Dynamics of Magnetospheric Plasmas

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The dynamical behavior of the magnetospheric plasmas which control the electrostatic charging of spacecraft is the result of the complex interaction of a variety of production, loss, transport, and energization mechanisms in the magnetosphere. This paper is intended to provide the spacecraft engineer with a foundation in the basic morphology and controlling processes pertaining to magnetospheric plasma dynamics in the inner magnetosphere, including the synchronous orbit region.

I. Introduction

MAGNETOSPHERIC plasmas play a critical role in the electrostatic charging of spacecraft. High-intensity fluxes of energetic (keV) electrons constitute a "negative current" to a spacecraft which tends to produce large negative charging of the spacecraft by itself. Such fluxes also may be backscattered and produce secondary electrons to give a negative current away from the spacecraft. On the other hand, cold dense magnetospheric plasmas can provide a source of positive ions to be attracted to the negatively charged spacecraft, thereby lowering the negative potential produced by such energetic electrons.[1] For the spacecraft engineer grappling with charging problems in this magnetospheric plasma environment, a background understanding of the dynamical behavior of the magnetospheric plasmas is essential.

The aim of the present paper is to provide this background. However, within the constraints of space allotted, this goal is difficult to achieve entirely. Magnetospheric dynamics are the result of a complex interplay of processes which start at the solar surface, project through the solar wind to the magnetopause boundary, and at the same time are controlled at the other "end" of the magnetosphere by the ionosphere relatively close to the Earth's surface. For instance, the electric field distribution that permeates the magnetosphere at any given time is controlled by the solar wind plasma parameters and magnetic field through the solar wind interaction with the sunward face of the magnetosphere. It is also controlled by the electrical conductivities at the base of the magnetic field lines in the ionosphere.

Acknowledging the intrinsically globally coupled nature of most important magnetospheric processes, the author will focus on the plasma dynamics in the general vicinity of geosynchronous orbit and inward in this paper. This seems appropriate in view of the great abundance of defense and communication satellites in geosynchronous orbit which are of direct concern to the spacecraft engineer concerned with charging. The author will discuss the sources of plasmas in the magnetosphere, the fundamental energization and transport processes known to be important for plasma dynamics in the inner and middle magnetosphere regions, and, finally, the specific dynamics of the cold and energetic plasmas in this region. It is hoped this discussion will provide at least a rudimentary background on the state of our knowledge of magnetospheric plasmas in the inner magnetosphere environment. However, it is not intended to be a state-of-the-art survey appropriate to the working magnetospheric scientist and does not critically examine areas of current controversy in the field.

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II. Morphology and Sources of Magnetospheric Plasmas

Figure 1 illustrates the basic topology of the large-scale magnetosphere and indicates the entry of plasmas from these source regions into the magnetosphere. Some of the important regions of the magnetosphere indicated in Fig. 1 are:

1) Magnetopause: The "boundary" of the magnetosphere which separates the high magnetic field, low-plasma density outer magnetosphere from the low magnetic field, high-plasma density associated with the (shaded) solar wind plasma.

2) Cusp: The region of separation between magnetic field lines "closed" across the dayside magnetosphere, connecting between the northern and southern hemisphere, and those which are "open" in that they extend from the Earth out into the solar wind or interplanetary medium. The high-altitude cusp is a region of weak magnetic field where solar wind plasma may enter the magnetosphere.

3) Magnetotail: The extended magnetospheric region on the antisunward side of the Earth where magnetic field lines are mostly "open."

4) Plasma sheet: The "closed" field line region fo the tail where energetic particles are temporarily stored.

5) Plasmasphere: A "donut-shaped" region surrounding the Earth where high-density plasma is supplied by the ionosphere.

6) Plasmapause: The boundary of the plasmasphere where the density drops, often sharply, from ~100 i/cc to ~1 i/cc typically.

Plasmas in the magnetosphere originating primarily in the solar wind, the supersonically expanding plasma atmosphere of the sun, and the Earth's ionosphere. Recently, Balsiger[2] and others have emphasized the need for distinguishing a third source of magnetospheric plasma; essentially, the plasmasphere. Of course, the plasmasphere itself has as its source the ionosphere, but Balsiger[2] distinguishes between energetic plasmas which are accelerated and injected directly presumably upward along magnetic field lines into the magnetosphere, and those which were first cold plasmas in the plasmasphere prior to their energization.

The principal means used to distinguish the origin of energetic plasmas is through examination of the ion composition, which is detected by ion mass spectrometers. The above three source regions can be distinguished (frequently) as follows:

1) Ion composition dominated by H^+, with 2-4% He^{++} and little O^+ or He^+, is similar to that of the solar wind at Earth orbit and, thus, is considered to be of solar wind origin.

2) Ion composition with significant amounts of O^+ and H^+ is of direct ionospheric origin.

3) Ion composition with 5-10% He and O^{++}/O^+ concentration ratios greater than or equal to about 0.1 is thought to originate in the plasmasphere.

The reason that the plasmasphere and direct ionosphere origin plasmas can be distinguished is that direct injection of energetic plasmas from the ionosphere takes place along field lines whose feet are located in the polar ionosphere. O^+ is the dominant ion present in the high-latitude ionosphere owing to the upward flow of light ions H^+ and He^+ along high-latitude magnetic field lines (see next section). With O^+ as the principal ion species in the polar ionsosphere, this ion dominates the composition of the inospheric plasmas which are energized and ejected out along the magnetic field lines. By contrast, the plasmaspheric flux tubes are closed for long periods of time and tend to retain the light ions H^+ and He^+ within the flux tubes; indeed, because of the lighter mass, these ions "float" to higher altitudes than O^+ and dominate the plasmaspheric composition above approximately 600 km or all the way to the equator. For instance, the energetic plasma detected at synchronous orbit which contains He^+ concentrations on the order 10% or greater (i.e., similar to the plasmasphere composition is thought to arise in the plasmasphere. The O^{++}/O^+ ratio present in energetic plasmas also can be used to detect a plasmaspheric origin. Geiss and Young[3] have shown that, due to the effect of thermal diffusion which is greatly enhanced for multiply charged ions such as O^{++}, the O^{++} produced by photoionization of O^+ in the topside ionosphere is spread out fairly evenly along the magnetic field lines to the magnetic equator. Since this thermal diffusion is not effective for O^+, the O^{++}/O^+ ratio should be much higher than in the topside ionosphere; satellite observations in the plasmasphere[4,5] have shown O^{++}/O^+ ratios of order unity. This thermal diffusion-induced enhancement of the O^{++}/O^+ ratio does not occur outside of the plasmasphere since it requires several-day buildup times on closed flux tubes; thus high O^{++}/O^+ ratios (greater than 10%) are used to identify energetic plasmas outside the plasmasphere (for instance, at synchronous orbit) as being of the plasmaspheric origin. Energization of plasmaspheric plasmas (which are "cold," with thermal energies on the order of 1 eV) is thought to occur[2] in the presence of electrostatic waves which induce heating in a resonant interaction with the natural gyromotion of the ions about the geomagnetic field. Such processes apparently can heat cold plasmaspheric ions to energies of several hundred electron volts.

In summary, there are three principal sources for the plasmas found in the geosynchronous orbit region: the solar wind, the polar ionosphere, and the plasmasphere. As the data from the GEOS-2 satellite indicate,[6] any of these sources may be dominant for the energetic plasmas there, although the plasmasphere usually is less important than the ionosphere or the solar wind. The GEOS-2 data indicate that the ionosphere and the solar wind typically contribute 50% each each of the plasmas at synchronous orbit on the average, with the solar wind contribution dominant during magnetically quiet periods and the ionsopheric contribution dominating during magnetic storms. Similar dependence on magnetospheric activity is found for energetic plasmas located in the magnetotail plasma sheet located further out on the nightside of the magnetosphere.[7]

III. Basic Motions of Magnetospheric Plasmas

In this section, as a basis for discussion of the large-scale dynamics contained in the following two sections, the fundamental motions and processes associated with transport and energization of magnetospheric plasmas are described. The first subsection deals with processes leading to transport along magnetic field lines, and the next subsection describes motions perpendicular to the field lines.

Processes Causing Motions along the Magnetic Field

As discussed in the previous section, plasmas of ionospheric origin frequently constitute a significant fraction of the plasma in the synchronous orbit region. Ionospheric plasmas are transported up along the magnetic field lines into equatorial regions, and frequently energized as well, by a variety of physical processes. Here we shall discuss briefly three of the principal processes: the polar wind, auroral parallel electric fields, and ion cyclotron acceleration.

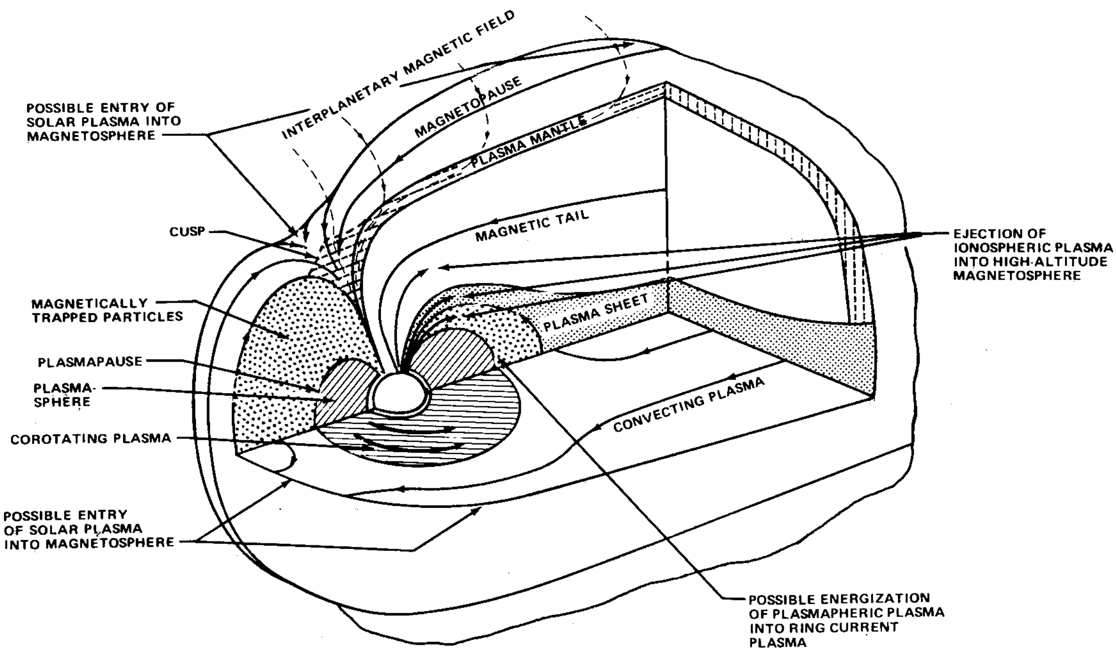

Fig. 1 The structure of the magnetosphere with an indication of the sources of magnetospheric plasma and their entrance to the high-altitude magnetosphere. Solar wind plasma from the magnetosheath (bow shock is not shown) is thought to enter at the polar cusps, the subsolar magnetopause, and the plasma mantle or boundary layer adjacent to the magnetopause. Ionospheric plasma is energized and injected upward along magnetic field lines from the ionosphere into the tail lobe, plasma sheet, and ring current regions. Plasmaspheric plasma is perhaps energized near the plasmapause to form part of the energetic component of the ring current plasma at times.

The concept of the polar wind as a supersonic flow of light ions H^+ and He^+ up from the topside ionosphere was first put forth by Axford[8] and Banks and Holzer.[9] For magnetic flux tubes "open" at least part of the time in their large-scale circulation due to large-scale electric fields, outside the plasmasphere, the plasma density and pressure are low and pressure-gradient-driven diffusion leads to a continual upward flow of plasma from the ionsphere. Because the H^+ and He^+ ions are lighter than O^+ and can escape the restraining gravitational force of the Earth more easily, these light ions tend to leave O^+ behind to be the dominant ion species in the polar ionosphere. However, since the ionospheric plasma must remain electrically neutral, a small upward-directed electric field is present to restrain the bulk of the very light electrons from also escaping easily. This electric field, which thus holds the electrons down and "bouys" the O^+ up to maintain charge quasineutrality, contributes a second force, in addition to the diffusion, which impels upward motion of the light ions. This polar wind flow of light ions has been surveyed extensively by Hoffman and Dodson,[10] who found the flow to be continually present outside the plasmapause at an altitude of 1400 km in the topside ionosphere. Until recently, satellites at higher altitudes had not measured this polar wind flow, evidently because such spacecraft acquire enough of a positive charge in the low-density regions to repel these very low-energy ions from entering ion detector apertures. However, very recently, a low-energy ion detector on the Dynamics Explorer-1 (DE-1) satellite has used a negatively biased ring about its aperture to "punch a hole" in the positive potential region around the spacecraft and attract low-energy ions to be measured. For sufficiently negative bias voltages (-4 to -8 V) the polar wind with temperature and flow characteristics roughly as theoretically predicted has been measured at altitudes of 2-3 Earth radii.

A second major process believed responsible for supplying plasmas of ionospheric origin to the equatorial magnetosphere is large electric fields directed parallel to the magnetic field in association with the auroras. Such parallel electric fields, creating field-aligned potential drops on the order of 10 kV or more, had long been suspected for the downward acceleration of electrons and other particles into the atmosphere to produce the aurora. Observations of upgoing ion beams[11,12] from the S3-3 spacecraft at about 1 R_e altitude indicated that upward electric fields were accelerating ionospheric H^+, He^+, and O^+ ions up to energies on the order of several kiloelectron volts in motion directed up out of the ionosphere and into the magnetosphere. Observations of counterstreaming electrons by the same spacecraft indicated that electric fields with downward components also are responsible for injecting ionospheric electrons into the magnetosphere as well. The basic mechanisms for producing these electric fields have not yet been clarified; however, the most common thread in the current theories is field-aligned electric currents, driven by the global magnetosphere-ionosphere convection electric field and current system. This can lead to the parallel electric fields by, for example[13]:

1) current-driven wave instabilities which impede the electrons and so impose a resistance to the electron flow and increase the electric field to maintain the current continuity to accelerate some electrons to high energies, or

2) the creation of so-called double layers, which are thin regions in which very large electric fields appear.

As may be evident from the discussion above, one of the major difficulties here is an unraveling of the cause/effect relationships involved.

A third upward injection process that has become apparent only in recent years is the importance of ion cyclotron acceleration. Field-aligned currents and perhaps other phenomena are believed to drive ion cyclotron waves (waves that, in a crude sense, have electrostatic field power at or near the local frequency of gyration of ions around the magnetic field line). In the simplest case, these waves constitute an electric field that rotates at the local ion gyrofrequency and can resonantly accelerate the circular motion of the ions about the magnetic field line to very high energies. Once the ions have large energies in perpendicular motion, they are then forced upward by the magnetic gradient force which basically acts on particles with perpendicular energy to move them from the strong magnetic field regions at low altitudes to the weaker field regions at higher altitudes in the magnetosphere by converting the perpendicular energy into parallel energy (Fig. 2). At this point the relative importance of the parallel electric fields and cyclotron acceleration for injection of ions into the magnetosphere is not clear. There are some indications that the strong parallel electric fields mainly occur above 5000-km altitude,[14,15] while cyclotron acceleration occurs commonly at altitudes down to 1400 km.[16] This may imply that the cyclotron acceleration can act as a "feeder" to the higher altitude parallel electric field regions.

Basic Motions Perpendicular to the Magnetic Field

The principal bulk transport of plasmas perpendicular to the magnetic field lines in the magnetosphere occurs via crossed electric and magnetic fields or because of either perpendicular gradients of magnetic field magnitude or strong curvature in the magnetic field lines. These motions are discussed briefly in this section.

Magnetospheric convection of plasmas occurs when dc electric fields are directed perpendicular to the local magnetic field and the bulk transport velocity is given in mks units as

$$v_E = \boldsymbol{E} \times \boldsymbol{B}/B^2 \tag{1}$$

For a synchronous orbit magnetic field B on the order of 100 $\gamma = 10^{-7}$T, an electric field $E = 5$ mV/m gives a convection velocity of 50 km/s, which has been reported at synchronous orbit.[17,18] The convection velocity does not depend on either charge or energy of the particle so that all particles are transported as a fluid element in $\boldsymbol{E} \times \boldsymbol{B}$ motion. This convective motion is the principal motion involved in the overall circulation of plasma in the magnetosphere from the tail regions toward the sunward face of the magnetosphere (dayside magnetopause).

Gradient drift results when charged particles with finite energy and thus finite gyroradii gyrate in inhomogeneous magnetic fields, which produces a drift perpendicular to the directions of both the magnetic field and its gradient, which expressed in mks units is

$$v_G = \frac{\epsilon_\perp}{qB^2} \boldsymbol{B} \times \nabla_\perp B \tag{2}$$

where $\epsilon_\perp$ is the energy in motion perpendicular to $\boldsymbol{B}$ and $\nabla_\perp$ the gradient operator perpendicular to the direction of $\boldsymbol{B}$. Unlike the convective drift, the gradient drift velocity increases with perpendicular energy and also depends on charge. At synchronous orbit energetic positive ions tend to drift westward around the Earth, while electrons drift eastward. However, for the same energy the drift does not depend on the ion mass so that different ion species are not separated for equal energies of gyromotion.

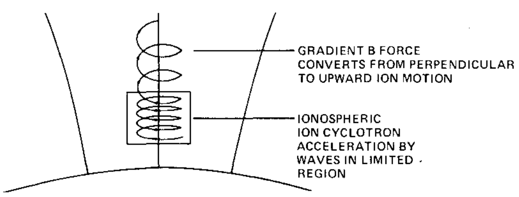

Fig. 2 A simplified illustration of the energization of ionospheric ions by cyclotron heating and the ejection into the magnetosphere through the magnetic field gradient force.

The curvature drift, as its name implies, occurs as a result of field line bending. Its dependence on energy and charge is similar to that of the gradient drift, and curvature drift velocity is given by

$$v_c = \frac{2\epsilon_{II}}{qB^3} B \times \nabla_\perp B \qquad (3)$$

where ϵ_{II} is the energy in motion parallel to B. For equatorially mirroring particles (i.e., particles which have pitch angles of 90 deg at the magnetic equator so that they never move away from it), there is no curvature drift.

For particles with arbitrary pitch angles, the gradient and curvature drifts may be combined as

$$v_{CG} = \frac{\epsilon}{qB^3}(1+\cos^2\alpha) B \times \nabla_\perp B \qquad (4)$$

where ϵ is the total energy and α the particle pitch angle.

For particles which have non-90-deg pitch angles at the equator, and thus exhibit bounce motion along the field lines, the net motion of the particles about the Earth due to gradient and curvature drifts must be "bounce-averaged" because these perpendicular drifts vary along the field lines.[19]

IV. Cold and Hot Plasma Dynamics in the Inner Magnetosphere

In this section, the dynamics of plasmas within the inner and middle magnetosphere, which are taken as the geosynchronous region inward, will be discussed. The discussion is separated into consideration of cold plasma dynamics, involving the formation and erosion of the plasmasphere and the creation of detached cold plasma clouds, and hot plasma dynamics, dealing with injection of energetic plasma sheet and ionospheric ions into the inner equatorial magnetosphere. For these purposes, the cold plasmas are taken generally to be plasmas with thermal energies on the order of 1 eV, typical of the ionosphere, and the hot plasmas are characteristically with energies on the order of 1 keV or greater.

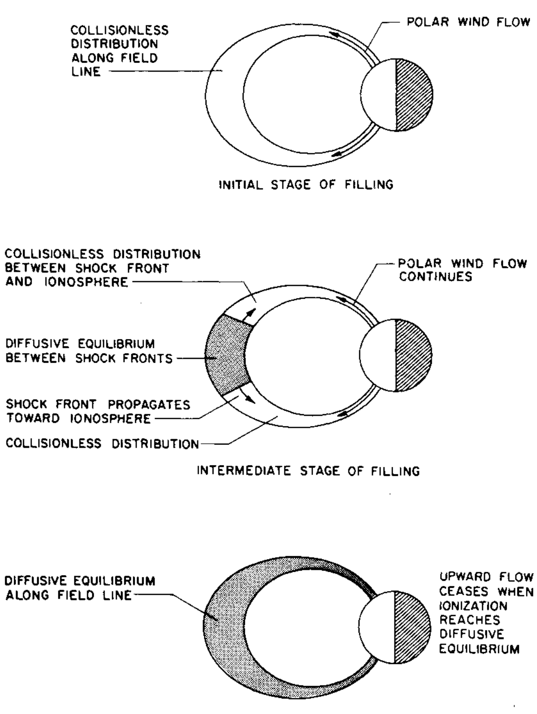

Fig. 3 The basic model for plasmasphere filling proposed by Banks et al.[20]

Dynamics of Cold Plasmas

In discussing the cold plasmas in the magnetosphere, it is necessary to begin with the plasmasphere, a toroidal-shaped region surrounding the Earth extending from the ionosphere to about $4R_e$ in equatorial geocentric distance, with a bulge to 6-$7R_e$ in the dusk local time sector. In this region, the plasma is cold ($kT<1$ eV) and very dense, with densities on the order of 10^3 near $3R_e$ in equatorial geocentric distance. The formation of the plasmasphere is influenced by both the polar wind flowing up from the ionosphere into magnetic flux tubes and the spatial and temporal distribution of the convection electric field. In the model of Banks et al.[20] for the filling of the plasmasphere (Fig. 3), a magnetic tube of flux is envisioned to be initially devoid of plasma, and the supersonic polar wind flows of ionospheric plasma from the conjugate ends of the flux tube meet near the magnetic equator. The model predicts a shock-like interaction between the opposing field-aligned streams which produces a high-density plasma slab around the magnetic equator whose edges propagate downward toward the ionosphere into the region where the flow changes from subsonic to supersonic flow. At this stage, the flow is upward but subsonic all along the flux tube. This more gentle flow then is thought to proceed until the plasma is in diffusive or hydrostatic equilibrium, i.e., the flux tube is filled. The details of this process are still uncertain, but there is no doubt that the upward plasma flows are ultimately responsible for filling the plasmasphere. The convection pattern determines the extent of the plasmasphere in that those flux tubes which in steady state have convection trajectories dominated by corotation and encircle the Earth can fill up with plasma and thus become part of the plasmasphere. Those flux tubes farther away from the Earth, whose convection trajectories take them to the dayside magnetopause where the geomagnetic field lines merge with the solar wind magnetic field to create open field lines where the polar wind plasma can flow out of the magnetosphere, do not have sufficient time to fill up with plasma, and, therefore, remain at low densities. The boundary between the region of high-density plasma in the plasmasphere and low densities outside is called the plasmapause. As the preceding discussion implies, the plasmapause is, in principle, the boundary between flux tube trajectories which encircle the Earth and those further out which intersect the magnetopause, and is determined by the convection electric field pattern.

The erosion or decrease in size of the plasmasphere occurs during magnetospheric storms or substorms, which are caused by changes in the solar wind characteristics. During such storm periods, the strength of the solar wind-induced convection electric field is increased and its dominance extends inward to regions where corotation was previously dominant and hence which were part of the plasmasphere. This causes these regions to drift away from the main plasmasphere, leaving the remaining plasmasphere smaller in size within the smaller region of Earth-encircling flux tube trajectories. Conversely, it is during the periods of quiet in the magnetosphere following these storm periods, that previously empty flux tubes reside on Earth-encircling trajectories, which encompass a larger region than during the storm period, and these flux tubes begin to fill up with plasma flowing from the ionosphere; thus, during quiet periods the plasmasphere expands.

The outer parts of the plasmasphere which drift away from the main body of the plasmasphere have been termed "detached plasma regions" and constitute regions of high-density cold plasma which move all the way from the plasmasphere to the dayside magnetopause due to the enhanced $E \times B$ sunward convection during these storm periods. They have been observed primarily in the afternoon dayside magnetosphere[21-23] and are thought to originate in the dusk bulge regions. There has been some controversy as to whether these regions are "blobs" which detach readily from the main plasmasphere[21] or streamers or plasma tails which tend to remain attached to the plasmasphere.[24] The presence of these plasma regions which can exist all the way to the dayside magnetospause means that such high-density cold plasma is occasionally present to affect spacecraft charging far outside the region normally occupied by the main plasmasphere.

As noted above, in addition to the high-density cold plasma associated with the plasmasphere, the high-altitude extension of the polar wind recently has been measured beyond the plasmapause, with energies on the order of 1 eV and densities in the range 1-10 particles/cm^3.[25] It will be of great interest to understand the dynamics of this polar wind plasma from measurements bv DE-1 as these become available.

Recently, the presence of "warm" plasma components with thermal energies on the order of tens of electron volts has been measured.[17,18,22,26,27] The complicated distribution functions for these ions indicate that many of the parallel electric field and cyclotron acceleration processes mentioned in Sec. II are effective in energizing these ionospheric-origin ions to their tens of electron volts energies. Typical densities for this warm plasma component are in the general range 0.1-10 particles/cm^3.[22]

Dynamics of Hot Plasmas

Most of the basic ideas on the hot plasma dynamics near synchronous orbit were put forth in the classic paper by DeForest and McIlwain,[28] with the major new concept since that time being the importance of injection of energetic plasmas from the ionosphere into the synchronous orbit region along magnetic field lines. From interpretation of energetic particle measurements made on ATS-5 (also the spacecraft and instrument which first detected strong negative charging), DeForest and McIlwain[28] developed a general model for the behavior of equatorial hot plasmas during and following magnetospheric substorms. At the onset of the substorm, a localized region of east-west electric field develops for a short period (~5-10 min) in the midnight near-Earth plasma sheet region of energetic plasma to move or inject this plasma earthward vis $E\times B$ drift into the synchronous orbit region. Following the decay of this electric field, the injected particles drift about the Earth via gradient and curvature drifts (as well as the residual pattern of $E\times B$-driven convection). For the highest energy particles (say, > 10 keV), the gradient and curvature drifts dominate the effects of convection, and for a given energy distribution of the injected particles, the highest energy particles travel fastest to any region located away from the midnight sector, resulting in energy dispersion of the particles. This energy dispersion in arrival time can be used graphically to find the time of arrival for infinite energy particles which may be considered the time of substorm onset. As noted earlier, the high-energy electrons drift eastward and the ions drift westward about the Earth. Figure 4 illustrates schematically the energy- and charge-dependent dispersion of injected particles.

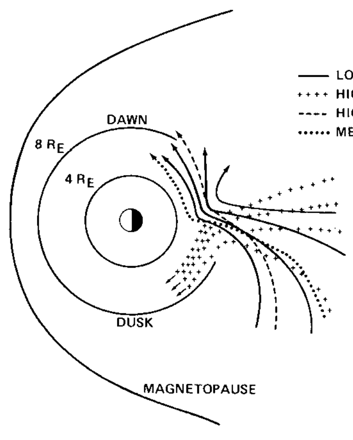

Fig. 4 Trajectories of different charged particles injected during a magnetospheric substorm.[26]

At intermediate energies, typically near 1 keV, the influences of the energy- and charge-dependent gradient and curvature drifts and the convection and corotation drifts become comparable in importance; this leads to some interesting effects. For example, in the duskside of the inner magnetosphere, the competing eastward drift due to corotation and the westward motion due to the gradient and curvature drifts lead to vortices of circulation of ions on the duskside fo the Earth.[19] Also identified by DeForest and McIlwain[28] were certain energies where ion fluxes were greatly reduced; those flux depletions were thought to result when ions located near midnight have no net east/west motion due to this type of cancellation, but still have an inward drift due to magnetospheric convection which moves the energetic ions into the dense plasmasphere where scattering interactions cause a loss of these ions.

The injection of energetic plasmas from the ionosphere into the equatorial synchronous orbit magnetosphere was perhaps first clearly indicated by the particle measurements from ATS-6[29,30] that among other things made the first observations of highly collimated field-aligned streams of energetic electrons with characteristics quite similar to those measured in the ionosphere just above bright discrete auroral forms. They suggested that such electrons were accelerated up from the ionosphere by downward parallel electric fields. These results are also of historical interest in that they convincingly demonstrated that auroras occurred on the closed magnetic field lines threading the geosynchronous orbit; up until this time there had been considerable question as to whether auroras occurred on closed or open field lines; now it is considered that they occur primarily and perhaps entirely on closed field lines. Field-aligned ion streams were also observed by ATS-6[22] and later by SCATHA[31,32] and were identified as being freshly injected from the ionosphere through the action of both parallel electric fields and cyclotron acceleration as discussed. In fact, Kaye et al.[32] found that for a certain class of ion distributions which were field-aligned at low energies and trapped (peak fluxes at 90 deg pitch angle) at higher energies, the ion composition of the low-energy field-aligned ions was dominated by O^+ along with H^+ and traces of He^+, indicative of an ionospheric origin, whereas the higher energy trapped ions have H^+ and O^+ as well as some He^{++}, indicative of the mix of ionospheric and solar wind-origin plasmas observed in the plasma sheet. Thus, it is believed that during substorms the ionospheric plasma is freshly injected up along magnetic field lines into the equatorial synchronous orbit magnetosphere to form the low-energy field-aligned component, while the trapped higher-energy ions result from Earthward injected plasma sheet plasma as discussed above. The typical energy demarcation found by Kaye et al.[32] was in the range 1-10 keV.

V. Summary

In this review the author has provided a simplified picture of the dynamics of magnetospheric plasmas, focusing on the near-Earth magnetosphere in the vicinity of geosynchronous orbit and inward. The author has described the three sources of magnetospheric plasmas: the solar wind, the high-latitude ionosphere, and the plasmasphere. The author has also discussed the basic motions of plasmas in the magnetosphere, both parallel and perpendicular to the magnetic field lines, and indicated some aspects of the large-scale dynamics of magnetospheric plasmas within the inner and middle magnetosphere.

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