# Ph.D. Physics

**SYLLABUS**
**(Effective from the Academic year 2021 – 2022 and onwards)**

## DEPARTMENT OF PHYSICS


## KARPAGAM ACADEMY OF HIGHER EDUCATION

**(Deemed to be University Established Under Section 3 of UGC Act, 1956)**
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**DEPARTMENT OF PHYSICS**
**FACULTY OF ARTS, SCIENCE & HUMANITIES**
**RESEARCH PROGRAM –PhD in PHYSICS**
**(2021–2022 Batch and onwards)**

| Course code | Name of the course | Instruction hours / week | credits | Maximum Marks (100) |
|---|---|---|---|---|
| 21RPHY101 | Paper-I: Research Methodology and Pedagogy | 4 | 4 | 100 |
| 21RPHY201 | Paper-II: Research Publication Ethics | 4 | 4 | 100 |
| 21RPHY301 | Paper-III: Special Paper I – Solar Energy and Its Utilization | 4 | 4 | 100 |
| 21RPHY302 | Paper-III: Special Paper II – Molecular Spectroscopy | | | |
| 21RPHY303 | Paper-III: Special Paper III – Thin Film Physics | | | |
| 21RPHY304 | Paper-III: Special Paper IV – Crystal Growth | | | |
| 21RPHY305 | Paper-III: Special Paper V – Solid state Ionics | | | |
| 21RPHY306 | Paper-III: Special Paper VI – Concepts of Nanophysics and Nanotechnology | | | |
| 21RPHY307 | Paper-III: Special Paper VII – Laser Physics | | | |
| 21RPHY308 | Paper-III: Special Paper VIII – Fluorescence Spectroscopy | | | |
| 21RPHY309 | Paper-III: Special Paper IX– Experimental Techniques In Materials Science | | | |
| 21RPHY310 | Paper-III: Special Paper X – Magnetic and Thermoelectric Properties of Materials | | | |
| Program Total | | 12 | 12 | 300 |

**21RPHY101 PAPER – I: RESEARCH METHODOLOGY & PEDAGOGY**

**Course Objectives**

- To develop a research orientation among the scholars and to acquaint them with fundamentals of research methods.
- To develop understanding of the basic framework of research process.
- To develop an understanding of various research designs and techniques.
- To identify various sources of information for literature review and data collection.
- To develop an understanding of the ethical dimensions of conducting applied research.
- Appreciate the components of scholarly writing and evaluate its quality.
- To show the scholars roadmaps of research from the beginning to the end and their intricacies;
- To inform and equip the scholars with essential knowledgebase and infrastructures for conducting research before landing up in the field.
- To understand the Research Pedagogy include article readings, discussions, etc.,

**Course Outcomes**

Upon completing this course, each scholar will be able to:

1. Demonstrate knowledge of research processes (reading, evaluating, and developing);
2. Perform literature reviews using print and online databases;
3. Identify, explain, compare, and prepare the key elements of a research proposal/report;
4. Define and develop a possible higher education research interest area using specific research designs;
5. Compare and contrast quantitative and qualitative research paradigms, and explain the use of each in higher education research;
6. Describe sampling methods, measurement scales and instruments, and appropriate uses of each;
7. Explain the rationale for research ethics, and the importance of and local processes for Institutional Review Board review; and
8. demonstrate how educational research contributes to the objectives of your doctoral program and to your specific career aspirations in higher education.

**Unit – I INTRODUCTION**

Ethics of Research – Objectives of Research – Historical Background of Physics Research – Research Works of Sir C.V. Raman, S.Chandrasekhar and Venkaraman Ramakrishnan (Nobel prize works only) (Nobel Lectures) – Experimental Research in Physics – Design of the experiment, Apparatus to be used, Results and Interpretation – Theoretical Research in Physics – Theory, Models, Methods to solve the problems, results and Interpretation – Literature Survey on Thesis Writing – Online literature survey – Science Citation Index – Impact factor of a journal – Thesis writing.

**UNIT II -PROBABILITY DISTRIBUTIONS**

Mean, Median peak value, and Standard Deviation – Binomial Distribution – Poisson Distribution – Gaussian or Normal Error Distribution – Modes of distributions.

**Error Analysis**

Instrumental and Statistical uncertainties – Propagation of errors – Estimation of means and errors – Method of least squares – Statistical fluctuations – Chi square test of a distribution

**UNIT III - NUMERICAL INTEGRATION**

Trapezoidal and Simpson's 1/3 rule for single integrals - Error estimates - Trapezoidal and Simpson's rule for double integrals

**Interpolation:** Two points Gaussian quadrature - Three points Gaussian quadrature - Cubic spline interpolation

**Eigen values:** Power method - Jacobi method (Only 2 x 2 and 3 x 3 matrices)

**Simulation techniques:** Monte Carlo simulation – Fuzzy logic.

**UNIT IV- COMPUTER APPLICATIONS IN PHYSICS RESEARCH**

**Programming in C:** Constants - Variables - Data types - Operators and Expressions - Input/Output Statements - Control statements - Functions - Arrays - One, two, multidimensional array declarations and initializations

**Simple applications using C - Program:** Program to integrate tabulated function using Trapezoidal rule - Program to integrate tabulated function using Simpson's 1/3 rule - Program to compute the solution of first order differential equation of the type y' = f(x,y) using RK4 method - Program to compute first order differential equation y' = f (x,y) using Milne's method - Program to compute the interpolation value at a specified value from a set of table points using natural cubic spline interpolation.

**UNIT V-PEDAGOGICAL METHODS IN HIGHER LEARNING**

Historical perspectives: Objectives and role of higher education – Learning and learning hierarchy – Information processing – Learning and outcomes – Motivation.

Education evaluation: A conceptual framework – Methods of evaluation – Self evaluation and student evaluation in higher education – Question banking – Diagnostic testing and remedial teaching.

**SUGGESTED READINGS**


1. E.Balagurusamy - Numerical methods , Tata McGraw Hill Publishing company Limited
2. Nye, J.F. (1985). Physical Properties of Crystals: Their Representation by Tensors and Matrices. Oxford University Press, New York.
3. P.Kandasamy - Numerical methods, K.Thilgavathy and K.Gunavathi, S.Chand and company limited
4. Numerical Mathematical Analysis by Scarborough J B, Oxford & Ibh, ISBN-10: 9788120417595
5. Bevington Philip, Robinson D. Keith – Data Reduction and Error Analysis for Physical Sciences, Mc Graw Hill Higher Education.
6. https://nptel.ac.in/courses/121/106/121106007/
7. https://nptel.ac.in/courses/109/105/109105115/
8. https://nptel.ac.in/courses/109/103/109103153/
9. https://nptel.ac.in/courses/107/108/107108011/

**21RPHY201 PAPER – II: RESEARCH PUBLICATION ETHICS**

**Course Objectives**

1. Provide students with the fundamental knowledge of research methods and design used in.
2. Facilitate students understanding for how using valid scientific methods of measurement and scaling can improve and create knowledge.
3. Analyse and interpret methods of quantitative and qualitative data.
4. Guide the students in developing, completing, writing, and presenting a valid and ethical research report.

**Course Outcomes**

After attending the course the scholars will

1. Understand ethical issues related to Research and Publications.
2. Gain knowledge on preparing patents and rights.
3. Understand and Publish ethically.
4. Impart knowledge on ways for avoiding plagiarism.
5. Write research papers/thesis and follow publication ethics of Journal

**UNIT I**

**Philosophy and Ethics:**

Introduction to Philosophy: Definition, nature and scope, concept, branches - Ethics: Definition, moral philosophy, nature of moral judgments and reactions.

**UNIT II**

**Scientific Conduct:**

Ethics with respect to science and research – Intellectual honesty and research integrity – Scientific misconduct: Falsification – Fabrication and Plagiarism (FFP) - Redundant publications: duplicate and overlapping publications – salami slicing - Selective reporting and misrepresentation of date.

**UNIT III**

**Publication Ethics:**

Publication Ethics: Definition, introduction and importance - Best practices / standards setting initiatives and guidelines: COPE, WAME, etc. - Conflicts of interest - Publication Misconduct: definition, concept, problems that lead to unethical behavior and vice versa, type -Violation of publication ethics, authorship and contributor ship - Identification of publication misconduct, complaints and appeals - Predatory publishers and journals.

**UNIT IV**

**Publication Misconduct:**

Group Discussions: Subject specific ethical issues, FFP, authorship - Conflicts of interest - Complaints and appeals: examples and fraud from India and abroad.

Software tools: Use of plagiarism software like Turnitin, Urkund and other open source software tools.

**UNIT V**

**Databases and Research Metrics:**

Database : Indexing database - Citation database: Web of Science, Scopus, etc

Research Metrics: Impact Factor of journal as per Journal Citation Report, SNIP, SJR, IPP, CiteScore - Metrics: h-index, g index, i10 index, altmetrics.

**UNIT VI**

**Development of e-content & IP:**

Integrated Library Management System (ILMS) : e-journals – e-books – e-shodhsindu – shodhganga – Database - e-content Development - Learning Management System (LMS) – e-PG- Pathshala – CEC (UG) SWAYAM – MOOCs – NPTEL - NMEICT.

IPR: Patent – Copyrights - Trademark – Geographical Indication.

**PRACTICE**

**Open Access Publishing:**

Open access publications and initiatives - SHERPA / RoMEO online resource to check polisher copyright & self-archiving policies - Software tool to identify predatory publications developed by SPPU - Journal finder / journal suggestion tools viz. JANE, Elsevier Journal Finder, Springer Journal Suggester, etc.

**SUGGESTED READINGS**


1. P. Oliver, (2003), The student's guide to research ethics, Open University Press Maidenhead,Philadelphia.
2. H. Zwart, (2010), Tales of Research Misconduct, Springer International Publishing AG.
3. Research Impact, https://guides.osu.edu/c.php?g=608754&p=4224917.
4. Diane Elkins et al. (2015). E-Learning Fundamentals: A Practical Guide.
5. Nick Rushby et al. Wiley Handbook of Learning Technology. Wiley Education. Wiley

**21RPHY301 PAPER – III : SPECIAL PAPER I : SOLAR ENERGY AND ITS UTILIZATION**

**Course Objectives**

- Solar energy harvesting and utilizing for day to day purposes has become order of the day.
- The scarcity and increasing need of the fossil fuel has made man to think about alternate sources, the easiest and best being Solar energy. Hence the course introduced to get knowledge of solar energy and its utilization.
- To introduce the students to the world of solar energy, its different uses, the different methods of harvesting solar energy.
- To understand the basic concepts of energies produced from various energy sources, advantages and disadvantages
- To learn the present energy scenario and the need for energy conservation
- To facilitate the students to achieve a clear conceptual understanding of technical and commercial aspects of Solar Power Development and Management.
- To enable the students to develop managerial skills to assess feasibility of alternative approaches and drive strategies regarding Solar Power Development and Management.
- To develop a comprehensive technological understanding in solar PV system components
- To Analyse the environmental aspects of renewable energy resources.

**Course Outcomes (COs)**

At the end of the course, Students will / can be able to

1. Describe the environmental aspects of non-conventional energy resources. In Comparison with various conventional energy systems, their prospects and limitations.
2. Know the need of renewable energy resources, historical and latest developments
3. explain the principles that underlie the ability of various natural phenomena to deliver solar energy
4. outline the technologies that are used to harness the power of solar energy
5. Describe the use of solar energy and the various components used in the energy production with respect to applications like - heating, cooling, desalination, power generation, drying, cooking etc
6. Appreciate the need of Wind Energy and the various components used in energy generation and know the classifications.
7. Gain the knowledge about the energy produced from biomass and biogas.
8. Understand the concept of Biomass energy resources and their classification, types of biogas Plants- applications
9. Compare Solar, Wind and bio energy systems, their prospects, Advantages and limitations.
10. Acquire the knowledge of fuel cells, wave power, tidal power and geothermal principles and applications.

**UNIT 1- RADIATION GEOMETRY**

Basis earth sun angles - Determination of Solar time - Derived Solar angles - Day length - Solar Radiation measurements - selective surfaces - Heat balance energy lost by radiation, convection and conduction - Physical characteristics of selective surfaces - Anti reflection coatings - Solar reflector materials - production methods of coatings.

**UNIT II - FUNDAMENTALS OF HEAT TRANSFER**

Transfer of Heat by Conduction: Study heat flow in a slab-steady heat flow in a cylindrical shell-Heat transfer through fins – Transient heat conduction. Thermal Radiation: Basic laws of radiation – Radiant heat transfer between two black bodies- Radiant heat transfer between grey bodies. Convention heat loss Evaluation of convective heat transfer co-efficient –Free convection from vertical planes and cylinders – Forced convection – Heat transfer for fully established flow in tubes.

**UNITIII - SOLAR THERMAL SYSTEMS**

General description of plate collector – thermal losses and efficiency of FPC –Energy balance equation – Evaluation of overall loss coefficient – Thermal analysis of flat plate collector and useful heat gained by the fluid performance of solar air heaters – Heating and drying of agricultural products Types of drier in use.

Solar concentrators and Receiver geometries – General characteristics of focusing collector systems Evaluation of optical losses – Thermal performance of focusing collectors.

**UNITIV-PHOTOVOLTAICS**

Description of the photovoltaic effect – Electrical characteristics calibration and efficiency measurement – silicon solar energy converters – Thermal generation of recombination centers silicon. Role of thin films in solar cells Properties of thin films for solar ells CdSe, CdTe, In P, Ga As, Cd Cu2, Cu In SnO2, Cd2SnO4 ZnO)- Transport properties of metal films – poly crystalline film silicon solar cells (Photovoltaic characteristics, junction analysis loss mechanisms) Amorphous silicon solar cells (Structural compositional optical and electrical properties)

**UNIT V- ENERGY STORAGE AND SOLAR APPLICATIONS**

Types of energy storage Thermal storage Latent heat storage – Electrical storage principle of operation of solar ponds-Non convective solar ponds – Theoretical analysis of solar pond – solar distillation – solar cooking –solar pumping.

**SUGGESTED READINGS**

1. Charles E. Backus (1976). Solar cells. IEEE Press
2. Garg, H.P. (1982). Treatise on solar energy volume I fundamentals of Solar Energy.
3. Kasturi Lal Chopra and Suhit Ranjan Das (1983). Thin film solar cells.

4. Rai, G.D. (1996). Solar energy utilization.
5. Rai, G.D.Thermal performances testing of FPC and CPC.
6. https://nptel.ac.in/courses/115/107/115107116/
7. https://nptel.ac.in/courses/115/103/115103123/
8. https://onlinecourses.nptel.ac.in/noc19_ph13/preview
9. https://onlinecourses.nptel.ac.in/noc20_mm05/preview

## 21RPHY302 PAPER – III: SPECIAL PAPER II: MOLECULAR SPECTROSCOPY

**Course Objectives**

- This paper gives an insight into the theoretical and practical aspects of spectroscopy. it is used as a tool for non-destructive testing of samples. It is important to know the physical aspects of spectroscopy.
- The major objectives of this course are to integrate theory and practice and to bring together different branches of both Academic studies and Industrial Research through the presentation of critical aspects of modern Spectroscopy.
- The course will provide a valuable theoretical introduction and an overview of modern topics in spectroscopy, which are of current interest and importance in Semiconductor Industry and Biomedicine.
- To give an understanding of wide range of techniques including optical Nearfield spectroscopy, Raman, and FTIR spectroscopy.
- To introduce electronic spectroscopy methods that are widely used in physics, chemistry and biological sciences.
- To recognize the symmetry of molecole
- To identify the active molecular motion
- To undestand rotational, vibrationa, Raman and electronic spectra.

**Course Outcomes (COs)**

After completing the course the students will / can able to

1. Understand the basic physical chemistry law that govern molecular spectroscopy
2. Describe the basic concepts of crystal field theory.
3. According to crystal field theory examines simple molecules.
4. Defines the basic concepts of molecular orbital theory.
5. According to molecular orbital theory examines simple molecules.
6. Identify the types of radiation in the atomic and molecular electronics.
7. Gain knowledge of the most common atomic and molecular spectroscopic methods and the atomic and molecular properties derived from those.

**UNIT I- MOLECULAR SYMMETRY**

Symmetry operation – symmetry elements – Different type of symmetry operations – symmetry point groups – Linear and non linear molecules – Representations of groups - Irreducible Representations and character – and character tables.

**UNIT II- MOLECULAR ORBITAL THEORY**

General principles – the LACO approximation – the Huckel approximation – Bonding character of orbitals - symmetry factoring of secular equations – Transformation properties of Atomic orbitals – Hybridization schemes of and orbitals Hybrid orbitals as linear combinations of Atomic orbitals – Valence Bond and Molecular orbital theory - Brief description of Hartree-Fock theory and Density functional theory

**UNIT III- MOLECULAR VIBRATIONS**

The symmetry of Normal vibrations – Determining the symmetry types of the Normal mode – Internal coordinates – symmetry coordinates - Normal coordinates – potential and kinetic energies in terms of symmetry coordinates – removal of redundant coordinates – application of group theory of Raman and IR activity.

**UNIT IV- INFRARED AND RAMAN SPECTROSCOPY**

**IR spectroscopy:** Practical aspects – Theory of I.R rotation vibration spectra of gaseous diatomic molecules – applications of I.R spectroscopy – Principles of F.T.I.R spectroscopy – FTIR instrumentation – Interpretation of data.

Classical and Quantum theory of Raman effect - Rotation vibration Raman spectra of diatomic and polyatomic molecules – Applications - Laser Raman spectroscopy – Sample handling techniques – Polarized Raman spectra of single crystals – Fundamentals of Surface Enhanced Raman Scattering (SERS)

**UNIT V - ELECTRONIC SPECTRA**

Electronic excitation of diatomic species - Resonance and Normal Fluorescence – Intensities of transitions - Phosphorescence population of triplet state and intensity- Experimental methods - Applications of Fluorescence and phosphorescence – UV spectrophotometry.

**SUGGESTED READINGS**


1. Chandra, A.K. Quantum chemistry.
2. Aruldhas, G. (2008). Molecular Structure and Spectroscopy. Pergamon Press, New Delhi.
3. Cotton, F.A. Chemical applications of group theory. Wiley Inter science.
4. Herzberg. Infra red Raman spectroscopy.
5. Puranik, P.G. Group theory application to molecular vibrations.
6. People, J.A. and Segai, G.A. (1965). Approximate self–consistent molecular orbital theory I. Calculations with complete neglect of Differential over lap. J . Che . Phy . Vol.43.
7. People, J.A. and Segai, G.A. (1965). Approximate self–consistent molecular orbital theory II. Calculations with complete Neglect of Differential over lap. J Che. Phy .Vol. 43 No .10.
8. People, J.A. and Segai, G.A. (1965). Approximate self–consistent molecular orbital theory III CNDD Results for AB-2 and AB,3 Systems .
9. Santry, D.P. and Segai, G.A. (1967). Approximate self – consistent molecular orbital theory IV. Calculations on Molecules including the Elements sodium through chlorine. J. Chem. . phys . vol. 47 – 158 – 174.

10. Segai, G.A. (1967) Calculation of Equilibrium bond lengths by the CNDO method. J.Chem.Phys . vol. 47 . 1876 – 1877.
11. Wioson, E.B. Cross. Molecular vibrations.
12. https://nptel.ac.in/courses/104/101/104101099/
13. https://nptel.ac.in/courses/104/106/104106122/
14. https://nptel.ac.in/courses/104/101/104101126/
15. https://onlinecourses.nptel.ac.in/noc20_cy08/preview

## 21RPHY303 PAPER – III: SPECIAL PAPER III. THIN FILM PHYSICS

**Course Objectives**

- Introduce physical concepts and mathematical tools used to describe surfaces, interfaces and thin films.
- To develop an intuition for surface and thin film physical principles through plotting of functions using Maple
- To relate the mathematical results to practical applications and experiments in thin film techniques.
- Develop an appreciation of the mathematical basis for experimental techniques for deposition and analysis of thin films
- Understand physical phenomena that can be exploited for the deposition of thin films
- To demonstrate knowledge of different thin film deposition strategies

**Course Outcomes (COs)**

At the end of the course, the students can/will be able to

1. Discuss the differences and similarities between different vacuum based deposition techniques
2. Evaluate and use models for nucleating and growth of thin films
3. Examine the relation between deposition technique, film structure, and film properties, discuss typical thin film applications,
4. Select proper deposition techniques for various applications.
5. Understand the basic concepts about the thin film technology
6. The importance of use of thin films in application and research.
7. The students gain experience in handling high vacuum equipment and using thin film growth techniques which to enables them to work at production units related to optical, mechanical, electronic coatings etc.

### UNIT I- PREPARATION OF THIN FILMS

Spray pyrolytic process – characteristic feature of the spray pyrolytic process – ion plating – Vacuum evaporation – Evaporation theory – The construction and use of vapour sources – sputtering Methods of sputtering – Reactive sputtering – RF sputtering - DC planar magnetron sputtering.

### UNIT II- THICKNESS MEASUREMENT AND NUCLEATION AND GROWTH IN THIN FILM

Thickness measurement: electrical methods – optical interference methods – multiple beam interferometry – Fizeau – FECO methods – Quartz crystal thickness monitor.

Theories of thin film nucleation – Four stages of film growth incorporation of defects during growth.

**UNIT III- ELECTRICAL PROPERTIES OF METALLIC THIN FILMS**

Sources of resistivity in metallic conductors – sheet resistance - Temperature coefficient of resistance (TCR) – influence of thickness on resistivity – Hall effect and magneto resistance – Annealing – Agglomeration and oxidation.

**UNIT IV- TRANSPORT PROPERTIES OF SEMICONDUCTING AND INSULATING FILMS**

Semiconducting films; Theoretical considerations - Experimental results – Photoconduction – Field effect thin films – transistors, Insulation films Dielectric properties – dielectric losses – Ohmic contracts – Metal – Insulator and Metal – metal contacts – DC and AC conduction mechanism .

**UNIT V - OPTICAL PROPERTIES OF THIN FILMS AND THIN FILMS SOLAR CELLS**

Thin films optics –Theory – Optical constants of thin films – Experimental techniques – Multilayer optical system – interference filers – Antireflection coating, thin films solar cells: Role, Progress, and production of thin solar cells – Photovoltaic parameter, thin film silicon (Poly crystalline) solar cells : current status of bulk silicon solar cells – Fabrication technology – Photo voltaic performance: Emerging solar cells: GaAs and $CulnSe_2$.

**SUGGESTED READINGS:**

1. Anderson, J.C. The use of thin films in physical investigation.
2. Berry, Koil and Harris. Thin films technology.
3. Chopra, K.L. Thin film Phenomena.
4. Chopra, K.L. and Das, S.R. Thin films solar cells.
5. George Hass and others (Ed). Physics of thin films, vol. 12.
6. Holland, L. Vacuum deposition of thin films.
7. Maissel, L.I. and Clang, R. Hand book of Thin films Technology.
8. Vilsan, J.L. Thin films processes.
9. https://nptel.ac.in/content/storage2/courses/112108092/module2/lec08.pdf
10. http://www.infocobuild.com/education/audio-video-courses/materials-science/FundamentalsOfMaterialProcessing2-IIT-Kanpur/lecture-37.html
11. https://www.youtube.com/watch?v=H2h0tz5KfPw
12. https://www.youtube.com/watch?v=p0XxWT2QdEk

## 21RPHY304 PAPER – III: SPECIAL PAPER IV: CRYSTAL GROWTH

### Course Objectives

- To strengthen the students with crystallographic and crystal growth techniques
- To provide the general characteristics of crystals, methods of preparation etc.
- Various thin films deposition techniques and thin film characterization techniques are also covered in the course.
- To give an idea about historical importance of crystals, methods of preparation and characterization of crystals etc.
- To explore the knowledge in fundamentals of materials syntheses, crystal growth techniques, zone refining, properties etc.,
- To provide the basic knowledge on crystal structure.

### Course Outcomes (COs)

After completing the course the students will / can able to

1. The student will learn about the crystal growth mechanisms and techniques.
2. Understand different crystals having a lot applications in electronics, energetics etc.
3. Acquire the theoretical concept behind electrical and thermal properties of metals
4. Understand the fundamental theories to describe the energy bands in metals
5. Gain the knowledge about Semiconductor Crystals and their properties
6. Gain the knowledge about phonons and its importance in thermal physics

### UNIT I- FUNDAMENTALS OF CRYSTAL GROWTH

Importance of crystal growth – Classification of crystal growth methods – Basic steps: Generation, transport and adsorption of growth reactants – Nucleation: Kinds of nucleation – Classical theory of nucleation: Gibbs Thomson equations for vapour and solution – Kinetic theory of nucleation – Becker and Doring concept on nucleation rate – Energy of formation of a spherical nucleus – Statistical theory on nucleation: Equilibrium concentration of critical nuclei, Free energy of formation.

### UNIT II- THEORIES OF CRYSTAL GROWTH

An introductory note to Surface energy theory, Diffusion theory and Adsorption layer theory – Concepts of Volmer theory, Bravais theory, Kossel theory and Stranski's treatment – Two-dimensional nucleation theory: Free energy of formation, Possible shapes and Rate of nucleation – Mononuclear, Polynuclear and Birth and Spread models – Modified Birth and Spread model – Crystal growth by mass transfer processes: Burton, Cabrera and Frank (BCF) bulk diffusion model, Surface diffusion growth theory.

**UNIT III - EXPERIMENTAL CRYSTAL GROWTH-PART-I: MELT GROWTH TECHNIQUES.**

Basics of melt growth – Heat and mass transfer – Conservative growth processes: Bridgman-Stockbarger method – Czochralski pulling method – Kyropolous method – Nonconservative processes: Zone-refining – Vertical and horizontal float zone methods – Skull melting method – Vernueil flame fusion method.

**UNIT IV- EXPERIMENTAL CRYSTAL GROWTH-PART-II: SOLUTION GROWTH TECHNIQUES.**

Growth from low temperature solutions: Selection of solvents and solubility – Meir's solubility diagram – Saturation and supersaturation – Metastable zone width – Growth by restricted evaporation of solvent, slow cooling of solution and temperature gradient methods– Crystal growth in Gel media: Chemical reaction and solubility reduction methods – Growth from high temperature solutions: Flux growth Principles of flux method – Choice of flux – Growth by slow evaporation and slow cooling methods – Hydrothermal growth method.

**UNIT V -EXPERIMENTAL CRYSTAL GROWTH-PART-III: VAPOUR GROWTH TECHNIQUES**

Basic principles – Physical Vapour Deposition (PVD): Vapour phase crystallization in a closed system – Gas flow crystallization – Chemical Vapour Deposition (CVD): Advantageous and disadvantageous – Growth by chemical vapour transport reaction: Transporting agents, Sealed capsule method, Open flow systems – Temperature variation method: Stationary temperature profile, Linearly time varying temperature profile and Oscillatory temperature profile.

**SUGGESTED READINGS**

1. Brice, J.C. (1986). Crystal Growth Processes. John Wiley and Sons, New York.
2. Mullin, J.W. (2004), Crystallization. Elsevier Butterworth-Heinemann, London.
3. Pamplin, B.R. (1975). Crystal Growth. Pergamon Press, Oxford.
4. Sunagawa Ichiro. (2005). Crystals: Growth, Morphology and Perfection. Cambridge University Press, Cambridge.
5. Vere, A.W. (1987). Crystal Growth: Principles and Progress. Plenum Press, New York.
6. https://nptel.ac.in/content/storage2/courses/103104045/pdf_version/lecture19.pdf
7. https://www.youtube.com/watch?v=G76H7A6_iyo
8. https://www.youtube.com/watch?v=8GsyipwtCIA
9. https://www.youtube.com/watch?v=db5nZCipJh8

**21RPHY305 PAPER – III: SPECIAL PAPER V: SOLID STATE IONICS**

**Course Objectives**

- To provide an introduction to the concepts underlying solid state Ionics
- To illustrate the wide range of materials and physical properties that currently available for ionic conductors
- To introduce the superionic conductors and their applications
- To establish the ionic conductors for energy applications
- To introduce the different mechanism of electrochemical energy storage materials and their applications
- To understand the ion transport mechanism via gas, liquid and solid phase materials.

**Course Outcomes**

Students will be able to:

1. calculate point defect concentrations using formation energies, develop Brouwer diagrams, describe several means of tailoring point defect concentrations through independent variables, and apply equilibrium thermodynamics to the case of defective solids
2. write point defect reactions in Kroger-Vink notation to describe defect processes, and apply a non-equilibrium thermodynamics and chemical kinetics framework to describe defect reactions and kinetic behavior
3. describe operation of various solid state ionics applications (including open circuit cells, cells using current, and cells generating current)
4. select measurement techniques appropriate for investigating solid state electrochemical material/device behavior and select materials appropriate for different functions within the devices.
5. use appropriate resources for finding up-to-date information on solid state ionics for continued learning.
6. Learn the superionic conductors and their real life applications.
7. Learn synthesis design and planning, different processing technoques and their chemical-physical fundamentals as well as basic method of characterisation of solids.

**UNIT I Introduction**

Crystalline solids – space lattice – the basis and crystal structure; crystal translational vectors, symmetry operation primitive lattice cell and unit cell symmetry elements, Fundamental type of lattice, atomic packing, atomic radius, lattice constants and density, crystal structure other cubic structure – type of bonding – Ionic bonding – Energy of formation of NaCl molecules, Madelung constants – potential energy of diagram of ionic molecules – calculation of repulsive exponent – Born Haber cycle characteristics of ionic bond.

**UNIT II Transport Properties of Ionic Conductors**

Ionic conductivity – Normal and super ionic conductors – Mass transport in crystals – Diffusion – Atomic diffusion theory – Experimental determination of the diffusion constant – Ionic conduction – Experimental results – for ionic conduction – The Einstein relation – Dielectric loss in ionic crystals – Electronic conduction in ionic crystals – Excess conductors – Deficit conductors – Amphoteric semiconductor.

**UNIT III**

Phenomenological Models – Huberman's Theory – Ries Strassler Toom's Theory – Weleh and Diene Theory – Lattice Gas theory – Free ion model – Domain Model – Rica and Roth Theory – The Path Probability Method – The static variables – the Path variables – The path Probability – Stationary state condition – Classification of Superionic solids – Crystalline and Amorphous – Glasses – Dispersed solid Electrolytes – polymers – Ion exchange resins – biological basis resins – Classification over conducting ion species – mode and mechanism of conduction in each case and their corresponding criteria to be superionic conductors.

**UNIT IV: Experimental Techniques and Methods**

Structural characterization – XRD surface Analysis, EXAFS, IPS and Quasi neutron scattering – Thermo dynamical characterization – Differential scanning calorimetry, Differential Thermal Analysis, Thermo Gravimetric Analysis and Thermo electric power – Ion transport properties – Electrical conductivity – Two probe method – four probe method – Immitance spectroscopy – Dynamical conductivity – state conductivity – polarisation characteristic – determination of small electronic transport numbers.

**UNIT V Electrochemical Techniques and Applications**

Fundamentals of electrochemistry, Linear Sweep Voltammetry, Cyclic Voltammetry, Chronoamperometry, Linear polarization, Electrochemical Impedance spectroscopy. Batteries: Primary and secondary batteries, Li-ion batteries, Supercapacitors: Electric double layer capacitor, Pseudocapacitor, Fuel Cells: Solid oxide Fuel cells, Direct Methanol Fuel Cells, Proton Exchange Membrane Fuel cells, Sensors: Oxygen sensors and electrochemical sensors, Electrochromic displays.

**SUGGESTED READINGS**

1. Superionic solid – Principles and applications (Ed. S.Chandra) North Holland 1981.
2. Solid state ionics (Eds. T Kudo and Fueki) VCH Publishers, Kodansha 1990.
3. Lectures on solid state physics (Eds. G Bush and H Schade), international series on Natural Philosophy Vol. 79 Pergamon, press 1976.
4. "Solid Electrolytes" (Eds. S Geller) Springer Verlag New York 1977.

5. Impedance Spectroscopy Theory, Experiment, and Applications, (Eds) Evgenij Barsoukov and J. Ross Macdonald, Wiley interscience (2005).
6. Physics of Electrolytes – Transport Processes solid Electrolytes and in Electrodes (Eds. J Hladik) Academic press, New york 1972.
7. Fundamentals of Electrochemistry, 2nd Edition, V.S.Bagotsky, Wiley Interscience. (2006).
8. Electrochemical Methods: Fundamental and Application, Allen J.Bard Wiley and Sons Publications (2001).
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10. https://nptel.ac.in/content/storage2/courses/112108150/pdf/PPTs/MTS_14_m.pdf
11. https://nptel.ac.in/content/storage2/courses/122101002/downloads/lec-8.pdf
12. https://nptel.ac.in/content/storage2/courses/103108100/module6/module6.pdf

**21RPHY306 PAPER – III: SPECIAL PAPER VI :**
**CONCEPTS OF NANOPHYSICS AND NANOTECHNOLOGY**

### Course Objectives

- To foundational knowledge of the Nanoscience and related fields.
- To make the students acquire an understanding the Nanoscience and Applications
- To help them understand in broad outline of Nanoscience and Nanotechnology.
- To familiarize with the on-going merge of the top-down approach of microelectronics and micromechanics with the bottom-up approach of chemistry/biochemistry.
- To demonstrate the potential of nanoscience and industrial applications of nanotechnology.
- To give you an insight into complete systems where nanotechnology can be used to improve our everyday life.

### Course Outcomes

Scholars will be able to:

1. understand the fundamental physical principles, which govern properties of the condense matter and in particular the role of dimensionality on the mechanical, thermal, optical, electricaland magnetic properties of materials
2. understand the physical basis of new phenomena that appear when the linear dimension of an object or device shrinks below a micrometer
3. be familiar with the methods for fabrications of nanostructures
4. understand and be able to explain the principles of newly characterization techniques for imaging and analysis of nanostructures and nanomaterials
5. understand and be able to explain the principles of operation of nanoelectronic and nanophotonic devices
6. became familiar with the whole concept of nanoscale science and technology and be able to apply their knowledge for understanding further developments in this rapidly emerging area.
7. Learn about the background on Nanoscience
8. acquire the basic knowledge of the physical phenomena, theoretical concepts and experimental techniques behind the recent vastly improved ability to observe, fabricate and manipulate individual structures on the nanometer scale.
9. Understand the synthesis of nanomaterials and their application and the impact of nanomaterials on environment
10. Apply their learned knowledge to develop Nanomaterial’s
11. Introduce a recent advancements in nano medicine.
12. Understand need of nanotechnology in Medical field.
13. learn developments in nanostructured materials used for medical implants.

**UNIT I- INTRODUCTION TO NANOTECHNOLOGY**

Defining nanotechnology, Historical development – Beyond Moore's law, Comparison of bulk and nano materials – change in band gap and large surface to volume ratio, Classification of nanostructured materials – one, two and three-dimensional confinement, quantum dots, quantum wires and quantum wells, scope of applications.

**UNIT II- SYNTHESIS AND CHARACTERIZATION**

Classification of fabrication methods – Top to bottom approach – Ball milling, etching etc bottom to top approach – Physical and chemical methods – Molecular Beam Epitaxy, optical and electron beam lithography, Ion implantation, sputtering, thermal evaporation, pulsed laser deposition, chemical vapor deposition, controlled precipitation, sol gel methods. Grain size determination – XRD (Debye Scherer equation), TEM, AFM, STM and Light scattering techniques. Composition analysis – ICP – AES, EDAX, SIMS.

**UNIT III- OPTICAL AND VIBRATIONAL PROPERTIES OF NANOPARTICLES**

Basic concepts – Band structure of solids, excitons, effective mass, reciprocal lattice, Brillouin zone, phonons etc. Size and dimensionality effects – Bulk to nano transition –Density of states, potential well - quantum confinement effect – weak and strong confinement regime. Blue shift of band gap - Effective mass approximation (Rigorous mathematical treatment not necessary). Phonon confinement effect and presence of surface modes. Characterization tools - UV – Visible absorption and Photoluminescence techniques, Raman and IR spectroscopy

**UNIT IV -CARBON NANOSTRUCTURES**

Carbon nanostructures – carbon molecules – carbon clusters. Fullerene - structure of $C_{60}$ and its crystal – larger and smaller fullerenes – other bucky balls. Carbon nanotubes – fabrication – structure – electrical properties – vibrational properties – mechanical properties. Applications of carbon nanotubes – Field emission and Shielding – computers – Fuel cells – Chemical sensors – Catalysis – Mechanical reinforcement.

**UNIT V -NANOMACHINES AND NANODEVICES**

Extension of conventional devices by nanotechniques – Bipolar and MOS transisitors – structure and technology, electrical characteristics, limitations, low temperature behavior. Microelectromechanical systems (MEMSs), Nanoelectromechanical systems (NEMSs), Resonant Tunneling Diode, Quantum Cascade lasers, Single Electron Transistors – Operating principles and applications.

**SUGGESTED READINGS**

1. Mick Wilson, Kamali Kannangara, Geoff Smith, Michelle Simmons and Burkhard Raguse "Nanotechnology", Overseas Press New Delhi 2005
2. W. R. Fahrner (Ed.) "Nanotechnology and Nanoelectronics", Springer 2006.

3. Charles P Poole Jr and Frank J Owens “Introduction to Nanotechnology”, Wiley student edition 2003.
4. https://nptel.ac.in/courses/118/104/118104008/
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**19RPHY307 PAPER – III: SPECIAL PAPER VII : LASER PHYSICS**

**Course Objectives**

- Laser is a versatile tool with applications in almost all fields from medical to astronomy, communications, welding, cutting etc.
- This paper explains the characteristics of lasers, different types of lasers and their construction to apply for industircal use. Applications of lasers in different fields are also explained.
- To provide up-to-date guidance of modern types of lasers and will give sufficient theoretical and, importantly, practical knowledge for designing and building actual lasers.
- To give exposure to students about the characteristics of different lasers, their fabrication techniques, applications etc.
- To make the student understand the principles of Lasers
- To enable the student to explore the field of Nonlinear optics
- To be able to apply the fundamental concepts of optics in lasers, optical fiber communications and optoelectronics

**Course Outcomes (COs)**

After completing the course the scholars can/will able to

1. Acquire fundamentals and principles of Laser action and Understand the basic conceptsof different types of lasers
2. Understand the absorption and spontaneous and stimulated emission in two level system,
3. Learn the basics & different parameters required to fabricate the lasers and their advantages and disadvantages in various fields.
4. The effects of homogeneous and inhomogeneous line broadening, and the conditions for laser amplification.
5. Classify fibers as single-mode, multimode step index and multi-mode graded index.
6. Describe modes in multimode fibers and mode field parameter in single-mode fibers
7. explain operational principles and construction of lasers
8. give an account of technological issues behind laser construction
9. describe optical components that can be used to tailor the properties of the laser
10. relate the laser operation principles to atom and molecular physics, solid state physics, quantum mechanics and physical optics.

**UNIT --I**

Radiative transitions and emission line widths. Radiative decay of excited states, homogeneous and inhomogeneous broadenings. Absorption, spontaneous and stimulated emissions. Einstein's A and B Coefficients. Absorption and gain of homogeneously broadened radiative transitions, gain coefficient and stimulated emission cross section for homogeneous and inhomogeneous broadening.

**UNIT II**

Necessary and sufficient conditions for laser action (population inversion and saturation intensity), threshold requirements for laser with and without cavity, laser amplifiers, rate equations for three and four level systems, pumping mechanisms. Laser cavity modes-longitudinal and transverse modes in rectangular cavity. FP cavity modes, Spectral and spatial hole burning, stability of laser resonator and stability diagram, unstable and ring resonators.

**UNIT III**

Q-switching and Mode locking, active and passive techniques, generation of giant pulses and pico second optical pulses, Properties of laser beam and techniques to characterize laser beam.

**UNIT IV**

Scattering: Scattering cross-section – Scattering amplitude – Partial waves – Scattering by a central potential: partial wave analysis – Significant number of partial waves – Scattering by an attractive square-well potential – Briet-Wigner formula – Scattering length – Expression for phase shift – Integral equation – The Born approximation – Scattering by screened coulomb potential – Validity of Born approximation - Laboratory and center of mass co-ordinate systems.

**UNIT V**

Introduction - Driving problems in biomedical imaging - Sources of imaging data: acquisition and noise - Elementary image processing - Grenander's Pattern Theory, Biomedical image analysis using MATLAB – Image registration – unaided and Interactive – Segmentation – Edge detection – Real time imaging applications.

**SUGGESTED READINGS:**

1. Laser Fundamentals - W T Silfvast, Cambridge University Press (1996)(Text)
2. Laser Electronics - J T Vardeyan. PHI, 2nd Ed (1989)
3. Lasers-Theory and Applications- Ghatak and Thyagarajan, McMillan (2002) (Text)
4. Principles of lasers - Svelto, Plenum Press (1948)
5. Solidstate laser engineering - Koechner, Springer Verlag (1993)
6. Laser Physics- Tarasov. Mir Publishers (1985)
7. John.L.Semmlow, Biomedical signal and Biomedical Image Processing – MATLAB based applications, Marcel Dekker Inc., 2004.
8. Rangaraj M. Rangayyan, Biomedical Image Analysis, CRC press.
9. https://nptel.ac.in/courses/104/104/104104085/
10. http://www.cdeep.iitb.ac.in/webpage_data/nptel/Electrical%20&%20Comm%20Engg/Optical%20Communication-backup/Course_home-M7.html
11. https://www.digimat.in/nptel/courses/video/104104085/L01.html
12. https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-974-fundamentals-of-photonics-quantum-electronics-spring-2006/lecture-notes/chapter7.pdf

**21RPHY308** **PAPER – III: SPECIAL PAPER VIII :**

## FLUORESCENCE SPECTROSCOPY

### Course Objectives

- To know the modern optical spectroscopic and imaging techniques and their applications to biology and chemistry.
- To get the knowledge an introduction to fundamental concepts of light-matter interaction, lasers and laser systems, detectors and other relevant aspects of instrumentation necessary for spectroscopy and imaging.
- To discuss various modern surface spectroscopic techniques and examples from classic and contemporary literature.
- To get an in-depth introduction to the principles of fluorescence spectroscopy and its applications to the Life Sciences.
- To gain the knowledge in the advanced X-ray diffraction techniques for opto-electronic materials characterisation.
- To understand the crystal growth and their interactive nature with light.

### Course Outcomes

After this course the scholars are expected to be able to:

1. explain the fundamental physical mechanisms involved in the generation of fluorescence light.
2. explain how interactions between biomolecules and electromagnetic radiation and environmental effects can generate changes in the measured fluorescence parameters, and how these changes can be exploited for monitoring of biomolecules and their interactions.
3. Mention the most important fluorescence techniques in the biomedical research field, and explain what type of questions these techniques can address.
4. Describe the physical principles of these fluorescence techniques,.
5. Based on knowledge on these techniques and their physical principles, describe and motivate what the factors are that limit their performance, and how the obtained measurements data are evaluated.
6. Follow, report on, and discuss relevant parts of the latest development in the field of fluorescence spectroscopy, and judge their applicability for different biomolecular studies.
7. more in detail estimate the usefulness of fluorescence methods within the students own area of research, and to provide well motivated, solid suggestions of how they can be applied in the area.

### UNIT - 1: Solvent and Environmental Effects on Fluorescence spectra

Stokes' shifts and solvent relaxation, general and specific solvent effects, other mechanisms for spectral shifts. Lippert equation, Derivation of Lippert equation, Applications of Lippert equation, Specific solvent effects. Temperature effects, Additional factors that affects the emission spectra - locally excited and internal charge transfer states, excites state intramolecular proton transfer, effects of viscosity, probe-probe interaction and effect of solvent mixtures.

**UNIT - 2: Fluorescence Quenching**

Introduction, quenchers of fluorescence, Theory of colloidal quenching, Derivation of SternVolmer equation, Interpretation of bimolecular quenching constants, theory of static quenching, Comparison between static and dynamic quenching. Combined dynamic and static quenching with examples. Deviation from the Stern-Volmer equation - Quenching sphere of action. Derivation of the quenching sphere of action, Origin of the Smoluchowski equation.

**Mechanisms and Dynamics of Fluorescence Quenching**

Introduction, comparison of quenching and resonance energy transfer, distance dependence of resonance energy transfer and quenching, encounter complexes and quenching efficiency, mechanisms of quenching: Intersystem crossing or heavy atomic effect, electron exchange, photoinduced electron transfer. Transient effects in quenching,

**Fluorescence Sensing**

Optical Clinical Chemistry and spectral observable, spectral observable for fluorescence sensing, Mechanism of sensing, sensing collisional quenching - oxygen sensing, chloride sensors, energy transfer sensing - pH and pCO2 sensing by energy transfer, glucose sensing by energy transfer, ion sensing by energy transfer, theory of energy transfer sensing.

**UNIT-3: X-RAY CRYSTALLOGRAPHY**

**Crystal and Symmetry:** Growth of single crystals, different methods, Optical properties, ferroelectric, piezoelectric, thermal properties of crystal, Crystal system- Bravais lattices- point group and space group, symmetry elements.

**Quasicrystals:** definition, preparation, symmetry orientation order in quasicrystals, Quasi-periodic space tiling procedure. Macromolecules: definition, examples of macromolecules or Bio-molecules-symmetry.

**X-rays:** Production, white radiation characteristics, radiation - absorption edge, filters - absorption by crystals.

**UNIT-4: DIFFRACTION OF X-RAYS**

Direct and reciprocal lattice, Ewald's sphere and Bragg's law, Spacing formula,Transformation equations, Interpretation of rotation photograph.

Scattering of X-rays by a distribution of electron, structure factor, calculation of electron density function, Fourier synthesis, the crystal symmetry and x-ray diffraction pattern, Friedel's law and its break down.

Electron and neutron diffraction, comparison with X-ray diffraction, significance of electron and neutron diffraction, characterization of quasicrystalline sample using electron diffraction.

The Laue method, The Powder method, rotation and Weissenberg methods, The Burger precession method.

**UNIT-5: INTENSITY DATA COLLECTION, STRUCTURE SOLUTION AND REFINEMENT**

The single crystal diffractometer method, intensity data collection, corrections to intensity data- Lorentz, polarization, spot shape and absorption effects, primary and secondary extinction effects, absolute scaling and temperature factors.

Fourier techniques, Phase problem, Patterson function and its significance, Heavy atom methods, Isomorphous replacement method, anomalous scattering method, direct methods.

Cyclic Fourier refinement, the difference Fourier refinement, correction for series termination effects, temperature correction, Least squares refinement.

Derived results- bond lengths, bond angles, standard deviations in bond lengths and angles, comparison and averaging of bond lengths and angles, least square planes, absolute configuration and thermal motion.

**SUGGESTED READINGS**

1. Fundamentals of Photochemistry, Rohtagi - Mukherjee K K, Wiley Eastern Ltd., 1992.
2. Principles of Fluorescence Spectroscopy, Joseph R Lakowicz, Plenum Press, New York, 1986
3. Photophysics of Aromatic Molecules, Birks J B, Wiley - Interscience, London 1970.
4. Azaroff. L.V.: Introduction to Solids, McGraw-Hill, New York, 1960.
5. Phillips. F.C. : Introduction to Crystallography, Longmans, London, 1966.
6. Cullity. B. D.: Elements of X-ray crystallography, prentice hall, 2001.
7. Ponerger. J. J.: X-ray Crystallography, John Wiley, New York, 1942.
8. Burger. M. J.: Crystal Structure Analysis, John Wiley, New York, 1960.
9. 9 Stout. H & Jensen. L. H.: X-ray Structure determination, McGraw Hill, London, 1973.
10. Duncan Mc Kie & Christins Mc Kie: Crystalline Solids, Nelson, London, 1973.
11. Azaroff. L.V. Elements of X-ray crystallography, McGraw-Hill , New York, 1968.
12. Woolfson, M. M.: X-ray Crystallography, Cambridge University Press, 1978.
13. Glusker, J. P. & True blood. K.N.: Crystal Structure Analysis, Oxford Univ. Press, 1985.
14. Bacon. G. E.: Neutron Diffraction, Oxford Univ. Press, 1962.
15. Methods of Experimental Physics, Vol. 6: Part A, Associate Press.
16. Janot. C, Quasicrystals, Oxford Science Publications, Clarendon press, Oxford, 1992.
17. https://nptel.ac.in/noc/courses/noc17/SEM2/noc17-cy01/
18. https://nptel.ac.in/courses/104/104/104104084/
19. http://web.iitd.ac.in/~sdeep/Fluorescence.pdf

**21RPHY309** **PAPER – III: SPECIAL PAPER IX :**
**EXPERIMENTAL TECHNIQUES IN MATERIALS SCIENCE**

**Course Objectives**

- To learn how to operate a number of important materials processing and characterization instruments as well as to analyze and interpret the resultant data.
- To learn the strengths and weaknesses of different materials processing and characterization techniques.
- To gain a better understanding of the important processing-structure-property relationships.
- To provide concepts on the several materials characterization techniques at the morphological, structural and chemical level, the acquisition of skills in the use and selection of advanced experimental techniques for characterization of materials.
- To solving problems in materials science and engineering. Several characterization techniques are discussed, from the most conventional to the most recent.
- To enable the knowledge that in the future so that the students can prioritize choices of materials characterization meet the needs and resources available.

**Course Outcomes**

At the end of the course, the students can/will be able to

1. Know the proper selection of material based on the performance of the system under study and development of new materials.
2. Know depending on the requests that the equipment or system shall be subjected, the characterization may include the evaluation of mechanical, electrical, magnetic, optical, chemical or thermal.
3. Know the advanced techniques for materials characterization, particularly of the most widely used materials as thin films, nanomaterials and advanced materials.
4. Understand samples preparation and the applicability of these techniques in order to provide the essential groundwork for select and ranking them.
5. Know the main techniques in the study include characterization methods based on microscopy, microanalysis and diffraction techniques, and surface and spectroscopy analysis.
6. Understand the solving problems in materials science and engineering.

**UNIT -1 METHODS OF MATERIALS BULK SYNTHESIS**

Solid state reaction - ceramic technique - microwave synthesis - sol-gel method - wet-chemical methods - Hydrothermal method.

**Growth of Single Crystals** - Introduction to Methods of Growth of Crystals –BCF theory- Czochralski Method - Bridgman, Zone Melting and Zone Refining Methods.

**UNIT-2 PREPARATION OF THIN FILMS**

Types of thin Film Growth process - Spin coating - vacuum evaporation - sputtering - Pulsed laser deposition - Vapor Methods – CVD – PVD - Fundamental aspects of Epitaxial Growth methods.

**UNIT – 3 STRUCTURAL CHARACTERIZATIONS AND IMAGING TECHNIQUES**

X-ray diffraction ((XRD) - Electron and neutron diffraction - elementary ideas of photoelectron spectroscopy (PES) - Basic principle of atomic resolution electron microscopy - Scanning and Transmission electron microscopy (SEM, TEM) - Scanning tunneling and atomic force microscopy (STM, AFM) techniques.

**UNIT – 4 OPTICAL CHARACTERIZATIONS AND SPECTROSCOPIC TECHNIQUES**

Ultraviolet / visible (UV/Vis) absorption spectroscopy - Raman and Infrared Spectroscopy - Fluorescence spectroscopy - Elementary idea of laser based non-linear techniques. Room temperature as well as low temperature Photoluminescence - Cathode Luminescence - Mössbauer spectroscopy - Impedance spectroscopy

**UNIT-5 PHYSICAL PROPERTY MEASUREMENTS**

Intensive and extensive properties - Physical property measurements (DSC, DTA, TGA,) - Transport properties (R-T) – Photoconductivity study (C-V, I-V) - Low conductivity measurement (Dielectric Spectroscopy) - P-E loops for ferroelectrics - magnetic properties of bulk and nano phases of material (VSM & SQUID).

**Suggested Readings:**


1. H.H. Willard, L.L. Merritt, J.A. Dean and F.A. Settle, Instrumental Methods of Analysis, 6$^{th}$ Ed., C.B.S. Publishers, New Delhi, 1991.
2. Metals Handbook, Characterization of Materials, 10$^{th}$ Ed., Vol. 9, American Soc. of Metals, Metals Park, Ohio, 1986.
3. G.A. Higgerson, Experiments in Materials Technology, Affiliated East-West Press, 1973.
4. L.C. Azzarof, Elements of X-ray Crystallography, McGraw-Hill, New York, 1968.
5. M.V. Heimendahl, Electron Microscopy of Materials-An Introduction, Academic Press, 1980.
6. Elton N. Kaufmann, Characterization of Materials volumes 1 and 2, John Wiley & Sons, Inc., Hoboken, New Jersey, 2003.
7. L. E.Murr. Electron and Ion microscopy and Microanalysis principles and Applications. Marcel Dekker Inc., New York, 1991.
8. V.Raghavan, Materials Science for Engineering, Prentice Hall of India Pvt Ltd, 2006.
9. Meissel. L.T and R. Glang., 2000 Handbook of thin film technology, Tata McGraw Hill, New Delhi.
10. https://nptel.ac.in/courses/113/102/113102080/

11. https://nptel.ac.in/courses/113/105/113105024/
12. https://nptel.ac.in/courses/113/101/113101096/
13. https://nptel.ac.in/content/storage2/courses/112104039/pdf_version/lecture1.pdf.

**21RPHY310 PAPER – III: SPECIAL PAPER X :**

**MAGNETIC AND THERMOELECTRIC PROPERTIES OF MATERIALS**

**Course objectives (Co):**

- The course contains origins of magnetism, diamagnetism, paramagnetism, crystal field environments, dipolar and exchange interactions, ferromagnetism, antiferromagnetism, magnetic domains, magnetic anisotropy and magnetostriction.
- To give an idea in the experimental techniques in magnetic characterization.
- To study different magnetic materials include transition metals, their alloys and oxides, rare earths and their oxides, organic and molecular magnets.
- To study the basic concepts of thermoelectric materials and their phenomenon
- To study the interaction of phonon electron scattering in semiconductor materials
- To study the effect of temperature on thermoelectric property.

**Course Outcomes (Cos)**

After completing the course students will/can able to

1. Use the models of magnetization and remagnetization in various cases;
2. Describe the kinetics of temporal processes in magnetic materials;
3. To calculate the contribution of magnetostatic energy, elastic energy and anisotropy in magnetic properties;
4. To solve theoretical and applied problems connected with professional activities;
5. Understand and be able to explain transport mechanisms (electronic and thermal transport), guiding the thermal/thermoelectric performance of any materials system. Understand and be able to explain how to choose a good material system and apply the strategies to improve thermoelectric performance.
6. Understand and be able to describe the different techniques for thermal/thermoelectric characterization of the samples with varying geometries. Be able to apply the knowledge into practical devices for different areas of applications, e.g., high power bulk applications or low power flexible and wearable applications.

**UNIT I**

Introduction -Classification Of Magnetic Materials-Factors Affecting Permeability And Hysterisis Loss- Magnetostatics - The magnetic dipole moment - Magnetic fields - Maxwell's equations - Magnetic field calculations - Magnetostatic energy and forces - Magnetism of electrons - Orbital and spin moments - Magnetic field effects-Theory of electronic magnetism - Magnetism of electrons in solids.

**UNIT-II**

Magnetism of localized electrons on the atom - The hydrogenic atom and angular momentum - The many-electron atom - Paramagnetism - Ions in solids; crystal-field interactions - Ferromagnetism and exchange - Mean field theory - Exchange interactions - Band magnetism - Collective excitations Anisotropy - Ferromagnetic phenomena - Antiferromagnetism and other magnetic order -Molecular field theory of antiferromagnetism - Ferrimagnets -Frustration - Amorphous magnets -Spin glasses - Magnetic models.

**UNIT-III**

Experimental methods - Materials growth - Magnetic fields - Atomic-scale magnetism -Domain-scale measurements - Bulk magnetization measurements -Excitations -Numerical method - Magnetic materials - Iron group metals and alloys -Rare-earth metals and intermetallic compounds - Interstitial compounds - Oxides with ferromagnetic interactions - Oxides with antiferromagnetic interactions -Miscellaneous materials.

**UNIT –IV**

The Thermoelectric and Related Effects -Introduction - Relations Between the Thermoelectric Coefficients Effects in a Magnetic Field - The Transport Effects - Thermoelectric Refrigerators and Heat Pumps - Thermoelectric Generators - Multi-Stage Devices –Application of the Thermomagnetic Effects - Optimisation and Selection of Semiconductor Thermoelements - Power Factor – The Materials Parameter -Mobility and Effective Mass - The Lattice Thermal Conductivity in Pure Crystals. The Effect of Temperature -The Importance of the Energy Gap

**UNIT –V**

Thermoelectric Properties of Metals and Semiconductors - Transport by Electrons Metals and Semiconductors - Bipolar Effects - Phonon Conduction - Phonon Drag -Minimising the Thermal Conductivity - Semiconductor Solid Solutions -Phonon Scattering by Point Defects - Boundary Scattering -Scattering of Electrons and Phonons - Fine-Grained Material with Large Unit Cells - Phonon-Glass Electron-Crystal-Applications of thermoelectric materials.

**SUGGESTED READINGS**

1. Introduction to Magnetic Materials, B. D. Cullity, C. D. Graham, John Wiley and sons, Inc, Publications,2009
2. Magnetism and Magnetic Materials, J. M. D. Coey, Cambridge University Press, 2012
3. The Quantum Theory of Magnetism, Second Edition, Norberto Majis, World Scientific Publishing Co. Pte. Ltd. 2007
4. Magnetism in Condensed Matter, Stephen Blundell, Oxford University Press, 2011
5. CRC Handbook of Thermoelectrics, Edited by D.M. Rowe, Ph.D., D.SC, CRC Press, Boca Raton London New York, 2004
6. Introduction to Thermoelectricity H. Julian Goldsmid, Springer Series in materials science *Edited by* R. Hull R. M. Osgood, Jr. J. Parisi H.Warlimont, 2009

7. Novel Thermoelectric Materials and Device Design Concepts, Editors: Skipidarov, Sergey, Nikitin, Mikhail (Eds.), Springer International Publishing,2019
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9. https://nptel.ac.in/content/storage2/courses/112108150/pdf/Web_Pages/WEBP_M16.pdf
10. https://www.nature.com/articles/nnano.2016.182