tropic vorticity equation, Eq. 1. Jupiter's axisymmetric zonal flow has been shown to be marginally stable, according to the barotropic stability criterion (*10*). The closed-streamline flows represented in Fig. 1 are also barotropically stable, but the proof of stability depends on the presence of boundaries at $y = \pm L$. The stability question needs to be investigated further.

To summarize, it is possible to formulate a hydrodynamic model of the GRS which is consistent with most observations, and which does not require a special forcing mechanism. The fact that both the zones and the GRS are anticyclonic regions with well-developed clouds is an important part of the model. The difference between the closed-streamline pattern of the GRS and the parallel-streamline pattern of the zones may be simply part of the initial conditions of the system coupled with the extremely long time constant of Jupiter's atmosphere.

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Io-Accelerated Electrons: Predictions for Pioneer 10 and Pioneer 11

Abstract. *Based on a model in which electrons are accelerated to energies of 100 kiloelectron volts through sheaths associated with Io, predictions are made about energetic electrons to be observed by Pioneer 10 and Pioneer 11 in the Jovian magnetosphere. This energetic electron source may be distinguishable from the solar wind diffusion source by the radial flux profile and by the characteristic electron energies.*

The Io sheath model in which electrons can be accelerated to energies of several hundred kiloelectron volts across sheaths in the vicinity of Io was first proposed by Gurnett (*1*). The sheath model requires that Io have a sufficiently good conductivity to act as a unipolar generator. The accelerating potential in this model is the motional electromotive force developed across Io (approximately 670 kv) due to its motion through the Jovian magnetosphere. The sheath model has been developed by Shawhan *et al.* (*2*), Hubbard (*3*), and Hubbard *et al.* (*4*) in order to further understand the detailed character of Io's interaction with the Jovian magnetosphere and atmosphere. Shawhan (*5*) has considered the consequences of 100-kev Io-accelerated electrons for decametric and decimetric radio emissions, x-ray emission, optical emissions, atmospheric ionization, and atmospheric heating. With the encounters of Jupiter by Pioneer 10 in December 1973 and Pioneer 11 about a year later, we wish to make specific predictions based on the Io sheath model which can be tested by experiments on these spacecraft. Also, these predictions may aid in interpreting the experimental results from the Pioneer/Jupiter program.

Sampling the energetic particle environment of Jupiter is one of the primary scientific goals of the Pioneer/Jupiter program, and the results may be used to ascertain the existence and significance of Io-accelerated electrons. Based on the assumptions of the Io sheath model and the expected range of physical parameters in the Jovian magnetosphere, several populations of Io-accelerated electrons are expected (*4*). Descriptions of these populations and their location, flux, and characteristic pitch angles, are given in Table 1. The precipitating electrons originate as photoelectrons from the side of Io facing Jupiter and are accelerated through a Debye sheath to energies up to 600 kev. The pitch angles (α) of these electrons lie well within the Jovian atmospheric loss cone ($\alpha < 3°$). If this beam does precipitate into the Jovian atmosphere, a backscattered population is also expected. If the beam is broken up by an instability along the field line, a significant fraction of backscattered electrons is still expected. Because of the motion of Io and the repelling force of the electric field in the Debye sheath, most of these backscattered electrons do not return to Io and are injected into trapped orbits in the Jovian magnetosphere. Because of the large electric fields and field gradients near the equatorial regions of Io, it is expected that a significant fraction of the photoelectrons emitted from these regions could attain large perpendicular energies. These electrons are also trapped and, with the backscattered electrons, make up a population of trapped electrons which can diffuse inward into the Jovian magnetosphere. It is our prediction that the inward diffusion of these electrons is sufficient to account for the primary energetic electron population in the Jovian radiation belt at $L \sim 2$ (synchrotron emitting region). (The magnetic shell parameter L is equal to R_J, Jupiter radii from the center of the planet, in the equatorial plane; however, the spacecraft frequently departs from the equatorial plane.)

In order to complete the current balance at Io, thermal plasma electrons from the vicinity of the satellite must be accelerated toward its surface. These electrons can attain energies of several hundred kiloelectron volts and are expected to produce intense x-ray emissions from the surface of Io (*5*). The Io sheath model does not treat protons explicitly. If Io has a tenuous atmosphere, then because of current balance conditions, protons and other atmospheric ions may also be accelerated to energies of several hundred kiloelectron volts.

Much consideration has been given to the problem of populating the radiation belts with high energy electrons and possibly protons (*6*). It is generally assumed that solar wind particles enter the Jovian magnetosphere and diffuse radially inward by violation of the third flux adiabatic invariant. This diffusion process may be driven, for example, by neutral wind turbulence at atmospheric altitudes causing fluctuating dynamo electric fields in the magnetosphere (*7*). Through inward diffusion and conservation of the first (magnetic moment) adiabatic invariant these particles gain perpendicular energy and increase in flux. Because the diffusion process is so slow, it may be that a significant fraction of this flux is swept up by the Galilean satellites (*8–10*). Consequently the flux and energy spectrum of the diffusing electrons that can reach the synchrotron emitting region is uncertain. If the sweepup effect is significant, then the solar wind diffusion mechanisms may be insignificant. Mead and Hess (*8*) estimate that the fraction which can survive the sweepup from Io is 10^{-23}. Coroniti (*10*), with a different diffusion model, obtains a fraction of 10^{-1} for Io and 0.75 for Europa. Figure 1 shows the upper limit to the electron flux and the nominal electron profile predicted by the Jupiter Radiation Belt Workshop model for inward diffusion without satellite sweepup (*11*). Also shown are predictions based on an inward diffusion model including the satellite sweepup effects calculated by Coroniti (*10*). (The curve has been scaled to give an electron flux of 2×10^{7} cm^{-2} sec^{-1} at $L = 2$).

Since the flux of electrons accelerated by Io originates from the face toward Jupiter, it is not subject to sweepup effects for inward diffusion. Magnetic moments at Io would range up to 20 Mev $gauss^{-1}$. Because of the increasing magnetic field both the flux and the energy of these electrons would increase for decreasing L values until synchrotron radiation losses became significant.

Considering the Pioneer 10 encounter with Jupiter specifically, the anticipated experimental results can be enumerated. It must be remembered that Pioneer 10 will pass in to 2.83 Jupiter radii (R_J) from the center of the planet, but will not pass through the Io flux tube itself (*12*).

1) Magnetospheric boundary to Io's orbit ($L \gtrsim 6$). Assuming that the magnetospheric boundary occurs at the pressure balance point between the solar wind and the Jovian magnetic field, the boundary would be at about 50 R_J (*13*). At this boundary some solar wind

Table 1. Electrons related to Io (energy $\lesssim$ 600 kev); L, magnetic shell parameter.

Population	Location	Flux	Pitch angle
Precipitating toward Jovian atmosphere	Io flux tube, $L = 6$	10^{7} cm^{-2} sec^{-1} kev^{-1} at atmosphere	$< 3°$ $\sim 0°$
Backscattered from Jovian atmosphere	$L < 6$	$\sim$ 10 percent precipitating flux (?)	$> 3°$
Trapped and diffusing inward toward Jupiter	$L \gtrsim 6$	$> 10^{5}$ cm^{-2} sec^{-1} averaged in time	$> 3°$
Accelerated toward the surface of Io	$L = 6$, localized to Io	10^{8} cm^{-2} sec^{-1}	$\sim 0°$

particles can couple into the magnetosphere and diffuse radially inward (*8–10*). Particles may also enter through the tail region (*10*). Whatever the flux level, it would increase inward, at least to the orbit of Callisto at $L = 26.5$, where the sweepup effect may be important. If it is important, then the flux would decrease abruptly toward lower L values; the same would happen at the orbits of Ganymede ($L = 15$), Europa ($L = 9.4$), and Io ($L = 5.9$). There seems to be general agreement that some decrease in flux, perhaps drastic, would occur at Io (*8–10*). If Io were a significant source of electrons, as predicted by the sheath model, then it would contribute outward diffusing electrons to this region. The fluxes would therefore increase toward lower L values at each of the satellite orbits (see Fig. 1) as seen by Pioneer 10. With both mechanisms operating, either one could dominate or there could be a crossover L value, depending on the sweepup effect. There is some possibility that the other Galilean moons could emit electrons of lower energy and of lower flux.

2) Just inside Io's orbit ($L \sim 6$). As the spacecraft crosses the L shell at Io, there should be a change in the electron characteristics. For the solar wind electrons the flux might decrease by a factor of 10^{-1} to 10^{-23} with decreasing radial distance and become insignificant. For the Io source the flux would increase with decreasing radial distance and the characteristic energy would be limited to the maximum motional potential of Io (about 700 kev). The pitch angle distribution would become more peaked along the magnetic field line.

3) Radiation belts ($L = 6$ to $L \sim 2$). Inside Io's orbit the population consists of inward diffusing solar wind electrons (and protons), Io-accelerated electrons with large pitch angles, and Io-accelerated electrons backscattered from the Jovian atmosphere. As these electrons diffuse inward the flux increases as about $L^{-4.5}$ and the energy increases as about $L^{-1.5}$ (*6*) until the synchrotron losses become insignificant. According to our model, the Io-accelerated electrons would have upper limits of 5 Mev for the energy and approximately 10^{7} cm^{-2} sec^{-1} for the flux (*5*).

Values for the flux and maximum energy (E_{max}) of Io-accelerated electrons are controlled by assumptions

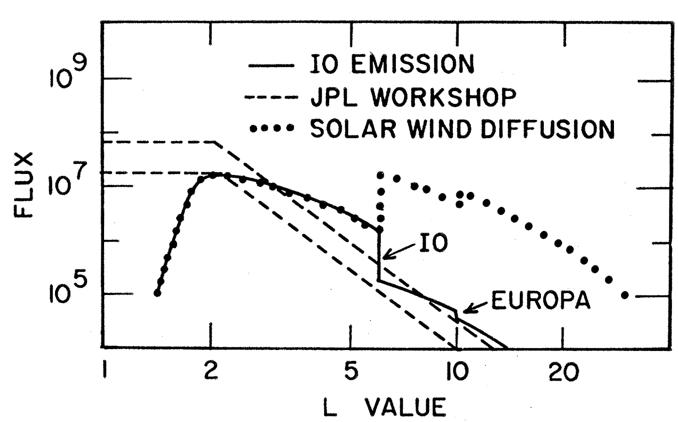

Fig. 1. Sketch of the energetic electron flux (electrons per square centimeter per second) as a function of the magnetic shell parameter L in the Jovian magnetosphere. The solid curve represents our predictions for the Io-accelerated electrons; the dashed curves represent the upper limit and nominal electron profiles from the Jupiter Radiation Belt Workshop model (*6*); and the dotted curve represents a diffusion model for solar wind electrons diffusing inward (*10*). The curves have been normalized to a value of 2×10^{7} cm^{-2} sec^{-1} at $L = 2$. The differences between the Io emission model and the solar wind diffusion model at the orbits of the Galilean moons are due to the possible satellite sweepup effects.

made in the model (*3, 4*). These values could change as more definitive physical measurements are made at Jupiter. The electron energy is limited by the maximum motional potential of Io. The energy scales with the equatorial surface magnetic field B at Jupiter: $E_{max} = (B/7 \text{ gauss}) \times 670$ kev. The fraction of this potential available to accelerate electrons depends on the thermal electron density surrounding Io. A density lower than about 10 cm^{-3} would decrease that potential below 300 kev and a density of 100 cm^{-3} or more would give the maximum potential (for an electron temperature of 10^5 °K). In the model discussed here the emitted flux is limited by the photoelectron emission current density at the surface of Io (3×10^{-7} amp m^{-2}) for a yield function of 0.01 electron per photon. If this yield function is higher, then the flux could be increased. Also, if Io has a significant atmosphere the flux would be controlled by the photoionization rate, which would yield a higher flux. An atmosphere of Io could also provide the conductivity required at Io by this model.

Other consequences of the electrons related to Io which may be observable by the Pioneer spacecraft include optical emissions and atmospheric heating. The ultraviolet photometer has channels to observe Lyman alpha emission and the He line at 584 Å (*14*). Shawhan (*5*) estimates an upper limit to the intensity of 10^3 to 10^4 kilorayleighs at the foot of the Io flux tube covering 10^4 km^2 (10^{-6} of the surface of Jupiter), and this might be observable in the dark atmosphere. Also, the energy from the beam of precipitated electrons that is not lost through other emissions could heat the atmosphere down to the cloud tops. An upper limit to the energy input is 8×10^4 erg cm^{-2} sec^{-1} locally, which exceeds the solar input by an order of magnitude (*5*). Perhaps a resulting hot spot would be observable with the infrared radiometer (*14*) since it has a resolution of about 0.01 R_J.

The Pioneer 10 and Pioneer 11 flybys of Jupiter offer a unique opportunity to test the many theories and models concerning the giant planet and its peculiarities. We make our predictions in this spirit and look forward to the experimental results, which will establish values for many parameters up to now estimated with great uncertainty.

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β_2-Microglobulin: Association with Lymphocyte Receptors

Abstract. *β_2-Microglobulin (β_2m) is a low-molecular-weight protein constituent of lymphocyte membranes. Amino acid sequence analysis has revealed a high degree of homology between the β_2m and certain regions of immunoglobulin molecules, suggesting a possible recognition function for the β_2m, in analogy with the immunoglobulins. The data presented demonstrate that highly specific antiserum against β_2m blocks lymphocyte reactivity against allogeneic cells in mixed leukocyte cultures and against phytohemagglutinin, both of which processes presumably function via a cell surface receptor on thymus-derived (T) lymphocytes. There is very little inhibition of T lymphocyte rosette formation with sheep red blood cells. The findings suggest a possible relation between the β_2m and recognition units on the T lymphocyte surface.*

β_2-Microglobulin (β_2m), a protein whose molecular weight is 11,600 (*1*), is associated with the outer membrane of many cells including lymphocytes (*2*), the main effector cells of the immunological system. The amino acid sequence of β_2m shows striking homology with certain parts of the immunoglobulin polypeptide chains (*3*). Given the importance of the immunoglobulin molecules in recognition processes of the immune system, an evaluation of the possible role of β_2m in this perspective seemed indicated.

We have attempted to evaluate possible receptor functions for β_2m on lymphocytes by studying the ability of highly specific antiserums to β_2m (anti-β_2m) to block recognition by lymphocytes; all studies were performed with rabbit antiserum to human β_2m and human lymphocytes. We have used two assay systems, each involving presumed thymus-derived (T) lymphocytes: (i) lymphocyte proliferation in vitro as measured by either the mixed leukocyte culture (MLC) test (*4*), which is an in vitro model of the recognition phase of the immunological reaction leading to homograft rejection (*5*), or by phytohemagglutinin stimulation; and (ii) rosette formation of lymphocytes with sheep red blood cells (SRBC's) (*6*). In MLC tests, as upon stimulation with antigens to which the donor of the cells is sensitized, specific clones of cells respond, different clones responding to different antigens (*7*). Phytohemagglutinin is considered a nonspecific stimulant; that is, there is no such clonal response. Similarly, SRBC rosettes in man are thought to be formed by all T cells.

Antiserums directed at cell surface components have been used in a variety of studies aimed at understanding lymphocyte cell surface topography (*8*) or the biological role of membrane components (*9*). Antibodies bind to the exposed membrane antigen against which they are directed and in addition can sterically block other very closely juxtaposed membrane components. Such binding could prevent both these structures from reacting with other antiserums, and possibly interfere with their biological function.

Our results show that antiserum to β_2m inhibits MLC reactivity, as well as the reactivity of lymphocytes to other mitogens, but does not interfere to the same extent with SRBC rosette formation.

Antiserum to human β_2m was pro-