PHY-815 Techniques of Experimental and Computational Physics

Credit Hours: 3-0

Pre-requisite: None

Course Objectives: This course is designed to introduce students with experimental techniques in Physics with emphasis on data analysis. Experiments from various fields of Physics are chosen to give experimental perspective of these fields to students at graduate level. By the end of the course, students will be able to:

- Design and conduct precision experiments using advanced laboratory instruments.
- Apply statistical and computational methods to analyze experimental data.
- Use numerical techniques to solve physical problems and model systems.
- Develop proficiency in scientific programming and simulation tools.
- Critically assess experimental uncertainties and computational approximations

Core Contents: This graduate-level course introduces advanced techniques in experimental physics alongside computational methods for data analysis, modelling, and simulation. Students will gain practical skills in designing experiments, precise measurements, instrumentation, error analysis, and computational tools including numerical methods and programming used in modern physics research.

Detailed Course Contents: Review of programming, modern physics, structure of atom, radiations and doses, interaction of charged particles with matter, energy transfer and scattering cross sections, interaction of photons with matter and consequences in terms of different effects, design and concept of accelerators, use of accelerators in medicine, X-rays: production and characteristics, radiation dose and dosimetry techniques.

Course Outcomes: At the end of the course, students will be able to understand:

- the fundamentals and classifications of radiation
- radiation dose distribution in water
- coulomb scattering and cross-sections
- production of X-rays

- interaction if charged particles and photons with matter
- energy transfer during interaction of photon with matter
- particle accelerators in medicine
- fundamentals of radiation dosimetry

Textbook:

1. An Introduction to Error Analysis" by John R. Taylor, 2^{nd} Ed, 1997.
2. Computational Physics" by Nicholas J. Giordano and Hisao Nakanishi, 2^{nd} Ed, 2006

Reference Books:

Research papers and online tutorials on experimental instrumentation and data acquisition systems

Weekly Breakdown		
Week	Section	Topics
1	Taylor 1-5	Course overview, objectives, and expectations, Importance of experimental and computational techniques in physics research, Basics of measurements, units, accuracy, precision, Types of errors: systematic, random, and gross errors, Propagation of uncertainties, Statistical treatment of data: mean, standard deviation, confidence intervals
2	Taylor 7-12	Weighted Averages, least square fitting, covariance and correlation, Binomial distribution, Poisson distribution, Chi-squared test
3	Hand outs	Instrumentation and data acquisition, Signal detection and amplification, Use of oscilloscopes, function generators
4	Lab + Handouts	Classical Mechanics: 1. To obtain the value of acceleration due to gravity by using simple and compound pendulum and its error analysis

5	Handouts and Lab	Elementary particle detection: ionizing radiation, charged particles, photons and electrons, neutrons, radiation safety, biological effects of radiations, kinds of particle detectors, solid angle, gaseous ionization detectors, scintillation detectors, pulse processing electronics, amplifiers, discriminators and single channel analyzers, processing logic signals, e/m ratio by Millikan's oil drop method
6	Lab	Nuclear Physics: To explore statistics of random independent events in physical measurements by varying the duration and number of trials of a radioactive decay; comparison of experimental data with theoretical statistical distributions: Gamma ray spectroscopy
7	Handouts	Quantization of Energy levels: The nuclear atom, electron orbits, quantization of electronic orbitals, radiative transitions, interaction of atoms with a magnetic field
8	Lab	Quantum Mechanics: 1. To demonstrate the concept of quantization of energy levels in atoms (Franck Hertz experiment)
Midterm Exam		
9	Handouts and Lab	Solid State Physics: Crystal structure, fundamental types of crystals, chemical methods for the synthesis of crystals, physical methods for the synthesis of crystal, basic characterization techniques, synthesis of some metal oxide/hydroxide in lab and its structural characterization by X-ray diffraction
10	Handouts and Lab	Motion of charge carriers in both electric and magnetic fields, principle of Hall effect, calculation of Hall voltage,

		Hall coefficient, charge carrier concentration, mobility, study of Hall Effect on silver and tungsten strips
11	Lab	Special Relativity: Determining the velocity of light
12	Handouts and Lab	Spectroscopy: Light production and detection, sources of light, thermal radiation, discrete line sources, lasers, measuring light intensity, Fourier Optics and Spectroscopy, photographic film, photomultiplier tubes, photodiodes
13	Handouts	Designing experiments informed by computational predictions, using simulations to interpret experimental data, discussion on computational techniques
14	Handouts	Integration and Differentiation: Numerical integration: trapezoidal, Simpson’s rule
15		Numerical differentiation methods, Error analysis in numerical methods
16	GN 1, 2.1-2.5	Solving ordinary Differential Equations: Euler’s method, Runge-Kutta methods, Stability and error in ODE solvers with examples