SIMULATION OF THE EARTH’ S MAGNETIC FIELD

Physics

1968

SovietRxiv

Abstract

Full Text

UDC 538.711

Physics

G. G. Managadze, I. M. Podgornyi

SIMULATION OF THE EARTH' S MAGNETIC FIELD

(Presented by Academician L. A. Artsimovich on 8 II 1968)

Practically all the available information on the interaction of the solar wind with the Earth' s magnetic field has been obtained from the processing of measurements performed on artificial satellites. Attempts to simulate the phenomena occurring in near-Earth space have not led to noticeable success, since it does not seem possible to set up an experiment while observing all the principles of similarity. The difficulties associated with exact simulation have given rise to experimental works in which almost no attention was paid to selecting the conditions of the experiment, and the conclusions were drawn mainly from the distribution of the plasma glow near the target. Naturally, the value of the data obtained in this way is not particularly great.

In the present work an attempt has been made to carry out limited simulation, i.e., to select the experimental parameters so as to reproduce the principal phenomena in space. In choosing the dimensionless parameters that determine the course of the principal phenomena in near-Earth space, the following principle was used: dimensionless parameters characterizing the course of the given phenomenon and equal, in order of magnitude, to unity in the solar wind are, as far as possible, preserved, while parameters much smaller or much larger than unity are also chosen, respectively, to be smaller or larger than unity, but without preserving the order of magnitude. As an example, let us consider four dimensionless parameters:

1. From measurements performed on artificial Earth satellites (^{1,2}), it follows that the Earth' s magnetic field is localized in a definite region, beyond which extends the region of the undisturbed solar wind. Such a picture is obtained in interaction with the magnetic field of a sufficiently hot plasma, for which the width of the skin layer is much smaller than the characteristic size of the experiment, i.e., the magnetic Reynolds number $\mathrm{Re}_m = 4\pi\sigma\bar{v}L/c^2$ is considerably greater than unity. Here σ is the plasma conductivity, $\bar{v}$ is the directed velocity of the plasma flow, L is the linear size of the magnetosphere, and c is the speed of light. For the solar wind $\mathrm{Re}_m \sim 10^{12}$. In our experiment $T_e \sim 15$ eV and $\bar{v} = 3 \cdot 10^7$ cm/sec; consequently, $\mathrm{Re}_m > 10^3$.

Figure 1 and Figure 2 plots

Figure 1: Figure 1 and Figure 2 plots

2. Under cosmic conditions there is supersonic flow, which must lead to the formation of a shock wave near the boundary of the magnetosphere. The Mach number $\mathrm{M} = \bar{v}/\sqrt{T_e/M_i}$ ($\sqrt{T_e/M_i}$ is the ion-sound speed) in the solar wind is 8-10. With the selected parameters of the laboratory experiment, M is 7-8.

In plasma located in a magnetic field, a disturbance can also propagate with the Alfvén velocity $v_A = H/\sqrt{4\pi n M_i}$. In the solar wind $\mathrm{M}_A = \bar{v}/v_A$ is ~ 8. To preserve such a value of M_A, it is necessary that the strength of the field frozen into the plasma, at a concentration of 10^{13} cm^{-3}, be ~ 30 Oe.

3. In cosmic plasma, Coulomb collisions are not the cause of dissipation of the energy of directed motion, since the ratio

of the mean free path of particles λ in the solar-wind plasma to the dimensions of the magnetosphere L is 10^3. At a plasma concentration in the flow of 10^{13} cm^{-3} and the chosen value of the temperature, $\lambda/L \sim 10$, i.e., in the model experiment as well the dissipation can be only collisionless in character.

4. The ratio of the radii of curvature of the trajectories of ions ρ_i and electrons ρ_e in the region of interaction of the flow with the Earth' s field to the dimensions of this region is considerably less than unity. For the chosen experimental conditions, $\rho_e/L \ll 1$, and $\rho_i/L \sim 1$. However, because of the smallness of the Debye radius,

Fig. 1. Distribution of the concentration on the dayside in the model experiment

Fig. 2. Distribution of the concentration on the dayside from IMP-2 satellite data. 9.X.1964.

ions cannot separate from the electrons; therefore the choice $\rho_i \sim L$ cannot be regarded as arbitrary.

The simulation experiments were carried out with a two-dimensional magnetic dipole, which made it possible to measure the plasma concentration with a laser interferometer without introducing additional disturbances by the measurement. The current in the rods of the dipole was ~ 5000 A, and the distance between their centers was 2 cm. In all experiments the rods were arranged so that the vector of the directed plasma velocity lay in the same plane as the rods.

When a two-dimensional dipole is streamlined by a plasma flow with the chosen parameters, the magnetic field of the dipole is deformed, forming a magnetosphere (^{3}), at whose boundary the relation $\rho v^2 \sim H^2/8\pi$ is satisfied. The width of the transition region between the magnetosphere and the region of undisturbed plasma flow exceeds by an order of magnitude the normal width

Fig. 3. Direction of the lines of force of the magnetic field of a dipole deformed by a plasma flow

Figure 2: Fig. 3. Direction of the lines of force of the magnetic field of a dipole deformed by a plasma flow

Fig. 4. Map of the Earth' s magnetic field according to artificial-satellite data

Figure 3: Fig. 4. Map of the Earth' s magnetic field according to artificial-satellite data

of the plasma-field boundary layer c/ω_0 $\Big(\omega_0 = \sqrt{4\pi e^2 n/m}$ is the Langmuir frequency).

The considerable width of the transition region indicates the development of instabilities, among which the two-stream instability and the excitation of ion sound should be mentioned first of all. In the unstable state of the plasma, rapid growth of the amplitude can cause nonlinear interactions between pulsation scales. The development of instabilities leads to irreversible processes analogous to turbulence in hydrodynamics, i.e., there appears the possibility of dissipation not associated with Coulomb collisions. In other words, conditions are created for the establishment of a shock wave in a collisionless plasma. Measurements performed near the boundary of the magnetosphere facing the plasma flow (i.e., on the dayside, if geophysical terminology is used) showed an increase in concentration analogous to that which takes place in near-Earth space. Figure 1 shows the results of measurements in the model experiment. In Fig. 2, for comparison, data from measurements on the IMP-1 satellite (^{5}) are given; here, however, in contrast to Fig. 1, the ordinate axis gives not the concentration, but the product of the concentration by the square root of the electron temperature. Since heating of the plasma must occur in the shock wave, the larger value of the maximum of the curve in Fig. 2 seems quite natural.

The criterion for the correctness of modeling processes in the magnetosphere is the shape of the lines of force on the night side, where, according to recent satellite measurements, there is a neutral layer separating regions with different directions of the lines of force. Previously, in model

Fig. 3. Direction of the lines of force of the magnetic field of a dipole deformed by a plasma flow

experiments a neutral layer, as far as we know, had never been observed. The basis for modeling the neutral layer was provided by experiments with sharp-pointed traps, in which the field was carried along by the plasma flow (^{8}).

The magnetic field of a two-dimensional dipole and its deformation when it is flowed around by a plasma stream with the parameters: $n = 5 \div 10 \cdot 10^{12}$ cm^{-3}, $T_e \sim 15$ eV, $\bar{v} = 3 \cdot 10^7$ cm/sec, $H_{\text{pl}} = 25$ oersted, was measured by means of magnetic probes.

Fig. 4. Map of the Earth' s magnetic field according to artificial-satellite data

The interaction of the plasma flow with the magnetic field leads to the stretching out of the lines of force on the night side parallel to the velocity vector of the undisturbed flow (Fig. 3). In this case, a rather extended region is observed in which the lines of force near the equatorial plane are parallel to the velocity vector above this plane and antiparallel below it, i.e., precisely the configuration is observed that corresponds to the neutral layer discovered with the aid of artificial Earth satellites. At large distances from the dipole, the lines of force intersect

the equatorial plane. Such crossing may be a consequence of various causes. Among them are:

1. The crossing of the plane was predicted by Dungey from consideration of the configuration obtained by superposing the fields of the solar wind and the magnetic field.
2. The crossing of field lines may be a consequence of current instability in the neutral layer (6, 7). In the present experiments the current density was ~ 5 A/cm^2 at a current concentration in the layer of $5 \cdot 10^{12}$ cm^{-3}. Estimates show (7) that the time for development of the instability exceeds the duration of the experiment.
3. Under the conditions of the present experiments it is impossible completely to exclude the possibility of an influence of the wall on the deformation of the magnetic field; therefore there is a certain, though small, probability that the form of the field far from the dipole is distorted by the presence of the wall. The distance between the rear wall and the center of the dipole is 50 cm.

For comparison, Fig. 4 gives the configuration of the Earth' s magnetic field as it is represented on the basis of individual measurements in space. At distances of 30–40 Earth radii, no crossing of the equatorial plane by field lines has been found. At present the possibility of crossing at greater distances is being discussed.

The authors express their gratitude to L. A. Artsimovich and G. I. Petrov for discussions and to E. M. Dubinin for assistance in carrying out the experiment.

Institute of Space Research
Academy of Sciences of the USSR

Received
7 II 1968

REFERENCES

1. N. Ness, *J. Geophys. Res.*, **70**, 2889 (1965).

2. N. Ness, C. S. Scearce, J. B. Seek, *J. Geophys. Res.*, **69**, 3531 (1964).

3. G. G. Managadze, B. I. Patrushev et al., VIII Intern. Conf. Phen. in Ionised Gases, Vienna, 1967, p. 465.

4. G. G. Managadze, I. M. Podgornyi, V. D. Rusanov, Report at the International Symposium on Shock Waves, Novosibirsk, August 1967.

5. R. Z. Sagdeev, in: *Collected Papers: Problems of Plasma Theory*, vol. 4, Moscow, 1964.

6. H. P. Furth, *Advanced Plasma Theory*, N. Y., 1964.

7. B. Coppi, G. Laval, R. Pellat, *Phys. Rev. Lett.*, **16**, 1207 (1966).

8. I. M. Podgornyi, V. N. Sumarokov, *Nucl. Fusion*, Part 1, Suppl. III, 87 (1962).

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

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.