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Short Contribution

ROCKET EXPERIMENTS AIMED AT DETECTING AN ELECTRIC FIELD IN THE IONOSPHERE

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To understand the processes occurring in the ionosphere, it is very important to study electric fields. It is desirable to conduct such an investigation by direct methods using instruments mounted aboard rockets and satellites.

The difficulties preventing the realization of such measurements are connected with three factors:

(*1*) The small strength of electric fields in the ionosphere, which puts serious requirements to sensitivity of instrumentation.

(*2*) The effect of the charge of the bodies situated in plasma, and of the formation of layers of a volume charge around the body which is inseparably connected with this body's charge (therefore, the strength of the electric field near the surface of the body is determined not only by its geometry but, at a given potential, by the thickness of these layers).

(*3*) The presence of currents produced by free charged particles and by photoeffect from the sounding body and instruments, mainly under the influence of solar ultraviolet radiation, which flow to the sounding body (these currents will subsequently be called interference currents since they hinder measurements).

To conduct measurements of the rocket's own charge and to elucidate the possibility of measuring an electric field in the ionosphere, experiments were carried out in the U.S.S.R. during the I.G.Y. which were aimed at measuring the strength of the electrostatic field near the surface of geophysical rockets of the U.S.S.R. Academy of Sciences. In 1959–1961, these experiments were continued with improved techniques. In the present report, only one of the results obtained during these experiments

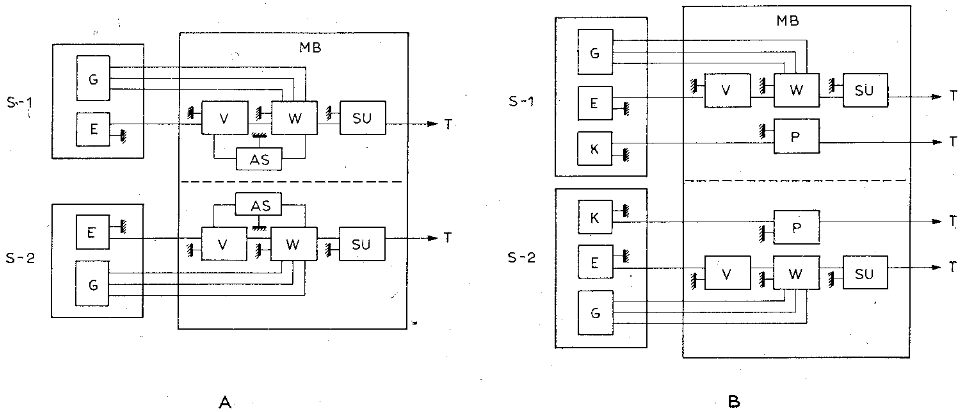

Fig. 1. Block-diagram of experiments aimed at measurements of the strength of an electric field in the ionosphere in 1957–58 (A) and 1960–61 (B). S-1, S-2 = sensors; E = electrostatic generator; G = electromagnetic generator; K = collector; MB = measuring block; V = amplifier; w = synchronous detector; AS = automatic sensitivity switch; SU = matching device; P = amplifier, and T = telemetry system.

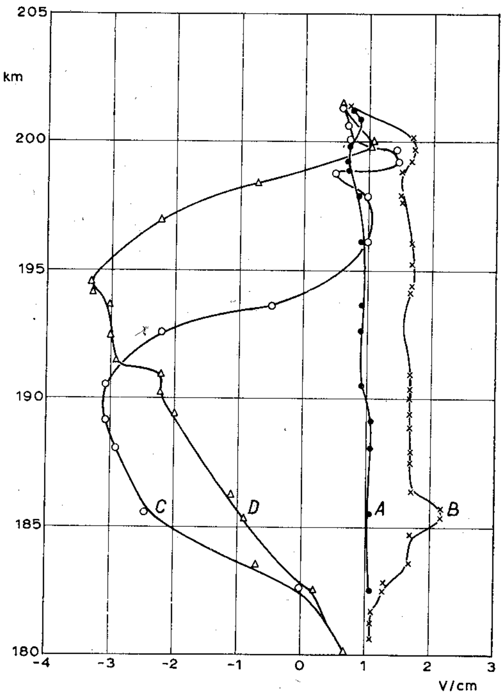

Fig. 2. Results of the experiment on September 9, 1957. *A* and *B* represent the strength of an electric field measured by one sensor at the ascent and at the descent of the rocket, respectively, and *C* and *D* are the same for the other sensor.

is considered, that concerning the detection of an electric field in the ionosphere. In the experiments, an electrostatic fluxmeter method was used which had previously been successfully employed in tropospheric measurements (IMIANITOV, 1957).

A block-diagram of the experiments conducted in 1957–1958 is presented in Fig. 1A. These experiments had the following main characteristics:

(*1*) The use of two sensors (which give voltage proportional to an electrostatic field strength near the rocket surface at the places where the sensors are installed) placed in diametrically opposite points of the cylindrical part of the rocket's surface.

(*2*) Simultaneous use of an automatic switch and a synchronous detector.

The use of two sensors permits, in principle, the separation of the field strength produced by the body's own charge from the strength component of the outer electric field in the direction of a straight line connecting the points where the sensors are mounted (IMIANITOV, 1957). The simultaneous use of an automatic sensitivity switch and a synchronous detector makes it possible to extend the measuring range and, for measured values of an electric field strength, to distinguish whether the changes of the output signal are caused by the measurement of working current produced by an electric field near the rocket's surface or by an interference current (GDALEVICH, 1962). The synchronous detector in experiments of 1957–1958 attenuated the effect of interference currents on output signals by approximately five times. At the same time, interference currents affected the automatic sensitivity switch the same as working currents. Therefore, if an input signal measured according to readings at the output at the moment the sensitivity switching was five times lower than the signal at which switching should take place, measured strength values would be determined by interference currents and not by working currents.

The sensitivity threshold of the instrumentation in use was 0.06 V/cm. The sensitivity switching should have occurred in the case of the absence of interference currents at $E = 6$ V/cm.

The first experiments aimed at measuring the electric field strength showed that the field strengths measured simultaneously by two sensors, at least at several heights, have essentially different values exceeding values of maximally possible instrument errors. Fig. 2 shows results of measurements near the apex of the trajectory. The experiment was carried out on September 9, 1957, at 19h54 at the sinking of the sun to 6°, which corresponds to the earth's shadow heigth of approximately 30 km. During its flights in the ionosphere, the rocket was not stabilized and could rotate. Analysis of the work of the sensitivity switch showed that, in this experiment, the interference current density value did not exceed $5 \cdot 10^{-10}$ A/cm^2, and the main part of measured values was connected with actual values of the electric field strength near the surface of the rocket flying in the ionosphere. Thus, since the sensors were situated symmetrically and at an equipotential surface, thicknesses of the volume charge surrounding the rocket were different at the places where the sensors were mounted. This difference of the thicknesses of the volume charge layers near the sensors can be caused by:

(*1*) the rocket motion, which produces inequality of charged particle flows to different sections of its surface;

(*2*) photoemission from part of the rocket's surface under the influence of solar ultraviolet and X-ray radiations;

(*3*) the medium motions connected with ionospheric winds or charged particle drift, and:

(*4*) the presence of the outer electrostatic field.

Since in Fig. 2 results are given which were obtained on a non-stabilized rocket, the difference of the strength near the apex measured by the sensors and identity in the apex itself can be ascribed to photoeffect and simultaneous rotation of the rocket.

To exclude the possibility of different influences exerted by photoeffect at various altitudes, the experiments were transferred to stabilized rockets in 1958. In Fig. 3, results are presented near the apex of the trajectory obtained in the experiment on a stabilized rocket which was launched on August 27, 1958 at 8h06. Analysis of the operation of the sensitivity switch showed that, in this altitude range,

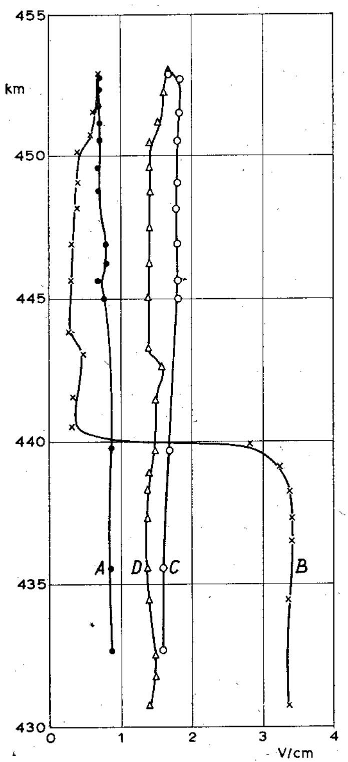

Fig. 3. Results of the experiment on August 27, 1958. *A*, *B*, *C* and *D* are the same as in Fig. 2.

the density of interference currents did not exceed $5 \cdot 10^{-10}$ A/cm^2 and the difference in strengths measured by sensors was not connected with interference currents.

The difference in thicknesses of layers of a volume charge connected with the rocket's motion is absolutely absent in the apex of the trajectory and is small near it. From Fig. 3 it is evident that the difference of measured strength values changes the magnitude and even the sign, though the location of the sensors with respect to the sun had not changed. Thus, the difference in strengths cannot be accounted for by photoeffect. If the difference in volume charge layers thicknesses is connected with medium motions, then, taking into account that at motion in the earth's magnetic field the charged particle flux neutrality is preserved only in the presence of the electric field, one can assert that the said difference is connected with the electric field. Thus, the first experiments showed that, without employing the effect connected with the presence of the outer electric field in the ionosphere, it is impossible to explain the results obtained (GDALEVICH, 1962). However, a relatively high value of instrument error $\Delta E = \pm \sqrt{\{0.16 + (0.15E)^2\}}$V/cm determined by maximum possible deviations of "zero" readings and sensitivity changes, and the influence (though very small) of interference currents in experiments of 1957–58, complicate the separation (from experimental results at all heights) of a part of the difference in strengths measured by the sensors, which is connected with the outer electric field in the ionosphere. In 1959–61, the experiments were continued with modernized apparatus. A block-diagram of experiments of 1960–61 is presented in Fig. 1B. The fundamental properties of these experiments are the following:

(*1*) The use of the grid design of the measuring and additional screen plates to decrease modulation and absolute magnitude of interference currents (IMIANITOV and SHVARTS, 1959), and:

(*2*) Direct measurement of interference currents flowing to the collector under the measuring plate.

In 1959, sensors were used with a grid design of the measuring and additional screen plates for a decrease of interference currents, the evaluation of whose magnitude was carried out on the basis of analysis of the operation of the sensitivity switch, as it was done in 1957–1958. In 1960–1961, the use was made of sensors with grid design of plates, and instead of an automatic sensitivity switch, d.c.-amplifiers were used in a measuring block for measurements of the magnitude of interference current, which penetrated through the sensor grid plates and reached the collector. In addition, the selection of the input circuit parameters and the use of special methods of tuning made it possible to tune a synchronous detector to minimum interference voltage with an accuracy of about 3° and, thus, to increase the signal voltage-to-interference voltage ratio (SHVARTS, 1961). It was feasible to tune a synchronous detector still more accurately, but taking into account that the shape of the curve of the signal voltage generated by the sensor at the expense of the instrument's design differs from the ideal one, further improvement was irrational. The results of experiments turned out to be, in general, the same as in 1957–1958, though the measurements taken made it possible to further decrease the effect of interference currents by approximately 30 times. Let us consider the results of the experiment of Fig. 4, conducted on a stabilized geophysical rocket of the Academy of Sciences, which was launched on November 15, 1961, at 15h00 (IMIANITOV et al., 1963). The measuring range of instrumentation in the experiment was $\pm$ 6 V/cm. The sensitivity threshold was 0.06 V/cm. The maximum measuring error did not exceed 0.4 V/cm. The results of measurement could be affected by the dependence of the readings of the instrument on the position of the field source which is displayed most sharply at low thicknesses of the layers of the volume charge. This led to the fact that absolute values of the electric field strength at the rocket surface were determined with an accuracy on the order of 20–25 %. It should be pointed out that during the flight, sensor 2 was sun-lit at an angle of 4°, the other sensor was in shadow. The current to the collectors of the sensors throughout the entire trajectory was lower than the limit sensitivity of current amplifiers, i.e., it did not exceed 10^{-9} A/cm^2. From Fig. 4, it is evident that the strength semidifference (curve III) which determines the value of the outer electric field strength varies within 0.5–1 V/cm. The upper limit of the value cannot be explained by the measuring error. Let us, for instance, consider the electric field strength variation between 200–300 km. If the error is not taken into account, the value of semidifference is 1 V/cm. When we take into account the method's error and inaccuracy in measurements of the actual value of the electric field strength near both sensors, 3.6 V/cm $\geqslant E_2 \geqslant$ 1.6 V/cm and 1.2 V/cm $\geqslant E_1 \geqslant\geqslant$ 0.1 V/cm. This means that the value of semidifference should be lower than 1.8 V/cm, but higher than 0.2 V/cm. Thus, at a definite altitude, there is a difference in readings of the two sensors which has a value at least on the order of tenths of a V/cm. This difference cannot be connected with the difference in the thickness of the volume charge layers connected with the rocket's motion or with photoemission under the influence of sunlight, since it is present in the apex of the trajectory, and the increase of the thickness under the influence of sun-

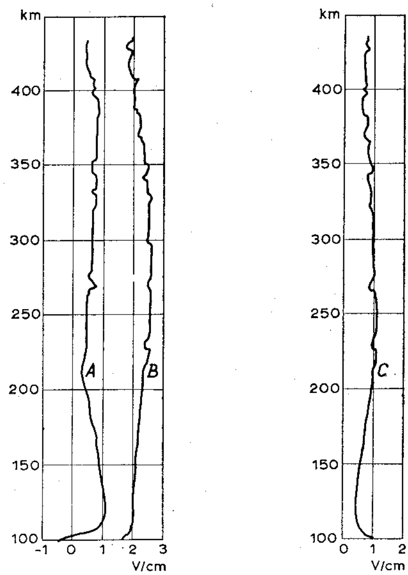

Fig. 4. Results of experiment on November 15, 1961. *A* represents the strength of an electric field measured by sensor 1 at the rocket's ascent. *B* is the same for another sensor. *C* represents the semi-difference of values of the strength of an electric field measured by sensors simultaneously at the rocket's ascent.

light at a given geometry of the experiment should have led to a decrease of the marked difference. Consequently, the difference of the field strength measured simultaneously by the sensors is connected with the outer electric field in the ionosphere.

It is possible to consider two cases which explain such a difference of 0.10 V/cm connected with the outer electric field: (*1*) a direct increase of the outer field strength near the rocket's surface; and (*2*) a variation of the thickness of layers near sensors due to directed motion of charged particles.

DIRECT INCREASE OF THE STRENGTH OF AN OUTER FIELD NEAR THE ROCKET'S SURFACE

Let us consider a scheme of the outer field amplification suggested by Imianitov. On a charged body with a circular cross section, two flat conducting plates 1 and 2, connected with the body by a conductor, are located at diametrically opposite points. For the sake of definiteness, assume that the charge of the body is negative. Before the appearance of an outer field, both plates are in equal conditions and the thickness of each is δ. Let us assume that, in a medium, a field is generated with the strength E_i, directed from the first plate to the second. This leads to an increase of positively charged particle flow to plate 1 and negatively charged particle flow to plate 2. The thickness of the layer near plate 1 will be $\delta_1 < \delta$ and near plate 2, $\delta_2 > \delta$. The field strength near the plates will vary at the expense of the appearance of an additional field E_1 and E_2 on the plates from the outer field E_i, and at the expense of the field variation from its own charge due to the change in the thickness of layers. If one supposes that the value of directed velocity acquired by particles in an outer field constitutes a small part of the value of thermal velocity, the deformation of layers in such cases is small. Therefore, in a weak field, $\delta_1 = \delta_2 = \delta$. An additional field generated by charge induced on plates 1 and 2 by an outer field also should not penetrate into the atmosphere beyond the layers with thickness δ. This supposition is true if the potential difference from an outer field at a section with length equal to the body diameter is much lower than the potential from its own charge. Since the body surface is equipotential, an outer field potential U fall at a section occupied by the body is concentrated at sections δ_1 and δ_2. Then, if the radius of the body $a \gg \delta$, $U = 2aE$. The field strength E of the body wall produced by an outer field E_i equals $E = E_i a/\delta$. For rockets in our experiments, the outer field strength amplification factor a/δ near their surface was close to one hundred. Thus, if the suggested amplification mechanism is correct, an electric field with the strength of 10^{-3} V/cm existed in the ionosphere at a time of the experiments, at least at some heights.

It should be pointed out that a formal picture of the amplification of a field near the rocket's surface has been considered. In reality, the process is more complex. In fact, the appearance of a body in a plasma in which an electric field E exists, causes the appearance of a volume charge of an opposite sign near the body since regions of partial shadowing appear near the body, on the one side for negatively charged particles and on the other side for positively charged particles (the appearance of these regions is similar to the appearance of the "rarefaction" region filled with electrons behind the body which moves with a velocity exceeding ion thermal velocity). Since electron velocities are higher than ion velocities, the filling of the region with excess positive ions by electrons will be more intense than filling of the electron region by ions. The dimensions of regions produced will depend on the ratio of the values of thermal and directed velocities of the particles, and the dimensions of the body and its potential. However, in the case where thermal velocities of particles are much higher than directed ones, the above amplification scheme can be considered acceptable.

If the supposition is untrue about small deformation of layers of a volume charge under the influence of particle motion caused by an outer electric field, this variation should be calculated by another way.

VARIATION OF THE THICKNESS OF LAYERS OF THE VOLUME CHARGE NEAR THE SENSORS DUE TO DIRECTED MOTIONS

At considerable deformation of the layers of the volume charge in the vicinity of the body surface, the field strength near the surface will change. If we consider the body potential invariable, the field strength to a first approximation will vary proportionally to the change of the layer thickness. The layer thickness variation will be determined as $v_0/v_\perp$, where v_0 is the flow directed motion velocity component orthogonal to the direction of the rocket motion and $v_\perp$ is thermal velocity. The field strength E at a given point of the body turns to be a function: $E = f[V/(v_0/v_\perp)]$ where V is the body potential. If E_1 and E_2 are measured at two diametrically opposite points 1 and 2 of the body, then:

$$\frac{E_1}{E_2} = \varphi\left(\frac{v_0}{v_\perp}\right)$$

Not dwelling upon the details of such a calculation, let us notice that, from the ratio cited, it follows that by measuring E_1 and E_2 it is possible to determine the particle flow velocity with respect to the body and if, as has been done in our experiments, the effect of the body motion on results of measurements is excluded, it is possible to determine the velocity of directed motion of particles v_0 in the corresponding direction. In an investigated altitude range, the particle drift can appear only due to the perpendicular component of the electric field E_1 with respect to v_0 and the earth's magnetic field strength H (GERSHMAN and GINZBURG, 1959). Thus, it turns out that the electric field strength in the ionosphere $E_1 = (v_0/c)H$, where c is velocity of light. From the results of the 1961 experiments, it follows that v_0 at different points of the trajectory amounted to 200–600 m/sec and, consequently:

$$E_1 = (1\text{–}3)\ 10^{-4}\ \text{V/cm}$$

Thus, measurements of the electric field strength at the surface of a rocket moving in the ionosphere can be used for determination of directed ion velocity which cannot be achieved by means of radio waves. If this ion motion is the result of a charged particle drift under the influence of E_1, the measurements will also enable us to determine the value of the stationary electric field in the ionosphere.

It should be noted that the measured values of the strength of an electrostatic field in the ionosphere on the order of 10^{-3}–10^{-4} V/cm do not contradict the data of indirect observations. In fact, inhomogeneous drift velocities in the F layer of the ionosphere usually have values of $1 \cdot 10^4$–$3 \cdot 10^4$ cm/sec. However, in some cases, they reach the values of $2 \cdot 10^5$ cm/sec which corresponds to $E_1 = 0.8 \cdot 10^{-3}$ V/cm (GERSHMAN and GINZBURG, 1959). It is interesting also to point out that, in a recent paper

(MEGILL et al., 1963), the value $E_1 = 2 \cdot 10^{-3}$ V/cm is used for the explanation of the intensity of the red line of atomic oxygen in medium latitude subvisual arcs.

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REFERENCES

GERSHMAN, B. N. i GINZBURG, V. L., 1959. *Izv. Vysshikh Uchebn. Zavedenii, Radiofiz.*, 2(1) : 8.
GDALEVICH, G. L., 1962. *Dokl. Akad. Nauk S.S.S.R.*, 146(5) : 1064.
IMIANITOV, I. M., 1957. *Instruments and Methods for Studies of Atmospheric Electricity*. G.I.T.T.L., Moscow, 384 pp.
IMIANITOV, I. M. and SHVARTS, YA. M., 1959. *Artificial Earth Satellites*, 1959(3) : 77.
IMIANITOV, I. M., GDALEVICH, G. L. i SHVARTS, YA. M., 1963. *Dokl. Akad. Nauk S.S.S.R.*, 148(6) : 1306.
MEGILL, L. R., REES, M. H. and DROPPLEMAN, L. K., 1963. *Planetary Space Sci.*, 7(11) : 45.
SHVARTS, YA. M., 1961. *Radiotekhn. i Elektron.*, 6(1) : 153.