Fall 2020

PHYS 741-001: Basic Plasma Physics with Space and Laboratory Applications

Alexander Kosovichev

New Jersey Institute of Technology
College of Science and Liberal Arts
Department of Physics
Basic Plasma Physics with Space and Laboratory Applications
PHYS 741
Fall 2020

Monday	**12:30PM – 1:50PM**	**Synchronous Online**
Tuesday	**12:30PM – 1:50PM**	**Synchronous Online**

NJIT Webex: https://njit.webex.com/join/sasha

Instructor
Prof Alexander Kosovichev
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Textbooks
1. Introduction to Plasma Physics: With Space, Laboratory and Astrophysical Applications 2nd Edition, by Donald A. Gurnett, Amitava Bhattacharjee, Cambridge University Press, 2017
2. Introduction to Plasma Physics and Controlled Fusion, by Francis F. Chen, Springer.2016

Grade
Your final grade will be based upon homework (20%), quizzes (20%), class participation (20%), and one Final Presentation (40%).
The grades you earn will determine your final grade based on the following table.

85% to 100%	A
80% to 84%	B+
70% to 79%	B
65% to 69%	C+
50% to 64%	C
40% to 49%	D
0% to 39%	F

Syllabus

Week 1
Basic concepts.
Debye shielding. Plasma ionization. Saha equation.

Week 2.
Particle motion in electric and magnetic fields I.
Coulomb collisions. Plasma resistivity.

Week 3
Particle motion in electric and magnetic fields II.
Particle motion in complex magnetic configurations.
Adiabatic invariants

Week 4
Kinetic theory of plasma.
Vlasov equation. Collective effects.

Week 5
Fokker-Planck Equation.
Collisions. Plasma Resistivity.

Week 6
MHD approximation.
Plasma as a fluid. Ohm's law.

Week 7
Energy and momentum transport.
Chapman-Enskog theory.
Plasma transport in magnetic field.
Ambipolar diffusion.

Week 8
Propagation of electromagnetic waves in plasma.
Plasma waves. Landau damping.

Week 9
Plasma radiation
Bremsstrahlung, recombination, synchrotron radiation.

Week 10
MHD waves. Non-linear effects in plasma.
Collisionless shocks.
Quasi-linear theory of Landau damping.

Week 11
Resistive instabilities. Magnetic reconnection.
Magnitosphere. Solar Flares.

Week 12
Plasma Applications.
Thermonuclear fusion. Tokamak.

Week 13
Dynamo theory.
Helicity. Laboratory dynamo experiments.
Solar cycle.

Week 14
Stochastic processes.
Particle acceleration. The origin of cosmic rays.

Week 15
Plasma experiments.

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Learning Objectives and Outcomes

Upon successful completion of this course, the student will be able to

1) Demonstrate comprehensive knowledge and understanding of theoretical principles of plasma physics, applications to laboratory experiments, and understanding of space plasma phenomena. Students will be able to: understand the basic principle of plasma as a state of matter, dynamics of charged particles in realistic magnetic field configurations, collective phenomena in plasma, kinetic theory, interaction of particle beams with plasma, the particle distribution function, the Vlasov equation and its solutions, the role of particle collisions, the mechanisms of plasma resistivity, the generalized Ohm's law, the behavior plasma as a fluid and its description in the magnetohydrodynamics approximation, the energy and momentum transport, the Chapman-Enskog theory, the transport phenomena in magnetic field, the ambipolar diffusion, dispersion properties of electromagnetic waves in plasma, various types of plasma waves, the Landau mechanism of wave damping, various mechanisms of plasma radiation: bremsstrahlung, recombination, synchrotron, MHD waves and relationship among various wave modes, non-linear effects in plasma, formation and properties of collisionless shocks, plasma instabilities, magnetic reconnection and its manifestation in space and astrophysical plasma, the theory of thermonuclear fusion and modern experiments, magnetic field generation by the dynamo mechanism, the role of magnetic helicity, laboratory dynamo experiments, the origin of cosmic magnetic fields, the origin of the solar activity cycle, stochastic processes in plasma, particle acceleration mechanisms, the origin of cosmic rays, and modern plasma laboratory experiments.

2) Describe the additional concepts that are necessary to understand the basic physical processes in plasma. For example, students will be able to define the relationship among various plasma regimes, from dynamics of charged particles to collective phenomena, and behavior of the plasma as a fluid; describe motion of charged particles in complex magnetic configurations; explain the plasma distribution function and the fundamentals of the kinetic theory; determine the role of particle collisions, plasma resistivity and the generalized Ohm's law; understand the energy and momentum transport in the presence of magnetic field; derive the magnetohydrodynamic equations, and explain the validity of the MHD approximation; describe propagation of electromagnetic waves in plasma; explain the physical mechanism of plasma waves, and the mechanism and universal nature of Landau damping; describe the basic radiation processes in plasmas with and without magnetic field; explain the role of nonlinear effects, and their properties in space plasma; describe the mechanism of magnetic reconnections and its applications in space and laboratory plasma; understand the basic principles of controlled thermonuclear fusion and principles of modern fusion devices; explain the mechanism of magnetic field generation and the role of plasma helicity; derive the criteria for the dynamo instability; explain the origin of the solar activity cycle; explain mechanisms of stochastic particle acceleration, and describe basic plasma laboratory experiments and applications.

3) Apply such knowledge to calculate properties of space and laboratory plasma in various conditions. For example, students will be able to: calculate the characteristic plasma parameters (the plasma frequency, Debye radius, the collision frequency, the energy and momentum transfer rates, the cyclotron frequency, the Larmor radius, the plasma resistivity, etc); interpret the plasma, electromagnetic and MHD waves using frequency-wavenumber diagram; formulate criteria of plasma instabilities; estimate the threshold and period of cyclic dynamo processes; use experimental and observational data of electromagnetic radiation to estimate plasma properties.

4) Demonstrate skills of locating, digesting, and presenting the contents of published research papers and monographs at the cutting edge of plasma physics and applications to clearly describe the issues at hand.

5) Apply such newly-acquired concepts to laboratory experiments, solar-terrestrial physics, astrophysics, as well as to broader industrial applications based plasma processing.