Planet Space. Sci. Pergamon Press 1959. Vol. 1, pp. 343–346. Printed in Great Britain.

IONIZING RADIATION DETECTED BY PIONEER II

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(*Received* 14 *May* 1959)

Abstract—The total ionizing component of cosmic radiation was measured up to an altitude of 1550 km. An upper bound to the ratio of average-to-minimum specific ionization was determined by comparing the ionization with the count-rate observations from the Explorer IV satellite. This result implied that protons are the predominant species which gave rise to the observed ionization.

Pioneer II was launched from Cape Canaveral, Florida, on November 7, 1958, and attained a maximum altitude of 1550 km. The payload contained an ionization chamber to measure the total ionizing component of cosmic radiation flux[1]. Ion chamber data were received during the first half hour of flight. The measured radiation levels are plotted versus altitude (see Fig. 1). The declination and longitude of the vehicle's position are given for each data point. Reportedly, the level of solar activity was low during the flight and unusual magnetic and corpuscular disturbances were absent. However, solar activity was moderate a few days prior to the flight.

The ionization chamber consisted of an aluminium-walled vessel, filled with spectroscopically pure argon to a pressure of 13·6 atm. The volume of the chamber was 43 cm^3 and the areal density of the cylindrical walls was 400 mg/cm^2. The ends of the cylinder were slightly thicker in order to attain the necessary structural strength. The areal density of the ends was 1200 mg/cm^2. The shell of the vehicle accounted for another 50 mg/cm^2 of shielding so that the minimum areal density traversed by a particle before reaching the sensitive volume of the chamber was 450 mg/cm^2. The solid angle subtended by the 1200 mg/cm^2 ends of the cylinder was 1 steradian. An additional amount of shielding due to the presence of a miscellany of electronic components, structure, and a retrorocket accounted for a solid angle of 1·5 steradians. For this solid

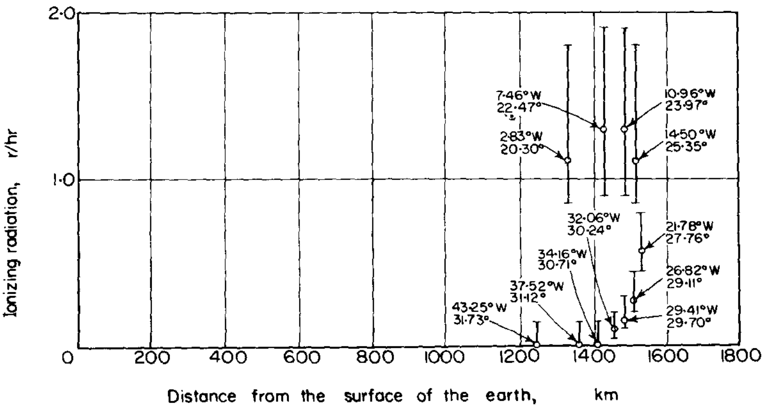

Fig. 1. Pioneer II. Ionizing radiation versus altitude including longitude and north latitude.

angle the shielding corresponded to an average areal density of 20 gm/cm^2.

The electronics was basically a design utilized for the CsI scintillation count-rate meter in Explorer IV[2]. A d.c. electrometer amplifier, with a range of 1000 r/hr, drove a subcarrier oscillator which, in turn, modulated the transmitter. Since the circuit was temperature dependent, in-flight calibration was provided by the substitution of a known voltage for the ionization chamber output. The duty cycle consisted of 180 sec of ionization chamber data followed by 20 sec of calibration voltage. With this calibration voltage on the input, the subcarrier frequency varied with the temperature of the circuit. Thus, by measuring the subcarrier frequency of the calibration signal, the effective temperature of the circuit could be determined.

Calibration of the ion chamber, itself, was accomplished by utilizing a Co^{60} source located at the Radiology Department of the UCLA Medical Center. Several sources of error were considered in determining the range of error to be assigned to each data point. Some of these sources lay in the drift and nonlinearity of the subcarrier oscillator in the vehicle, the demodulating equipment on the ground and the recording apparatus. The asymmetry of the error flags is due to the fact that the output was, approximately, a logarithmic function of the radiation level. This relationship was used so that the instrument would have a comparatively large dynamic range.

The significance of the information on ionizing radiation which was gathered during the brief life of Pioneer II lies in the fact that it clearly indicates an increase of such radiation with decreasing north latitude. At the apogee of the orbit, in the altitude range of 1500 to 1550 km, the vehicle traversed 7° of latitude. Thus for an essentially constant altitude, the variation of ionization with latitude was observed. Fig. 2 shows the variation of ionization with latitude when the chamber was located at 1525 ± 25 km, altitude.

Further, it is possible to obtain a bound for the average specific ionization of the observed radiation at this altitude by combining the results of this experiment with those of other satellites. Such correlations generally involve special consideration relating to the possibility

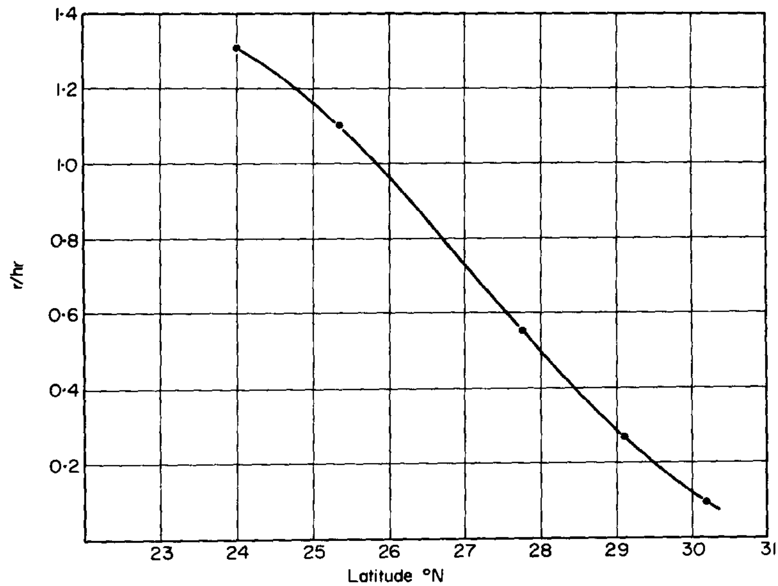

Fig. 2. Pioneer II. Ioniziation versus latitude at an altitude of 1525 ± 25km.

of temporal variation of the intensity in the interval between the two measurements, differences in the positions of the two experiments and differences in the shielding of the detectors. The earth satellite, Explorer IV, was well suited for such a correlation because it was in orbit at the same time that ionization data was gathered, and it traversed the same region of space as Pioneer II. A partial summary of the data gathered by instruments on the Explorer IV satellite has been presented by van Allen[(2)]. The counting rates from two Geiger tubes were used to determine the contours of equal counting rates. One tube was shielded by a minimum of 1·2 gm/cm² for certain directions and a maximum of 5·0 gm/cm² for other directions. The counting rate reported for this tube at an altitude of 1550 km, 20° N geomagnetic latitude, and 80° W geographic longitude was 1200 count/sec.*

In using these data for a determination of average specific ionization, differences in the positions of the two vehicles were considered. At the altitude of 1550 km, the coordinates of Pioneer differed from the Explorer in longitude only, and consideration of the trapping mechanism indicates that the counting rates are almost independent of geomagnetic longitudes but are strongly dependent on geomagnetic latitudes. Thus, it was expected that 1200 c/s would be the count rate reported in the Explorer satellite when its position was the same as the position of Pioneer. Verification of this expectation was obtained by a cursory check of some of the unreduced tapes of Explorer IV. This check revealed that the count rate was between 1000 and 2000 counts/sec† and further substantiates the fact that the counting rates are strongly dependent on geometric latitudes alone.

The minimum shielding around the ionization chamber was 450 mg/cm². Since the minimum shielding around the Geiger tube was 1·2 gm/cm², it was possible for low-energy particles to penetrate the ionization chamber without triggering the Geiger tube. This led to an upper bound of 5 for the ratio of average-to-minimum specific ionization.

In order to arrive at this value, the average specific ionization σ was determined by use of $\sigma = I/J_0$* where J_0 is the total number of particles crossing a sphere of unit cross sectional area, and I is the ionization within the sphere[(3)].

The upper bound of σ occurred for the maximum value of I and the minimum value of J_0. These variables would become extreme values if all the radiation was sufficiently hard to penetrate 5 gm/cm² shielding, but not hard enough to penetrate 20 gm/cm² shielding. In this case, the omnidirectional geometrical factor was 0·705 cm² and, assuming an efficiency of 85 per cent for detection of the radiation, the omnidirectional intensity[(2)]

$$J_0 = 1200/0{\cdot}85 \times 0{\cdot}705 = 2000 \text{ c/s}.$$

Maximum value of I was obtained by observing that 12 per cent of 4π solid angle was completely shielded from radiation. Increasing the maximum value of I by 12 per cent yields 1·45 r/hr. Thus,

$$\frac{I}{I_m} = 6{\cdot}86 \times 10^3 \frac{1{\cdot}45}{2000} = 4{\cdot}97.$$

It is interesting to note that this value of specific ionization implies that β (the ratio of the velocity of the particles to the velocity of light) of the particles responsible for the ionization is approximately 0·45. Such a low value for β excludes the singly-charged small-mass particles as the predominant species which gave rise to the observed ionization, because these particles would not have sufficient energy to penetrate the walls of the ionization chamber at its minimal areal density. For example, an electron with a β ratio of 0·45 has less than 80 keV kinetic energy. Thus it is more likely that

* Geomagnetic coordinates were determined from the 1955 *Dip Equator*, U.S. Navy Hydrographic Office.

† C. E. McIlwain, verbal communication.

* This formula may be related to roentgen per hour by noting that 1 r/hr $= 5{\cdot}8 \times 10^5$ ion pair/sec cm³ air STP, and that for a sphere of unit cross sectional area (vol $= 0{\cdot}77$ cm³) $I = 0{\cdot}77 \times 5{\cdot}8 \times 10^5$ r. Thus, $\sigma/\sigma_m = 6{\cdot}86 \times 10^3$ r$/J_0$, where J_0 has units of count/cm² sec, and σ_m, the minimum specific ionization in air, is taken as 65 ion pair/cm air STP.

the more massive particles, probably protons with an average energy of 120 MeV, are the predominant species which gave rise to the observed ionization.

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