EE 471 – INTRODUCTION TO PLASMAS

Designation: EE elective course for electrical, aerospace, and nuclear engineering majors.

University Bulletin Description: EE (AERSP 490, NUC E 490) 471: (3) Plasma oscillations; collisional phenomena; transport properties; orbit theory, typical electrical discharge phenomena.
Prerequisite: EE 330.

Prerequisites by topics:
1. Strong understanding of electromagnetics.
2. Understanding of vector calculus and differential equations.
3. Understanding of basic chemistry, physics of motion, and wave equations.
4. Proficiency in the use of a mathematical analysis program.
5. Ability to do library and Internet research and to write a research paper.

Textbook/Required Materials:
Introduction to Plasma Physics and Controlled Fusion, 2nd Ed., Chen , Plenum, 1984

Learning Outcomes:
This course is designed to give seniors and graduate students a working knowledge of plasma phenomena, models to describe such phenomena, and applications of plasmas. This course stresses a physical understanding of plasma phenomena, backed up with mathematical formulation. Students should be able to do the following upon completion of this course:
1. Describe various plasma phenomena (such as why sheaths form, what waves will propagate, etc.) in a physical (qualitative) sense.
2. Develop the mathematical basis to back up the qualitative understanding, e.g., dispersion functions for wave propagation.
3. Examine plasma phenomena at micro and macro scales, i.e., single-particle and collective models.
4. Be able to draw analogies between plasmas and other physical systems, such as solid-state devices.

Topics:
1. Introduction
   Introduction to methods of theoretical description of plasmas, concept of temperature, quasi-neutrality and plasma oscillations, Debye shielding.
2. Single-particle motions in given electric and magnetic fields
   Uniform electric and magnetic fields, non-uniform magnetic field, grad-B drift, curvature drift, magnetic mirrors, non-uniform electric field, finite Larmor radius effects, time-varying electric field, polarization drift, time-varying magnetic field, plasma heating by adiabatic compression.
3. Fluid description of plasmas, the plasma approximation
   The fluid equation of motion, pressure, equation of continuity, equation of state, complete set of fluid equations, fluid drifts perpendicular and parallel to magnetic field, the plasma approximation.
4. Waves in plasmas, the CMA diagram
   Representation of waves, phase and group velocities, sinusoidal time variations, dispersive media, plasma oscillations, electron plasma waves, ion acoustic waves, electrostatic electron oscillations perpendicular to magnetic field, electrostatic ion waves perpendicular to magnetic field, electromagnetic waves, electromagnetic waves perpendicular and parallel to magnetic field, cutoffs and resonances, the whistler mode, the Alfven wave, Clemmow-Mullay-Allis (CMA) diagram.
5. Diffusion and resistivity, magnetohydrodynamics
   Diffusion and mobility in weakly ionized gases, decay of plasma by diffusion, steady state solutions, recombination, diffusion across a magnetic field, collisions in fully ionized plasmas, the single-fluid MHD equations, diffusion in fully ionized plasmas.
6. Plasma instabilities

Equilibrium and stability, MHD equilibrium, diffusion of magnetic field into a plasma, Buneman instability, beam-plasma instability, two-stream instability, the gravitational instability.

7. Kinetic description of plasmas, Landau damping
   The meaning of the velocity distribution function, equations of kinetic theory, moments of the Boltzmann equation, plasma oscillations and Landau damping, Landau damping of ion-acoustic waves.
8. Nonlinear effects
   DC sheaths, ion-acoustic solitons.
9. Kinetics of electrons in a weakly ionized gas placed in an electric field
   Motivation for studies and related applications, plasma display panels, transient luminous events in the middle atmosphere.

Class/Laboratory schedule: Two 75-minute lectures per week.

Computer usage:

1. Proficiency in one of the major mathematical programs (e.g., Mathematica, MatLab, MathCAD) is expected to solve homework problems.
2. Individual semester projects may elect to use Particle-In-Cell (PIC) plasma simulation codes, spacecraft charging codes (*e.g.*, SEE Charging Handbook), or other plasma simulation codes.
3. Computer experiments are discussed in class and provided as four separate homework assignments. Well tested plasma simulation codes are supplied. Existing computer lab assignments cover single particle dynamics, various drifts, plasma confinement, non-linear effects and plasma instabilities.

Laboratory Projects/Assignments:
There is no specific laboratory component to this course, although students may elect to perform laboratory experiments as part of their semester project.

Contribution to Meeting the Requirements of Criterion 5. Curriculum:
This course contributes to both the engineering topics and design components.
Topics pertaining to economics, environmental, sustainability, ethical, social, and political issues are addressed in discussion over appropriate course for U.S. energy policy and the search for viable fusion reactors.

Relationship to Program Outcomes:

- O.1.1. Graduates will possess mathematics skills necessary for electrical engineering.
- O.1.2. Graduates will have a theoretical and practical background in both physics and chemistry.
- O.1.3. Graduates will have attained computer proficiency.
- O.2.4. Graduates will understand fundamental electricity and magnetism concepts and be able to use them in applications.
- O.3.1. Graduates will have in-depth technical knowledge in one or more areas of specialization.
- O.3.2. Graduates will have practical understanding of the major electrical engineering concepts and demonstrate application of their theoretical knowledge of the concepts.
- O.4.2. Graduates will develop an appreciation of continuing educational and professional development.
- O.5.2. Graduates will possess good oral and written communication skills.
- O.6. Graduates will appreciate their role as engineers in society.

Prepared by: Victor Pasko **Date:** March 7, 2008