**PONDICHERRY UNIVERSITY**
**PUDUCHERRY 605 014**

# M. Sc.(Astrophysics)

## Scheme & Syllabus

# 2011-12 Onwards

# M.Sc. Programme in Astrophysics

Department of Physics will mentor the **M.Sc. Programme in Astrophysics**, which is to be introduced from the academic year 2011-12.

Astronomy is one of the oldest fields of scientific enquiry. It is an observational science that studies celestial objects (planets, stars, galaxies ...) that make up the Universe and phenomena that may hold the key to understand their nature, as well as the origin and evolution of the Universe. Astrophysics deals with the physics of the Universe and applies many disciplines of physics, including mechanics, electromagnetism, statistical mechanics, thermodynamics, quantum mechanics, relativity, nuclear and particle physics, and atomic and molecular physics.

Indian astronomers and physicists, in ancient as well as in recent times have made important contributions to Astronomy and Astrophysics. Today, a number of institutions (IIA, IUCAA, ARIES, TIFR, PRL, OU...) and facilities (ground-based optical/infrared telescopes at VBO, Hanle, Girawali, Nainital, Mt. Abu; radio telescopes at Ooty, GMRT, Gauribidanur) for research in astronomy and astrophysics exist in the country. Also, space-based facilities like ASTROSAT, ADITYA for work in X-ray, Ultraviolet/Optical and High-Altitude facilities (HAGAR, MACE..) for work in the Gamma-ray waveband are coming up. India is also planning to join the International Astronomy Community in the development of a Giant Segmented Mirror Telescope (GSMT).

There is, however, an acute shortage of young students with adequate background in basic astronomy/astrophysics who could take up research in astronomy/astrophysics and use these state-of-the-art facilities. In most Indian universities, there are no teaching programmes at the MSc level fully devoted to astronomy/astrophysics. **The proposed M.Sc Programme in Astrophysics of the Pondicherry University is intended to bridge this gap and help train bright, motivated, young students to take up research careers in astrophysics**

This M.Sc. programme is designed to impart sound understanding of basic physics, astrophysical processes and the necessary background knowledge of present-day developments in astronomy including practical training in instrumentation and observations at astronomical observatories in the country. The Pondicherry University is planning to introduce M.Sc. Astrophysics from this academic year, 2011-2012.

In addition to main papers covering the core areas in Physics, the programme is planned to cover advanced courses in Astrophysics including the following by experts in the relevant fields.

- Stellar Structure
- Diffuse Matter in Space
- Galactic Structure & Dynamics
- Stellar Evolution
- Physics of Compact Objects
- General Relativity and Cosmology

The students who pass out of this course will have good job and research opportunities.

**Details of the programme**

**Programme Duration:**

Two years (Four Semesters); Total number of credits: 77

**Eligibility criteria:**

B.Sc. Physics/Electronics/Mathematics/Applied Physics with a minimum percentage of 55 marks in part III.
4 Year B.E/B.Tech in Electronics /ECE/Electrical/EEE/Optics/Engineering Physics/Applied Physics/Mechanical/Instrumentation/Computer Science with a minimum percentage of 55 marks in main subjects.

**Admission criteria:**

Pondicherry University – All India Entrance Examination: The questions will have emphasize in undergraduate level Physics

**Intake:** 10 students

**Teaching and Learning Methods:**

Lectures, tutorials and seminars form the main methods of course delivery enhanced by individual and group project work, laboratory work, computing workshops and industrial/Institution visits. Some of the specialized courses will be conducted in coordination with the Faculty of Indian Institute of Astrophysics, Bangalore/ IUCAA, Pune in Pondicherry or Bangalore/Pune.

**Assessment Methods:**
Assessment will be as per Choice Based Credit System (CBCS) which includes continuous assessment and end semester examinations.

**Scheme of Courses and Credits for M.Sc. Astrophysics:**

| **First year**: | **Odd semester** | **Even Semester** |
|---|---|---|
| Compulsory subjects | 4 (16) | 4 (16) |
| Elective Subjects | 1 (3) | 1 (3)* |
| Practical – Laboratory | 1 (3) | 1 (3) |

| **Second year**: | **Odd semester** | **Even Semester** |
|---|---|---|
| Compulsory subjects | 5 (20) | -- |
| Elective Subjects | -- | 2 (6)* |
| Practical – Laboratory | 1 (3) | -- |
| Project | | 4 |

*Depending on Students choice & faculty availability all three or two Groups (A/B/C) will be offered

**PONDICHERRY UNIVERSITY**

***2 year M. Sc (Astrophysics) Programme***

**CONTENTS**

**APHYS-111: MATHEMATICAL METHODS IN PHYSICS** **(4 credits)**

**UNIT – I: Linear Algebra** **6 hours**

Linear vector spaces – Dual space – Basis sets – Orthogonality and completeness – Hilbert space – Linear operators – Linear dependence and independence

**UNIT – II: Vectors and Tensors** **12 hours**

Scalars, vectors and tensors in index notation – Del and Laplacian operators – Vector calculus in index notation – Dirac delta function – Representation and properties – Fundamentals of tensors – Algebra of Cartesian tensors – Outer product – Contraction and quotient theorems – Kronecker & Levi-Civita tensors – Examples and applications in physics.

**UNIT – III: Complex Variables** **15 hours**

Elements of analytic function theory – Cauchy-Riemann conditions – Singularities, poles and essential singularities – Cauchy's integral theorem – Cauchy integral formula – Residue theorem and contour integration Residue method for real integration – Taylor and Maclaurin expansion – Laurent and Taylor series of complex functions – Introduction to conformal mapping.

**UNIT – IV: Special Functions** **12 hours**

Beta, Gamma, Delta and Error functions – Bessel, Hermite, Legendre, Associated Legendre and Laguerre functions – Generating functions – Series solutions – Recurrence relations – Properties of special functions and their applications in physics.

**UNIT –V: Differential Equations** **15 hours**

First order ODE's – Second order linear ODE's – Differential operators – Physical modeling – Higher order linear ODE's – Homogeneous and inhomogeneous differential equations – Series solution of ODE's – Frobenius method – Strum-Liouvllie problem **-**Introduction to partial differential equations – Introduction to curvilinear coordinates – Cylindrical polar and spherical polar systems – Review of vector calculus – Divergence, curl and Grad in polar system – Solution by analytical methods – Solution of (i) Laplace, (ii) Poisson, (iii) Helmholtz wave and (iv) diffusion equations in Cartesian and polar coordinate systems.

**Textbooks**


1. G. Arfken 2000. *Mathematical Methods for Physicists* (5$^{th}$ Edition) Academic Press.
2. Erwin Kreyszig (2005). *Advanced Engineering Mathematics*. 9$^{th}$ Edition. John Wiley.
3. R.K. Jain, S.R.K. Iyengar (2007). *Advanced Engineering Mathematics.* 3$^{rd}$ Edition. Narosa.


**Supplementary Reading**


1. K. F. Riley, M. P. Hobson and S. J. Bence, *Mathematical Methods for physics and engineering* (Cambridge Univ. Press, 1998)
2. M. P. Boas (2005). *Mathematical Methods in the Physical Sciences* (3$^{rd}$ Edition) Wiley.
3. Potter M C and Goldberg J (1988). *Mathematical Methods*. Prentice Hall.
4. Sokolnikoff I S and Redheffer R M. *Mathematics of Physics and Modern Engineering*. McGraw Hill.
5. Spiegel M R. *Theory and Problems of Complex Variable*. Schaum's Series. McGraw Hill.
6. Spiegel M R. *Theory and Problems of Fourier analysis*. Schaum's Series. McGraw Hill.

**APHYS- 112: CLASSICAL MECHANICS** **(4 credits)**

**Unit I:** **15 hours**

Mechanics of a system of particles – conservation laws of linear and angular momenta for systems not subjected to external forces and torques – constraints – principle of virtual work – Lagrangian equations of motion and a few applications – motion in a central field – Kepler's problem – scattering – laboratory and CM frame – differential scattering cross section – scattering by a central field.

**Unit II:** **15 hours**

Variational method – Hamilton's equations of motion – canonical transformations – generating functions – infinitesimal contact transformations – Lagrange and Poisson brackets – Hamilton, Jacobi theory.

**Unit III:** **15 hours**

Rigid body rotation – rotating frame – Eulerian angles transformation between rotating and stationery frames – Coriolis and centrifugal forces – moment of inertia tensor – Euler's equations – symmetric top precession – theory of small oscillations – normal co-ordinates and vibrations of a discrete system – Forced oscillations.

**Unit IV:** **15 hours**

Special theory of relativity: Inertial frames – Lorentz transformations – length contraction, time dilation and Doppler effect – Minkowski space – Energy momentum four vectors – Introduction to general relativity.

**Text Book**


1. H. Goldstein. Classical Mechanics. Narosa.


**Supplementary Reading**


1. T. G. Takwale and P. S. Purnaik. Introduction to classical mechanics. Tata McGraw Hill.
2. D. T. Greenwood. Classical dynamics. Prentice Hall.
3. A. K. Raychaudri. Classical mechanics. Oxford University Press.
4. Synge and Griffith. Principles of mechanics. McGraw Hill.
5. K. G. Gupta. Classical mechanics of particles and rigid bodies. Wiley Eastern.

**APHYS-113: QUANTUM MECHANICS -I** **(4 credits)**

**Unit I: Quantum theory of spherically symmetric systems** **12 hours**
Particle in a spherically symmetric potential – Angular wave function – Radial equation for a free particle, spherical trap – Hydrogen atom – Spin of an electron – Addition of angular momenta.

**Unit II: Symmetry in Quantum Mechanics** **6 hours**
Symmetries, Conservation laws, and Degeneracies – Discrete symmetries, Parity, or Space Inversion – Lattice translation as a discrete symmetry – Time reversal discrete symmetry.

**Unit III: Pictures of Quantum Mechanics** **6 hours**
Schrodinger picture – Heisenberg picture – Interaction picture – Relation among different pictures – Ehrenfest theorem.

**Unit IV: Time independent perturbation theory** **12 hours**
Non-degenerate perturbation theory – Degenerate perturbation theory – The fine structure of hydrogen – The Zeeman effect – The Stark effect – Hyperfine splitting

**Unit V: Variational Principle and WKB approximation** **6 hours**
The ground state of helium – The hydrogen molecular ion – WKB approximation – Tunneling through potential barriers.

**Quantum theory of scattering** **12 hours**
Scattering theory – scattering particles – potential scattering – partial wave analysis – phase shifts scattering length – integral equations in terms of Green's function – Born approximation and its validity.

**Textbooks**

1. Ghatak and Loganathan. Quantum mechanics. MacMillan.

**Supplementary Reading**

1. L. I. Schiff. Quantum mechanics. McGraw Hill.
2. Dicks and Whike. Introduction to quantum mechanics.
3. J. L. Powell and B. Craseman. Quantum mechanics. Addison-Wesley.
4. V. K. Thankappan. Quantum mechanics. Wiley Eastern.
5. G. Baym. Quantum mechanics.
6. R. P. Feynman. Feynman lectures on physics. Vol. III. Narosa.
7. H. A. Bethe and R. Jakiw. Intermediate quantum mechanics.
8. Benjamin and Cummings. Quantum mechanics. Merc Backe.
9. A. Messiah. Quantum mechanics. Vol. I and II. Addison Wesley.
10. Davydov. Quantum mechanics. Pergamon press.
11. P. A. M. Dirac. The principles of quantum mechanics.
12. P. Roman. Advanced quantum theory.
13. J. J. Sakuri. Advanced quantum mechanics.

**APHYS-114: ELECTRONICS (4 credits)**

**Unit I** **12 hours**

Non-linear resistive devices – NTC, PTC, VDR – Structure, working and applications – Diodes – (Rectifier and Zener) – Tunnel diode – V-I Characteristics. Transistors – (BJT, FET, UJT, MOSFET) – Structure and working, small signal models and equations for V-I characteristics under different conditions, frequency limits and applications.

**Unit II** **12 hours**

Microwave devices and components: IMPATT, GUNN – Klystron, Magnetron – Structure and working, Transmitting and receiving antenna, wave guides, traps, connectors and couplers, filters and matching circuits.

Opto-electronics devices: Radiative and nonradiative transistors, absorption. Bulk and thin film devices – LDR, Photodiode, Solar cell, LED, diode Lasers – Structure, working and factors affecting performance.

**Unit III** **12 hours**

Analog circuits: Linear circuits – operational amplifiers – parameters and their importance applications – Summing, difference, inverting, non-inverting, integrating, differentiating amplifiers – Non-linear circuits – absolute rectifiers, Clipping, Clamping circuits, logarithmic amplifiers, Filters, modulation and demodulation circuits, Timers and Phase-locked loop.

**Unit IV** **12 hours**

Digital circuits: Combinational logic circuits using standard TTL and CMOS LSI chips- gates, latches, multiplexer/demultiplexer, decoder and encoders, Half and full adder, ALU. Sequential logic circuits – Counters – synchronous, asynchronous, binary and decade, divide by N counters, Shift registers – Serial to parallel and vice-versa.

**Unit V** **12 hours**

Microprocessor: 8-bit microprocessor – 8085 Architecture, organization, buses, addressing modes, instruction set, instruction types, Timing and sequencing, Instruction and machine cycle, Timing diagrams – Assembly language programming – simple programs for arithmetic and logical operations, Interrupts – handling interrupts, Interfacing microprocessors – peripheral devices PPI(8255), USART(8251), PIC(8279), DMA(8257) – data transfer modes.

**Textbooks**

1. Unit I & III – Integrated Electronics by Millman & Halkias
2. Unit II (first part) – Physics of Semiconductor devices by Simon M.Sze.
3. Unit II (for microwave topics) – Electronic and Radio Engineering by Terman
4. Unit IV – Digital Principles by Malvino & Leach
5. Unit V – Microprocessor Architecture and Programming 8085 by Ramesh S. Gaonker.

**APHYS – 115: NUMERICAL AND TRANSFORM TECHNIQUES (3 credits)**

**UNIT – I: 10 hours**

Representing numbers in a computer – Machine precision – Introduction to numerical errors – Errors in mathematical approximations – Error propagation – Introduction to MATLAB – Workspace – Creating arrays – Matrix operators – Generating vectors – Accessing sub-matrices – Control flow statements – Infinite loops – Introduction to *M*-files – Graphics in MATLAB – Creating 2D graphs – Creating parametric function plots – Introduction to Mesh and Surface plots – Introduction to toolboxes.

**UNIT – II: 10 hours**

Matrices and linear system of equations – Gauss-Jordan elimination method – Gauss method to compute the Inverse – LU decomposition – Cholesky decomposition – Review of rotation matrices – Householder transformation – QR decomposition – Gauss-Seidel iterative method – Eigenvalues and eigenvectors of a real symmetric matrix by Jacobi's method – Determination of largest eigenvalue by Power method.

**UNIT – III: 10 hours**

Introduction to Lagrange polynomials – Numerical differentiation and integration – Trapezoidal single segment and multiple segment rules – Simpson's single segment and multiple segment rules – Newton-Cotes formulas – Romberg integration – Gaussian quadrature formula – Estimation of errors in evaluating the integrals – Introduction to random numbers – Random number generation – Monte-Carlo integration. Numerical solution of ordinary differential equations - solution by Taylor's series – Euler's method – Runge Kutta methods with Runge's coefficients. Numerical solution of partial differential equations using finite difference method.

**UNIT – IV 12 hours**

Evolution of Fortran language – Different Fortran compilers – Skeleton of a general Fortran 90 program – Free source format and character set – Specifications – Derived types – Control Structure – CASE construct – New features of DO loop: EXIT, CYCLE statements, Control clauses – Concept of internal, and external procedures, modules and INTERFACE blocks – Concept of scope – CONTAINS statement – Procedure Arguments – Optional arguments – Keyword arguments – Recursive procedures – Modules – Array Processing – Terminology and Specifications – Whole array operations – Vector subscripts – Array assignment – Array constructor – Allocatable dynamic array – Pointers and Dynamic Data Structures – Concept of pointers – Example programs.

**UNIT – V: Laplace Transforms and Fourier Transforms 12 hours**

Laplace transforms – Inverse transforms – Linearity and Shifting theorems – Laplace transform of derivative of a function – Laplace transform of integral of a function –Application to solve differential equations. Introduction to Fourier analysis – Half range Fourier series – Harmonic analysis and applications – Forced oscillations – Finite and infinite Fourier transforms – Fourier sine and cosine transforms – Complex Fourier transforms – Fourier expansion and inversion formulas – Convolution theorem – Applications to solutions of partial differential equations.

**Textbooks**


1. Richard Hamming. *Numerical Methods for Scientists and Engineers.* Dover publications.
2. Duane C. Hanselman and Bruce L. Littlefield (2004). *Mastering MATLAB 7*. Prentice Hall.
3. Jerry Peek, Grace Todino-Gonguet, John Strang (2002). *Learning the UNIX Operating System*, 5$^{th}$ Edition. O'Reilly Media, Inc.
4. F. Mittelbach, M. Goossens, J. Braams, D. Carlisle, C. Rowley (2004). LaTeX Companion (2$^{nd}$ Edition). Addison-Wesley.
5. Stephen Chapman (2003). *Fortran 90 / 95 for Scientists and Engineers* (2$^{nd}$ Edition) McGraw Hill.
6. Harvey M. Deitel and Paul J. Deitel (2007). *C++ How to Program* (6th Edition). Prentice Hall.
7. G. Arfken, *Mathematical Methods for Physicists* (5$^{th}$ Edition) (Academic Press, 2000).
8. Erwin Kreyszig (2005). *Advanced Engineering Mathematics*. 9$^{th}$ Edition. John Wiley.
9. R.K. Jain, S.R.K. Iyengar (2007). *Advanced Engineering Mathematics*. 3$^{rd}$ Edition. Narosa.


**Supplementary Reading**


1. J.M. Thijssen (1999). *Computational Physics*. Cambridge University Press.
2. Tao Pang (1997). *An Introduction to computational physics*. Cambridge University Press.
3. Rubin H. Landau (1997). *Computational Physics: Problem solving with computers*. John Wiley.
4. James B. Scarborough. *Numerical mathematical analysis*. Oxford IBH.

5. W. S. Brainerd, C. H. Goldberg and J. C. Adams (1995). *Programmer's Guide to Fortran 90*. Springer.
6. Michael Metcalf and John K. Reid (1999). *Fortran 90/95 Explained*. Oxford University Press.
7. Michael Metcalf, John Reid and Malcolm Cohen (2004). *Fortran 95 / 2003 Explained (Numerical Mathematics and Scientific Computation)*. Oxford University Press.
8. Bjarne Stroustrup (2000). *The C++ Programming Language* (3rd Edition).
9. K. F. Riley, M. P. Hobson and S. J. Bence, *Mathematical Methods for physics and engineering* (Cambridge Univ. Press, 1998)
10. M. P. Boas (2005). *Mathematical Methods in the Physical Sciences* ($3^{rd}$ Edition) Wiley.
11. Potter M C and Goldberg J (1988). *Mathematical Methods*. Prentice Hall.Sokolnikoff I S and Redheffer R M. *Mathematics of Physics and Modern Engineering*. McGraw Hill.
12. Spiegel M R. *Theory and Problems of Complex Variable*. Schaum's Series. McGraw Hill.
13. Spiegel M R. *Theory and Problems of Fourier analysis*. Schaum's Series. McGraw Hill.

**APHYS – 116: Programming in C and C++** **(3 credits)**

**UNIT – I: Unix Operating System** **12 hours**

Introduction to operating system – General OS architecture – Evolution of Unix operating system – Architecture of the Unix OS – The kernel – Memory management – Virtual memory – Paging – Segmentation – Shells and GUI – Directory structure – File systems in Unix – Mount point – Processes and threads – Multi-threading – Semaphores – Mutex – CPU process scheduling – Concept of deadlock – Services and Daemons – Introduction to Networking – Network file systems – Elements of system administration – Principles of topography – Typesetting in LaTeX – Elements of bibliography and citation – The Harvard system.

**Unit II : Elements of C Programming Language**

Algorithms and flowchart; Structure of a high level language program; Features of C language; constants and variables; expressions; Input and output statements; conditional statements and loop statements; arrays; functions; character strings; structures; pointer data type; list and trees.

**UNIT – III: C++** **12 hours**

Introduction – Algorithms – Control Structures – if Selection Statement – if-else statement – do-while repetition Statement – Nested Control Statements – Assignment Operators – Increment and decrement operators – break and continue Statements – Logical Operators – C++ math library functions – Function definitions with multiple parameters – Function prototypes – C++ standard library header files – Random Number Generation – Inline functions – Arrays – Declaring arrays – Examples using Arrays – Passing arrays to functions – Pointer variable declarations and initialization – Pointer Operators – Passing arguments to functions by reference with pointers – Using const with pointers – Introduction to operator overloading.

**UNIT – IV: Laboratory Exercise Session** **12 hours**

Swapping of two numbers – Counting – Factorial Computation – SINE computation – Base Conversion – Factoring Methods – Array Techniques – Display the Pascal Triangle – Generate prime numbers between 1 to *N* – Generate Fibonacci series up to *N* number – Concatenating two strings – Reversing the string – Finding the substring of a given string – Summation of a sin, cos and exponential series – Matrix computations – Random number generation.

**Textbooks**

1. Jerry Peek, Grace Todino-Gonguet, John Strang (2002). *Learning the UNIX Operating System*, 5th Edition. O'Reilly Media, Inc.
2. F. Mittelbach, M. Goossens, J. Braams, D. Carlisle, C. Rowley (2004). LaTeX Companion (2nd Edition). Addison-Wesley.
3. Stephen Chapman (2003). *Fortran 90 / 95 for Scientists and Engineers* (2nd Edition) McGraw Hill.
4. Harvey M. Deitel and Paul J. Deitel (2007). *C++ How to Program* (6th Edition). Prentice Hall.

**Supplementary Reading**

1. W. S. Brainerd, C. H. Goldberg and J. C. Adams (1995). *Programmer's Guide to Fortran 90*. Springer.
2. Michael Metcalf and John K. Reid (1999). *Fortran 90/95 Explained*. Oxford University Press.
3. Michael Metcalf, John Reid and Malcolm Cohen (2004). *Fortran 95 / 2003 Explained (Numerical Mathematics and Scientific Computation)*. Oxford University Press.
4. Bjarne Stroustrup (2000). *The C++ Programming Language* (3rd Edition).

**APHYS-110 Laboratory** **[3 credits]**

**General Experiments**

1. Faraday effect using white light.
2. Determination of Lande's g factor of electron by ESR.
3. Study of Geiger-Muller counter.
4. Thermal diffusivity of brass.
5. Determination of polarization and dipole moment of a liquid.
6. Fourier analysis of a square wave.
7. Study of superconductivity.
8. Microwaves bench using klystron tube.
9. Determination of absorption coefficient of aluminum using GM counter.
10. Measurement of Earth's Magnetic Field using Hall effects probe.
11. Study of black body radiation and verification of Wien's law using prism based spectrometer.
12. Determination of wavelengths of H and He spectra using grating based spectrometer.
13. Measurement of universal gravitational constant using torsional balance.
14. Determination of charge of an electron using Milkon's oil drop method.
15. Verification of Coulomb's law.
16. Verification of Faraday's law of induction and Lenz's law using variable gap magnet and induction coil.
17. Determination of speed of light in air by Focult's rotating mirror.
18. Measurement of charge to mass ratio (e/m) of an electron using Helmholtz coil.
19. Hall Effect
20. Band gap measurements with four probe method

**Electronics Experiments**

1. Integrator and differentiator using operational amplifier.
2. Wein bridge oscillator using operational amplifier.
3. Study of comparator using operational amplifier.
4. Study of multivibrators using operational amplifier.
5. Logic gates and Boolean algebra.
6. Half and full adder using logic circuits.
7. Decoders using logic circuits.
8. Study of flip flops.

**Text Books**


1. D. P. Khandelwal. A laboratory manual for undergraduate course. Vani Publishing.
2. V. Y. Rajopadhye and V. L. Purohit. Text book of experimental physics.
3. H. Singh. B.Sc practical physics. S. Chand & Co.
4. T. C. Hayes and P. Horowitz. Students manual for the art of electronics. Cambridge University Press.
5. Sanish Kumar Gosh. A text book of practical physics. New Central Books.
6. J. P. Holman. Experimental methods for engineers. Tata McGraw Hill.
7. L. K. Maheswari. Laboratory manual for introductory electronics experiments. New Age International.
8. Srinivasan and Balakrishnan. A text book of practical physics. Vols. I, II. S. Viswanathan Publishers.
9. D. Chatopadhyay and P. C. Ratshit. An advanced course in practical physics. New Central Books.
10. B. Ghosh. Advanced practical physics. Vols. I, II. Sreedhar Publishers.

**APHYS- 121 – STATISTICAL PHYSICS** **(4 credits)**

***Unit I: Ensemble and equilibrium*** **15 hours**

Fundamental concepts of phase space, microstate (semiclassical) Liouville's theorem- Classical treatment – introduction to the concept of density of states. Statistical systems and ensembles – ergodicity microstates and macrostates – equilibrium states – microcanonical ensemble- Derivation for equation of state using microcanonical ensemble.

***Unit II: Partition function and its application*** **15 hours**

Canonical ensemble- partition function of canonical ensemble- Thermodynamical quantities by partition function- Ideal gas, paramagnetic crystal, diatomic molecule in canonical ensemble- Negative temperature - Schottky anomaly- Grand canonical ensemble- partition function- chemical potential- Criteria of classical statistical physics- equipartition theorem - Gibb's paradox.

***Unit III: Quantum Statistics*** **15 hours**

Introduction to quantum statistics- Ideal quantum gases- Bosons- Fermions- Derivation of expressions of Bose-Einstein, Fermi-Dirac and Maxwell-Boltzmann distribution functions using GCE partition functions- Bose-Einstein condensation- Superfluidity of Helium- Fermion gas and Fermi function- Thermodynamical properties of fermion gas- Fermi surface- specific heat of electrons in Fermi surface- Pauli paramagnetism.

***Unit IV: Advanced topics*** **15 hours**

Phase transitions- First and second order phase transitions- critical point- order parameter- Scaling hypothesis- critical exponents - ferromagnetic phase transition- Ising model- Bragg William approximation- fluctuations in ensembles- One dimensional random walk- power spectrum- electrical noise- Non-equilibrium statistical mechanics- Onsager reciprocity relations, thermo-electric phenomena.

**Text Book**

1. F. Reif. Introduction to statistical and thermal physics. McGraw Hill.
2. K. Huang. Statistical Physics. John Wiley.

**Supplementary Reading**

1. F. Reif. Statistical Physics (Berkeley series in Physics). McGraw Hill.
2. A.N. Matveev. Molecular Physics. Mir Publishers.
3. E. S. R. Gopal. Statistical Mechanics & Properties of Matter. MacMillan.
4. Agarwal & Grisner. Statistical Mechanics. Wiley Eastern.
5. F. Mandl. Statistical Physics. ELBS.
6. D. Chandler. Introduction to Statistical Physics (and solution manual). Oxford University Press.
7. R.P. Feynman. Lectures on statistical physics. Narosa.
8. R. Kubo. Statistical physics. Springer.
9. Landau and Lifshitz. Statistical Physics. Pergamon Press.
10. R. C. Tolman. Principles of statistical mechanics. Oxford University Press.
11. I. Prigogine. Order out of chaos. Fontana paperback.

## APHYS – 122: ELECTRODYNAMICS (4 credits)

**UNIT – I: Boundary value problems & Special techniques** **15 hours**

Boundary conditions and uniqueness theorems — Conductors and second uniqueness theorem — Boundary value problems with linear dielectrics — Multipole expansion — Origin of coordinates in multipole expansions.

**UNIT – II: Magnetostatics and Electrodynamics** **15 hours**

Lorentz force law and Biot-Savart law — Scalar and vector potentials — Multipole expansion of vector potential—Calculation of field of a magnetized object—Amperes law in magnetized materials and Auxiliary field **H** — Magnetostatic boundary conditions — Faraday’s law and Lenz’s law — Calculation of energy density in magnetic fields — Electrodynamics before Maxwell — Maxwell’s correction of Ampere’s law — Derivation of Maxwell’s equations in vacuum and in matter.

**UNIT – III: Electromagnetic waves** **15 hours**

Electromagnetic waves in vacuum — Wave equation for ***E*** and ***B*** — Reflection, refraction of electromagnetic waves — Snell’s law and Fresnel’s law — Poynting theorem and its derivation — Electromagnetic waves in matter — Propagation of electromagnetic waves in linear media — Reflection and transmission at normal and oblique incidence — Absorption and dispersion of electromagnetic waves — Electromagnetic waves in conductors — Reflection at a conducting surface — Interference, diffraction and polarization.

**UNIT – IV: Potentials and Radiation** **15 hours**

Potential formulation — Gauge transformations — Coulomb and Lorentz gauge — Retarded potentials of continuous charge distribution — Derivation of Jefimenko’s Equations — Retarded potentials of point charges — Lienard-Wiechert potential — Fields of a moving point charge — Electric dipole radiation — Energy radiated by an oscillating electric dipole — Radiation from moving charges — radiation fields — Derivation of Larmor formula – Relativistic formulation of Maxwell's equations.

**Textbook**

1. David J Griffiths (1999). *Introduction to electrodynamics*. 3rd edition. Prentice Hall.

**Supplementary Reading**

1. John David Jackson (1999). *Classical Electrodynamics*. 3rd edition. John Wiley & Sons.
2. Matthew N. O. Sadiku (2002). *Elements of Electromagnetics*. 3rd edition. Oxford University Press.

**APHYS-123: ATOMIC AND MOLECULAR PHYSICS** **(4 credits)**

**Unit I: Classical Theory of Radiation** **12 hours**

Maxwell's equation and electromagnetic waves. Poynting vector. Classical dipole radiation. Simple harmonic oscillator. Absorption cross-section. Thomson and Rayleigh scattering formula. Bremstrahlung, Gyromagnetic, Synchrotron and Cerenkov radiations.

**Unit II: Quantum Theory of Radiation** **12 hours**

Time dependent Schrodinger equation. Perturbations and transition probabilities. Hamiltonian for pure radiation. Interaction of matter and radiation. Einstein co-efficients and oscillator strengths.

**Unit III: Time dependent perturbation theory** **12 hours**

Time dependent perturbation theory – transition probability – constant perturbation – harmonic perturbation – Fermi Golden rule – radiative transitions in atoms – dipole transition – selection rules – sudden and adiabatic approximation.

**Unit IV: *Microwave Spectroscopy:*** **12 hours**

Classification of Molecules -The rotation of Molecule – Rotational spectra of Rigid Diatomic molecule- Isotope Effect in Rotational Spectra- Intensity of Rotational Lines- Non-rigid Rotator- Vibrational Excitation Effect- Linear Polyatomic molecules- Symmetric top molecules- Asymmetric top molecules – Stark effect- Quadrupole Hyperfine interaction – Microwave spectrometer – Information derived from Rotational spectra – ***Infrared Spectroscopy:*** Vibrational Energy of a Diatomic molecule – The Diatomic Vibrating Rotator – Break down of Born-Oppenheirmer Approximation – The Vibrations of Polyatomic molecules – Rotation-Vibration spectra of Polyatomic molecules – Analysis by Infra-red Techniques- IR spectrophotometer – Fourier Transform- IR spectrophotometer- Applications – Frank-Condon principle and dissociation energy.

**Unit V: *Raman Spectroscopy:*** **12 hours**

Theories of Raman scattering – Rotational Raman Spectra – Vibrational Raman Spectra – Mutual Exclusion principle – Raman Spectrometer – Polarisation of Raman Scattered light – Structural determination from Raman and IR spectroscopy - Near IR FT-Raman spectroscopy – ***Laser Spectroscopy:*** Basic principles: Comparison between conventional light sources and lasers-Saturation-Excitation methods-Detection methods-Laser Wavelength Setting-Doppler Limited Techniques.

**Textbooks**

H. E. White. Introduction to Atomic Spectra. McGraw Hill.
B. P. Straughan and S. Walker. Spectroscopy Vol. I, II, III.
D. A. Long. Raman Spectroscopy.
T. M. Sugdan and C. N. Kennay. Microwave Spectroscopy of Gases.
Tores and Schawlow. Microwave Spectroscopy. McGraw Hill.
Schnoider and Berstin. High Resolution NMR. McGraw Hill.
Assenheim. Introduction to ESR. Plenum Press.
T. P. Das and E.E. Hahn. Nuclear Quadrupole Resonance Spectroscopy. Academic Press.
Goldanskil. Mossbauer effect and its application to Chemistry. Von Nestrand.

**APHYS 124 NUCLEAR AND PARTICLE PHYSICS (4 credits)**

**Unit I : Nuclear Properties and Nuclear Models : 12 hours**

Basic nuclear properties: nuclear size, Rutherford scattering, nuclear radius and charge distribution, nuclear form factor, mass and binding energy, Angular momentum, parity and isospin symmetry, Magnetic dipole moment and electric quadrupole moment; Liquid drop model of the nucleus, Bethe-Weizs cker binding energy/mass formula, Fermi model, Shell model and collective model, super-heavy nuclei.

**Unit II : Nuclear Forces – 2-body bound state and scattering : 12 hours**

Nature of nuclear forces: charge independence, charge symmetry and isospin invariance of nuclear forces; the Deuteron problem – properties of deuteron, Schr dinger equation and its solution for ground state of deuteron, rms radius; spin dependence of nuclear forces, electromagnetic moment and magnetic dipole moment of deuteron and the necessity of tensor forces; n-p and p-p scattering at low energy, partial wave analysis and phase shifts, scattering length, significance of the sign of scattering length, effective range theory, Wigner's hypothesis, introductory ideas about Bartlet, Majorana and Heisenberg exchange forces, Yukawa meson theory
.

**Unit III : Nuclear Decay and Nuclear Reactions : 12 hours**

Stability of nuclei, $\beta$ decay and electron capture, gamma decay, Fermi's theory of allowed $\beta$ decay, Selection rules for Fermi and Gamow-Teller transitions, Parity non-conservation and Wu's experiment. Nuclear Reactions : different types of reactions, quantum mechanical theory, resonance scattering and reactions — Breit-Wigner dispersion relation; compound nucleus formation and break-up, statistical theory of nuclear reactions and evaporation probability, optical model; principle of detailed balance, transfer reactions,nuclear fission – cross section, fission products, spontaneous fission; nuclear fusion – thermo-nuclear reactions.

**Unit IV : Elementary Particle Physics – Basic concepts: 12 hours**

Historical introduction to Elementary Particles : photon and electron, mesons, Dirac equation and antiparticles, neutrinos, strange particles, quark model of hadrons; quarks and leptons as the fundamental constituents of all matter, interactions between fundamental particles – Strong, Electromagnetic and Weak interactions; kinematics of basic particle interaction processes: photon-electron processes – photoelectric, Compton and pair-production processes; low energy weak interactions involving neutrino – Fermi theory; neutrino physics – theory of 2-flavour oscillation. solar and atmospheric neutrino anomalies, neutrino experiments.; basic particle detectors – ionization counters, proportional counters, GM counters, scintillation detectors, Cherenkov detectors

**Unit V : Elementary Particle Physics – Symmetries 12 hours**

Symmetries, Groups and Conservation Laws; classification of hadrons by isospin and hypercharge, SU(2) and SU(3); discrete symmetries – parity (P) and charge conjugation(C); CP violation in neutral kaon system; particle decays and conservation laws; CPT theorem (statement only); basic ideas of gauge symmetries – electrodynamics as a gauge theory, non-abelian gauge symmetries as the basis of strong and weak interactions; color quantum number and basic ideas of quantum chromodynamics (QCD), asymptotic freedom, gluons, and jets in electron-positron collisions; basic ideas of spontaneous symmetry breaking, and higgs boson; the basic idea of unification of forces – electro-weak unification, the Standard Model of Particle Physics and Grand Unified Theories; verification of Standard Model with high energy particle colliders.

**Text books**


1. B.L. Cohen, *Concepts of nuclear physics* (Tata McGraw-Hill, New Delhi, 1989)
2. J.M. Reid, *The atomic Nucleus* (Manchester University Press, 1984)
3. K. Heyde, *Basic ideas and concepts in nuclear physics : an introductory approach*, $2^{nd}$ ed. (Institute of Physics, Bristol, 1999).
4. A. Das and T. Ferbel, *Introduction to nuclear and particle physics* (John Wiley, New York, 1994).
5. B.R. Martin, *Nuclear and particle physics, $2^{nd}$ ed.* (Wiley, New Delhi, 2009).
6. G.D. Coughlan, J. E. Dodd, and B. M. Gripaios, *The Ideas of Particle Physics: An Introduction for Scientists, 3rd ed.* (Cambridge Univ. Press., 2006).
*7.* A. Bettini, *Introduction to elementary particle physics* (Cambridge Univ. Press, 2008).

## APHYS-125 MICROPROCESSORS AND APPLICATIONS (3 credits)

**Unit I: Architecture of 8 bit Microprocessor** **12 hours**

Addressing modes – instruction and times – classification – machine control operator – FORMAT – Types of memory –R/W, (RAM) – ROM, PROM, EPROM, EEPROM – I/O interfacing and addressing – display and keyboard interfacing and programming – interrupts, stacks, subroutines, 8155, 8355, 8212 clock generator and bus drives

**Unit II: Assembly Language Programming** **12 hours**

Programming exercise for 8085 – involving addition, subtracting and logical operations only – Monitor programme – assemblers, basic interpreters. Serial and parallel data transmission: Perriperheral chips – intel 8275, 8279, USART, instrumentation buses, RS232C, IEEE488 bus CAMAC buses.

**Unit III: Digital Interfacing** **12 hours**

KB, displays optical motor shift encoders – analogue interfacing D/A and A/D converters – process control – digital filters.

**Unit IV: Trends in Microprocessor Technology** **12 hours**

16 bit CPU, 8086, 8088 – 8086 internal architecture. Assembly language programming of 8086 – simple sequence programs Flags Jumps while – Do implementation IF – THEN, IF-THEN-ELSE and multiple – IF-THEN-ELSE programme – 8086 instruction and assembly direction. Computer systems peripherals, Raster scan, CRTs vector scan CRTs – Floppy disk controllers, hard disk interfacing Data communication networks – serial data transmission mode IBM PC architect.

**Textbooks**


1. Ramesh S. Goanker. Microprocessor architecture, programming and applications with 8085/8085A. Wiley Eastern.
2. D. V. Hall. Microprocessors and interfacing. McGraw Hill.
3. L. A. Leventhal. Assembly language programming. Prentice Hall.
4. Kenneth L. Sherl. Microprocessors and programmed logic. Prentice Hall.
5. G. V. Rao. Microprocessors and microcomputer system.

**APHYS- 230: ADVANCED PHYSICS LABORATORY (2 CREDITS)**

***Condensed Matter Physics Experiments:***

1. X-ray diffraction.
2. Impedance spectroscopy.
3. Infrared spectroscopy.
4. Differential scanning calorimetry with thermal analysis.
5. UV-VIS-IR spectroscopy.
6. High field magnetic hysteresis using VSM.
7. Superconductivity.
8. Emission spectroscopy.

***Electronics Experiments:***

1. First order active filters using operational amplifier.
2. Second order active filters using operational amplifier.
3. Counters and registers using logic circuits.
4. Decade counting unit.
5. Study of 8-bit microprocessor.
6. Study of 16 bit microprocessor.
7. Study of 8051 microcontroller.
8. Study of lockin amplifier.
9. Amplitude modulation.
10. Detection of AM signals.
11. Study and detection of Frequency modulation.
12. Pulse modulation.
13. Study of multiplexing and demultiplexing.
14. Digital multiplexer.
15. LabVIEW and Virtual instrumentation laboratory.

***LASER Experiments:***

1. Numerical aperture of optical fiber and propagation of light through optical fiber.
2. Intensity profile of laser through optical fiber and determination of refractive index profile.
3. Refractive index by Brewster angle setup.
4. Study of Faraday effect using He-Ne laser with AC modulator.
5. Study of electrooptic effect (Pockel effect) with AC modulator.
6. Study of Kerr effect.
7. Study of acoustooptic effects.
8. Study of fundamental, 2nd , 3rd harmonic generation using Q switched pulses using Nd:YAG laser.
9. Study of laser bean characteristics (beam divergence, spot size, intensity profile) using He-Ne laser.
10. Digital holography.
11. Fiber optics experiments.
12. Determination of wavelength of He-Ne laser with Michelson interferometer
13. Determination of wavelength of He-Ne laser with Fabry-Peort interferometer
14. Determination of the refractive index of the air and glass slab.
15. To verify the Malus law for light polarization
16. To determine the light intensity vs distance relationship for the point source of light
17. Single slit and double slit diffraction experiment
18. Zeeman Effect

**Text Books**


1. T. C. Hayes and P. Horowitz. Students manual for the art of electronics. Cambridge University Press.
2. R. S. Sirohi. A course of experiments with He-Ne lasers. Wiley Eastern.
3. J. P. Holman. Experimental methods for engineers. Tata McGraw Hill.
4. L. K. Maheswari. Laboratory manual for introductory electronics experiments. New Age International.
5. D. Chatopadhyay and P. C. Ratshit. An advanced course in practical physics. New Central Books.
6. B. Ghosh. Advanced practical physics. Vols. I, II. Sreedhar Publishers.

**APHYS 231- FUNDAMENTALS OF ASTROPHYSICS (3 credits)**

**9 hours**

**Unit 1: Introductory astronomy:** History of Astronomy; Overview of the major constituents of the universe; Solar System, Planets - laws of motion of planets, inner planets, outer planets; Extrasolar planets- Methods of detection of extrasolar planets; Black body radiation-specific intensity, luminosity; Basics of radiative transfer-emission coefficient, absorption coefficient, source function

**9 hours**

**Unit 2: Stellar Astronomy:** Stars-general Distances to stars - trignometric parallax; Stellar brightness - luminosity, flux, apparent magnitude, magnitude system, distance modulus, colour index, extinction, colour temperature, effective temperature, Stellar masses and radii – measuring masses, binary stars - visual binary, eclipsing binary, spectroscopic binary; Measuring stellar radii; Stellar spectra – colours of stars, Motion of stars-radial velocity, proper motion, spectral classification of stars,luminosity classification of stars, HR diagram, Stellar population- Population I and II, Star clusters-open clusters, globular clusters, Variable stars; Energy generation in stars: PP chain

**9 hours**

**Unit 3: Galactic astronomy:** Milky way; Hubble classification of galaxies-Spiral galaxies, Elliptical galaxies, Irregular galaxies, Dwarf galaxies; Masses of galaxies-Rotation curves of galaxies; Dark matter

**9 hours**

**Unit 4: Extragalactic Astronomy**: Groups and clusters of galaxies, Interacting galaxies; Active galaxies-Seyfert galaxies, radio galaxies, FRI and FRII sources, Quasars- accretion, accretion efficiency, superluminal motion, Eddington luminosity; radiation mechanisms in active galaxies; gravitational lensing

**9 hours**

**Unit 5: Cosmology**: Distances- direct distances-trignometric parallax; indirect distances-standard candles,main sequence fitting, cepheids variables, RR Lyrae variables, Supernovae, gravitational lensing; Expansion of the universe-Hubble's law, redshift; Newtonian Cosmology; microwave background, early universe

**References:**

Shu F., The physical universe, University of California, 1982
An introduction to Modern Astrophysics, Bradley W. Carroll & Dale A. Ostlie
Harwit M. Astrophysical concepts
Fundamental Astronomy
Radiative processes in Astrophysics , G. B. Rybicki & Lightman A. P.

**APHYS 232 RADIATIVE PROCESSES** **(3 credits)**

**9 hours**

**Unit 1: Fundamentals of Radiative Transfer:** The electromagnetic spectrum, Radiative flux, Specific intensity. Principles of radiative transfer, Radiation field, Equation of transfer, Formal solution, Emission and absorption of radiation, Einstein coefficients, Maser emission, Thermodynamic equilibrium, Blackbody radiation, Kirchhoff's law, Scattering effects and radiative diffusion.

**9 hours**

**Unit 2: Basic Theory of Radiation Fields:** Maxwell's Equations, Plane electromagnetic waves, The radiation spectrum, Polarization and Stokes Parameters, Electromagnetic potentials. **Radiation from Moving Charges:** Retarded Potentials of single moving charges: The Lionard-Wiechart Potentials, The velocity and radiation Fields, Radiation from non-relativistic systems of particles, Thomson scattering (Electron Scattering).

**9 hours**

**Unit 3: Relativistic Electrodynamics:** Four-Vectors, Covariance of electromagnetic phenomena, Physical understanding of field transformations, Fields of a uniformly moving charge, Emission from relativistic particles, Invariant phase volumes and specific intensity. **Synchrotron Radiation:** Total power, Spectra, Polarization, Self-absorption.

**9 hours**

**Unit 4: Compton Scattering:** Fundamental processes, Inverse-Compton spectra, The Compton Y parameter, The Kompaneets equation, Repeated scattering. **Bremsstrahlung:** Emission from Single-Speed Electrons, Thermal Bremsstrahlung Emission, Thermal Bremsstrahlung (Free-Free) Absorption, Relativistic Bremsstrahlung.

**9 hours**

**Unit 5: Plasma Effects:** Model of a cold electron plasma. The plasma frequency. Phase and group velocity, Index of Refraction. Wave propagation in a magnetized plasma. Faraday rotation and depolarization. Plasma effects in high-energy emission processes: Cerenkov radiation and the Razin effect.

**References:**

1. Rybicki, G.B., & Lightman, A.P., **Radiative Processes in Astrophysics**, John Wiley, 1985.
2. Chandrasekhar S., **Radiative Transfer**, Dover Pub., New York, 1960
3. Jackson, J. D., **Classical Electrodynamics**, Wiley, New York, 1975
4. Krishan, V., **Astrophysical Plasmas and Fluids**, Kluwer Academic Pub., 1999

**APHYS 233- STELLAR PHYSICS** **(3 credits)**

**9 hours**

**Unit 1**: Introduction to stars: HR diagram, a discussion on the variety of stellar phenomena.

**9 hours**

**Unit 2:** Stellar Structure: The equations of stellar structure; stellar opacities; Lane-Emden equation and stellar polytropes.

**9 hours**

**Unit 3:** Energy Generation in Stars: Calculation of thermonuclear reaction rates for resonant, non-resonant and beta-decay reactions; the various reaction chains: pp-I, II, III and CNO cycle; He-burning, C-burning, Si-burning, photo-dissociation. Neutrino emission from stars: The solar neutrino "problem" and its solution, neutrinos from supernovae; terrestrial detection of stellar neutrinos

**9 hours**

**Unit 4:** Stellar degeneracy and Equations of State (EoS): Stellar degeneracy; Chandrasekhar mass, EoS of matter at near-nuclear and nuclear densities

**9 hours**

**Unit 5:** Final stages of stellar evolution: Supernovae (a basic understanding of the core-collapse process and the structure of the progenitor); Neutron stars (NS) - a basic knowledge of NS structure; an overview of the problems associated with determining a unique equation of state for NS; various manifestations of NS.

**References:**

1. Supernovae & Nucleosynthesis -- Arnett.
2. Introduction to Stellar Astrophysics, Vol. 3 : Stellar structure and evolution -- Erika Bohm-Vitense.
3. Black Holes, White Dwarfs & Neutron stars -- Shapiro & Teukolsky.
4. Stellar Structure & Evolution -- R. Kippenhahn & A. Weigert.
5. Principles of Stellar Evolution -- D. Clayton.
6. Neutrino Astrophysics -- J. Bahcall

**APHYS 234 FLUIDS AND PLASMAS** **(3 credits)**

**Unit 1:** ***Fluids and plasmas, the universal states of matter- an overview*** **9 hours**

Collective and quasi-neutral, electrostatic potential in a plasma, Debye screening, Coulomb collisions, Electric resistivity, Optical properties of a plasma, Coherent radiation, Strongly coupled plasma, Dusty Plasma, Techniques for studying plasmas, Waves and instabilities in plasmas, Plasmas in curved space-time, Neutral fluids, *Statistical description of a system of large number of particles:* Phase space, Gibb's ensemble, Liouville equation, Distribution functions, Correlation functions , One particle distribution function, BBGKY hierarchy, Collisionless Boltzmann equation, Self consistent force, Vlasov equation, The Boltzmann collision model, the Krook collision model , The Fokker-Planck collision model, application to stellar systems, The Kinetic and the fluid descriptions, fluid velocity, stress tensor, pressure, shear stresses, Mass, momentum and energy conservation laws, Plasmas as electromagnetic fluids, Maxwell equations ,Two-fluid description of a plasma, Magnetohydrodynamics- the single fluid description of a plasma, Mass, momentum and energy conservation laws,

**Unit 2:** ***Charged particle motion in electromagnetic and gravitational fields*** **9 hours**

Why study single particle motion, motion in a uniform magnetic field, in a uniform electric and magnetic fields, in magnetic and gravitational fields, Drift orbit theory, Particle drifts in inhomogeneous magnetic field, grad B parallel B drifts, Van Allen radiation belts, slowly varying fields, Adiabatic invariants , magnetic moment, Magnetic mirror, longitudinal adiabatic invariant, motion in nonuniform electric field, in spatially periodic electric field, motion in time varying electric and magnetic fields, motion of a star in a galaxy, fluid drifts

**Unit 3:** ***Magnetohydrodynamics of conducting fluids*** **9 hours**

Electrically conducting fluids, validity of MHD, equations of MHD, ideal fluids, viscous and resistive fluids, Equilibrium of fluids, hydrostatic equilibrium, MHD equilibrium, MHD waves, dispersion and polarization characteristics, gravitohydrodynamic waves, MHD instabilities, The Rayleigh Taylor Instabilities, The Kelvin-Helmholtz instability, Virial theorem

**Unit 4:** ***Two-fluid and kinetic descriptions of Plasmas*** **9 hours**

Electron and proton plasmas, static equilibrium, radiating and accreting fluids, dynamic equilibrium, waves in two fluids, electron plasma oscillations, ion-plasma oscillations, electron plasma waves in magnetized fluids, ion-plasma waves in magnetized fluids, electromagnetic waves in electron-proton fluids, electromagnetic waves in magnetized plasma fluids, Ambipolar diffusion, Kinetic equilibrium of a plasma, Kinetic description of waves and instabilities

**Unit 5:** ***Nonconducting Astrophysical fluids*** **9 hours**

Whence such fluids, equilibrium of fluids, waves in fluids, instabilities, shocks, turbulence, turbulent flows, quantification of turbulence, flow invariants, Spectral representation, The Kolmogorov-Oboukov law, 2D turbulence, Through Navier- Stokes equations, MHD turbulence and Dynamo

**References:**


1. Aitchison, Introduction to Fluid dynamics
2. Sturrock,P., Plasma Astrophysics, Academic Press, 1967.
3. Vinod Krishan, Astrophysical Plasmas and Fluids, Kluwer Academic Press, 1999
4. Landau & Lifshitz., Fluid Mechanics, 2nd ed., Butterworth-Heinemann, 1998
5. Shu, Physics of Astrophysics: Gas Dynamics

**APHYS 235 ASTRONOMICAL TECHNIQUES (3 credits)**

**9 hours**

**Unit I:** Celestial Sphere: Coordinate systems (horizon, equatorial, ecliptic, galactic), precession, nutation, aberration, parallax, radial velocity, proper motion, time (JD, LST, UT, hour angle), heliocentric corrections.

**9 hours**

**Unit II:** Detectors: Photodetection (photoelectric effect, photosensitive element), Photomultiplier tube, Detectors at different wavelengths and their properties (CCD, CMOS, ICCD, L3CCD, Photon-counting system), spectral response, noise, background, signal to noise ratio, sensitivity, quantum efficiency.

**9 hours**

**Unit III:** Astronomical Techniques : Different telescope designs (Refracting and Reflecting telscopes, viz., Newtonian, Cassegrain, coude, Nasmyth, Schmidt), Astrometry (transit circle, observations, analysing astrometric data), photometry (magnitudes, filter systems, photometers, stellar parameters, extinction), Imaging (surface photometry, extended sources), spectroscopy (prisms, gratings, spectrographs, low and high resolution spectroscopy), calibration, polarimetry (polarisers, converters, depolarisers, polarimeters, Stokes parameters, interpretation of polarimetric output).

**9 hours**

**Unit IV:** High Resolution Techniques: atmospheric effects on optical imaging, speckle interferometry, aperture synthesis with single telescope, image reconstruction techniques, adaptive optics (Wavefront sensing, wavefront correction, wavefront reconstructions, brief introductions on Fizeau, Michelson stellar interferometry and intensity interferometry, long baseline optical interferometry.

**9 hours**

**Unit V:** Detection at other bands: Radio telescope, Brightness and antenna temperatures, Sensitivity, Brightness distribution, Radio interferometer, Fringe visibility, Very long baseline interferometry, neutrino astronomy, gravitational wave astronomy.

**References:**

Smart, W.M., Spherical Astronomy, 6th ed., Cambridge University Press, 1977.
Christiansen, W.N., & Hogbohm, J.A.: Radio Telescopes
Roy, A.E., & Clarke, D.: Astronomy Principles and Practice.
Kitchin, C.R.: Astrophysical Techniques.
Saha S. K. : Diffraction-limited Imaging with Large and Moderate Telescopes.
Saha S. K. : Aperture Synthesis: Methods and Applications to Optical Astronomy.

Introduction to Optical Stellar Interferometry : A.Lebeyrie, S.G.Lipson & P.Nisension
The Intensity Interferometry : Its Applications to Astronomy : R.H.Brown

Optical Radiation Detectors : E.L.Dereniak & D.G.Crowe
Optical Sources, Detectors & Systems : R.Kingston
Applications of Thermal Imaging : Ed. S.G.Burnay, T.L.Wilman & C.H.Jones
Astronomical Optics : D.J.Shroeder
Astronomical Techniques : W.A.Hiltner
Krauss J. D., 1966, Radio Astronomy, McGraw Hill, NY.
Thompson R. A., Moran J. M., Swenson G. W. (Jr.), 2001, Interferometry and Synthesis in Radio Astronomy, John Wiley \& Sons, Inc, New York.
Tyson R. K., 1991, Principles of Adaptive Optics, Acad. Press.

**APHYS 240 RESEARCH PROJECT** **(4 credits)**

I. A list of experiments for Physics Lab (PH419):

II. The student is required to perform any 10 experiments.

1. Verification of the Lorentz formula for force between a current and magnetic field.
2. Determination of the earth's magnetic field from the study of the null point for a bar magnet. Confirmation with a magnetometer.
3. e/m ratio by Thomson's method
4. Wavelength measurement of Na source using Michelson Interferometer
5. Study of Fabry Perot interferometer , for accurate measurement of tiny displacements.
6. Zeeman effect study using Lummer Goehrcke plate. Measurement of eh/mc.
7. Determination of h by Einstein's photoelectric effect formula, using visible and UV light.
8. Coherence and width of spectral lines using Michelson Interferometer.
9. To study magneto-optic rotation.
10. Measurement of the Stefan Constant
11. Black Body curve (limited by the high temperature that can be reached)
12. Maxwell's velocity distribution, using rotating sectors
13. Maxwell's velocity distribution, from the study of spectral lines at difference temperatures (gases in rarefied atmospheres) and deviations as pressure broadening takes over.
14. Brownian motion and verification of the Einstein-Smoluchowski formula
15. Study of Hall parameter of these substances and compare with carrier concentration.
16. Magneto-resistance studies.
17. Vibration of a suspended simple pendulum, coupled non-linear pendulum.

**APHYS 241 GENERAL RELATIVITY AND COSMOLOGY (3 credits)**

**Unit – I:. Review of special theory of relativity: 9 hours**

Poincare and Minkowski's 4-dimensional formulation, geometrical representation of Lorentz transformations in Minkowski's space and length contraction, time dilation and causality, time-like and space-like vectors, Newton second law of motion expressed in terms of 4-vectors.

**Review of tensor calculus:**

Idea of Euclidean and non-Euclidean space, meaning of parallel transport and covariant derivatives, Geodesics and autoparallel curves, Curvature tensor and its properties, Bianchi Identities, vanishing of Riemann-Christoffel tensor as the necessary and sufficient condition of flatness, Ricci tensor, Einstein tensor

**Unit-II:. Einstein's field equations 9 hours**

Inconsistencies of Newtonian gravitation with STR, Principles of equivalence, Principle of general covariance, Metric tensors and Newtonian Gravitational potential, Logical steps leading to Einstein's field equations of gravitation, Linearised equation for weak fields, Poisson's equation.

**Unit – III : Applications of general relativity: 9 hours**

Schwarzschild's exterior solution, singularity, event horizon and black holes, isotropic coordinates, Birkhoff's theorem, Observational tests of Einstein's theory.

**Unit-IV: . Gravitational Collapse and Black Holes (Qualitative): 9 hours**

Introduction: Qualitative discussions on: White Dwarfs, Neutron stars and Black Holes, Static Black Holes (Schwarzschild and Reissner-Nordstrom). Rotating Black Holes, Kerr Metric (derivation not required), Event Horizon, Extraction of energy by Penrose process, Kerr-Neumann Metric (no derivation). No hair theorem, Cosmic Censorship Hypothesis.

**Unit-V: Cosmology: 9 hours**

Introduction, Cosmological Principles, Weyl postulates, Robertson-Walker metric (derivation is not required), Cosmological parameters, Static Universe, Expanding universe, Open and Closed universe, Cosmological red shift, Hubble's law. Olber's Paradox. Qualitative discussions on: Big Bang, Early Universe (thermal history and nucleosynthesis), Cosmic Microwave Background Radiation, Event Horizon, Particle Horizon and some problems of Standard Cosmology.

**Books Recommended:**

1. J. V. Narlikar- General Relativity and Cosmology (MacMillion, 1978).

2. S. Weinberg- Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity (Wiley, 1972).

3. P. G. Bergmann- Introduction to Theory of Relativity (Prentice-Hall, 1969).

4. J. V. Narlikar –Introduction to Cosmology (Cambridge Univ, Press, 1993).

5. A. K. Roychaudhuri, S. Banerjee and A. banerjee- General Relativity, Astrophysics and Cosmology (Springer-Verlag, 1992).

6. S. Banerji and A. Banerjee – General Relativity and Cosmology (Elsevier, 2007)

7. R. Resnick – Introduction to Special Theory of Relativity.

8. S. Banerji and A. Banerjee – The Special Theory of Relativity (Prentice Hall of India, 2002)

9. W.G.V.Rosser – Introduction to the Theory of Relativity.

P. A. M. Dirac, General Theory of Relativity, Princeton, 1975.
S. Dodelson, Modern Cosmology , Academic Press, 2003.
A. Liddle, An Introduction to Modern Cosmology, Wiley, 2003.

**Additional references:**

P. J. Peebles, Principles of Physical Cosmology, Princeton, 1993.
S. Weinberg, Gravitation and Cosmology, Wiley, 1972.
A. Taylor and J. Wheeler, Exploring Black Holes, Addison-Wesley, 2000.
C. Misner, K. Thorne and J. Wheeler, Gravitation, Freeman, 1973.
H. Ohanian and R. Ruffini, Gravitation and Spacetime, Norton, 1994.
A. Linde, Particle Physics and Inflationary Cosmology, Harwood, 1990.

**APHYS 242 PHYSICS OF COMPACT OBJECTS (3 credits)**

**Unit I: White dwarfs, neutron stars and black holes (12 hours)**
Introduction to Compact objectsFormation of compact objectsphysical properties of white dwarfs, the Chandrasekhar limit comparison with observations: masses and radii-
physical properties and,discovery of neutron starsobservation of neutron star masses and maximum mass limit- properties of Schwarzchild black holes

**Unit II: Pulsars (12 hours)**
Discovery and properties of pulsars ,the dispersion measure the magnetic dipole model for pulsarsthe life history of pulsars , HulseTaylor binary pulsar and the evidence for gravitational waves

**Unit III: Xray binaries (12 hours)**
Introduction to Xray binarieshigh and low mass Xray binaries ,Xray pulsarsmass flow in binary systems, Rocche lobe overflow and wind accretionthe binary Xray pulsar: Her X1 and the black hole system: Cygnus X1

**Unit IV: Accreting compact objects (12 hour s)**
Nonrelativistic spherical accretion – standard acrretion disk theory – accretion disk spectra ,
accretion onto Neutron stars - the magnetosphereemission from accreting neutron starsWhite dwarf accretion Active Galactic Nuclei – types of AGN multi wavelength spectra of AGN

**Textbooks**

1.Shapiro S. & Teukolsky, S., Black Holes, White Dwarfs and Neutron Stars, John Wiley, 1983.
2.Accretion power in astrophyscs, J. Frank, A. King and D. Raine, Cambridge University Press, 2002.
3. An Introduction to Active galactic Nuclei, B.M.Peterson, Cambridge University Press, 1977

**APHYS 243 DIFFUSE MATTER IN SPACE** **(3 credits)**

***Unit I: Introduction and general properties of the Interstellar Medium;*** **8 hours**

Discovery of interstellar gas and dust - Galactic distribution of ISM, the "Oort Limit" - Phases of ISM, pressure equilibrium - Models of the ISM: Thermal Stability & Equilibrium, two-phase models, the coronal hot gas and Multi-Phase Models.

***Unit II: Neutral Atomic Gas (HI Regions)*** **8 hours**

Interstellar absorption lines: Radiative Transfer, line formation, equivalent widths, curve of growth, gas-phase abundances in the ISM - The HI 21cm hyperfine structure line: excitation, absorption & emission - HI clouds.

***Unit III: Ionized Gas (HII Regions)*** **8 hours**

Photoionization equilibrium, Ionization Structure, HII nebulae (Strömgren Spheres) - Thermal Structure of Nebulae:Heating, Cooling (recombination, free-free, and collisional excitation), thermal Equilibrium - Spectra of HII regions.

***Unit IV: Coronal Gas*** **8 hours**

Collisional Ionization, Radiative & Dielectronic Recombination - Heating & Cooling of Hot Gas - Spectrum of the Hot ISM : UV and FUV Absorption Lines , Diffuse Soft X-ray Continuum

***Unit V: Interstellar Dust and Molecules*** **8 hours**

Scattering, absorption, extinction and polarization by interstellar dust - Optical and material properties of dust: Grain sizes and shapes, Grain Materials, Grain Mixture Models - Grain Formation & Destruction - Interstellar CO and other tracer molecules, H2 formation.

***Unit VI: Sources and Sinks of ISM*** **8 hours**

Mass loss from stars: stellar winds, planetary nebulae and supernovae - formation of shells, supershells and clouds-star formation in molecular clouds- galactic chemical evolution

**Text Books**

1. Spitzer, L., Physical Processes in the Insterstellar Medium, John Wiley and Sons, 1998.
2. Sutherland, R. & Dopita, M., Diffuse Matter in the Universe, Springer-Verlag, 2003.
3. Kwok, Sun, Physics and chemistry of the interstellar medium, University Science Books, 2007
4. Osterbrock, D.E. & Ferland, G.J., Astrophysics of Gaseous Nebulae and Active Galactic Nuclei, University Science Books, 2006

**APHYS 244 STELLAR ATMOSPHERES** **(3 credits)**

**Unit 1 : Spectral line formation and causes of line broadening** **12 hours**

Radiation laws and basic ideas on spectral line formation. Explanation of stellar spectra in terms of Boltzmann and Saha equations. Natural damping. Collisional damping. Statistical broadening of hydrogen lines. Stark effect in helium lines. Electron pressure in early type stars. Superposition of Doppler and damping profiles. Theory of the curve of growth. Application of the curve of growth to the study of solar and stellar atmospheres. Limitations of the curve of growth method.

**Unit 2: Equation of transfer** **12 hours**

Definitions concerning the radiation field. Hypothesis of plane parallel and spherically symmetric stratification. Local thermodynamic equilibrium. Radiative equilibrium. Equation of transfer. Formal solution of the equation of transfer. Explanation of limb darkening. Grey approximation. Solution of equation of transfer for a grey atmosphere. Temperature distribution and limb darkening for a grey atmosphere. Departures from greyness. Blanketing effect.

**Unit 3: Continuous spectra of stars** **12 hours**

Limb darkening observations of Sun. Determination of absorption coefficient from limb darkening observations. Sources of opacity in the solar atmosphere. Sources of continuous opacity in various types of stars. Models of stellar atmospheres. Convection in stellar atmospheres. Schwarzchild's criterion for convection and its application to stellar atmospheres. Discussion of convection zones in stellar atmospheres. Abundances of elements in normal stars. Composition of differences in population I and II stars. Anomalous abundances in cool stars. Peculiar A stars and metallic line stars. Magnetic field in stars.

**Unit 4: Formation of absorption and emission lines** **12 hours**

Line strength. Profile of a line. Line depth. The line source function: Transition coefficients and emission and absorption coefficients. Equation of transfer for line frequencies: Schuster – Schwarzschild model with pure scattering in a line. Milne- Eddington model with pure absorption and scattering. Effect of interlocking and non-coherent scattering. Variation of line profiles over a solar disc. Moving atmospheres. Extended layers of stars.

Mechanism of emission line formation. Thermal emission and its application. Fluorescence, Rosseland cycle. Zanstra's mechanism. Bowen's mechanism. Collisional excitation.

**REFERENCES**

1) L.H.Aller: Astrophysics.
2) J.Greenstein(Ed): Stellar Atmospheres.
3) Hynek: Astrophysics.
4) Mihalas: Stellar Atmospheres.2$^{nd}$ edition
5) E.Ambartzumian: Theoretical Astrophysics.
6) K.D.Abhyankar: Astrophysics Stars and Galaxies.
7)David F. Gray; Observations and Analysis of Stellar Photospheres, 3$^{rd}$ edition,

**APHYS 245 GALACTIC STRUCTURE & DYNAMICS (3 Credits)**

**Unit-I 12 hours**

Structure of our Galaxy - Distribution of stars, gas, and chemical elements in the disk and spheroid. Other galaxies: surface profile, photometric, spectroscopic, and morphological properties, fundamental plane. Stellar kinematics - solar Motion, standards of rest, velocities and velocity dispersions of disk and spheroid stars.

**Unit-II 12 hours**

Viral theorem, Galaxy collisions, Dynamical friction in galaxy – collisions, Methods of distance determination, Spectra and redshift, Clusters of galaxies-different types of galaxy clusters, galaxy-galaxy encounters , Radio galaxies and quasars, Active galactic nuclei.

**Unit-III 12 hours**

Galactic rotation curves, Differential rotation, Velocity dispersion of galaxies, galaxy clusters and gravitational lensing, Cosmic microwave background, Recent status of CMBR, Supermassive black holes in galaxies, Dark matter and Dark energy,

**Unit-IV 12 hour**

Equilibria of Stellar Systems, the Collisionless Boltzmann Equation, Gravitational Potential. Orbits, Epicycles. The Jeans Equations and applications, the Jeans Theorems, Isothermal and King models. Keplerian and solid body rotation profiles.

**Text Books**

1. Binney, J. and Treamine: S, Galactic Dynamics, Princeton University press, 1994.
2. Binney, J. and Merrifield, Galactic Astronomy, Princeton University press, 1998.
3. Cosmology by J V Narlikar.
4. Theoretical Astrophysics, vol II Stars and Stellar Systems, T. Padmanabhan, Cambridge University press.
5. Astronomy by R. H. Baker

**APHYS 246 SUN AND SOLAR SYSTEM** **(3 credits)**

**Unit 1 The Sun** **12 hours**

Surface features of the sun in white and monochromatic light. Internal structure, photosphere, chromosphere and corona. Sun spots and magnetic fields on the sun. Solar activity, solar wind and solar-terrestrial relationship.

**Unit 2 Planets and their Satellites** **12 hours**

Surface features, Internal structure, Atmospheres and Magnetic fields of Earth, Moon and Planets. Satellites and rings of planets. Results of space probes. Origin of the solar system.

**Unit 3 Asteroids, Meteors and Meteorites** **12 hours**

Discovery of minor planets (Asteroids), their orbits and physical nature. Origin of the minor planets. Meteors and Meteorites. Observation of meteor showers and sporadic meteors. Orbits of sporadic meteoroids and meteor showers. Meteorites, its types and composition. Meteorite craters.

**Unit 4 Comets** **12 hours**

Discovery and designation. Periodic comets. Physical nature. Spectra. Brightness variation. Gas production rates, dust and ion tails. Nature of dust particles and origin of comets.

**References**

1. R.G.Whitten and I.G.Popoff: Fundamentals of Astronomy
2. Kaula. W.M.: An Intoduction to Planetary Physics.
3. Harold Zirin: Astrophysics of the Sun.
4. W.N.Hess and G.Mead(Ed): Introduction to Space Science.
5. W.Liller(Ed): Space Astrophysics.
6. Gibson: The Quiet Sun.
7. K.S.Krishnaswamy: Physics of Comets.
8. G.Abell: Exploration of the Universe.
9. K.D. Abhayankar: Astrophysics of the solar system.