ST. XAVIER'S COLLEGE, MUMBAI

Est. 1869 | YEARS

(An autonomous college affiliated to The University of Mumbai)

Syllabus for the M.Sc
Subject: Physics
(Specialization Astrophysics)

(Credit Based Semester and Grading System with effect from the academic year 2019–2020)

Programme Education Objectives (PEO)

M. Sc. in Physics (Astrophysics) programme should inculcate the following broad attributes in the learner:

- Achieving global standards of domain knowledge and applications.
- Taking creative and independent initiatives towards new scientific ventures.
- Improving scientific temperament of the society at large.

Programme Outcome (PO)

After completing M.Sc. in Physics (Astrophysics) program the learner of shall be able to:

1. Demonstrate and apply sound domain knowledge and competence in Physics, Astronomy & Astrophysics in teaching, industry and research.
2. Develop and put into practice effective academic and creative written and oral communication and presentation skills in Physics.
3. Demonstrate the ability to analyze, interpret, evaluate and critique texts, discourses and new developments.
4. Identify, select, organize, use research techniques to carry out research and value intellectual property rights.
5. Choose and use advanced computer applications, develop algorithms & domain specific digital tools.
6. Understand, investigate and evaluate concepts from diverse disciplines such as physical and biological sciences, social sciences, religion, philosophy, history.
7. Compare, contrast and relate the course content with civic and environmental problems.
8. Demonstrate awareness and show sensitivity for the underprivileged, the differently abled and the discriminated and understand gender diversity.
9. Discuss and assess values of human dignity, empathy, integrity, moral courage, social justice, inclusivity.
10. Identify, analyze and discuss the problems and social issues in our country by applying scientific methods.
11. Develop professionalism, organizational skills and employability skills, make decisions, put into practice self-, time- and change management and solve problems at micro and macro levels.
12. Cultivate self-awareness, inner strength and creative and original thinking, attitude to continuously update and upgrade one's knowledge and expertise.

MSc. PHYSICS **Course: SPHY0701**
Title: MATHEMATICAL PHYSICS
Learning Objectives:

- To understand mathematical concepts used for solving physics problems.
- To learn the computational techniques and numerical methods for solving physics problems.

Number of lectures: 60

UNIT I: **[15 lectures]**

Computation Physics:
Introduction: [Self Study: Computer arithmetic: Binary, octal and hexadecimal number systems, floating point arithmetic] . Errors, Significant digits and Numerical Instability, Computer algorithms and languages.
Basic numerical methods: Approximation of a function, Numerical calculus, Solving Ordinary differential equations, Numerical methods for matrices, Spectral analysis and Gaussian quadrature, Partial differential equations.
Only Introduction: Molecular dynamics simulations, The Hartree–Fock method, Density functional theory, Modeling continuous systems, Monte Carlo simulations, Numerical renormalization.

UNIT II: **[15 lectures]**

Tensors: Index notation, Kronecker and Levi Civita tensors, inner and outer products, contraction, symmetric and antisymmetric tensors, quotient law, metric tensors ,covariant and contravariant tensors, simple applications to general theory of relativity and Klein-Gordon and Dirac equations in relativistic quantum mechanics.
Integral transforms: three dimensional fourier transforms and its applications to PDEs (Green function of Poisson's PDE), convolution theorem, Parseval's relation, Laplace transforms, Laplace transform of derivatives, Inverse Laplace transform and Convolution theorem, use of Laplace's transform in solving differential equations.

UNIT III: **[15 lectures]**
Infinite Series:
Fundamental concepts – convergence test: Cauchy's ratio test, Gauss's test – alternating series – algebra of series – Taylor expansion – Binomial theorem – power series – asymptotic series – Stirling's formula.
General treatment of second order linear differential equations with varying coefficients, Power series solutions, Frobenius method, Bessel ,Legendre, Hermite and Laugerre polynomials.

UNIT IV: **[15 lectures]**

Complex Variables:
Limits, Continuity, Derivatives, Cauchy-Riemann Equations, Analytic functions, Harmonic functions, Elementary functions: Exponential and Trigonometric, Conformal mapping (Self

Study), Taylor and Laurent series, Residues, Residue theorem, Principal part of the functions, Residues at poles, zeroes and poles of order m, Contour Integrals, Evaluation of improper real integrals, improper integral involving Sines and Cosines, Definite integrals involving sine and cosine functions.

Main references:

1. M.L. Boas, Mathematical methods in the Physical Sciences, Wiley India 2006.
2. G. Arfken and H. J. Weber: Mathematical Methods for Physicists, Academic Press, 2005.
3. E. Kreyszig Advance Engineering Mathematics, 8th ed. John Wiely and Sons, 1999.
4. An Introduction to Computational Physics, Second Edition, Tao Pang, Cambridge University Press

Additional references:

1. A.K. Ghatak, I.C. Goyal and S.J. Chua, Mathematical Physics, McMillan
1. A.C. Bajpai, L.R. Mustoe and D. Walker, Advanced Engineering Mathematics, John Wiley
2. E. Butkov, Mathematical Methods, Addison-Wesley
3. J. Mathews and R.L. Walker, Mathematical Methods of physics
4. P. Dennery and A. Krzywicki , Mathematics for physicists
5. T. Das and S.K. Sharma, Mathematical methods in Classical and Quantum Mechanics
6. R. V. Churchill and J.W. Brown, Complex variables and applications, V Ed. Mc Graw. Hill
7. A. W.Joshi, Matrices and Tensors in Physics, Wiley India
8. Mathematical physics by B. D. Gupta

Evaluation Methods:

Continuous Internal Assessment and End Semester Exam:

Assignments, Research paper Review, written test, problem solving, presentations.

Course outcome:

Learner should be able to:

1. Understand the concepts of tensors, differential equations with varying coefficients, integral transforms and series and complex variables.
2. Master the fundamentals of numerical methods, computer algorithms and programming languages .
3. Develop skills to solve physics problems by analytical methods.
4. Develop skills to solve problems in physics using computational methods.
5. Use online resources for selecting innovative applied or interdisciplinary problems.
6. Solve the selected problems by both analytical and computational methods and compare the results obtained.

MSc. PHYSICS **Course: SPHY0702**
Title: CLASSICAL MECHANICS

Learning Objectives:

- To understand mechanics through Lagrangian and Hamiltonian formalism.
- To apply these methods to relevant aspects of physical systems.
- To understand the principles of Chaos, Canonical Perturbation Theory, Formulations for Continuous Systems and fields.

Number of lectures: 60

UNIT I: **[15 lectures]**

Formalism:
Survey of the Elementary Principles (Pre-requisite):
Mechanics of a particle, Mechanics of a system of particles, Constraints, D'Alembert's principle and Lagrange's Equations, Velocity dependent potentials and the dissipation function, simple application of Lagrangian formulations
Variational Principles and Lagrange's Equations
Hamilton's principle, some techniques of the calculus of variations, Derivation of Lagrange's Equations from Hamilton's principle, Extension of Hamilton's principle to Non-holonomic systems, Advantages of a variational principle formulation, conservation theorems and symmetry properties.
The Central Force Problem:
Reduction to equivalent one-body problem, Equation of motion and first integrals, Equivalent one dimensional problem and Classification of Orbits, The Virial theorem. The differential equation for the orbit and integrable law Power-Law potential, Conditions for closed orbit, Kepler problem: Inverse-square law force, motion in time in Kepler problem

Unit II: **[15 lectures]**

Oscillations:
Formulation of the problem, The Eigenvalue equation and the Principal axis transformation, Frequency of free vibration and normal co-ordinates, free vibrations of a linear triatomic molecule, Forced vibrations and the effect of dissipative forces, Beyond small oscillations: The damped driven pendulum
The Hamilton Equations of Motion:
Legendre transformations and the Hamilton equations of motion, Cyclic co-ordinates and conservation theorems, Routh's procedure, the Hamiltonian formulation of relativistic mechanics, Derivation of Hamilton's equations from a variational principle, The principle of least action
Unit III: **[15 lectures]**

Canonical Transformations:
The equations of Canonical Transformation, Examples of Canonical transformation, The Harmonic oscillator, The symplectic approach to Canonical transformation, Poisson Brackets and

Other Canonical Invariants, Equation of Motion, Infinitesimal Canonical Transformation and Conservation Theorems in the Poisson Bracket Formulation, The Angular Momentum Poisson Bracket Formulation, Symmetry Groups of Mechanical Systems, Liouville's Theorem

Hamilton-Jacobi Theory and Action-Angle Variables:

The Hamilton-Jacobi Equation for Hamilton's Principal Function, The Harmonic Oscillator Problem as an Example of the Hamilton-Jacobi Method, Hamilton-Jacobi Equation for Hamilton's Characteristic Function, Separation of Variables in the Hamilton-Jacobi Equation, Ignorable Coordinates and the Kepler Problem, Action-angle Variables in Systems of One Degree of Freedom, Action-angle Variables for Completely Separable Systems, The Kepler Problem in Action-angle Variables.

Unit IV: **[15 lectures]**

Classical Chaos:

Periodic Motion, Perturbations and the Kolmogorov-Arnold-Moser Theorem, Attractors, Chaotic Trajectories and Liapunov exponents, Poincare Maps, Henon-Heiles Hamiltonian, Bifurcations, Driven-damped Harmonic Oscillators and Parametric Resonance, The Logistic Equation, Fractals and Dimensionality.

Canonical Perturbation Theory:

Introduction, time-dependent Perturbation Theory, Illustrations of Time-dependent Perturbation Theory, Time-independent Perturbation Theory, Adiabatic Invariants.

Introduction to the Lagrangian and Hamiltonian Formulations for Continuous Systems and fields:

The Transition from a Discrete to a Continuous System, The Lagrangian Formulation for Continuous Systems, The Stress-energy Tensor and Conservation Theorems, Hamiltonian Formulation, Relativistic Field Theory, Examples of Relativistic Field Theory, Noether's Theorem.

References:

1. Classical Mechanics by H. Goldstein 3rd edition, Narosa Publishing Home, New Delhi.
2. Classical Mechanics by N.C. Rana and P.S. Joag, Tata McGraw-Hill Publishing Company Ltd. New Delhi.
3. Classical Mechanics by Gupta Kumar Sharma, Pragati Prakashan.
4. Classical Mechanics by Mondal, Prentice-Hall of India, Pvt. Ltd., New Delhi.
5. Classical Mechanics by J. C. Upadhyaya, Himalaya Publishing House.

Evaluation Methods:

Continuous Internal Assessment and End Semester Exam:

Assignments, Research paper Review, written test, problem solving, presentations.

Course outcome:

Learner should be able to:

1. Have understanding of fundamental concepts of Newtonian mechanics and it's applications to various physical systems, natural and man made.
2. Should be able to use advanced concepts of mechanics theory, such as the Lagrange's and the Hamilton's Formulation to understand complex mechanical systems.

3. Understand the foundations of chaotic motion and distinguish different chaos phenomena.
4. Apply their knowledge and skills to solve problems in modern physics.
5. Use their critical thinking skills to formulate and solve quantitative problems in applied physics.
6. Use computational methods to study deterministic and nondeterministic chaotic systems.

MSc. PHYSICS **Course: SPHY0703**
Title: QUANTUM MECHANICS

Learning Objectives:

- To understand general formalism and Dirac notation in quantum mechanics .
- Applications in three dimensional problems, perturbations, scattering.
- To understand the principles of relativistic quantum mechanics.

Number of lectures: 60

UNIT I: **[15 lectures]**
Formalism:
Linear Vector Spaces and operators, Dirac notation, Hilbert space, Hermitian operators and their properties, Matrix mechanics: Basis and representations, unitary transformations, the energy representation. Schrodinger, Heisenberg and interaction picture.
Wave packet: Gaussian wave packet, Fourier transform.
Schrodinger equation solutions: one dimensional problems:
General properties of one dimensional Schrodinger equation, Harmonic oscillator by raising and lowering operators.

UNIT II: **[15 lectures]**
Schrodinger equation solutions: Three dimensional problems:
Orbital angular momentum operators in cartesian and spherical polar coordinates, commutation and uncertainty relations, spherical harmonics, two particle problem- coordinates relative to centre of mass, radial equation for a spherically symmetric central potential.
Angular Momentum: Ladder operators, eigenvalues and eigenfunctions of L*2 and Lz using spherical harmonics, angular momentum and rotations.
Total angular momentum J; ; eigenvalues of J*2 and Jz.
Addition of angular momentum, coupled and uncoupled representation of eigenfunctions, Clebsch Gordon coefficient for j1 = j2 = 1⁄2 and j1 =1 and j2 = 1⁄2. Angular momentum matrices, Pauli spin matrices, spin eigenfunctions, free particle wave function including spin, addition of two spins.

UNIT III: **[15 lectures]**
Perturbation Theory:
Time independent perturbation theory: First order and second order corrections to the energy eigenvalues and eigenfunctions. Degenerate perturbation Theory: first order correction to energy.

Time dependent perturbation theory: Harmonic perturbation, Fermi's Golden Rule, sudden and adiabatic approximations, applications.
Approximation Methods
Variation Method: Basic principle, applications to simple potential problems, He- atom.
WKB Approximation: WKB approximation, turning points, connection formulas, Quantization conditions, applications.

UNIT IV: [15 lectures]
Scattering Theory:
Laboratory and centre of mass frames, differential and total scattering cross-sections, scattering amplitude, Partial wave analysis and phase shifts, optical theorem, S-wave scattering from finite spherical attractive and repulsive potential wells, Born approximation
Relativistic Quantum Mechanics- The Klein Gordon and Dirac equations. Dirac matrices, spinors, positive and negative energy solutions physical interpretation. Non-relativistic limit of the Dirac equation.

Main references:
1. D J Griffiths, Introduction to Quantum Mechanics 4th edition
2. A Ghatak and S Lokanathan, Quantum Mechanics: Theory and Applications, 5th edition.
3. Richard Liboff, Introductory Quantum Mechanics, 4th edition, Pearson.
4. N Zettili, Quantum Mechanics: Concepts and Applications, 2nd edition, Wiley.
5. J. Bjorken and S. Drell, Relativistic Quantum Mechanics, McGraw-Hill (1965).
Additional References
1. W Greiner, Quantum Mechanics: An introduction, Springer, 2004
2. R Shankar, Principles of Quantum Mechanics, Springer, 1994

Evaluation Methods:

Continuous Internal Assessment and End Semester Exam:

Assignments, Research paper Review, written test, problem solving, presentations.

Course outcome:
Learner should be able to:
1. Understand general formalism and Dirac notation in quantum mechanics.
2. Master the applications of quantum mechanics in one dimensional and three dimensional physics problems.
3. Learn the details of perturbation theory , approximation and variation methods .
4. Understand the quantum mechanical scattering theory and fundamentals of relativistic quantum mechanics.
5. Use online resources for selecting innovative applied or interdisciplinary problems related to any of the methods specified .
6. Use computational or analytical methods to solve the selected problems.

MSc. PHYSICS **Course: SPHY0704**
Title: ASTRONOMY AND ASTROPHYSICS: AN OVERVIEW

Learning Objectives:

- **To understand Tools of Astronomy and celestial mechanics.**
- **To introduce basic astronomical principles in the study of the planets, stars and galaxies.**

Number of lectures: 60

UNIT I: [15 lectures]

Celestial Mechanics and Astrometry:

The celestial Sphere, Positions of stars, Proper motions of stars and planets, Distances of nearby stars.

Tools of Astronomy:

Telescopes: Basic Optics, Optical Telescopes, Radio Telescopes, Infrared, Ultraviolet, X-ray, and Gamma-Ray Astronomy – detectors and observatories

Gravitational Waves detectors and Neutrino detectors

All-Sky Surveys and Virtual Observatories.

UNIT II: [15 lectures]

The Solar System:

The Sun, The Physical Processes in the solar system, The Terrestrial and the Giant Planets, Formation of Planetary Systems.

Basic Stellar Parameters:

The brightness of the stars, Color-magnitude diagrams (The HR diagrams), The luminosities of the stars, Angular radii of stars, Effective temperatures of stars, Masses and radii of stars: Binary stars, Search for Extrasolar Planets

UNIT III: [15 lectures]

The Nature of Stars:

Spectral classification, Understanding stellar spectra, Population II stars, Stellar rotation, Stellar magnetic fields, Stars with peculiar spectra, Pulsating stars, Explosive stars, Interstellar absorption

UNIT IV: [15 lectures]

Our Galaxy And The Interstellar Matter:

The shape and size of our Galaxy, Interstellar extinction and reddening, Galactic coordinates, Galactic rotation, Stellar population, Inter Stellar Medium, The galactic magnetic field and cosmic rays

Extragalactic Astronomy:

Normal galaxies- Morphological classification and kinematics, Expansion of the Universe, Active galaxies, Clusters of galaxies, Large-scale distribution of galaxies, Gamma ray bursts

References:

Introduction to Stellar Astrophysics, Volume 1, *Basic stellar observations and data,* By Erika Bohm-Vitense, Cambridge University Press

An Introduction to Modern Astrophysics, Second Edition, By Carroll B.W., Ostlie D.A., Pearson Addison Wesley.

"Astrophysics for Physicists" by Arnab Rai Choudhuri, Cambridge University Press, 2010

Galactic Astronomy: Structure and Kinematics by Mihalas & Binney, W.H.Freeman & Co Ltd; 2nd Revised edition 1981.

Evaluation Methods:
Continuous Internal Assessment and End Semester Exam:
Assignments, Research paper Review, written test, problem solving, presentations.

Course Outcome:

Learner should be able to:

1. Have knowledge of the expanse of the universe and the nature of the planets, stars and galaxies.
2. Understand how the astronomical observations are done for these celestial objects.
3. Apply mathematical tools and physics laws to understand the nature of planets, stars and galaxies.
4. Use online resources to analyse the data obtained from various astronomical observations.
5. Evaluate the results of this analyses and interpret the nature of the Solar system, variety of stars and galaxies.
6. Create new observational programs or data analyses and interpretation projects in astronomy.

MSc. PHYSICS **Course: SPHY0801**
Title: STATISTICAL MECHANICS

Learning Objectives:

- To bring an understanding of the principles of Classical and Quantum statistics and its applications to realistic problems.
- To acquire the skills for: isolating relevant aspects of a physical system, producing appropriate model to develop statistical description of system, determining major thermodynamic properties and examine appropriate limiting behaviors (high and/or low temperature, classical limit, etc.).

Number of lectures: 60

UNIT I: **[15 lectures]**
(Review)
The statistical basis of thermodynamics : Macroscopic and microscopic states, physical significance of number of microstates, statistics & thermodynamics, The classical ideal gas, entropy and Gibb's paradox
Ensemble Theory: phase space, Liouville's theorem, microcanonical ensemble, quantum states and the phase space
The Canonical Ensemble: equilibrium between a system and heat reservoir, various statistical quantities in the canonical ensemble, partition function, the classical systems, energy fluctuations, Equipartition theorem and Virial theorem, harmonic Oscillators, statistics of paramagnetism, thermodynamics of magnetic systems, negative temperatures
The Grand Canonical Ensemble: equilibrium between a system and a particle-energy reservoir, system in a grand canonical ensemble, density and energy fluctuations in the grand canonical ensemble, thermodynamic phase diagrams, phase equilibrium and the Clausius- Clapeyron equation

UNIT II: **[15 lectures]**
Formation of Quantum Statistics: Quantum-mechanical ensemble theory-the density matrix, statistics of the various ensembles, systems composed of indistinguishable particles, density matrix and the partition function of a system of free particles.
Theory of simple gases: an ideal gas in a quantum-mechanical microcanonical ensemble, an ideal gas in other quantum –mechanical ensembles, statistics of the occupation numbers, kinetic considerations, gaseous systems composed of molecules with internal motion, chemical equilibrium
Ideal Bose system: Thermodynamic behavior of an ideal Bose gas, Bose-Einstein condensation in ultracold atomic gases, thermodynamics of blackbody radiation, [self study: the field of sound waves, inertial density of the sound field, elementary excitations in liquid helium-II]
Ideal Fermi Systems: Thermodynamic behavior of an ideal Fermi gas, magnetic behavior of an ideal Fermi gas, the electron gas in metals, ultracold atomic Fermi gas, statistical equilibrium of white dwarf stars, statistical model of the atom

UNIT III: **[15 lectures]**

Thermodynamics of the Early Universe: observational evidence of the Big Bang, evolution of the temperature of the Universe, relativistic electrons, positrons and the neutrinos, neutron fraction, annihilation of the positrons and electrons, Neutrino temperature, primordial nucleosynthesis, recombination

Statistical mechanics of interacting systems(method of cluster expansions): cluster expansion for a classical gas, Virial expansion of the Virial coefficients, exact treatment of the second virial coefficient, cluster expansion for quantum –mechanical system, [self study: correlations and scattering]

Statistical mechanics of interacting systems (method of Quantized fields): The formalism of second quantization, low-temperature behavior of an imperfect Bose gas, low-lying states of an imperfect Bose gas, energy spectrum of a Bose liquid, States with quantized circulation, quantized vortex rings and the breakdown of superfluidity, low-lying states of an imperfect Fermi gas, energy spectrum of a Fermi liquid-Landau's phenomenological theory, condensation in Fermi systems.

UNIT IV: **[15 lectures]**

Phase transitions:

Criticality, Universality and scaling:

Problem of condensation, condensation of van der Waals gas, a dynamical model of phase transitions, the lattice gas and the binary alloy, Ising model in the zeroth approximation, Ising model in the first approximation, The critical exponents, Thermodynamic inequalities, Landau's phenomenological theory, Scaling hypothesis for thermodynamic functions, [self study: role of correlations and fluctuations, the critical exponents, mean field theory problems]

Exact results for various models:

One-dimensional fluid models, one-dimensional Ising model, Ising model in two dimensions, [self study: n-vector model in one dimension spherical model in arbitrary dimensions, ideal Bose gas in arbitrary dimensions, other models]

The renormalization group approach:

The conceptual basis of scaling, some simple examples of renormalization, the renormalization group-general formulation, [self study: applications of the normalization group, finite size scaling]

Fluctuations and nonequilibrium Statistical mechanics:

Equilibrium thermodynamic fluctuations, the Einstein-Smoluchowski theory of the Brownian motion, approach to equilibrium: the Fokker- Planck equation, [self study: The Langevin theory of the Brownian motion, spectral analysis of fluctuations, the fluctuation dissipation theorem, the Onsager relation]

References:

1. Statisticl Mechanics, R. K. Pathria & Paul D. Beale, 3rd edition, Elsevier publication 2011
2. Statistical Mechanics, Kerson Huang, 2nd edition, John Wiley & Sons publication 1987
3. Fundamentals of Statistical and Thermal Physics, F. Reif, 1st edition, Levant books publication 2010
4. Introductory Statistical Mechanics, Roger Bowley and Mariana Sanchez, south asia edition, Oxford Science Publications 2013

5. Introduction to Statistical Mechanics , S. K. Sinha, 3rd edition, Narosa Publication 2011
6. Elements of Nonequilibrium Statistical Mechanics, V. Balakrishnan, Ane's student edition, Ane Books Pvt Ltd 2014

Evaluation Methods:

Continuous Internal Assessment and End Semester Exam:

Assignments, Research paper Review, written test, problem solving, presentations.

Course outcome:
Learner should be able to:
1. Understand the concept of phase space and arguments leading to ensemble theories
2. Master statistical basis of classical and quantum thermodynamics.
3. Apply specific type of theories in specific problem sets and experimental situations.
4. Understand phase transitions and various fluid models.
5. Creatively apply the fluid models to various practical situations.
6. Understand basic principles of non-equilibrium quantum statistics.

MSc. PHYSICS **Course: SPHY0802**
Title: ELECTRODYNAMICS AND SOLID STATE PHYSICS
Learning Objectives:
- To understand dispersion and propagation of Electromagnetic waves.
- To analyze radiating systems and multipole fields.
- To study characteristics of phonons, optical and magnetic properties of solids.

Number of lectures: 60

UNIT I: **[15 lectures]**

Plane Electromagnetic Waves And Wave Propagation:

Plane Waves in a Nonconducting Medium, Linear and Circular Polarization; Stokes Parameters, Reflection and Refraction of Electromagnetic Waves at a Plane Interface Between Two Dielectrics, Polarization by Reflection, Total Internal Reflection; Goos–Hänchen Effect, Frequency Dispersion Characteristics of Dielectrics, Conductors, and Plasmas, Simplified Model of Propagation in the Ionosphere and Magnetosphere, Magnetohydrodynamic Waves, Superposition of Waves in One Dimension; Group Velocity, Illustration of the Spreading of a Pulse As It Propagates in a Dispersive Medium, Causality in the Connection Between D and E; Kramers–Kronig Relations, Arrival of a Signal After Propagation Through a Dispersive Medium

Waveguides, Resonant Cavities and Optical Fibers:

Fields at the Surface of and Within a Conductor, Cylindrical Cavities and Waveguides, Waveguides, Modes in a Rectangular Waveguide, Energy Flow and Attenuation in Waveguides, Perturbation of Boundary Conditions, Resonant Cavities, Power Losses in a Cavity; *Q* of a Cavity, Earth and Ionosphere as a Resonant Cavity: Schumann Resonances Multimode Propagation in Optical Fibers, Modes in Dielectric Waveguides, Expansion in Normal Modes; Fields Generated by a Localized Source in a Hollow Metallic Guide.

UNIT- II **[15 lectures]**
Radiating Systems, Multipole Fields and Radiation:

Fields and Radiation of a Localized Oscillating Source, Electric Dipole Fields and Radiation, Magnetic Dipole and Electric Quadrupole Fields, Center-Fed Linear Antenna, Multipole Expansion for Localized Source or Aperture in Waveguide, Spherical Wave Solutions of the Scalar Wave Equation, Multipole Expansion of the Electromagnetic Fields, Properties of Multipole Fields, Energy and Angular Momentum of Multipole Radiation, Angular Distribution of Multipole Radiation, Sources of Multipole Radiation; Multipole Moments, Multipole Radiation in Atoms and Nuclei, Multipole Radiation from a Linear, Centre-Fed Antenna

Scattering and Diffraction:

Scattering at Long Wavelengths, Perturbation Theory of Scattering, Rayleigh's Explanation of the Blue Sky, Scattering by Gases and Liquids, Attenuation in Optical Fibers, Spherical Wave Expansion of a Vector Plane Wave, Scattering of Electromagnetic Waves by a Sphere, Scalar Diffraction Theory, Vector Equivalents of the Kirchhoff Integral, Vectorial Diffraction Theory, Babinet's Principle of Complementary Screens, Diffraction by a Circular Aperture; Remarks on Small Apertures, Scattering in the Short-Wavelength Limit, Optical Theorem and Related Matters.

UNIT- III **[15 lectures]**
Lattice Vibrations And Thermal Properties:
Vibrations of Monoatomic Lattice, normal mode frequencies, dispersion relation. Lattice with two atoms per unit cell, normal mode frequencies, dispersion relation., Quanization of lattice vibrations, phonon momentum, Inelastic scattering of neutrons by phonons, Surface vibrations, Inelastic Neutron scattering. Anharmonic Crystal Interaction. Thermal conductivity – Lattice Thermal Resistivity, Umklapp Process, Imperfections
UNIT- IV **[15 lectures]**
Optical And Magnetic Properties Of Solids:
Optical Properties: Scattering, transmission and absorption in solid. optical properties of semiconductors, optical transitions, excitons, activators, Franck-Condon principle, color centers, photoluminescence and thermoluminescence.

Magnetic Properties:
Magnetic properties: dia , para and ferromagnetic materials, Origin of magnetism – various theories, temperature dependence, domain structure ferromagnetic domains, antiferromagnetism, magnetic hysteresis and coercive force.

References:-

1 Classical Electrodynamics by J. D. Jackson, 3rd edition, John Wiley and Sons pvt. Ltd.
2 Classical Electromagnetic Radiation, 3rd edition, M. A. Heald and J. B. Marrion, Saunders college Publishing.
3 Electromagnetic Waves and Radiating Systems, 2nd edition, E. C. Jordan and K. G. Balmain, Prentice Hall Inc.
4 Solid state Physics – N.N. Ashcroft and N.D. Mermin
5 Charles Kittel "Introduction to Solid State Physics", 7th edition John Wiley & sons.
6 M.A.Wahab "Solid State Physics –Structure and properties of Materials" Narosa Publications 1999.

M. Ali Omar "Elementary Solid State Physics" Addison Wesley (LPE).

Evaluation Methods:
Continuous Internal Assessment and End Semester Exam:
Assignments, Research paper Review, written test, problem solving, presentations.
Course outcome:
Learner should be able to:

1. Understand and analyze dispersive properties of materials, conductor, dielectrics and plasmas, and the dispersion and propagation of Electromagnetic waves in them.
2. Application of this knowledge to analyze the behaviour of electromagnetic fields in Waveguides.
3. Understand radiating systems and analyze Multipole Radiation in Atoms and Nuclei.
4. Understand the lattice vibrations and thermal properties of solids, phonons and their dispersive and thermal properties.
5. Understand optical properties of materials and various models of magnetism.
6. Be creative and outline the importance of solid state physics in the modern society, for example, Synthesise and characterize novel materials which can be used for devices.

MSc. PHYSICS **Course: SPHY0803**
Title: ATOMIC, MOLECULAR & NUCLEAR PHYSICS

Learning Objectives:

- To study atomic systems and their interaction with electromagnetic fields.
- To understand fundamentals of nuclear and particle physics.
- To study Physics of nuclear detectors and accelerators.

Number of lectures: 60

UNIT I: **[15 lectures]**

One-electron atoms:

Fine structure of hydrogenic atoms, The Zeeman effect, The Stark effect, The Lamb shift, Hyperfine structure and isotope shifts, Problems

Two-electron atoms:

The Schrodinger equation for two-electron atoms, Para and ortho states, Spin wave functions and the role of the Pauli exclusion principle, The independent particle model, The ground state of two-electron atoms, Excited states of two-electron atoms, Doubly excited states of two-electron atoms. Auger effect (autoionization), Resonances Problems

UNIT II: [15 lectures]

Many-electron atoms: The central field approximation, The periodic system of the element, The Thomas-Fermi model of the atom, The Hartree-Fock method and the self-consistent field, Corrections to the central field approximation, L- S coupling and j-j coupling, Problems

The interaction of many-electron atoms with electromagnetic fields:

Selection rules, The spectra of the alkalis, Helium and the alkaline earths, Atoms with several optically active electrons. Multiplet structure Interaction with magnetic fields. Zeeman Effect, The quadratic Stark effect, X-ray spectra

Some applications of atomic physics: Magnetic resonance and the measurement of gyromagnetic Masers and lasers, Controlled thermonuclear fusion, Astrophysics Problems

UNIT III: [15 lectures]

Deuteron Problem and its ground state properties, Estimate the depth and size of (assume) square well potential, Tensor force as an example of non-central force, nucleon-nucleon scattering-qualitative discussion on results, Spin-orbit strong interaction between nucleon, double scattering experiment..

Nuclear Models: Shell Model (extreme single particle): Introduction, Assumptions, Evidences, Spin-orbit interactions, Predictions including Schmidt lines, limitations, collective model.

Nuclear Reactions: Kinematics, scattering and reaction cross sections, Compound nuclear reaction, direct nuclear reaction.

UNIT IV: [15 lectures]

Nuclear Detectors: Gamma ray spectrometer using NaI scintillation detector, High Purity Germanium detector, Multi-wire Proportional counter.

Accelerators: Cockroft Walten Generator, Van de Graaf Generator, Sloan and Lawrence type Linear Accelerator, Proton Linear Accelerator, Cyclotron and Synchrotron.(self study)

Introduction to the elementary particle Physics : The Eight fold way, the Quark Model, the November revolution and aftermath, The standard Model, Revision of the four forces, cross sections, decays and resonances, Introduction to Quantum Chromodynamics. Weak interactions and Unification Schemes (qualitative description), Properties of Neutrino, helicity of Neutrino, Parity, Qualitative discussion on Parity violation in beta decay and Wu's Experiment, Charge conjugation, Time reversal, Qualitative introduction to CP violation and TCP theorem.

References:

1 Robert Eisberg and Robert Resnick, Quantum physics of Atoms, Molecules, Solids, Nuclei and Particles, John Wiley & Sons, 2nd ed, (ER)
2 B.H. Bransden and G. J. Joachain, Physics of atoms and molecules, Pearson Education 2nd ed, 2004 (BJ)
3 G. K. Woodgate, Elementary Atomic Structure, Oxford university press, 2nd ed, (GW).
4 Introductory Nuclear Physics, Kenneth Krane, Wiley India Pvt. Ltd.
5 Introduction to Elementary Particles, David Griffith, John Wiley and sons.
6 Techniques for Nuclear and Particle Physics Experiments, W.R. Leo, Springer-Verlag
7 Radiation Detection and Measurement, Glenn F. Knoll, John Wiley and sons,Inc.
8 Particle Accelerators, Livingston, M. S.; Blewett, J.

Evaluation Methods:

Continuous Internal Assessment and End Semester Exam:

Assignments, Research paper Review, written test, problem solving, presentations.

Course Outcomes:
Learner should be able to :
1. Understand and analyse the simple atomic structure described by quantum physics and interaction of atoms with electromagnetic fields.
2. Apply simple atomic model to analyse problems on physical and biological sciences.
3. Understand complex atomic models and its consequences.
4. Use various spectroscopy techniques to understand theory of the atomic models.
5. Understand nuclear models and reactions and how nuclear reactors and detectors are built for energy production and detection.
6. Master the design of particle accelerators to produce elementary particles and learn the physics of elementary particles

MSc PHYSICS **Course: SPHY0804**

Title: ELECTRONICS AND DIGITAL IMAGE PROCESSING

Learning Objectives:

- To develop an understanding of digital electronics and machine level language in electronic communication for data acquisition systems.
- To study how digital images are represented and manipulated in a computer, including reading and writing from storage, and displaying.

Number of lectures: 60

UNIT I: **[15 lectures]**

Digital Electronics

Review: Logic families TTL and CMOS devices, Tri-State Devices, Flip flops, Registers and Counters, Concept of Control lines Such as Read/Write Chip Enable.

Encoders, Decoders, Latch, Multiplexers and their use in Combinational Logic design, De-multiplexers and their use in Combinational Logic design, De-multiplexer tree. Memory Classification, Charge Coupled Device memory.

Data transmission system: Network models (OSI), layers in OSI model, Addressing modes, Analog and digital signals, D to A, A to D conversion, data rate limit, data transmission modes.

Modulation and detection in analog and digital systems; Sampling and data reconstructions; Quantization & coding; Time division and frequency division multiplexing; Equalization.

Information Encoding, Error Detection and Correction: Introduction, representing different symbols, Minimizing errors, Error classification, types of errors, redundancy, detection versus correction, hamming distance, cyclic redundancy check, checksum.

UNIT II: [15 lectures]

Introduction to image Processing:

Fundamentals, Human visual perception, components of image processing system.

Image Formation and Representation
Introduction, Image formation, Sampling and Quantization, Binary image, Three-dimensional imaging, Image file formats.

UNIT III: [15 lectures]

Color and Color Imagery
Introduction, Perception of colours, Color space and transformation, Color interpolation.
Image Transformation
Introduction, Fourier transforms, Discrete cosine transform, WH transform, Principal component analysis.

UNIT IV: [15 lectures]

Image enhancement and restoration

Introduction, Spatial image enhancement techniques, Histogram based contrast enhancement, Frequency domain method of image enhancement, Noise modelling, Image restoration.

Image Segmentation

Edge, Line and Point Detection, Edge detector, Image Thresholding Technique, Region growing, Waterfall algorithm for segmentation, connected component labeling, Document Image Segmentation.

Reference:

1. Malvino and Leach, Digital Principles and Applications, TMH Publication, Fourth edition
2. R.P. Jain, Modern digital electronics, TMH Publication, Fourth edition
3. B.A. Forouzan, Data communications and networking, TMH Publications, Fourth edition
4. Kennedy and Davis, Electronic communication systems, Fourth edition.
5. Image Processing: Principles and applications by Tinku Acharya and Ajoy K. Ray, A John Wiley & Sons, Inc., Publication.
6. Digital image processing, third edition, Gonzalez and woods, Pearson, Prentice Hall.

Evaluation Methods:

Continuous Internal Assessment and End Semester Exam:

Assignments, Research paper Review, written test, problem solving, presentations.

Course Outcomes:

Learner should be able to :

1. Review the fundamental concepts of digital image processing.
2. Analyze images in the frequency domain using various transforms.
3. Evaluate the techniques for image enhancement and interpret image segmentation techniques.
4. Understand programming for electronic data acquisition systems using the machine language.
5. Understand electronic communication systems and analyse various techniques to overcome electronic error in data encryption/decryption.
6. To understand and develop controller based electronic system for data acquisition in various physics experiments.

MSc. PHYSICS **Course: SPHY0901**
Title: PHYSICS OF RADIATION AND MATTER

Learning Objectives:
- To study radiative processes in matter and its applications.
- To study relativistic electrodynamics.

Number of lectures: 60

UNIT I: **[15 lectures]**
Review: Fundamentals Of Radiative Transfer: The Electromagnetic Spectrum; Elementary Properties of Radiation, Radiative Flux, The Specific Intensity and Its Moments, Radiative Transfer, Thermal Radiation, The Einstein Coefficients, Scattering Effects; Radiative Diffusion
Basic Theory Of Radiation Fields: Review of Maxwell's Equations. Plane Electromagnetic Waves. The Radiation Spectrum. Polarization and Stokes Parameters. Electromagnetic potentials. Applicability of Transfer Theory and the Geometrical Optics Limit
Radiation From Moving Charges: Retarded Potentials of Single Moving Charges - The Lienard-Wiechart Potentials, The Velocity and Radiation Fields, Radiation from Nonrelativistic Systems of Particles, Thomson Scattering (Electron Scattering), Radiation Reaction. Radiation from Harmonically Bound Particles

UNIT II: **[15 lectures]**

Special theory of relativity: Review: Covariance of Electromagnetic Phenomena, Fields of a Uniformly Moving Charge, Emission from Relativistic Particles, Invariant Phase Volumes and Specific Intensity.
Kinematics and Dynamics of Relativistic Particles and Electromagnetic Fields:
Matrix Representation of Lorentz Transformations, Infinitesimal Generators, Thomas Precession, Invariance of Electric Charge; Covariance of Electrodynamics, Transformation of Electromagnetic Fields, Relativistic Equation of Motion for Spin in Uniform or Slowly Varying External Fields.
Lagrangian and Hamiltonian for a Relativistic Charged Particle in External Electromagnetic Fields, Motion in a Uniform, Static Magnetic Field, Motion in Combined, Electric and Magnetic Fields, and in Nonuniform, Static Magnetic Fields, Adiabatic Invariance of Flux Through Orbit of Particle, Lowest Order Relativistic Corrections to the Lagrangian for Interacting Charged Particles: The Darwin Lagrangian, Lagrangian for the Electromagnetic Field.
Bremsstrahlung: Emission from Single-Speed Electrons. Thermal Bremsstrahlung Emission. Thermal Bremsstrahlung (Free-Free) Absorption, Relativistic Bremsstrahlung

UNIT III: **[15 lectures]**

Synchrotron Radiation: Total Emitted Power, Spectrum of Synchrotron Radiation: A Qualitative Discussion, Spectral Index for Power-Law Electron Distribution, Spectrum and Polarization of Synchrotron Radiation, Polarization of Synchrotron Radiation. Transition from Cyclotron to Synchrotron Emission, Distinction between Received and Emitted Power. Synchrotron Self-Absorption. The Impossibility of a Synchrotron Maser in Vacuum

Compton Scattering: Cross Section and Energy Transfer for the Fundamental Process, Inverse Compton Power for Single Scattering, Inverse Compton Spectra for Single Scattering, Energy Transfer for Repeated Scatterings in a Finite, Thermal Medium: The Compton Y Parameter, Inverse Compton Spectra and Power for Repeated Scatterings by Relativistic Electrons of Small Optical Depth, Repeated Scatterings by Nonrelativistic Electrons: The Kompaneet's Equation, Spectral Regimes for Repeated Scattering by Nonrelativistic Electrons
Plasma Effects: Dispersion in Cold, Isotropic Plasma, Propagation Along a Magnetic Field; Faraday Rotation, Plasma Effects in High-Energy Emission Processes: Cherenkov Radiation, Razin Effect

UNIT IV **[15 lectures]**

Revision: Atomic Structure (Self Study)
Radiative Transitions: Semi-Classical Theory of Radiative Transitions, The Dipole Approximation, Einstein Coefficients and Oscillator Strengths, Selection Rules, Transition Rates: Bound-Bound Transitions for Hydrogen, Bound-Free Transitions (Continuous Absorption)for Hydrogen, Radiative Recombination etc., Line Broadening Mechanisms
Revision: Pure Rotation Spectra, Rotation-Vibration Spectra, Electronic-Rotational-Vibrational Spectra Energy Levels (Self Study)
Molecular Structure: The Born-Oppenheimer Approximation, Electronic Binding of Nuclei: The H_2^+ Ion, The H_2 Molecule
Application to Astrophysical systems: Stellar Atmospheres: The Description of the Radiation Field, Stellar Opacity, Radiative Transfer, The Transfer Equation, The Profiles of Spectral Lines; The Interstellar Medium: Interstellar Dust and Gas and Radiation (Ref. Carroll and Ostlie, chapter 9 and 12)

Reference:

1 Radiative Processes In Astrophysics by George B. Rybicki and Alan P. Lightman, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.
2 Classical Electrodynamics by J. D. Jackson, 3rd edition, John Wiley and Sons pvt. Ltd.
3 Electromagnetic Waves and Radiating Systems, 2nd edition, E. C. Jordan and K. G. Balmain, Prentice Hall Inc.
4 Quantum Chemistry by Ira Levine, Pearson publications, chapter 13

Evaluation Methods:

Continuous Internal Assessment and End Semester Exam:

Assignments, Research paper Review, written test, problem solving, presentations

Course Outcome:

Learner should be able to:
1. Have knowledge of the radiative processes in the presence of matter.
2. Understand how the radiation and matter interact in different physical states of matter.

3. Apply mathematical tools and physics laws to understand the nature of radiation in stars and interstellar medium.
4. Use online resources to analyse the data obtained from various astronomical observations which leads to understanding of electromagnetic radiation.
5. Evaluate the results of this analyses and interpret the nature of the Solar system, variety of stars and galaxies.
6. Create new observational programs or data analyses and interpretation projects to further our knowledge of radiative processes in Astrophysics.

MSc. PHYSICS **Course: SPHY0902**
Title: STELLAR STRUCTURE AND EVOLUTION

Learning Objectives:

- To study stellar models, the structure of stellar interior and its atmosphere.
- To study star's life cycle from formation to death.

Number of lectures: 60

UNIT I: **[15 lectures]**

Stellar Atmospheres and the Structure:
Stellar Atmospheres: The Description of the Radiation Field, Stellar Opacity, Radiative Transfer, The Transfer Equation, The Profiles of Spectral Lines;
The Interiors of Stars: Hydrostatic Equilibrium, Pressure Equation of State, Stellar Energy Sources, Energy Transport and Thermodynamics, Stellar Model Building, The Main Sequence;

UNIT II: **[15 lectures]**

Stellar Models, Star Formation:
Influence of convection zones on stellar structure, Calculation of stellar models, Models for main sequence stars, The Sun: The Solar Interior, The Solar Atmosphere, The Solar Cycle;
The Interstellar Medium and Star Formation: Interstellar Dust and Gas, The Formation of Protostars, Pre-Main-Sequence Evolution

UNIT III: **[15 lectures]**

Stellar Evolution:
Main Sequence and Post-Main-Sequence Stellar Evolution: Evolution on the Main Sequence, Evolution of low mass stars, Evolution of massive stars, Pulsating stars, The Cepheid mass problem, Post-Main-Sequence Evolution of Massive Stars, The Classification of Supernovae, Core-Collapse Supernovae, Gamma-Ray Bursts, Cosmic Rays; Observational tests of stellar evolution theory

UNIT IV: **[15 lectures]**

The End States of Stellar Evolution:
The Degenerate Remnants of Stars: White Dwarfs, The Chandrasekhar Limit, Neutron Stars, Pulsars;
The Black Holes: General Theory of Relativity and Black Holes;
Close Binary Star systems and Evolution: Gravity in close binary star system, Accretion disks, White dwarfs in semi-detached binaries, Type Ia supernovae, Neutron stars and Black holes in Binaries;

References:

1 An Introduction to the Theory of Stellar Structure and Evolution, Dina Prialnik, second edition, Cambridge University Press, 2011.
2 An Introduction to Modern Astrophysics, Second Edition, By Carroll B.W., Ostlie D.A., Pearson Addison Wesley.
3 Introduction to Stellar Astrophysics, Volume 3, *Stellar structure and evolution* , By Erika Bohm-Vitense, Cambridge University Press
4 The Physical Universe: An Introduction to Astronomy By F. H. Shu, 1982, University Science Books.

Evaluation Methods:

Continuous Internal Assessment and End Semester Exam:

Assignments, Research paper Review, written test, problem solving, presentations.

Course Outcome:

Learner should be able to:
1. Have knowledge of the star's life cycle from formation to death and the processes that change our vast universe slowly but continuously.
2. Understand how the energy is generated in the interior of the Sun and how this store of energy is received by planets such as earth.
3. Apply mathematical tools and physics laws to understand the structure of stellar interior and its atmosphere.
4. Analyse the data obtained from various astronomical observations to develop stellar models.
5. Evaluate the results of this analyses and understand the nature of the Sun and other stars of different types.
6. Create new observational programs or data analyses and interpretation projects to understand the different stages of stellar evolution.

MSc. PHYSICS **Course: SPHY0903**
Title: GALAXIES: FORMATION, STRUCTURE AND DYNAMICS

Learning Objectives:

- To study observational facts about galaxies and large scale structures in the universe.
- To study cosmological perturbations, gravitational collapse and collisionless dynamics in the formation of a galaxy.
- To study structures of different types of galaxies and their clustering and evolution.

Number of lectures: 60

UNIT I: **[15 lectures]**

Galaxies and The Large scale structure:
Introduction : The Diversity of the Galaxy Population, Basic Elements of Galaxy Formation, Time Scales, A Brief History of Galaxy Formation;
Observational Facts: Galaxies, statistical properties of galaxy populations, Clusters and Groups of Galaxies, Galaxies at High Redshifts, the large scale structure, The Intergalactic Medium, The Cosmic Microwave Background, The Homogeneous and Isotropic Universe;
Cosmological Background: brief overview of the expanding universe and the early universe.

UNIT II: **[15 lectures]**

Galaxy Formation:
Cosmological Perturbations: Newtonian Theory of Small Perturbations, Relativistic Theory of Small Perturbations, Linear Transfer Functions, Statistical Properties, The Origin of Cosmological Perturbations;
Gravitational Collapse and Collisionless Dynamics: Spherical Collapse Models, Collapse of Homogeneous Ellipsoids, Collisionless Dynamics, Collisionless Relaxation, Gravitational Collapse of the Cosmic Density Field;
Probing the cosmic density field: Large-Scale Mass Distribution, Large-Scale Velocity Field, Clustering in Real Space and Redshift Space, Clustering Evolution, Galaxy Clustering, Gravitational Lensing, Fluctuations in the Cosmic Microwave Background.

UNIT III: **[15 lectures]**

Galaxy Dynamics:
Formation and Structure of Dark Matter Halos: Density Peaks, Halo Mass Function, Progenitor Distributions and Merger Trees, Spatial Clustering and Bias, Internal Structure of Dark Matter Halos, The Halo Model of Dark Matter Clustering;
Formation and Evolution of Gaseous Halos: Basic Fluid Dynamics and Radiative Processes, Hydrostatic Equilibrium, The Formation of Hot Gaseous Halos, Radiative Cooling in Gaseous Halos, Thermal and Hydrodynamical Instabilities of Cooling Gas, Evolution of Gaseous Halos with Energy Sources, Observational Tests;

UNIT IV: **[15 lectures]**

Galactic Evolution:

Disk Galaxies: Mass Components and Angular Momentum, The Formation of Disk Galaxies, The Origin of Disk Galaxy Scaling Relations, The Origin of Exponential Disks, Disk Instabilities, The Formation of Spiral Arms, Chemical Evolution of Disk Galaxies;

Galaxy Interactions and Transformations: High-Speed Encounters, Tidal Stripping, Dynamical Friction, Galaxy Merging, Transformation of Galaxies in Clusters;
Elliptical Galaxies: Structure and Dynamics, The Formation of Elliptical Galaxies, Observational Tests and Constraints, The Fundamental Plane of Elliptical Galaxies, Stellar Population Properties, Bulges, Dwarf Ellipticals and Dwarf Spheroidals;
Active Galaxies: The Population of Active Galactic Nuclei, The Formation and Evolution of AGN, AGN and Galaxy Formation

References:

Galaxy Formation And Evolution by Houjun Mo, Frank Van Den Bosch, Simon White, Cambridge University Press, 2010.

Extragalactic Astronomy and Cosmology, An Introduction, by Peter Schneider, Springer

Galactic Dynamics (Second Edition), by James Binney & Scott Tremaine, Princeton University Press.

Evaluation Methods:

Continuous Internal Assessment and End Semester Exam:

Assignments, Research paper Review, written test, problem solving, presentations.

Course Outcome:

Learner should be able to:

1. Have knowledge of the different types of galaxies and their clustering and evolution which is the expanse of the universe.
2. Understand the technology used for cosmological observations done for these celestial objects.
3. Apply mathematical tools and physics laws to understand the nature of galaxies and their clustering.
4. To analyse the data obtained from various astronomical observations using the online resources.
5. Evaluate the results of this analyses and interpret the nature of the galaxies and the black holes in the center.
6. Create new observational programs or data analyses and interpretation projects in galactic astronomy and cosmology.

MSc. PHYSICS **Course: SPHY0904**
Title: GENERAL RELATIVITY AND COSMOLOGY

Learning Objectives:
- To understand the relation of gravitation to curvature of the space-time.
- Applications of the Einstein's filed equations to gravitational waves, black holes etc.
- Applications of General Relativity to classical cosmology.

Number of lectures: 60

UNIT I: **[15 lectures]**

Special Relativity:
Tensor analysis in special relativity: The metric tensor, Definition of tensors, The (0,1) tensors: one-forms, The (0,2) Tensor, Metric as a mapping of vectors into one-forms, (M,N) tensors, Index 'raising' and 'lowering', Differentiation of tensors;
Perfect fluids in special relativity: Fluids, Dust, General fluids, Perfect fluids, Importance for general relativity, Gauss' law;

UNIT II: **[15 lectures]**

Curved Space-Time and Gravitation:
Preface to curvature: On the relation of gravitation to curvature, Tensor algebra in polar coordinates, Tensor calculus in polar coordinates, Christoffel symbols and the metric, Non coordinate bases;
Curved manifolds: Differentiable manifolds and tensors, Riemannian manifolds, Covariant differentiation, Parallel-transport, geodesics, and curvature, The curvature tensor, Bianchi identities: Ricci and Einstein tensors, Curvature in perspective;
Physics in a curved spacetime: The transition from differential geometry to gravity, Physics in slightly curved spacetimes, Curved intuition, Conserved quantities – Killing vector formulation. Geodesic deviation.

UNIT III: **[20 lectures]**

General Relativity and its applications:
The Einstein field equations: Purpose and justification of the field equations, Einstein's equations, Einstein's equations for weak gravitational fields, Newtonian gravitational fields;
Experimental tests of GR: Precession of Mercury orbit, Bending of light, Gravitational lenses, cosmological redshift;
Gravitational radiation: The propagation of gravitational waves, The detection of gravitational waves, The generation of gravitational waves, The energy carried away by gravitational waves, Astrophysical sources of gravitational waves;
Spherical solutions for stars: Coordinates for spherically symmetric spacetimes, Static spherically symmetric spacetimes, Schwarzschild geometry and black holes: Trajectories in the Schwarzschild spacetime, Nature of the surface $r = 2M$, General black holes, Real black holes in astronomy, Quantum mechanical emission of radiation by black holes: the Hawking process;

Static perfect fluid Einstein equations, The exterior geometry, The interior structure of the star, Exact interior solutions, Realistic stars and gravitational collapse; Maxwell equations in curved space, Reissner-Nordstrom metric, Kerr metric.

UNIT IV: **[10 lectures]**

Classical Cosmology:
The isotropic universe: The Robertson–Walker metric, Dynamics of the expansion, Common big bang misconceptions, Observations in cosmology. The age and distance scales: The distance scale and the age of the universe, Methods for age determination, Large-scale distance measurements, The local distance scale, Direct distance determinations, Summary.
Thermal History and cosmic microwave backgound.

References:

A First Course in General Relativity, Second Edition, by Bernard F. Schutz , Cambridge University Press

Introduction to general relativity: spacetime geometry by Sean Carroll

Introducing Einstein's relativity by Ray d'Inverno

Cosmological Physics by J. A. Peacock, Cambridge University Press

Evaluation Methods:

Continuous Internal Assessment and End Semester Exam:

Assignments, Research paper Review, written test, problem solving, presentations.

Learning Outcome:

Learner should be able to:

7. Have knowledge of Special and general theory of relativity.
8. Understand the relation of gravitation to curvature of the space-time.
9. Apply mathematical tools and physics laws to understand the nature of massive objects such as neutron stars, black holes and centers of galaxies.
10. To understand the theory of the expanding universe and classical cosmology.
11. Critically analyse and interpret results of modern cosmological observations and data.
12. Apply the knowledge of general theory of relativity and develop new projects in galactic astronomy and cosmology.

MSc. PHYSICS **Course: PHY10PROJ**
Title: M.Sc. Dissertation **Semester IV**
Credits: 24

Learning Objectives:

- To identify an area of the physics and/or astrophysics courses studied where some extension of previously known theories or a new method of analysis and solution can be sought.
- To work out such new ideas through collection of new data and/or analytical or numerical computations relevant to the problem.
- To acquire scientific communication skills and write a comprehensive theses based on the work done.
- To make a presentation of the work and defend the theses.

Scope : Physics, Astronomy and Astrophysics
Students are expected to come up with a comprehensive project work in subjects of physics, astronomy and astrophysics courses they have studied or extension thereof. They can avail guidance of Faculty members from the college or other college approved institutions. They have to do literature review, Reading and Independent Study. The problem chosen can be based on observational data and/or theoretical concepts. At the end of the course they have to present a thesis. This will be evaluated by regular internal evaluation and a final viva.
The project topics should be chosen so as to inculcate culture of independent research.

Course Outcome:

Learner should be able to :

1. Identify an area for research where the knowledge base can be potentially augmented.
2. Understand the shortcoming/lacunae in state of existing knowledge through literature review.
3. Propose / design a possible solution to the problem at hand through a synopsis.
4. Collaborate with other researcher and laboratories around in the pursuit of the proposed solution through collection and/or data analysis and numerical simulations.
5. Present the entire work in the form of a bound thesis.
6. Defend the work through a presentation and a viva exam to a panel of evaluators.

General guidelines for Fourth Semester Dissertation- MSc Course

1. Students of MSc course program are required to do Dissertation during the IVth semester. There are no other courses to be credited during this semester and students are expected to devote their whole semester for the research work related to project.
   The IVth semester project carries total 24 credits. Thus this Dissertation is equivalent to the full course load of 4 courses like any other semester.

2. All the MSc students of the Department of Physics are already exposed to different areas of research through multiple projects in their practical courses. These projects have been tethered to their theory courses. Along with these projects students have gone through well curated and thoroughly designed lab courses also. Now they have to come up with a MSc thesis

containing good quality as well as quantity of work. A strong experimental, computational, or theoretical physics content is must for this work.

3. At the end of the semester the student must produce a thesis. A thesis must state the problem, summarise previous knowledge, detail the advances made by them in the chosen topic, and discuss its significance.
4. Students should decide on their supervisor and their thesis topic(in consultation with the supervisor) during the previous semester, i.e. the IIIrd semester. A dissertation proposal, signed by the proposed supervisor, should be submitted to the Course Coordinator by the due date towards the end of the IIIrd semester. If the proposal is not deemed satisfactory, student will improve/change their proposal during the semester break and resubmit on the 1st day of semester IV.
5. Any Physics Department faculty member is an acceptable thesis supervisor.
6. A student can choose to work with a professor from an institute/university other than Xavier's for his/her dissertation. In that case the student has to discuss with the course coordinator and get an approval. There will be a co-supervisor from the Xavier's Department of Physics. Discuss your proposal with both, the supervisor and the co-supervisor, and fill up the dissertation proposal form after that. The form should be signed by both supervisors.
7. If a student wants to do a dissertation under the supervision of a faculty from any department of St. Xavier's college other than the Physics Department, then the student has to discuss with the course coordinator if a departmental co-supervisor is required. Student will then write the dissertation proposal and submit as above.
8. The students will work regularly throughout the semester. They will have at least **one** session with the supervisor every week and will remain in e-mail contact with the supervisor. (Specially for an out state supervisor). The supervisor will maintain a record of weekly attendance and a record of progress of the student.
9. There will be a mid-term review: presentation and evaluation of the work done so far and future plans.
10. A copy of the thesis, signed by the dissertation supervisor, must be submitted to Academic Programs on the thesis due date, at the end of March.
11. This submitted copy of the final thesis will be kept in the department archives. All theses submitted shall become the permanent physical property of the College.
12. St. Xaviers College will retain the ownership of the copyright of the dissertation / thesis. (This will stay until St. Xavier's comes up with a thorough copyright norms).
13. IVth semester research projects may lead to publications in internationally & Nationally reputed journals. Thus the students are encouraged to finish their work early and apply to various journals for publication.

Evaluation

1. Supervisor will evaluate the proposal of the thesis for 100 Marks. (Weightage 15%)

2. For mid semester review (in IVth semester), a brief project report (3-5 pages) must be presented by 10 January to the supervisor. The report should consist of the work already done and to be done in next few months.
3. Mid-year semester Evaluation will be conducted by the supervisor (along with one more invited referee) any time in the middle of January. Student must present the work. In the case of students who will be doing project outside the city of Mumbai, the supervisor (along with one more invited referee) will conduct the mid-semester presentation via a video link. Based on the report and presentation, the referee and supervisor will independently give marks out of 100. An average of the two should be calculated. It will have 20% weightage in overall grades. The evaluation report with marks should be submitted by 30 January.
4. After mid semester evaluation, for any student to continue the project, a minimum score of 40 marks out of 100 is mandatory. If a student scores less than 40 marks then he/she has to start the project afresh. It can be with the same supervisor or a new supervisor.
5. The supervisor will give marks out of 100 based on continuous assessment throughout the semester IV and the thesis(for a weightage of 15%) .
6. The MSc thesis on the work done during the dissertation is to be submitted at the end of March. A committee of two referees will give marks out of 100 for the thesis (Average for a weightage of 20%) .
7. The project will be evaluated at the end of the IV semester by an open defence. The thesis defence has to be carried out at least in front of two evaluators. They will give marks out of 100(Average for a weightage of 30%).
8. Based on the marks obtained in various components, the total marks out of 100 will be calculated as per weightage given below.

Time of evaluation	**Components of assessment**	**Average Marks out of 100 given by**	**Weightag e in total marks**
Mid Semester	End of semester III approval of title, proposal evaluation start of semester IV	Supervisor	15%
	Mid set Report and Presentation	Referees + Supervisor (Average)	20%
End of semester X	Continuous evaluation for semester IV and thesis	Supervisor	15%
	MSc Thesis	Referees (Average)	20%
	Defence and viva	Discipline wise Committee	30%

9. The final Score or Grade point for the project is derived from the total marks out of 100 by converting it to a 10 point scale (up to one decimal place). This score will be used for calculating the final CGPA with 24 credits for the project work.

10. Students getting less than 40% will fail in the project. They can start a new project for another semester, provided the total duration of the program is within 4 years.

SYLLABUS FOR MSC IN PHYSICS (ASTROPHYSICS SPECIALIZATION) LABORATORY COURSES

Semester I **Course code PHY07PR**

The laboratory course will include experiments based on the following:
Classical Mechanics, Quantum Mechanics, Numerical methods and Computational techniques (Python Programming), Basic Astronomy experiments and data analysis.
There will be projects undertaken by the students that are related to the theory courses of the semester.
List of Experiments:

Numerical methods and Computational techniques (Python Programming)

- root finding (using e.g. Newton-Raphson method)
- system of linear equations (using e.g. LU decomposition)
- ordinary differential equations (using e.g. Runge–Kutta methods)
- integration (using e.g. Romberg method and Monte Carlo integration)
- partial differential equations (using e.g. finite difference method and relaxation method)
- matrix eigenvalue problem (using e.g. Jacobi eigenvalue algorithm and power iteration)
- Solving FD Method, FFT

Classical Mechanics

- Swinging Atwood's machine, Double pendulum, Orbital trajectories simulation, Rotating top with high speed camera, Coupled harmonic Oscillator.

Quantum Mechanics

- Measurements of planks constant, Simulations of wave functions and CG Coefficient, Tutorials.

Optical Astronomy Instruments and observational techniques

- Parallax Method for distance measurement, Temperature of an artificial star, Identifying Fraunhofer absorption lines in Sun's spectrum, Solar Limb Darkening and tracking sunspots, Locating celestial objects, Basic Photometry.

References:-

1. 'An Introduction to Computational Physics' Second Edition Tao Pang cambridge university press

2. M. E. J. Newman and G. T. Barkema, Monte Carlo Methods in Statistical Physics. Oxford University Press, 1999.
3. Computational Physics. J. M. Thijssen, Cambridge - 2007.
4. Steven E Koonin and D C Meredith, Computational Physics [fortran version], Perseus Books.
5. Numerical Recipes, Cambridge Univ Press.
6. NUMERICAL METHODS IN ENGINEERING WITH PYTHON Second Edition Jaan Kiusalaas CAMBRIDGE UNIVERSITY PRESS.

Semester II **Course code PHY08PR**

The laboratory course will include experiments based on the following: Simulations Lab for Statistical Mechanics, Electrodynamics lab (microwave and radio wavelength experiments to be included), Atomic, Molecular & Nuclear Physics, Electronics (data acquisitions systems etc.) & Digital Image Processing.
There will be projects undertaken by the students that are related to the theory courses of the semester.

List of Experiments:

Statistical Mechanics

- Simulations Lab (Ref: Chapter 16, Statistical Mechanics by Pathria & Beale) (Any 4)
  Introduction and Statistics, Monte Carlo simulations, Molecular dynamics, Particle simulations, Computer Simulation caveats

Electrodynamics & SSP

- FDTD Method, Microwave transmitter, Receivers, Wave guides
- Phonon Dispersion relation (simulation), Optical Band gap using FTIR, Magnetoresistance

Atomic, Molecular & Nuclear Physics

- Zeeman effect (Normal, Anomalous), Molecular Spectra by using Spectrophotometer, Simulations

Electronics (data acquisitions systems etc.) & DIP

- Study of 3:8 Decoder (74LS138) and 8:3 Encoder (74LS148) and their applications. (RPJ) & Study of 8:1 Multiplexer (74LS151) and1: 4 De-multiplexer (74LS155) and their applications. (RPJ)
  Study of ROM and its addressing using decoder. (RPJ & RG)
  Writing Assembly Language Programs using Direct Register Addressing, Indirect Addressing (RG)
  Applications of Microprocessors/ Microcontroller
  Ref: R.P. Jain, Modern digital electronics, Fourth edition
  R. Gaokar, Microprocessor Architecture, programming and Applications with the 8085, 5th Edition, Prentice Hall of India.

- Lab course : AstroImageJ (AIJ) is simply generic ImageJ (IJ) with customizations to the base code and a packaged set of astronomy specific plugins.
- Intensity transformations, Image corrections, FFT based Image transformations (Using Python)

Semester III **Course code PHY09PR**

Laboratory Courses

Laboratory Courses

The laboratory course will include the following:

Optical and Infrared Astronomy: Observations and data analysis, Archival data analysis (UV, x-ray and gamma ray astronomy), Computational Astrophysics (Stellar & Galactic Dynamics), Observational / Theoretical Astrophysics Project (on GR and Cosmology). There will be projects undertaken by the students that are related to the theory courses of the semester.

Astronomical observations and data analysis using open access archived databases
- Radio, Optical and Infrared Astronomy

Astronomical data analysis using open access archived databases
- UV, x-ray and gamma ray astronomy

Computational Astrophysics (Stellar & Galactic Dynamics)
- Numerical Methods and Computational Techniques

GR and Cosmology
- Simulations, Tutorials

Semester IV **Course code PHY10PROJ**

Dissertation

Credits: 24

Scope : Physics, Astronomy and Astrophysics

Students are expected to come up with a comprehensive project work in subjects of physics, astronomy and astrophysics courses they have studied or extension thereof. They can avail guidance of Faculty members from the college or other college approved institutions. They have to do literature review, Reading and Independent Study. The problem chosen can be based on observational data and/or theoretical concepts. At the end of the course they have to present a thesis. This will be evaluated by regular internal evaluation and a final viva.

The project topics should be chosen so as to inculcate culture of independent research.