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K. I. GRINGAUZ, V. G. KURT, V. I. MOROZ, and I. S. SHKLOVSKII

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Abstract

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IONIZED GAS AND FAST ELECTRONS IN THE VICINITY OF THE EARTH AND IN INTERPLANETARY SPACE

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As is shown by consideration of the experimental material obtained during the flight of the second Soviet space rocket (^{1}), Figs. 3 and 4, the first half of its trajectory can be divided into four segments: 1) the segment up to $R = 22\,000$ km (R is the distance from the surface of the Earth), where in all traps with negative and zero potential considerable positive collector currents were recorded, whereas in the trap with a potential of +15 V relative to the body either very small negative currents or currents equal to zero occur; 2) the segment $22\,000$ km $< R < 50\,000$ km, where the collector currents of all traps fluctuate between zero and certain negative values ($I_k < 6 \cdot 10^{-10}$ a); 3) the segment $50\,000$ km $< R < 70\,000$ km, where in all traps negative currents occur simultaneously, with the largest recorded values being -10^{-9} a, while the upper limit of the currents falls to $-3 \cdot 10^{-10}$ a; 4) the segment where $R > 70\,000$ km, on which the currents of all traps fluctuate between zero values and magnitudes close to $5 \div 6 \cdot 10^{-10}$ a (which, apparently, determine the maximum value of the photocurrent from the inner grid to the collector). The general picture of the results is consistent for all three flights of Soviet space rockets.

For estimating the ion concentration from the data of the measured collector currents of the traps, essential importance attaches to knowledge of the electric potential of the container relative to the medium, which depends on a number of factors, including the magnitude of the flux of energetic electrons N_e in the second radiation belt, whose maximum, as is known, lies at distances from the Earth corresponding to our first segment. Important conclusions about the magnitude of N_e can be drawn from measurements of currents in three-electrode traps.

From this point of view, analysis of the current measurements in the "+15 V" trap is of particular interest. If the plasma temperature is not too high (for example, $T \leqslant 10^5$ °K), then positive ions obviously cannot enter this trap. However, electron fluxes with energy $E \gtrsim 200$ eV should be recorded in this trap. If one adopts estimates of electron fluxes with energy $E > 20$ keV in the region of the maximum of the outer radiation belt of $10^9 \div 10^{11}$ cm^2 s^{-1} ($^{2-7}$), then the currents in the "+15 V" trap should be of the order of $5 \cdot 10^{-9} \div 5 \cdot 10^{-7}$

a. Meanwhile, in the first segment the negative currents in this trap (after subtraction of the photocurrent from the inner grid) do not exceed $1 \cdot 10^{-10}$ a. It follows from this that the upper limit of the flux of electrons with energy $E > 200$ eV in the region of the outer radiation belt must be $N_e \leqslant 2{\cdot}10^7$ cm^{-2} s^{-1} (N_e is the flux per 1 cm^2 into a hemisphere).

The absence of large negative currents in the "+15 V" trap at the maximum of the outer radiation belt could be explained by the assumption of considerable secondary electron emission from the collector under bombardment of the latter by electrons.

radiation belt. However, secondary electrons cannot have sufficient energy to overcome the retarding field that exists between the inner grid of the trap and the collector.

Nor is it possible to explain the small values of the negative currents in the "+15 V" trap, when passing through the maximum of the outer radiation belt, by compensation of the current of "radiation" electrons by the current of positive plasma ions at a large negative potential of the container body. The latter could be due to a considerable current of radiation electrons to the container body. However, consideration of the dependence of the current of the "+15 V" trap on N_e, for any plasma concentration n_i, shows that such compensation is impossible for the given trap. Figure 1 gives an example of such a dependence for $n_i = 10^3$ cm^{-3}. As $N_e \to \infty$, the negative current of the trap $I_k \to \frac{1}{4} j_\phi S$, where j_ϕ is the density of the photocurrent from the surface of the container and S is the cross section of the trap. The adopted value of the photocurrent density $j_\phi = 2.5 \cdot 10^{-10}$ A $\cdot$ cm^{-2} is more likely too low than too high. For the "0 V" trap (and also the "−5 V" trap), compensation, as is seen in Fig. 1, is possible only for a certain quite definite ratio of n_i and N_e, i.e., only on a small segment of the trajectory, since the characteristics of the plasma and of the flux of radiation electrons (which determine the potential of the container) vary within wide limits, and independently. In reality, however, the readings of the currents of all the traps practically do not show entry into the region of the outer radiation belt.

Fig. 1. Dependence of the collector currents of the traps I_k with $\varphi_{g2} = 0$ (1) and $\varphi_{g2} = +15$ V (2), and of the container potential Φ (3), on the flux of radiation electrons N_e, at an ion concentration of the stationary plasma $n_i = 10^3$ cm^{-3}.

The small magnitude of the currents of the "+15 V" trap on the first segment of the trajectory permits only one conclusion: fluxes of electrons with energies greater than 200 eV in the region of the outer radiation belt do not exceed $2 \cdot 10^7$ cm^{-2} sec^{-1}. This result substantially contradicts the idea of large fluxes of electrons with $E \simeq 20 \div 30$ keV at the maximum of the outer radiation belt. The count rate observed in experiments $^{(2-5)}$ was explained by the authors as a flux of X-ray radiation arising in the body of the container and in the counter shields under the action of comparatively soft electrons ($E \simeq 20 \div 30$ keV). In

Fig. 2. Belt arrangement scheme

Figure 1: Fig. 2. Belt arrangement scheme

our opinion, the observed count rate must be explained by considerably smaller fluxes of much harder electrons. In this connection, at the maximum of the outer radiation belt the density of the kinetic energy of the electrons must be many orders of magnitude smaller than the energy density of the geomagnetic field, and the minimum of magnetic-field intensity found at an altitude of 14,000 km (7) is apparently not connected with the diamagnetism of energetic electrons in the radiation belt.

In the region 50,000 $< R <$ 70,000 km, the negative currents of all the traps, reaching 10^{-9} A, can be explained only by fluxes of electrons with energy $E >$ 200 eV, $N_e \simeq 1 \cdot 10^8 \div 2 \cdot 10^8$ cm^{-2} sec^{-1}. Since in the region of the second radiation belt $N \leqslant 2 \cdot 10^7$ cm^{-2} sec^{-1}, we arrive at the idea of the existence of a third, outermost belt (or shell), consisting of electrons of comparatively low energies. The fact that preceding experiments did not detect this outermost belt can be explained by the very insignificant content in it of electrons of comparatively high energies ($\gtrsim$ 100 keV).

Figure 2 shows the scheme we propose for the spatial distribution of the radiation belts surrounding the Earth, taking into account the new results presented above. The inner boundary of the third belt has been drawn along the lines of force of the magnetic field, in analogy with how this was done for the first and second belts (3,5). The measurement results obtained on the first Soviet space rocket (which contained less information) give grounds to suppose that the inner boundary of the third belt on 2 January 1959 was lower ($R \sim 30\,000$ km).

It should be noted that, according to experiments carried out on the third Soviet artificial satellite, at comparatively low altitudes ($R = 1800$ km) above moderate geomagnetic latitudes there were directly recorded fluxes of electrons with energy $E \simeq 10$ keV, reaching $3 \cdot 10^8$ cm^{-2} sec^{-1} (8). This may mean that in the region of the so-called second radiation belt the concentration of soft electrons has a minimum. However, one must take into account that experiment (8) was not simultaneous with that described in the present communication.

Fig. 2. Belt arrangement scheme

It can be shown that, for such small electron fluxes in the radiation belts as those given above, they have no effect on the potential of the rocket body, which is determined by the photoelectric effect from ultraviolet solar radiation and by plasma currents. Calculations show that under such conditions the body potential differs from zero by no more than a few volts if the concentration of plasma ions is $n_i \geq 10$ cm^{-3}, and its temperature is not too high (for example, $T = 10^4$ °K).

From the readings of the trap with zero potential on the first section of the trajectory, one can quantitatively estimate the concentration of plasma ions. The large scatter (“modulation”) of the current readings of the traps with zero and negative potential is explained mainly by the effect of the change in the orientation of the traps relative to the container velocity vector during its rotation. If the plasma ions are assumed to be protons (for which there are serious grounds), then their thermal velocities are close to the velocity of the container. The results of the estimates depend on the adopted plasma temperature.

Figure 3 gives the dependence of n_i on R for plasma temperatures $T = 1.8 \cdot 10^3$, 10^4, and $5 \cdot 10^4$ °K (higher temperatures are in any case excluded for $R < 10\,000$ km, since they contradict the observed depth of modulation). These estimates have been made from the maximum current values, in order, as far as possible, to eliminate the effect of changes in trap orientation. However, as is clear from examination of the curves in Fig. 3 of paper (^{1}), errors in the concentration associated with incomplete allowance for the indicated effect may reach a considerable magnitude; for example, an error by a factor of 2 is quite possible.

It follows from Fig. 3 that the plasma under investigation is not an interplanetary ionized gas—it is an extended envelope that is an ionized component of the very outermost part of the Earth' s atmosphere, the so-called “geocorona.” Attention is drawn to the noticeable increase in the density gradient of the “geocoronal” plasma beginning at $R \sim 15\,000$ km, whereas at smaller distances the density changes only slightly. It is significant that the sharp “break” in density is indicated by the decrease of the currents in all traps and, thus, cannot be explained by errors due to orientation. It is quite natural that in different traps the currents fall in different ways—

because the dependence of the currents on the orientation and on the potential of the outer grid is superposed on the effect due to the real change in concentration.

In Fig. 3, 1 the theoretical relative distribution of the concentration of hydrogen plasma at $T = 1.8 \cdot 10^3$°K, obtained from the barometric formula with allowance for the curvature of the layers, is given. Comparison of the theoretical curve with the experimental results shows that the small observed gradient of the concentration of the “geocoronal”plasma (for $R < 15\,000$ km) is easily explained, whereas the “break”in the concentration n_i, beginning at $R \cong 15\,000$ km, requires special analysis. This question will be discussed separately. If the geocoronal plasma is assumed to be nitrogen-oxygen, then the concentration would change little in comparison with Fig. 3. To explain the part of the curve with a small gradient, a temperature of $\cong 15\,000$°K would be required.

It should be noted that the phenomenon of an increase in the gradient would also remain for a larger value of the adopted photon density from the container (for example, $2 \cdot 10^{-9}$ $\text{a} \cdot \text{cm}^{-2}$); only at a distance of $20\,000 \div 22\,000$ km would the estimate of the concentration increase to $n_i \cong 100$ cm^{-3}.

Figure 3

Figure 2: Figure 3

Fig. 3. Dependence of the ion concentration n_i on the distance R from the surface of the Earth. 1—theoretical distribution at $T = 1.8 \cdot 10^3$°K; 2—4—experimental results: 2—at $T = 1.8 \cdot 10^3$°K, 3—at $T = 1 \cdot 10^4$°K, 4—at $T = 5 \cdot 10^4$°K. a—at an altitude of 470 km according to(12), b—at an altitude of 800 km from measurements on the third artificial Earth satellite.

For $R > 22\,000$ km only an upper limit for n_i can be estimated. The latter lies in the range 30—60 cm^{-3}, depending on various assumptions about the properties of the medium. This value is certainly below the lower limit (600 cm^{-3}) found from measurements of the polarization of the zodiacal light (for example, (9)). From this it may be concluded that the polarized component of the zodiacal light is due to the scattering of sunlight by dust particles, and not by free electrons, as was assumed, for example, by Behr and Siedentopf (9). V. G. Fesenkov (10) and Van de Hulst (11) showed that the polarization of the dust component can be sufficiently high.

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