PHYSICAL REVIEW LETTERS

VOLUME 4 | FEBRUARY 15, 1960 | NUMBER 4

CURRENT SYSTEMS IN THE VESTIGIAL GEOMAGNETIC FIELD: EXPLORER VI*†

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(Received January 21, 1960)

The purpose of this Letter is to present some preliminary data taken by the magnetometer carried by the satellite Explorer VI. These data indicate the existence of a temporally and spatially variable current system which strongly perturbs the geomagnetic field at geocentric distances of 5 to 7 R_e (earth radii).

The Explorer VI orbit is extremely eccentric with an apogee of 48 800 km and a perigee of 6700 km geocentric. The period of rotation is approximately $12\frac{3}{4}$ hours. The plane of the orbit is inclined 47° with respect to the geographic equator. In terms of the orbital orientation with respect to the sun, apogee occurs between local dusk and midnight, i.e., 2100 hours local time, with perigee occurring at 0900 local time.

The magnetometer used was a search coil mounted on the inner shell of the spin-stabilized vehicle, as in Pioneer I.[1,2] The telemetered data consisted of a sinusoid whose amplitude is a measure of $|B_\perp|$, the component of the magnetic field perpendicular to the spin axis of the vehicle. A theoretical estimate of the expected field was made by extrapolation of the surface field, using an eccentric dipole model.[3] These field estimates were combined in a computer program with the trajectory of the satellite and the orientation of its spin axis to yield expected values of $|B_\perp|$.

Figure 1 presents some representative, preliminary data for orbital sweeps occurring on August 10, August 24, and September 1, 1959. A feature which is typical of the results obtained

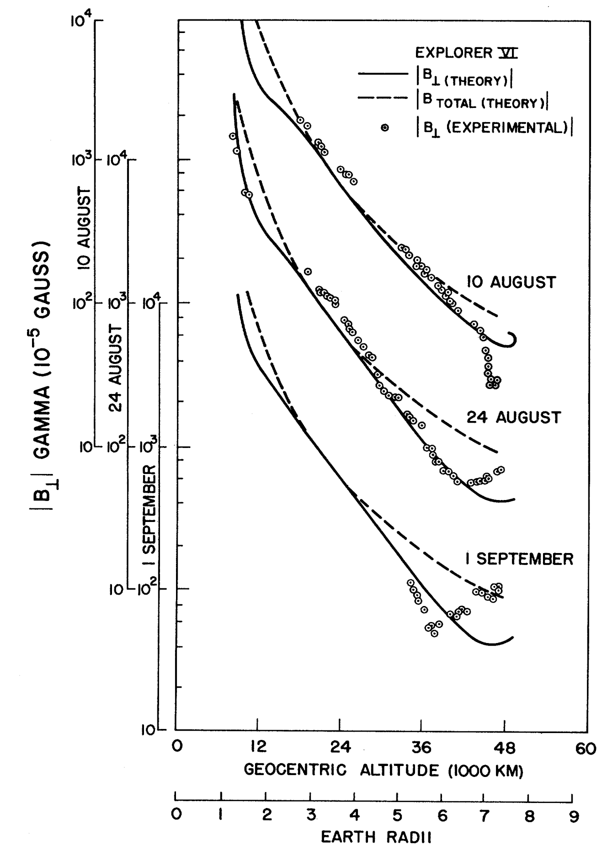

FIG. 1. Representative values of $|B_\perp|$ for ascending leg of the orbit on August 10, August 24, and September 1. The values shown in the figure are geometry dependent. The small variations shown in the inner region for August 10 and August 24 are being studied.

thus far is the reasonable agreement between the expected and the measured field at distances less than 5 to 6 R_e and the regular occurrence of large-scale deviations at greater distances. Thus, on August 10 the field displayed an abrupt, negative anomaly at $7R_e$ with indication of a field recovery with increasing altitude. On August 24, it displayed a positive-going anomaly beginning at $6.5R_e$. The data of September 1 showed a negative deviation which began at $5R_e$ and reached a minimum at $5.8R_e$. This was followed by a field increase to twice the expected value. These data were obtained on moderately quiet geomagnetic days.

It is of interest to compare these data with the results of Pioneer I[1] and the Russian cosmic rocket, Mechta.[4] In the former case, good agreement between observation and theory was obtained throughout the interval from 3.7 to 7 R_e. There is a disparity, however, between the Mechta data and the results of both Explorer VI, to this time, and Pioneer I. Neither the general depression of the field nor the anomaly at 3 to 4 R_e, which were observed by Mechta, has been detected. This disparity may disappear upon examination of more data.

The data presented in this note indicate the existence of an extraterrestrial current system beyond $5R_e$ which causes a perturbation of the geomagnetic field. It appears likely that such a current system will take the form of a toroidal ring. However, it is obvious that neither a solitary pass nor repeated orbiting which shows an anomaly in one region of the outer atmosphere constitutes unambiguous proof of annular current closure.

Figure 1 suggests the occurrence of two types of deviation and additional data, not shown, tend to bear this out. The possibility that such differences are not the result of fundamentally different kinds of current systems but are the effects of the orbital geometry is being investigated. The positive-going deviation observed on August 24 was repeated, to a lesser extent, on August 25. The deviation of September 1 occurred also on September 2, and investigation has shown that the negative-going deviation of August 10 is probably the initial portion of the same type of field variation. Figure 2 presents the amplitude of the deviation in the outer zone for August 9, August 10, September 1, and September 2. The similarity in the slopes of these curves strongly suggests similar characteristics and a similar cause for the perturbations. The data of August

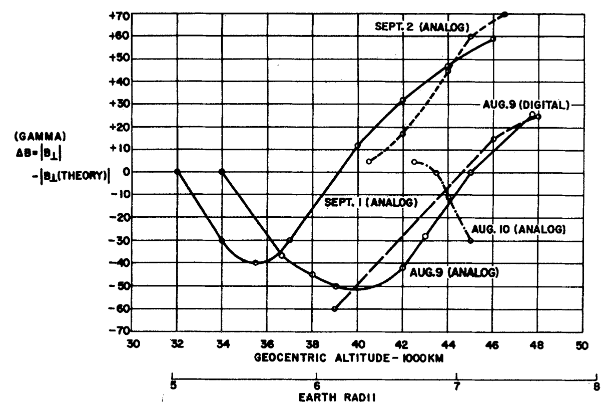

FIG. 2. The difference between the measured and expected values of $|B_\perp|$ shown for representative days. The repeatability of the slopes argues for a similar cause of the perturbations.

24 and August 25, representing the other type of deviation, have not been included so as to avoid confusion. In addition to not showing a region of decreased field, the slopes of the latter do not agree with those shown in Fig. 2.

The deviation of the type shown in Fig. 2 argues for a spatially confined current system such that a field reversal occurs as one passes through or near the current. Another obvious feature of this comparison is the difference in the altitudes at which the deviations were observed. This suggests that variations of several thousand kilometers in the location of the current system (as indicated by the position of the deviation minimum) may occur within intervals of 24 hours or less.

It is noteworthy to consider that these extraterrestrial currents appear in the region from 5 to 7 R_e. The unperturbed dipole field line through this region intersects the earth in the vicinity of the quiet day, southern auroral limit. The existence of a relationship between these currents and auroral activity is under investigation.

From the dynamics of a neutral plasma contained by a magnetic field, it is known that the individual particles will execute complex oscillations with a net drift azimuthally.[5] Because the direction of drift is charge dependent, this drift should appear as a net current flowing toroidally. Since the plasma in the exosphere is confined in just this way, convection currents capable of perturbing the geomagnetic field might be expected.[6] In addition to the large-scale deviations discussed above, the preliminary data indicate a general increase in the magnetic field strength throughout most of the inner zone (see Fig. 1) as well as irregular deviations. Although a longitudinal drift of the total plasma field should exist and provide a current, the resultant field depression, seen by a magnetometer presumed to be interior to such a region, is difficult to evaluate and requires knowledge of the velocity distribution function for the charged particles. It does appear from the data, however, that the commonly postulated condition, $\nabla \times \vec{H} = 0$, is inadmissible in the outer atmosphere.[7]

The authors wish to thank Professor L. Davis for helpful discussions.

*Presented at the Explorer VI Session of the Cleveland Meeting of the American Physical Society, November 29, 1959 [Bull. Am. Phys. Soc. 4, 416 (1959)].

†This program was carried out under the auspices of the National Aeronautical and Space Administration.

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[3] E. H. Vestine, J. Geophys. Research 58, 127 (1953).

[4] S. Dolginov and N. Pushkin, Pravda, July 15, 1959.

[5] See H. Alfvén, Cosmical Electrodynamics (Oxford University Press, New York, 1953), p. 27.

[6] S. F. Singer, Trans. Am. Geophys. Union 38, 175 (1957).

[7] See J. W. Dungey, Cosmical Electrodynamics (Cambridge University Press, Cambridge, 1958), Chap. 8, p. 150; and Proc. Phys. Soc. (London) 406, 229 (1955).

MEASUREMENT OF THE GRAVITATIONAL RED SHIFT USING THE MÖSSBAUER EFFECT IN Fe^{57}

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(Received January 27, 1960)

The change in the frequency of spectral lines with gravitational potential, generally referred to as the gravitational red shift, was first predicted by A. Einstein in 1907.[1] The effect can be calculated from the time dilatation in a gravitational potential which follows from the principle of equivalence. From the point of view of a single coordinate system two atomic systems at different gravitational potentials will have different total energies. The spacings of their energy levels, both atomic and nuclear, will be different in proportion to their total energies. The photons are then regarded as not changing their energy and the expected red shift results only from the difference in the gravitational potential energies of the emitting and absorbing systems. Astronomical observations, though somewhat ambiguous, have tended to confirm this effect.[2] The recent discovery by Mössbauer[3] of recoilless nuclear resonance absorption of gamma rays as a precise resonance process has suggested to several groups[4-6] the possibility of using this effect to measure the gravitational red shift. More specifically the discovery that Fe^{57} could absorb 14.4-kev gamma rays in a resonance whose width is approximately 6.4×10^{-13} of the gamma-ray energy[4,6,7] has made this experiment a practical possibility.

We have performed this experiment using a total difference in height of 12.5 meters. A source of Co^{57} of approximately 30 millicuries was electrodeposited on the surface of an iron disk which was then heated for five hours at 700°C in a hydrogen atmosphere, then for an equal length of time in a vacuum. This disk was mounted on a transducer device which consisted of a coil mounted between the poles of an electromagnet and supported on an elastic spider. The gamma rays passed through an evacuated tube with 0.005-in. Mylar windows on both ends. Antiscattering baffles were mounted inside the tube. The detector consisted of a proportional counter with a five-inch diameter window also covered by 0.005-in. Mylar. The counter was filled with krypton gas to approximately $\frac{1}{4}$ atmosphere pressure. Krypton is especially favorable because its absorption edge is just below the energy of the 14-kev gamma rays.[8] A five-inch diameter foil containing 4 mg/cm^2 of Fe enriched in Fe^{57} to 24.1% was directly above the counter.

The transducer was driven sinusoidally at 50 cps and counts were recorded in two scalers for alternate halves of the cycle. Two other scalers were switched simultaneously and recorded tim-