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POSSIBLE INTERPRETATION OF THE RESULTS OF MEASUREMENTS ON THE NEAR-LUNAR SATELLITE "AMS LUNA-10"

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SUMMARY

This paper discusses the nature of the near-lunar field and the possibility of dete.ting the Earth's magnetic tail in connection with the results of magnetic and plasma measurements in the vicinity of the Moon on the artificial satellite "LUNA-10".

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The appearance of the present note has been stimulated by the discussion of the results of magnetic and radiation measurements [1, 2], performed in the vicinity of the Moon on the near-lunar satellite "LUNA-10". The publication of this communication offers also interest because in the issue of the periodical, referred-to below [3], there will appear also the communication by NESS, whose preprint has been kindly sent by him to our address also.

I. The fundamental question, which is the main subject of discussion, is the question of the nature of the observed near-lunar magnetic field.

Of 11 sessions, during which information was obtained relative to the magnetic field in the vicinity of the Moon, seven were completed in periods when the Moon was knowingly outside the Earth's magnetic tail, namely the sessions of 11, 12, 13 April and 18, 19, 20, 21 April (days near new moon). The magnetic field measured during these days is characterized by all the singularities described in the detailed work devoted to the experiment [4]:

(*5 VOZMOZHNAYA INTERPRETATSIYA REZUL'TATOV IZMERENIY NA OKOLOLUNNOM SPUTNIKR LUNA-10.6

(**) Subject discussed at IZMIRAN Seminar in November 1966.

1) the magnetic field has a regular character;

2) the field does not decrease with the distance from the surface of the Moon according to the dipole, or any more rapid law;

3) the field component $T_{\perp}$, perpendicular to the axis of rotation of the satellite, not dependent on container deviation or magnetometer "zeros", constitutes ~ 15 gammas as an average, which exceeds by about three times the field magnitude in free interplanetary space;

4) the variability of field's longitudinal component $T_{\parallel}$ reveals a specific agreement with the variability of the index of geomagnetic activity.

The presence of the Earth's magnetic tail in fullmoon and close days is a peculiarity that has an independent significance, without affecting essentially the question of the nature of the near-lunar field, inasmuch as the Moon is knowingly situated outside the Earth's magnetosphere tail during about 85% of the lunar month. Naturally, it follows at the same time, that one should bear in mind that the accounting for the possible influence of the shock front ahead of the Earth's magnetosphere increases the duration of Earth's action upon the near-lunar space.

When resolving the question of the nature of the near-lunar magnetic field it would of course be very important to have complete data on field orientation in space with, at the same time,a prolonged series of continuous observations. Despite the absence of such full information, we have a certain possibility of discussing to what extent the observed near-lunar field corresponds to either assumptions.

It was already mentioned in [4] that the observed field may appear deformed (amplified) by the interplanetary field, trapped by either an interplanetary or Moon's proper field of another origin (for example, residual magnetization field). The small field variability in magnitude and direction during the motion of the satellite along the orbit compelled us to deny ourselves the last of the enumerated possibilities [4].

The field amplification could take place, for example, during incidence upon the Moon of a plasma flux with a magnetic field, of which the lines of force can not very definitely penetrate into the Moon (diamagnetic effect), being compelled to flow past it, alongside with the plasma; this is attended by the well known effect of amplification of the incident field in the region directly adjacent to the body, past which the plasma flow takes place. The magnetic flux from the interplanetary magnetic field through the cross-section of the Moon is equal in its absence to

$$\pi R_{\Lambda}^{2} F_{1},$$

where R_{Λ} is the radius of the Moon, F_1 is the unperturbed interplanetary field. If the Moon had an infinite conductivity, its magnitude at the height h from the surface of the Moon would be on account of interplanetary field deformation $F_2 > F_1$, whereupon

$$h = R_{\Lambda} \sqrt{1 + F_1 / F_2}.$$

If during the estimate of F_2 we indicated only the component $T_{\perp}$ of the measured field, of which the determination has an absolute character, and assuming $F_1 = 5\gamma$, we would have $h = 1.15\ R_{\Lambda}$, inasmuch as $T_{\perp} = 15\gamma$. Meanwhile, in orbit's aposelion we have $h \approx 1.7\ R_{\Lambda}$. Consequently, the explanation of field amplification at the expense of field deformation with conservation of the magnetic flux requires the admission that the effective radius of the Moon is greater than R_{Λ}. This increase of the "effective radius" may be attained at the expense of interplanetary magnetic field trapping by the Moon, or of the existence at the Moon of a residual field of another nature. In the first case we must admit the finiteness of the value of Moon's conductance (electrical conductivity), which is quite natural.

In this regard it is interesting to note that the motion of the Moon in interplanetary medium corresponds to the intermediate case of magnetized plasma incidence upon a body with conductance $\sigma = 0$ and on a body with conductance $\sigma = \infty$. In the incidence upon a body with $\sigma = 0$ there must be observed an effect of plasma "sweep out" by the body: the lines of force penetrate freely into it, while the plasma, where the incident field is frozen-in, is neutralized during the interaction with the body. For a finite value of σ, part of the lines of force penetrate into the body and are carried by it if the rate of field diffusion through the body is less than the body motion velocity in the outer medium. Data on the magnitude of Moon's conductance are not available if we discount the estimates related to the most superficial layer [5]. We may ascribe to the Moon, with specific foundation, the conductance which is determined for the non-conducting layer of the terrestrial globe according to data on annual and D_{st}-variations of the geomagnetic field. According to [6,7], the mean conductance of the Earth's non-conducting layer, of which the thickness in various regions of the terrestrial globe varies from 100 to 1000 km, constitutes $5 \cdot 10^9 \div 9 \cdot 10^9\ sec^{-1}$. If we assume for the Moon $\sigma \approx 10^9\ sec^{-1}$, the rate of diffusion will result about equal to $3 \cdot 10^2$ cm/sec, which is much less than the velocity of solar flux relative to the Moon.

Thus, on the basis of fairly rough admissions, we still may conclude that the mechanism of interplanetary field trapping by the Moon may take place. This may, in its turn, explain the increase of the "effective radius". i. e., the amplification of the field near the Moon at sufficiently great distances at the expense of interplanetary magnetic field "accumulation" in the vicinity of the Moon, having a finite conductance.

On the basis of the above considerations one may attempt to construct a qualitative model of the near-lunar field. According to [8], most probable is the assumption that, taking into account the rotation of the Moon, the component along the Moon's axis of rotation must be steadier. In this case the field topology may have the form illustrated in Fig.1.

The lines of force of the interplanetary field are represented in Fig.1 a in their projection on a plane perpendicular to the direction of motion of solar plasma (these are the slightly bent solid lines in the central part); shown also are the lines of force of the near-lunar field (short thin lines), the orbit of AMS LUNA-10 (dash-dotted line) and the Moon (solid circle at the center of Fig.1 a).

The meridional cross-section of the near-lunar field (thin bent lines) in the plane containing the direction of motion of the plasma and the perpendicular to the ecliptic plane is shown in Fig. 1 σ, alongside with the projection on the same plane of the orbit of the satellite (heavy straight line). With such a field topology the results of magnetic measurements (uniformity of the field, absence of notable variations in the direction of the field in various portions of the orbit) may be given quite natural an explation. The interplanetary field component perpendicular to the ecliptic plane must play a fundamental role in the formation of a near-lunar field of topology indicated. Its existence is revealed by direct measurements on the satellite IMP-1 [9]. Despite the variability in time, this component is directed to the south of the ecliptic plane in a great number of cases ($\sim 66\%$), which allows us to explain the constance of near-lunar field's direction (when averaging for a large time interval).

2. The magnetic measurements on the AMS LUNA-10 were analyzed from the standpoint of the possibility of bringing into light the influence of the Earth's magnetic tail. As is well known [10], the basic signs of magnetic tail's influence at great distances from the Earth, distinguishing it from the interplanetary magnetic field, are the characteristic radial direction of the field relative to the Sun and the change of sign above and below the neutral layer.

The magnetic measurements from LUNA-10 could have been started only after its egress into the lunar orbit. Inasmuch as the measurements were discrete, the only realistic way of bringing to light the effect of the magnetic tail is the comparison of measurements conducted in the new moon and fullmoon period. Analysis of the results of such a comparison may be undertaken in the assumption that the magnetic field of the tail is capable of composing itself with the near-lunar field. This possibility was utilized by the authors of ref.[4]. Comparison of the readings on the fullmoon days of 4 April and 4 May with the readings on the day of new moon (20 April) has shown that the difference in field values between fullmoon and new moon periods has a different sign. This sign variation is in correspondence with the sign variation of the level of geomagnetic activity for the same days [4]. At the same time one could have expected that during the two fullmoon days the Moon was located in a single (northern) bunch of lines of force of the tail, where the geomagnetic field has one and the same sign.

The cross-section of the Earth's magnetosphere tail is represented in Fig.2 in a projection on the plane Y_{SE}, Z_{SE}, perpendicular to the line Sun-Earth (for an observer from the Earth). The shaded region corresponds to the daily variation of neutral layer's position; the shift of the plane of the neutral layer to the north of the ecliptic plane corresponds to the seasonal variation of the angle between the direction of solar plasma flow and the axis of the geomagnetic dipole (transition to the summer in northern hemisphere). The solid heavy straight line represents the projection of the orbit of the Moon on the plane of Earth's magnetosphere tail cross-section. The dots along the line denote the beginning and the end of days. The vertical strokes correspond to observation sessions. The inclined strokes inside the shaded sector correspond to the position of neutral layer's plane at the moments of time, corresponding to the group of last sessions of 5 April. Shown also in Fig.2 is the position of the Moon corresponding to the session of 4 May.

Therefore, it is simpler to link the change in sign of the difference of field values between fullmoon and new moon with the level of activity, and not with the influence of the tail. In other words, with such an approach the making apparent of the effect of Earth's magnetosphere tail by magnetic measurements may be concealed by the variations of the near-lunar field linked with the variations of solar wind intensity. In connection with this it would be necessary to discuss the possibility of bringing to light the effect of the Earth's magnetosphere tail by magnetic measurements on LUNA-10 in a more general form, starting from the fact that the magnetosphere tail extension to 60 R_E was established by measurements on LUNA-10 with the aid of plasma traps [2, 11], and to 80 R_E according to data of magnetic measurements on Explorer-33 (see ref. [12]).

If we assume that the conduction in the vicinity of the Moon does not differ essentially from the conductance of interplanetary medium, where according to [13] $\sigma \approx 10^{12} \div 10^{14} \text{sec}^{-1}$, we may consider within the framework of magnetohydrodynamic representations that any external magnetic field (for example, the field of the geomagnetic tail) can not penetrate into the region of another field (for example, into the region of the amplified interplanetary field in the vicinity of the Moon) in a time less than $\tau = 4\pi\sigma L^2/c^2$, where σ, L are respectively the conductance and the characteristic dimension of lunar magnetosphere and c is the speed of light. Estimates of τ for the penetration of the interplanetary field into the Earth's magnetosphere could be found, for example, in [14]. For $\sigma \approx 10^{12}$ sec^{-1} and $L \approx 2.7 \cdot 10^8$ cm (this dimension is determined by the major semi-axis of the AMS orbit)it constitutes about 10^7 sec. A qualitative illustration of the general pattern of the passage of lunar magnetosphere through the geomagnetic tail is represented in Fig.3 (transverse section of the part of the northern bunch of lines of force, shown in the form of circles with dots at center; projection of the lines of force of the lunar magnetosphere on the same plane for an observer on Earth is shown by thin solid lines at the center of the figure).

When during its motion along the orbit the Moon is found to be inside the Earth's magnetic tail, the topology of the lunar magnetosphere is determined by the tail's magnetic pressure. During new moon periods the topology of the near-lunar field is determined by the directed pressure of solar wind. If these pressures are close in magnitude, the near-lunar satellite, situated deep within the lunar magnetosphere, may distinguish the substitution of one pressure by another only by indirect data, to which we shall refer below. The magnitude of the magnetic pressure of Earth's magnetosphere tail is in its turn dependent on the solar wind intensity,and its variations in periods of fullmoon relative to new moon will also lead to variations in the value of the near-lunar field, similar to those observed.

According to [3] the failure to bring to light the effect of the Earth's magnetic tail in the experiment on LUNA-10 is linked with the location of the Moon during the sessions of 5 April and 4 May near the neutral layer.

Starting from the above representations, the passage of the Moon from one half of the tail (the northern) into the neutral layer cannot either be detected by a magnetometer situated inside the lunar magnetosphere, for the weakening of Moon's magnetosphere squeezing at the expense of magnetic pressure decrease is compensated by the increase of plasma pressure.

3. Within the framework of the above expounded representations the results of radiation measurements on AMS LUNA-10, are those which lend themselves to natural explanation [11]. During the passage of lunar magnetosphere through the Earth's magnetic tail the solar wind protons can not penetrate inside the Earth's magnetosphere, inasmuch as for them the Larmor radius ($\sim$900 km for protons with energy $\sim$ 1 kev in a magnetic field of $\sim 5\gamma$) is substantially smaller than the characteristic dimension of the terrestrial magnetosphere. Thus, the magnetic tail of the Earth somehow shields the lunar magnetosphere, located inside it, from the solar wind protons. At the same time, solar protons may penetrate into the lunar magnetosphere moving in interplanetary medium beyond the region of influence of the Earth's magnetic tail, inasmuch as the Larmor radius for protons is close in order of magnitude to the dimension of lunar magnetosphere*. The isotropization of the flux of solar protons in the vicinity of the Moon [2, 11] may serve as an indirect corroboration of the proposed model of the near-lunar field.

One should note the qualitative distinction in the character of motion of lunar magnetosphere in an unperturbed interplanetary space and in the Earth's magnetic tail. In the first case we are concerned with super-Alfven solar plasma flow past the Moon. When the lunar magnetosphere passes through the geomagnetic tail the motion has a subsonic character (motion velocity of the Moon along the orbit $\sim 10^5$ cm/sec). In connection with this the formation of a shock wave ahead of the lunar magnetosphere during the latter's passage through the Earth's magnetic tail is found to be impossible. As to the existence of a shock wave ahead of the Moon's magnetosphere in an unperturbed interplanetary space, the situation remains uncertain, inasmuch as in its order of magnitude, the Larmor radius for solar protons is comparable with the dimension of the lunar magnetosphere.

4. When discussing the results of measurements on AMS LUNA-10, specific assumptions were made on account of the limitation of experimental data. It is obvious that the effects of magnetohydrodynamic interaction of the interplanetary medium with the planets of the solar system, devoid of proper magnetic field, must take place in still larger scales because of essential distinction in characteristic dimensions. These effects may serve as an important means for the study of the inner structure of the planets. The study of these questions in a theoretical context as well as in conjunction with target-directed field investigations in the vicinity of the Moon, Mars and Venus appear to be of extreme importance.

The authors avail themselves of the opportunity to sincerely acknowledge the participation of all colleagues in the discussion of the present work.

**** THE END ****

(*) In the course of the discussion of this work, analogous ideas were expressed by K. I. Gringauz.

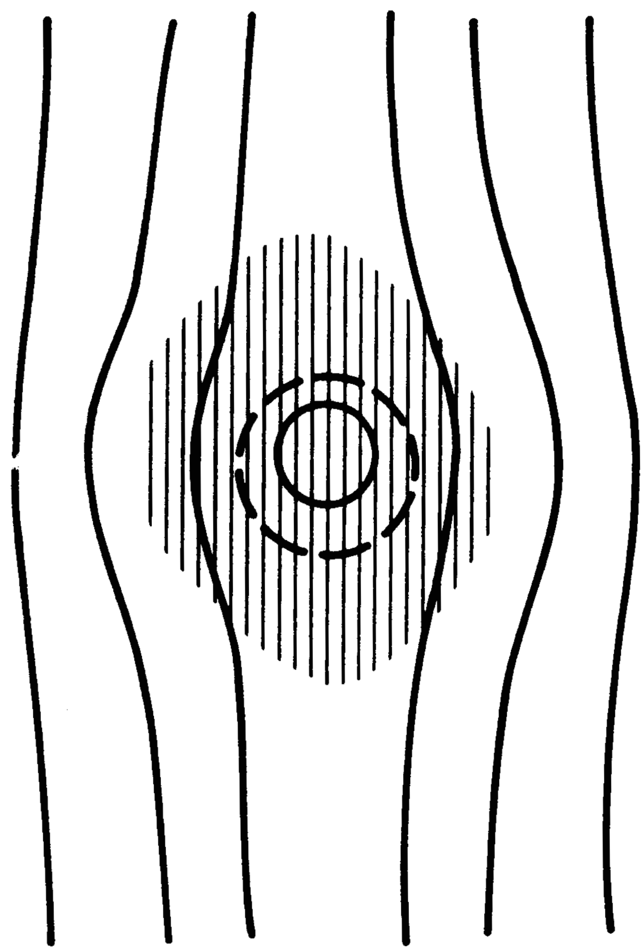

FIG. 1a

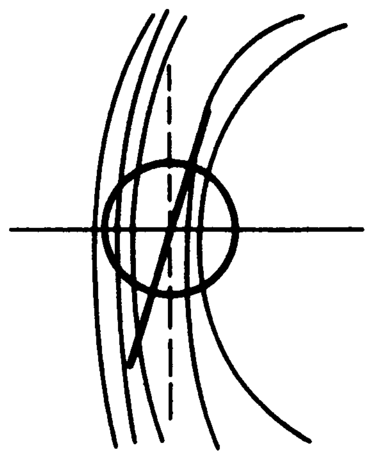

FIG. 1δ

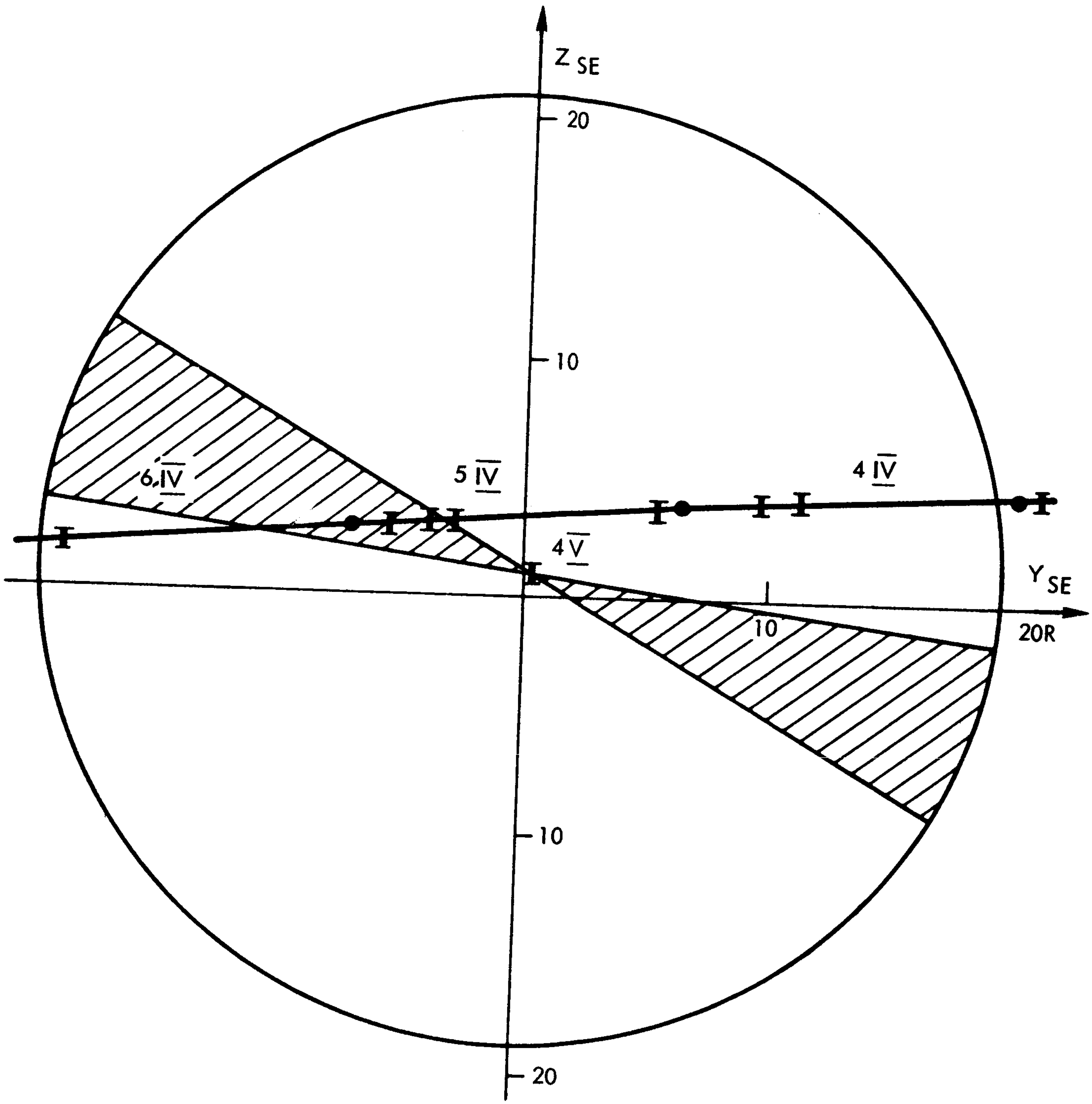

FIG. 2

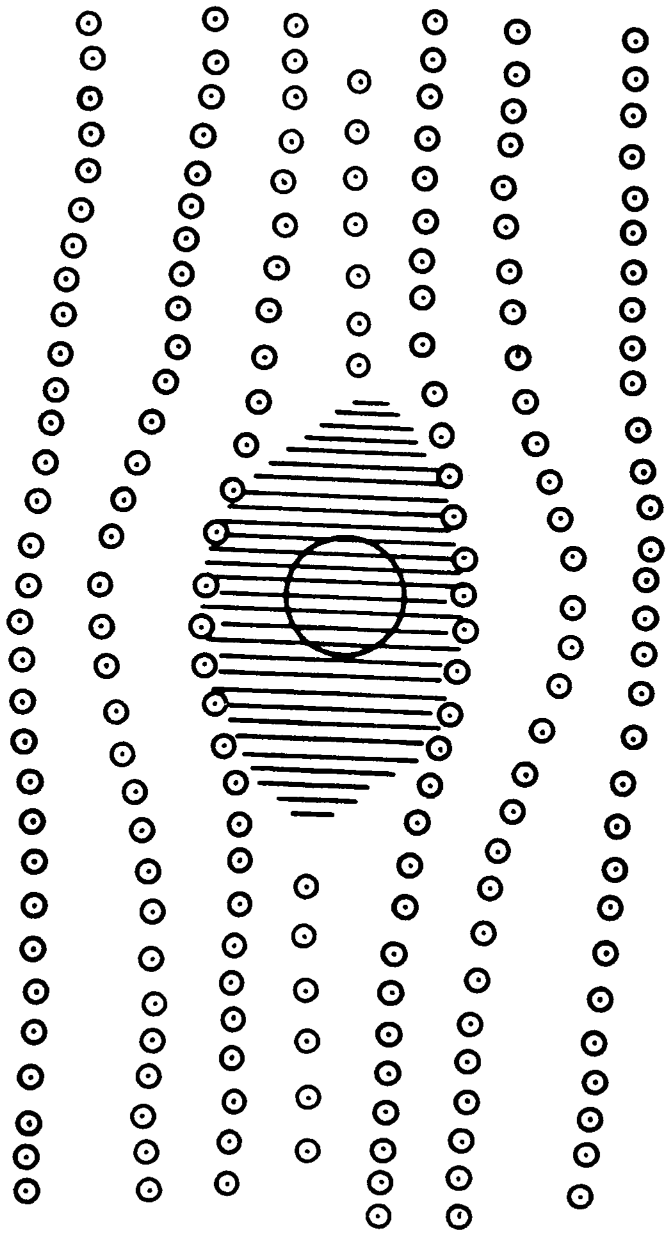

FIG. 3

R E F E R E N C E S

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[Follow plates Figs.1, 2. 3, 4.]

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