CHAPTER V

SUMMARY AND RELEVANT ASPECTS OF MAGNETOSPHERE-IONOSPHERE COUPLING

As discussed in previous chapters the neutral atmosphere, the Earth's environment is one of charged particles whose motions are controlled primarily by the ambient magnetic field. The solar terrestrial interaction involves the transfer of energy from the particle and field environment of the interplanetary medium to the particle and field environment of the Earth. In essence the Earth's charged particle environment can be broken down into two distinct regions: one the magnetosphere, where the medium is a magnetized collisionless plasma and the other the ionosphere which is also a magnetized plasma but in which collisional processes are important due to the relatively high concentrations of neutral particles at the top of the neutral atmosphere.

The Earth's magnetosphere-Ionosphere system may be considered as a finely tuned magnetohydrodynamic system which received the energy from external environment and dissipates part of that energy internally while returning the balance to the external environment. The system is capable of dissipating large amount of energy internally through steady state processes, however, when the amount of energy received is excessive many plasma instability mechanism come into play and energy is dissipated through explosive unstable process. Both the steady state and non-steady state processes result in continual changes in the energy transfer and dissipation in the magnetosphere-Ionosphere system.
The sun is the source of strong flux of charged particles called as the solar wind. The solar wind carries with it the sun's magnetic field so that the interplanetary medium is effectively a magnetized plasma. At the radial distance of the Earth's orbit, the velocity of the solar wind plasma is normally ~ 300-500 Km/Sec and the imbedded interplanetary magnetic field (IMF) is of the order of 5 - 15 nT. The Earth has an intrinsic magnetic field which is basically dispolar in character. However, by the interaction of solar wind the Earth's magnetic field on the frontside is compressed while the field lines in the lee of the Earth are stretched out to a great distance in the anti-earthward direction. This region was termed as the magnetotail in which most of the phenomena are associated with magnetosphere-ionosphere coupling system. The current system defined as Birkeland current or field-aligned current links the outer region of magnetotail to the ionosphere. Observations of currents in space by magnetometer aboard rockets and satellites showed that the field-aligned currents are constant features on high latitude geomagnetic field lines at the substorm times. The latitudinal width of the current sheet is around tens of kilometers. The latitudinal width of large scale current system is around a few 100 Km.

The determination of the three-dimensional electric current configuration associated with magnetospheric substorms has been one of the central problems in magnetospheric-Ionospheric coupling systems. Until very recently, attempts at inferring the current distribution have
relayed primarily upon magnetic observations made on the Earth surface. By using worldwide distribution of the ground magnetic perturbation vectors, several equivalent current systems for the polar magnetic substorms put to forward, which were quiet successful to identify the patterns or mode of the global magnetic disturbance field. However, it must be emphasized that magnetic perturbations observed on the Earth's surface arise from ionospheric, field-aligned and magnetospheric currents, as well as from an induced current flowing within the Earth. In principle, the separation of the magnetic fields of these different current sources cannot be properly made from ground magnetic measurements alone (Chapman, 1935). Therefore, it was difficult to deduce the 'real' three-dimensional current system only from the ground magnetic measurements.

Subsequently, a combined study of ground magnetic perturbations, simultaneous auroral displays, auroral precipitation and electric fields in the ionosphere made it possible to construct a first-approximation model of the three-dimensional current flow. However, such correlated studies of spatial relationships among the auroral luminosity, the field-aligned currents and the auroral electrojets have been limited by the lack of simultaneous data for a variety of substorm conditions and for wide local time intervals. In addition, the sparse network of ground-based magnetic observatories makes it difficult to study the auroral electrojet configuration with sufficient detail. Therefore, although several possible three-dimensional current systems for the substorm have been proposed, they
must be regarded as 'equivalent' three-dimensional current models at best.

In the last decade, with the advent of new techniques, attempts have been made to remove these difficulties to a significant degree. Of particular importance are the polar-orbiting ISIS, DMSP, TRIAD, and S 3-2 satellites which can provide us with plentiful information on characteristics of field-aligned currents and their relationship to both auroral intensity and auroral electrojet flow. In coherent scatter radars auroral latitudes can also determine simultaneously most of the electromagnetic properties in the ionosphere including the electric fields, conductivities, currents, neutral winds and Joule heat dissipation (see Banks and Doupnik 1975). Recent efforts to improve the ground-based magnetometer network by operating several meridian chains have made it possible to determine the auroral electrojet locations with an accuracy of 1° in latitude (see, Akasofu et al., 1980). By combining different observations, various workers have established the 'real' three-dimensional current model that can account for the complexity in behaviour of the ionospheric electric fields and currents and the field-aligned currents during different substorm period. The plausibility of the model current system can be tested by theoretical and computer simulation studies, in which efforts are made to clarify problems as to what parameters are essential to reproduce the observed characteristics of the electric fields and currents.

As discussed in chapter 1 the field-aligned currents are associated with the acceleration of charged particles
which leads to the varieties of phenomenon observed on the auroral field lines. Amongst these were phenomena of double layer, electrostatic shocks anomalous resistivity. Kinetic Alfv‘en wave etc. as discussed in chapter 1. These various theories explained many observational features, however, none have been established on the firm basis. More observations are needed and a unified theory have to be still proposed that can explain the acceleration process more satisfactorily.

There have been two stream of thoughts to explain magnetosphere-ionosphere coupling system. One considers the field line reconnection process by virtue of which the magnetic energy is transfered to the particles by the annihilation of magnetic field and leads to the auroral dynamics (Eastman and Frank, 1981; G. Haerendel, 1980). The other recognized the magnetospheric energy source by various phenomena occurring during the substorm times that lead to auroral structures. Few authors have also suggested the ionosphere as the energy source to derive the field-aligned current patterns. For the detail structures it is suggested to refer the reviews by Akasofu and Kan, 1981; Kamide 1981, Kamide 1979; Kan 1981; Mozer et al., 1980; Singh et al., 1987 and others.

In the present thesis we have considered the energy source to derive the field-aligned current patterns of the magnetospheric origin. In the first chapter we have studied about the basic phenomena of magnetosphere-ionosphere systems and consequences of field-aligned current systems at
the substorm times. An explanation has been offered to discuss the generation of Birkeland current by change in vorticity caused in the boundary layer plasma flow in geomagnetic tail, in essence creating the charge densities which flow along the magnetic field lines, may be causes of field-aligned current system. The nature of electric fields, and the existing theories of acceleration of charged particles by these electric fields have been presented which would provide the basis for the further development in magnetohydrodynamic shocks. The micropulsations which are effect of magnetosphere-ionosphere coupling system have also been presented.

It has been suggested that field-aligned currents develop in regions of magnetosphere where the plasma vorticity has a non-zero total time derivative. Under most circumstances the regions where the most intense time derivatives of $\mathbf{\Omega}$ are located are at the front side magnetopause and at the neutral point in distant tail (as is evident from the plasma convection lines shown in Fig.5.1). The direction of the vorticity vectors in the morning and afternoon hemispheres are reversed, leading to field-aligned current directed into the ionosphere across the noon sector and on the dawnside of the neutral point, with current directed out of the ionosphere being found in the dusk region and on the eveningside of the neutral point.

The asymmetry in flow patterns arises from the presence of the co-rotation electric field. The local time regions where there is net inflow and outflow of current are established from the results of Hughes and Rostoker (1977)
and Hughes et al., (1979). The convective patterns are typical of those proposed for moderately strong magnetospheric activity by Harel and Wolf (1976). The boundary layer and ring current flow patterns are in accord with the observations as presented by Paschmann (1979). The actual vorticity pattern at the neutral point is inferred, as there are no observations available at distances from earth of ~ 150 RE, where the neutral point is expected to be located on the average (Rostoker et al., 1982). However, the patterns are consistent with the large-scale electric field observations in the nightside ionosphere if these electric field map normally (see, for example, Mozer (1970) and Rostoker and Bostrom (1976)) into the outer magnetosphere. The vortices are also related to the shear flow patterns of the boundary layer plasma sheet which may excite Kelvin-Helmhotz instabilities which can derive currents and may lead to the micropulsations observed in the auroral regions. Rostoker et al., (1982). Thompson, (1983); Kivelson and Southwood, (1985); (1986); Southwood and Kivelson, (1986). The effects of plasma vortices are to be further investigated concerning to the magnetosphere-ionosphere coupling system.

In the chapter 2 we have presented the effect of plasma pressure anisotropy in the plasma sheet region of geomagnetic tail, on the field-aligned current system. An explicit expression for the current system has been derived and the enhancement of field-aligned currents due to pressure anisotropy is predicted. The effects of plasma vorticity, gradient drift currents on the field-aligned current, system are also emphasized to some extent. The pressure anisotropy
discussed in this chapter lead to various plasma instabilities which have to be discussed in the light of magnetosphere-ionosphere coupling system. For stable tail equilibria the magnitude of anisotropy is restricted: even for very small anisotropies the neutral sheet beams firehose-unstable \( P_{||} > P_{\perp} \) or mirror unstable \( P_{||} < P_{\perp} \), (Notzel et al., 1985). These instabilities may lead to the energization of plasma sheet particles which can flow forwards the ionosphere and may contribute to the current system which have to be investigated in further studies. The current pattern has to be investigated in the light of plasma sheet boundary parameters, plasma sheet particles, magnetic field patterns in neutral sheet, electric field, magnetic field plasma and ion composition as recently reported by Cattell et al., (1986).

In the chapter 3 we have studied the auroral acceleration by examining the behaviour of non-linear Alfvén waves. It has been shown that linearly polarized large amplitude Alfvén waves (parallel propagating magnetohydrodynamic waves) carrying currents steepen and form MHD shocks which we have defined as the mechanism for the auroral acceleration. It is suggested that the enhancement in \( + \) above the auroral electrojet at altitude above 1400 Km are evidence for a mass density discontinuity near \( -1 \) RE which causes downward propagating large amplitude Alfvén waves to steepen and form MHD shocks. The applicability of the theory explaining the observed plasma flux along the magnetic field lines at the substorm times is also indicated. Steepening of the non-linear Alfvén waves which leads to the formation of MHD shocks in
the acceleration region would provide various clues regarding inverted V structures and the structures of auroral arcs. Due to the appearance of MHD shock the geomagnetic field lines will be in the tilted form leading to the gradient in the magnetic field which would lead to the various current driven instabilities in the presence of magnetic field gradients. The enhanced field-aligned current due to these steep gradients may excite various topside current driven instabilities which may be mechanism for the release of MHD shock energy. These electrodynamical nature of release of shock energy has to be investigated in detail so that it can relate perpendicular electric field. The study on shock forming would lead to the structures of discrete auroral arcs. The auroral electrodynamics with current and voltage generators and the current driven instabilities have recently been presented by Lysak (1985).

In chapter 4, an alternative approach has been developed for the oscillations of a slab of magnetized plasma which takes into consideration the organized azimuthal structure of Pc 4-5 pulsations as well as their azimuthally localized character. Our equation is analytically of the same form as that for a thin vibrating rectangular membrane and it is shown that magnetospheric convection influences both the frequency and amplitude of the pulsations. It follows from the analytical development that the $\beta$ of the plasma being greater than one is a necessary condition for oscillations to take place. Our results suggest that oscillations exist over an azimuthal extent centered on a reversal in polarity of the north-south component of the
ionospheric electric field. The theory presented in this chapter corresponds to the giant pulsations which are the rare phenomena and occasionally observed. The studies on micro-pulsations provide a large-body informations for magnetosphere ionosphere coupling system and an appreciable amount of energy is driven by these pulsations, however, in terms of hydromagnetic waves (Greewald and Walker, 1980). The model suggested in the theoretical part and evidences presented correspond to magnetospheric phenomena, however it can be extended to the other regions of magnetospheric structures according to the availability of data and observations provided by various rockets and satellites. The energy source to excite such types of oscillations that is to excite the membrane has to be still located on the firm basis.

The last chapter discussed here deals with the summary and the relevant aspects of magnetospheric-ionospheric coupling system according to the availability of informations which have been published in the past years. However we contend that the study on magnetosphere-ionosphere coupling will proceed for the longer period of time according to the observations available and a unified theory is yet to be emerged, which may be acceptable for explaining all the observations simultaneously and be acceptable to the majority of scientists working in this fascinating field.