The radial dependence of this proton flux at the magnetic equator is about L^{-9} for $10 \geqq L \geqq 5$.

The drop-off in the proton flux inside $L \simeq 3.6$ is not understood, but it may be the result of either a flux-limiting instability such as the ion-cyclotron instability or absorption by the satellite Amalthea, whose orbital radius is 2.55 R_J. Absorption by the Galilean satellites appears not to have been as effective as thought possible (*6*) for particles of the energies we are discussing here. Only the effect of Io appears in our data, as shown in Fig. 4.

From the foregoing results it is clear that only in the central region of the Jovian magnetic field ($R \lesssim 20$ R_J) does the radiation behave in a manner which is similar to that at the earth. In the region beyond 20 R_J extending to the magnetopause boundary both electrons and protons are highly concentrated near the magnetic equator, especially on the dawn side. For the region between 30 R_J and the magnetopause both the observed magnetic field (*4*) and the early models for the field which incorporate the effects of a strong equatorial plasma flow (*7*) are qualitatively consistent with our particle observations. In future publications we will report detailed studies of fluxes, spectra, and relative abundances of protons, electrons, and helium nuclei to test further the validity of these ideas.

Although the radiation levels encountered were near the design maximum, our instrument survived the exposure and remains in operation.

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21 December 1973

Energetic Electrons in the Magnetosphere of Jupiter

Abstract. *Observations of energetic electrons ($\gtrsim$ 0.07 million electron volts) show that the outer magnetosphere of Jupiter consists of a thin disklike, quasi-trapping region extending from about 20 to 100 planetary radii* (R_J). *This magnetodisk is confined to the vicinity of the magnetic equatorial plane and appears to be an approximate figure of revolution about the magnetic axis of the planet. Hard trapping is observed within a radial distance of about 20* R_J. *The omnidirectional intensity* J_0 *of electrons with energy $\gtrsim$ 21 million electron volts within the region* $3 < r < 20$ R_J *is given by the following provisional expression in terms of radial distance* r *and magnetic latitude* θ: $J_0 = 2.1 \times 10^8 \exp[-(r/a) - (\theta/b)^2]$. *In this expression* J_0 *is particles per square centimeter per second*; $a = 1.52$ R_J *for* $3 \leqq r \leqq 20$ R_J; *and* $b = 15°$ *for* $3 \leqq r \leqq 10$ R_J, *diminishing gradually for larger* r. *There is tentative evidence for mild effects of the Galilean satellite Europa and possibly Io and Ganymede but not Callisto.*

This is a preliminary report of in situ observations of energetic electrons in the magnetosphere of Jupiter during the Pioneer 10 encounter 26 November to 11 December 1973. The University of Iowa experiment comprises seven miniature Geiger-Müller tubes in various physical arrangements and with various levels of shielding such as to respond to electrons in several energy ranges from 70 kev to tens of million electron volts and protons in several energy ranges from 700 kev to tens of million electron volts. No one of the individual detectors distinguishes uniquely between protons or electrons as causing its response. A full analysis of the relative responses of the entire array of detectors will provide separate energy spectra of electrons and protons by using laboratory-determined unit response functions and an identification matrix. Overall calibrations were provided by observations during the outbound pass of Pioneer 10 through the magnetosphere of the earth on 3 March 1972 and during several solar energetic particle events, especially those of July and August 1972.

Data reported herein refer only to energetic electrons. The particle identification is based on a simplified version of the above analysis and on auxiliary information provided by other Pioneer 10 experimenters which shows negligible contributions by protons to the responses of several of the detectors in our experiment.

The counting rates of all of our detectors rose discontinuously from their

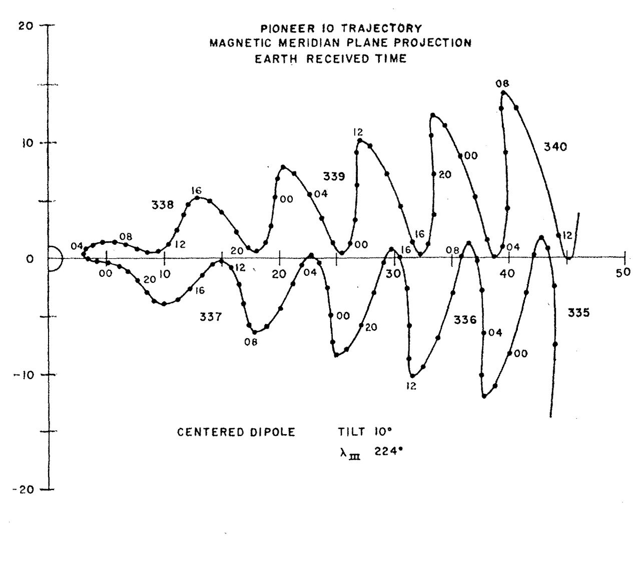
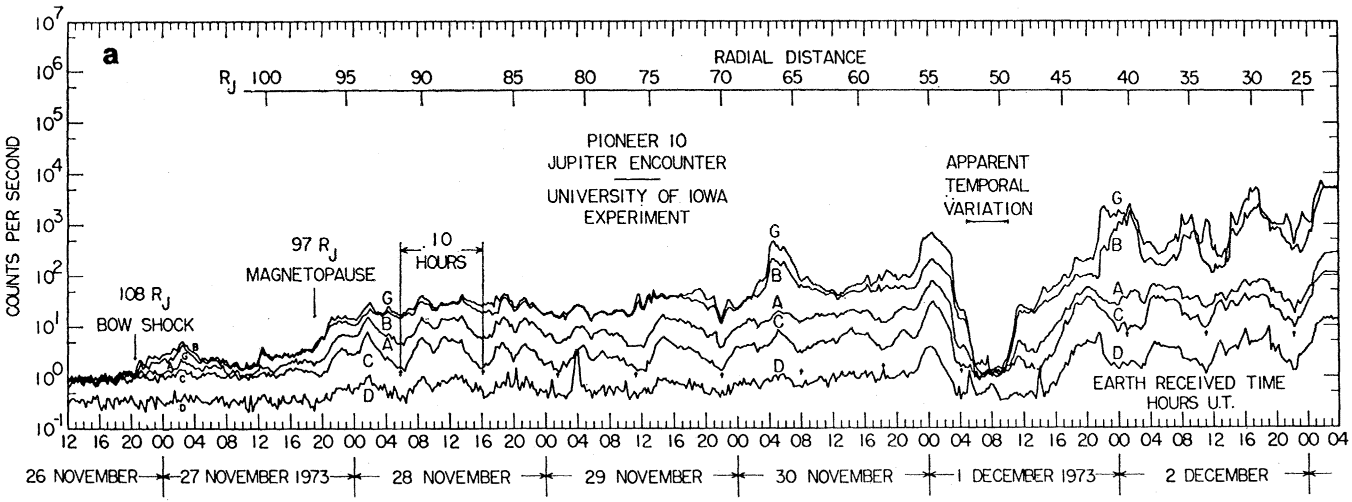


Fig. 1. Projection of the encounter trajectory of Pioneer 10 on a magnetic meridian plane of Jupiter for an assumed centered magnetic dipole having a tilt of 10° to the axis of figure with its pole at system III longitude λ_{III} = 224°. The local time of the asymptote to the inbound hyperbolic trajectory is about 10 hours and of the asymptote to the outbound trajectory, about 5 hours.

interplanetary rates at 2030 U.T. (earth received time of the telemetric signal) on 26 November 1973 (Fig. 2a). The radial distance r of the spacecraft from the center of Jupiter at the correspondingly earlier "spacecraft time" was 108 R_J, with R_J taken to be the equatorial radius of the planet, 71,880 km according to Hubbard and Van Flandern (*1*); and the Sun-Jupiter-probe angle (SJP) was 36°, approximately in the ecliptic plane. This event was identified as a weak bow shock by magnetometer and plasma analyzer experimenters. After about 1 day of low and irregular counting rates, a second and more marked increase in all counting rates began at 1900 U.T. on 27 November, in approximate coincidence with the disappearance of directed flow of plasma as characteristic of a mag-



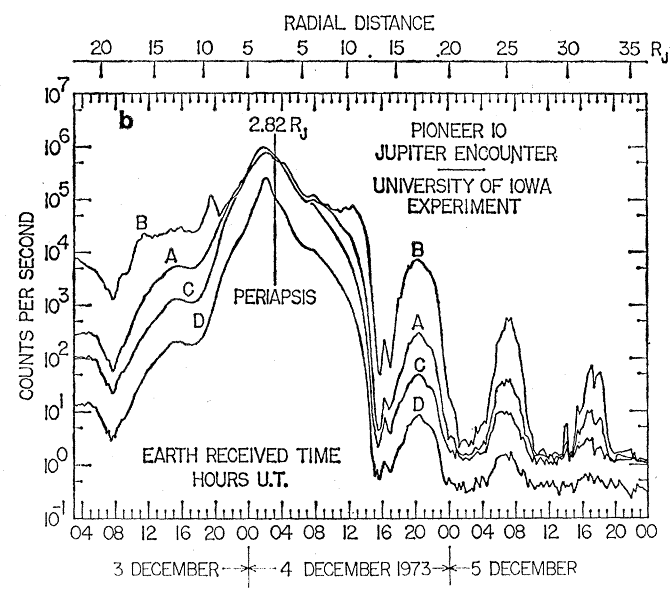
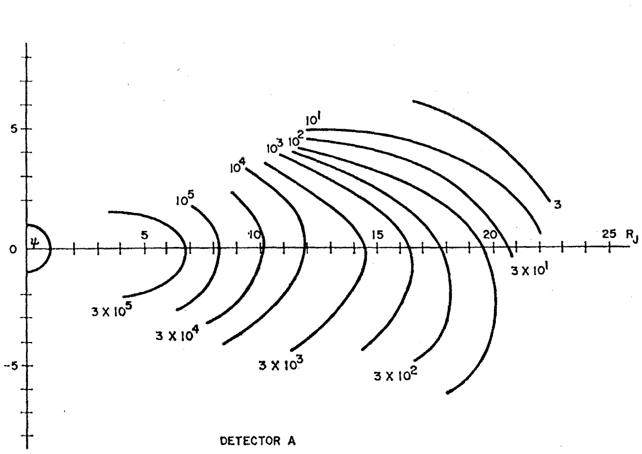


Fig. 2. (a) Observations during the inbound portion of the encounter with Jupiter. (b) Observations during the central and outbound portions of the encounter with Jupiter. Letters *B, A, C,* and *D* designate Geiger-Müller tubes having increasing physical shielding in the order given; *G* designates a Geiger-Müller tube arranged in "scatter geometry." All counting rates have been corrected for dead time.



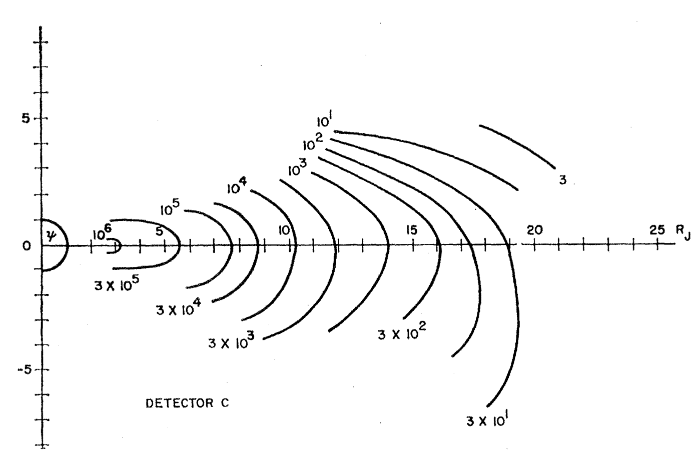


Fig. 3 (left). Provisional iso-counting rate contours for detector A in a magnetic meridian plane, based on Figs. 1 and 2b. Other assumptions as to the location and tilt of the dipole may eliminate the skewness of contours at the larger radii. Fig. 4 (right). Similar to Fig. 3 for detector C.

netopause crossing ($r = 97\ R_J$ and SJP = 35°). Thereafter, until a radial distance of $r \approx 52\ R_J$ there was a regular periodic variation of all rates, with a period of 10.0 ± 0.5 hours. This period is identified with the planet's system III rotational period of 9.9249 hours. The well-defined minima are consistent with decimetric radio astronomical determinations of a dipolar tilt of 10° with pole at system III longitude $\lambda_{III} = 224°$ (Fig. 1). A more refined study is in progress. The regular pattern was disrupted by an apparent temporal variation between 0445 and 1030 U.T. on 1 December, during which all counting rates dropped to their magnetosheath values. Thereafter, the periodic pattern, with some significant differences in detail, resumed.

Beginning at about 0800 U.T. on 3 December ($r = 19\ R_J$), all counting rates began a strong upward climb of several orders of magnitude and reached their greatest values at 0210 U.T. on 4 December. The periapsis of the hyperbolic encounter trajectory occurred at 0315 U.T., about an hour later (Fig. 1) ($r = 2.82\ R_J$). The rates then declined to a strong minimum at 1545 U.T. ($r = 13.4\ R_J$) (Fig. 2b). Then the periodic pattern of variation of counting rates (see Fig. 1) resumed with broader minima and flatter maxima than on the inbound leg of the trajectory and with the previously observed 10-hour periodicity. This pattern was still being observed through 8 December ($r = 65\ R_J$ and SJP = 102°).

Preliminary iso-counting rate contours in a magnetic meridian plane are given in Figs. 3 and 4. Approximate expressions for the counting rates of detectors A and C as a function of radial distance r and magnetic latitude θ are of the form

$$R = k\exp[-(r/a) - (\theta/b)^2] \qquad (1)$$

For detector A, $k = 2.0 \times 10^7$ and $a = 1.62\ R_J$ for $6 \leq r \leq 20\ R_J$; b declines from 20° at 7 R_J to 10° at 20 R_J. The unidirectional intensity in particles per square centimeter per second per steradian for electrons of energy $E_e > 8$ Mev is found by multiplying the rate of detector A by 100.

For detector C, $k = 1.0 \times 10^7$ and $a = 1.52\ R_J$ for $3 \leq r \leq 20\ R_J$; b declines from 16° at 3 R_J to 10° at 20 R_J. The omnidirectional intensity in particles per square centimeter per second for electrons with $E_e > 21$ Mev is found by multiplying the rate of detector C by 21.

On the basis of data from both inbound and outbound legs of the trajectory, it appears that energetic electrons in the outer magnetosphere of Jupiter are confined to a thin disklike region in the vicinity of the magnetic equatorial plane with approximate rotational symmetry about the magnetic axis. As the planet rotates the disk wobbles up and down across the spacecraft (Fig. 1) with a 10-hour period. This "magnetodisk" is interpreted as a region having a greatly distended magnetic field, a physical situation most clearly foreseen by Piddington (*2*). There is an analogous region in the earth's magnetosphere but only on its night side (*3*). The enormously greater centripetal force required of the magnetic field at Jupiter to confine thermal plasma is presumably responsible for wrapping the quasi-trapping region entirely around the planet as envisioned by Piddington.

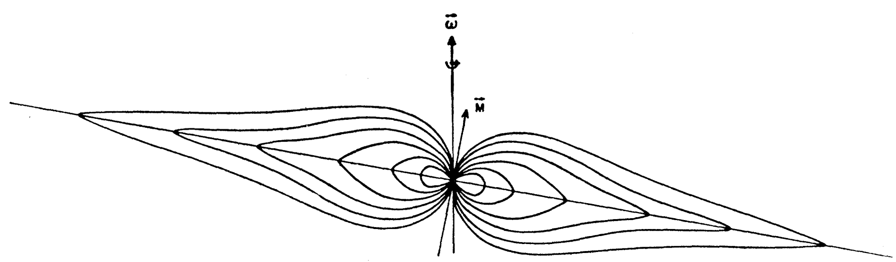


Fig. 5. Disk model of Jupiter's magnetosphere. Schematic diagram showing the hard trapping region within about 20 R_J and the magnetodisk region of quasi-trapping extending outward to approximately 100 R_J. Data on inbound and outbound legs of the trajectory at local times differing by 5 hours suggest approximate rotational symmetry about the magnetic axis *M*. A variation of this model is one (suggested by Axford) in which the outer part of the disk is envisioned as moving up and down parallel to itself rather than wobbling as a rigid disk as the planet rotates.

The more familiar hard trapping region extends out to approximately 20 R_J. Energetic electrons are confined rather closely to the equatorial plane as given by Eq. 1 and the associated values of k, a, and b. Figure 5 is a schematic representation of the foregoing.

A distinct dip in the counting rates of the lower energy detectors was observed as the spacecraft crossed the magnetic shell through the orbit of Europa on the inbound leg of the trajectory. There are much less well defined and highly tentative signatures at the crossings of the orbits of Ganymede and Io on the inbound leg and of Io, Europa, and Ganymede on the outbound leg (*4*).

There was no apparent degradation of the University of Iowa experiment throughout the encounter.

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Energetic Particle Population in the Jovian Magnetosphere: A Preliminary Note

This is a preliminary account of the Jovian encounter as viewed by the Pioneer 10 particle detector systems of Goddard Space Flight Center and the University of New Hampshire. The systems were designed to measure the charge, energy, and angular distribution of galactic and solar cosmic rays as well as the energetic particles in the Jovian magnetosphere. In the outer Jovian magnetosphere, the two cosmic ray detector systems provided excellent data on high energy protons and electrons, as well as measuring energetic helium nuclei. A third detector system, especially designed for high intensity fluxes,