole, exotic matter, redshift function, throat radius, Energy conditions, Null Energy Condition, Morris-Thorne wormhole; Thin shell wormholes, Darmoise-Israel formalism, static and dynamic wormholes, stability analysis.

4. Cosmology: Olbers' paradox, Cosmological principle, maximally symmetric spaces, Killing vectors, Robertson- Walker metric. Redshift of galaxies and Hubble's law. Magnitude-red shift relation, Hubble's constant and deceleration parameter. Friedmann equations and standard models. Closed, flat and open universes. Age of the universe, critical density. Galaxy clusters and problem of missing mass or missing light, dark matter. Thermal history of early universe, helium formation, decoupling of matter and radiation, microwave background radiation. Cosmological constant and the late time acceleration.

[12 lectures]

REFERENCES

1. A General Relativity Workbook - Thomas A. Moore; University Science Books- Mill Valley, California.
2. Gravity- An Introduction to Einstein's General Relativity- James B. Hartle ; Pearson
3. Gravitation -Charles W. Misner, Kip S. Thorne and John Archibald Wheeler; Princeton University Press.
4. A first course in general relativity- Bernard F. Schutz; Cambridge University Press
5. General Relativity- M.P.Hobson, G.P.Efstathiou and A.N.Lasenby; Cambridge University Press
6. Gravitation and Cosmology- Steven Wienberg; Wiley
7. Introduction to Cosmology- J.V. Narlikar ; Cambridge University Press
8. General Theory of Relativity - S. P. Puri– Pearson
9. The General Theory of Relativity – Farook Rahaman; Cambridge University Press
10. General Relativity- Robert M. Wald – Overseas Press
11. An Introduction to Modern Astrophysics- Bradley W. Carroll and Dale A. Ostlie; Addison-Wesley Publising Company, Inc.
12. Introducing Einstein's Relativity- Ray d'Inverno; Clarendon Press, Oxford.
13. Astronomy and Astrophysics - Michael Zeilik and Stephen A. Gregor; Thomson Learning