Central University of Himachal Pradesh

Department of Physics and Astronomical Science

M. Sc. Physics

4th Semester

Syllabus

2020

Computational Physics

Course Code: PAS 428 A **Course Type: Core Compulsory**
Course Credit: 4

Course Contents

Unit 1: Ordinary Differential Equations: (8 hours)

- Euler method, Application to Radioactivity, Effect of Air Resistance and Projectile motion
- Euler-Cromet Method and Verlet method, Application to SHO
- Predictor-corrector method (Heun's) method, Application to Damped Harmonic Osicllator
- Second order Runge-Kutta method, Application to Forced Oscillations
- Chaos in the Driven Non-linear Pendulum
- Study of Planetary motion
  - Kepler's Laws, Inverse Square law and Stability of Planetary orbits
  - Precession of the Perihelion of Mercury
- Higher-order Runge-Kutta method; Application to Coupled Oscillations

Unit 2: Partial Differential Equations: (8 hours)

- Finite Difference methods: Elliptic Equations- Laplace equation, solution techniques and boundary conditions;
- Parabolic Equations- Heat Conduction Equation, explicit and implicit methods
- Crank-Nicholson Method; Application to Schrodinger equation.
- Solving the Schrodinger equation using Numerov method

Unit 3: Random Processes and Monte-Carlo Methods (8 hours)

- Random number generation-uniform and non-uniform distributions.
- Random Walks and Diffusion equation
- Monte Carlo Integration-Hit and miss, Sample Mean integration
- Metropolis Algorithm
- The Ising Model
- Mean Field Theory and Monte-Carlo method
- Ising Model and second order phase transitions
- Variational Monte-Carlo technique: Appliction to solving for the ground state of quantum mechanical systems in 1D and 2D

Unit 4: Molecular Dynamis **(8 hours)**

- Introduction to the method and properties of dilute gas
- Pair-potential, Emebeded Atom Method, Tersoff potential and Potentials for ionic solids
- Verlet, Velocity-Verlet and Predictor-Corrector Algorithms
- Initialisation and Periodic Boundary Conditions
- Type of Ensemble
- Equilibration
- Data production errors involed
- Structural properties: equlibrum lattice constant, cohesive energy, radial distribution, etc

Unit 5: Matrix methods and Spectral Methods: **(8 hours)**

- Matrix mehods for solving various QM potentials
- Application to square well potential
- Square well potential in the presence of Electric field
- Pseudospectral technique to solve the time dependent Schroedinger quation
- Application to study few ID potentials and scattring

Prescribed Textbooks:

1. Nichols J.Giordano and Hisao Nakanishi, "Computational Physics" Prentice Hall, 2006
2. Paul L.DeVries, A first Course in Computational Physics (2nd edition), Jones and Barlett Publishers (2010)
3. June Gunn Lee,"Computational Materials Science, An Introduction", CRC Press, 2012.

References:

1. R.C. Verma, "**Computer Simulations in Physics**",
2. H.Gould, J.Tobochnick, W.Christian, An Introduction To Computer Simulation Methods: Applications to Physical Systems (3rd Edition), Addison-Wesley (2006).
3. J. M. Thijssen, Computational Physics, Cambridge University Press (1999).
4. Konstantinos Anagnostopoulos, Computational Physics: A Practical Introduction to Computational Physics and Scientific Computing, Lulu.com (2014).

5. R.Fitzpatrick, Introduction to Computational Physics, http://farside.ph.utexas.edu/teaching/329/329.html.

6. R.H.Landau, M.J.Paez, C.C. Bordeianu, Computational Physics: Problem Solving with Computers (2nd edition), John Wiley and Sons (2007).

7. Papers on Matrix methods from American Journal of Physics

Computational Physics Laboratory

Course Code: **PAS 427** **Course Type: Core Open**
Course Credit: 2

Course Contents:

Statistical Mechanics Simulations:

Worksheet based Simulations:

Lab 1: Microstates, Macrostates and Steady-state equllibrium
Lab 2: Ergodic Hypothesis Demonstration

Simulations in Scilab:

Lab 3: Boltzmann Distibution: P(E) vs E
Lab 4: Boltzmann Speed Distribution and Maxwell's velocity distribution
Lab 5: Joule's Expansion and Entropy

Quantum Mechanics Simulations:

Lab 6: Solving the Time-Dependent Schrodinger Equation and obtaining the spreading of Gaussian wavepacket
Lab 7: Studying the Scattering of Gaussian wavepacket
Lab 8: Scattering from a step potential and a barrier potential

Theoretical Nuclear Physics

Course Code: PAS 527 **Course Type: Elective Specialization**

Credits: 4

Course Objectives:

The course is designed to study the following, Interaction of nuclear radiation like charged particles, neutrons, gamma and positron with matter and how these radiations are detected. Study of decay laws, theory and use in the structure exploration of nuclei. Nuclear reactions, kinematics, reaction cross-sections, different types and theories developed. Nuclear Fission, characteristics and applications. Basic fusion process it characteristics, solar fusion etc.

Course Contents

Unit 1: Interaction of nuclear radiation with matter **(10 hours)**

- Interaction of charged particles with matter
- Interaction of neutrons with matter: energy loss and energy distribution after collision
- Interaction of gamma radiation with matter: attenuation of gamma rays, Compton Effect, photoelectric effect and pair production.
- Interaction of positron with matter
- Detection of nuclear radiation

Unit 2: Radioactive Decay **(10 hours)**

- Radioactive decay law, Quantum theory of radiative decays, production and decay of radioactivity, Growth of Daughter activities.
- Alpha decay: energetic, decay constant, hindrance factors, alpha particle spectra
- Fermi theory of β-decay, Electron and positron energy spectra, electron capture decay, parity non conservation in β-decay, nuclear structure information from β-decay.
- Theory of γ-decay and internal conversion and nuclear structure information from γ-decay

Unit 3: Nuclear reactions **(12 hours)**

- Cross-sections, reciprocity theorem, Elastic scattering and method of partial waves, relationship between differential and scattering amplitude.
- Free particle, turning the potential on, scattering amplitude and elastic scattering cross-section, reaction cross-section.
- Scattering by simple potential, square well potential.
- Theory of resonance: General aspects, logarithmic derivative and cross-section, Breit-Wigner formula, R-Matrix theory.

Unit 4: Nuclear Fission and Fusion **(8 hours)**

- Fission: Characteristics of Fission, Energy In Fission, Fission and Nuclear Structure, Controlled Fission Reactions, Fission Reactors, Radioactive Fission Products, Fission Explosives.
- Basic fusion processes, characteristics of fusion and solar fusion.

Prescribed Text Books:

1. Introductory Nuclear Physics, K. S. Krane, John Wiley& Sons Ltd
2. An Introduction to Nuclear Physics, W. N. Cottingham, D. A. Greenwood, Cambridge University Pres

Other Resources/Reference books:

1. Fundamentals In Nuclear Physics from Nuclear Structure to Cosmology Jean-LouisBasdevant, James Rich, Michel Spiro, Springer
2. B.R. Martin, Nuclear and Particle Physics, John Wiley& Sons Ltd.
3. R.R. Roy and B.P. Nigam, Nuclear Physics: Theory and experiment, New age International (P) limited, Publishers.

Elementary Particles & Interactions

Course Code:PAS 549 **Course Type: Elective Specialization**

Course Credits: 4

Course Objectives:

An Overview of Elementary particle physics, Symmetry Principles, conservation laws and Quark Model, Feynman Calculus, QED, and Renormalization, QCD, Weak Interactions and Electroweak Standard Model, Physics Beyond the Standard Model

Course Contents

Unit-1: Introduction and Dirac Equation (5 hours)

- Historical Introduction of Elementary particles, Classification, Quantum numbers & Conservation laws
- Four Forces, Range of Forces, Yukawa Potential, Zero Range Approximation
- Dirac Equation: High energy units, Antiparticles and Bilinear covariants

Unit-2: Symmetries and Quarks (5 hours)

- Symmetry, Group and Conservation laws, Parity, Charge conjugation, Time reversal
- CombiningRepresentations, Young's Tableaux, SU(2), SU(3) groups
- Quark Model

Unit-3: S- Matrix, Wick's Theorem and QED (10 hours)

- The S-Matrix expansion, Wick's theorem
- Electrodynamics of spin 0, ½ particles, Lifetimes and cross-sections, The Golden rule, The Feynman rules for a toy theory, Lifetime of the A, Feynman Rules for QED, Inelastic electron and muon scattering
- Loops, Renormalization and Running coupling constants.

Unit-4: QCD and Weak Interactions (8 hours)

- Structure of Hadrons, Partons and QCD
- Parity Violation and the V-A Form of the weak current, Interpretation of the Coupling G, Trace theorems, Muon decay, Charged current neutrino-electron scattering, Neutrino-quark scattering, First observation of weak neutral currents, Neutral current, Neutrino-quark scattering
- The Cabibbo Angle, Weak Mixing Angles, CP Violation: The Neutral Kaon System.

Unit-5: Electroweak Interactions, Standard Model and Beyond (12 hours)

- Electroweak theory, Lagrangian in particle physics, Weak spin, Gauge invariance, Standard Model Largrangian, U(1) terms, SU(2) terms, Neutral currents, Charged currents, Quark Lagrangian, Fermion gauge boson Lagrangian
- Standard model masses, Spontaneous symmetry breaking, Abelian Higgs mechanism, Higgs mechanism in the Standard Model
- Grand Unified Theories, Supersymmetry, Strings, etc...

Prescribed Textbooks:

1. Halzen, F. and Martin A.D.: Quarks and Leptons, John Wiley & Sons, 1984.
2. Griffiths, D.: Introduction to Elementary particles, John Wiley & Sons.

Other Resources/Reference books:

1. Martin, B.R. and Shaw, G: Particle Physics, John Wiley & Sons Ltd. 2009.
2. A. Lahiri and P.B. Pal: A First book of quantum field theory, 2nd edn, Narosa publ. house.
3. Gordon, Kane, Modern Elementary Particle Physics, Addison-Wesley Pub. Co. Inc. 1987.
4. Donald, H. Perkins: Introduction to High Energy Physics, Cambridge University Press.
5. Khanna, M.P.: Introduction to Particle Physics, PHI Learning Pvt. Ltd., New Delhi 1999.
6. Tayal, D.C.: Nuclear Physics, Himalaya Publishing House Pvt. Ltd.

Cosmology

Course Code: PAS- 539 A **Course Type: Elective Open**
Course Credit: 2
Course Objectives:
You have studied physics at various length scales, from the scale of a nucleus to a few light years (as for example in the solar system). Cosmology goes further beyond. It is the study of the large scale structure of the universe at length scales extending to billions of light years. The questions we ask in this branch of science are the following. How did the universe form ? When did it have it'sbeginning ? Why did it had the beginning in the way it did ? How do galaxies form ? When did the first elements like the hydrogen and helium form ? ... . The study of these questions needs an understanding of gravity (as it governs the dynamics at large scales) and hence general relativity, which is a theory of gravity, is an essential tool (cosmology is also called relativistic cosmology for this reason). Moreover, we shall also need a basic understanding of modern particle physics (which we shall gather along the way). We shall learn how cosmologists have gathered data and how relativists have interpreted them through their theories. We shall also learn about the cosmic microwave background radiation (CMB) and how they have led to the conclusion that our universe had a beginning and is now expanding in an accelerated mode. The aim of this course is to provide you the tools for a further study in cosmological physics.

Course Content

Unit 1: Tensors and their algebra **(3 hours)**

- Vectors and their transformation laws.
- Covariant and contravariant tensors.
- Transformation properties of tensors.
- Levi-Civita and Kronecker delta, tensor densities.

Unit 2: Tensor calculas **(4 hours)**

- Differentiation of tensors.
- Christoffel symbol and transformation properties.
- Covariant derivative, Concept of parallel transport.
- Geodesics and stationary property.
- Gauss' and Stokes' theorems.

Unit 3:Tensors on curved spacetime **(3 hours)**

- The Riemann and Ricci tensors, Ricci scalar.
- The Bianchi identities.
- Properties of the curvature tensors.

Unit 4: Einstein's equations **(4 hours)**

- Einstein's tensor and the Einstein equation.
- The Newtonian approximation

- The Einstein equations with matter and cosmological constant.
- Einstein's equations from an action principle:
- The action for gravity and it's variation.
- The action for matter and electromagnetic fields.

Unit 5: Cosmology **(6 hours)**

- The Weyl postulate and the cosmological principle.
- The Friedmann- Robertson- Walker spacetime
- Kinematics of FRW spacetime, redshifts, luminosity distance.
- Dynamics of FRW spacetime.
- Thermal history of the universe, the first three minutes.
- The present scenario: what we have learnt from the CMB spectrum.

Prescribed Textbooks:

1. P. A. M. Dirac: General relativity, Princeton Univ. Press.
2. S. Weinberg: General relativity and cosmology, Wiley .

Other Resources/Reference Books:

1. J. V. Narlikar: Cosmology, Cambridge Univ. Press.
2. S. Weinberg: Cosmology, Oxford Univ. Press.
3. S. Weinberg: The first three minutes, Basis books.