Geophysics

V. P. Dokuchaev

1960

SovietRxiv

Abstract

Full Text

Geophysics

V. P. Dokuchaev

ELECTRIC DISCHARGE DURING THE FLIGHT OF METEORS IN THE EARTH' S ATMOSPHERE

(Presented by Academician V. G. Fesenkov, 22 X 1959)

It is known that the flight of meteors in the Earth' s atmosphere is accompanied by various electromagnetic phenomena (^{1}). In addition to intense optical radiation, intrinsic radio emission from ionized meteor trails has been observed at long and medium wavelengths (^{2,3}). During the flight of bright bolides and meteorites, deflections of the compass magnetic needle have been recorded. In some photographs of large meteors one can see a luminous halo around the flying particle. In the auroral zone, the passage of meteors leads to the "ignition" of the visible aurora. It is possible that ordinary meteors participate in producing micropulsations of the Earth' s magnetic field (^{4}).

The experimental facts listed above can be explained by an electric discharge in a gas arising during the flight of meteors in the upper layers of the Earth' s atmosphere.

However, for it to occur a mechanism is needed that explains the appearance of sufficiently strong electric fields with intensity E exceeding the breakdown value E_{br}.

Gas discharge in the ionosphere, as applied to auroras, was considered by A. I. Lebedinskii (^{5,6}), and by Wulf as applied to the intrinsic glow of the night sky (^{7}). In these works it was assumed that the gas discharge takes place in induction electric fields. A strong induction field arises in the auroral zone as a result of the motion of fast corpuscles of solar origin across the lines of force of the geomagnetic field. Wulf was interested in altitudes of ~ 200 km, where the breakdown field strength is small. In the meteor altitude region, 80–120 km, homogeneous electric fields do not exceed the breakdown value. The Earth' s electric field rapidly decreases upward from the Earth' s surface and at the indicated altitudes does not exceed 10^{-7} V/cm. The induction electric field E_i is created in this region by wind fields and is determined by the formula (^{8,9})

$$E_i = \frac{1}{c}[\mathbf{VH}_0], \tag{1}$$

where $\mathbf{V}$ is the velocity of the medium; $\mathbf{H}_0$ is the Earth' s magnetic field. Taking $V = 100$ m/sec, $H_0 = 0.3$ gauss, we obtain $E = 3 \cdot 10^{-5}$ V/cm. In (^{8}) it is shown that, owing to polarization of the ionospheric E-layer, an electric field is formed with intensity $E_p = \frac{\sigma_2}{\sigma_1} E_i = 10^{-4}$ V/cm, where σ_1 and σ_2 are, respectively, the transverse and Hall electrical conductivities (^{8}). Thus, in the meteor region there are induction electric fields with intensity $E_0 = 10^{-5}$ V/cm.

The passage of a meteor through the upper layers of the atmosphere is accompanied by the formation of a strongly ionized trail, consisting mainly of electrons and ions of the meteoric substance (meteoric plasma). The concentration of electrons in the trail exceeds by several orders of magnitude the electron concentration in the surrounding ionospheric plasma. Thus, for a meteor of magnitude $+5$, the initial concentration is $N_0 \approx 10^9$ electrons/cm^3, whereas even at the maximum of the ionospheric E-layer at an altitude of 110 km, $N_m \ll 2.5 \cdot 10^5$ electrons/cm^3.

In view of this, it may be assumed that the meteoric particle leaves behind a cloud of well-conducting gas, surrounded by gas of substantially lower conductivity. It is significant that this cloud has the form of a greatly elongated solid cylinder with mean length $l = 10$ km and radius $R = 5$ m. On the other hand, it is known that any conductor placed in an external electric field E_0 becomes polarized and distorts the topology of this field in such a way that, near the pointed ends of the conducting body, an intensified inhomogeneous electric field arises. This is due to the corresponding distribution of polarization charges on the surface of the conductor.

In order to estimate the effect of electric-field enhancement near the ends of the meteor trail, we approximate it by a greatly elongated ellipsoid of revolution; this technique is used in electrostatics in calculating the field of a charged filament of finite dimensions (^{10}). In the case when the external electric field E_0 is oriented along the major axis of the conducting ellipsoid of revolution (the axis of the trail), the intensified electric field near its vertices is readily found (^{10}):

$$E_{\max} = \left(\frac{l}{r_t}\right)^2 \frac{E_0}{\lg(2l/r_t) - 1}, \tag{2}$$

where $r_t^2 = 4Dt + r_0^2$ is the effective radius of the trail (the minor semiaxis of the ellipsoid); D is the diffusion coefficient; r_0 is the initial radius of the trail.

It is evident that the enhancement of the field E_0, in which the moving meteor forms its ionized trail, will be most intense in the head part of the trail, since the radius of the initial section will increase during the flight as a result of diffusion and the field, in accordance with formula (2), will decrease. Taking as average values $r_t = 5$ m, $l = 10$ km, the intensified field in the head part of the trail will be $E_{\max} = 10^6 E_0 = 10$ V/cm. The field proves to be enhanced along the entire length of the ellipsoid, but the greatest enhancement occurs near the vertex in a region of size $d = 0.1l$. Consequently, the greatly elongated, needle-like form of the trail leads to an enhancement by a factor of 10^6 of the weak electric field of the surrounding medium. The degree of enhancement depends on the angle at which the meteor flies relative to the electric-field lines E_0; when it flies across them, enhancement is practically absent. It is easy to verify that the surface force $E^2/4\pi$, exerted by the intensified field on the surface polarization charges, does not exceed the partial pressure of the meteoric plasma and does not exert any noticeable mechanical effect on trails with electron density $N_0 \ll 10^{10}$ electrons/cm^3.

The breakdown value of the electric-field strength leading to the occurrence of an electric gas discharge may be found by using the known expression (^{12})

$$E'_{\text{br}} = \frac{Ap}{B + \lg(pd)}, \tag{3}$$

where p is the gas pressure in mm Hg; d is the length of the discharge gap in cm; $A = 2.6 \cdot 10^3$ and $B = 0.68$ are constants associated with the ionization coefficients by electrons and ions (^{11}). At the mean altitude of the meteoric region $h = 92.5$ km, let us take $p = 10^{-3}$ mm Hg (^{13}) and $d = 1$ km—

average size of the region of enhanced field. Substituting these values into formula (3), we obtain $E'_{\text{br}} = 1$ V/cm. Perpendicular to the Earth' s magnetic field the breakdown field strength increases:

$$E''_{\text{br}} = \frac{\sigma_0}{\sigma_1} E'_{\text{br}}, \tag{4}$$

where σ_0 and σ_1 are the electrical conductivities, respectively, along and across the geomagnetic field (^{9}). At an altitude $h = 110$ km, $E''_{\text{br}} = 10$ V/cm. A comparison of the breakdown field strengths and the enhanced field in the head part of the meteor trail indicates the possibility that the breakdown conditions are fulfilled (^{11}). Thus, the strengthening of the electric field near a flying meteor leads to the formation of one of the forms of gas discharge.

On the basis of the foregoing, one may conclude that the luminous halo adjacent to the moving meteor arises as a consequence of corona formation in the head part of the ionized trail. The corona encompasses the entire region of the nonuniform electric field and has a diameter on the order of $1 \div 2$ km. The flight of bright meteors, in the case of strong electric fields, may be accompanied by a transition from a corona discharge to a spark discharge of the lightning type. The development of a spark-discharge channel is facilitated by the presence of a conducting cylindrical trail, the head part of which will grow at a speed of $\sim 5 \div 10$ km/sec (^{11}), which will lead to an overestimate of the true speed observed by means of radar installations. The radio emission of both corona and spark discharges will create interference with radio reception on long waves.

In a spark discharge the electric current along the trail increases considerably, which may lead to micropulsations of the Earth' s magnetic field. Let us give approximate estimates of the magnitude of the current in the case of electrical breakdown. We shall assume that the trail decays under the action of diffusion and recombination processes. In this case the concentration of the meteor plasma is determined by the formula (^{14})

$$N(r,t) = \frac{Q}{\pi r_t^2(1+kQt)} e^{-r^2/r_t^2}, \tag{5}$$

where Q is the initial linear density of electrons, and k is the recombination coefficient. The current density in the absence of breakdown is $j_0 = \Sigma E_0$, where the conductivity is $\Sigma = \sigma N(r,t)$. The total current I_0 through the cross section of the trail is easily found by integrating j_0 over this cross section:

$$I_0 = \int_0^\infty \int_0^{2\pi} r j_0(r,t)\, dr\, d\varphi = \frac{\sigma Q E_0}{1+kQt}. \tag{6}$$

According to the general theory of electrical discharge, the enhanced current may be estimated approximately by the formula $I \sim I_0 e^{\alpha d'}$, where α is the electron ionization coefficient and d' is the effective discharge gap. Taking into account the nonuniformity of the electric field and the spatial charge associated with it, the exponent is $\alpha d' = 8$. Consequently, the current is enhanced by a factor of 3000. For $\sigma = 100$ cm^3/sec, $Q = 10^{13}$ el/cm, $E_0 = 10^{-5}$ V/cm, the initial current is $I_0 = 10^{-2}$ A, whereas the enhanced current reaches $I \sim 30$ A. Such a current is capable of producing micropulsations of the Earth' s magnetic field $\Delta H_0 = 10^{-7}$ G.

The calculations presented remain valid for meteorites flying in an electric field which, near the Earth' s surface in clear weather, has an average value $E_0 = 1$ V/cm. An amplification of the field by a factor of 10^4 in the head part of the meteoritic ionized cloud can also exceed the breakdown field strength in the troposphere, $E_{\text{br}} = 3 \cdot 10^4$ V/cm. The lights

St. Elmo' s fire and electrical discharges in the form of lightning, arising during the fall of meteorites, have been noted by some observers (1).

Scientific-Research Radiophysical Institute
at Gorky State University
named after N. I. Lobachevsky

Received
23 VII 1959

REFERENCES

1. I. S. Astapovich, *Meteor Phenomena in the Earth' s Atmosphere*, Moscow, 1958.

2. Yu. N. Khlyustov, Bull. All-Union Astron.-Geod. Soc., No. 10, 37 (1951).
3. D. W. R. McKinley, P. M. Millman, Proc. IRE, 37, 364 (1949).
4. A. G. Kalashnikov, Izv. Acad. Sci. USSR, Geophys. Ser., No. 6 (1952).
5. A. I. Lebedinsky, DAN, 86, 913 (1952).
6. A. Y. Lebedinsky, *The Airglow and the Aurorae*, 1955, pp. 222–223.
7. O. R. Wulf, J. Geophys. Res., 58, 531 (1953).
8. D. F. Martin, Phil. Trans., A246, 281 (1953).
9. V. P. Dokuchaev, Izv. Acad. Sci. USSR, Geophys. Ser., 5, 783 (1959).
10. Ya. I. Frenkel, *Electrodynamics*, Moscow–Leningrad, 1935.
11. Ya. I. Frenkel, *Theory of Phenomena of Atmospheric Electricity*, Moscow–Leningrad, 1949.
12. A. Engel, M. Steenbeck, *Physics and Technology of Electrical Discharge in Gases*, vols. 1 and 2, Moscow–Leningrad, 1935.
13. M. Nicolet, Proc. IRE, 47, 93 (1959).
14. O. V. Dobrovolsky, Bull. Stalinabad Astron. Observatory, No. 1, 15 (1952).

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

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