St. Xavier's College (Autonomous), Ahmedabad-380009

M.Sc. Physics Syllabus

Semester-4

CORE Paper. Instrumentation and Microcontroller
Course Code: PPH-4801
No. of credits: 4
Learning Hours: 60

Course Objectives

At the end of the course student will be able to

1. Study the drawbacks of two wire transmission lines at high frequency and the application of waveguides

2. Study the microwave junction and microwave sources including the klystron family.

3. Study and work with the microcontroller 8051, and will be designing the program including data transfer operation, arithmetic, logical, Boolean, and branching programs.

4. Design the Schmitt trigger, Astable Multivibrator and triangular wave generator using comparator circuits.

5. Know the importance of PLL IC, demonstrate the working of phase detector, comparator and *VCO*.

6. Design frequency multiplication using PLL.

7. Explain FM demodulation, FSK demodulator and AM detection.

8. Understand different concepts of Transducers, including those for measurement of temperature, strain, motion, position and light.

9. Choose proper transducer to make sensitive measurements of physical parameters like pressure, flow, displacement, velocity, temperature etc.

10. Locate different types of transducers and sensors used in real life applications.

11. Solve numerical based on above concepts and topics

Course Structure

Unit-1

Microwaves Transmission lines and waveguides: - line equations, impedance, reflections and voltage standing wave ratio, rectangular waveguides. Scattering(S) Parameters. Microwave T-Junctions: - H-plane Tee junction, E-plane Tee- junction, E-H (Hybrid or Magic) Tee. Directional couplers, isolator, Circulator. Microwave Sources and Devices - Two cavity Klystron amplifier, Multicavity Klystron, Reflex Klystron, Travelling wave tube (TWT), Magnetron, Gunn diode, lMPATT diode, Crystal Detector and PIN diode.

Unit-2

Microcontroller 8051 Microcontrollers-Introduction, MCS-51 Architecture, Registers in MCS- 51. A: 8051 Pin Description, Connections, I/O Ports and Memory Organization- 8051 Pin Description, 8051 Connections, 8051 Parallel I/O Ports, Memory Operations. B: Addressing Modes supported by 8051, Know the instruction set of MCS-51 microcontrollers, Data transfer instructions, Arithmetic instructions, Logical Instructions, Boolean variable manipulation instructions, program branching instructions.

Unit-3

OPAMP Applications Schmitt trigger, square wave generator, triangle wave generator Phase Locked Loop Introduction, Basic principles, Phase Detector and comparator, voltage-controlled oscillator (VCO), low pass filter, monolithic phase locked loop, PLL applications, frequency Multiplication/division, frequency translation, AM detection, FM demodulation, FSK demodulator.

Unit-4

Primary Sensing Elements and Transducers Mechanical Devices as Primary Detectors, Pressure Sensitive Primary Devices, Flow Rate Sensing Elements, Transducers, Characteristics Choice of Transducers, Resistive Transducers, Potentiometers, Strain Gauges, Resistance Thermometers, Thermistors, Thermocouples, Variable inductance Transducers, Capacitive Transducers, Piezoelectric Transducers, Hall Effect Transducers, Photo voltaic cell, Semiconductor Photo Diode, Photo Transistor.

Reference Books

1. Microwave Devices Circuits, Samuel Y Liao, Pearson

2. Microwave Radar Engineering, M Kulkarni, Umesh Publications

3. Microcontrollers (Theory and Applications) By Ajay V Deshmukh.

4. Linear Integrated circuit 4th edition, By Roy Choudhury and Jain, New Age International

5. Electronic Instrumentation by H S Kalsi, TMH Edition

6. A course in Electrical Electronic Measurements Instrumentation, AK Sawhney, Dhanpat Rai Co.

7. Electronic Instrumentation and Measurement Techniques, Cooper Helfric, Prentice Hall

St. Xavier's College (Autonomous), Ahmedabad-380009

M.Sc. Physics Syllabus

Semester-4

CORE Paper: Adv. Theoretical Physics
Course Code: PPH-4802
No. of credits: 4
Learning Hours: 60

Course Objectives

At the end of the course student will be able to

1. Understand the Basic Fundamental of Statistical Mechanics.

2. To explain the Dirac equation and its free-particle solutions, to explain the existence of antiparticles

3. Describe the classical and quantum mechanical treatment to understand many-body problem, describe the Kohn-Sham equation, pseudo-potential, exchange correlation functions for the material properties.

4. **Understand and apply** the fundamental principles of molecular dynamics, including Newton's equations of motion, interatomic potentials, and numerical integration algorithms.

5. **Perform and analyze** MD simulations using appropriate ensembles (NVE, NVT, NPT), thermostats, and barostats to study structural, dynamic, and thermodynamic properties of materials.

6. **Develop practical skills** in preparing input structures, selecting potentials, running simulations, and visualizing results using tools such as XCrySDen, VMD, and ASE-GUI.

7. **Comprehend** the theoretical foundations of many-electron systems, including Hartree–Fock, Thomas–Fermi–Dirac, and Kohn–Sham formalisms with various exchange–correlation functionals.

8. **Apply** self-consistent field (SCF) methods using suitable basis sets and pseudopotentials to obtain ground-state properties of materials.

9. **Perform and interpret** practical DFT simulations for structural optimization, electronic structure (band, DOS), and energy calculations using visualization tools like XCrySDen, VESTA, and ASE-GUI.

Course Structure

Unit-1

Statistical Foundations & Ensembles

Introduction to Phase Space – Microstates and macrostates; concept of ensemble. Microcanonical Ensemble – Entropy and temperature; connection with thermodynamics. Canonical Ensemble – Boltzmann factor, partition function, and thermodynamic quantities. Grand Canonical Ensemble – Chemical potential and particle exchange; grand partition function. Free Energy & Thermodynamic Relations – Helmholtz and Gibbs free energies; fluctuations. Classical vs Quantum Statistics – Maxwell–Boltzmann, Bose–Einstein, and Fermi–Dirac distributions.

Problem-Solving: Calculation of phase space volume for simple systems (free particle, harmonic oscillator). Problems on partition functions and derivation of thermodynamic quantities. Problems on canonical ensemble (energy fluctuations, mean energy). Applications of grand canonical ensemble: ideal gas, photon gas. MB, BE, and FD distributions – examples and limiting cases. Conceptual and numerical problems connecting ensembles and free energy.

Unit-2

Applications & Advanced Topics

Ideal Bose and Fermi Gases – Thermodynamic behavior and quantum degeneracy. Bose–Einstein Condensation (BEC) – Critical temperature and physical examples. Principle of Detailed Balance – Microscopic reversibility and transition rates. Blackbody Radiation & Planck's Law – Derivation from Bose statistics. Phase Transitions – First and second order; order parameter and critical behavior. Magnetism & Ising Model – Dia-, para-, and ferromagnetism; introduction to 1D Ising model.

Problem-Solving: Calculations for ideal Bose and Fermi gases (pressure, energy, specific heat). Derivation and numerical examples of Planck's law and Stefan–Boltzmann law. Problems on phase transition curves and critical exponents. Ising model: partition function for small systems and mean-field approximation. Diffusion Equation & Random Walk – Derivation and simple numerical examples. Brownian Motion – Einstein relation and fluctuation-dissipation problems.

Unit-3

Introduction to Molecular Dynamics (MD) Simulation

[A]. Newton's equations of motion, Interatomic potentials: pairwise, many-body, Lennard-Jones, Force calculation and energy minimization, Verlet, Velocity Verlet, Leapfrog algorithms, Time step and numerical stability, Constraint algorithms, Microcanonical (NVE), Canonical (NVT), Isothermal–isobaric (NPT), Thermostats and barostats: Andersen, Nosé–Hoover, Berendsen

[B]. Practical molecular dynamics (MD) calculations: preparing atomic structures, Structure optimization, choosing appropriate interatomic potentials, and setting simulation parameters like temperature, pressure, and timestep, use of ensembles such as NVE, NVT, or NPT using algorithms like velocity-Verlet, with trajectories. Post-simulation, structural (RDF), dynamic (MSD, diffusion), and thermodynamic properties, visualization tools like XCrySDen, VMD, ASE-GUI etc.

Unit-4

Introduction to Density Functional Theory (DFT)

Many-electron Schrodinger equation, variational method for many-electron system, Hartree–Fock theory overview, Thomas Fermi -Dirac methods, Hohenberg–Kohn theorems, Kohn–Sham equations and self-consistent field (SCF) approach, Exchange–correlation functionals: LDA, GGA, hybrid functionals (PBE, B3LYP, etc.), Plane-wave vs localized basis sets, Pseudopotentials: norm-conserving, ultrasoft, PAW.

Practical aspects of DFT calculations: XCrySDen, VESTA, GDIS, and **ASE-GUI** for structure visualization included geometry optimization, total energy, forces, stress, convergence tests: k-point sampling, cutoff energy, Band structure and density of states (DOS), Charge density, Cohesive energy, binding energy, adsorption energy, Case study: DFT of graphene, Si.

Reference Books

1. Statistical Mechanics, Kerson Huang, Wiley

2. Quantum Mechanics (Second Edition) G. ARULDHAS PHI Learning Private Limited

3. A Text Book of Quantum Mechanics P.M Mathew and K Venkatesan TATA McGRAW-HILL PUBLISHING COMP. LTD

4. Quantum Mechanics Theory and Application (5th Edition) Ajoy Ghatak and S Lokanathan Trinity Press

5. Quantum Mechanics Leonard Schiff McGRAW-HILL PUBLISHING COMP. LTD

6. The ABC of DFT Kieron Burke and friends Department of Chemistry, University of California, Irvine.

7. Electronic Structure: Basic Theory and Practical Methods by R. Martin

8. Frenkel and B. Smit, Understanding Molecular Simulation From Algorithms to Applications, 2nd ed., Academic Press (2002).

9. M. P. Allen and D. J. Tildesley, Computer Simulation of Liquids, Oxford University Press, Oxford (1987).

10. Koch, Wolfram; Holthausen, Max C., A chemist's guide to density functional theory, 2. ed., Weinheim, Wiley-VCH, cop. 2001

11. Sholl, David S.; Steckel, Janice A., Density functional theory: a practical introduction, Hoboken, N.J., Wiley, c2009

12. Density-Functional Theory of Atoms and Molecules" by Parr and Yang.

13. The ABC of DFT", by Kieron Burke, http://dft.uci.edu/doc/g1.pdf

14. Modern Quantum Chemistry, Introduction to Advanced Electronic Structure Theory", Szabo and Ostlund.

St. Xavier's College (Autonomous), Ahmedabad-380009

M.Sc. Physics Syllabus

Semester-4

CORE Paper: Nuclear Physics & Atomic-Molecular Physics
Course Code: PPH-4803
No. of credits: 4
Learning Hours: 60

Course Objectives

At the end of the course student will be able to

1. Understand the importance of models in describing the properties of nuclei and nuclear collisions.

2. Understanding of nuclear reactions mechanisms, compound nuclei and direct reactions.

3. Understand of Parity non-conservation in weak-interaction and relativistic kinematics.

4. Solve numerical based on above concepts and topics.

Course Structure

Unit-1

Elementary ideas of alpha, beta and gamma decays and their selection rules. Binding energy, semi-empirical mass formula, liquid drop model. Evidence of shell structure, single-particle shell model, its validity and limitations. Rotational spectra.

Unit-2

Nature of the nuclear force, form of nucleon-nucleon potential, charge-independence and charge-symmetry of nuclear forces. Deuteron problem. Nuclear reactions, reaction mechanism, compound nuclei and direct reactions.

Unit-3

Elementary particles: The four basic forces, Particles and antiparticles, Families of particles, conservation Laws, particle interactions and decays, energetics of particle reactions, the quark model, the standard model, Numerical Examples. Introduction to Universe.

Unit-4

Quantum states of an electron in an atom. Electron spin. Spectrum of helium and alkali atom. Relativistic corrections for energy levels of hydrogen atom, hyperfine structure and isotopic shift, width of spectrum lines, LS JJ couplings. Zeeman, Paschen-Bach Stark effects. Frank-Condon principle. Born-Oppenheimer approximation. Electronic, rotational, vibrational and Raman spectra of diatomic molecules, selection rules.

Reference Books

1. Nuclear Physics, Kenneth Krane

2. Nuclear Physics, S B Patel

3. Nuclear Physics, S N Ghoshal

4. Atomic Molecular Spectra Laser By Raj Kumar

St. Xavier's College (Autonomous), Ahmedabad-380009

M.Sc. Physics Syllabus

Semester-4

CORE Paper: Atmospheric Sciences & Plasma Physics
Course Code: PPH-4804
No. of credits: 4
Learning Hours: 60

Course Objectives

At the end of the course student will be able to

1. Fundamentals of plasma physics describing variety of plasma occurring naturally/artificially

2. Single particle picture under various electromagnetic field configuration, which will help to understand concept of confinement in tokamak device.

3. Collision phenomena in plasma describing collisional transport and resistivity.

4. Fluid and kinetic description of plasma state, plasma waves and its experimental aspects

5. This overall prepare students foundation for further advanced plasma course like magnetically confined thermonuclear fusion reactor: tokamak

6. Get the knowledge of radiative transfer within different layers of Atmosphere

7. Able to solve problems related to atmospheric science using their computational skills

8. Understand the vast field of Atmospheric science

9. Solve numerical based on above concepts and topics.

Course Structure

Unit-1

Introduction to Plasma Physics: Occurrence of plasma in nature, definition of plasma, concept of temperature, Debye shielding, plasma parameter, criteria for plasmas, applications of plasma physics.
Single Particle Motions: Introduction, uniform E and B fields, non-uniform B field, non-uniform E field, time-varying E field, time varying B field, adiabatic invariants

Unit-2

Plasma as Fluids: Relation of plasma physics with ordinary electromagnetics, fluid equation of motion, fluid drifts perpendicular to B, fluid drift parallel to B, plasma approximation.

Waves in Plasmas: Introduction to waves, plasma oscillations, electron plasma waves, sound waves, ion waves, validity of plasma approximation, comparison of ion and electron waves, electrostatic electron oscillations perpendicular to B, electrostatic ion waves perpendicular to B, lower hybrid frequency, electromagnetic waves with $B = 0$, experimental applications, electromagnetic waves perpendicular to B, cut-offs and resonances, electromagnetic waves parallel to B, hydromagnetic waves, magnetosonic waves, CMA diagram.

Unit-3

Electrostatics: Gauss's law and its applications, Laplace and Poisson equations, boundary value problems. Magnetostatics: Biot-Savart law, Ampere's theorem. Electromagnetic induction. Maxwell's equations in free space and linear isotropic media; boundary conditions on the fields at interfaces.

Scalar and vector potentials, gauge invariance. Electromagnetic waves in free space. Dielectrics and conductors. Reflection and refraction, polarization, Fresnel's law, interference, coherence, and diffraction. Dynamics of charged particles in static and uniform electromagnetic fields.

Unit-4

Fundamentals of Radiative Transfer; Radiative transfer equation and solution of it in simple cases; Remote Sensing; Radiative Effects of aerosols.

Reference Books

1. Fundamental Astronomy, Hannu Karttunen, Springer

2. Radiative Transfer in the Earth System‖ by Charlie Zender

3. Electrodynamics, David Griffiths, Cambridge University Press

St. Xavier's College (Autonomous), Ahmedabad-380009

M.Sc. Physics Syllabus

Semester-4

CORE Paper. Physics Laboratory
Course Code: PPH-4805L
No. of credits: 4
Learning Hours: 60

Course Objectives

At the end of the course student will be able to

1. Will be able to demonstrate the Zeeman Effect.

2. Will be able to demonstrate Hysteresis Loop Tracer.

3. Will be able to demonstrate the Electron Spin Resonance (ESR)

4. Will be able to demonstrate the Optical Fiber Experiment.

5. Will be able to measure the Permittivity of Air.

6. Will be able to demonstrate the Kerr Effect.

7. Will be able to measure Mutual Inductance using Lock-in Amplifier.

8. Will be able to demonstrate Phase Locked Loop (PLL).

9. Will be able to demonstrate Data Acquisition using Coupled Pendulum and Microcontroller 8081.

10. Will be able to demonstrate Pulse Width Modulation and LVDT Transducer and Strain Gauge

Course Structure

1. Zeeman Effect

2. Hysteresis Loop Tracer

3. Electron Spin Resonance (ESR)

4. Optical Fiber Experiment

5. Measurement of Permittivity of Air

6. Kerr Effect

7. Measurement of Mutual Inductance using Lock-in Amplifier

8. Phase Locked Loop (PLL)

9. Data Acquisition using Coupled Pendulum

10. Microcontroller 8081

11. Pulse Width Modulation

12. LVDT Transducer and Strain

St. Xavier's College (Autonomous), Ahmedabad-380009

M.Sc. Physics Syllabus

Semester-4

CORE Paper. Project and Dissertation
Course Code: PPH-4806L
No. of credits: 4
Learning Hours: 60

Course Objectives

At the end of the course student will be able to

1. Will be trained in identifying Projects by doing literature survey in forms of Research papers, journals and looking for ideas in internet.

2. He/She is also encouraged to come with original ideas which explain the concepts of Physics and electronics.

3. Will be trained in having -Hands on experience with designing projects using various instruments, collecting data and in its analyses.

4. Will be able to document his project by writing synopsis and project report

Course Structure

Students are expected to finish their Project work by the end of Semester 4 and submit their Dissertation. The internal as well as external evaluation will be based on their Project.