GOA UNIVERSITY
Taleigao Plateau, Goa 403 206

# REVISED MINUTES

of the 5th Meeting of the Standing Committee of

X ACADEMIC COUNCIL

**Day & Date**

Tuesday, 14th February, 2023 & Thursday, 23rd February, 2023

**Time**

10.00 a.m.

Venue
Council Hall,
Administrative Block
Goa University

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| **D 3.3** | **Minutes of the Board of Studies in Physics meeting held on 04.11.2022.**<br>The Standing Committee of the Academic Council approved the minutes of the Board of Studies in Physics meeting held on 04.11.2022 with a suggestion to Replace Terminology 'Learning Outcomes' with 'Course Outcomes'<br>**(Action: Assistant Registrar Academic-PG)** |
| **D 3.4** | **Minutes of the Board of Studies in Social Work meeting held by circulation.**<br>The Standing Committee of the Academic Council approved the minutes of the Board of Studies in Social Work meeting held by circulation with the following suggestions:<br>1. Heading for the Courses listed under the structure to be mentioned. (Research Specific Elective Courses and General Elective Courses)<br>2. Terminology 'Optional Courses' to be replaced with 'Elective Courses'.<br>3. Terminology 'Recommended readings' to be replaced with 'References/Readings'.<br>4. Uniform format for the References/Readings to be followed.<br>**(Action: Assistant Registrar Academic-PG)** |
| **D 3.5** | **Minutes of the Board of Studies in Public Administration meeting held on 01.07.2022.**<br>The Standing Committee of the Academic Council approved the minutes of the Board of Studies in Public Administration meeting held on 01.07.2022 with the following suggestions:<br>1. Data Analysis under the content of the syllabus to be added for Course code PATR-501 Qualitative and Quantitative Research Methodology.<br>2. Heading for the Courses listed under the structure to be mentioned. (Research Specific Elective Courses and General Elective Courses)<br>3. Course, objectives of PATR-501 - Qualitative and Quantitative Research Methodology to be checked.<br>**(Action: Assistant Registrar Academic-PG)** |
| **D 3.6** | **Minutes of the Board of Studies in Mathematics meeting held on 03.11.2022.**<br>The Standing Committee of the Academic Council approved the minutes of the Board of Studies in Mathematics meeting held on 03.11.2022 with the suggestion to verify the title of the Course Code MTTE- 407 as the same Course is offered at UG level.<br>**(Action: Assistant Registrar Academic-PG)** |
| **D 3.7** | **Minutes of the Board of Studies in English meeting held on 17.10.2022.**<br>The Standing Committee of the Academic Council approved the minutes of the Board of Studies in English meeting held on 17.10.2022 with the following suggestions:<br>1. Terminology 'Optional Courses' to be replaced with 'Elective Courses'.<br>2. Terminology 'Recommended readings' to be replaced with 'References/Readings'. |

**GOA UNIVERSITY**
**Taleigao Plateau, Goa 403 206**

# F I N A L A G E N D A

**For the 5th Meeting of the Standing Committee of**

**X ACADEMIC COUNCIL**

**Day & Date**

**Tuesday, 14th February, 2023**

**Time**

**10.00 a.m.**

**Venue**
**Conference Hall**
**Administrative Block**
**Goa University**

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| | 2) List of Recommended Readings to be reduced.<br>3) 'Self -Study' to be removed from the Pedagogy.<br><br>As per the above suggestion of the Academic Council, the Chairperson, Board of Studies in Women's Studies has made necessary changes and re-submited the Research Methodology Course for Ph.D. in Women's Studies.<br><br>The revised syllabus for the Research Methodology Course for Ph.D. in Women's Studies is placed as **Annexure I** **(Refer page No. 126)** for consideration of the Academic Council.<br><br>The Academic Council may kindly consider.<br>**(Back to Index)** |
| **D 3.3** | **Minutes of the Board of Studies in Physics meeting held on 04.11.2022.**<br>**Part A**<br>(i) Recommendations regarding courses of study in the subject or group of subjects at the undergraduate level: NIL<br>(ii) Recommendations regarding courses or group of subjects at postgraduate level:<br>1. BoS discussed and finalized the syllabus for the courses to be offered in semesters III and IV. The same is attached at **Annexure I** **(Refer page No. 129).** As there are no faculty members available to teach Biophysics specialization, BoS only approved the syllabus of earlier approved courses. It was decided to add more Research Specific Elective courses depending on the expertise of the recruited faculty members.<br>2. BoS also added one more discipline specific elective course in Semester II. This is given at the end of Annexure I.<br>3. Syllabus for Research Methodology course (Pre PhD Paper-I) was also discussed and finalized. **(Annexure II Refe page No. 180).**<br><br>**Part B**<br>(i) Scheme of the Examinations at Undergraduate Level: NIL<br>(ii) Panel of examiners for different examinations at Undergraduate Level:<br>BoS finalised the panel of examiners for B.Sc. Physics Semester V and VI and B.Sc. B.Ed. Physics courses of Semester V to VIII. These are included in a sealed envelope.<br>(iii) Scheme of the examinations at post-graduate level:NIL<br>(iv) Panel of examiners for different examinations at post-graduate Level: NIL<br><br>**Part C**<br>(i) Recommendations regarding preparation and publication and selection of Anthologies in any subject or group of subjects and the names of person recommended for appointment to make the selection: NIL<br><br>**Part D**<br>(i) Recommendations regarding general academic requirements in the Departments of University or affiliated colleges: NIL<br>(ii) Recommendation of Academic Audit committee and status thereof :NIL<br><br>**Part E** |

**D 3.3 Minutes of the Board of Studies in Physics meeting held on 04.11.2022.**

**Annexure I**

M.Sc. Physics Syllabus from Academic year 2023-24

The syllabus of M.Sc. Physics consists of five categories of courses:

(a) Discipline Specific Core Courses (PHTC) – Total Credits 32
(b) Discipline Specific Optional Courses (PHPE) – Total Credits 8
(c) Research Specific Optional Courses (PHSR/PHBR/PHCR) – Total Credits 12
(d) Generic Optional Courses (PHSG/PHBG/PHCG) – Total Credits 12
(e) Bridge courses (PHOB)

| Code | Title | Credits | Hours |
|---|---|---|---|
| PHOB-100 | Bridge Course in Mathematical Methods | 2 | 30 |
| PHOB-101 | Bridge Course in Thermal Physics | 2 | 30 |
| PHOB-102 | Bridge Course in Optics | 2 | 30 |
| PHOB-103 | Bridge Course in Quantum Mechanics | 2 | 30 |
| PHOB-104 | Bridge Course in Electrostatics and Magnetostatics | 2 | 30 |
| PHOB-200 | Introduction to Biology and Biophysics | 3 | 45 |
| Semester I | | | |
| PHTC-401 | Mathematical Methods of Physics | 4 | 60 |
| PHTC-402 | Classical Mechanics | 4 | 60 |
| PHTC-403 | Electromagnetic Theory | 4 | 60 |
| PHTC-404 | Electronics | 4 | 60 |
| PHPE-401 | Electronics Practical | 2 | 60 |
| PHPE-402 | Computer Programming in Fortran Practical* | 2 | 60 |
| PHPE-403 | Computer Programming in C Practical* | 2 | 60 |
| PHPE-404 | Computer Programming in Python Practical* | 2 | 60 |
| *Any one course | | | |
| Semester II | | | |
| PHTC-405 | Quantum Mechanics | 4 | 60 |
| PHTC-406 | Statistical Mechanics | 4 | 60 |
| PHTC-407 | Nuclear and Elementary Particle Physics | 4 | 60 |
| PHTC-408 | Atomic Physics | 4 | 60 |
| PHPE-405 | General Physics Practical# | 4 | 120 |
| PHPE-406 | Methods of Experimental Physics# | 4 | 120 |
| #Any one course | | | |

| Semester III | | | | | |
|---|---|---|---|---|---|
| PHSR-501<br>PHCR-501<br>PHBR-501 | Solid State Physics I | Advanced Quantum Mechanics | Molecular Biophysics | 4 | 60 |
| PHSR-502<br>PHCR-502<br>PHBR-502 | Solid State Physics II | Advanced Statistical Mechanics | Methods of Biophysics | 4 | 60 |
| PHSG-501<br>PHCG-511<br>PHBG-521 | Solid State Physics Practical | Numerical Techniques Practical | Biophysics Practical | 4 | 120 |

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|---|---|---|---|
| PHSG-5xx<br>PHCG-5xx<br>PHBG-5xx | Generic Optional Courses (to be chosen from Set I or from any other disciplines or from SWAYAM) | 8 | 120 |
| Semester IV | | | |
| PHSR-5xx<br>PHCR-5xx<br>PHBR-5xx | Courses worth 4 credits to be chosen from Set II or from SWAYAM in consultation with Dissertation Guide | 4 | 60 |
| PHGD-599 | Dissertation | 16 | |

Suggested Optional Courses

| Set I – Generic Electives (Sem III) | | Credits | Set II – Research Electives (Sem IV) | | Credits |
|---|---|---|---|---|---|
| PHSG-502 | Nuclear Reactor Physics | 2 | PHSR-503 | X-ray Spectroscopy for Condensed Matter | 2 |
| PHSG-503 | Advanced Optics | 2 | PHSR-504 | Optical Spectroscopy for Condensed Matter | 2 |
| PHSG-504 | Physics of Energy Materials | 2 | PHSR-505 | Nuclear Spectroscopy for Condensed Matter | 2 |
| PHSG-505 | Physics of Ferroic Materials | 2 | PHSR-506 | Introduction to Crystallography and X-ray Diffraction | 2 |
| PHSG-506 | Nanoscience and Technology | 2 | PHSR-507 | Magnetism in Condensed Matter Physics | 2 |
| PHSG-507 | Laser Physics and Applications | 2 | PHSR-508 | Microscopy Techniques for Condensed Matter | 2 |
| PHSG-508 | Experimental Techniques in Physics | 2 | PHSR-509 | Thin film Physics | 2 |
| PHSG-509 | Documentation using Latex (Skill) | 2 | PHSR-510 | Physics of Glasses | 2 |
| PHSG-510 | Astronomy and Astrophysics | 2 | PHCR-503 | Simulation Techniques | 2 |
| PHCG-502 | BEC and Superfluidity | 2 | PHCR-504 | Physics of Quantum Materials | 2 |
| PHCG-503 | Introduction to Quantum information and computing | 2 | PHCR-505 | Superconductivity | 2 |
| PHCG-504 | Introduction to Particle Physics | 2 | PHCR-506 | Advanced Particle Physics | 4 |
| PHBG-502 | Solid State and Biomaterials | 4 | PHCR-507 | Numerical methods and Fortran parallel programming using openMP | 2 |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSR-501 **Title of the Course:** Solid State Physics I
**Number of Credits:** 3
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Should have basic knowledge of Quantum Mechanics and Statistical Mechanics | |
| **Objective:** | 1. To introduce fundamental concepts of solids like crystalline order, symmetry in solids, simple crystal structures and their properties.<br>2. To acquaint with the concept of reciprocal lattice and its importance in structure determination using x-rays.<br>3. To introduce different types of crystal bindings and elastic properties of solids.<br>4. To familiarize the concept of lattice vibration and their role in thermal and optical properties of solids. | |
| **Content:** | **Crystal Structure**<br>Crystals - Lattice, Bravais lattice, primitive unit cell, symmetry of molecules and crystals, symmetry operations and symmetry elements, Lattices in one, two and three dimensions, Space groups, definitions of directions, coordinates and planes.<br>Simple crystal structures: NaCl, CsCl, diamond, hexagonal close-packed structure, cubic ZnS structure and their properties, Non ideal crystal structures – random stacking and polytypism<br>Reciprocal Lattice - Diffraction of waves by crystals, Bragg law, Scattered wave amplitude - Fourier analysis, reciprocal lattice vectors, diffraction conditions, Laue equations, Brillouin zones, Geometric structure factor, Atomic Structure factor<br>Point Defects General Thermodynamic Features, Color centres, Line Defects: Dislocations | 20 hours |
| | **Crystal Binding and Elastic Constants**<br>Crystals of inert gases - Van der Waals - London interaction, repulsive interaction, equilibrium lattice constants, cohesive energy, Ionic Crystals - Electrostatic or Madelung Energy, evaluation of Madelung constant, covalent crystals, bonding in metals and Hydrogen bonds, Atomic Radii, Analysis of elastic strains, elastic compliance and stiffness constants, elastic waves in cubic crystals | 13 hours |
| | **Thermal Properties**<br>Vibrations of a one -dimensional monatomic lattice, first Brillouin zone, group velocity, long wavelength limit, derivation of force constant from experiment. Vibrations of a one-dimensional diatomic lattice. Quantization of elastic waves, phonon momentum, Inelastic scattering by Phonons, Phonon Heat capacity, Planck distribution, normal mode enumeration, density of states in one dimension, density of states in three dimensions Debye model for density of states, Debye $T^3$ law, Einstein model of the density of states, Thermal conductivity - Thermal resistivity of phonon gas, Umklapp process | 15 hours |

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| | **Optical and Dielectric Properties**<br>Macroscopic electric field, local electric field at atom, dielectric constant and polarizability, Complex dielectric constant, Classical theory of electronic polarization and optical absorption, Structural Phase transitions, Ferroelectric Crystals and Displacive transitions Optical reflectance, Excitons, Raman effect in crystals. Luminescence and Luminescence centres | 12 hours |
| **Pedagogy:** | Lectures/ tutorials/ assignments.<br>Sessions will be interactive in nature to enable peer group learning. | |
| **References/ Readings** | 1. Introduction to Solid State Physics, C. Kittel, Wiley India (2019)<br>2. Elementary SolidState Physics; Principles and Applications, M. A. Omar Addison Wesley (2000)<br>3. Solid State Physics, Niel W. Ashcroft, N. David Mermin, Harcourt Asia Pte Ltd. (2001)<br>4. Solid State Physics, G. Bums, Academic press, Inc. London (1985)<br>5. Solid State Physics, A. J. Dekker, McMillan, India (1985)<br>6. Solid State Physics, J. S. Blakemore, W. B. Sauders, Philadelphia (1969) | |
| **Learning Outcomes:** | 1. Student will understand the fundamental aspects related to structure of solids, lattice symmetry, and structure determination.<br>2. Student will be exposed to various aspects of crystal binding and the elastic properties of solids<br>3. Student will recognize the idea of vibrating lattice, its quantization and the role of phonons in thermal and optical properties of solids. | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSR-502 **Title of the Course:** Solid State Physics II
**Number of Credits:** 4
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Should have basic knowledge of Quantum mechanics and statistical mechanics | |
| **Objective:** | 1. To introduce electronic properties of solids<br>2. To introduce the concept of formation of bands in solids.<br>3. To acquaint with techniques associated with measurement of band structure and transport phenomena in solids.<br>4. To introduce students to different types of magnetic order and superconductivity in solids | |
| **Content:** | **Metals: Drude and Sommerfeld models**<br>Free electron theory – Drude model - assumptions, failures of Drude model, Sommerfeld model, Successes and failures of the Sommerfeld model, Electrical conductivity, Experimental electrical resistivity of metals, Heat capacity of electron gas, Experimental heat capacity.<br>**Nearly Free electron model**<br>Periodic potential, born – von Karman boundary conditions, | 7 hours |

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| | Schrodinger equation in a periodic potential, Bloch's theorem, electronic band structure, single electron energy state, degenerate electron levels, Consequences of the nearly free electron model, Fermi surface. | 7 hours |
| | **Tight binding model**<br>Band arising from a single electronic level, electronic wavefunctions, General points about the formation of tight binding bands, Group I and II metals, Group IV elements, transition metals, comparison of tight binding and nearly free electron band structure, crystal momentum, effective mass, holes. | 7 hours |
| | **Semiconductors and Insulators**<br>Band structure of Si and Ge, Band structure of direct gap III-V and II-VI semiconductors, Optical absorption and excitons, Thermal population of bands in semiconductors, Intrinsic carrier density, Impurities and extrinsic carrier density, degenerate semiconductors. | 7 hours |
| | **Measurement of Band structure**<br>Lorentz force and orbits, Landau levels, electronic density of states in a magnetic field, quantum oscillatory phenomena, de Hass – van Alphen effect, Cyclotron resonance, interband magneto optics, electron spectroscopy – angle resolved photoelectron spectroscopy, Some case studies – Copper, $Sr_2RuO_4$. | 7 hours |
| | **Transport Properties**<br>Thermal and electrical conductivity of metals, electron-electron scattering – Fermi liquid behaviour, Electrical conductivity of semiconductors, Disordered systems and hopping conduction, Hall effect, magnetoresistance in metals, magnetophonon effect, magnetoresistance in two dimensional systems, quantum Hall effect, fractional quantum Hall effect. | 7 hours |
| | **Magnetic Properties**<br>Magnetic moments, Quantum mechanics of spin, Atom in mangetic field, Magnetic susceptibility, Diamagnetism, Paramagnetism, Semiclassical treatment, Quantum Theory of Paramagnetism, Hund's Rules, Crystal field, Paramagnetic Susceptibility of Conduction electrons, Van Vleckparamagnetism, Adiabatic demagnetization<br>Ferromagnetism, The Weiss model of a ferromagnet, Origin of molecular field, Magnons, Domains, Antiferromagnetism, Neel's theory, Ferrimagnetism | 12 hours |
| | **Superconductivity**<br>Experimental survey- Occurrence of Superconductivity, Destruction of superconductivity by magnetic fields, Meissner effect, Heat capacity, Energy gap, microwave and infrared properties, Isotope Effect<br>Theoretical Survey - Thermodynamics of the transition, London equation, Coherence length, BCS theory, Flux quantization, Type II superconductors, Tunnelling, Josephson effects, High Tc superconductivity (introduction) | 6 hours |
| **Pedagogy:** | Lectures/ tutorials /assignments. | |

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| | Sessions will be interactive in nature to enable peer group learning. | |
| **References/ Readings** | 1. Band theory and Electronic Properties of Solids, J. Singleton, Oxford University Press, (2014)<br>2. Introduction to Solid State Physics, C. Kittel, Wiley India (2019)<br>3. Solid State Physics, Niel W. Ashcroft, N. David Mermin, Harcourt Asia Pte Ltd. (2001)<br>4. Elementary Solid State Physics; Principles and Applications, M. A. Omar Addison Wesley (2000) | |
| **Learning Outcomes:** | 1. Student will learn about electronic properties of solids<br>2. Student will understand formation of bands, their importance in classification of solids and theoretical models of calculation of band structure.<br>3. Student will get familiarized with some the techniques of band structure measurement and comprehend the effect of band structure on electronic transport properties of solids.<br>4. Student will recognize diverse types of magnetic orders in solids and phenomenon of superconductivity. | |

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**Programme:** M. Sc. (Physics)(Solid State Physics)
**Course Code:** PHSG-501 **Title of the Course:** Solid State Physics Practical
**Number of Credits:** 4
**Effective from AY:** 2021-22

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| **Prerequisites for thecourse:** | None | |
| **Objective:** | This course aims at developing advanced level experimental skills and competence in the analysis of experimental data on structural, magnetic, transport and optical properties of solids and relate them to different physical concepts studied in the theory courses, PHSR-501 and PHSR-502. | |
| **Content:** | 1. X-ray diffraction: Analysis of diffraction patterns of cubic crystal structures to determine their lattice constant, intensity ratios, and lattice type<br>2. Measurement of dispersion relation of monoatomic and diatomic lattices using electrical equivalent circuits.<br>3. Measurement of Resistivity of a metal and a Semiconductor by Four Probe Method<br>4. Measurement of Thermoelectric Power of a metal<br>5. Determination of Magnetic Susceptibility and Magnetic Moment of a Paramagnetic Material by Gouy's Method.<br>6. Determination of Magnetic Susceptibility and Magnetic Moment of a Paramagnetic Liquid by Quinke's Method.<br>7. Study of Hysteresis loop of magnetic materials.<br>8. Determination of Lande's Splitting Factor, g, in an organic radical. | 120 hours |

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| | 9. Study of Elastic behaviour of solids using a composite piezoelectric oscillator<br>10. Measurement as well as determination of Transition Temperature of a Ferroelectric Material Dielectric Constant and understanding failure of mean field theory<br>11. Measurement of Activation Energy of F-Centres in Alkali Halide Crystals Thermoluminescence<br>12. Determination of a Hall Coefficient and Nature of a Semiconductor and Mobility of Charge Carriers<br>13. Analysis of frequency dependence of Dielectric constant of a material.<br>14. Study of optical properties of a material - absorption, excitation and emission spectra.<br>15. Measurement of thermal conductivity of a good and poor thermal conductor.<br>16. Raman effect – demonstration applied to a particular material.<br><br>A minimum of 12 experiments are expected to be done by the students. | |
| **Pedagogy:** | Laboratory experiments, self-study | |
| **References/ Readings** | 1. Experimental Manuals assigned to each experiment.<br>2. Introduction to Solid State Physics, C. Kittel, 7th Edition, John Wiley & Son, Inc. New York (1997).<br>3. Advanced Practical Physics for Students, B.L. Worsnop& H.T. Flint, (1927).<br>4. Solid State Physics, A. J. Dekker, McMillan, India (1985).<br>5. Physics Lab. Experiments 7/e, Jerry D. Wilson, D. C. Heath and Company (2009). | |
| **Learning Outcomes** | 1. Quantitative measurements and evaluation of various properties and constants introduced in the theory courses of Physics.<br>2. Verification of different laws and concepts learned in the theory courses of Physics<br>3. Development of fine and intensive experimental skills.<br>4. Interpreting results, error analysis, writing reports, analyzing data. | |

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**Programme:** M. Sc. (Physics)(Computational Physics)
**Course Code:** PHCR-501 **Title of the Course:** Advanced Quantum Mechanics
Number of Credits: 4
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Should have knowledge of Quantum Mechanics | |
| **Objective:** | To introduce advanced topics in the field of quantum mechanics such as many-body systems, relativistic wave | |

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| | equations and relativistic fields | |
| **Content:** | **Second Quantization**<br>Identical Particles, Many-Particle States, and Permutation Symmetry, Completely Symmetric and Antisymmetric States, Bosons: States, Fock Space, Creation and Annihilation Operators, The Particle-Number Operator, General Single- and Many-Particle Operators, Fermions: States, Fock Space, Creation and Annihilation Operators, Single- and Many-Particle Operators, Field Operators: Transformations Between Different Basis Systems, Field Operators, Field Equations, Momentum Representation: Momentum Eigen functions and the Hamiltonian, Fourier Transformation of the Density, The Inclusion of Spin. | 8 hours |
| | **Spin-1/2 Fermions**<br>Noninteracting Fermions, The Fermi Sphere, Excitations, Single-Particle Correlation Function, Pair Distribution Function, Density Correlation Functions, and Structure Factor, Ground State Energy and Elementary Theory of the Electron Gas, Hamiltonian, Ground State Energy, in the Hartree–Fock Approximation, Modification of Electron Energy Levels due to the Coulomb Interaction, Hartree–Fock Equations for Atoms. | 10 hours |
| | **Bosons**<br>Free Bosons, Pair Distribution Function for Free Bosons, Two-Particle States of Bosons, Weakly Interacting, Dilute Bose Gas, Quantum Fluids and Bose–Einstein Condensation, Bogoliubov Theory of the Weakly Interacting Bose Gas, Superfluidity. | 10 hours |
| | **Green's Function**<br>Interaction representation, driven harmonic oscillators, Wick's theorem and generating functionals. Green's functions, Green's function for free fermions, Green's function for free bosons. Adiabatic concept, Gell-Mann Low theorem, generating functions for free fermions, spectral representation. Many particle Green's function | 10 hours |
| | **Relativistic Wave Equations**<br>Klein-Gordon equation, Plane wave solution, charge and current densities, hydrogen atom. Dirac equation, algebra of Dirac matrices, covariance of Dirac equation, plane wave solutions, equation in an electromagnetic field. Properties of Dirac electron. The spin of the Dirac particle, Magnetic dipole moment of electron, Velocity operator, Expectation value of the velocity. Parity, Charge conjugation and time reversal operations, Parity operation, Charge conjugation, and Time reversal operation. Dirac's hole theory, Feynman's theory of Positrons. | 10 hours |
| | **Quantization of Fields and Radiation Theory**<br>Wave equation for a field, Conjugate field momentum,Hamiltonian, density conservation laws, quantum condition and quantization of scalar field, quantization of complex scalar and Schrodinger fields, Quantization of electromagnetic fields, Interaction of radiation with | 12 hours |

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| | matter spontaneous and induced emission, Thomson scattering, cross-section for photoelectric effect, Heisenberg-Kramer formula, Rayleigh and Raman scattering. Quantization of Schrodinger field by anticommutator, Atomic level shift, Lamb shift. | |
| **Pedagogy:** | Lectures/ tutorials/assignments. Sessions will be interactive in nature to enable peer group learning. | |
| **References/ Readings:** | 1. Advanced Quantum mechanics, Franz Schwabl,Springer(2005)<br>2. Advanced Quantum mechanics, J. J. Sakurai, Addison-Wesley (1967).<br>3. Quantum Mechanics, B. H. Bransden and C. J. Joachain, Pearson (2004)<br>4. Quantum Mechanics, S. N. Biswas, Books and Allied Pvt. Ltd. (2015)<br>5. Quantum Mechanics:Theory and Applications, A. K. Ghatak and S. Lokanathan, Springer (2004)<br>6. Introduction to Many Body Physics, P. Coleman, Cambridge University Press (2015) | |
| **Learning Outcomes** | 1. In the first unit students will learn the formalism of second quantization and its application to the most important problems of weakly interacting electron gas and Bose gases and Green's Function.<br>2. In the second unit students will learn about the Klein-Gordon and Dirac equation, and their important aspects.<br>3. In the third unit students will learn about quantization of Klein-Gordon, Dirac and radiation fields | |

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**Programme:** M. Sc. (Physics) (Computational Physics)
**Course Code:** PHCR-502 **Title of the Course:** Advanced Statistical Mechanics
Number of Credits: 4
**Effective from AY:** 2023-24

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| **Prerequisites for thecourse:** | Should have attended Quantum Mechanics and Statistical Mechanics courses. | |
| **Objective:** | To introduce advanced statistical methods to study phase transition and critical phenomena. | |
| **Content:** | **Phase Transition and Critical Phenomena**<br>First and second-order transitions, critical phenomena, morphology, fluctuation and correlation and response, Critical exponents, scaling inequalities, how to study critical phenomena.<br>**Models and Universality**<br>Ising models and its ground state, Ising models and its applications, other models and their ground states, Universality in different models.<br>**Mean Field theory**<br>Mean field theory for fluids, critical exponent of a fluid system, Mean | 8 hours<br><br><br><br><br>6 hours<br><br><br><br>12 hours |

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| | field theory for magnetic systems, Mean field equation of state and its solution, Mean field critical exponents, correlation length and correlation function, Bethe approximation, Bethe approximation for 2D Ising model, Landau theory of Phase transition, Critical exponents from Landau theory.<br>**Transfer Matrix method**<br>Transfer matrix and 1D Ising model, Determination of magnetization, susceptibility, specific heat, and correlation length. Spin-1 Ising model and potts model, 2D Ising model.<br>**Series expansion method (Perturbation method)**<br>High-temperature expansion and 1-D Ising model, High and low-temperature expansions for 2D Ising model, Duality and critical temperature, approximation techniques<br>**Monte Carlo method (Numerical method)**<br>Ensemble average in Monte Carlo method, Ergodicity, Detailed balance, and Metropolis algorithm, Monte Carlo Simulation for 2D Ising model, Measurements and errors.<br>**Scaling and renormalization**<br>Homogeneous function, Homogeneity of free energy and scaling, Renormalization group, Renormalization Group, Renormalization operation, Free energy function, correlation length, Critical exponents, fixed point, and universality. | <br><br><br><br><br><br>6 hours<br><br><br><br>6 hours<br><br><br><br>8 hours<br><br><br><br>14 hours |
| **Pedagogy**: | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **References/ Readings:** | 1. Statistical Mechanics, R. K. Pathria and P. D. Beale, Elsevier, London, 2011.<br>2. Statistical Physics, L. D. Landau and E. M. Lifshitz, Third Edition, Part 1: Volume 5 (Course of Theoretical Physics, Volume 5), Butterworth-Heinemann (1980)<br>3. Statistical Mechanics of Phase Transitions, J. M. Yeomans, Oxford University Press, New York, 1994.<br>4. Introduction to Phase Transitions and Critical Phenomena, H. E. Stanley, Oxford University Press, New York, 1987.<br>5. Principles of Condensed Matter Physics, P. M. Chaikin and T. C. Lubensky, Cambridge University Press, Cambridge 2013.<br>6. Statistical Mechanics and Critical Phenomena: A brief overview, in Computational Statistical Physics, S. B. Santra and P. Ray, edited by S. B. Santra and P. Ray, Hindustan Book Agency, New Delhi, 2011. | |
| **Learning Outcomes** | Students will be able to learn Physics of phases and phase transitions, critical phenomena, elementary excitations, models, and Monte Carlo method etc. | |

**Programme:** M. Sc. (Physics) (Computational Physics)
**Course Code:** PHCG-501 **Title of the Course:** Numerical Techniques Practicals

**Number of Credits: 4**
**Effective from AY:** 2023-24

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| **Prerequisites for thecourse:** | Basic knowledge of Computer programming | |
| **Objective:** | Tointroducethemethodsofsolvingmathematicalproblems thatoccur inphysics usingnumerical techniques. | |
| **Content:** | 1. FindingErrors:its sources,propagationandanalysis<br>2. FindRootsoffunctions:bisection,Newton-Raphson,secantmethod,fixed-pointiteration.<br>3. SolutionofLinearequations:GaussandGauss-Jordan elimination,Gauss-Seidel,LUdecomposition.<br>4. EigenvalueProblems.<br>5. Leastsquarefittingoffunctions.<br>6. Interpolation.<br>7. Numericaldifferentiation.<br>8. Numericalintegration.<br>9. SolutionsofODEby initialvalueproblems,Euler'smethod,secondandfourthorderRunge-Kuttamethods.<br>10. Boundaryvalueproblems byfinitedifferencemethod.<br>11. Random number generation and MonteCarlo simulation.<br>12. Optimization techniques. | 120 hours |
| **Pedagogy:** | Lectures/Laboratorypracticals. Sessionsshallbeinteractive innaturetoenable peergrouplearning. | |
| **References/ Readings:** | 1. NumericalRecipes:TheArtofScientificComputing, W.H.Press,S.A.Teukolsky,W.T. Vetterling,B.P.Flannery,Cambridge UniversityPress, 1986.<br>2. NumericalMathematicsandComputing,Thomson HigherEducation,W.Cheney,D.Kincaid,USA, 2012.<br>3. NumericalmethodsforPhysics,A. L.Gercia,CreateSpaceIndependent Publishing, 2015.<br>4. Computational Physics, S. E. Koonin, and D. C. Meredith, Westview Press, 1998.<br>5. S. Chapra, R. Canale, Numerical Methods for Engineers, McGraw Hill Education, 7th edition, 2016. | |
| **Learning Outcomes** | Students will earn basic algorithms,advanced,and cutting-edge numerical techniques used in Computational Physics. | |

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**Programme:** M.Sc (Physics)(Biophysics)
**Course Code:** PHBR-501 **Title of the Course:** Molecular Biophysics
**Number of Credits:** 4
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | PHOB-200 | |
| **Objective:** | This course is intended to enrich the students with the basics of molecular biophysics. The students will learn about the different physical process occurring in biological systems. | |
| **Content:** | **Cellular Biophysics**<br>General organization of the cell, Structure of biomolecules, cellular mechanics and transport, Chemical bonding, ionization energy, electron affinity, electron negativity, strong bonds and weak, bond energies in biomolecules, Interatomic potentials for strong and weak bonds, cellular mechanics, transport mechanism<br>**Structure of Proteins, DNA and Enzymes Kinetics**<br>Basics aspects of protein structure, Polypeptide chain geometrics, estimates of potential energy, results of potential energy calculations, hydrogen bonding, hydrophobic & hydrophilic interactions and water as universal solvent in biological systems, Primary structure sequencing of polypeptide, haemoglobin, homologies in proteins, Secondary structure alpha and beta conformation, collagen structure, stability of alpha helix, Ramchandran plot, Tertiary structure, structure of myoglobin and hemoglobin, Quaternary structure, symmetry consideration, Analysis of subunits and chain arrangement of subunits, stability of globular quaternary structure. Protein folding rules, pathways and kinetics<br>Nucleic acids, purines and pyrimides, double helical structure of DNA, polymorphism of DNA, RNA structure, thermodynamics of DNA supercoiling, chromosome structure<br>Enzymes, enzyme kinetics, Michaelis-Menten equation, Inhibitors, kinetics of competitive, non-competitive and uncompetitive inhibitors<br>**Membrane Biophysics**<br>Fundamental aspects of biological membrane, Various membrane models, Carbohydrate, Lipids & Proteins, Components of cell membrane, Composition of biological membranes- lipid molecules, proteins, glycoprotein, membrane, skeletons, forms of lipids and proteins, electrical properties of lipids and proteins, principles of membrane organization & stability, Biogenesis of cell membrane, Molecular motion in membrane & membrane fluidity, Protein lipid interactions,<br>Electric properties of membranes: electric double layer,<br>Poisson-Boltzmann theory of electric double layer, Gouy-Chapman model of electric double layer, free energy of electric double layer, bonds and adhesion of electrified molecules on the surface of a membrane, Hodgkin Huxley equation, membrane impedance, Zeta, Stern & total electrochemical potential, Helmholtz-Smoluchowski equation; it's correction by Debye-Huckle theory, transmembrane potential & it's measurement by microelectrodes. Neurobiophysics<br>Transport across membranes: diffusion and osmosis, Selectivity & ion specificity of biomembrane, Ion | 8 hours<br><br><br><br><br><br><br>20 hours<br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br>20 hours |

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| | channel structure and gating function, Ion channel types and characterization, transport of macromolecules with & without vesiculation& by intermediate mechanism, Transport and communication between cells and organelles.<br>**Molecular biomechanics**<br>Biological motion, free energy transduction, chemochemical machines, pumps and motors as chemochemcial machines, flux force dependence, molecular motors, mechanochemistry of molecular motors, biomolecular forces, biomechanics of muscle contraction and cardiovascular system. | 12 hours |
| **Pedagogy:** | Lectures/ Tutorials/Assignments.<br>Sessions shall be interactive in nature to enable peer group learning. | |
| **References/Readings** | 1. Introduction to Molecular Biophysics, Jack A Tuszynski and Michal Kurzynski First Edition, CRC Press (2003).<br>2. Biophysics: An Introduction, Rodney Cotterill, Wiley (2002).<br>3. Applied Biophysics, A Molecular Approach for Physical Scientist, Thomas A Weigh Wiley (2007).<br>4. Molecular & Cellular Biophysics, Mayer & Jackson, Cambridge (2006).<br>5. Biophysics, VasanthaPattabhi and N. Goutham First Edition, Narosa (2002).<br>6. Biomembrane structure and Function, Ed. Chapman D., Macmillan, (1983).<br>7. Introduction to Biological Membrane, Jain R K, John Wiley& Sons (1988).<br>8. Text Book of Physiology, Guyton & Hall, 12$^{th}$ Edition, Elsevier (2010).<br>9. Molecular motors, Schliwa, Wiley-VCH Verlag GmbH & Co (2003). | |
| **Learning Outcomes:** | 1. The students will be familiarized with the basic concepts of molecular biophysics.<br>2. The students will have gained sufficient knowledge in the structure and functioning of molecular processes.<br>3. The students will be exposed to the recent developments in biomechanics and molecular motion. | |

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**Programme:** M.Sc (Physics)(Biophysics)
**Course Code:** PHBR-502 **Title of the Course:** Methods in Biophysics
**Number of Credits:** 4
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | PHOB-200 | |
| **Objective:** | The aim of course is introduced various experimental techniques used in biophysical systems. The student will learn about the basic and advanced characterization tools for biophysics. | |

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| **Content:** | **Separation techniques I**<br>Electrokinetics methods: electrophoresis, electrophoretic mobility (EPM), factors affecting EPM, Paper, PAGE, SDS-PAGE, Disc gel, gradient gel, electrophoresis of nucleic acid and its application, Pulse field electrophoresis, single cell gel electrophoresis, Isolectrophoresis, preparative electrophoresis, 2-D gel electrophoresis, Capillary, Iso-Electric focusing, applications in biology and medicine. Chromatography, TLC, adsorption, partition, ion exchange, gel filtration, affinity and FPLC, GLC,<br>**Separation techniques II**<br>HPLC: mobile phase systems, modes of operations, application, Hydrodynamics method: fundamental principles' Centrifugation: principle, preparative centrifuge, analytical, ultracentrifuge, sedimentation and diffusion, Ultracentrifugation and their applications in molecular weight, size determination. Viscosity and its application, dialysis, solvent fractionation, isoelectric precipitation,<br>**Spectroscopic methods**<br>Principles of spectroscopic techniques, Ultraviolet-visible spectroscopy, circular dichroism and optical rotatory dispersion, fluorescence spectroscopy, infrared spectroscopy, Raman spectroscopy, Atomic Absorption spectroscopy- Inductively coupled plasma atomic emission spectrophotometry. Electron spin resonance, Nuclear Spin resonance, X-ray spectroscopy<br>**Microscopic Techniques**<br>Principle, instrumentation and application of optical microscopy, image formation, magnification, resolving power. optimum resolution, image defects, different types of Microscopy: Dark field, Phase contrast, polarization microscopy, Interference microscopy, Fluorescence microscopy, Electron microscopy: Electron guns, Electron lens, electrostatic focusing, magnetic focusing, SEM, STEM, Atomic force microscopy. | 15 hours<br>15 hours<br>15 hours<br>15 hours |
| **Pedagogy:** | Lectures/Tutorials/Assignments.<br>Sessions shall be interactive in nature to enable peer group learning. | |
| **References/ Readings** | 1. Methods in Molecular Biophysics, Igor N S, N Zaccai& J Zaccai, First Edition, Cambridge (2007).<br>2. Principle of Biochemistry, D Voet, J Voet and CW Pratt, Third Edition, John Wiley and Sons, (2008).<br>3. DNA Cloning, Grover Vol. I, II, III, First Edition, Oxford (1987).<br>4. Biophysics VasanthaPattabhi and N. Goutham, First Edition, Narosa (2002).<br>5. Advanced Methods in Protein Microsequencing, Wittmann, First Edition, Springer (1986).<br>6. Fundamentals of Molecular Spectroscopy, Banwell, Fourth Edition, McGraw Hill (1994).<br>7. Essential Biophysics, Narayanan First Edition, New Age Publications (2000). | |

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| | 8. Handbook of Molecular Biophysics (Methods & Application) Henrik G Bohr, First Edition, Wiley (2009). | |
| **Learning Outcomes:** | 1. The students will be familiarized with the basic experimental techniques used in biophysics.<br>2. The students will expand their knowledge on various spectroscopic and microscopic methods in characterization. | |

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**Programme:** M.Sc (Physics)
**Course Code: PHBG-501Title of the Course:** Biophysics Practical
**Number of Credits:** 4
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | PHOB-200, basic knowledge in experimental techniques in chemistry and biology | |
| **Objective:** | This laboratory course is intended to provide basic laboratory training in the experiments in biophysics. Important biophysical phenomena will be tested and studied. The experiments will start from familiarization of basic characterization tools and protocols followed by advanced experiments. | |

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| **Content:** | Short lectures on general protocols of biophysics experiments.<br>The following experiments are to be performed/demonstrated:<br><br>Experiments to be performed<br>1. Microscopic techniques: The study of biological samples/cells using fluorescence /DIC microscopy<br>2. Protein-protein interactions using spectroscopy (fluorescence/UV visible) techniques<br>3. Study of DNA-Protein interaction using fluourimetry<br>4. Study of fluorescence sensitivity and quenching, fluorescence recovery after photobleaching (FRAP)<br>5. PAGE and SDS PAGE Demonstrations<br>6. Classification of gram –ve& +ve organisms, observe cell growth/ survival by colony forming assay, estimation of cell viability by dye exclusion and colony formation assay, observe cell death by physical and chemical agents<br>7. Preparation of buffers and pH analysis<br>8. Determination of the titration curve of Proteins, amino acids & calculation of the pKa values<br>9. Isolation of Proteins- Casein from milk, Hb from RBC.<br>10. Study of interaction of acridine orange with DNA<br>11. Enzyme Assays (LKH, beta galactosidase, acid phosphatase, arginase, Succinic De –hydrogenase): Time, Temp, enzyme concentration, cofactors. LKH: Km &Vmax<br>Demonstrations via online videos<br>12. Gel filtrations chromatography<br>13. DEAE cellulose chromatography of DNA<br>14. Study of phase transition of membrane phospholipids and Study of the membrane potential using fluorescence spectroscopy.<br>15. To study the charge characteristics of cells through micro Electrophoresis<br>16. Osmolarity: Determination of osmotic pressure of salts.<br>17. Study of diffusion of biomolecules/ions (Fick's Law) | 120 hours |
| **Pedagogy:** | Laboratory work, Presentations, demonstrations. | |
| **References/ Readings** | 1. Introduction to Experimental Biophysics: Biological Methods for Physical Scientists, Jay Nadeau, CRC Press (2012).<br>2. Introduction to Practical Biochemistry, Plummer, D. T. 3rd edition. McGraw-Hill Publishing Co. (1987).<br>3. Basic Methods for the Biochemical Lab, Holtzhauer, M. 1st English edition. Springer (2006).<br>4. Experimental techniques in bacterial genetics, Stanley R. Maloy, John and Bartlett (1989). | |
| **Learning Outcomes:** | 1. The students will be familiarized with the basic experimental methods in biophysics.<br>2. The students will have gained sufficient knowledge in the various characterization and spectroscopic tools. | |

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| | 3. This course will also enable the students to have an understanding of some of the advanced techniques in experimental biophysics | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSG-502 **Title of the Course:** Nuclear Reactor Physics
**Number of Credits:** 2
**Effective from:**2023-24

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| **Prerequisites for thecourse:** | Should have basic knowledge of nuclear physics, thermodynamics, quantum mechanics, and solid state physics | |
| **Objective:** | To introduce students to the fundamental principles of neutron and their interaction with matter. To understand the phenomenon of diffusion and slowing down of neutron and waste disposal. | |
| **Content:** | **Introduction**:<br>Discovery of neutron, Fundamental properties of neutron, decay of neutron, moment of the neutron, Classification of neutron energy: slow neutrons, thermal neutrons, Epithermal neutrons, Resonance neutron, Intermediate neutrons, Fast neutrons.<br>**Interaction of Neutrons with Matter**:<br>Interaction of neutrons with matter, cross-section, variation of cross section with neutron energy. Neutron flux, Maxwellian distribution, Fissile and fertile materials, Neutron life cycle, Fermi four factor formula $k_{eff}$.<br>**Neutron Diffusion**:<br>Diffusion theory approximation, neutron leakage, diffusion equation. Thermal diffusion length, One group critical equation for bare reactor. Boundary conditions and extrapolation distance, measurement of diffusion length<br>**Slowing down of Neutrons**:<br>Slowing down length, lethargy, slowing down in a mixture. Moderations.<br>**Calculation of Critical Size of Reactors**:<br>Critical equation, One group model, four factor formula and calculation of parameters. Critical size of sphere. Effect of reflector.<br>**Power Operation**:<br>Reactor kinetics, prompt neutron lifetime, stable reactor period, the Inhour equation, Fission product poisoning. Fuel burn-up. Measurement or reactor power and period.<br>**Radiological Protection**:<br>Units of radiation and radioactivity, Radiation protection standards, Radiation monitoring instruments.<br>**Reactor Fuels and Materials:**<br>Uranium resources and requirements. Isotope separation. (one method), reprocessing of spent fuel, Nuclear fuel management. | 2 hours<br>4 hours<br>5 hours<br>5 hours<br>5 hours<br>5 hours<br>2 hours<br>2hours |

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| **Pedagogy:** | Lectures / tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning. | |
| **References/ Readings** | 1. Nuclear Reactor Engineering, S. Glasstone and A. Sesonske, Van Nostrand Reinhold Co., (1963).<br>2. Fundamentals of Nuclear Reactor Physics, E. E. Lewis, Elsevier (2008).<br>3. Introduction to neutron Physics, L.F. Curtiss, D. Van Nostrand Co., (1969).<br>4. Introduction to the theory of Thermal Neutron scattering, G. L. Squires, Dover Publication, Inc. (1996).<br>5. Safe Handling of Radioisotopes (Safety Series no.1) (1958). | |
| **Learning Outcomes** | Students will be able to<br>1. Understand neutron interaction with matter<br>2. Familiarise with the main features of a nuclear reactor and conditions that determine its criticality.<br>3. Understand neutron diffusion and slowing down<br>4. Gain insight on the management of nuclear waste | |

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**Programme:** M. Sc. (Physics) (Solid State Physics**)**
**Course Code:** PHSG-503 **Title of the Course:** Advanced Optics
**Number of Credits:** 2
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Should have studied basic courses in optics and electromagnetic theory, quantum mechanics with good understanding in mathematics. | |
| **Objective:** | This course is aimed at understanding intermediate to advanced optics. This course includes fundamental theoretical optics to applied optics and a brief introduction to quantum optics. | |
| **Content:** | **1. Light Waves**<br>Eikonal equations, laws of reflection and refraction, guided optics, Lagrange and Hamiltonian formulation of optics, ABCD matrix, thin lens formula, Gaussian optics, Aberrations.<br>**2. Coherence of light and Fourier Optics**<br>Fourier transforms in one and two dimensions, convolution operations, spatial frequency filtering, phase contrast microscopy, Correlation function, The Wiener–Khinchin Theorem, Linewidth, Spatial coherence, Interference spectroscopy, Temporal coherence, Stellar intereferometers, Fourier transform properties of lenses.<br>**3. Optical Modulation and nonlinear optics**<br>Electro-optical effects, acousto-optical effect, Raman-Nath diffraction, Magneto-optics.<br>Nonlinear optical media, second-order and third order optical effects, Kerr optical effect, self-focussing,optical bistability, second and third harmonic generation, coupled mode equations, Ultrafast optics.<br>**4. Introduction to Quantum Optics** | 7 hours<br><br><br><br>8 hours<br><br><br><br><br><br><br>8 hours |

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| | Quantum states of electromagnetic fields, coherent and squeezed states, Operators, ordering procedures and star products, *Q*, *P* and Wigner functions of a density operator, Correlation functions and quantum coherence,<br>Nonclassical light, Quantum entanglement, Bell's inequalities, Cavity QED, Quantum cryptography. | 7 hours |
| **Pedagogy**: | Lectures/ tutorials/ term papers/assignments/. Sessions shall be interactive in nature to enable peer group learning. | |
| **References/ Readings** | 1. Modern Optics, B. D. Guenther, Oxford University Press, 2015<br>2. Optical Electronics, AjoyGhatak and K. Thyagarajan, Cambridge University Press, 2017.<br>3. Optics- Principles and Applications, Sharma K. K., Academic Press, Elsevier 2006<br>4. Photonics-Optical Electronics in Modern Communications, Yariv and Yeh, Oxford University Press, 2007<br>5. Fundamentals of Photonics, B.E.A. Saleh and M. C. Teich, John Wiley and Sons, 2019<br>6. Introduction to Fourier Optics, J. Goodman, Roberts and Company Publishers; 3rd edition (December 10, 2004)<br>7. Nonlinear Optics, R. W. Boyd, Elsevier 4$^{th}$ Edition, 2020<br>8. Quantum optics: an introduction, Marc Fox, Oxford University Press, 2009 | |
| **Learning Outcomes** | 1. Understanding advanced theoretical concepts in optical physics<br>2. Knowledge in recent advances in optics | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSG-504 **Title of the Course:** Physics of Energy Materials
**Number of Credits:** 2
**Effective from AY:** 2023-24

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| Prerequisites for thecourse: | Student should have basic understanding of the physics concepts related to thermodynamics and electrodynamics. | |
| Objective: | 1. To develop the understanding of different energy materials, their properties and how to make use of them for energy extraction<br>2. To understand the basic principle of different energy extraction phenomenon. | |

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| Content: | **Photovoltaic Energy materials**<br>Sources of energy: renewable and non-renewable sources, solar power and photovoltaic materials, photovoltaic devices<br>**Energy Storage materials**<br>Electrochemical energy conversion and storage, Battery materials, fuel cells, supercapacitors, metal-organic framework for hydrogen storage, materials for water splitting.<br>**Thermoelectric Materials**<br>Introduction, The Seebeck and Peltier effects, thermoelectric figure of merit, Measuring the thermoelectric properties, Heat conduction by the crystal lattice, Materials for Peltier cooling, Generator materials, Thermoelectric refrigerators and generators.<br>**Magnetocaloric materials**<br>Magnetocaloric effect in the phase transition region, Methods of investigation of magnetocaloric properties, Magnetocaloric effect in different types of materials, Magnetocaloric effect in nanosized materials, Magnetic refrigeration | 7 hours<br><br><br>8 hours<br><br><br><br>8 hours<br><br><br><br><br><br>7 hours |
| Pedagogy: | lectures/ tutorials /viva/ seminars/ term papers/assignments/ presentations | |
| References/ Readings | 1. Handbook of Energy Materials, Edited by Ram Gupta, Springer Singapore, 2022<br>2. Energy Materials, Duncan W. Bruce, Dermot O'Hare, Richard I. Walton, Wiley, 2011<br>3. Solar Cell Device Physics, Stephen J Fonash, 2$^{nd}$ Edition, Academy Press, 2010.<br>4. Materials for Solar Energy Conversion: Materials, Methods and Applications, R. Rajasekar (Editor), C. Moganapriya (Editor), A. Mohankumar (Editor), Wiley, 2022.<br>5. The Physics of Thermoelectric Energy Conversion, H Julian Goldsmid, Morgan & Claypool Publishers, 2017.<br>6. The Magnetocaloric Effect and its Applications, A.M. Tishin, Y.I. Spichkin, CRC press (Taylor and Francis group), 2016. | |
| Learning Outcomes: | Students will understand the basic principles of energy extraction devices such as solar cells. This course will also help student in understanding the physics of thermoeleastic and magnetocaloric effects for energy applications. | |

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**Programme:** M. Sc. (Physics)(Solid State Physics)
**Course Code: PHSG-505** **Title of the Course: Physics of Ferroic Materials**
**Number of Credits: 2**
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Basic knowledge of Solid State Physics/Chemistry | |

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| **Objective:** | To introduce various types of ferroic materials and its applications to the students. | |
| **Content:** | **Phase Transition**<br>Landau Theory of phase transition – first order and second order.<br>**Ferroelectrics**<br>*P–E* Loop, Relationships Between Dielectric, Piezoelectric, Pyroelectric, and Ferroelectric, Origin of Ferroelectrics, Structure-Induced Phase Change from Paraelectric to Ferroelectric, Soft Phonon Mode, Ferroelectric Domains and Domain Switching, Domain Structure, Ferroelectric Switching, Ferroelectric Materials – $BaTiO_3$, $PbTiO_3$, Antiferroelectric $PbZrO_3$, $Pb(Zr_xTi_{1-x})O_3$ (PZT), Relaxor Ferroelectrics.<br>**Ferromagnetics**<br>General Introduction to Ferromagnetics, Domain and Domain Wall, Magnetoresistance Effect and Device, Anisotropic Magnetoresistance (AMR), Giant Magnetoresistance (GMR), Colossal Magnetoresistance (CMR), TunnellingMagnetoresistance (TMR), Spin-Transfer Torque Random-Access Memory (STT-RAM), Magnetostrictive Effect and Device Applications, Magnetostrictive Properties of Terfenol-D, Magnetostrictive Ultrasonic Transducer, Magnetoelastic Effect, Magnetomechanical Strain Gauge, Multiferroics, Magnetoelectric Effect, Why Are There so Few Magnetic Ferroelectrics? Single Phase Multiferroic Materials, ME Composite Materials, MultilayeredHeterostructures.<br>**Ferroelastics**<br>Shape Memory Alloy, SMA Phase Change Mechanism, Nonlinearity in SMA, One-Way and Two-Way Shape Memory Effect, Superelastic Effect (SE), Application Examples of SMAs, Ferromagnetic Shape Memory Alloys, Formation of Twin Variants, Challenges for Ni–Mn–Ga SMA, Device Application of MSMA. | 4 hours<br><br>9 hours<br><br>9 hours<br><br>8 hours |
| **Pedagogy:** | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **References/ Readings** | 1. Ferroic Materials for Smart Systems: From fundamentals to device applications, Jian Dai, Wiley VCH (2020)<br>2. Introduction to Ferroic Materials, V. K. Wadhavan, Taylor & Francis (2000)<br>3. Ferroic Functional Materials: Experiment, Modeling and Simulation, JörgSchröder, Doru C. Lupascu, Springer (2018) | |
| **Learning Outcomes** | 1. Students will learn about different Ferroic phase transitions.<br>2. Students will gain knowledge about characteristics and applications of ferroelectric, ferromagnetic and ferroelastic materials. | |

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**Programme:**M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSG-506 **Title of the Course:** Nanoscience and Technology
**Number of Credits:** 2
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Basic knowledge of Solid-State Physics / Solid State Chemistry | |
| **Objective:** | This course is aimed at introducing different concepts of nanoscience and technology. It aims at presenting the recent developments in the field of nanomaterials including synthesis and characterization methods. | |
| **Content:** | **Introduction to Nanomaterials**<br>Introduction to Nanoscience, Physics and Chemistry of solid surfaces, Size effect on thermal, electrical, electronic, mechanical, optical and magnetic properties of nanomaterials- surface area and aspect ratio-band gap energy- quantum confinement size.Classifications of nanomaterials - Zero dimensional, one-dimensional and two-dimensional nanostructures- Kinetics in nanostructured materials-multilayer thin films and superlattice clusters of metals, semiconductors and nanocomposites. Nanoparticles through homogeneous and heterogeneous nucleation- Oswald ripening process | 7 hours |
| | **Synthesis of nanostructures**<br>Top down and bottom-up approaches–Mechanical alloying and mechanical ball milling Mechanical and chemical process, Inert gas condensation technique – Arc plasma and laser ablation. Sol gel processing-Solvothermal, hydrothermal, precipitation, Spray pyrolysis, Electro spraying and spin coating routes, Self-assembly, self-assembled monolayers (SAMs). Langmuir-Blodgett (LB) films, micro emulsion polymerization- templated synthesis, pulsed electrochemical deposition Vapor deposition and different types of epitaxial growth techniques (CVD, MOCVD, MBE, ALD)- pulsed laser deposition, Magnetron sputtering - lithography: Photo/UV/EB/FIB techniques, Dip pen nanolithography, Etching process: Dry and Wet etching, micro contact printing | 8 hours |
| | **Characterization tools in Nanoscience**<br>Optical microscopy: Use of polarized light microscopy – Phase contrast microscopy –Interference Microscopy – hot stage microscopy - surface morphology –<br>Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), HRTEM use in nanostructures. Atomic Force Microscopy (AFM) Scanning Force Microscopy-Shear force Microscopy-Lateral Force Microscopy-Magnetic Force microscopy.<br>Scanning Tunnelling Microscopy: Principle- Instrumentation-importance of STM for nanostructures – surface and molecular manipulation using STM -3D map of electronic structure. | 8 hours |
| | **Applications of Nanoscience** | |

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| | Nanomaterials for energy applications, Nanoelectronics, Nanomagnetism and devices, Nanophotonics, Surface plasmons, Nanobio applications, Environmental issues. | 7 hours |
| **Pedagogy:** | Lectures/ tutorials/ term papers/assignments/. Sessions shall be interactive in nature to enable peer group learning. | |
| **References/ Readings** | 1. Nanostructures &Nanomaterials: Synthesis, Properties & Applications G. Cao, Imperial College Press, 2004.<br>2. Textbook of Nanoscience and Nanotechnology, Murthy. B.S. Murty, P. Shankar, James Murday and Baldev Raj, University Press, Springer Berlin (2013)<br>3. Principles of nano-optics, L. Novotny and B. Hecht, Cambridge University Press, 2009.<br>4. Lithographic pattern formation via metastable state rare gas atomic beam, Nanotechnology, M. Baker et al., 15, 1356, 2004.<br>5. Fabrication of polymer photonic crystals using nanoimprint lithography, Helmut Schift, Sunggook Park, Bokyung Jung, Choon-Gi Choi, Chul-SikKee, Sang-Pil Han, Keun-Byoung Yoon and Jens Gobrecht, Nanotechnology 16, 261, 2005.<br>6. Nanolithography- Dip-Pen, R.D. Piner, Science 283, 661, 1999.<br>7. Surface plasmonsubwavelength optics,Barnes, W., Dereux, A. &Ebbesen, T., Nature 424, 825, (2003)<br>8. Surface Plasmons on Smooth and Rough Surfaces and on Gratings Heinz Raether, Springer Tracts in Modern Physics, Vol. 111, Springer Berlin 1988.<br>9. Plasmonics: Fundamentals and Applications, Stefan Maier, Springer 2007. | |
| **Learning Outcomes** | 1. Gain knowledge in Nanoscience and Nanotechnology<br>2. Understand various techniques in cutting-edge nanoscience<br>3. To be aware of recent advances in nanotechnology and its applications | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSG-507 **Title of the Course:** Laser physics and applications
**Number of Credits: 2**
**Effective from AY: 2023-24**

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| **Prerequisites for the course:** | Student should have basic knowledge of Atomic Physics. | |
| **Objective:** | 1. To develop understanding of construction and operation of different Laser systems.<br>2. To understand advances in laser physics and its Applications | |

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| **Content:** | **Introduction to lasers:**<br>Definition, brief history of Lasers, unique Properties of laser, coherence, fundamental wave and quantum properties of light, Laser Safety: Various hazards due to laser radiation-eye, skin, chemical etc., safety measures and standard ANSI<br>**Laser Amplifiers and Resonators:**<br>Conditions for producing a laser – population inversions,<br>Gain and gain saturation, Development and growth of laser beam, Requirements for obtaining population inversion, laser pumping requirements and techniques.<br>laser cavity modes: longitudinal and Transverse, Q switching, mode-locking, pulse shortening techniques, ultrashort - pulsed laser and amplifier system, Ring lasers, Cavities for producing spectral narrowing of laser output.<br>**Laser systems and their applications**<br>He -Ne laser, Ar ion laser, Molecular Gas lasers: $CO_2$ laser, Excimer lasers, Laser systems involving high-density gain media: Organic dye lasers, solid state lasers: Ruby laser, Nd-YAG and glass lasers.<br>Applications of lasers in materials engineering (cutting, welding, cladding, peening, surface engineering), communication, LIDAR, Medical Applications (dentistry, LASIK, laser lithotripsy, dermatology etc), Laser Cooling and Trapping of Atoms, Spectroscopic applications (RAMAN, LIBS). | 6 hours<br><br><br><br><br>8 hours<br><br><br><br><br><br><br><br><br>16hours |
| **Pedagogy:** | Lectures/ tutorials/laboratory work/project work/ vocational training/viva/ seminars/ term papers/assignments/ presentations/ self-study/ Case Studies etc. or a combination of some of these.<br>Sessions will be interactive in nature to enable peer group learning. | |
| **References/Readings** | 1. Laser Fundamentals, second edition William T. Silfvast, Cambridge publication, 2004<br>2. Laser Electronics, third edition, Joseph T. Verdeyen, Prentice Hall series, 1994.<br>3. Basics of laser physics, second edition, Karl F. Renk, Springer, 2012.<br>4. Laser Physics and application, Tarasov. L, Mir Publication, 1987.<br>5. Principles of Laser Plasmas, Bakefi, George, John Wiley & Sons Inc., 1977.<br>6. Laser application, William V. Smith, Artech House Publishers, 1970.<br>7. Lasers: Fundamentals and Applications (Graduate Texts in Physics), second edition, K. Thyagarajan, AjoyGhatak, Springer publication, 2012.<br>8. Laser application, Ross Monte, Academic press New York, 1974. | |
| **Learning Outcomes:** | 1. Student will understand the basic principle and operation of different types of Lasers.<br>2. Student will get exposure to applications of Lasers in different | |

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| | fields. | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSG-508 **Title of the Course:** Experimental Techniques in Physics
**Number of Credits:** 2
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Students enrolling for this course should have knowledge in basic mathematical concepts | |
| **Objective:** | This course introduces the concepts in experimental physics, instrumentation and error analysis | |
| **Content:** | **Data Interpretation and Error Analysis**<br>Data interpretation and analysis. Uncertainties, Statistical analysis of uncertainties, Precision and accuracy, Parent and Sample Distributions, Mean and Standard Deviation of Distributions, Binomial Distributions, Poisson Distribution, Gaussian or Normal Error Distribution, Lorentzian Distribution; Approximation and Errors in Computing: Significant Digits, Numerical Errors, Modelling errors, Conditioning and Stability, Convergence of Iterative Processes. Error analysis, propagation of errors. Least squares fitting, Linear and nonlinear curve fitting, chi-square test | 15 hours |
| | **Measurements and Instrumentation**<br>Transducers (temperature, pressure/vacuum, magneticfields, vibration, optical, and particle detectors), low current and voltage measurements, High and low temperature measurements, thermocouples, photoresistors, thermal and electronic conduction measurements, optical measurements, photon counting techniques, low and high magnetic field measurements, Measurement and control. Signal conditioning and recovery. Impedance matching, amplification (Op-amp based, instrumentation amp, feedback), filtering and noise reduction, shielding and grounding. Fourier transforms, lock-in detector, box-car integrator, modulation techniques. High frequency devices (including generators and detectors) | 15 hours |
| **Pedagogy:** | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **References/ Readings** | 1. Data Reduction and Error Analysis for the Physical Sciences 3rd Ed. by Philip R Bevington and D Keith Robinson, McGraw – Hill (2003)<br>2. An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements, 2nd Ed. John R. Taylor, University Science Books (1997)<br>3. Methods of Experimental Physics, M. I. Pergament, CRC Press (2019)<br>4. Experiments in Physics, R. Srinivasan, K. R. Priolkar and T. G. | |

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| | Ramesh, Indian Academy of Sciences (2018)<br>5. Practical Physics, G. L. Squires, 4th Edition, Cambridge University Press, (2015)<br>6. Introduction to Measurements and Instrumentation, A. K. Ghosh, PHI Learning Pvt. Ltd., (2012) | |
| **Learning Outcomes** | On completion of this course, students will be able to understand the basics concepts in measurement techniques, experimental physics and error analysis. | |

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**Programme:** M. Sc. (Physics)
**Course Code:** PHSG-509 **Title of the Course:** Documentation using Latex
**Number of Credits:** 1T + 1P
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Nil | |
| **Objective:** | This course provides an introduction to technical writing with Latex. | |
| **Content:** | **Introduction**<br>Introduction and Installation of the software LaTeX. Understanding Latex compilation.<br>**Module 1.**<br>Basic Syntax of Latex, Writing equations, Matrix, Tables<br>**Module 2.**<br>Page Layout – Titles, Abstract, Chapters, Sections, References, Equation references, citation. List-making environments, Table of contents, generating new commands, Figure handling, numbering, List of figures, List of tables, Generating index.<br>**Module 3.**<br>Packages: Geometry, Hyperref, amsmath, amssymb, algorithms, algorithmic graphic, color, tiles listing<br>**Model 4.**<br>Classes: article, book, report, beamer, slides.<br>**Module 5.**<br>Applications to:<br>Writing Resume<br>Writing question paper<br>Writing articles/ research papers<br>Presentation using beamer.<br>Preparing Poster. | 5 hours<br><br><br>6 hours<br><br><br>7 hours<br><br><br><br><br>6 hours<br><br><br>3 hours<br><br><br>18 hours |
| **Pedagogy:** | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **References/ Readings:** | 1. LaTeX in 24 Hours: A Practical Guide for Scientific Writing, DilipDatta, Springer, (2017).<br>2. LaTeX: A Document Preparation System, Leslie Lamport, Addison-Wesley Professional (1994).<br>3. The LaTeX Companion, 2nd edition (TTCT series), Frank | |

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| | Mittelbach, Michel Goossens, Johannes Braams, David Carlisle, Chris Rowley, Addison-Wesley Professional, 2004. | |
| **Learning Outcomes** | By the end of this course, the student will have acquired proficiency with LaTeX, as well as many powerful features of LaTeX which include:<br>1. Download and install a comprehensive LaTeX distribution.<br>2. Create basic types of LaTeX documents (article, report, letter, book).<br>3. Format words, lines, and paragraphs, design pages, create lists, tables, references, and figures in LaTeX.<br>4. Typeset complicated mathematics.<br>5. Import graphics,<br>6. Listing content and references<br>7. Develop large documents.<br>8. Create professional presentations using LaTeX. | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:**PHSG-510 **Title of the Course:** Astronomy and Astrophysics
**Number of Credits:**2
**Effective from AY:** 2023-24

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| **Prerequisites for thecourse:** | Should have basic knowledge of electromagnetic theory, classical mechanics, thermodynamics | |
| **Objective:** | The objective of this course is to develop an understanding of the scale, constituents, radiative process and stellar astronomy. A descriptive course includes the methods astronomy in different bands of electromagnetic radiation. | |
| **Content:** | **Fundamentals of Astrophysics**<br>Major contents of universe, Black body radiation, specific intensity, flux density, luminosity, Magnitudes, Color index, Color temperature, effective temperature, Brightness temperature, Excitation temperature, kinetic temperature, stellar atmospheres | 4 hours |
| | **Astronomical Scales and techniques**<br>Units of measurement, celestial coordinates, precession, Mass, length and time scales in Astrophysics, Parallax method. Standard Candle method. Cepheid variable method. RedShift. | 5 hours |
| | **Astronomy in different bands of electromagnetic radiation**<br>Electromagnetic radiation, Optical astronomy , Radio astronomy , Infrared, UV and X-ray astronomy. | 5 hours |
| | **Radiative Processes**<br>Basics of theory of radiation field, radiation transfer equation, thermal radiation, radiative diffusion, basics of radiative transfer, elementary stellar atmospheres, relativistic electrodynamics, emission of electromagnetic radiation, scattering, Brehmstrahlung, synchrotron radiation, inverse-Compton process, plasma effects. | 6 hours |
| | **Stellar Physics** | |

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| | Electromagnetic spectrum, spectral classification of stars, HR diagram, stellar opacities, Energy Generation in Stars: Calculation of thermonuclear reaction rates, the various reaction chains: PP chain and CNO cycle, He-burning, C-burning, Si-burning, photo-dissociation, neutrino emission from stars, Chandrashekhar limit.<br>**Physics of Compact Objects**<br>Properties of black holes, white dwarfs, and neutron stars, formation of compact objects, equilibrium configurations, equations of state, stability criteria, and mass limits, the influence of rotation and magnetic fields, pulsar phenomena, black hole spacetimes, Hawking radiation, mass flow in binary systems, spherical and disk accretion, high-temperature radiation processes, pulsar spin-up, compact x-ray sources and x-ray bursts, supermassive black holes in star clusters and galactic nuclei, gravitational and neutrino radiation from supernova collapse and binary coalescence. | 5 hours<br><br>5 hours |
| **Pedagogy**: | Lectures / tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning. | |
| **References/ Readings** | 1. Radiative Processes in Astrophysics,Rybicki, G.B., &Lightman, A.P., John Wiley, 1985.<br>2. Astronomy Principles and Practice,Roy, A.E., & Clarke, D., 4th ed., Institute of Physics, 2003.<br>3. Astrophysics for Physicist, A R Choudhuri, Cambridge press,2010<br>4. The Structure of the Universe, J.V. Narlikar, Oxford University Press, 1977 | |
| **Learning Outcomes** | On completion of this course, the students will get necessary foundation in astronomy and astrophysics that will prepare them for the advanced study in Astrophysics. | |

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**Programme:** M. Sc. (Physics) (Computational Physics)
**Course Code:** PHCG-502 **Title of the Course:** BEC and Superfluidity
**Number of Credits:** 2
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Should have basic knowledge of electrodynamics, thermodynamics and quantum mechanics, and solid-state physics | |
| **Objective:** | To introduce up-to-date experimental and theoretical progress in BEC and superfluidity. | |

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| **Content:** | **Superfluid Helium-4**<br>Introduction, Classical and quantum fluids, the macroscopic wave function, Superfluid properties of He II, Flow quantization and vortices, the momentum distribution, quasiparticle excitations.<br>**Superfluid Helium-3**<br>Introduction, The Fermi liquid normal state of He-3, the pairing interaction in liquid He-3, Superfluid phases of He-3.<br>**Bose-Einstein Condensates-Theory**<br>Ultracold atomic gases. Bose-Einstein condensation in an ideal gas. Interacting Bose-Einstein condensates. Dynamics of Bose-Einstein condensates. Elementary excitations. Bose-Einstein condensates at finite temperatures. Two-dimensional Bose gases. Quantum vortices in Bose-condensed gases. True and quasi condensates in one-dimensional trapped gases. Solitons in 1D Bose-condensed gases. Strongly interacting 1D Bose gases. Rapidly rotating Bose gases.<br>**Bose-Einstein Condensate-: Experiment**<br>Ultracold quantum gases: What? Why? How? Atom-laser interaction, Bloch sphere Dressed state picture, Optical Bloch equations Light forces, Molasses cooling, Sisyphus cooling<br>Atomic beam oven, Zeeman slower, Magneto-optical trap<br>Optical dipole trap, Magnetic trap, Technology, Evaporative cooling, Characterizing a BEC. | 8 hours<br><br><br><br>5 hours<br><br><br>10 hours<br><br><br><br><br><br><br><br><br>7 hours |
| **Pedagogy:** | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **References/ Readings** | 1. Superconductivity, Superfluids and Condensates James F. Annett, Oxford Series in Condensed Matter Physics (2004).<br>2. Statistical Mechanics, R.P. Feynman, Westview Press, (1972).<br>3. Statistical Mechanics, K. Huang, Wiley Eastern Limited, (1988).<br>4. Theory of quantum liquids, Ph. Nozieres and D. Pines, , Vol II, CRC. (2019).<br>5. Bose-Einstein condensation, S. Stringari and L. Pitaevskii, Clarendon Press, (2003).<br>6. Bose-Einstein condensation in dilute gases, C.J. Pethick and H. Smith, Cambridge University Press, (2011).<br>7. Laser Cooling and Trapping, H. J. Metcalf and P. van der Straten, Springer (1999).<br>8. Making an ultracold gas, D. Jervis and J. H. Thywissen, arXiv:1401.7659, (2014). | |
| **Learning Outcomes** | Students will be able to understand the basics of superfluidity, BEC, and different laser cooling and trapping techniques to create and characterize ultracold quantum gases in the lab. | |

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**Programme:** M. Sc. (Physics) (Computational Physics)

**Course Code:** PHCG-503 **Title of the Course:** Introduction to Quantum Information

and Computing
**Number of Credits: 2**
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Basic knowledge of Quantum mechanics. | |
| **Objective:** | This course provides an introduction to the theory and practice of quantum computation. | |
| **Content:** | **Introduction**<br>Need of Quantum Computing, Postulates of Quantum Mechanics, Qubits, Bloch sphere representation, Multiple Qubit States, Quantum Gates, and Quantum Circuits.<br>**Quantum measurement and communication protocols**<br>No-Cloning Theorem and Quantum Teleportation, Super Dense Coding, Density Matrix, Bloch Sphere, Measurement Postulates.<br>**Quantum Algorithms**<br>Deutsch Algorithm, Simon Problem. Grover's Search Algorithm, Grover's Search Algorithm, Quantum Fourier Transform, Shor's Factorization Algorithm.<br>**Quantum Information theory**<br>Classical Information Theory, Shannon Entropy, Shannon's Noiseless Coding Theorem, Von Neumann Entropy, EPR and Bell's Inequalities, Cryptography and RSA Algorithm, Quantum Cryptography<br>**Quantum error correction and experimental aspects**<br>Quantum error correction, Experimental Aspects of Quantum Computing. | 8 hours<br>5 hours<br>7 hours<br>7 hours<br>3 hours |
| **Pedagogy**: | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **References/ Readings:** | 1. Quantum Computation and Information, Michael A. Nielsen and Issac L. Chuang, Cambridge University Press (2002).<br>2. Quantum Computing, Mikio Nakahara and Tetsuo Ohmi, CRC Press (2008).<br>3. Quantum Computer Science, N. David Mermin, Cambridge University Press (2007)<br>4. Quantum Information theory, Mark M. Wilde, Cambridge University Press (2017)<br>5. Introduction to Quantum Computation and Information H.-K.Lo, T. Spiller, S. Popescu, World Scientific, (1998).<br>6. Principles of Quantum Computation and Information. G. Benenti, G. Casati, G. Strini, World Scientific (2004). | |
| **Learning Outcomes** | 1. Students will be able to understand basic quantum gates, circuits, and algorithms.<br>2. Students will be able to understand the basics of Quantum Information Theory and the importance of Quantum error correction. | |

**Programme:** M. Sc. (Physics)
**CourseCode:**PHCG-504 **Title of the Course:** Introduction to ParticlePhysics
**Number of Credits:** 2
**Effective from AY:** 2023-24

| | | |
|---|---|---|
| **Prerequisites for the course:** | Basic knowledge of Quantum Mechanics | |
| **Objective:** | To introduce students the fundamental principles and concepts in particle physics and particle accelerators | |
| **Content:** | **Introduction to Elementary Particles:**<br>Historical introduction, Mesons, Baryons, antiparticles, neutrinos, strange particles,<br>The eightfold way and the quark model | 4 hours |
| | **Cross-section and decay rates:**<br>Cross-sections, decay rates, resonances, Breit-Wigner formula | 3 hours |
| | **Relativistics Kinematics:**<br>Lorentz Transformations and Four-vectors<br>Energy and Momentum conservations<br>Classical and Relativistic Collisions, examples andapplications | 5 hours |
| | **Elementary Particle Dynamics:**<br>Introduction to Feynman diagrams and four forces<br>Quantum Electrodynamics (QED), Quantum Chromodynamics (QCD), and Weak interactions<br>Weak and Electromagnetic couplings of W and Z<br>Decays and conservationlaw, and unificationschemes. **Symmetries** | 7 hours |
| | Symmetries, groups, and conservation Laws<br>Angular momentum and addition of angular momenta<br>Flavor Symmetries, Discrete Symmetries, Parity, Charge Conjugation and CP symmetries<br>Neutral Kaons, CP Violation and Time Reversal and the TCP Theorem | 7 hours |
| | **Particle accelerators:**<br>Introduction to modern accelerators LHC at CERN and and RHIC and BNL, event rates and luminosity. Large detector systems at electron-positron, electron-proton and hadron colliders. | 4 hours |
| **Pedagogy:** | Lectures/tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning. | |

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| **References/ Readings** | 1. Introduction to Elementary Particles by David Griffiths, Wiley (2008)<br>2. Modern Particle Physics by M. Thomson, Cambridge University Press India (2016)<br>3. Quarks and Leptons, by F. Halzen and A. D. Martin, John Wiley (1984) | |
| **Learning Outcomes** | Student will be able to<br>1. Classify elementary particles and fundamental forces, draw Feynman diagrams for reactions.<br>2. Learn particles states and their quantum numbers, conservation laws, and symmetries in nature.<br>3. Learn modern particle accelerators and its working | |

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**Programme:** M.Sc (Physics)(Biophysics)
**Course Code:** PHBG-502 **Title of the Course:** Solid state and Biomaterials
**Number of Credits: 4**
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | None | |
| **Objective:** | This course is intended to introduce the concepts in biomaterials. The students will have a good understanding of the different bio materials and their properties. A brief introduction to new and advanced materials for biological applications will also be covered in the course. | |
| **Content:** | **Introduction to Solid State**<br>Crystal structure, Crystal Binding, Phase changes, crystal imperfections, defects and dislocations, non-crystalline solids, surface energy, contact angle, surface tension, Types of materials-ceramics, metals, semiconductors, polymers, composites, Impact of biomaterials | 15 hours |
| | **Properties of Materials**<br>Mechanical properties-elasticity, stress, strain, tensile strength, plastic deformation, hardness, thermal properties, optical properties, | 15 hours |
| | **Biomaterials I**<br>Introduction to biomaterials, property requirements for biomaterials, concept of biocompatibility, structure of cells and biological tissues, cell material interaction and response to foreign bodies, histocompatibility, genotoxicity. | 15 hours |
| | **Biomaterials II**<br>Important biometallic alloys: Ti-based, stainless steels,<br>Co-Cr-Mo alloys, Nitinol, Tantalum and magnesium, Bioinert, Bioactive and bioresorbable ceramics, Processing and properties of different bioceramic materials silicates, aluminates, Zirconia, hydroxyapatite tricalciumphosphatecalciumsulfate, bioactive glasses, Synthesis of biocompatible coatings on structural implant materials, | 15 hours |

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| | Microstructure and properties of glass-ceramics, common biocompatible polymers and their properties, biodegradable polymers, Natural biomaterials, design concept of developing new materials for bioimplant applications, Nanobiomaterials | |
| **Pedagogy:** | Lectures/Tutorials/Assignments<br>Sessions shall be interactive in nature to enable peer group learning. | |
| **References/ Readings** | 1. Biomaterials Science: An introduction to Materials in Medicine, Edited by Ratner, Hoffman, Schoet and Lemons, Third Edition, Elsevier Academic Press (2012).<br>2. Introduction to Biomaterials: Basic Theory with Engineering Applications, MauliAgrawal, Ong, Appleford and G. Mani, First Edition, Cambridge Press, (2013).<br>3. Biomaterials Science and Biocompatability, Fredrick H. Silver and David L. Christiansen, Piscataway, First Edition, Springer (1999).<br>4. Biomaterials: An Introduction, John B Park and Roderik S Lakes, Third Edition, Springer, (2007).<br>5. Nanobiomaterials: Classification, Fabrication and Biomedical Applications, Ed: Wang, M. Ramalingam, X. Kong L. Zhao, First Edition, Wiley (2018).<br>6. Nanobiomaterials, Roger Narayan, First Edition, Elsevier (2017). | |
| **Learning Outcomes:** | 1. The students will be familiarized with the basic types of biomaterials and their properties.<br>2. The students will have gained sufficient knowledge in the biomaterials and their applications.<br>3. The students will be exposed to the recent developments in biomaterial engineering and nanobiomaterials. | |

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**Programme:** M. Sc. (Physics)(Solid State Physics)
**Course Code:** PHSR-503 **Title of the Course:** X-ray Spectroscopy
**Number of Credits: 2**
**Effective from AY:** 2023-24

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| **Prerequisites for thecourse:** | Basic knowledge of Solid State Physics/Chemistry and Electromagnetic waves | |
| **Objective:** | To introduce students to various techniques in x-ray spectroscopy and their applications to condensed matter physics, chemistry and material science. | |

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| **Content:** | **X-rays: Sources and Interaction with matter**<br>X-rays: Waves and photons, Scattering, Absorption, Refraction and Reflection.<br>X-ray tubes, Synchrotron radiation, Bending magnet sources, Undulator radiation, Wiggler radiation. X-ray detection<br>**Scattering of X-Rays**<br>Scattering from an electron, scattering from an atom, scattering from a molecule, scattering from liquids and glasses, small angle x-ray scattering, scattering from a crystal, Debye-Waller factor, measured intensity from a crystallite.<br>**X-ray Absorption**<br>Absorption coefficient, absorption edge, Definition: x- ray absorption fine structure (XAFS), x-ray absorption near edge structure (XANES), extended x-ray absorption fine structure (EXAFS), History, Theory of XAFS, XAFS Experiment, Beamline and optics, Data acquisition, treatment and modelling, XANES as fingerprint technique, x-ray magnetic circular dichroism.<br>**Photoelectron Spectroscopy**<br>Photoelectric Effect, history of x-ray photoelectron spectroscopy (XPS), theoretical model – three step model, instrumentation, the electron mean free path, Auger electrons, core level binding energies in atoms, molecules and solids, final state effects, valence band in solids, band structure, angle resolved photoelectron spectroscopy (ARPES). | 6 hours<br><br><br><br><br>8 hours<br><br><br><br><br>8 hours<br><br><br><br><br><br><br>8 hours |
| **Pedagogy:** | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **References/ Readings** | 1. Elements of Modern X-ray Physics, Jens Als-Nielsen and Des Mc Morrow, 2nd Edition, Wiley 2011.<br>2. Elements of X-ray Diffraction, B.D.Cullity and S. R. Stock, 3rd edition,Pearson Education, 2014.<br>3. Introduction to XAFS, Grant Bunker, Cambridge University Press, 2010.<br>4. Photoelectron Spectroscopy, Principles and Applications, Stefan Hufner, Springer 2003. | |
| **Learning Outcomes** | 1. Student will gain knowledge about characteristics of different X-ray sources, especially synchrotron radiation sources;<br>2. Students will understand the principles, experimental equipment, basic data analysis methods with respect to X-ray diffraction (XRD), X-ray photoemission and X-ray absorption spectroscopy,<br>3. Student will understand the kind of structural information obtained from the three x-ray spectroscopic methods. | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSR-504 **Title of the Course:** Optical Spectroscopy
**Number of Credits:** 2

**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Should have studied courses in classical mechanics, electromagnetism, elementary quantum mechanics and nuclear physics. | |
| **Objective:** | To introduce different optical spectroscopic techniques that can be used for characterization of materials, especially in condensed matter. | |
| **Content:** | **Electronic Spectroscopy**<br>One-electron and two-electron atoms: spectrum of hydrogen, helium and alkali atoms; Many electron atoms: Hund's rule, L-S and j-j coupling, Spectroscopic terms, Lande interval rule; Interaction with Electromagnetic fields: Zeeman, Paschen Back and Stark effects, electron spin resonance spectroscopy, Hyperfine structure and isotope shift, selection rules; Lamb shift, Electromagnetic radiation, Absorption and Emission of radiation, Line width and its broadening mechanisms, Spontaneous and stimulated emissions, Einstein coefficients, Introduction to lasers and laser spectroscopy<br><br>**Molecular Spectroscopy**<br>Microwave spectroscopy, Infrared spectroscopy, the vibrating diatomic molecule – simple harmonic oscillator, the anharmonic oscillator, the diatomic vibrating rotator, Interaction of rotation and vibrations, the vibrations of polyatomic molecules, Raman spectroscopy– Electronic spectra of diatomic molecules – Born-Oppenheimer approximation, vibrational coarse structure – progressions. Intensity of vibrational transitions – the Franck-Condon principle. Optical absorption: Free carrier absorption-optical transition between bands-direct, and indirect-excitons, Luminescence in crystal - excitation and emission - decay mechanism, Fluorescence, Phosphorescence, Crystal Field Theory, Spectroscopy of transition metals complexes, Fluorescence spectroscopy, Introduction to time-resolved spectroscopy | 15 hours<br><br>15 hours |
| **Pedagogy**: | Lectures/ tutorials/seminars/ term papers/assignments/ presentations/ self-study. Sessions shall be interactive in nature to enable peer group learning. | |
| **References/Readings** | 1. Physics of Atoms and Molecules, B. H. Bransden and C. J. Joachain,2$^{nd}$ Edition, Pearson; 2008.<br>2. Fundamentals of Molecular Spectroscopy, C. N. Banwell and E. M. McCash, 4$^{th}$ Edition, Tata McGraw, 2004<br>3. Introduction to Atomic Spectra, H. E. White, Tata McGraw Hill, 1934.<br>4. Lasers Theory and Applications, K. Thayagarajan and A.K Ghatak, Macmillan (Tata McGraw Hill) 1995. | |

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| | 5. Handbook of Molecular Spectroscopy, D. SatyanarayanaInternational Publishing House, 2015, 1st edition<br>6. Solid State Luminescence,A. H. Kitai, Chapman and Hall London; 1993.<br>7. Luminescence of Solids edited by D. R. Vij, Plenum Press, New York, 1998. | |
| **Learning Outcomes** | 1. Understand different optical spectroscopic techniques<br>2. Better understanding of atomic and molecular physics<br>3. Apply the techniques in experimental characterisation of materials. | |

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**Programme:**M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSR-505
**Title of the Course:** Nuclear Spectroscopy for Condensed Matter
**Number of Credits:** 2
**Effective from AY:** 2022-23

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| **Prerequisites for the course** | Should have studied classical mechanics, electromagnetism, elementary quantum mechanics and nuclear physics. | |
| **Objectives** | To introduce the concept of methods that uses properties of a nucleus to probe material properties | |
| **Content** | **Properties of a nucleus:**<br>Nuclear magnetic dipole moment, nuclear electric dipole moment, nuclear decays, magnetic and electric hyperfine interactions<br>**Nuclear Magnetic Resonance (NMR) Spectroscopy:**<br>Principles, classical treatment of NMR (Bloch equations), quantum theory of NMR, experimental methods, Chemical shift, Knight shift in metals, spin-lattice relaxation, spin-spin relaxation, applications.<br>**Mossbauer Spectroscopy:**<br>Principles, The Debye-Waller Factor, Mossbauer Sources and Experimental Apparatus, Isomer Shifts, Electric quadrupole interaction, Magnetic Dipole Interaction, Quadratic Doppler effect, Results from Mossbauer spectroscopy.<br>**Neutron Scattering:**<br>Neutrons and Neutron Sources, neutron spectrometer and detectors, the process of neutron scattering, response function and correlation function for inelastic neutron scattering, results from neutron scattering.<br>**muon spin rotation (μSR) spectroscopy:**<br>Muons and muon spin rotation, influence of internal fields, results from μSR<br>**Positron annihilation spectroscopy (PAS):**<br>Positrons in solids, positron sources and spectrometers, results from PAS | 4 hours<br><br>6 hours<br><br>6 hours<br><br>6 hours<br><br>4 hours<br><br>4 hours |
| **Pedagogy** | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |

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| **Reference/Readings** | **Text Books/References:**<br>1. Nuclear condensed matter physics: nuclear methods and applications, G. Schatz and A. Weidinger, John Wiley; 1997.<br>2. Solid-state spectroscopy, H. Kuzmany, Springer, 1998.<br>3. Concepts of Modern Physics, A. Beiser, McGraw Hill Education, $6^{th}$ Edition, 2003<br>4. Methods in Physical Chemistry, R. Schafer and P. C. Schmidt, Wiley-VCH Verlag GmbH & Co. 2012 | |
| **Learning Outcomes** | Student will be known with<br>1. NMR, Mossbauer, neutron scattering, μSR, and PAS spectroscopic techniques<br>2. Apply the techniques in experimental characterization of materials. | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSR-506
**Title of the Course:** Introduction to Crystallography and X-ray Diffraction
**Number of Credits:** 2
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Basic knowledge of Solid State Physics / Solid State Chemistry | |
| **Objective:** | This course is designed to familiarize students with general aspects of symmetry, crystal structure and X-ray diffraction and use the basic understanding in the characterization of materials. | |
| **Content:** | **Introduction to Symmetry and Crystal Structures**<br>Symmetry elements and their operations, Unit cell and crystal systems, Bravais lattice, Point groups and space groups and their stereographic representations, Herrmann-Mauguin and Schoenflies notations, Group-subgroup-supergroup relationships, Equivalent points, General and special positions, Deriving general positions of space groups, Wyckoff notations and site symmetry, Shifting of origin in lattice, Crystal directions and planes, Miller indices, Real space vs reciprocal lattice, Close packed structures, Octahedral and tetrahedral sites, Asymmetric unit, Concept of Z and Z′, Metric matrix, Deriving bond length and bond angles, Introduction to quasicrystals and their importance | 7 hours |
| | **X-ray Scattering and Structure Factors**<br>White and Characteristic X-rays, Laboratory and synchrotron X-ray sources and their properties, Coherent and incoherent scattering, Scattering of X-rays by an electron, atom and crystal, Atomic scattering factor, Structure factor, Fourier transform, Electron density, Laue's equations, Bragg's law, Ewald's sphere, Limiting sphere and reflecting sphere, Bragg's law in reciprocal space, Systematic absences, Deriving conditions for systematic absences, Phase problem in crystallography, Solution to the phase problem, Direct method, Patterson method, $\nabla F$ synthesis, L-P corrections, Temperature factors, Absorption and extinction of X-rays, Friedel's | 8 hours |

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| | law and Absolute configuration determination, Anomalous scattering, Laue method, X-ray detectors<br>**Single Crystal X-ray Diffraction (SCXRD)**<br>Pros and cons of single crystal and powder X-ray diffraction, Single crystal growth and selection, Indexing of crystals, Data collection, Data reduction, Space group determination, Structure solution and refinement, Parameters/constraints/restraints, Anisotropic displacement parameters (ADPs), Reliable (R) factor, Twining, Treatment of disordered structures, Introduction structure refinement software: OLEX2 and WinGX, Crystal structure analysis, CIF preparation, Validation of structures,<br>Examples: X-ray data of aspirin and $KHSO_4$<br>**Powder X-ray Diffraction (PXRD)**<br>Importance of PXRD method, Background of methodology, Geometrical basis of PXRD, Sample preparation, background noise determination, Indexing powder pattern, Le-bail profile fitting, Rietveld refinement, phase identification and quantification, Crystallite size and strain determination, Example: PXRD of $CeO_2$<br>**Total X-ray Scattering and Pair Distribution Function (PDF)**<br>Short- and long-range order, Bragg and diffuse scattering concepts, atomic scattering amplitude, Debye's scattering intensity, Total scattering structure function, atomic PDF, Structure and reaction mechanism, Examples: Ni and $WO_3$ nanoparticles | 5 hours<br><br>5 hours<br><br>5 hours |
| **Pedagogy:** | Lectures/tutorials/term papers/assignments/presentations/self-study | |
| **References/ Readings** | 1. Fundamentals of Crystallography, C. Giacovazzo, Oxford Science Publications, 2011.<br>2. X-ray Structure Determination: A Practical Guide, G. H. Stout and L. H. Jensen, John Wiley and Sons, New York, 1989.<br>3. Elements of X-ray Diffraction, B.D.Cullity and S. R. Stock, 3rd edition,Pearson Education, 2014.<br>4. The Basics of Crystallography and Diffraction, C. Hammond, Oxford Science Publications, 2015.<br>5. Jens Als-Nielsen and Des Mc Morrow, Elements of Modern X-ray Physics, 2nd Edition, Wiley 2011.<br>6. Crystal Structure Determination, W. Massa, Springer, 2000.<br>7. The Rietveld Method, R. A. Young, Oxford University Press, 1993.<br>8. Underneath the Bragg Peaks: Structural Analysis of Complex Materials, T. Egami and S. J. L. Billinge, Pergamon Materials Series, Volume 16, 2012 | |
| **Learning Outcomes:** | 1. The student is expected to acquire basic understanding of crystallography and X-ray diffraction in the solid state.<br>2. Have basic knowledge of single crystal, powder X-ray diffraction and PDF methods.<br>3. Able to use X-ray scattering methods as an experimental tool for materials characterization. | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSR-507**Title of the Course:** Magnetism in Condensed Matter Physics
**Number of Credits: 2**
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Basic knowledge of Solid-State Physics / Solid State Chemistry | |
| **Objective:** | This course is designed to familiarize students with general and specific aspects of magnetic interaction in condensed matter and methods of magnetic measurements. | |
| **Content:** | **Magnetic structures and interactions**<br>Diamagnetism, Paramagnetism, Ferromagnetism, Antiferromagnetism, Effect of magnetic field, Ferrimagnetism, Dipolar interactions, Exchange interactions – origin, direct and indirect exchange, Indirect exchange in ionic solids, indirect exchange in metals, Double exchange, Anisotropic exchange<br>**Measurement of magnetic order**<br>Magnetic fields, Atomic scale magnetism, Domain scale measurements, Bulk magnetism measurements – magnetization and magnetic susceptibility, Neutron scattering, other techniques<br>**Order and broken symmetry**<br>Broken symmetry, Landau theory of ferromagnetism, Heisenber and Ising models (1D and 2D), Consequences of broken symmetry, Phase transitions, Rigidity, Excitations – magnons, Domains, Domain walls, Magnetocrystalline anisotropy, Domain wall width, Magnetization process, Observation of domain wall, small magnetic particles, Stoner-Wohlfarth model, Soft and hard materials<br>**Magnetism in metals**<br>Pauli paramagnetism, spontaneously spin-split bands, spin- density functional theory, Landau levels, Landau diamagnetism<br>**Competing interactions and low dimensionality**<br>Frustration, Spin glasses, Superparamagnetism, One dimensional and two-dimensional magnets – spin chains, Spinons Haldane chains, Spin-Peierls transitions, spin ladders, Magnetoresistance, Magneto-optics | 11 hours<br><br><br><br><br><br>4 hours<br><br><br><br><br>8 hours<br><br><br><br><br><br><br><br>3 hours<br><br><br>4 hours |
| **Pedagogy:** | Lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **References/Readings** | 1. Magnetism in Condensed Matter, Stephen Blundell,Oxford University Press 2001.<br>2. Magnetism and magnetic materials, J. M. D. Coey, Cambridge University Press, 2010.<br>3. Theory of Magnetism, D. C. Mattis, Springer Verlag, 1981. | |
| **Learning Outcomes** | 1. The student is expected to acquire basic understanding of Magnetism and magnetic interactions in solids.<br>2. Distinguish between different types of magnetic order and magnetically frustrated states. | |

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| | 3. Have basic knowledge of different experimental methods of measuring magnetization at bulk, domain size and atomic level. | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSR-508
**Title of the Course:** Microscopy Techniques for Condensed Matter
**Number of Credits:** 2
**Effective from AY:** 2023-24

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| **Prerequisites for the course** | Basic knowledge of Solid State Physics, | |
| **Objectives** | Student will be able to gain knowledge about working principle, instrumentation, material imaging and data analysis using imaging techniques such as Transmission electron microscopy, scanning electron microscopy and scanning probe microscopy. | |
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| **Content** | **Transmission Electron Microscopy (TEM)**<br>Interaction of electrons with matter, elastic and inelastic scattering, secondary effects, Instrumentation: Electron sources, pumps and holders, lenses, apertures, and resolution, Diffraction in TEM: Selected area diffraction, specimen preparation, Imaging and interpretation.<br>**Scanning Electron Microscopy (SEM)**<br>Electron beam -specimen interaction, Backscattered electrons, Secondary electrons, SEM instrumentation, specimen preparation, Image formation and interpretation, Image defects, data analysis using Image J, Energy Dispersive Spectroscopy (EDS).<br>**Scanning Probe Microscopy (SPM)**<br>Introduction, principle, Atomic Force Microscope instrumentation (AFM), Forces Between Tip and Sample, Technical Aspects of Atomic Force Microscopy, Calibration of AFM Measurements, Static Atomic Force Microscopy, Amplitude Modulation (AM) Mode in Dynamic Atomic<br>Force Microscopy, Intermittent Contact Mode/Tapping Mode, Frequency Modulation (FM) Mode in Dynamic Atomic Force Microscopy—Non-contact Atomic Force Microscopy, AFM image artefacts, Applications of AFM, Scanning Tunnelling Microscopy (STM): Overview, Experimental Realization of Spectroscopy with STM, Normalized Differential Conductance, Relation Between Differential Conductance and the Density of States, Asymmetry in the Tunnelling Spectra, Energy Resolution in Scanning Tunneling Spectroscopy, Barrier Height Spectroscopy, Spectroscopic Imaging with examples, Vibrational Spectroscopy with the STM, Principles of Inelastic Tunneling Spectroscopy<br>with the STM, Examples of Vibrational Spectra Obtained with the STM | 10 Hours<br><br><br><br><br><br>10Hours<br><br><br><br><br>10Hours |

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| **References** | 1. Transmission Electron Microscopy-A Textbook for Materials Science, David B. Williams and C. Barry Carter, Springer US, 2nd edition, 2009.<br>2. Scanning Electron Microscopy and X-Ray Microanalysis, Joseph I. Goldstein, Dale E. Newbury, Joseph R. Michael, Nicholas W.M. Ritchie, John Henry J. Scott, David C. Joy, Fourth Edition, Springer<br>3. Atomic Force Microscopy, Peter Eaton, Oxford University Press, 2010<br>4. Scanning Probe Microscopy: Atomic Force Microscopy and Scanning Tunneling Microscopy, Nano Science and Technology, Bert Voigtlander, Springer, 2015,<br>5. Introduction to Scanning Tunnelling Microscopy, C. Julian Chan, Second Edition, Oxford Science Publication, 2007<br>6. Transmission electron microscopy of metals, Thomas G., John Wiley, 1996. | |
| **Learning Outcomes:** | 1. The student will be able to understand basic principle, working, data capture and data analysis of TEM, SEM and SPM.<br>2. The student will also gain knowledge about applications TEM, SEM and SPM | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSR-509 **Title of the Course:** Thin film Physics
**Number of Credits: 2**
**Effective from AY:** 2023-24

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| **Prerequisites for thecourse:** | Basic knowledge of concepts in physics, chemistry, electrochemistry and experimental techniques. | |
| **Objective:** | To introduce various types of thin films techniques, growth mechanisms and their applications. | |
| **Content:** | **Introduction to Thin Films**<br>Definition of thin films, Comparison of thin and thick films, Theory of growth of thin films: Nucleation, condensation, Capillarity model, Atomistic model, comparison of models, various stages of film growth.<br>**Physical, Electrochemical, Chemical Deposition Techniques**<br>Overview of vacuum techniques, physical vapour deposition, chemical vapour deposition, molecular beam epitaxy, sputtering, electron –beam deposition, pulsed laser ablation.<br>Electrodeposition: deposition mechanism and preparation of compound thin film, anodization, chemical bath deposition, successive ionic layer adsorption reaction method (SILAR) method<br>Spray pyrolysis: deposition mechanism and preparation of compound thin films, sol-gel method, hydrothermal method.<br>**Characterization of Thin Films** | 4 hours<br><br><br><br><br>8 hours<br><br><br><br><br><br><br><br><br><br>10 hours |

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| | Thickness measurement - Tolansky technique, Talystep (styles) method, Quartz crystal microbalance, Stress measurement by optical method, Gravimetric method.<br>Influence of thickness on the resistivity of thin films, Hall Effect & Magneto-resistance in thin films, Fuch-Sondhemir theory, TCR and its effects.<br>Mechanical properties: Contact angle (hydrophobicity and hydrophillicity), Adhesion and its measurement with mechanical and nucleation methods, stress measurement by using optical method.<br>Structural characterization: X-ray diffraction (GI-XRD)<br>**Emerging Thin Film Materials and Applications**<br>Patterning techniques (Photolithography), Diamond Films, Thin film resistors, capacitors, Junction devices (Diodes, Transistors, Solar cells), ICs, Thin film sensors (gas and humidity), Thin films for information storage (Magnetic and optical recording), Metallurgical applications, Photo thermal converters, Optical coatings, Electro acoustics and telecommunication | 8 hours |
| **Pedagogy:** | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **References/ Readings** | 1. Hand book of Thin Film Technology, Maissel and Glang, (McGraw Hill) 1970.<br>2. Thin Film Phenomena, K. L. Chopra (McGraw Hill), 1969.<br>3. Material Science of Thin Films, M. Ohring (Academic Press), 2nd edition, 2001.<br>4. Thin Film Process, J. L. Vossen and Kern (Academic Press) 1st edition, 1991<br>5. Vacuum Technology, A. Roth, 3rd updated and revised edition, (North Holland), 1990<br>6. Properties of Thin Films, Joy George, 1st edition (Marcel and Decker), 1992<br>7. Handbook of semiconductor electrodeposition, R.K. Pandey, S.N. Sahu, S. Chandra, Marcel Dekker, 1996. | |
| **Learning Outcomes** | 5. Students will learn about different thin film techniques and growth mechanism involved.<br>6. Students will gain knowledge about characteristics and applications of thin film materials in various fields. | |

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**Programme:** M. Sc. (Physics) (Solid State Physics)
**Course Code:** PHSR-510 **Title of the Course:** Physics of Glasses
**Number of Credits: 2**
**Effective from AY:** 2023-24

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| **Prerequisites for thecourse:** | Should have basic knowledge of Solid-state Physics, Thermodynamic and statistical mechanics | |

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| **Objective:** | To introduce students to the Physics governing amorphous materials. The course includes the preparation of amorphous materials, kinetics and their characterization methods. | |
| **Content:** | **Amorphous materials**<br>Introduction, Definition, difference between crystalline and amorphous materials, properties of amorphous materials, Examples of amorphous materials, Methods of preparation of amorphous materials.<br>**Glasses**<br>Historical perspective of glass, Types of glasses. Refractive index, color, density, porosity, transparency, viscosity<br>**The Glass transition**<br>The glass transition-change in volume with temperature, glass formation vs crystallization, Thermodynamic phase transition, Entropy, Relaxation, Factors determining glass transition temperature, Theory of glass transition, kinetics of glass formation,<br>**Structure of glass**<br>Network former, network modifier, Intermediates, Structure and topology, Zachariasen random Network theory, coordination number, radial distribution function, structural modelling<br>**Experimental techniques**<br>Microscopy, X-ray diffraction, small angle scattering, vibrational spectroscopy, Raman spectroscopy, Thermal analysis. | 5 hours<br><br><br><br><br>3 hours<br><br><br>8 Hours<br><br><br><br><br><br>9 hours<br><br><br><br><br>5 hours |
| **Pedagogy:** | Lectures / tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning. | |
| **References/ Readings** | 1. Physics of Amorphous materials, S R Elliott, Longman, Harlow, 1990<br>2. The Physics of Amorphous materials, Richard Zallen, Wiley VCH, 2004.<br>3. Elements of X-ray Diffraction, B.D.Cullity and S. R. Stock, 3rd edition, Pearson Education, 2014.Introduction to the Theory of Thermal Neutron Scattering, G. L. Squires, Cambridge University Press (1978)<br>4. Understanding solids: the science of materials, J D Richard Tilley, Wiley publication, 2004<br>5. Infrared and Raman spectra of Inorganic and coordination compounds, K Nakamoto, 6 th Edition Wiley Publication,2009 | |

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| **Learning Outcomes** | On completion of this course, the students will get necessary foundation in amorphous materials that will prepare them for research in in glass and other amorphous materials | |

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**Programme:** M. Sc. (Physics)
**Course Code:** PHSR-511 **Title of the Course:** Nanomaterials for Energy Applications
**Number of Credits:** 2
**Effective from AY:** 2023-24

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| **Prerequisites for thecourse:** | Basic knowledge of Solid State Physics/ Solid State Chemistry | |
| **Objective:** | 1. To emphasize the role of nanostructures in energy materials research,their synthesis and their advantages in energy extraction and storage. | |
| **Content:** | **State-of-the-Art of Nanostructures in Solar Energy Research**<br>Introduction, Motivations for Solar Energy, Nanostructures and Different Synthesis Techniques, Nanomaterials for Solar Cells Applications, Advanced Nanostructures for Technological Applications, Theory and Future Trends in Solar Cells. | 4 hours |
| | **Metal Oxide Semiconductors and Their Nanocomposites Photovoltaic and Photocatalytic Applications**<br>Introduction, Metal Oxide Nanostructures for Photovoltaic Applications, $TiO_2$Nanomaterials and Nanocomposites for the Application of DSSC and Heterostructure Devices, ZnONanomaterials and Nanocomposites for the Application of DSSC and Heterostructure Devices, Fabrication of DSSCs with Vertically Aligned $TiO_2$ nanotubes, ZnONanorods (NRs) and Graphene Oxide Nanocomposite Based Photoanode, ZnONanocomposite for the Heterostructures Devices, Fabrication of Heterostructure Device with Doped ZnONanocomposite, Metal Oxide Nanostructures and Nanocomposites for Photocatalytic Application, Future Directions. | 12hours |
| | **Advanced Electronics: Looking beyond Silicon**<br>Introduction, Limitations of Silicon-Based Technology, Need for Carbon-Based Electronics Technology, Carbon Family, Electronic Structure of Graphene and CNT, Synthesis of CNTs, Carbon Nanotube Devices, Advantages of CNT- Based Devices, Issues with Carbon-Based Electronics. | 6 hours |
| | **Energy storage devices**<br>Definitions, Battery, Fuel Cells and supercapacitors comparisons,Fundamentals of battery, design principle and operation of fuel cell, types of fuel cells, conversion efficiency of fuel cell, operating characteristics of fuel cells, Advantages and future potential of fuel cells, limitation of fuel cell. Basic understanding of supercapacitor working, principle and types of supercapacitors, potential applications using different supercapacitor materials and their limitations, coupling with Batteries and Fuel Cells. | 8 hours |
| **Pedagogy**: | lectures/ tutorials /viva/ seminars/ term papers/assignments/ presentations | |
| **References/ Readings** | 1. Advanced Energy Materials, AshutoshTiwari, SergiyValyukh, John Wiley and Sons, 2014.<br>2. Organic nanostructured thin film devices and coatings for clean energy, Sam Zhang, CRC Press (Taylor and Francis group) 2017.<br>3. Nanostructured thin films and coatings, Sam Zhang, CRC Press, 1st Edition, 2010.<br>4. Physical Properties of Carbon Nanotubes, R. Saito, G | |

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| | Dresselhaus, M S Dresselhaus, Imperial college Press, 2005.<br>5. Nanoscience and carbon nanotubes, A.S. Bhatia, Deep and deep publication, 2009.<br>6. Electrochemistry of porous materials, Antonio DominechCarbo, CRC Press (Taylor and Francis group) 2010<br>7. Computational methods for nanoscale applications, Tsukerman Igor, Springer, 2008.<br>8. Renewable Energy Sources, John Twidell, Tony Weir, Taylor and Francis group, 2nd Edition, 2006.<br>9. Non-Conventional energy Sources, G.D Rai, Khanna Publishers 2003.<br>10. Electrochemical supercapacitor for energy storage and delivery, fundamentals and application, Aiping Yu, Victor Chabot, Jiujun Zhang, CRC press, 2013<br>11. Materials for Supercapacitor Applications, M. AuliceScibioh, B. Viswanathan, Elsevier, 2020 | |
| **Learning Outcomes:** | Student will gain knowledge of different nanostructured energy materials and their use for diverse energy applications<br>Student will understand the basic principle of operation of nanostructured energy extraction/storage devices. | |

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**Programme:** M. Sc. (Physics)(Computational Physics)
**Course Code:** PHCR-503 **Title of the Course:** Simulation Techniques
**Number of Credits:** 2 (1T+1P)
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Basic knowledge of Computer programming, Quantum mechanics and Statistical mechanics. | |
| **Objective:** | Tointroducecomputational methods for simulating many-body systems in condensed matter physics. | |
| **Content:** | Monte Carlo methods for classical spin systems<br><br>Exact diagonalization of quantum lattice models<br><br>The density matrix renormalization group and tensor network methods | 7T+4P=19 hours<br><br>1T+2P=7 hours<br><br>7T+4P=19 hours |
| **Pedagogy:** | Lectures/Laboratorypracticals. Sessionsshallbeinteractive innaturetoenable peergrouplearning. | |
| **References/ Readings** | 1. Computational Physics, Second Edition, J. Thijssen, Cambridge University Press, 2012.<br>2. An Introduction to Computational Physics, Second Edition Tao Pang, Cambridge University Press, 2006 | |

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| | 3. The density-matrix renormalization group in the age of matrix product states, U. Schollwock, Annals of Physics **326**, 96192 (2011) | |
| **Learning Outcomes** | Studentswilllearn methods computational methods for simulating many-body systems in condensed matter physics. | |

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**Programme:** M. Sc. (Physics)
**Course Code:** PHCR-504 **Title of the Course:** Physics of Quantum Materials
**Number of Credits:** 2
**Effective from AY:** 2023-24

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| **Prerequisites for the course** | Should have studied modern physics | |
| **Objectives** | The aim of this course is to give a background relevant to research in the physics of topological materials and low dimensional structures and quantum devices. | |
| **Content** | **Physics of topological materials:**<br>Berry phase, Dirac fermions, Hall conductance and its link to topology, and the Hofstadter problem of lattice electrons in a magnetic field, Linear response theory, Topological phases of matter such as Chern insulators and two- and three-dimensional topological insulators. Angle, Spin, and Depth Resolved Photoelectron Spectroscopy on Quantum Materials, Results of topological insulators, HgTe, $Bi_2Se_3$ family ($Bi_2Te_3$,$Sbi_2Te_3$) topological semimetal $Na_3Bi$, quantum spin Hall insulator $WTe_2$ | 12 hours |
| | **Physics of low dimensional systems:**<br>Concepts about heterostructures and resulting low dimensional systems such as quantum wells, nanowires and quantum dots. Quantum physics applied to such systems. Optical properties of low dimensional systems (transition rules, polarisationetc). Electron transport properties of 2D and 1D system. Quantised conductance with Landauer-formalism. Scattering phenomena in 1D. Devices based on quantum phenomena and Coulomb blockade. | 12 hours |
| | **Low dimensional quantum magnetism:**<br>Dimers, Shastry-Sutherland network, Dimers, Bose-Einstein condensation, Chains, spin liquids, phase transitions, spin gap, long-range order, Ladders, Nersesyan-Tsvelik network,<br>Layers, triangular, Kagome and honeycomb lattices, Examples. | 8 hours |
| **Pedagogy** | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **Reference/ Readings** | **Text Books/References:**<br>1. Solid State Physics, N. W. Ashcroft and N. D. Mermin, Cengage Learning Publishers, 1976 1st Edition.<br>2. Band Theory and Electronic Properties of Solids, John Singleton, Oxford University Press, (2012) | |

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| | 3. Topological Materials, B. Yan and S-C. Zhang, Rep.Prog. Phys. **75** (2012) 096501<br>4. Quantum Spin Hall Effect in Graphene, Kane C L and Mele E J, *Phys. Rev. Lett.* **95** (2005)226801<br>5. Simple Quantum Spin Hall Effect, Bernevig B A and Zhang S C 2006 *Phys. Rev. Lett.* **96** 106802.<br>6. Topological Quantum Materials from the viewpoint of Chemistry, N. Kumar, S. N. Guin, K. Manna, C. Shekhar, C. Felser, Chemical Reviews **121** (2021) 2780-2815.<br>7. Angle, Spin and Depth resolved photoelectron spectroscopy on Quantum Materials, P. D. C. King et al. Chemical Reviews **121** (2021) 2816-2856.<br>8. Milestones of low-d quantum magnetism A. Vasiliev et al npj Quantum Materials 3 (2018) 8368 | |
| **Learning Outcomes** | Students who complete this course will emerge with a broad understanding and perspective on recently developed quantum materials such as topological materials and low-dimensional materials. | |

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**Programme:** M. Sc. (Physics)
**Course Code:** PHCR-505 **Title of the Course:** Superconductivity
**Number of Credits:** 2
**Effective from AY:** 2023-24

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| **Prerequisites for the course** | Should have basic knowledge of electrodynamics, thermodynamics and quantum mechanics, and solid state physics | |
| **Objectives** | To introduce an up-to-date experimental progresses and theories of superconductivity | |
| **Content** | **Basic Experimental Aspects**<br>Introduction, Conduction in metals, Zero-resistivity, Meissner-Ochsenfeld effect, Perfect diamagnetism, Type-I and type-II superconductors, Application of low and high temperature superconductors.<br>**Superconducting Materials**<br>Classical Superconductors: Elemental superconductors, superconducting compounds and alloys, A15 compounds, Chevrel phase compounds and their crystal structure,<br>experimental studies on these materials, Phase diagrams.<br>High-temperature Superconductors: La-Ba/Sr-Cu-O systems, Y-Ba-Cu-O systems, Bi-Sr-Ca-Cu-O systems, Ti-Sr-Ca-Cu-O systems, superconductivity in rare-earth and actinide compounds, organic superconductors, $MgB_2$ and Iron Arsenide systems, their crystal structure, phase diagrams experimental studies on these materials, Phase diagrams.<br>**Theoretical Aspects**<br>Phenomenological theories: Thermodynamics of superconducting transition, expressions for critical temperature $T_C$, critical field $H_C$, | 2 hours<br><br><br><br><br>10 hours<br><br><br><br><br><br><br><br><br><br><br><br><br>18 hours |

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| | London's theory, Pippard non-local theory, Ginzburg-Landau Theory.<br>Microscopic theory: BCS theory, the electron-phonon interaction, the Cooper pair formation, BCS ground state, Consequences of the BCS theory and comparison with experimental results, Coherence of the BCS ground state and the Meissner-Ochsenfeld effect.<br>Possible Mechanisms of high TC Superconductors | |
| **Pedagogy** | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **Reference/ Readings** | **Text Books/References:**<br>1. Superconductivity, Superfluids and Condensates, James F. Annett, Oxford Series in Condensed Matter Physics (2004).<br>2. Superconductivity, J.B. Ketterson and S.N. Song, Cambridge Univ. Press (1999).<br>3. Introduction to Superconductivity, M. Tinkham, McGraw Hill (1996).<br>4. Introduction to Solid State Physics, C. Kittel, Wiley, Eight Ed. (1997).<br>5. Solid State Physics, H. Ibach and H. Luth, Springer (2012). | |
| **Learning Outcomes** | Student will<br>1. gain knowledge of different families of superconducting materials.<br>2. learn about theories on conventional superconductors and possible mechanisms of unconventional superconductivity. | |

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**Programme:** M. Sc. (Physics)
**CourseCode:**PHCR-506 **Title of the Course:** Advanced ParticlePhysics
Number of Credits: 4
**Effective from AY:** 2022-23

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| **Prerequisites for the course:** | Introduction to Particle Physics (PHCG-504) and Nuclear and Elementary Particle Physics (PHTC-407), Quantum Mechanics (PHTC-405) | |
| **Objective:** | To introduce students the core principles in particle physics | |
| **Content:** | **Feynman Calculus:**<br>Decays, scattering and cross-sections<br>Fermi Golden rule, Golden rule for two particle decays and scattering of particles<br>Two-body scattering in the COM frame<br>Feynman rules for a toy theory and higher-order Feynman diagrams<br>**Quantum Electrodynamics:**<br>Dirac equation, solutions to the Dirac equation, and bilinear covariants<br>Photon, Feynman rules for QED and examples | 10 hours<br><br><br><br><br><br><br><br>12 hours |

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| | Casimir's Trick, cross-sections and lifetimes, and renormalization<br>Hadronproduction in e+e- collisions<br>Elastic electron-proton scattering<br>**Quantum Chromodynamics:**<br>Feynman rulesfor Chromodynamics<br>Color factors, quark and antiquark<br>Pair annihilation in QCD<br>Asymptotic Freedom<br>**Weak Interactions:**<br>Charged leptonic weak Interactions<br>Decay of muon, neutron, and pion<br>Charged weak interactions of quarks<br>Neutral weak interactions<br>Electroweak unificationand chiral fermion states<br>Weak isospin and hypercharge, electroweak mixing<br>**Gauge Theories:**<br>Lagrangian formulation of classical particle mechanics and Lagrangians in relativistic field theory<br>Local gaugeinvariance and Yang-Mills Theory<br>Chromodynamics, Feynman rules and Mass term<br>Spontaneous symmetry-breaking<br>Higgs Mechanism<br>**Neutrino Oscillations:**<br>Solar neutrino problem and neutrino oscillations<br>Neutrino mixing and neutrino mixing matrix | 10 hours<br><br>12 hours<br><br>12 hours<br><br>4 hours |
| **Pedagogy:** | Lectures/tutorials/assignments. Sessions shall be interactive in nature to enable peer group learning. | |
| **References/ Readings** | 1. Introduction to Elementary Particles by David Griffiths, 2nd edition, Wiley (2008)<br>2. Quarks and Leptons, by F. Halzen and A. D. Martin, John Wiley (1984)<br>3. Introduction to High Energy Physics by D. H. Perkins, 4th edition, Cambridge (2000)<br>4. Modern Particle Physics by M. Thomson, Cambridge University Press India (2016) | |
| **Learning Outcomes** | Student will be able to<br>1. Learn Feynman diagrams, rules and calculate cross-section for QED, QCD and Weak processes. Classify particles and fundamental forces.<br>2. Learn about QED, QCD and Weak interactions in details<br>3. Gain understanding of Lagrangian formulation and local gauge invariance, spontaneous symmetry-breaking and Higgs mechanics. | |

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| | 5. Understand neutrino oscillations and mixing. | |

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**Programme:** M. Sc. (Physics) (Computational Physics)
**Course Code:** PHCR-507 **Title of the Course: Introduction to** Parallel Programing using openMP
**Number of Credits: 2**
**Effective from AY:** 2023-24

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| **Prerequisites for the course:** | Students enrolling for this course should be comfortable with programming in FORTRAN | |
| **Objective:** | This is an introductory course in shared memory parallel programming suitable for students working on parallel/HPC applications and interested in parallel programming. | |
| **Content:** | **Parallel Programming with OpenMP**<br>What is Parallel Computing?<br>Why would one make codes parallel?<br>Shared and Distributed Memory OpenMP<br>Who would use OpenMP? | 8 hours |
| | **How do you make your existing codes parallel?**<br>How does one make existing codes parallel?<br>How does one compile code to run OpenMP?<br>How does one decide if a loop is parallel or not?<br>What are Private and Shared variables?<br>How can one do Summations?<br>Summary | 8 hours |
| | **Basic Linear Algebra using OpenMP and OpenMP tasks**<br>Numerical Integration<br>Matrix Multiplication<br>Solution of linear equations<br>Solution of Ordinary differential equations | 14 hours |
| **Pedagogy:** | lectures/ tutorials/ seminars/ assignments/ presentations/ etc. or a combination of some of these. | |
| **References/ Readings:** | 1. Introduction to Parallel Computing, Second Edition, AnanthGrama, Anshul Gupta, George Karypis, Vipin Kumar, Addison Wesley, (2003).<br>2. OpenMP Tutorial from LLNL (https://computing.llnl.gov/tutorials/openMP<br>3. Computer Programming in FORTRAN 90 and 95, V. Rajaraman, Prentice-Hall of India, New Delhi (1999).<br>4. Fortran 95, Martin Counihan, UCL Press Limited University College London (1996).<br>5. Fortran 95/2003: for Scientists and Engineers, Stephen Chapman, McGraw-Hill (2007). | |

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| **Learning Outcomes** | Students will be able to understand the basics of parallel programming using OpenMP, understanding of numerical methods to solve linear and non-linear algebraic equations, and understanding of eigenvalue problems. | |

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**Programme:** M. Sc. (Physics)
**Course Code:** PHPE-406 **Title of the Course:** Methods of Experimental Physics
**Number of Credits:** 4(1L+3P)
**Effective from AY:** 2021-22

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| **Prerequisites for the course:** | Nil | |
| **Objective:** | This course seeks to develop understanding of principles of measurement of various fundamental quantities in a Physics laboratory. | |
| **Content:** | 1. **Measurement of temperature**<br>Thermocouple, diode and semiconductor sensors, RTD, pyrometer, Langmuir probes,<br>2. **Measurement of resistance**<br>Two probe measurement and four probe measurement using constant current source and constant voltage source, Lock-in amp, discharge of capacitance<br>3. **Measurement of capacitance**<br>RC circuit, DC bridges, AC Bridges<br>4. **Measurement of radiation**<br>GM counter, ionization chambers, scintillation detector, solid state detectors, CCD detectors<br>5. **Measurement of magnetic flux**<br>Force methods, induction methods (including SQUID), Hall probe, indirect methods (MOKE)<br>6. **Measurement of frequency**<br>Resonance methods<br>7. **Estimation of errors in measurement.**<br>Precision and accuracy, estimation of errors, propagation of errors, general formula, least square fitting, non-linear least square | 1 hours + 15 hours<br>1 hours + 15 hours<br>1 hours + 15 hours<br>1 hours + 15 hours<br>1 hours + 15 hours<br>1 hours + 15 hours<br>9 hours |
| **Pedagogy:** | Lectures and Laboratory Experiments. | |
| **References/ Readings** | 1. P. R. Bevington and D. K. Robinson, Data Reduction and Error Analysis for the Physical Sciences, McGraw Hill (Indian Edition) 2015.<br>2. R. Srinivasan, K. R. Priolkar and T. G. Ramesh, A Manual on Experiments in Physics, Indian Academy of Sciences, 2018. | |
| **Learning Outcomes** | 1. Understand the advantages and disadvantages of using a technique or probe for making scientific measurements.<br>2. Demonstrate the ability to use selected pieces of measuring | |

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| | devices.<br>3. Estimate and translate errors and report quantities up to last significant digit | |

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**Annexure II**

**Programme:** Ph.D (Physics)
**Course Code: Title of the Course: Research Methodology**
**Number of Credits:** 4
**Effective from AY:** 2022-23

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| Prerequisites for the course: | M.Sc. in Physics | |
| Objective: | The aim of course is to orient Pre-PhD students towards research by introducing them to research methodology and data analysis in science. The basic principles of different experimental methods and characterization techniques will be covered along with computer programming and numerical methods. | |
| Content: | **UNIT I**<br>What is research?, Research methods and research methodology, Basic and applied research, Selection of a research topic, Literature survey, Internet as a medium of research, Reference collection, Assessing the current status, Hypothesis, Mode of approach, Actual investigation - experiment, analysis and results; Theoretical research, Critical thinking, Investigation, Survey, A*b initio,* semi-empirical, empirical search; Inquiry, Quest, Exploration, Innovation (innovative ideas), Discovery and invention in science; Knowledge and creativity, Presenting a scientific seminar-oral report, Art of writing a research paper and thesis, Outline of a report, Layout of a research report/ PhD thesis, Documentation in Latex, Quality of research, quantitative measurement by Impact factor, h-index, Scientometry. | 15 hours |
| | **UNIT II**<br>Uncertainties in measurements: Measuring errors, Uncertainties, Parent and sample distributions, Mean and standard deviation of distributions, Binomial distributions, Poisson distribution, Gaussian or normal Error distribution, Lorentzian distribution; Approximation and errors in computing: Significant digits, Numerical errors, Modelling errors, Conditioning and stability, Convergence of iterative processes.<br>Error analysis: Instrumental and statistical uncertainties, Propagation of errors, Application of error equations, Method of least squares, Statistical fluctuations, Probability tests, □2 test of a distribution.<br>Curve fitting (Regression analysis); Least square fit to a straight line, Error estimation of the fitted parameters, Limitations of the least | 15 hours |

square method, Least squares fit to a polynomial, matrix solution, Goodness of a fit, Linear correlation coefficient, Multivariable correlations.

**UNIT III (For Experimental students)** 30 hours

**1. Methods of Material Preparation:**
Crystal growth, Single crystal, Zone melting, Epitaxy, Compaction and sintering, Methods of quenching, Sol-gel process, Deposition technique, Chemical analysis.

**2. Vacuum Techniques:**
Production and measurement of vacuum, Different types of vacuum systems and gauges, their working and limitations, Leak detection

**3. Methods of Characterization:**
X-ray diffraction, Raman Spectroscopy, IR Spectroscopy, UV-Visible spectroscopy, Mossbauer spectroscopy, Electrical transport and magnetic measurement techniques, Scanning and transmission electron microscopy, Differential scanning calorimetry – Principles, instrumentation and applications.

**UNIT III (For Theory students)** 30 hours

**1. Computer Programming and Numerical Techniques:**

C/Fortran/Python programming,
Finite differential calculus, Interpolation and extrapolation, Roots of equations, Solution of simultaneous Linear algebraic equation, Linear and non-linear least squares, Curve fitting, Numerical differentiation and integration, Fourier transform techniques, Numerical solution of ordinary differential equations, Matrix Eigen value problem, Monte Carlo and Maximum entropy method.

Pedagogy: Test paper/Assignments/Presentations/Self-study

References/ Readings

1. Research Methods for Science, M. P. Marder, Cambridge University Press, 2011.
2. Research Methodology Techniques and Trends Khanzode, V, APH Publishing Corporation House, 1995.
3. Research Methodology, S. Rajasekar, P. Philominathan, V. Chinnathambi, arXiv: physics /0609001v3 (2006)
4. Data Reduction and Error Analysis for the Physical Sciences 3rd Ed. by Philip R Bevington and D Keith Robinson, McGraw – Hill (2003)
5. An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements, 2nd Ed. John R. Taylor, University Science Books (1997)
6. Preparative Solid State Chemistry, P. Haggenmuller, Academic Press, London (1972)
7. Crystal Growth, C. H. L. Goodman, Plenum Press, New York

8. Elements of X-ray Diffraction, B. D. Cullitty, Stock S. R. Prentice Hall, New Jersey (2001)
9. Fundamentals of Vacuum Technology, A. Pipko, V. Pliskovsky, B. N. Korolev, Mir Publishers, Moscow (1984)
10. Thin Film Technology and Applications, K. L. Chopra, Tata McGraw-Hill, New Delhi (1985)
11. An Introduction to Electron Microscopy Instrumentation, Imaging and Preparation, Andres Kaech (reading material)
12. Fundamentals of Molecular Spectroscopy, C. Banwell and E. M. McCash, Tata McGraw-Hill, New Delhi, (2000)
13. Numerical Recipes in C, C. W. Press, S. A. Teukolsky, W. T. Vetterling and B. P. Flannery, Cambridge University Press (2008)
14. Introduction to numerical programming: a practical guide for scientists and engineers using Python and C/C++, Beu, Titus A., CRC Press (2015)
15. Fortran 90/95 for Scientists and Engineers, Stephen J. Chapman, McGraw-Hill Higher Education, (2004)
16. Computer Programming in Fortran 90 and 95, V. Rajaraman, PHI Learning Pvt. Ltd. (1997)

Learning Outcomes:

1. The students will get familiarize in research methodology and data analysis and expected to adopt it in their research work.
2. The students expand their knowledge in different experimental characterization techniques and theoretical methods.
3. The student may show better planning, execution and presentation in their research.

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