Radiation Belt-Results of the Direct Measurements of Interplanetary Plasma and Magnetic Field by Explorer X

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It is not yet clear whether the conditions recorded by Explorer X beyond 22 earth radii were typical of interplanetary space or whether they were still affected by the earth's magnetic field. If the former assumption is correct, the observations of Explorer X indicate that the interplanetary plasma is divided into regions of two different types with linear dimensions of the order of 10^{11} cm, separated by sharp boundaries.

In the regions of the first type the magnetometer records a fairly regular magnetic field, with a strength of the order of about 20γ: the plasma probe does not give any detectable signal.

In the regions of the second type, the magnetometer records a magnetic field, irregular both in magnitude and in direction, with an average strength about half as large as that found in the regions of the first type. The plasma probe records a flux of protons of the order of 4×10^8 particles$\cdot$cm^{-2} sec^{-1}. The protons are distributed over a rather wide spectrum, peaked at about 500 ev. They appear to come from the direction of the sun, with a possible angular spread not greater than about $\pm25°$.

One may try to fill at least tentatively the gaps in the picture provided by the still crude experimental results with the following arguments.

(1) It appears reasonable to assume that in both regions the plasma moves with approximately the same velocity. From the mean energy of the protons found in regions of the second type, we find that this velocity is about 3×10^7 cm$\cdot$sec^{-1}. Since the probe was capable of recording protons with velocities up to about 10^8 cm$\cdot$sec^{-1}, we conclude that the lack of a signal in the regions of the first type is not due to the fact that the proton velocity is too high, but to the fact that their density is too low. From the sensitivity of the probe, we obtain an upper limit of about 0.2 cm^{-3} for the proton density in these regions.

(2) The energy spread of the protons observed in the regions of the second type indicates that, in the frame of reference of the plasma, the protons have random motions with a mean velocity of the order perhaps of 1/4 the bulk velocity of the plasma. This velocity (which is not inconsistent with the upper limit for the angular spread specified above) corresponds to a kinetic energy of about 30 ev. The random velocities might correspond either to thermal agitation, or to turbulent motions.

(3) The irregular magnetic field found in the regions of the second type indicates that the lines of force are twisted around by turbulent motions of the plasma. One should then expect that the mean density of energy corresponding to these turbulent motions is about the same as that of the magnetic field, which may be estimated to be approximately 250 ev$\cdot$cm^{-3}. This would give a kinetic energy of about 25 ev per proton. Thus the random motions which give rise to the energy spread mentioned under (2) may be largely of a turbulent character. However, an appreciable contribution from thermal agitation is not ruled out.

(4) One would expect an approximate pressure balance at the boundaries between the regions of the two types in the moving plasma, which mean approximately equal energy densities within such regions. In the regions of the first type the energy is practically all in the magnetic field and amounts to about 1000 ev$\cdot$cm^{-3}. In the regions of the second type, the energy is divided between the magnetic field, the turbulent motion and the thermal motion of the plasma. It is thus natural that the magnetic field should be weaker in the regions where an appreciable density of

plasma is found. However, the experimental data are still too crude to check the presumed pressure balance quantitatively.

During the active life of Explorer X, a sudden commencement was recorded on the earth. Simultaneously Explorer X recorded an increase in the strength of the magnetic field, in the proton flux, and in the mean energy of the individual protons. Presumably the sudden commencement was due to the arrival of a shock front initiated by a solar flare that had occurred about 29 hours earlier. From the transit time, one finds a value of 1.5×10^{8} cm·sec^{-1} for the velocity of this shock front. Behind the front, one would expect to find a plasma moving with a velocity somewhat smaller than that of the front, but of the same order of magnitude. Protons with velocity of the order of 1.5×10^{8} cm·sec^{-1} have energies of the order of 10,000 ev. On the other hand, the protons detected by the plasma probe had energies of the order of 1,000 ev. Moreover, while the existence of a second group of protons with energies of the order of 10,000 ev could not be ruled out, it is certain that the recorded protons were not the low-energy tail of a broad distribution peaked at about 10,000 ev. The theoretical interpretation of this result is still unclear.

Magnetic Effect

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I shall attempt to describe how we think the magnetic effects in the earth storm arise. These consist of the reverse impulse, the increase known as the sudden commencement, its continuation as the initial phase of the storm for an hour or so, after which a much larger diminution in field occurs during some hours, followed by a slow recovery to normal over a period of days.

If an electric field exists in the space surrounding the earth, Alfvén's electric field theory of storms describes how certain features of the ring-current, polar electrojets, and the aurora might arise. An electric field has not yet been detected by space experiments. If such an electric field is small, as many workers believe, the Chapman-Ferraro theory of the initial phase of magnetic storms which first appeared about 30 years ago remains basic in our approach in the theory of magnetic storms. According to this theory a solar emission produces a solar stream which overtakes the earth on its afternoon side, and then envelops the earth's magnetic field to form a magnetosphere some earth-radii in size.

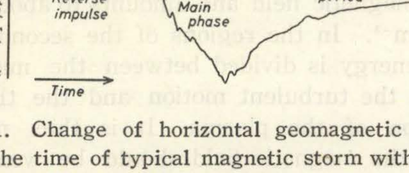

Fig. 1. Change of horizontal geomagnetic force at the time of typical magnetic storm with *SC** observed in moderate latitudes.

In the case of the preliminary reverse impulse, it seems likely that due to stronger compression of the earth's field on the sunward side there will arise magnetic field gradients in the equatorial plane directed towards the sun, somewhat sunward of the dawn and evening half-planes. These will create driving forces in the direction $\boldsymbol{B}\times$ grad B displacing and separating protons and electrons in a radial direction. In the process of charge equalization, which takes place along field lines of the geomagnetic field there will be a transient dumping of accelerated protons and electrons into the polar caps. Thus in Fig. 2, it is easy to imagine charges distributed in four sequences from the left: plus, minus, plus and minus, which will drive the Hall currents of the reverse