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ON RESULTS OF EXPERIMENTS WITH CHARGED PARTICLE TRAPS IN THE SECOND RADIATION BELT AND IN THE OUTERMOST BELT OF CHARGED PARTICLES

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Abstract: Results are presented of laboratory experiments with charged particle traps identical with those installed in Soviet space probes. It is shown that the traps efficiently record fluxes of electrons with energies on the order of tens of keV.

The data presented confirms the conclusion that significant soft electron fluxes do not exist in the outer radiation belt.

Резюме: Приводятся результаты лабораторных экспериментов с ловушками заряженных частиц, идентичными тем, которые были установлены на советских космических ракетах. Показано, что ловушки весьма эффективно регистрируют потоки электронов с энергиями порядка десятков кэв. Приведенные данные подтверждают вывод (7) об отсутствии значительных потоков мягких электронов во внешнем радиационном поясе.

In the papers by S. N. Vernov, A. E. Chudakov, and others [1, 2] and by J. A. Van Allen, J. A. Simpson, R. L. Arnoldy, and others [3–6] published in 1959–1961 and devoted to descriptions of the outer radiation belt investigations, the electron flux values were estimated as 10^{10}–10^{11} cm^{-2} sec^{-1}. These estimates contradict the results of measurements of the currents produced by a flux of charged particles getting into three-electrode traps mounted on the same space probes, on which were mounted devices used by S. N. Vernov and others [2]. In the papers by K. I. Gringauz, V. G. Kurt, V. I. Moroz, and I. S. Shklovsky published in April–July 1960 [7, 8], it was pointed out that the upper boundary of electron fluxes in the outer radiation belt did not exceed $(2\text{–}3) \times 10^7$ cm^{-2}sec^{-1} during the experiments (1)–(6). It was pointed out that the counting rates observed in the experiments with cosmic ray counters should be accounted for not by the influence of soft electrons with a maximum energy distribution lying in the region of $\sim$ 30 keV, as was done in (1)–(6), but by the action of electron fluxes which are more than 1000 times lower than those given in the papers by J. A. Van Allen, S. N. Vernov *et al.* and with much greater energies.

In fig. 1, a diagram is presented of the spatial distribution of the charged particle belt around the Earth, taken from paper [7]. Also indicated are the estimates of the fluxes in the second belt as well as the outermost belt of charged particles which was discovered during the same three-electrode trap experiments.

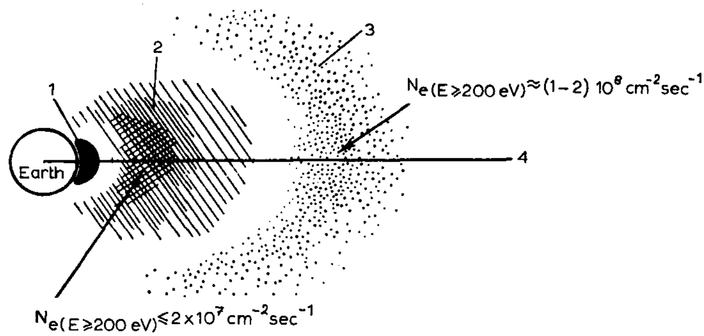

Fig. 1.

In the outermost belt which was not detected by the cosmic ray counter,s electron fluxes were recorded with energies of more than 200 eV and lower than $\sim$ 20 keV, which exceeded the electron fluxes in the second belt by one order of magnitude.

The authors of the present report subjected the traps, identical in their design to those used on Lunik II, to radiation by electron fluxes with energies similar to that ascribed to the soft electrons in the second and outermost belts. The aim of the experiment was to prove that the absence of considerable negative currents in the traps during the space rockets' passage through the second radiation belt is not due to spurious effects (such as the high secondary electron emission from the collector due to soft electron fluxes in the radiation belt). At the same time, it was necessary to estimate the errors in the determination of the electron flux in the outermost belt caused by this same effect. The results of these experiments were mentioned in the report by K. I. Gringauz at the Second International Space Science Symposium in Florence in 1961 [9]. At present, we are going to give more detailed data.

A diagram of the experiment is presented in fig. 2.

The electron flux produced by an electron gun (1) was focused by means of a cylinder (2). The voltage variation on the cylinder with respect to the anode (3) made it possible to change the energy of the electrons from 150 eV to 40 keV. Control measurements of the value of the total current were carried out by means of a special probe (4) which was put in the path of the stream, and whose design ensured the possibility of conducting absolute measurements. After each control measurement the probe was removed. The focus of the electron beam was checked upon by a removable luminescent screen (5). The trap (6) could be turned relative to the direction of the electron flux. The voltage on its outer and inner grids could be varied during the experiment.

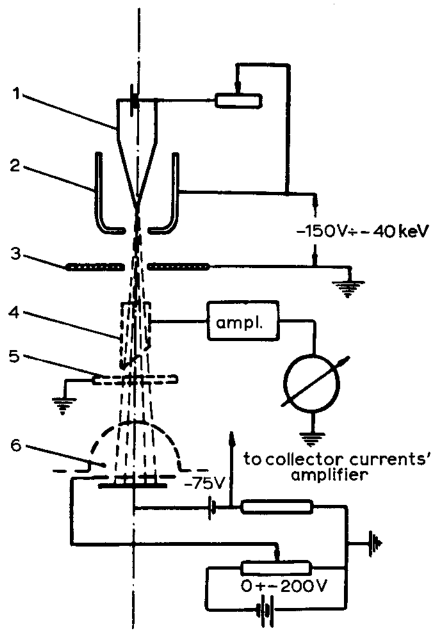

Fig. 2.

Fig. 3 shows the dependence of the current in the circuit of the trap collector on the inner grid potential for different energies of the electrons in the incident beam with a constant value of $I_0 = 5 \times 10^{-9}$ amperes.

The upper scale of the abscissa shows the change of the inner grid potential φ_{g_1} with respect to the zero level, which corresponds to the potential of the body of the instrumentation container. The lower scale shows the variation of the inner grid potential φ_{kg_1} with respect to the collector. From the curves of fig. 3, one can see the wellknown effect of the decrease of the secondary electron emission coefficient with the increase of the energy of primary electrons [10]. The measured negative collector current also decreases with the increase of the energy of the incident stream. For each value of the energy of the incident stream, the φ_{g_1} change in the interval -150 to -200 volts does not cause any change in the collector current. The collector current decrease is accounted for chiefly by the fact that with the increase of the primary flux energy, there is an increase in the proportion of the number of electrons leaving the collector surface with a high velocity (inelastically scattered or reflected electrons) which correspondingly cannot be retarded by the inner grid ($\varphi_{g_1} = 200$ volts) [11, 12].

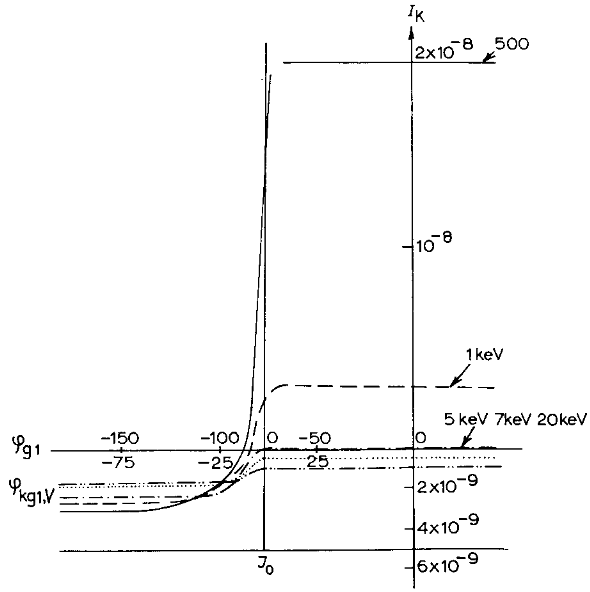

Fig. 3.

Fig. 4 shows the dependence of the ratio of the collector current I_K to the value of the current I_0 (which corresponds to the incident electron flux measured by a control probe) on the energy of the incident electron fluxes which differ in magnitude (I_0 varied from 10^{-10} amp to $5 \text{–} 10^{-9}$ amp). A constant potential of $\varphi_{g_1} = 200$ volts was kept on the inner grid, and the outer grid potential φ_{g_2} varied from 0 to 50 volts. From the curves of fig. 4, it is evident that the I_K/I_0 ratio in the investigated energy range practically does not vary during the considerable variations of the incident electron current. Thus it is evident that the values of the fluxes of electrons with energies up to 40 keV determined by means of three-electrode traps of the type installed on Lunik II have turned out to be no more than 2–3 times lower than the actual values. From this, it follows that the estimate by means of such traps of the order of magnitude of the electron currents with the above indicated energies is correct.

It should be noted that the recorded collector currents of the traps of the type considered can be determined, generally speaking, by the difference of the electron fluxes with energies exceeding $e\varphi_{g_1}$ (φ_{g_1} is the negative potential of the inner grid) and the fluxes of protons with energies more than $e\varphi_{g_2}$ (φ_{g_2} is the positive potential of the outer grid).

However, the probability is slight that measurements of the electron flux would be greatly changed by a proton flux. If we assume that the concentration of energetic protons is equal to that of energetic electrons, the energy of the protons necessary to greatly influence the current produced by the electrons. This means that currents produced by fluxes of electrons with energies on the order of tens of keV's would be influenced only by fluxes of protons with energies on the order of tens of MeV's. It follows from [13] that such protons at a nickel trap collector of ~ 0.4 mm thickness could be recorded only with a very low efficiency.

It should be noted that it follows from [14] that electrons with energies up to 1 MeV should be retarded by such a collector effectively, which ensures their effective recording by the traps.

Thus, the experiments confirmed the conclusion drawn in [7] and [8] (1960); i.e., that in the second radiation belt, the flux of soft electrons does not exceed some units multiplied by $10^7 \text{cm}^{-2}\text{sec}^{-1}$ and the counting rate in the charged particle counters observed in the second belt is not due to large fluxes of electrons with energies on the order of tens of keV, but due to fluxes of much more energetic particles.

In conclusion, we shall consider the remarks in the paper by Winckler and Kellogg [15] relative to the measurements made by traps in the outermost belt of charged particles. According to calculations carried out

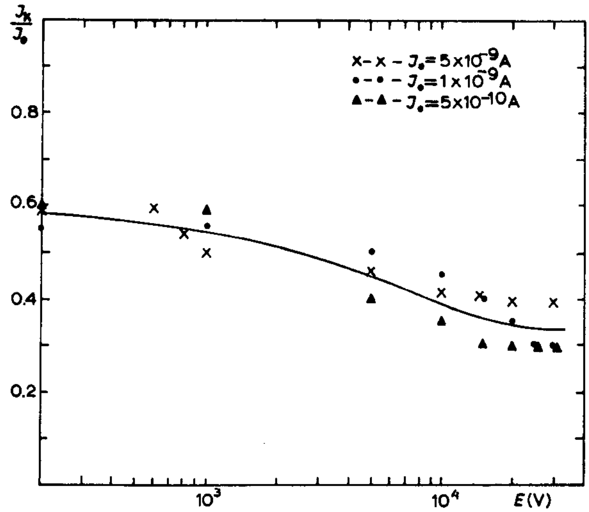

Fig. 4.

by the authors [15], the electron currents in the outermost belt should be on the order of 10^9 el/cm²sec.

Trap experiments [16] have given a value for the flux equal to 2×10^8 el/cm²sec. Winckler and Kellogg have pointed out that during the abovementioned measurements, the amplifiers of the traps were close to saturation and would not have been able to measure electron currents on the order of 10^9 el/cm²sec, which should have occurred according to their calculations. This remark is correct. One should, however, bear in mind that the currents measured quite definitely have not reached the amplifier saturation level. On the other hand, since the traps could not record fluxes of electrons with energies lower than 200 eV, it is quite probable that the total flux can reach the value of 10^9 el/cm² sec due to these electrons with energies $E<200$ eV.

Electrons with energies of 10 keV recorded by L. R. Davis [17] in the region of the outermost belt on the Explorer XII satellite apparently belong to the energetic portions of the electron spectrum of this belt.

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