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MEASUREMENTS OF THE MAGNETIC FIELD IN THE VICINITY OF THE MOON ON THE ARTIFICIAL SATELLITE LUNA-10

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During the period from 3 IV to 4 V 1966, measurements were made of the magnetic-field intensity in the vicinity of the Moon from the first artificial satellite, Luna-10. The measurements were carried out during separate communication sessions on the visible portions of the orbit by means of a three-component ferrosonde magnetometer. The measurement range was 50γ ($1\gamma = 10^{-5}$ oersted) for each component, and the sensitivity threshold for measuring the magnetic field was 1γ.

As it moved along its orbit, the satellite was given a rotation about a certain axis. From the magnetometer readings the following were determined: the magnitude of the intensity of the total magnetic-field vector T and its components along the axis of rotation $T_\parallel$ and perpendicular to this axis $T_\perp$. The error of the component $T_\parallel$, due to error in determining the zero point of the magnetometer and magnetic deviation, could amount to $\pm 10\gamma$ in its absolute value. The component $T_\perp$ did not depend on zero shift or magnetic deviation, and its error was $\pm 2\gamma$. The total error in measuring the absolute value of the modulus T is estimated to be of the order of $\pm 10\gamma$. The error in determining relative changes of the modulus T is about $\pm 5\gamma$.

Fig. 1.

Figure 1 presents the mean values of the scalar magnitude of the magnetic field T on the observation days and the corresponding positions of the Moon relative to the Earth–Sun line. Throughout the entire measurement period, the field intensity in modulus and in components lay within the following limits: $T = 23 \div 40\gamma$, $T_\perp = 12 \div 16\gamma$, $T_\parallel = 18 \div 38\gamma$. In absolute magnitude, the measured field values agree with the estimate of the upper field in the immediate vicinity of the Moon, obtained during the flight of the second Soviet space rocket ([1]).

Analysis of the character of the magnetograms on all observation days and of the relationship of the field components $T_\parallel$ and $T_\perp$ made it possible to establish that during the observation period the magnetic field in the vicinity of the Moon had a homogeneous structure and changed little in direction when moving along the orbit from perilune to apolune.

The observed field may be the sum of the Moon' s own field and interplanetary fields of solar origin. On the days of full moon, to these fields there is possibly added the magnetic field of the "tail" of the magnetosphere ([2,3]). In discussing the nature and possible sources of the observed-

of the magnetic field, it is necessary to keep in mind the following circumstances characterizing the space conditions of the experiment:

a) During the entire period of observations, spots and magnetically active regions on the Sun were observed only in the northern hemisphere of the Sun, with a predominant southern magnetic polarity in the leading spot. According to the existing point of view, the interplanetary magnetic fields in this case had a radial component directed toward the Sun.

b) During the period of measurements of the magnetic field on the Luna-10 satellite, mainly small changes in the index of geomagnetic activity were observed: K was equal to $1 \div 3$, and only in the second full moon (4 V), during the observation session, $K = 4$.

c) During full moons the Moon is north of the plane of the ecliptic, where the "southern" lines of force of the geomagnetic field are located, which are then also directed toward the Sun.

A. **Variability in time of the circumlunar field.** A correlation is observed in the sign of the change of the magnetic field in the vicinity of the Moon and the index of magnetic activity on the surface of the Earth. This conclusion was drawn by comparing the modulus T and the field components $T_\parallel$ and $T_\perp$ at the full moons of 5 IV (T_1°) and 4 V (T_2°): $T_1^\circ - T_2^\circ = -12\gamma$; $T_{\parallel 1}^\circ - T_{\parallel 2}^\circ = -13\gamma$; $T_{\perp 1}^\circ - T_{\perp 2}^\circ = 0$; for these days $\Delta K = -3$ ($\Delta K = K_1^\circ - K_2^\circ$).

The agreement in sign between the change in the index K of magnetic activity on the surface of the Earth and the change in the circumlunar field is also retained when compared with measurements at the new moon of 20 IV ($T^\bullet$): $T_1^\circ - T^\bullet = -6\gamma$; $T_{\parallel 1}^\circ - T_\parallel^\bullet = -5\gamma$; $T_{\perp 1}^\circ - T_\perp^\bullet = -2\gamma$. Correspondingly, $K_1 - K^\bullet = -2$.

The greatest variability when K changes is shown by the longitudinal component of the field $T_\parallel$. On 19 IV $T_\parallel = 18\gamma$ ($K = 2$), on 4 V $T_\parallel = 38\gamma$ ($K = 4$).

It is known that the change in the intensity of interplanetary fields correlates with the change in the index of magnetic activity ([4]). It is natural to suppose that in the observed circumlunar field these very fields constitute a substantial part. The constancy of the sign of the observed circumlunar field over the entire observation period is in agreement with the character of the active regions on the Sun during the observation period. However, the intensity of the circumlunar field exceeds the intensity of interplanetary fields in free space by a factor of 4-

Fig. 2.

Figure 1: Fig. 2.

6. Such a significant difference should be ascribed to the influence of the Moon. This influence may be of different nature.

B. **Possibility of the existence of the Moon' s own magnetic field.** It cannot be excluded that in the past the Moon may have had a sufficiently intense magnetic field, and at present has retained, at least, residual magnetization in its rocks. By analogy with the Earth, in this case one may assume that this magnetization is closer to the axis of rotation than to the equatorial plane. It may also be assumed that the Moon did not have its own field close to the axis, but was magnetized under the action of solar magnetic fields, the intensity and sign of which differ from the intensity and sign of interplanetary fields during the period of measurement. In both these cases one should speak of the Moon' s own magnetic field.

Since the orbit of Luna-10 was inclined to the Moon' s equator at an angle of 72°, in the first case one could have expected that, when moving from pericenter to apocenter, the field would change substantially in direction. This was not observed in the session of 5 IV. Moreover, under a dipole law the field should have changed by a factor of 1.8 during such a displacement. In fact, the field decreased from 28 to 27γ, and the angle of the field vector with the axis of rotation β changed only by 4°.

With magnetization in a direction close to the equatorial plane of the Moon, one would have expected a change in the sign of the field when changing

of lunar longitude from session to session. Such a change in the sign of the field was not observed. Thus, observations on the Luna-10 satellite did not reveal an intrinsic magnetic field of the Moon of dipole nature and appreciable intensity. The significant excess of the circumlunar field over the intensity of interplanetary fields in free space is possibly connected with deformation of the field by the Moon, which has finite conductivity and appreciable magnetic permeability of the rocks.

Fig. 2.

In the first case the main role should be played by the mechanism of magnetohydrodynamic flow of plasma and fields around the body of the Moon. To explain a significant deformation of interplanetary fields due to static magnetization of rocks, it must be assumed that the rocks of the lunar surface have a magnetic permeability $\chi \simeq 0.5$, which is unlikely.

B. The field of the Earth' s magnetic tail. According to theoretical estimates $(2, 3)$, the Earth' s magnetic field on the night side can extend to $100 R_{\mathrm{E}}$ (R_{E} is the radius of the Earth). The effect of the Earth' s magnetospheric tail can be detected by comparing magnetometer readings during periods of full moon T° and new moon $T^{\bullet}$, provided that the level of magnetic activity is the same. As was already mentioned, the latter condition was not fulfilled, and a correlation was established between the field intensity and the magnetic-activity index. Comparison of the field at new moon on 20 IV and at the second full moon (4 V) gives

$$T_2^{\circ} - T^{\bullet} = +6\gamma; \quad T_{\|2}^{\circ} - T_{\|}^{\bullet} = +8\gamma; \quad T_{\perp 2}^{\circ} - T_{\perp}^{\bullet} = 2\gamma.$$

In comparison with the first full moon, the differences changed sign, in full agreement with the change in the sign of the difference ΔK.

The mean values of the field T and of the components $T_{\|}$ and $T_{\perp}$ for three days near the first full moon (5, 8, 9 IV) and near new moon (19, 20, 21 IV) do not give an appreciable difference:

$$\overline{T}_1^{\circ} - \overline{T}^{\bullet} = -2\gamma; \quad \overline{T}_{\|1}^{\circ} - \overline{T}_{\|}^{\bullet} = 0; \quad \overline{T}_{\perp 1}^{\circ} - \overline{T}_{\perp}^{\bullet} = -2\gamma.$$

The mean values $\overline{K}$ on the days of new moon somewhat exceeded the mean K at full moon: $\overline{K}^{\bullet} = 3.3$; $\overline{K}^{\circ} = 2.7$. Consequently, the effect of the tail of the Earth' s magnetosphere is smaller than the effect of variations of the interplanetary field. It may be concluded that, in the present experiment, the extension of the tail of the Earth' s magnetic field to distances of $60R_{\mathrm{E}}$ was not established by direct magnetic measurements.

Conclusion. 1. A study has been carried out of the magnetic-field intensity in the vicinity of the Moon. During the observation period a regular field was measured, whose intensity in modulus and in components lay within the limits: $T = 23 \div 40\gamma$; $T_{\|} = 18 \div 38\gamma$; $T_{\perp} = 12 \div 16\gamma$.

2. A correlation has been established between the intensity T, and especially $T_{\|}$, of the circumlunar field and the index of magnetic activity on the surface of the Earth, by analogy with the same correlation with the intensity of interplanetary fields.

3. No field of dipole nature was detected, nor any field variability according to a faster law, which would have occurred for nonuniform magnetization of the Moon.

4. The field of the Earth' s magnetic tail was not detected. The possible magnitude of the magnetic tail at a distance of $60R_{\mathrm{E}}$ does not exceed 5γ.

5. The most reliably measured quantity $T_{\perp}$ is on the average 15γ, which exceeds interplanetary fields in free space under

the same indices of magnetic activity. The explanation for such an increase should be sought in the perturbing action of the Moon, which has a certain effective conductivity and magnetic permeability. Some of the questions indicated can be clarified by measurements on the far side of the Moon.

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Note: Figure translations are in progress. See original paper for figures.