RESULTS OF EXPERIMENTS ON THE DETECTION OF THE LUNAR IONOSPHERE, CARRIED OUT ON THE FIRST ARTIFICIAL SATELLITE OF THE MOON

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RESULTS OF EXPERIMENTS ON THE DETECTION OF THE LUNAR IONOSPHERE, CARRIED OUT ON THE FIRST ARTIFICIAL SATELLITE OF THE MOON

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On the Luna-10 spacecraft, among other instruments, two charged-particle traps were installed, intended for the registration of positive ions and electrons of low energies (⌒1). In the present communication we give preliminary results of the processing of data obtained with the aid of these traps.

Hypotheses concerning the existence near the Moon of a region with an increased (in comparison with interplanetary space) concentration of charged particles—the lunar ionosphere—are based on the fact that the gravitational field of the Moon is sufficient to retain atoms of heavy gases (for example, argon), the sources of which may be both streams of solar plasma and the radioactive decay of potassium. In addition, hydrogen atoms evaporating from the surface of the Moon (neutralized protons of the solar wind) as a result of charge exchange with positive ions of the solar-wind streams may also create a certain concentration of low-energy protons near the Moon. Calculations ($^{2\text{-}}$4) for various models of the ionosphere lead to particle concentrations in the range $5 \cdot 10^1 \div 10^3$ cm^{-3}. Experimental estimates of the upper limit of the electron concentration n_e in circumlunar space were obtained from observations of the refraction of radio waves during occultations by the Moon of a number of radio sources. From the occultation of the Crab Nebula in 1956 an estimate $n_e \sim 10^3$—10^4 cm^{-3} was obtained, depending on the height of the homogeneous atmosphere h, from 80 to 5000 km (⌒5). In 1963, from observation of the occultation of the radio source 3C273, the upper limit of n_e at the lunar surface was lowered to a value of 100—200 cm^{-3} (on the assumption that $h \sim 80$ km) (^{6,}7).

The difficulties of directly measuring the concentration of charged particles in the Moon' s ionosphere, apart from the smallness of the quantity to be determined, are aggravated by the uncertainty of information about the electric potential of the satellite. In connection with this, on Luna-10 there were used both a trap intended to measure the concentration of thermal positive ions,

Fig. 1

Figure 1: Fig. 1

whose registration is possible if the satellite potential $\varphi_{\text{sp}} \lesssim 0$, and a trap intended to measure the concentration of thermal electrons, registered at $\varphi_{\text{sp}} \gtrsim 0$. The layout of the traps and the values of the voltages on the electrodes relative to the satellite body are shown in Fig. 1. The ion trap (a) is a modulation trap and consists of two identical traps with connected collectors, similar in construction to the trap described in (⌢8). Such a design makes it possible to broaden considerably the angular characteristic of the trap. An alternating rectangular voltage from -3 to $+7$ V was applied to the modulation grid. The alternating component of the collector current was registered by a resonance amplifier tuned to the modulation frequency.

In the design of the electron trap, in comparison with the three-electrode traps with constant potentials on the electrodes installed on other Soviet spacecraft (^{8,}9), changes were introduced in order to reduce the magnitude of the photocurrent from the outer grid and the parts fastening it. The potentials of the outer grids of the traps were changed once every 2 min.

changed stepwise and were either 0 or -50 V for the ion trap and either 0 or $+50$ V for the electron trap. The signal at the output of the electron-trap amplifier is proportional to the collector current if the latter is negative, and is absent if the current is positive.

The arrangement of the traps on the Luna-10 spacecraft and the projection of the Moon' s orbit onto the plane of the ecliptic for the instants of time under consideration are shown schematically in (1).

If the velocity of the spacecraft exceeds or is close to the mean thermal velocity of the ions, then the current of the ion trap I_p depends substantially on the orientation of the plane trap relative to the velocity vector. Measurements of the collector currents of each of the traps considered were made during radiocommunication sessions once every 2 min, with the satellite' s rotation period being ~ 40 sec. It is possible that precisely for this reason the measured values of I_p varied in a rather irregular manner. Most of the readings (out of a total number of ~ 450) lie within the limits $(3 \div 5) \cdot 10^{-12}$ A.

Fig. 1

Figure 2 shows the values of I_p measured in interplanetary space (A) and while the Moon was in the presumed extension of the "tail" of the Earth' s magnetosphere (1) at various heights H above the lunar surface ( ). From the graph (constructed using values of I_p obtained on different revolutions of the satellite around the Moon) it is seen that there is no noticeable dependence of I_p on H. A comparison of the values of I_p when the Moon is in the tail of the Earth' s magnetosphere and in interplanetary space confirms the conclusion made in (1)

Fig. 2

Figure 2: Fig. 2

that the fluxes of charged particles in the lunar orbit differ in these regions of space. (Thus, in the first case the mean value is $I'_p = (2.3 \pm 0.1) \cdot 10^{-12}$ A, while in the second $I''_p = (3.1 \pm 0.1) \cdot 10^{-12}$ A.) If it is assumed that the current of the modulation trap is determined only by thermal ions (on another possibility, see below), then from the measured values of I_p one can estimate the upper limit of their concentration, assuming that $\varphi_{\text{sp}} \lesssim 0$ and that the maximum values of I_p correspond to coincidence of the normal to the trap collector with the direction of the velocity vector. The field-of-view sector of this trap (at the 0.1 level) amounts to $\sim 1/3$ of all space; therefore the latter assumption (with a large number of measurements on different parts of the orbit around the Moon) appears quite probable.

The effective area of the trap collector is 14 cm^2. Taking into account all that has been stated, the maximum values of I_p give an estimate of the upper limit of the ion concentration $n_i \sim 100$ cm^{-3}, if the directed velocity of the satellite (~ 1 km/sec) is assumed to be much greater than the thermal velocity of the ions (i.e., if the lunar ionosphere is assumed to consist of heavy ions). If the ionosphere consists of hydrogen ions with a temperature of $\sim 10^3$—10^4 °K, this estimate should be lowered somewhat (by a factor of 2-3).

The current of the electron trap I_e in the majority of measurement sessions varies over wide limits from 10^{-10} to $2.2 \cdot 10^{-9}$ A (see Fig. 3). All readings can be divided into two fairly sharply distinct groups– "large" currents ($(1.8 \div 2.2) \cdot 10^{-9}$ A) and "small" currents ($(1 \div 9) \cdot 10^{-10}$ A), while intermediate current values are almost never encountered.

The "large" values of I_e are apparently explained by the entry into the trap, during the satellite' s rotation, of a flux of photoelectrons emitted-

under the action of solar radiation from the nearest parts of the surface of the spacecraft. An estimate of the photocurrent from the trap grids, taking account of laboratory measurements, gives (3-4) $\cdot 10^{-10}$ A. The "small" values of I_e in cases when the Moon is in the tail of the Earth' s magnetosphere (see, for example, Fig. 3A) and in interplanetary space (see Fig. 3B) also

Fig. 2

differ noticeably. Thus, in the magnetosphere the mean value of I_e is $(4.8 \pm 0.1) \cdot 10^{-10}$ A, whereas in interplanetary space I_e does not fall below $4 \cdot 10^{-10}$ A, and its mean value is $(7.2 \pm 0.1) \cdot 10^{-10}$ A.

Interpreting the "small" current values as being produced by isotropic fluxes of electrons and assuming $\varphi_{\text{SC}} \geq 0$, one can estimate the upper limit of the concentration of low-energy electrons in circumlunar space. For the indicated mean values, taking into account a possible shift of the zero level due to fluxes of ions

Fig. 3

Figure 3: Fig. 3

with $E > 20$ eV entering the trap, an estimate of the concentration of electrons with energy $E \sim 1$ eV gives $n_e \sim 80$ cm^{-3} for the Moon located in interplanetary space, and $n_e \sim 60$ cm^{-3} for the Moon in the Earth’ s magnetosphere.

Of interest is an estimate of the value n_e from data obtained during the session of 3 May 1966, when the satellite was in the Moon’ s shadow and the photocurrent should have been absent. In this session the current of the electron trap fell to $\sim 2 \cdot 10^{-11}$ A, which, taking into account the indicated zero shift, gives $n_e \sim$ 15-20 cm^{-3}. It is possible, however, that the decrease in the current of the electron trap is a consequence of a shift of the satellite potential toward negative values (because of the cessation of photoemission from its surface).

It should be pointed out that there are a number of effects occurring in measurements with modulation and electron traps, whose allowance may lead to other explanations of the origin of the observed currents and, consequently, to a reduction of the indicated estimates of the upper limit of the concentration of thermal charged particles in the ionosphere of the Moon. In a modulation trap, with oblique incidence of a beam of charged particles, there occurs, to a certain though small extent, modulation of the flux of ions with energy $E \gg eU_m$ (U_m is the alternating voltage on the modulation grid). An approximate calculation for the trap under consideration shows that the alternating component of the current is proportional to thousandths of the flux of solar-wind protons. Taking for the estimate the maximum value of the solar-wind flux measured by the integral traps on the Luna-10 satellite (1), we obtain, for proton energies ~ 200 eV, a value of the alternating component of the current $I \sim 3 \cdot 10^{-12}$ A, which is close to the actually observed value I_p. A number of other facts—the absence of any noticeable dependence of the modulation-trap current on the potential at the outer grid and the absence of any noticeable altitude variation of the current—also testify in favor of the supposition that the alternating current of the modulation trap is produced by a flux of ions with an energy considerably exceeding the thermal energy. It is obvious that taking these factors into account can only lead to a decrease in the estimate given for the upper limit of the concentration of thermal ions.

Fig. 3

The estimate of the value of n_e from the electron-trap data should be corrected for the possible “interception” of low-energy electrons by other electrodes of the trap. According to preliminary laboratory measurements, for electrons with energy $E \sim 1$ eV the above estimates of n_e apparently must be increased by a factor of 3-4. On the other hand, one cannot exclude the possibility that part of the electron-trap current is produced by a flux of photoelectrons from the satellite surface. Taking this circumstance into account can only lead to a decrease in the obtained estimate of the upper limit of n_e.

It may be supposed that the estimates of the upper limit of the concentration of thermal charged particles in circumlunar space from the data of both the ion trap ($n_i \lesssim 100$ cm^{-3}) and the electron trap ($n_e \lesssim 300$ cm^{-3}) are most likely appreciably overestimated owing to the influence of the indicated side effects, a more detailed discussion of which will be given later.

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