Investigation of the Magnetic Field of the Moon

SH. SH. DOLGINOV, E. G. YEROSHENKO, L. N. ZHUZGOV, and N. V. PUSHKOV

This paper is devoted to a description of the problems related to the experiment and the experimental data concerning the field of the moon which were obtained during the flight of the second Soviet cosmic rocket.

As a consequence of the analysis of the measuring apparatus' sensitivity threshold, according to measurement data in a weak geomagnetic field, some 45,000 to 60,000 km from the center of the earth, and of the analysis of noise level in the orbital space of the moon, coupled with measurements directly near the moon and up to 55 km from its surface, no notable magnetic field of the moon was revealed. It is estimated that the dipole magnetic moment of the moon must be smaller than 1/10,000 of the earth's magnetic moment.

THE remarkable achievements of the Soviet rocket technology have made possible the organization of the first experiment for a direct investigation of the magnetic field in the surroundings of the closest heavenly body.

On September 14, 1959, at 0 hr, 2 min, and 24 sec, the second Soviet cosmic rocket delivered to the moon a container with a scientific apparatus, including devices for magnetic field measurement.

Investigation of the Moon's Magnetic Field during the Flight of the Second Soviet Cosmic Rocket

Measurements were carried out by a magnetometer with magneto-saturated even-harmonic pickups. Pickups of the latter type measure projections of the field's total vector on the longitudinal axes of the pickups. When they are directed perpendicularly to the field, the signal from the corresponding magnetometer equals zero. Three mutually perpendicular pickups (x,y,z), interrogated by a telemetry system, allow one to obtain the information concerning the total vector of the magnetic field for an arbitrary orientation of the container. All three channels of the magnetometer had independent pickups and independent electron and supply units. The signal from every pickup was transmitted by two channels of telemetry. When a signal was present in one channel, the second one showed zero count. For each turn of the pickup relative to the field, channels changed places.

Therefore, the device makes it possible to discern the signs of the field's projection, operating at a given time on one pickup or another.

Magnetometers of this type are relative devices. Estimation of the distinction of magnetometers' zero points from the field's absolute zero was completed in laboratory conditions by investigation of these devices and of the magnitude of magnetic deviations of the airborne apparatus. However, the final determinations of the zero points of magnetometers were made under actual conditions, by calculations at great distances from the earth and the moon, beyond the sphere of action of these magnetic fields.

The limitations linked with the relative character of the devices used were eliminated to a significant degree, due to container rotation and pickup sensitivity to the sign of the field. Signals connected with solid magnetic deviation and displaced zeros of the magnetometers themselves, constant in time, at least in specific time intervals, do not depend on container orientation, whereas the effect of the external magnetic field on the rotating pickup varies with container's rotation frequency and depends on the orientation of pickup axes relative to the field's vector.

In the following, we shall note that the field's projection acting on the pickup, installed at angle ψ to the horizon and at angle φ to the plane of the magnetic meridian, is

$$H = T_0(\sin I \sin\psi + \cos I \cos\psi \sin\varphi)$$

where T_0 and I are the strength and the inclination of the field vector, respectively.

At periodic variation of the angle φ, the constant signal, determinable by the first term of that expression, will modulate with the frequency variation of the angle φ. The depth of modulation is determined by the correlation of the first and second terms of the foregoing expression.

Under laboratory conditions, the magnetometers used make it possible to measure the magnetic field variation in several gammas. Under conditions in the cosmic rocket's container, the real sensitivity threshold must be estimated.

Data related to measurements in the terrestrial magnetic field at a distance of 45,000 to 60,000 km from the center of the earth are presented in Fig. 1.

The top graph shows the theoretical values of the field at those distances, computed with the dipole and quadrupole terms of the potential function. On the other graphs, solid lines indicate the field projections on every pickup, and the dotted line is the envelope of these projections. The enveloping projections of channels x and y, the pickups of which lie in a single plane in mutually perpendicular directions, constitute sinusoids of decreasing amplitude with a period of the order of 840 sec. Since pickups x and y are disposed at a 90° angle, the phases of these sinusoids shifted by 90°, as expected. The container's rotation during the indicated period took place around an axis near that of the third pickup z, perpendicular to pickups x and y. The projection of the field on the pickup z did not modify the sign. The scattering in magnitude of the measured projections is determined by pickup's precession around the axis, which does not coincide with the vector of the magnetic field, has an 86-sec period, with discretion of measurement and errors.

Thus, the detection of sufficiently small fields by means of magnetometer data is based on comparison with the zero-point channels, determined by means of a great number of measurements at substantial distances from the earth and

Translated from Geomagnetizm i Aeronomiia, Akademii Nauk SSSR (Geomagnetism and Aeronomy, Academy of Sciences USSR), no. 1, 21–29 (1961). Translated by Andre L. Brichant, NASA Technical Information Division. This paper was reviewed for publication by Walter M. Elsasser, Department of Physics, School of Science and Engineering, University of California, San Diego, Calif.

the moon, outside their magnetic fields, and on the detection of the characteristic modulation of specific period and phase connected with the character of container's rotation.

Graphs allow us to establish that, with an arbitrary orientation of pickups in the terrestrial field on separate magnetometer channels, facts of action of outer fields of the order of 20 to 30 gammas may be established reliably.

As the container drifts farther from the earth, at great distances, the relationship signal-to-noise ratio naturally decreases. Aside from the forementioned criteria of outer magnetic field presence, the character and the magnitude of signal background in space must be determined, especially where all possibility of influence of magnetic fields of the earth and the moon is excluded; where, according to present-day concepts, fields greater than 2 to 5 gammas may not be expected in magnetically quiet days; and, finally, where conditions of signal transmission are simultaneously about the same as those immediately near the moon. Results of measurements by magnetometer components during the 50-min flight of the container along a sector of the trajectory 33,000 to 40,000 km away from the surface of the moon, are plotted in Fig. 2.

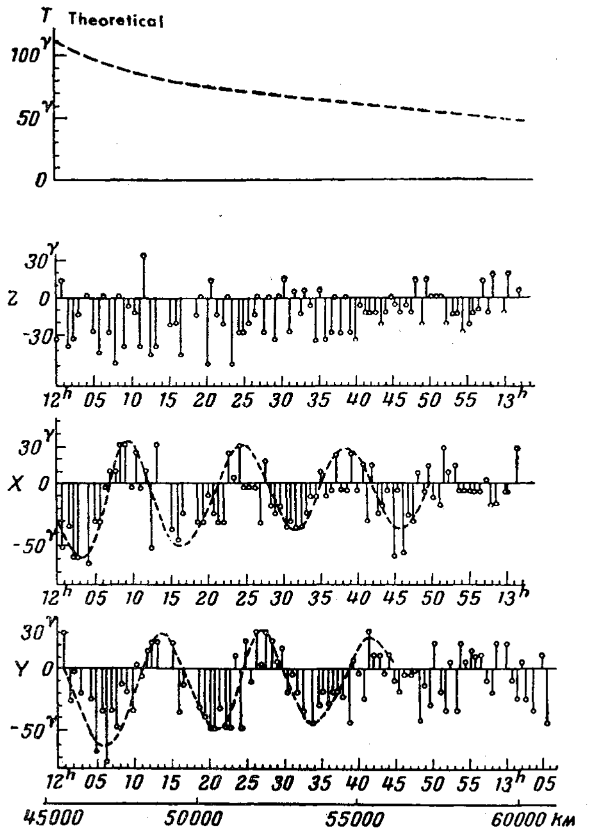

Fig. 1.

As a whole, the recordings represent alternating fluctuations with a periodicity equal to that of the interrogator. The mean value of these fluctuations is ±30 gammas. The maximum deflection reaches the magnitude of 60 gammas. Aside from alternating readings, there are observed one-sign readings during 6 to 8 min over separate channels, for example, as may be seen at the origin of the *y* graph of the channel.

The ordinate values, averaged by sliding time intervals, equal to the half-period of container's rotation, are plotted by solid-line curves. As may be seen from the graphs, the modulation with a 14-min characteristic period is not apparent, although, according to cosmic particle counters, the rotation of the container during the indicated period actually took place.

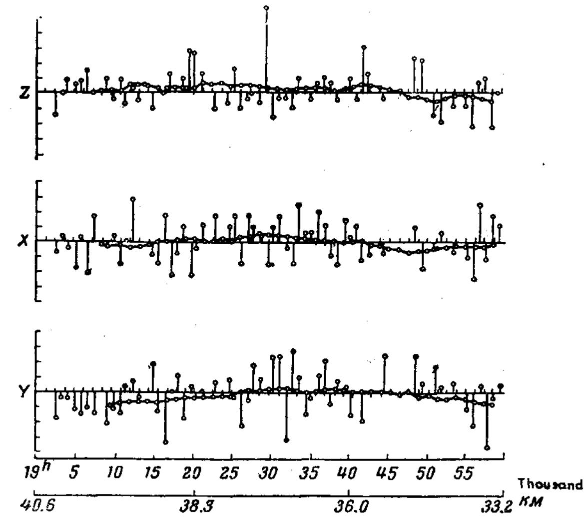

Fig. 2.

Analysis of materials similar to those plotted in Fig. 2 makes it possible to assert that, in the vicinity of the moon, to a distance of one radius to surface, no indication of an external magnetic field of 20 to 30 gamma intensity was detected, which would be similar to those examined earlier in a terrestrial field of equal intensity.

Fig. 3 represents the information for a distance of two lunar radii from its surface obtained from the three magnetometer's channels. These measurements gave 23 readings during a period of 22 min. The last information from magnetometer pickups was received at a distance of 55 km from the moon's surface. Values along channels *x*, *y*, *z* were computed relative to the zero points determined at a distance of 4000 to 14,000 km from the surface of the moon.

In view of the importance of the latter measurements, all signals visible on films are given here. Those signals that were not in accord with the accepted criteria of reliability due to a high level of interference are indicated by small crosses.

The signal of channel *z* does not differ in magnitude and character of investigation from signals on the pre-lunar section of the trajectory. However, one may notice in sepa-

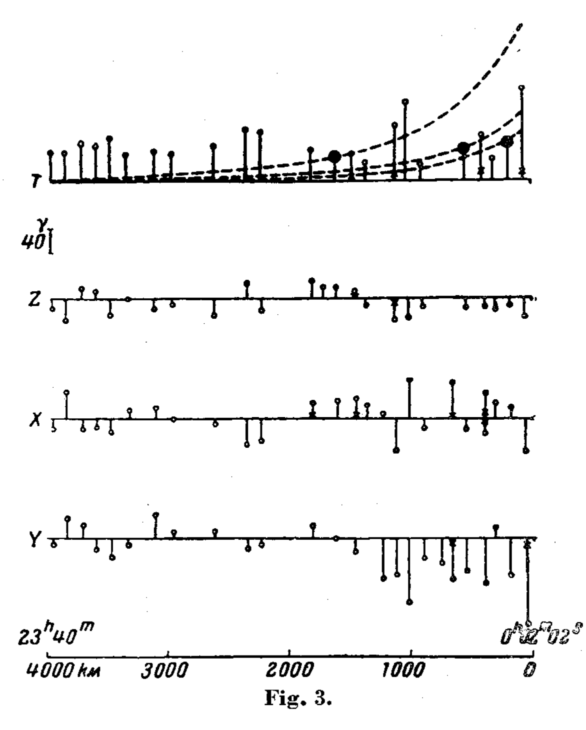

Fig. 3.

rate parts x and y of the graphs a tendency to a concerted variation of readings, which may possibly be linked with container's rotation, i.e., the growth of signals over one channel accompanied by a decrease of signals over the other. However, it should be noted that cases of monotonous variation of the continuity of signals are not scarce even on the pre-lunar part of the trajectory (Fig. 2). As a whole, readings along channels x and y are not in agreement, although curves similar to those of Fig. 1, obtained in the small terrestrial field, may not be expected here due to the short period of measurement in the immediate vicinity of the moon.

The experimental data must satisfy still another condition: the values of the total field's vector, computed from the data of components x, y, z of the field, must decrease according to the inverse cube law of distance from the center of the moon. After the forementioned estimation of signal reliability along separate channels of the magnetometer, the computation of the values of the total vector from the data of separate channels becomes a formal operation. This must be borne in mind when examining graphs of Fig. 3. In the upper graphs the values of the total vector and the theoretical curves linked with separate readings (indicated by small circles) are plotted, assuming that they are more reliable. As may be seen from the graphs, the aggregate of the computed field values does not satisfy either of the theoretical curves brought forth sufficiently.

Therefore, as a result of the analysis of experimental materials at fractional distances of the lunar radius from the surface of the moon, we discovered no reliable indications of the presence of an external magnetic field on the moon.

Using the aggregate of experimental data obtained at fractional distances of the radius from the surface of the moon, we may determine the magnitude of uncertainty of our knowledge of the moon's field. For that purpose we used a theoretical curve closest to experimental values. Thus determined, the effective magnetic moment of the moon cannot, in any case, be greater than $6 \cdot 10^{21}$ CGSM (cm gr/sec magnetic units), which constitutes about 1/10000 of the earth's magnetic moment.

The result obtained, which attests to the absence of a noticeable dipole-type field near the moon, agrees well with the results of measurement of cosmic radiation near the moon.[1] It is well known that no cosmic radiation belts were detected near the moon.

The first magnetic field measurements near the moon, completed during the flight of the second Soviet cosmic rocket, made it possible to establish that the moon does not have a notable magnetic field. Its dipole magnetic moment can only be less than 1/10,000 of the earth's magnetic moment. This result gives evidence in favor of the contemporary hypothesis of the origin of the earth's magnetic field. Aside from making the lower boundaries more precise, subsequent experiments may provide information as to whether the moon had a magnetic field in the past and on the genesis of its surface and its cosmogonic history.

—Submitted December 13, 1960

[1] Vernov, S. I., Chudakov, A. E., Vakulov, I. V., Logachev, Yu. I., and Nikolayev, A. G., "Radiation measurements during the flight of the second cosmic rocket," *Iskusstvennye Sputniki Zemli (Artificial Earth Satellites)* (1960), no. 5.

FEBRUARY 1963 AIAA JOURNAL VOl. 1, NO. 2

Outer Radiation Belt of the Earth at 320 km Altitude

S. N. Vernov, I. A. Savenko, P. I. Shavrin, V. I. Nesterov, and N. F. Pisarenko

The existence of the earth's outer radiation belt, clearly limited to the high latitude region, was shown as a result of investigations completed on the second and third Soviet artificial earth satellites (1).[1]

The scintillation and gas-discharge counters aboard the second Soviet spaceship permitted a detailed investigation of the outer radiation belt near the earth and a determination of its boundaries in relation to the longitude. The second spaceship's orbit was nearly circular, and it was situated within an altitude range of 306 to 339 km (2).

An automatic memory device aboard the spaceship provided the means for a continuous flow of information on radiation intensity at indicated heights within the ±65° latitude range and along the whole of the earth. The output from the scintillation and gas-discharge counters was read into the memory every three minutes.

The scintillation counter consisted of a cylinder-shaped NaI(Tl) crystal (height—14 mm, diameter—30 mm) and an FEU-16 photomultiplier, and the energy threshold of the counter's channel was 25 kev. The gas-discharge counter was of the STS-5 type (halogen-quenched counter).

Translated from *Iskusstvennye Sputniki Zemli* (*Artificial Earth Satellites*) (Publishing House of the Academy of Sciences USSR, 1961), no. 10, pp. 34–39. Translated by Andre L. Brichant for NASA Headquarters.

[1] Numbers in parentheses indicate References at end of paper.

The distribution of radiation intensity around the earth, as recorded by the scintillation counter, is shown in Fig. 1. The numbers indicate the intensity in pulse $\cdot$ cm^{-2} $\cdot$ sec^{-1}, assuming that the radiation incident on the crystal was isotropic. It follows from Fig. 1 that during the passing of the spaceship from the Equator to ±40–50° latitudes, the intensity registered by the scintillation counter gradually increased from 3–5 pulse $\cdot$ cm^{-2} $\cdot$ sec^{-1} to about 8–10, because of latitude effect of cosmic rays, and then in most cases sharply increased to 20–600 pulse $\cdot$ cm^{-2} $\cdot$ sec^{-1} in the region of 50° to 65° of geographic latitudes, and it remained only at times at the 13–15 cm^{-2} $\cdot$ sec^{-1}. The regions of increased intensity that cannot be explained by latitude effect of cosmic rays are crosshatched and bounded by a dash-dotted line.

It is quite natural to assume that this sharp increase in the rate of the scintillation counter is due to particles from the earth's radiation belts. To demonstrate that assumption, we analyzed the connection between the zones of increased intensity in the Northern and Southern hemispheres, and we also examined the relationship between the limits of the increased intensity with the characteristics of the earth's magnetic field. We finally established the content and appraised the energy of the registered radiation.

In Fig. 2 circles indicate the points at which the counting rate of the scintillator corresponded to intensities greater than 30 pulse $\cdot$ cm^{-2} $\cdot$ sec^{-1}. The following geographic zones of in-