NPRE-446: Radiation Interaction with Matter I

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Schedule:
Lectures: MWF, 11:00 – 11:50, 101 Transportation Building
Recitation: W, 4:00 – 5:30pm, 100H Talbot Laboratory

Course Website: http://zhang.engineering.illinois.edu/teaching.html

Credit: 3 undergraduate or graduate hours

Prerequisite: MATH 285, PHYS 211–214, or equivalent.
Linear Algebra (MATH 125) is not required, but highly recommended.

Grading:

1) Homework (30%). Late homework is accepted, but 10% of the score will be deducted *per day* until 50% is reached.

2) Quizzes (10%). Quizzes will be given in class randomly. No make-ups are allowed unless a doctor's note is provided for medical reasons before classes.

3) Mid-term exam (30%), Final exam (30%). A *letter size hand-written only cheat sheet* (otherwise half of the score will be deducted) is allowed during the exam. The cheat sheet will be collected at the end of the exam, but will not be graded.

Academic dishonesty and plagiarism of any kind on a homework, project, quiz, or exam will result in at least an "F" for that assignment, and maybe, depending on the severity of the case, an "F" for the entire course. Furthermore, they may be subject to appropriate referral to the university for further action.

Description:

The classical and quantum theories of the interaction of radiation (heavy and light charged particles, electromagnetic waves, photons, and neutrons) with matter are the core components of nuclear science and engineering. At UIUC, we offer a sequence of four courses at different progressive levels on this subject:

Part 1. (Undergraduate, Required) *NPRE-446 Radiation Interaction with Matter I*, covers classical mechanics, classical electrodynamics, and quantum mechanics.

Part 2. (Undergraduate, Required) *NPRE-447 Radiation Interaction with Matter II*, covers nuclear physics including nuclear properties, nuclear structure, radioactive decay, interactions of radiation with matter, and nuclear reactions.

Part 3. (Graduate, Required) *NPRE-521 Interaction of Radiation with Matter*, covers quantitative treatments of single interaction event in nuclear physics.

Part 4. (Graduate, Elected) *NPRE-529/CSE-529 Interaction of Radiation with Matter II: Multiple Events and Computational Methods*, covers equilibrium and non-equilibrium statistical mechanics, liquid theories, and atomistic simulations.

The sequence, in the aggregate, aims to provide the students with solid trainings on essential physical principles, mathematical competence, and computational skills.

Topical Outline:

The superscript number indicates the approximate week number. The superscript * indicates optional advanced topics.

1. Classical Mechanics

   Newton's formalism[1], principle of virtual work[*], principle of least action[2], Euler-Lagrange equation[2], Lagrange multiplier[*], Rutherford scattering[2], Legendre transformation[2], Hamilton's equations[2], conservation laws and symmetry[2], canonical transformation[*], sympletic condition[*], canonical invariants[*], Poisson bracket[3], Liouville's theorem[3], Hamilton-Jacobi equation[*]

2. Classical Electromagnetic Interaction

   Vector calculus[3], Maxwell equations[3,4], Lorentz force density[4], energy and momentum of electromagnetic fields[4] (Poynting vector[4], Maxwell stress tensor[*]), Maxwell equations in matter[4], boundary conditions[4], electrostatics (Poisson equation[5], conductor[*], capacitor[*], Laplace equation[5], uniqueness theorem[5], method of images[5], separation of variables[*], multipole expansion[*]), magnetostatics[*], electromagnetic waves (wave equation[5], electromagnetic spectrum[5], propagation[6], polarization[6], reflection[*], refraction[*], electromagnetic wave in conductor[7], wave guide[*]), electromagnetic radiation (gauge transformation[7], retarded potential[7], Jefimenko's equations[7], Lorentz force Lagrangian[7], electric dipole radiation[7], magnetic dipole radiation[*], Lienard–Wiechert potential[8], Larmor formula[8], bremsstrahlung/synchrotron/Cherenkov radiation[8], Abraham-Lorentz force[*]), electromagnetic wave scattering[*] (Rayleigh scattering[*]), special relativity[*]

3. Non-relativistic Quantum Mechanics and Atomic Structure

   Limitations of classical theory[9] (stable atomic model, black-body radiation, photoelectric effect, Compton scattering), wave-particle duality[9], operators[9], Schrödinger equation[9], eigen states[9], observables[9], statistical interpretation[9], probability conservation[9], bound/unbound states (square potential[10], Harmonic oscillator[10], ladder operators[10], free particle[11], δ potential[11]), formalism (Hilbert space[12], Bra-ket notation[12], Hermitian[12], time evolution[12]), matrix representation[13], uncertainty principle[13], atomic orbitals[14], identical particles[14], perturbation method[*], Bohn approximation[*], Fermi's golden rules[*], double differential scattering cross section[*]

Recommended Texts:

Essential Physics (Basic Level):

1. J. R. Taylor, *Classical Mechanics,* University Science Books (2005).
2. (*Required) D. J. Griffiths, *Introduction to Electrodynamics,* 4th edition, Pearson (2012).
3. (*Required) D. J. Griffiths, *Introduction to Quantum Mechanics,* 2nd edition, Pearson (2004).

Essential Physics (Advanced Level):

4. H. Goldstein, C. Poole and J. Safko, *Classical Mechanics,* 3rd edition, Addison-Wesley (2001).
5. J. D. Jackson, *Classical Electrodynamics,* 3rd edition, Wiley (2001).
6. J. J. Sakurai, *Modern Quantum Mechanics,* 2nd edition, Addison-Wesley (2010).

Nuclear Physics:

7. S. Yip, *Nuclear Radiation Interactions,* World Scientific (2014).
8. W. E. Meyerhof, *Elements of Nuclear Physics,* McGraw-Hill (1967).
9. K. S. Krane, *Introductory Nuclear Physics,* 3rd edition, Wiley (1987).
10. R. D. Evans, *The Atomic Nucleus,* McGraw-Hill (1955).
11. D. J. Griffiths, *Introduction to Elementary Particles,* 2nd edition, Wiley (2008).