Chapter 1

DYNAMICS OF MAGNETOSPHERIC PLASMA AND OBSERVATIONAL EVIDENCES OF KINETIC ALFVEN WAVE

1.1 Introduction ................................................................. 01
1.2 The Magnetosphere .................................................... 02
1.3 Magnetosphere-Ionosphere Coupling ............................ 05
1.4 Dynamics of Aurora .................................................... 08
1.5 Plasma-Sheet ............................................................. 17
1.6 Alfven Wave ............................................................. 27
1.7 Kinetic Alfven Wave .................................................... 35
1.8 The General Distribution Function ............................... 40
1.9 Kinetic Theory .......................................................... 41
1.10 Summary ............................................................... 46
1.1 INTRODUCTION

Plasma is a gas of charged particles, which consists of equal numbers of free positive and negative charge carriers. Having roughly the same number of charges with different signs in the same volume elements guarantees the plasma quasineutrality in the stationary state. On average plasma looks electrically neutral to the outside, since the randomly distributed particle electric charge fields mutually cancel.

Since the particles in plasma have to overcome the coupling with their neighbors, they must have thermal energies above some electronvolts. Thus typical plasma is a hot and highly ionized gas. While only a few natural plasmas, such as flames or lighting strokes, can be found near the Earth’s surface, plasmas are abundant in the universe. More than 99% of all known matter is in the plasma state. Lightning is an example of plasma present at Earth’s surface shown in the Figure-1.1.

The plasma in the magnetosphere consists mainly of electrons and protons. The sources of these particles are the solar wind and the terrestrial ionosphere. In addition, there are small fractions of He\(^+\) and O\(^+\) ions of ionospheric origin and some He\(^++\)
Lightning is an example of plasma present at Earth's surface. Typically, lightning discharges 30 thousand amps, at up to 100 million volts, and emits light, radio waves, x-rays and even gamma rays. Plasma temperatures in lightning can approach 28,000 kelvins and electron densities may exceed $10^{24}$/m$^3$. 
ions originating from the solar wind. However, the plasma inside the magnetosphere is not evenly distributed, but is grouped into different regions with quite different densities and temperature (Baumjohann and Treumann, 1997).

In the present investigation study of the kinetic Alfven wave in magnetospheric plasmas has been undertaken and therefore this very first chapter of the thesis is devoted to discuss some general aspects of magnetospheric plasma with special references to kinetic Alfven waves.

1.2 THE MAGNETOSPHERE

That over 99.9% of space is in a plasma state underscores the importance of plasma science in understanding space phenomena. It is therefore no surprise that ample challenging opportunities exist in applying plasma physics to magnetospheric studies. All planets in our solar system visited by spacecraft are found to possess a magnetosphere which may be defined as a cavity around a celestial object arising from the deflection of solar wind flow by the object’s intrinsic magnetic field or associated atmosphere. Magnetospheres of mercury, Earth, Jupiter, Saturn, Uranus, and Neptune are due to the planets' intrinsic magnetic field whereas that
of Venus and Mars (comets as well) are due to their associated atmospheres (Lanzerotti and Krimigis, 1985; Lui, 1992).

A sketch of the magnetosphere is given in Figure-1.2. The solar wind flow is deflected by Earth’s magnetic field, resulting in the formation of a cavity which we call the **magnetosphere**. Because the solar wind flow is supersonic and super-Alfvenic, a shock front called the **bow shock** is formed which slows down and thermalizes the oncoming solar wind to become the magnetosheath. Adjacent to the magnetosheath is the magnetopause which contains a current layer and defines the outer surface of the magnetosphere. On the dayside at high altitudes, there is an abrupt transition between magnetic field lines permeating only the dayside region and adjacent field line extending into the downstream known as the **magnetotail**. This demarcation gives rise to an indentation region on the dayside magnetopause and is referred to as polar cusp.

The magnetopause is an imperfect shield that allows a small fraction (≤ 1%) of magnetosheath plasma to cross the magnetopause and enter into the magnetosphere. The intruded plasma forms a layer called the **magnetopause boundary layer**. The entry plasma which is eventually swept downstream at high latitudes into the magnetotail is referred to as the plasma mantle.
Figure – 1.2

3d View of the Earth’s Magnetospheric Cavity
whereas the entry plasma at lower latitudes is called the **low latitude boundary layer**.

A large portion of the magnetotail consists of two low density region known as the **tail lobes**, one in the northern half and the other in the southern half of the tail (Lui, 1992). Most of the magnetotail plasma is concentrated around the tail midplane in an about $10 \text{ R}_E$ thick plasma sheet. Near the Earth, it reaches down to the high-latitude auroral ionosphere along the field lines. Average electron densities and temperatures in the plasma sheet are $n_e \approx 0.5 \text{ cm}^{-3}$ and $T_e \approx 5 \times 10^6 \text{ K}$ with $B \approx 10 \text{ nT}$.

The outer part of the magnetotail is called **magnetotail lobe**. It contains highly rarified plasma with typical values for the electron density and temperature and the magnetic field strength of $n_e \approx 10^{-2} \text{ cm}^{-3}$, $T_e \approx 5 \times 10^5 \text{ K}$, and $B \approx 30 \text{ nT}$, respectively (Baumjohann and Treumann, 1997).

In between the two lobes lies the plasma sheet carries a dawn to dusk electric current across the tail. This current is a diamagnetic current, i.e. $j = \vec{B} \times \vec{v}_p / B^2$, since the plasma equilibrium is maintained by the balance between the pressure force $\vec{v}_p$ and the $\vec{j} \times \vec{B}$. Here, $p$ is the isotropic plasma pressure, $j$ is the current density, and $B$ is the magnetic field. Bordering the tail lobe at its
lower latitude interface is the plasma sheet boundary layer which is often the most dynamic plasma region of the magnetotail with magnetic field-aligned currents flowing towards or away from the Earth. Most of the field-aligned currents are carried by electrons due to their higher mobility (Lui, 1992).

1.3 MAGNETOSPHERE-IONOSPHERE COUPLING

The solar wind particles enter the magnetotail and by reconnection processes travel along the magnetic field to hit the ionospheric region. This transient phenomenon is known as the magnetosphere-ionosphere coupling.

Basic structures and fundamentals of existing theories of magnetosphere-ionosphere coupling system have been described in various previous review and research papers (Shawhan et al., 1978; Kamide, 1979, 1982; Mozer et al., 1980; articles in Akasofu and Kan, 1981; Nishida, 1982; Kan, 1982; Stern, 1983; Chieu et al., 1983; Tiwari and Rostoker, 1984; Kan and Burke, 1985; Lysak, 1986; Chiu, 1986; Smits et al., 1986; Burch, 1988, Lyons et al., 1988; Heelis, 1988; Hultqvist, 1988; Ludin, 1988 and Foster et al., 1989).

From the perspective of large-scale numerical modeling of geospace, magnetosphere-ionosphere (MI) coupling describes the
physical interaction between the collision less plasma of a global magnetospheric model (GM) and the neutral and ionized gases of a global ionospheric-thermospheric model (GIT). This coupling introduces feedback and scale-interactivity in the form of Maxwell shear stresses and time-variable mass and energy fluxes at the boundaries of the two models. The "MI coupling region" as illustrated in Figure-1.3 (Lotko, 2004) may be regarded as the spatial domain between the low-altitude boundary of the GM model (located above the Alfven speed maximum near 1-2 R_E altitude) and the high-altitude boundary of the GIT model (located above the F2 peak) (Lotko, 2004).

Treatment of the MI coupling region as a distinct spatial region is necessary for several reasons. The speed of propagation of ultralow frequency electromagnetic signals traversing the MI coupling region (the Alfven speed ) can approach the speed of light in large-scale auroral plasma cavities (Persson et al., 1988). The implied constraints on numerical stability of an MHD code make extension of a GIT or GM model into this region impractical for realistic condition. In effect, transmission, reflection and absorption of electromagnetic power flowing into and out of the region (Lysak and Dum, 1983; Vogt and Haerendel, 1998; Strelsov and Lotko, 2003; Keiling et al., 2003)
Figure – 1.3

(Lotto, 2004) Illustration of a 2D section of a dissipative MI coupling region located a GM model and a GIT model. The configuration of upward and downward field-aligned currents $J_{||}$, with associated north-south electric fields $E_{NS}$ and east-west magnetic fields $B_{EW}$, Poynting flux $P_{||}$ and electron flux $\varepsilon_{\text{el}}$ in the coupling region resemble in situ satellite measurements reported by Lotko et al., (1998). Poynting flux flows into the region through the high-altitude boundary and is partially absorbed before entering the ionosphere at the low-altitude boundary. Upward accelerated electrons in the downward current region carry energy flux into the GM domain and deplete the conductivity $\Sigma$ in the GIT domain. Downward accelerated electrons in the upward current region carry energy flux into the GIT domain and enhance the ionization and conductivity of the ionosphere. Ion up flows $F_{\text{ion}}$ enter the MI coupling region from the GIT domain and leave the region through the GMM boundary after further energized in the coupling region. The Alfvén speed profile in the E- and F-regions and in the MI coupling region illustrated on the left, with the speed of light $c$ indicated at the bottom. The altitudes where electromagnetic energy transmission (Poynting), collisionless acceleration and heating and collisional Joule dissipation prevail are indicated on the right.
occur almost instantaneously on the numerical cadence of a global simulation (Lotko, 2004).

The formation of parallel electric fields in the MI coupling region, and the myriad non-MHD plasma processes that accompany parallel electric fields (Paschmann et al., 2003), are not easily incorporated into a large-scale MHD model. A simple parameterization of the processes that produce field-aligned electron beams (Lyons, 1992; Carlson et al., 1998; Chaston et al., 2003; Cattell et al., 2004) and the energy flux they carry into the ionosphere-thermosphere and magnetosphere is needed (Lotko, 2004).

Lastly, the collisionless physics of ion acceleration and heating in the MI coupling region is a subgrid phenomenon in large-scale models. For this reason, ionospheric upwelling (Moore et al., 1999), the development of a transonic polar wind (Banks and Holzer, 1969; Yau et al., 1984), and the outflow of auroral and polar cusp ions (Collin et al., 1998; McFadden et al., 1998; Tung et al., 2001) are probably best modeled in the form of flux sources at the boundaries of large-scale models (Lotko, 2004).

The current generation of MI coupling models employed in global simulation all treats the MI coupling region as an integrated
electrostatic circuit element. The auroral and polar distribution of ionospheric electric potential is calculated from the familiar 2D elliptic equation (Vasyliunas, 1970) based on current continuity, Ohm’s law, and the scalar potential representation for the ionospheric electric field. The conductivity in the Ohm’s law is determined either by an empirical formula in standalone GM models (Fedder et al., 1995; Raeder, 2003) or by ion production and transport in the GIT component of a coupled magnetosphere-ionosphere-thermosphere (CMIT) model (Raeder et al., 2001; Ridley et al., 2003). The LFM and Raeder coupling modules also include an active element in the conductivity that depends on variable electron precipitation. The monoenergy of the precipitating electrons in these modules is derived from the linearized Knight (1973) formula relating the field-aligned potential drop to the upward field-aligned. Electron precipitation modifies the Joule heating rate and the thermodynamics of the thermosphere and ionosphere in the CMIT models of Raeder, et al., (2001); and Lotko, (2004).

1.4 DYNAMICS OF AURORA

The most visible manifestation of solar terrestrial interaction is aurora borealis observed in the southern hemisphere
and aurora australis in northern hemisphere. This multicolored luminosity has fascinated natural scientists down through the ages and it was nineteenth century our understanding of the phenomena was put on the firm basis. The auroras were recognized as atmospheric radiations emitted by the bombardment of energetic particles coming from far away regions of the magnetotail. The solar wind carries away a part of the solar energy and fills up the interplanetary space with plasmas of solar origin, on the way of expansion part of the solar wind energy is deposited in the earth's magnetosphere and also in other magnetized planets like Jupiter and Saturn whereby numerous attractive drama are played there in. "Aurora" is epilogue of a series of dramas that are played on the stage of the solar terrestrial plasma system. **Aurora** can be defined as light emitted from excited atmospheric atoms and molecules due to bombardment of hot electrons and protons that precipitate down into the ionosphere from the magnetosphere along magnetic field lines. This seemingly simple phenomenon not withstanding the research of auroral physics is not that easy because of complexity and diversity of occurrence conditions of auroral arcs whose activities and forms are different depending on local times, latitude and magnetic activities. There is several observational evidence of
quiet and even active discrete auroral arcs which result from localized acceleration processes along the magnetic field lines.

Akasofu (1974) examined how various auroral patterns (such as rayed arcs, patches, torches, Ω bands) in the combined all sky camera records are represented by large-scale structures in the satellite viewed pictures. Based on several photographs of the DMSP auroral forms, Akasofu (1976) also examined overall features of auroral characteristics in different local times sectors. From these studies has emerged a schematic distribution pattern showing the main characteristics of aurora during an auroral substorms (Shrivastva, 2002).

During a typical magnetospheric substorms a large portion of the energy extracted from the solar wind that remains in the Earth’s magnetosphere is ultimately deposited in the terrestrial ionosphere by intense beams of electrons with energy fluxes ranging between 1 and 100 ergs cm$^{-2}$ s$^{-1}$ at 100km altitude and which create the aurora. A large fraction of this extremely efficient collisionless electron energization process occurs in the auroral acceleration region at altitudes between 1000km and 3.5 R$_{E}$ (Mozer and Hull, 2001; Reiff, 1993; Mozer et al., 1980; Wygant, et al., 2002).
The **auroral zone** is one of the most intriguing regions in the Earth's magnetosphere. A variety of plasma physics processes occur on auroral filed lines, from large-scale MHD phenomena to the microphysics of plasma instabilities, solitary waves, and radio emissions. It is well known that the aurora occurs on magnetic field lines along which field-aligned currents (FACs) flow (Birkeland, 1908; Iijima and Potemra, 1976). It has long been believed that field-aligned potential drops associated with FACs cause the field-aligned acceleration of electrons related to the formation of the aurora (Winckler et al., 1958, Evans, 1968, 1974; Mozer and Fahleson, 1970; Frank and Ackerson, 1971; Block, 1972; Gurnett and Frank, 1973; Mozer et al., 1977, 1980, Robert et al., 2003). Field-aligned ion beams streaming away (up flowing) from the Earth at high altitudes are also commonly observed in the auroral zone (Shelley et al., 1976; Ghielmetti et al., 1978; Gorney et al., 1981; Reiff et al., 1986, 1988). These observations indicate the presence of a parallel electric field that leads to field-aligned acceleration. In addition to parallel fields, many different types of plasma waves have been detected in the auroral zone, including lower hybrid waves, cyclotron harmonics, plasma oscillations, whistler waves, Alfven waves, and both electrostatic band and electromagnetic broadband emissions.
(Gurnett and Frank, 1972, 1977; Temerin, 1978; Kintner et al., 1978; Gurnett et al., 1984; Temerin and mozer, 1984; Shawhan, 1985; Boehm et al., 1990; Cairns and Menietti, 1997; Schriver, 1999).

Earth's aurora occurs statistically and often simultaneously in an oval-shaped belt Keiling et al., (2003) (Figure-1.4 & 1.4A) around the magnetic poles (Akasofu, 1966). Magnetic field lines connect this auroral oval to the magnetosphere, the atmosphere that is dominated by Earth's magnetic field and filled with plasma. The locus of auroral activity (the auroral oval) at high latitudes is present at all times with variable intensity. The dayside and nightside auroras are associated with different magnetospheric phenomena (Meng and Lundin, 1986). The nightside aurora is the result of the sudden release (over the time period of tens of minutes to hours) of large amount of energy, which is periodically extracted from the solar wind and stored in the magnetic field of the magnetotail (Baker et al., 1997). Through an unknown sequence of energy transfer processes, a large fraction of this energy is transported to the auroral acceleration region (located at an altitude of 5000 to 15,000 km above the polar regions) (Reiff et al., 1993), where electron energization processes occur to create the intense electron beams that cause the aurora. In contrast, the dayside aurora
(Keiling et al., 2003). Morphology of the aurora as seen from two cameras onboard the Polar satellite and as inferred from in situ, high-altitude Poynting flux measurements from Polar. (A) The aurora in the visible spectrum over the Northern Hemisphere [the image from the Visible Imaging System camera (Frank et al., 1995)]. This image shows the instant global morphology of auroral luminosity delineating an oval-shaped band. The dayside is to the left. Scattered sunlight during the day makes the aurora invisible to the human eye. (B) A map of average auroral intensity in the Northern Hemisphere recorded in the UV spectrum [Lyman-Birge-Hopfield (long)]. This map is composed of 17,372 images taken by the UVI (Torr et al., 1995) during four months of operation (1 April 1997 to 28 July 1997). This figure is slightly modified from Liou et al. (1997). The numbers around the outside circle are the local times at the given locations. The numbers down the middle of the plot are magnetic latitudes. (C) Average wave Poynting flux flowing toward Earth as measured at high altitude (25,000 to 38,000 km) in the Northern Hemisphere obtained from 1 year of Polar measurements and then scaled along converging magnetic field lines to ionospheric altitudes (100 km). More intense downward Poynting flux (brown, red, and yellow) delineates the auroral oval. Blue indicates very little or no flux. (D) Similar to C but for upward Poynting flux (i.e., away from Earth). Very little return Poynting flux exists at high altitude.
is connected to the cusp region and is driven by uncertain mechanism. In either case, it is expected that the aurora is powered by energy flow along the magnetic field lines. However, the altitude away from the ionosphere at which the energy flow becomes dominantly field-aligned has not been determined. In addition, the form of energy that dominates is not known, considering that it could be either kinetic particle energy or electromagnetic energy carried by quasi-static field-aligned currents (FACs) (for a tutorial on FACs in space, Cowley, 2000). In addition to in situ measurements, the Ultraviolet Imager (UVI) (Torr et al., 1995) onboard Polar takes images of ionospheric auroral emissions. These images show the global morphology of auroras in the UV spectrum, but they can also be used to estimate energy depositions through electron beams into the ionosphere causing the auroral emissions. The average global distribution of auroral luminosity in the Northern Hemisphere derived from a large set of images taken over a period of 4 months coincides with the statistical location of the auroral oval with three distinct emission intensifications centered at 22:30, 15:00, and 09:00 local time (Figure-1.4B) (Liou et al., 1997; Keiling et al., 2003). In the auroral regions the electric fields are primarily north-south, while in the polar cap electric field is directed from down to dusk. Two types
of currents are driven by the electric field. There is, of course the
direct or Pedersen current flowing parallel to electric field. However,
in a thin region of the ionosphere between 100-200 Km, the \( E \times B / B^2 \)
drift of ions and electrons is influenced by the fact that the ions tend
to collide more often with the neutral background gas than do the
electrons (because of the difference in the collision cross sections).
For a northward electric field (in the evening sector) the electrons
and ions both drift westward, however, the fact that the ions are more
impeded than the electrons leads to an eastward current termed as
the Hall-current. In the morning sector the southward electric field
result in a westward hall current. The east west currents flowing in
the aural oval are called the **auroral electrojets**. Satellite and
ground based magnetometer studies have revealed that there is
downward current flow across the noon sector auroral oval which
diverges into the ionosphere to feed the eastward and westward Hall
electrojets. These electrojets come together in the evening sector
where the ionosphere current diverges to flow out of the ionosphere
parallel to the magnetic lines of force.

Now the auroral oval acts as a high conductivity channel,
so that current continuity conditions demand the north-south
Pedersen currents diverge into and out of the ionosphere at the
conductivity discontinuity between the dark ionosphere and the part of the ionosphere activated by particle bombardment. There resulting antiparallel current sheets are called Birkeland currents, and their configuration has been well established by satellite Magnetometer measurements. The entire complex E field and current configuration are shown in the Figure-1.5 and Figure-1.6.

Somewhere between 2000 and 10,000 Km altitude was a potential drop which was capable of accelerating electrons to energies of several KeV and driving them into the high latitude ionosphere where they could stimulated auroral emissions. At the same time, ions were accelerated upward along the magnetic lines of force into the outer magnetosphere. This situation is shown schematically in Figure-1.7. Not only do the accelerated electrons stimulated auroras but by the very fact that they are lost in the ionosphere, they constitute a net upward field-aligned current. Above the acceleration region the protons and heavier ions (e.g. O+) carry the upward current. Thus the magnetosphere maximizes the upward current by using an acceleration mechanism to maximize the velocity of the current density J = nev, the upward current is maximized by maximizing v while the downward current takes advantage of the large number density n of available ionospheric electrons. If the
Figure - 1.5

For the Auroral Oval
E ~ 50 mV/m
d ~ 500 km
I ~ 5 \times 10^5 A
P ~ 10 GW
R ~ 1/25\Omega

Energy Budget in the Auroral Oval

The complete high latitude current configuration in the auroral oval
Figure – 1.6

Current System
The Electric Circuit

The acceleration region above an auroral surge. Energetic electrons are accelerated into the ionosphere where they cause discrete auroras, and positive ions are accelerated upwards. Both sets of accelerated particles carry upward current.
downward flow at the front side of the magnetosphere is increased through an increase in the level of the solar-terrestrial interaction, the nightside upward current can only be enhanced through operation of the accelerator. This leads to the production of keV electrons and their precipitation leads to marked enhancements of auroral luminosity. In fact these episodes of acceleration in a given region of space develop rapidly (in a matter of seconds) and die down after a few minutes. The process for accelerating auroral electrons appears, therefore, to be characteristic of instability. A magnetospheric substorms can be thought of instability. A magnetospheric substorm can be thought of as sustained series of such acceleration episodes (Tiwari, 1993).

The poynting fluxes at higher altitude were compared to magnetically conjugate, ionosphereic electron energy flux (Keiling et al., 2002). This was achieved by tracing Polar's location along magnetic field lines, using the International Geomagnetic Reference Field (IGRF), into the ionosphere (~ 100km) and using simultaneous ultraviolet images (UVI) of the aurora (Figure-1.8). In addition to information on the spatial location of auroras, estimates of energy flux of auroral electrons depositing energy into the ionosphere can be inferred from the images (Torr et al., 1995). The UVI instrument
(Keiling et al., 2002) Experimental setup

(Keiling et al. 2003) Sketch of Polar's orbit and the two contributions of Poynting flux flowing along magnetic field lines into the polar region. Three distinct regions exist above the polar region and extend out into space: cusp, polar cap, and plasma sheet. The Polar spacecraft crosses these regions on an elliptical, polar orbit at altitudes between 25,000 and 38,000 km in the Northern Hemisphere. During the course of 1 year, the orbital plane processes by 360°. The Poynting flux is carried by static fields (convection electric fields and magnetic fields associated with FACs) and Alfvén waves. It is mostly dissipated by Joule heating in the ionosphere and particle acceleration in the aurora acceleration region. The in situ wave Poynting flux measured by Polar delineates the statistical location of auroras.
utilizes four different filters to provide spectral information on the aurora. In this study, images were obtained using a filter centered on 1700 Å with a band width of ~80 Å. These filters respond to molecular N$_2$ Lyman-Birge-Hopfield (LBH)-long wavelength emissions, which are primarily due to electron impact excitation. The intensity of auroral emissions at this wavelength is approximately proportional to the total energy flux deposited by auroral electrons in the ionosphere. Its accuracy is estimated to be ~ 50% (Germany et al., 1998; Keiling, et al., 2002) observational measurement shown in the Figure-1.9.

1.5 PLASMA-SHEET

The stresses due to the interaction of the magnetosheath flow with the Earth's magnetic field lead to the formation of a long magnetotail in the region behind the earth shown in the Figure-1.10. The region around the midplane of the magnetotail (Viz. the neutral sheet) is dominated by a population of energetic particles termed the plasma-Sheet. This region maps down to the ionosphere to a latitudininally localized region where, infect, the auroras are observed. Thus it is the plasma sheet particles which are in the end, responsible for the generation of the auroras. The observations suggest that after a prolonged (40-70 h) quiet period, the energy of
(Keiling et al., 2002)(a–l) Measurements from the Polar satellite on 21 April 1997 during a plasma sheet crossing. Figures a–f show images of the aurora from the Ultraviolet Imager (UVI) instrument on board Polar during the same plasma sheet crossing shown. These images also provide an indicator of the total energy deposited in the ionosphere by electrons (color scale). Small arrows indicate the track of the satellite. Figures g–l show one electric field component (6-s averaged) approximately normal to the plane of the plasma sheet, the east-west component of the magnetic field (model subtracted), the Poynting flux component along the magnetic field, the electron density, and energy time spectrograms of ions and electrons, respectively.
Figure – 1.10

A schematic showing the solar wind, bow shock, planet Earth, the magnetosphere and the plasma-sheet. The inset how electrons spiraling down magnetic field lines may energies the atmospheric gases to emit light.
protons in the plasma becomes less than 1 KeV even in the central part of the sheet. This fact implies that during a quiet period the plasma sheet particles replenished by magnetosheath plasma. Further, since the soft spectra are observed more frequently at greater Zsm Values (namely in the upper and lower boundary layers of the plasma sheet), the replenishment process is likely to begin first in the upper and lower boundary regions and perhaps also first at great distance and then gradually at smaller distances.

On the other hand, a single substorms seems to be able to energize such cool plasma particles to a very high energy (20 KeV). The energized plasma is seen during the recovery phase of substorms. During such a period, the entire plasma in the plasma sheet is energized, and the average energy of protons often becomes greater than 25 KeV even in the upper or lower boundary of the plasma sheet.

The average energy of electrons is substantially softer in the upper and lower boundary regions of the plasma sheet than in the region surrounding the midplane of the plasma sheet (Hones, 1968), which may generate the pressure anisotropy in the plasma sheet. The plasma sheet boundary layer lies between the hot, dense plasma sheet and the tenuous lobe plasma of Earth's
magnetotail. This region is the site of field-aligned currents and strong plasma flows and is generally regarded as a primary transport region in the magnetotail (Eastman et al., 1985). Although different authors have offered a number of different definitions of the plasma sheet boundary layer (Eastman et al., 1984; Takahashi and Hones, 1988; Baumjohann et al., 1988), we here consider this region to correspond to the presence of a single streaming or two couterstreaming proton components with speeds of order 1000 km/s in the spacecraft frame (deCoster and Frank, 1979; Forbes et al., 1981; Birn et al., 1981). These components are hot, with temperatures of order several hundred electron volts. Very hot (T~several keV) isotropic ions also are sometimes observed in the plasma sheet boundary layer, as are other plasma components including cool ions (Orsini et al., 1984), and both hot and cool electrons (Angelopoulos et al., 1989). However, the cool ions are not as well diagnosed as the hot ions, and the electrons do not strongly contribute to the physics of interest here, so that we will concentrate on the dynamics of the energetic ions (Gary, et al., 1990).

A singular property of the two proton components is the evolution of their shapes when displayed as contour plots in two-dimensional velocity space (Forbes et al., 1981). As the observing
spacecraft traverses the plasma sheet boundary layer, the Earthward-traveling proton component appears first on the lobeward side, followed by the tailward-directed component on field lines closer to the plasma sheet. Both components exhibit crescent-shaped distributions which, after the very hot plasma sheet ions appear as a background, merge to form a ring-shaped distribution in two dimensions but which apparently constitutes a relatively narrow shell in three-dimensional velocity space. As the spacecraft progresses further into the boundary layer, the shell distribution broadens in velocity, eventually merging into the hot thermal proton distribution of the central plasma sheet.

Historically, the PSBL has been regarded as a region of energy transfer between the distaint tail and the auroral ionosphere (Eastman et al., 1984; Fairfield 1987). However, it is only recently, with the availability of the necessary measurements from the Polar spacecraft, that a relatively complete inventory of the important energy transfer mechanisms along plasma sheet magnetic field lines above the bulk of the auroral acceleration region has become possible. Recent observations (Wygant et al., 2000) (hereinafter referred to as W1) at altitudes of 4-6 $R_E$ in the PSBL and deeper within the plasma sheet show that large amounts of energy are
transferred earthward by the Poynting flux carried by Alfven waves. This enhanced Alfvenic Poynting flux dominates other forms of energy flux along plasma sheet magnetic field lines and coincides with magnetically conjugate intense aurora. The Alfvenic Poynting flux coincided with a nearly equal ($\times \frac{1}{2}$) enhancement in the net local electron kinetic energy flux was also $\sim$1-2 orders of magnitude less. The poynting flux due to the steady state magnetic field perturbations associated with the field-aligned currents and the convection electric field was estimated to be $\sim$1-2 orders less than the Alfvenic poynting flux. Polar observations by W1 provide evidence that the Alfvenic poynting flux is responsible for transferring the power needed for the acceleration of all energized auroral particles populations accelerated into the ionosphere and also streaming out into the magnetosphere, as well as the Joule heating of the ionosphere. This makes the transmission of intense Alfven poynting flux along plasma sheet magnetic field lines a crucial link in magnetospheric dynamics. It provides constraints on the nature of the energy conversation processes in the distant tail and on the nature of collisionless auroral acceleration processes at lower altitudes. It also provides a source of free energy for driving particle acceleration and heating all along plasma sheet magnetic field lines (Wygant, et al., 2002). Recent
studies using the Polar satellite show that very large amplitude electric fields (\(E_\perp > 100 \text{ mV m}^{-1}\)) are often observed in the plasma sheet boundary layer (PSBL) at geocentric distances of 4-7 \(R_E\) (Wygant et al., 2000; Keiling et al., 2001). It was shown that the dominant electric field component is perpendicular to the nominal plasma sheet. Previous studies of electric fields, using ISEE ½ (Mozer, 1981; Cattell et al., 1982) and Geotail (Cattell et al., 1994; Streed et al., 2001), provided evidence for large-amplitude spiky electric fields at geocentric distances from 4 to 100 \(R_E\), but the measurements were restricted to the components that lie in the ecliptic plane. In a statistical study using 2 years of polar electric field data (\(E_\perp\)), Keiling et al., (2001) showed that these fields delineate the statistical auroral oval similar to the low-altitude (\(\sim 1 \text{ R}_E\)) electric field distribution observed by high-altitude electric fields to auroral processes. It was also shown in the Polar study that the fields do not only map like quasi-static electric fields, as shown by previous studies (Mozer, 1981; Levin et al., 1983), but are also consistent with the propagation of Alfven waves along converging magnetic field lines. Wygant et al., (2000) showed for two Polar case studies that the perpendicular electric fields in the PSBL at 4-6 \(R_E\) were associated with Alfven waves, which carried large and sufficient
poynting flux toward the ionosphere to power magnetically conjugate
auroral emissions. Keiling et al., (2000) have shown that large
Alfvenic Poynting flux often occurs in the PSBL during the expansion
phase of substorms. These recent Polar observations have clearly
demonstrated the connection between auroral phenomena and
energy transfer processes by large Alfven waves in the PSBL.
al., (2001) also showed that large Poynting flux occurs in the central
plasma sheet during times of auroral substorms.

Theoretical and observational results offer a variety of
scenarios for the conversion and transfer of stored magnetic energy
in the magnetotail to ultimately the kinetic energy of auroral
electrons. Reconnection processes in the tail have been invoked,
which could convert magnetic energy of a stretched magnetotail into
field-aligned particle beams and bulk plasma flows (Baker et al.,
1996, and references therein). Bursty bulk flow (BBF) has been
investigated in association with the transport of energy from the
distant tail to the near-tail region using Geotail data (Angelopoulos et
equatorial magnetotail demonstrated that such events were closely
associated with auroral brightenings (Fairfield et al., 1999).
Reconnection processes or BBF might also be the source of Alfvén waves in the PSBL above the auroral acceleration region, reported by Wygant et al., (2000) and Keiling et al., (2000), which then carry electromagnetic energy toward the ionosphere. The earliest reports for the importance of Alfvén waves for energy transport in the auroral ionosphere and magnetosphere came from ground-based observations in the auroral zone. The ground-based observations give indications of strong ULF (1-10 mHz) Alfvén wave activity at both boundaries of the auroral region with auroral arcs near the equatorial border of the auroral regions (Samson et al., 1991, 1996; Liu et al., 1995; Keiling et al., 2002). The Polar satellite has an 18-hour polar orbit (originally 80° inclination), with perigee and apogee of 2.2 and 9 $R_E$ (geocentric distance), respectively. Hence it offers the opportunity to examine the plasma sheet and its poleward boundary at geocentric distances of 4-7 $R_E$. This region stands intermediate between the auroral acceleration region at 1-3 $R_E$ and the more distant portions of the magnetotail. A study of this region can be of relevance for processes in the auroral acceleration region and in the magnetotail. In addition, the Polar spacecraft is the first spacecraft that allows high-resolution three-dimensional (3-D) measurements of the electric field in this region. It is interesting to
note that the magnitude of the poynting flux observed with other satellites and rockets (Kelley et al., 1991; Louarn et al., 1994; Nagatsuma et al., 1996; Kletzing et al., 1996) at low altitudes is smaller than Polar's mapped poynting flux, supporting the scenario where the high-altitude poynting flux is dissipated in the acceleration of electrons. For example, Nagatsuma et al., (1996), using the Akebono satellite, reported Alfven waves at altitudes below 8000 Km with equal amplitudes of incident and reflected waves. The reported poynting flux (up to 4 ergs cm$^{-2}$ s$^{-1}$) was much smaller than our Polar observations. Hence, together with our observation of mostly downward poynting flux, suggests that the high-altitude Poynting flux is indeed dissipated through particle acceleration within the auroral acceleration region (Keiling et al., 2002). In identifying the different processes for the transport of energy in the magnetotail, it is now known that both plasma transport and electromagnetic energy in the form of field-aligned currents (FACs) and Alfven waves carry large amounts of energy earthward in association with substorms. Quasi-static FACs is closely associated with auroral system maps into the auroral oval (Iijima and Potemra, 1976), transmitting power from the tail to the ionosphere. During substorms, additional FACs form which enhance the energy transfer. Discrete bursts of high-velocity plasma
flow in the equatorial plane (BBF) carry considerably energy earthwards (Angelopoulos et al., 1992; Fairfield et al., 1999). For some events it was shown that they occur in close temporal and magnetic conjugacy to auroral brightening (Fairfield et al., 1999). On the other hand, the study by Wygant et al., (2000) show that large Alfvenic poynting flux at high altitudes is also magnetically conjugate to intense auroral emissions, which shows the importance of Alfven waves as a means of energy transport from the distant magnetotail to the acceleration region. Further, it supports the view that Alfven waves contribute to the arc generation process. Including the works of Keiling et al., (2000) and Toivanen et al., (2001), showing large poynting flux during the substroms expansion phase, in their Figure-1.11 (Keiling et al., 2002) illustrates the connection of auroral phenomena, such as auroral brightening, negative H bay, and Alfven wave energy flow in the PSBL. Keiling et al., (2002) shown that the Alfvenic energy flux is sufficient to account for magnetically conjugate, low-altitude auroral phenomena, it is important to investigate whether BBF and Alfven waves occur simultaneously, and if so, whether they are generated from the same process in the magnetotail and which one is the dominant energy transport mechanism.
(Keiling et al., 2002) Cartoon showing the connection of auroral phenomena, such as auroral brightening, negative H bay, and large Alfve´n waves in the plasma sheet boundary layer (PSBL). Alfve´n waves, possibly generated at the reconnection site, propagate toward the ionosphere along magnetic field lines. Electrons accelerated by the Alfve´n waves precipitate into the ionosphere, causing auroral brightening. Simultaneously, ground magnetometer data show magnetic bays.
1.6 ALFVEN WAVE

Alfven waves are the low frequency waves (below ion-cyclotron frequency) that propagate in magnetized plasma. Alfven waves play key role in many naturally occurring interactions, for examples, changes in the auroral current magnitude and spatial configuration, or changes in the magnetospheric configuration.

Alfven waves are of fundamental importance in laboratory and space plasma from the solar corona to planetary ionospheres. When ions are strongly magnetized, these waves communicate information about changes in electrical current configuration and magnetic field topologies.

The Alfven wave named after Swedish space physicist H. Alfven in one of the most important waves in magnetized plasma. Hannes Alfven was a lifetime fellow of IEEE and 1970 Nobel Laureate for physics. After a life of exceptional scientific achievement his discoveries laid the foundation of major parts of modern plasma physics, and its application in areas as diverse as industrial process, thermonuclear research, space physics, astrophysics and cosmology. His discovery of a new kind of waves, now called Alfven waves, was initially met with disbelief and accepted only years later. With the evaluation of plasma physics, and space plasma physics,
the significance of this discovery has related terms such as Alfven velocity, Alfven number etc. which have become among the most frequently used terms in plasma physics,

Alfven waves in plasma were first generated and detected by Allen Baker, Pyle and Willcox at Berkely, California and by Jephcott in England in 1959 during the ‘slow pinch’ discharge in hydrogen plasma between two electrodes aligned along a wave magnetic field.

Alfven wave is the dominant low frequency transverse mode of magnetized plasma, which displays a continuous spectrum even in the bounded plasma. This is mainly due to the degeneracy of the wave characteristic. i.e., the frequency (ω) is primarily determined by the wave number in the direction parallel to the ambient magnetic field (k⊥) and is independent of the perpendicular wave numbers, the direction along which the wave energy propagate and is identical to the ambient magnetic field lines.

The Alfven wave has been studied extensively in the past (for references, we refer to the review paper of Hasegawa and Uberoi, (1982). According to the idle magneto hydrodynamics a plane Alfven wave in homogeneous magnetized plasma (also called a “Shear Alfven wave”) has frequency and polarization
\[ \omega_A^2 = k_{||}^2 u_A^2 \]
\[ u \times (k \times \vec{B}) = 0 \]

Where \( k \) is the wave vector, \( k_{||} \) is its component along the unperturbed magnetic field vector \( \vec{B} \), \( u_A^2 = \frac{|\vec{B}|^2}{\mu_0 \rho} \) is the square of the Alfven speed (\( \rho \) is the mass density) and \( u \) is the perturbing fluid velocity vector. A localized disturbance propagates along a magnetic field line without affecting neighboring ones because the group velocity \( \frac{d\omega}{dk} \) is parallel to \( \vec{B} \), and both the mass density and the pressure remain unperturbed because \( u \) is perpendicular to \( k \). If the homogeneous equilibrium is perturbed into an inhomogeneous one, the eigen frequencies \( \omega = \pm \omega_A \), as a consequence of their infinite degeneracy (they are independent of \( k_{||} \)), are perturbed into continuous spectra, and possibly also into an infinite set of point eigen values, some of which may be unstable. Accordingly, magneto hydrodynamic instabilities (with the exception of flutes, characterized by \( k_{||} = 0 \)) can be viewed as plane Alfven waves driven unstable by equilibrium in homogeneities (Spies et al., 1990).

Some of unique properties of the fluid Alfven waves are destroyed by kinetic effects, but are recovered in the long
wavelength limit. Thus the Landau damped kinetic Alfven wave merges into the undamped magneto hydrodynamic Alfven wave when the ratio of wavelength and some characteristic length related to the gyro radii become large, and the kinetic Alfven wave can be viewed as a modification of the fluid Alfven wave resulting from gyro radius effects. This aspect has hitherto found little attention as is reflected by common terminology: The kinetic Alfven wave is often called a “low frequency wave”, while the magneto hydrodynamic Alfven wave is often called a “high frequency wave” (Spies et al., 1990).

The Occurrence of Alfven waves in the aurora has been reported from sounding rockets (Bohem et al., 1990) as well as spacecraft, including S3-3, Freja, and Viking (Mozer et al., 1977; Wahlund et al., 1994; Aikio et al., 1996). These waves are identified with \( E_i/B_i \) ratios of the order of the Alfven speed and perpendicular scale sizes (defined as the distance traveled by the space craft perpendicular to the background magnetic field while observing one full oscillation) of a few electron skin depths \( \left( \frac{c}{\omega_{pe}} \right) \). In addition these waves’ forms may be significantly steepened as they propagate (Tiwari and Rostoker, 1984) forming what has been identified from
Freja spacecraft observations as Solitary kinetic Alfven waves (SKAW).

Some recent studies of in situ observations by the Freja and Fast satellites have clearly shown that the physical nature of strong electric spikes in the auroral ionosphere and magnetosphere, which are characterized by the perturbed electric and magnetic fields of $\Delta E \approx 100\text{mv}$ and $\Delta B \approx 10\text{nT}$, and the time duration of $\Delta t \approx 10\text{ms}$ can be explained in terms of the Solitary kinetic Alfven wave (SKAW) (Louarn et al., 1994; Volwerk et al., 1996; Huang et al., 1997; Chaston et al., 1999)

The Alfven wave dispersion relation has two branches. The compressional wave and the shear wave. The compressional wave is isotropic and characterized by fluctuation in both the magnetic field strength and plasma density. The shear wave is highly anisotropic propagating along the ambient magnetic field direction and to first order is characterized by fluctuations in the direction but not in magnitude of magnetic field. (Walter et al., 1994; Leneman et al., 2000)

Low frequency fluctuations in the magnetic field that have been interpreted as Alfven waves have been observed by sounding rocket (Boehm et al., 1990) and satellites (Chmyrev et
al., 1988; Lundin et al., 1994). These observations have been associated with short scale length, cross field density gradients and electron precipitations. Large changes in the flux of precipitating auroral electron very commonly occur on scale lengths comparable to the electron skin depth (Borovsky, 1993). These narrow current channels are potential sources of Alfvén wave radiation (Maggs and Morales, 1996; Gakelman et al., 1997).

Intense, transversely localized fields are frequently measured on Polar orbiting satellites (Kletzing et al., 1983; Dubinin et al., 1985; Weimer and Gurnett, 1993; Marklund et al., 1994; Mishin and Forster 1995; Aikio et al., 1995; Karlsson and Marklund, 1996) and rockets (Boehm et al., 1990) and are thought to be the lower magnetosphere signatures of auroral arcs and black auroras. Because the periods of ULF Alfvén’s waves are compatible with fundamental field line oscillations and the time scale of particle bounce motions along auroral field lines DAWs [Dispersive Alfvén waves] are considered as powerful agent to explain various observed phenomena in magnetosphere-ionosphere coupling (Streltsov et al., 1998).

These works describe high field aligned electron bursts in a broad energy range from thermal (1 eV) up to a couple of keV
and strong electromagnetic spikes reaching electric fields ~100 to ~200 mV/m and magnetic fields ~30 to ~50 nT associated with inertial Alfven waves. With regard to models an important Alfven wave model has been described in a number of works (Seyler et al., 1995; Seyler and Wahlund, 1996; Clark and Seyler, 1990). The ionosphere–magnetosphere coupling mediated by standing Alfven waves have also been treated theoretically (Lysak, 1991; Trakhtengertz and Feldstein, 1984; Streltsov and Lotko, 1991). Detection of Alfven wave turbulence has been made by Intercosmos Bulgaria 1300 satellites (Chmyrev et al., 1985, 1989) as well as more recently with the Freja satellite (Wahlund et al., 1998) studying the association of auroral particle perception and the inertial Alfven wave. A numerical treatment of the finite gyro radius effect in DAW is included by Lysak and Lotko (1996).

Analytical (Lysak and Dum 1983; Vogt and Haerendel 1998; Fedorov et al., 2001) and numerical (Streltsov et al., 2002; Streltsov and Lotko, 2003) studies indicate that small scale Alfven waves incident on an auroral acceleration region (AAR) are strongly reflected by it. The signatures of intense small scale Alfven waves observed above an AAR are therefore not expected to penetrate below the AAR. Yet intense small-scale electric fields and currents
are commonly associated with auroral current systems at altitudes well below auroral acceleration region (Chemyrev et al., 1988; Dubinin et al., 1988; Louarn et al., 1994; Marklund et al., 1995; Stasiewicz and Potemra, 1998). The phenomena suggest that small scale electromagnetic structures observed below an AAR must be generated at low altitude (Streltsov et al., 2003).

First predicted by Hannes Alfven (Alfven, 1942), Alfven waves have been observed nearly everywhere in the nightside magnetosphere: plasmasphere (Oskai et al., 1998), auroral zone (Dubinin et al., 1990; Knudsen et al., 1992), central plasma sheet (CPS) (Takahashi et al., 1988), plasma sheet boundary layer (PSBL) (Wygant et al., 2000; Keiling et al., 2000), and tail lobes (Ober et al., 2001; Keiling et al., 2001). Their importance in the substroms process has first been pointed out by Samson et al., (1991), who used ground-based observation in the auroral zone and showed that strong ULF (1-10 mHZ) Alfven wave activity was present at both boundaries of the auroral region. The most energetic Alfven waves have recently been found in the PSBL. It was shown that these waves are magnetically conjugate to auroras (Wygant et al., 2000; Keiling et al., 2002) and occur during times of substroms expansion phase (Keiling et al., 2000). Since shear Alfven waves propagate
along magnetic field lines, the observations show that one important role of these waves is to carry significant electromagnetic energy from remote regions, possibly the reconnection region, to the auroral regions. Once they reach the auroral region, the Alfvén waves are one candidate for the acceleration of electrons that cause the aurora (Goertz, 1984; Lysak, 1990; Chaston et al., 2000). It is suggested that large-scale shear Alfvén waves (presumably those reported in the PSBL) become kinetic Alfvén waves in the small-scale limit, which can provide the parallel electric field necessary for auroral electron acceleration. Some evidence exist that Alfvén waves also accelerate electrons above the auroral acceleration region along magnetic field lines (Wygant et al., 2002; Morooka et al., 2004; Keiling et al., 2005).

1.7 KINETIC ALFVÉN WAVE

The kinetic Alfvén wave is the Alfvén wave for which wave particle interaction is important. This wave has received much attention recently in connection with particle acceleration along the field lines. The kinetic Alfvén wave can also be an active agent to heat the plasma in the solar corona. Moreover, the structure of the auroral arcs seems to be determined partly by this wave since the
latitudinal scale of the arcs is comparable to the ion gyro radius. The kinetic Alfven wave has been invoked in association with the magnetosphere dynamics since it is successful in explaining the ultra low frequency (ULF) waves observed in the magnetosphere. Many theoretical attempts have been made to apply the kinetic Alfven wave instability to magnetospheric plasma; most of them lack a careful check as to applicability of the theory. The kinetic Alfven waves have vast application to the Tokomak type plasma to the thermonuclear temperatures. Kinetic Alfven waves are found to have a two dimensional structure with electrostatic and magnetic components with phase velocity (Parallel to the external magnetic field $B_0 \hat{Z}$) much smaller then the electron thermal velocity.

The kinetic Alfven wave can be excited in plasma either by drift wave instability or resonant mode conversion of a surface magnetohydrodynamic wave. The kinetic Alfven wave was first introduced by Hasegawa and Chen (1975) in relation to plasma heating. Hasegawa and Chen (1976) introduced that kinetic Alfven wave propagate into the higher density side of the plasma and after the mode conversion dissipate due to both linear and non linear processes and heat the plasma. Hasegawa and Mima (1978) have discussed the application to diffusion of electrons and formation of
the stable auroral red arcs as well as viscous interaction between the
solar wind and the magnetosphere.

Kinetic Alfven waves are of much importance in
laboratory and space plasma. These waves may play an important
role in energy transport, inducing field aligned current, in particle
acceleration and heating and to explain inverted V-structures in the
magnetosphere-ionosphere coupling in solar flares and the solar
wind, and Ultra low frequency (ULF) emission in the earth's
magnetosphere. (Hasegawa, 1977; Goertz and Bosewell, 1979;
Goertz 1984; Maghaddam-Taaheri et al., 1996; Klimushkin, 1997;
Huang et al., 1997).

Evidence of large amplitude kinetic Alfven waves/spikes
is found at the plasma sheet boundary layer (PSBL) at altitudes of 4-6RE. Measurements from the Polar spacecraft show the existence of
small scale Alfven waves that carry a large net poynting flux along
magnetic field lines towards the earth. Both structures are typically
observed in the PSBL but have also been observed deeper in the
plasma sheet. The small-scale spikes have electric field amplitudes
up to 300 mV m\(^{-1}\) and associated magnetic field variations between
0.5 and 5nT. The analysis has shown that the larger-scale Alfven
waves have periods of \(~20\text{-}60\text{s}\) and carry enough poynting flux to
explain the generation of the most intense auroral structures observed in the polar ultraviolet Imager data set (Wygant et al., 2000, 2002). Recently, observations from the Polar and Cluster satellites have indicated that large amplitude kinetic Alfven waves are observed throughout the plasma sheet, particularly at the plasma sheet boundary layers, during sub storms (Wygant et al., 2000, 2002; Keiling et al., 2003).

At lower altitudes, observations of intense, small perpendicular-scale electric fields by the S3-3 (Mozer et al., 1980), Viking (Block and Falthammer, 1990), DE 1 (Weimer and Gurnell, 1993), Freja (Louarn et al., 1994), Fast Auroral snapshot (FAST) (Carlson et al., 1998; Ergun et al., 1998), the Polar spacecraft (Mozer et al., 1997) and sounding rockets have been interpreted in terms of kinetic Alfven waves, Alfven waves, and electrostatic shocks (Wygant et al., 2002).

Dusty plasma is three component plasma with electrons and a dispersed phase of very massive charged grains of solid matter. Dusty plasma is usually encountered in the space and astrophysical situations (Mendis and Rosenberg, 1994; Northrop, 1992; Goretz, 1989). A recent focus of attention in space plasma physics and astrophysics is the study of wave phenomena in dusty
plasma whose constituents are electrons, ions and negatively charged dust grains (De Angelis et al., 1988; Goertz, 1989; Rao et al., 1990; D'Angelo, 1990; D'Anglo and Song, 1990). The presence of highly charged, massive dust particles change the plasma parameters and affect the wave propagation characteristics by giving rise to new waves which have qualitatively different dependences on plasma density and temperature. A number of authors (De Anglis, 1992; Northrop, 1992; Sheehan et al., 1990; Carlile et al., 1991; De Angelis et al., 1988; Rao et al., 1990) have analyzed the different kinds of waves that can propagate through dusty plasma.

Electrostatic waves such as ion cyclotron and ion-acoustic (D'Angelo, 1990) as well as drift waves (Shukla & Bharuthram, 1991) have been analyzed to exist in dusty plasma. D'Angelo and Song (1990) and Bharuthram and Shukla (1992b) have investigated the Kelvin-Helmholtz instability in a dusty plasma with sheared ion flow. In past (Rawat and Rao, 1993) have shown the existence of Kelvin-Helmholtz instability of the dust acoustic waves by considering shear in the dust flow.

Many authors have investigated the role of dust on kinetic Alfven waves in dusty plasma with external magnetic fields. (Kotsarenko et al., 1996) have studied low frequency kinetic Alfven
waves in dusty plasma using a fluid analysis, which does not include Landau damping. Das et al., (1996) have considered kinetic Alfven wave analysis in plasma with magnetized massive dust grains, and have studied damping due to charge fluctuations. Using a fluid model, (Shukla and Rahman, 1996) recently investigated shear Alfven waves and other low frequency electromagnetic waves in non uniform dusty magnetoplasma. In addition to that low frequency, long wavelength kinetic Alfven waves in multi-beam dusty plasma with application to comet and planetary rings have been considered (Reddy and Lakhina, 1996).

1.8 THE GENERAL DISTRIBUTION FUNCTION

In the most of the theoretical work carried out so far in the analysis of kinetic Alfven waves the velocity distribution function have been assumed either an ideal Maxwellian or bi-Maxwellian ignoring the steepness of the loss cone feature. Plasma in mirror like device and in the auroral region with curved and converging magnetic field may considerably depart from a Maxwellian distribution and become anisotropic provided there is a relatively low degree of plasma collisionality. Thus kinetic Alfven waves generated in highly anisotropic PSBL and propagating towards auroral
ionosphere may be suitably discussed with general distribution as compared to ideal Maxwellian distribution.

1.9 KINETIC THEORY

In general, the dynamics of plasma can be described by solving the equation of motion for each individual particle. Since the electric and magnetic fields appearing in each equation include the internal fields generated by every other moving particles all equations are coupled and have to be solved simultaneously. Such a full solution is not only too difficult to obtain, but also of no practical use, since one is interested in knowing average quantities like density and temperature rather than the individual velocity of each particle. Therefore, one usually makes certain approximations suitable to the plasma conditions. It has turned out that four different approaches are most useful. The simplest approach is the single particle motion description. It describes the motion of a particle under the influence of external electric and magnetic fields. This approach neglects the collective behavior of plasma but is useful when studying very low density plasma, like found in the ring current. The magneto hydrodynamics approach is the other extreme and neglects all single particle aspects. The plasma is treated as a single
conducting fluid with macroscopic variables, like average density, velocity, and temperature. The approach assumes that the plasma is able to maintain local equilibrium and is suitable to study low frequency wave phenomena in highly conducting fluids immersed in magnetic fields. The **multi-fluid approach** is similar to the magnetohydrodynamic approach, but accounts for different particle species (electrons, protons, and possible heavier ions) and assumes that each species behaves like a separate fluid. It has the advantage that differences in the fluid behavior of the light electrons and the heavier ions can be taken into account. This can lead to charge separation fields and high frequency wave propagation. The fluid theory offers the advantage of relative mathematical simplicity but is limited to relatively long wavelength plasma phenomena. The **kinetic theory** is mathematically more complex but describes properly the plasma instabilities with wavelength of the order of or shorter than an ion gyro radius. The kinetic theory is in principle more accurate than the fluid theory, although in some circumstances it may lead to an unsolvable mathematical problem. The kinetic theory is the most developed plasma theory. It adopts a statistical approach. Instead of solving the equation of motion for each individual particle, it looks at the development of the distribution function for the system of particle
under consideration on phase space. Yet even in kinetic theory certain simplifying assumptions have to be made and there are different flavours of kinetic theory, depending on the kind of simplication mode (Baumjohann and Treumann, 1997).

There are two conventional approaches to the theory of the properties and processes of plasma: the *macroscopic (thermodynamic, fluid) description* and the *microscopic (kinetic, statistical) description* (Krall and Trivelpiece, 1973).

The *macroscopic approach* is based on describing quantities such as average velocity and temperature as a function of position and time. These are the quantities emphasized in the measurement of plasma properties. The *microscopic description* of plasma is based on the configuration and velocity-space distribution of the plasma particle, the correlation between these particles, and the micro fields produced by the particles. The microscopic quantities are more difficult to measure directly, but frequently they play a dominant role in determining the macroscopic properties of plasma.

A study of *kinetic theory* of plasma adds depth to the concepts of equilibrium, waves and stability already explored in the fluid framework. Further, the kinetic theory provides a formal basis
for the heuristic idea that formed the basis even for the fluid
description, namely, that of including the average fields due to many
particles, and often neglecting the short-range forces of the nearest
neighbor particles. Plasma kinetic theory also provides a method of
investigating the influence of collision among the plasma particle and
the calculation of the transport properties of fully ionized plasmas.
Further, to treat the scattering and emission of radiation by plasma, it
is necessary to develop a kinetic description that "sees" individual
plasma particles (Krall and Trivelpiece, 1973).

The kinetic equation has the advantage that both the
average distribution $f(x, v)$ and the average fields do not depend any
more on the single co-ordinates of all the single particles of a
species, but only depend on the phase space co-ordinates $(x, v, t)$. The ensemble average has smeared out the exact positions of the
particles over the phase space volume occupied by the particle
group under consideration (Baumjohann and Treumann, 1997).

The most fundamental kinetic description of a collision
less plasma system is to employ the Vlasov equation to obtain
particle distribution functions for all particle species and compute the
electric field and magnetic fields from the particle density and plasma
current by the Maxwell's equations. (Johnson and Cheng, 1999)
In the kinetic theory important global effects such as background density, temperature and magnetic field gradients, magnetic field curvature, large plasma β, and pressure anisotropy are retained, while important kinetic effects, such as finite Larmor radius, resonant wave particle interactions, and bounce resonance are added. These kinetic effects are essential when describing multiscale coupling processes (Johnson and Cheng, 1997a). In the presence of background gradients, finite Larmor radius effects couple global distribution with kinetic Alfven waves which can strongly interact with ions because the perpendicular wavelength is the order of the ion gyroradius. Wave particle interaction leads to anomalous particle transport and dissipation which can significantly alter the background equilibrium on the transport timescale as demonstrated at the magnetopause for kinetic Alfven wave (Johnson and Cheng, 1997b, 1999).

Thus in the present thesis, the basic mathematical methodology has been developed in detail and adopted to describe kinetic Alfven wave in accordance to the observational evidences.
1.10 SUMMARY

In the present chapter we have presented the brief description of the configuration of magnetosphere which is being recently adopted for research in the space plasma. The phenomenon of magnetosphere-ionosphere coupling is described as the substorms induced event. The dynamics of aurora is presented on which our study is concentrated. The plasma-sheet region which links the auroral region by the magnetic field lines is described. The basic observation evidences of Alfven wave and kinetic Alfven wave are given along with their definitions. Elementary ideas regarding general distribution function and kinetic theory are presented. The above description provides the background model of the study undertaken in the subsequent chapters.