PHY-467 Space Plasma

Credit Hours: 3-0

Prerequisite: None

Course Objective: The aim of this course is to explore the physical processes which occur in the space environment. Theories of solar wind propagation and its interaction with the earth are developed and compared with data from satellites and ground based observatories. The course will also provide a brief revision of key elements of electromagnetic theory. Magnetohydrodynamics (MHD) will be developed and applied, with application of kinetic theory to areas where MHD breaks down. The reasons why space plasma physics is important for modern day life will be discussed. The magnetospheres of other planets will be compared to Earth's.

Course Contents: Overview: the solar atmosphere, solar wind and interactions with planetary bodies, The fluid theory of plasmas, frozen-in theorem (use example of Parker spiral of interplanetary magnetic field), The shape of the Earth's magnetosphere: the balance of thermal, dynamic and magnetic pressures, Magnetic reconnection and how it dominates energy flow in the magnetosphere, Convection and sub-storm phenomena, Coronal mass ejections and geomagnetic storms, Ionosphere and plasma-sphere Aurora, Trapped particles, ring current and radiation belts, Effects of terrestrial disturbance: satellite health and safety, satellite orbit prediction, disruption to communication, navigation, radar systems and power distribution networks, Applications in fusion research and astrophysics

Detailed Course Contents: Definition of a plasma, Debye shielding, the plasma parameters, the geophysical plasma, the ionosphere Magnetoshperic currents, theoretical approaches in plasma physics, some related problems, Field equations in plasma, gyration, electric drifts – polarization drift etc., magnetic drifts, Magnetic moment, magnetic mirror, adiabatic heating, longitudinal invariant, energy anisotropy, Dipole field, Bounce motion, drift motion of trapped particles, magnetic and electric drifts revisited, sources and sinks in plasma, Radiation belts, ring current in plasma, magnetic disturbance and magnetic storms, Partially Ionized Plasmas, fully ionized plasmas, unmagnetized and magnetized plasmas, Ionosphere Formation: The Chapman Layer, Ionospheric conductivity, Equatorial Electrojet, Sq Current, Auroral Emissions, Diffusion and frozen flux, the convection electric field, Merging and Reconnection, Corotation and Plasmasphere, High-Latitude Electrodynamics, Auroral Electrojets, Magnetospheric Substorms, Substorm Currents, Exact Phase Space Density, Average Distribution Function, Kinetic, Boltzamnn and Volsov equations, Velocity Anisotropic Distributions, Juttner Distribution, Energy Distributions, Kappa and Power law distributions, Measured Distribution Functions, Velocity Moments, the concept of temperature in plasma, mutli fluid theory and equations in plasma, Single fluid theory, Stationay and equillibria fields in plasma, Validity of Magnetohydrodynamics in Plasmas, Introduction to Magnetohydrodynamic Equations.

Learning Outcomes: Having successfully completed this curse the students will be able to:

- Interpret geomagnetic field measurements in terms of currents flowing in Earth's ionosphere and magnetosphere.
- Describe the phases and features of magnetic storms and substorms, and their causes.
- Calculate fundamental properties of a plasma given appropriate information.
- Apply fluid theory to large scale plasmas.
- Use kinetic theory to explain the motions of charged particles in the ionosphere and near-Earth space.
- Apply basic electromagnetism to derive the kinetic theory of plasmas.
- Explain the main consequences of magnetic reconnection for Earth's magnetosphere.
- Explain how particle collisions produce Hall and Pedersen currents in the ionosphere.

Text Book:

i. **Main Text Book:** W Baumjohann & R A Treumann. Basic Space Plasma Physics. Imperial College Press (2012).

ii. **Reference Books:**
    - An Introduction to Plasma Physics and Its Space Applications, Volume 2, Luis Conde, IOP Publishing Limited 2020.
    - Physics of Fully Ionized Gases, Lyman J Spitzer. Dr. Spitzer, Princeton University Press, 1960.

iii. Supporting Books:

- Principals of plasma diagnostics, Ian Hutchinson, I. H. Hutchinson, Cambridge University Press, 1990.
- Introduction to Plasma Physics and Controlled Fusion, F. F. Chen, 3rd ed. 2016 Edition.
- Plasma Physics and Fusion Energy, Jeffrey P. Freidberg, Cambridge University Press, 2008.

Weekly Breakdown		
Week	***Section***	***Topics***
1	BT 1.1 – 1.2.3	Definition of a plasma, Debye shielding, the plasma parameters, the geophysical plasma, the ionosphere
2	BT 1.3 – 1.4	Magnetoshperic currents, theoretical approaches in plasma physics, some related problems
3	BT 2.1 – 2.4	Field equations in plasma, gyration, electric drifts – polarization drift etc., magnetic drifts
4	BT 2.5.1-2.5.7	Magnetic moment, magnetic mirror, adiabatic heating, longitudinal invariant, energy anisotropy
5	BT 3.1 – 3.4	Dipole field, Bounce motion, drift motion of trapped particles, magnetic and electric drifts revisited, sources and sinks in plasma
6	BT 3.5 – 3.6	Radiation belts, ring current in plasma, magnetic disturbance and magnetic storms
7	BT 4.1 – 4.3	Partially Ionized Plasmas, fully ionized plasmas, unmagnetized and magnetized plasmas, Ionosphere Formation: The Chapman Layer
8	BT	Ionospheric conductivity, Equatorial Electrojet, Sq Current,

	4.4 – 4.6	Auroral Emissions
	Mid Term Exams	
9	BT 5.1 – 5.3	Diffusion and frozen flux, the convection electric field, Merging and Reconnection, Corotation and Plasmasphere
10	BT 5.4 – 5.6	High-Latitude Electrodynamics, Auroral Electrojets, Magnetospheric Substorms
11	BT 5.7 – 6.2	Substorm Currents, Exact Phase Space Density, Average Distribution Function, Kinetic, Boltzamnn and Volsov equations
12	BT 6.3 – 6.4	Velocity Anisotropic Distributions, Juttner Distribution, Energy Distributions, Kappa and Power law distributions, Measured Distribution Functions
13	BT 6.5 – 7.1	Velocity Moments, the concept of temperature in plasma, mutli fluid theory and equations in plasma
14	BT 7.4 – 7.5	Single fluid theory, Stationay and equillibria fields in plasma, Validity of Magnetohydrodynamics in Plasmas, Introduction to Magnetohydrodynamic Equations
15		Revisions
16	**Final Exams**	