Table 1. Combining these results we can obtain a weighted mean of $0.029 \pm 0.014\ \text{cm}^{-3}$.

There is no strong evidence to suggest any inhomogeneity in the electron distribution, as the individual estimates of the electron density are all substantially in accord with the mean value of about $0.03\ \text{cm}^{-3}$ when their errors are taken into consideration.

This value for the mean electron density is derived essentially from those pulsars within about 500 pc of the Sun (that is, dispersion measures $<15\ \text{pc cm}^{-3}$) since the estimates of n_e for the more distant objects all have large errors and therefore carry little weight in the formation of the mean. This value of the mean electron density is consistent with estimates over much larger distances in the Galaxy and indicates that the Sun does not lie in a region which is particularly rich or poor in interstellar plasma. The estimates of the local space density of pulsars made by Taylor and Manchester[5] and by Davies, Lyne and Seiradakis[2] were based on assumed mean electron densities of 0.03 and $0.025\ \text{cm}^{-3}$ respectively. As the most numerous pulsars in the Galaxy have a very low luminosity, we observe them only within a few hundred parsecs of the Sun. To estimate the local space density of pulsars reliably, it is important to have a good estimate of the local mean electron density near the Sun, or better still a direct measure of distance. It seems therefore that their estimates of the pulsar space density will not be seriously in error due to this assumption and that the rather high pulsar birth rates of between 1 every 4 and 1 every 15 yr required to sustain the derived galactic pulsar population are accordingly still justified. More precise measurements are in progress and will help to determine whether supernovae occur often enough to be the sole birth places of pulsars.

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On the Pioneer 11 observation of the ring of Jupiter

SHORTLY before closest approach to Jupiter, the imaging experiment on board Voyager 1 detected a ring of particulate matter around the planet as the spacecraft crossed the equatorial plane of Jupiter. The radial position of the ring is at approximately $1.7R_J$ (jovian radii), the total ring thickness is reported to be $\leqslant 30$ km and the radial extent $\leqslant 10^4$ km (refs 1, 2). Although this discovery was rather unexpected, the possible existence of a dust belt within the orbit of the innermost satellite, Amalthea, actually had been suspected as a result of the Pioneer 11 measurement of the jovian trapped radiation belt[3,4]. In this note we briefly outline this interesting observation and evaluate some of the basic properties of this newly discovered ring.

During the Pioneer 11 flyby of Jupiter in December 1974, the minimum distance of the spacecraft to the centre of the planet was as small as $1.6R_J$ and hence the intensity variations of the trapped radiation belt charged particles between the outer magnetosphere and the region around $1.6R_J$ were sampled by energetic particle detectors. As in the earlier Pioneer 10 encounter, absorption structures near the orbits of Ganymede ($L = 15.0$), Europa ($L = 9.4$) and Io ($L = 5.9$) were found in the particle fluxes in certain energy channels[3,5–7]. Sometimes the intensity dropped by a factor of 10 in the vicinity of the satellite sweeping corridors. Because of its closer encounter distance, Pioneer 11 enabled a survey to be made of the jovian radiation belt near Amalthea. As well as two absorption features apparently related to Amalthea there are two minima at $L \approx 1.6$ and 1.7 not accounted for by any known satellite[3]. On one hand, such minima may be simply caused by the anamolous precipitation of the mirroring charged particles into the planetary upper atmosphere at this radial distance as a result of the large quadrupole moment of the jovian magnetic field[4,8]. On the other hand, the absorption effect of a small satellite or a ring of dust particles can also produce just such structure in the intensity variations of the charged particles[3,4]. It has been noted, in any case, that even with the anomalous precipitation effect operating in reducing the particle fluxes near the minima in question some particulate matter may still exist and help to sweep up the charged particles in this region[9]. In the light of the Voyager 1 discovery, it seems appropriate to reconsider the Pioneer 11 data in terms of the dust belt interpretation. Because the distances of closest approach to Jupiter for both Voyager spacecraft are more than $4.9R_J$, no information can be obtained for the trapped radiation belt in the vicinity of the ring. This certainly makes the measurements of Pioneer 11 even more interesting. In this letter, we make some estimates (in a manner essentially similar to the treatment discussed by Van Allen[10] for the saturnian rings) of the optical thickness of the ring, number density, as well as the average size of the ring particles. Only proton ($E \geq 80$ MeV) data from the UCSD Trapped Radiation Detector instrument described by Fillius[3] will be used in the present discussion. This calculation, together with the Voyager 1 imaging result, should provide preliminary information on the new ring of Jupiter.

The satellite absorption effect is determined by two basic factors[11–13]: (1) the effective absorption cross-section of the satellite, and (2) the time scale for the charged particles to diffuse across the sweeping corridor of the satellite. Furthermore, the absorption process will be affected by the drift frequency and pitch angle of the particle motion in the dipole field of the planet. If, for a certain kinetic energy, the drift frequency is comparable to the frequency of the relative motion between the satellite and the co-rotating magnetosphere and the two motions are in opposite directions, the resulting 'resonance' would tend to suppress the satellite absorption effect. At the same time, because of the 10° tilt of the magnetic dipole moment with respect to the rotation axis of the planet, mirroring charged particles with equatorial pitch angle larger than 70° would be able to diffuse past the satellite more easily without being absorbed[11]. In the case of absorption of charged particles by a ring of particulate matter, the pitch angle effect might still be important in determining the degree of absorption; but the drift frequency should not influence the particle absorption since the ring particles are presumably distributed uniformly along the whole orbit. The only energy-dependent factor then would be the stopping range of the charged particles, that is the integrated mass intercepted by the charged particles as they diffuse across the ring plane. For 100-MeV protons, the stopping range is typically a few grammes for matter of various composition (ice, aluminium and so on). Hence, if most of the ring particles have sizes of >1 cm, just one pass would be enough to absorb the impacting proton; and the survival probability of the energetic protons as they diffuse inward past the ring can be written as

$$P = \exp(-2N_b\tau_\perp) \qquad (1)$$

where N_b is the total number of bounces executed by the mirroring protons and $\tau_\perp$ is the optical thickness in the direction perpendicular to the ring plane. The value of $\tau_\perp$ is related to the number density and average diameter (d) of the ring particles, and the thickness of the ring place ($l_\perp$) by the following expression,

$$\tau_\perp = \pi n d^2 l_\perp / 4 \qquad (2)$$

The value of N_b can be approximated by taking the ratio of the pertinent diffusion time scale t_d to the bounce period t_b of the

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100-MeV protons. In the Pioneer measurements, the radial diffusion coefficient (D) for 100-MeV proton is estimated to be $\approx 10^{-6}\ \mathrm{s}^{-1}$ at the orbit of Io ($L = 5.9$) and $10^{-8}\ \mathrm{s}^{-1}$ at the orbit of Amalthea ($L = 2.6$) (see ref. 12). If D is proportional to L^3 or L^4 the corresponding value at $L \approx 1.7$ is $\approx 7 \times 10^{-9}\ \mathrm{s}^{-1}$. Now, according to the preliminary report[1,2], the total radial extent of the ring is $\gtrsim 9 \times 10^3$ km ($\Delta L \gtrsim 0.1$). At the same time, an upper limit for ΔL of about 0.16 can be set from the Pioneer data[3]. The diffusion time scale can then be approximated as[14]:

$$t_d = \Delta L^2/4D \qquad (3)$$

with $\Delta L \approx 0.1$.

Therefore $t_d \approx 3.6 \times 10^5$ s. The bounce period of mirroring charged particles is given by[15]

$$t_b \approx 5.2 r_0/V \qquad (4)$$

where r_0 is the equatorial radial position of the mirroring charged particle and V its velocity. For $r_0 = 1.7R_J$ and $V = 1.2 \times 10^{10}\ \mathrm{cm\ s}^{-1}$ we have $t_b \approx 5.2$ s; and hence $N_b \approx 7 \times 10^4$. Judging from the depth of the minima in the proton intensity as measured by the UCSD experiment we can put $P = 0.1$ (that is, the flux is reduced by a factor of 10 across the absorption structure). From this we can immediately obtain $N_b \tau_\perp \approx 2.3$ and therefore $\tau_\perp = 6.2 \times 10^{-6}$ for the absorbing particles. Such a small optical thickness may be compared with $\tau_\perp \approx 1$ for the B ring of Saturn[16] and a value between 10^{-7} and 10^{-2} for the D′ ring suspected to exist beyond the outer edge of the A ring[17,18]. [The result that the $\tau_\perp$ value of the ring of Jupiter should be a factor of 6×10^{-6} smaller than that of the saturnian B ring is in good agreement with the most recent IR detection of Jupiter's ring[19]. In this observation it is concluded that the number of particles in Jupiter's ring should be of the order of 10^5 less than that in Saturn's if both ring systems have similar kinds of particles and the viewing geometries are about the same.]

If the ring plane thickness $l_\perp$ is known we can derive the product nd^2 using equation (2). No exact value of $l_\perp$ is yet known—only that it is less than 30 km (refs 1, 2). Considering a thickness of ~1 km estimated for the saturnian rings[20] it may be reasonable to adopt $l_\perp \approx 1$ km for the ring of Jupiter as a working number. The actual thickness is not likely to be larger or smaller by a factor of 10. Substitution of this value into equation (2) gives $nd^2 \approx 8 \times 10^{-11}\ \mathrm{cm}^{-1}$; that is

$$n \approx 8 \times 10^{-11}/d^2\ \mathrm{cm}^3 \qquad (5)$$

With the total volume of the ring given as $U = 2\pi r_0 \Delta r l_\perp$ (thus $U \approx 6 \times 10^{24}\ \mathrm{cm}^3$ if $r_0 = 1.7R_J$, $\Delta r = 0.1R_J$ and $l_\perp = 1$ km) and the density of the ring particles is $2\ \mathrm{g\ cm}^{-3}$, the total mass of the ring can be expressed as

$$M \approx 5 \times 10^{14} d \text{ grammes} \qquad (6)$$

Thus $n \approx 8 \times 10^{-11}\ \mathrm{cm}^{-3}$ and $M \approx 5 \times 10^{14}$ g if $d \approx 1$ cm, and $n \approx 8 \times 10^{-21}\ \mathrm{cm}^{-3}$ and $M \approx 5 \times 10^{19}$ g if $d \approx 1$ km.

From simple geometrical considerations we find the maximum optical path ($l_\parallel$) along the ring plane as it is observed edge-on to be about $1.1R_J$, therefore the corresponding optical thickness ($\tau_\parallel$) can be approximated as $\tau_\perp \times (l_\parallel/l_\perp)$, and this gives $\tau_\parallel \approx 0.5$. If the ring particles have a certain size distribution, the bodies with diameter much less than 1 cm may contribute significantly to a total light reflecting area ($A \approx 6 \times 10^{14}\ \mathrm{cm}^2$ if $\tau_\perp \approx 6 \times 10^{-6}$) even though their absorption power is rather limited (since most of the mass is likely to be concentrated in the large particles). In this manner, the effective optical thickness may be increased by one or two orders of magnitude—but probably not by a factor much larger—considering the absence of the ring from ground-based observations in the past. If we argue that the ring particles are as old as the Solar System, their size must be large enough to resist orbit decay caused by the Poynting–Robertson effect. Following the similar treatment for the saturnian ring particles[21], the minimum diameter can be estimated to be ≈ 1 m, at least, for particles carrying most of the mass. A determination of the size distribution could possibly be achieved by analysing the absorption effect on electrons and protons of different energies (since they have different stopping ranges). Before this is attempted, little can be said.

In this connection, we would like to mention that detailed examination of the Pioneer 11 data with a small time resolution may also provide vital information on the radial structure of the ring. For example, the radial distance of the 2:1 two-body resonance with Amalthea is $1.61R_J$. It would be interesting to see if there is energetic particle signature along the magnetic flux tube in this vicinity indicating the existence of a gap reminiscent of the Cassini's division in the saturnin rings. Or, the orbital resonance may actually define the mass concentration of the ring as previously suggested for the narrow rings of Uranus (but for a different type of orbital resonances) (see refs 22–24). The Pioneer 11 energetic charged particle data might then provide information on the dynamical models of ring formation as well.

Thus, based on the Pioneer 11 UCSD proton ($E \geq 80$ MeV) measurement of the absorption structures in the vicinity of the ring of Jupiter, the optical thickness of the absorbing ring particles in the direction perpendicular to the ring plane is estimated to be about 6×10^{-6}, and the corresponding value as the ring is seen edge-on is approximately 0.5. If the ring is as old as the Solar System, most of the mass should be concentrated in particles with diameter larger than 1 m and the total mass of the ring would be larger than 5×10^{16} g. Comparison with the Voyager imaging data may narrow down the uncertainty. But only further analysis of the energetic charged particle data can give us more insight about the size distribution and radial structure of the ring.

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Compositional differences between Arctic aerosol and snow

UNIQUE information on trace elements in polar atmospheres is available through records of deposition in snow and ice. Proper interpretation of these data requires a knowledge of the nontrivial chemical relationship between the deposition and its parent aerosol. Because several complex processes determine the trace-element content of precipitation, polar ice and snow cannot be considered *a priori* to have the same composition as polar aerosol[1]. In most of the current literature, such an assumption is usually made. Within the past year or so, the first tests of the long-term relationship between aerosol and deposition have been (inadvertently) produced for the Antarctic and