Charge composition of the high-energy electrons and positrons in the Van Allen radiation belts

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(Submitted 29 January 1986)
Pis'ma Zh. Eksp. Teor. Fiz. **43**, No. 5, 240–241 (10 March 1986)

Electrons are predominant in the stream of high-energy electrons and positrons in the inner Van Allen radiation belt according to an experiment carried out with the Mariya time-of-flight scintillation magnetic spectrometer on an orbiting space station consisting of Salyut 7, Soyuz T13, and Kosmos 1669.

There can no longer be any doubt that the streams of high-energy electrons and positrons which were originally detected in Refs. 1 and 2 and then studied in Refs. 3–6 constitute an important component of the inner Van Allen radiation belt.[7] This fact was somewhat surprising, since there is no generally accepted model for the formation of a Van Allen belt which would lead us to expect the appearance of significant streams of electrons and positrons with energies of a few tens of megaelectron volts. This fact furthermore contradicts the model of an electron-positron "halo" in which an important feature would be a constant intensity of the electrons and positrons over the entire inner region of space from a hundred kilometers to a few tens of thousands of kilometers.[7]

The experimental observation of electron-positron streams stimulated several calculations and the derivation of several theories, which have basically reduced to an explanation of this phenomenon in terms of an interaction of the protons of the Van Allen belt with the residual atmosphere, which produces pions, which then undergo a chain of decays. The final products of this chain of decays—electrons and positrons—are trapped by the magnetic field.[7,8]

Obviously, the "belt" of electrons and positrons resulting from this process should consist for the most part of positrons, while other mechanisms, e.g., acceleration mechanisms, might lead to a different relation between the flux densities of the different kinds of particles. One of the most important steps in this research is therefore to experimentally measure the ratio of the flux densities of electrons and positrons.

In an effort to solve this problem we carried out an experiment on an orbiting space station consisting of Salyut 7, Soyuz T13, and Kosmos 1669. The Mariya apparatus uses the classical method of determining the sign of the charge of a particle from its deflection in a static magnetic field. Measurements of the time of flight of the detected particles, combined with a magnetic analysis, make it possible to select electrons and positrons in the energy range 30–150 MeV against the background of the flux density of other particles, primarily protons (the probability for false events is less than 10^{-5}). The characteristics of the apparatus were calculated by the Monte Carlo

 0021-3640/86/050306-02$01.00

method and also found by calibration in beams of monoenergetic electrons and positrons at the synchrotron of the Lebedev Physics Institute, Moscow.[9]

The apparatus is installed on the orbiting station in such a way that in measurements at the Brazilian magnetic anomaly, where the extensions of the Van Allen belt reach the orbital altitude of the station, the particles which are detected are for the most part particles of the Van Allen belt, trapped by the magnetic field.

The total duration of the measurements was 100 h; 1% of this time corresponded to the Brazilian anomaly. Analysis of telemetry data and of data recorded magnetically and returned to earth leads to the following conclusions: 1) The ratio of the number of positrons detected to the total number of electrons and positrons is 0.23 ± 0.06 for the central part of the Brazilian anomaly, while outside this region it is 0.64 ± 0.05. 2) The positron intensity increases by a factor of 2.0 ± 0.6 at the Brazilian anomaly in comparison with the intensity outside this region, while the intensification in the case of electrons is by a factor of 13.2 ± 2.3.

This experiment thus demonstrates the following: First, the belt of high-energy electrons and positrons consists primarily of electrons. Second, the proton-interaction mechanisms mentioned above for the production of these particles[7,8] are not the governing mechanisms for the Van Allen belt. Third, since the electron intensity is extremely substantial ($\sim 10^3\ m^{-2} \cdot s^{-1} \cdot sr^{-1}$), there appears to be an effective mechanism for acceleration of particles.[10] A detailed analysis of the experimental data from the Mariya experiment will contribute to an identification of this acceleration mechanism.

We wish to thank V. A. Dzhanibekov and V. P. Savinykh for carrying out the experimental work on board the orbiting station. We also thank V. Yu. Chesnokov, M. V. Guzenko, N. I. Shvets, and V. V. Mikhaĭlov for active assistance in this study.

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Translated by Dave Parsons