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The Magnetospheres of Jupiter and Earth

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The magnetic fields of Earth and Jupiter carve cavities out of the solar wind, which in turn influences the dynamics and structure within the magnetospheres of these planets. From a knowledge of the factors which influence the terrestrial magnetosphere, expectations for the Jovian magnetosphere are deduced.

The shape of the Jovian magnetosphere should be similar to that of Earth, with the size of the magnetosphere slightly larger relative to the size of the planet and the size of the auroral zone slightly smaller. The fraction of the incident solar wind energy injected into the magnetosphere should be comparable for Earth and Jupiter.

Major dissimilarities may occur because of the following fundamental differences:

(1) The solar-wind-induced plasma flow should be smaller than the corotational flow essentially throughout the Jovian magnetosphere.

(2) The centrifugal and gravitational forces balance at a point well within the region of Jupiter's magnetosphere dominated by corotation.

(3) Drift periods for energetic particles trapped in the magnetosphere are generally smaller than the rotation period for Earth, but much much larger for Jupiter.

(4) In the polar-cap regions of Earth, energy deposition into the ionosphere from the solar wind and solar EUV radiation are comparable, but for Jupiter's polar cap ionosphere, the solar wind input should be clearly dominant.

INTRODUCTION

Jupiter and Earth are the only planets known to have significant magnetic fields. In the outermost regions of these planets' atmospheres, the dynamics will be dominated by the magnetic field and these regions are referred to as magnetospheres. The magnetosphere of Earth has been extensively studied in the past decade and much has been learned. By appropriate scaling, we can turn knowledge of the terrestrial magnetosphere into expectations for the Jovian magnetosphere. Thus, this paper is complementary to the excellent review by Carr and Gulkis (1969) of parameters of the Jovian magnetosphere deduced primarily from radio measurements of Jupiter. The following discussion is divided into three sections. In the first, the size, shape, and structure of the Jovian magnetosphere are considered. In the second, we discuss energetic particles, and in the third, expected and potential energy sources.

Table I gives the values of basic parameters of Earth and Jupiter used in this paper. The magnetic fields of the planets will be assumed to be centered dipoles for the purposes of this paper. The surface magnetic field of Jupiter at the equator is probably about 10 gauss, but could be

TABLE I

PHYSICAL CONSTANTS OF EARTH AND JUPITER I

	Earth	Jupiter
Radius	6400 km	70,000 km
Distance to Sun	1 a.u.	5.2 a.u.
Rotation period	24 hr	10 hr
Surface acceleration of gravity	9.8 m/sec^2	24.5 m/sec^2
Surface field	0.3 gauss	1 gauss 10 gauss

smaller, so some calculations for a 1-gauss surface field have been made. There is evidence in the decametric noise bursts that the surface field may depart substantially from a dipole, but these departures should be small at large distances in the magnetosphere and should not greatly affect the calculations we make.

While the solar wind parameters may fluctuate widely, the average values are reasonably well defined, the values used in this study being given in Table II. This table gives the density in gm/cc and protons/cc, the velocity, the pressure resulting from the bulk flow of the gas (expressed in Newtons per square meter), and the travel time from the Sun. The magnetic field parameters are the total magnetic field strength, which decreases roughly linearly with distance beyond the Earth, the typical magnitude of the magnetic field component normal to the ecliptic plane, and the angle between the magnetic field direction and the Sun–planet line. The solar wind is assumed to flow radially out from the Sun at constant velocity with density decreasing as the distance squared. For a discussion of solar wind flow, see Dessler (1967). While earlier work suggested that the solar wind might terminate at distances as small as 5 a.u. (and hence, perhaps, inside the orbit of Jupiter), more recent work places the termination at a much larger distance of about 100 a.u. (McDonough and Brice, 1970).

Size, Shape, and Structure

The extent of the Jovian magnetic field in the solar direction is determined by a balance between magnetic field pressure and solar wind pressure (see, for example, Beard, 1960).

The distance to the bow, R_{bow}, will be given by

$$R_{bow} = R_J\left(\frac{2B^2{}_{SJ}}{\mu N m V^2}\right)^{1/6},$$

where R_J is the radius of Jupiter, B_{SJ} is the surface field at the equator, μ is the magnetic permeability of free space, N is the solar wind number density, m the particle (proton) mass, and v the solar wind velocity. Using the parameters of Table II, we obtain $26R_J$ for a surface field of 1 gauss and $53R_J$ for a 10-gauss surface field (compared with $10R_E$ for earth). The boundary of the terrestrial magnetosphere is generally well defined and the shape well known (at least in the equatorial plane). The distance to the boundary in the dawn–dusk meridian is about $1\frac{1}{2}$ times the distance to the bow, and beyond this point the tail flares out at an angle of about 10 degrees. A sketch of the field-line shape is given in Fig. 1. Note that in the extended "tail," field

TABLE II

Average Solar Wind Parameters at Earth and Expected Values at Jupiter[a]

	Earth	Jupiter
Density	7 protons/cm^3	0.26 protons/cm^3
B_{sw}	7 γ	1 γ
$B_\perp$	1.5 γ	0.05 γ
Angle to radial	45°	80°
Pressure	4×10^{-17} Nt/m^2	7×10^{-19} Nt/m^2
Velocity	400 km/sec	400 km/sec
Travel Time	104 hr	540 hr

[a] Values are given for the density, flow velocity (and resulting pressure), travel time from the Sun, the magnitude of the total solar wind magnetic field strength (B_{sw}) and a typical magnitude for the component normal to the ecliptic plane ($B_\perp$).

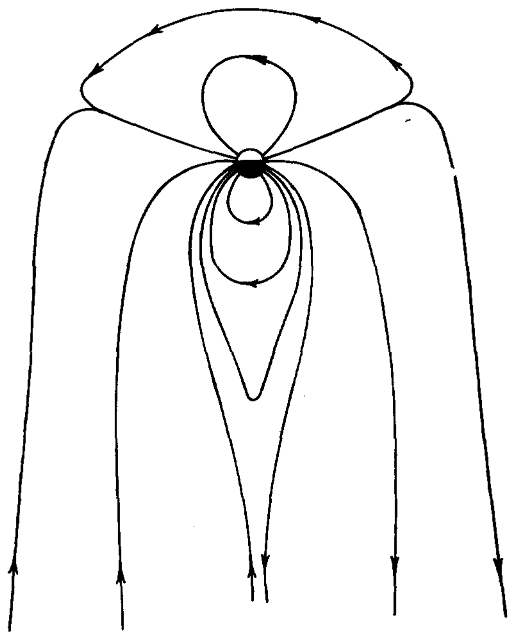

FIG. 1. The shape of the magnetic field structure for Earth with a distance to the magnetopause at the bow of $10R_E$. The shape is expected to be the same for Jupiter, but the size of the planet will be somewhat smaller relative to the size of the magnetosphere.

lines are essentially "open" while in the "body" of the magnetosphere, field lines are closed. Thus the magnetosphere is naturally divided into two regions, one of open field lines and one of closed field lines. For the Earth, the open field line regions map down onto the polar cap at a colatitude of about 10 degrees at noon and 20 degrees at midnight. It is interesting to note that the most active aurorae are found on a locus called the auroral oval (Akasofu, 1964) which is in the closed field line region, a few degrees lower in latitude and roughly parallel to the boundary described above.

In models of the Earth's magnetosphere (Williams and Mead, 1965) the *shape* of the magnetic field structure is independent of solar wind pressure. The only "free" parameter is the distance to the bow measured in planetary radii. Thus, to get a scaled model of the magnetic field configuration of Jupiter, the same magnetic field shape as for the Earth is used and the size of the planet is then scaled to give the correct distance to the bow in planetary radii. In Fig. 1, the distance to the bow is 10 Earth radii, but to make this figure applicable for Jupiter with a 10-gauss field, we need only reduce the size of the planet 5.6 times to make the distance to the bow $56R_J$, and we then have the expected magnetic field configuration for Jupiter. Near the surface of the planet, the solar wind influence on the magnetic field shape is negligible (i.e., the field may be approximated by a dipole) so that the open field line–closed field line boundary can be mapped from the terrestrial to the Jovian polar cap using a dipole magnetic field. The open field line region then has a radius of 9 degrees or 6 degrees for surface fields of 1 and 10 gauss with dayside colatitudes of 6 degrees and 4 degrees, respectively. The location of these boundaries for Earth and for Jupiter are shown in Fig. 2.

In the terrestrial magnetosphere, there is another boundary between different regions in the body of the magnetosphere which is much better defined than the boundary between open and closed field lines. This boundary is called the plasmapause. It arises from motion of the magnetosphere induced by the solar wind. [For a detailed discussion, see Brice (1967).] Dynamical friction at the boundary of the magnetosphere causes the terrestrial plasma near the boundary (and the frozen-in magnetic field) to move in the direction of the solar wind, i.e., away from the Sun. This is balanced by a flow of plasma and field toward the Sun in the interior of the magnetosphere. Thus open field lines within the tail move toward the Earth, become closed, and flow through the body of the magnetosphere toward the dayside boundary where they are opened and swept back into the tail. The time taken to fill these flux tubes with plasma from the ionosphere is several days, while the transit time in the body of the magnetosphere is of the order of 1 day. These field lines thus remain "empty," i.e., contain very low density plasma. Field lines close to the Earth simply corotate, are never "open," and are "full" of plasma, i.e.,

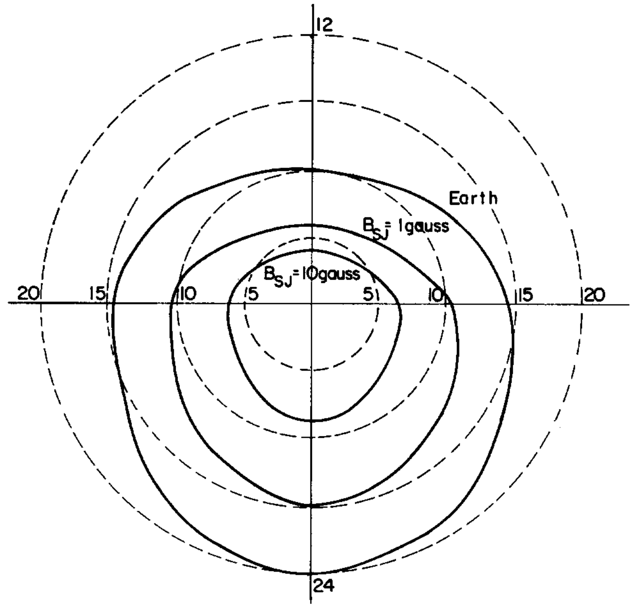

FIG. 2. Location on the polar cap of the boundary between open and closed magnetic field lines for Earth and for Jupiter with assumed surface equatorial dipole fields of 1 and 10 gauss. Coordinates are magnetic latitude and local time.

have densities in equilibrium with the ionosphere. The boundary between "empty" and "full" flux tubes is usually well defined ($\sim 0.1 R_E$) while the change in density across the boundary may be as large as two orders of magnitude. This boundary occurs at a distance where the solar-wind-induced flow velocity is about equal in magnitude to the corotation velocity. These velocities, $\mathbf{v}$, are associated with electric fields, E, in accordance with the equation, $\mathbf{E} + \mathbf{v} \times \mathbf{B} = 0$.

There are two models of solar wind drag, one due to Axford (1964) and one due to Dungey (1961) and Petschek (1966). Both give electric fields in the dawn–dusk direction of about $3kV/R_E$, in rough agreement with observations. This field equals the corotation electric field at about $5R_E$. A recent model of plasma flow in the equatorial plane of Earth (Brice, 1967) is shown in Fig. 3a. Figure 3b sketches the corresponding flow expected for Jupiter.

For Axford's (1964) model, the potential across the magnetosphere, ϕ, is given by

$$\phi = 2UBt,$$

where U is the solar wind velocity; B, the dipole magnetic field at the dawn–dusk boundary of the magnetosphere; and t, the thickness of the boundary layer. For a sphere the thickness, t, is given by Knudsen and Katz (1958) as

$$t \doteqdot 7[(\nu R_0)/U]^{1/2},$$

where ν is the kinematic viscosity (2×10^{10} m^2/sec was used, scaling as $T^{1/2}/\rho$ from the value used by Axford for the Earth where T and ρ are the expected solar wind temperature and density respectively), and R_0 is the distance to dawn (dusk) magnetospheric boundary

$$R_0 \doteqdot 1.5\ R_{bow}$$

The electric field is then

$$E = \phi/3\ R_{bow}.$$

For a surface field of 10 gauss, the dawn–dusk electric field is $1\frac{1}{2}$ kV/R_J, while for 1 gauss it is 2 kV/R_J.

The electric field for the Dungey-Petschek model depends on the rate of merging of the terrestrial and solar wind magnetic fields on the bow side of the

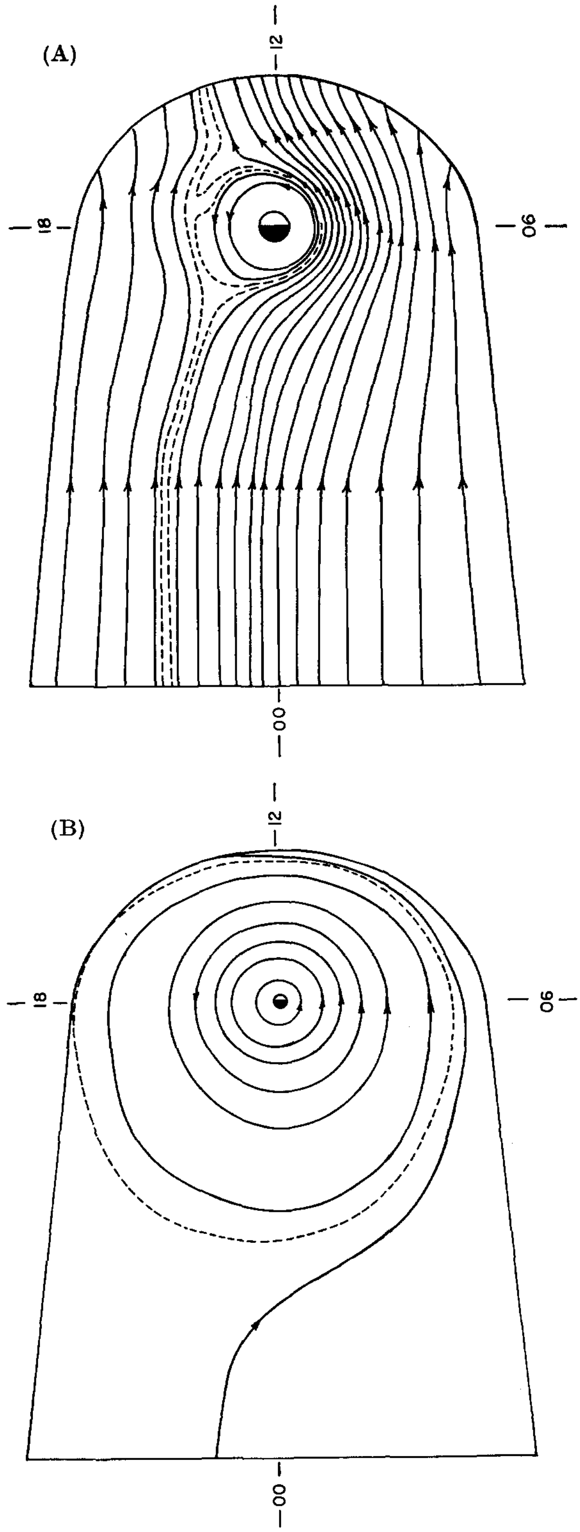

FIG. 3. (A) The flow pattern for thermal plasma in the terrestrial equatorial plane derived by Brice (1967) and (B) the corresponding flow expected for Jupiter.

Earth. This rate depends in a not-well-determined way on the southward component of solar wind magnetic field. At Jupiter the component of magnetic field normal to the ecliptic will be relatively small (see Table II) and this may reduce the merging rate by a factor of 5 or so.

For Earth, the Dungey-Petschek electric field is given by

$$E = U_A B_{sw},$$

where U_A is the Alfven velocity in the solar wind and B_{sw} is the solar wind magnetic field. Using this formula for Jupiter we obtain about 3 kV/R_J. Thus the solar wind induced "convective" electric field should be about an order of magnitude smaller for Jupiter than for Earth. The larger rotation velocity and much larger surface field at Jupiter both contribute to producing larger corotational electric fields at Jupiter and these will dominate the convective fields almost everywhere. The "plasmapause boundary" will coincide with the magnetosphere boundary (or magnetopause) at dusk and be just within the magnetosphere at dawn. (The separation is estimated to be about $2R_J$ for a 1-gauss field or $1 R_J$ for a 10-gauss field. See Fig. 3B for a sketch of the flow pattern expected in the Jovian equatorial plane.) Thus almost throughout the entire body of the Jovian magnetosphere, the dominant influence should be Jupiter and the solar wind influence should be only peripheral. The ratio of the corotational electric field to the solar-wind-induced field is shown as a function of distance (measured in planetary radii in the equatorial plane and called L) in Fig. 4. In this figure, the electric field assumed is 3 kV per R_E for Earth and 3 kV per R_J for Jupiter.

There is an additional boundary within the magnetosphere which appears to have little significance for Earth but may be very important for Jupiter. This separates the region dominated by gravitation and

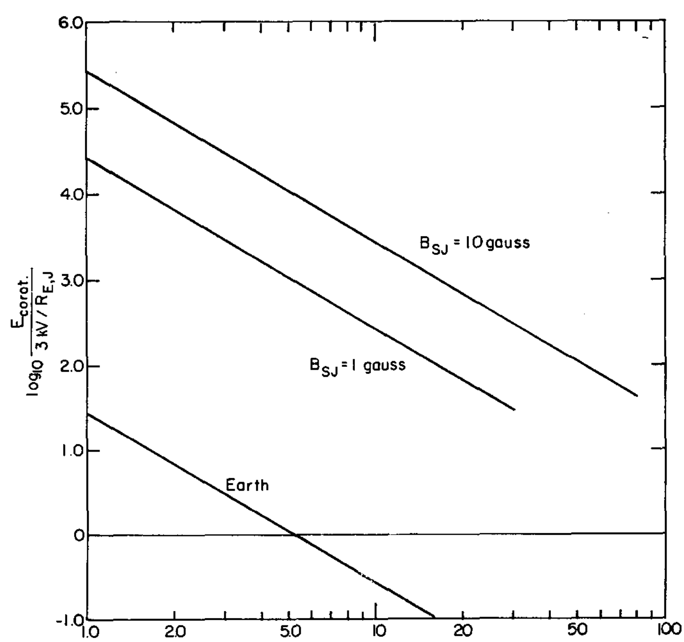

FIG. 4. The ratio of magnitudes of the convective electric fields to the corotational electric field in the equatorial plane for Earth and for Jupiter with assumed surface fields of 1 and 10 gauss, plotted as a function of distance measured in planetary radii (L). Note that the corotational electric field is everywhere orders of magnitude larger than the convective field for Jupiter, whereas on Earth either field may dominate, depending on location.

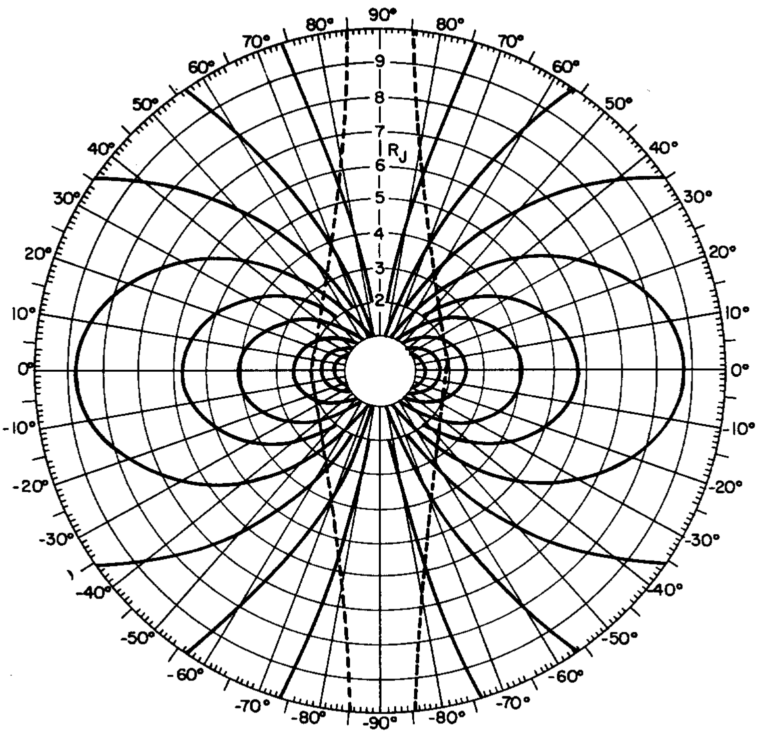

FIG. 5. A meridional section showing magnetic lines which intersect the Earth at latitudes of 30°, 40°, 50°, 60°, 65°, 70°, 75°, 80°, and 85° (heavy lines) and the locus of points where the components in the magnetic field direction of centrifugal and gravitational force cancel (dashed lines). A corotating magnetosphere and colinear centered dipole field are assumed.

one dominated by centrifugal force. The distribution of thermal plasma will be greatly affected by the magnitude and direction of the net (centrifugal plus gravitational) force. In the equatorial plane these balance at $2.2R_J$ for a corotating magnetosphere. For the plasma distribution, since plasma diffuses preferentially along the magnetic field, the important factor is the net component of force in the magnetic field direction. The dashed line in Fig. 5 is the locus of points in a meridional plane where these *components* are balanced. (Since the forces are not in general colinear, this locus meets the equator not at $2.2R_J$ but at slightly less than $2R_J$.) For the Earth, the forces balance at about $6.5R_E$, which is beyond the plasmapause. Here the plasma is not in diffusive equilibrium, and the velocity is not dominated by corotation so that no substantial difference is noticed between the plasma distribution inside and outside this boundary. The same should not be true of Jupiter, where the boundary is well inside the plasmapause and substantial effects should be noticed. A more detailed discussion of the distribution of thermal plasma is contained in a paper by Ioannidis and Brice (1970). Parameters relating to the magnetospheric size and shape are summarized in Table III.

ENERGETIC PARTICLES

Energetic particles are of interest for the major role they play in the physics of the terrestrial magnetosphere and because they are almost certainly responsible for the nonthermal decimetric and decametric radiation on Jupiter (see Carr and Gulkis, 1969; Goldreich and Lynden-Bell, 1969). Potential sources of energetic particles are the solar wind and cosmic rays, as well

TABLE III

PHYSICAL CONSTANTS OF EARTH AND JUPITER II[a]

	Earth	Jupiter	
Synchronous orbit	$6.5R_E$	$2.2R_J$	
Surface field	0.3 gauss	1 gauss	10 gauss
Radius of auroral zone	15°	9°	6°
Dayside latitude	80°	84°	86°
Dawn–dusk magnetospheric boundary	$15R_E$	$39R_J$	$80R_J$
Dusk plasmapause	$5R_E$	$39R_J$	$80R_J$
Dawn plasmapause from boundary	$12R_E$	$2.2R_J$	$1.2R_J$

[a] Parameters of the magnetosphere of Earth and Jupiter, including the radius of the open magnetic field line region on the polar cap (defined loosely as the "auroral zone"), the dayside latitude of this region, the distance to the magnetospheric boundary or magnetopause in the dawn–dusk plane, the equatorial location of the plasmapause at dusk and the separation between the magnetopause and plasmapause at dawn.

as the interaction between Jupiter's inner satellites and the magnetic field as suggested by Brice (1968), Piddington and Drake (1968), and Goldreich and Lynden-Bell (1969).

Beyond the shock boundary where thermalization occurs, solar wind particles (electrons and protons) will have energies of the order of 1 kV at Earth and Jupiter. The magnet moment, μ, of these particles in the solar wind is then about 15 megavolts (MV)/gauss at Earth or 100 MV/gauss at Jupiter. Unless the fields experienced by the particle change substantially during a gyroperiod, the first adiabatic invariant will not be violated and μ will be conserved. Violation may occur in a "neutral sheet" where the magnetic field goes to zero and the gyroperiod becomes very large or in the presence of large amounts of electromagnetic noise near the gyrofrequency (whistler mode noise for electrons, Alfven waves for protons). If we assume that μ is conserved, a solar wind particle which diffuses in to 7 planetary radii ($L = 7$) would have an energy of about 13 kV for Earth, or 2.6 MV for Jupiter. For $L = 2$, we get 500 kV for Earth, 100 MV for Jupiter.

Trapped energetic particles have two components of drift, one due to corotational and convective electric fields and the other due to gradients in the magnetic field. The former causes drift along electrostatic equipotentials (i.e., perpendicular to E) at constant energy. The latter may cause drift across equipotentials (i.e., parallel or antiparallel to E) with associated change in energy. If the convective electric field is fluctuating in magnitude (as it does on Earth) this can cause energization and diffusion of energetic particles associated with violation of the third adiabatic invariant (for a discussion of adiabatic invariants, see Northrup, 1963).

The period for magnetic field gradient drift around the Earth for terrestrial trapped particles is given by (Lew, 1961)

$$T = \frac{3}{\epsilon}\frac{1+\epsilon}{2+\epsilon}\frac{m_e}{m}\frac{R_E}{R_0}\frac{G}{F} \quad \text{hours},$$

where $\epsilon = \gamma - 1$ is the kinetic energy/mc^2; R_0, the equatorial distance to the magnetic shell on which the particle drifts; m_e, the electron mass; m, the particle rest mass; and G/F is a factor which varies from 1.0 to 1.5 for particles with pitch angles in the equatorial plane of 90° and 0°, respectively (i.e., mirror points in the equatorial plane or at very low altitudes). The drift period scales as the magnetic moment of the planet and inversely as the distance from the center of the planet so that for the same L value (i.e., distance measured in planetary radii) the drift period is about 3 orders of magnitude longer for Jupiter than Earth. The period for Jupiter is given by

$$T = \frac{1100}{\epsilon}\frac{1+\epsilon m_e}{2+\epsilon m}\frac{R_J}{R_0}\frac{G}{F} \text{ hours.}$$

For Earth this drift is typically much faster than corotation. (For a 40-kV electron at $L = 7$, the drift period is a few hours.) At Jupiter, the rotation is faster, while the drift is much, much slower, so that this "grad B" drift is much slower than corotation, and the total drift velocity will be very close to the corotation velocity. One can readily calculate the minimum time required to bring a solar wind particle to a given L value (i.e., to a given energy, assuming μ is conserved), by third invariant violation driven by convective electric fields. It is assumed that the convective electric field is uniform and is switched from zero to its maximum value in perfect synchronism with the particle drift (i.e., with a cycle time very close to 10 hours). For Jupiter, the number of particle orbits for $L = 7$ is about 100, giving a minimum acceleration time from 1 kV to 2.6 MV of 10^3 hours. If the acceleration is not synchronous but quasi-random, then 10^4 orbits will be required or 10^5 hours. As the particles approach the planet, the energy gain required to conserve μ increases rapidly (as B, i.e., as L^{-3}) while the potential across the orbit decreases (as L) so that to accelerate a particle to $L = 2$ would take at least 10^5 hours and diffusion would take 10^9 hours. For Earth the computed diffusion times of about 1 hour for $L = 7$ (13 kV) and 100 hours at $L = 2$ (500 kV) are consistent with observations of injection of energetic particles associated with large magnetic storms. These parameters are summarized in Table IV.

Energy Sources

The principal source of free energy in the terrestrial magnetosphere is the solar wind. The typical energy incident on the terrestrial magnetosphere is about 10^{12-13} watts, of which about 1% or 10^{10-11} watts is injected into the magnetosphere (Axford, 1964). For Jupiter, the incident energy is about 10^{15} watts. Using the Axford drag model, the energy injected into the magnetosphere is calculated to be 0.9 and 4×10^{13} watts for 1 and 10 gauss surface fields respectively, while for Dungey-Petschek drag we get 1 and 3×10^{13} watts, respectively. These again are very close to 1% of the incident solar wind energy flux. Estimates of parameters relating to convection of the magnetosphere are summarized in Table V.

Photoelectrons from the terrestrial ionosphere have fluxes of a few 10^8 for Earth

TABLE IV

Parameters of Injected Solar Wind Particles[a]

		Earth	Jupiter
μ_{sw}		15 MV/gauss	100 MV/gauss
T_{Drift}		3 hr	~10^3 hr
Rotation period		24 hr	10 hr
$L = 7$	K.E.	13 kV	2.6 MV
	$T_{Diffusion}$	1 hr	10^5 hr
$L = 2$	K.E.	0.5 MV	100 MV
	$T_{Diffusion}$	10^2 hr	10^9 hr

[a] Parameters relevant to energetic particles injected from the solar wind, including the first adiabatic invariant (the magnetic moment) in the solar wind, μ_{sw}, a typical drift period for energetic particles, the energy reached and time required for diffusion by third invariant violation to distances of 7 and 2 planetary radii, respectively.

TABLE V

PARAMETERS RELATING TO MAGNETOSPHERIC CONVECTION[a]

Surface field Model	1 gauss		10 gauss	
	Axford	Petschek	Axford	Petschek
E field electrostatic (kV/R_J)	2	3	1.25	3
Potential (kV)	131	230	180	480
Energy input (watts)	9×10^{12}	10^{13}	4×10^{13}	3×10^{13}
Corotational electric field	$\frac{9.1 \times 10^4}{L^2}$	kV/R_J	$\frac{9.1 \times 10^5}{L^2}$	kV/R_J
Integrated Pedersen conductivity	20–200 mhos		2–20 mhos	
Joule heat	5.10^{11}–5.10^{12} watts		10^{11}–10^{12} watts	

[a] Parameters relating to magnetospheric convection. For assumed surface fields of 1 and 10 gauss and the Axford and Petschek models of solar wind drag, estimates are given of dawn–dusk electrostatic electric fields in the equatorial plane and the corresponding potential across the magnetosphere, together with estimates of the energy input. Using assumed values of the height integrated Pederson conductivities, the associated Joule heating of the ionosphere is estimated. Note that if the polarity of Jupiter's magnetic field is opposite to Earth, the convective electric field will be directed from dusk to dawn, not dawn to dusk.

with a mean energy of about 20 eV, giving a total input of almost 10^9 watts. If the photoelectron flux scales with the incident solar illumination, we estimate about 2×10^9 watts input into the Jovian magnetosphere. Piddington and Drake (1968), Brice (1968), and Goldreich and Lynden-Bell (1969) have suggested that the interaction of satellites with the Jovian magnetic field may produce energy through currents along field lines between the satellite and the conducting ionosphere. The energy input is estimated to be about 10^{11} watts if the only significant source of resistance is the ionosphere, where the height-integrated Pedersen conductivity is estimated to be about 20 mhos [using the Gross and Rassool (1964) model ionosphere]. This energy would come from the rotational energy of the planet as the effect of IO is to partially stop a small part of the ionosphere from corotating. If the whole ionosphere were prevented from rotating by the magnetosphere (a highly unlikely event), the energy input to the magnetosphere would be about 10^{18} watts. For Earth, most of the solar wind energy input is deposited in the polar cap in an area about twice that of the open field line region. The energy input to this part of the polar cap ionosphere is a few ergs/cm^2 sec, or about the same as the EUV solar luminosity deposited in the midlatitude ionosphere. For Jupiter, the solar wind energy deposited on the polar cap could be as large as 100 ergs/cm^2 sec. Thus, the solar wind energy tends to be the dominant energy source for the terrestrial polar ionosphere (large zenith angles reduce the solar EUV input) and should completely dominate the Jovian polar ionosphere. The total solar input (about 10^6 ergs/cm^2 sec or 1 kW/m^2 at Earth) of course dominates all the above energy sources, but only a tiny fraction of this is deposited in the outermost atmosphere.

An additional small energy input comes from the 10-degree tilt between the magnetic axis and the rotational axis. The energy input is given by

$$W = \frac{2}{3} \frac{M^2 \Omega^4}{\mu C^3} \sin^2(10°),$$

where M is the magnetic moment, Ω the angular rotation, C the velocity of light in vacuum, and μ the permeability of free space. This gives about 10^5 watts. This is believed to be the principal source of energy loss for the "pulsars" (Pacini, 1967) but is not significant for Jupiter.

Summary

The size of the magnetosphere of Jupiter is expected to be thirty to fifty times the size of the terrestrial magnetosphere. The influence of the solar wind should be confined to large distances from the planet, while forces associated with corotation of the planet should dominate throughout most of the magnetosphere. The energetic particle precipitation onto the polar regions may be much larger than for Earth. However, this last conclusion could conceivably be seriously in error. Injection of plasma into the terrestrial magnetosphere occurs in "substorms", of duration about an hour and separated typically by about 3 hours. If this time scales as the size of the planet, it could become longer than the rotation period. The dawn–dusk electric fields which inject plasma could then be severely reduced due to the rotation of the planet. This would give an "outer radiation belt" or ring current much weaker than for Earth, whereas the inner radiation belt appears from its synchotron radiation to be much stronger than for Earth. Energetic charged particles have drift velocities generally larger than the corotation velocity for Earth, but much smaller for Jupiter. Principal energy sources for Jupiter should be the solar wind, photoelectrons, and that arising from the interaction of the inner satellites with the magnetic field. Further details of this work appear in Brice (1968) and Ioannidis (1970).

Acknowledgments

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