PERSONALIA

Georgiĭ Timofeevich Zatsepin (on his sixtieth birthday)

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Georgiĭ Timofeevich Zatsepin is a prominent Soviet physicist, a Corresponding Member of the USSR Academy of Sciences, and a specialist in the fields of cosmic rays, high-energy physics, and neutrino astrophysics.

He was born on May 28, 1917 into the family of a noted Moscow surgeon. Medicine was an almost hereditary profession among the Zatsepins, and only an early-recognized vocation to physics diverted Georgiĭ Timofeevich from this family tradition. Having completed intermediate schooling, he entered the Physics Department of Moscow University and graduated with distinction in 1941 with a major in "The Atomic Nucleus and Radioactivity."

In 1944, after his scientific work had been interrupted for several years by the war, Zatsepin became a graduate fellow of the Academy of Sciences Physics Institute (FIAN). His sponsor was Dmitriĭ Vladimirovich Skobel'tsyn, and his subject extensive cosmic-ray air showers. The basic direction of Zatsepin's work was determined and his scientific interest and approach to investigation were shaped during this time. He defended his candidate's dissertation ("The Vertical Profile and Density Spectrum of Extensive Air Showers") in 1950, and his doctorate dissertation ("Extensive Air Showers and the Nuclear Cascade Process") in 1954. In his work, Zatsepin perfected experimental techniques for acquisition of more and more detailed information on each individual event. This approach was originally referred to as the correlation-hodoscope method. Detectors adjusted specifically to register muons and "nuclear-active" shower particles were used to supplement electron flux density measurements. Zatsepin developed a large-ionization-chamber method for study of energy fluxes in the central part of the shower. He performed his first fundamental experiments at the FIAN's Pamir Mountain Station, but later he took part in the design of the complex Moscow State University (MGU) installation for study of extensive air showers at sea level.

The main objective that Zatsepin pursued in these studies was that of establishing the nature of the elementary processes in the interaction of cosmic-ray particles at very high energies. From the standpoint of the contemporary state of knowledge and technique, this problem is improbably difficult, and requires a combination of profound intuition with very rigorous analysis of the complex experimental data. Zatsepin succeeded not only in founding this new direction, but also in acquiring a number of important results bearing on the nature of the particle interaction at high energies. This was made possible by the idea of the nuclear-cascade process, which he advanced in 1949. The method developed for quantitative calculations (the method of successive generations) made it possible to relate the observed experimental data with hypotheses as to the characteristics of the elementary-particle interaction event. In 1951, for his discovery of the nuclear-cascade process, Zatsepin was awarded a First Degree USSR State Prize, which he shared with Skobel'tsyn and N. A. Dobrotin.

The nuclear-cascade scheme made it possible not only to explain the deviations of extensive air shower characteristics from the predictions of electromagnetic cascade theory that had been observed by Zatsepin and other authors (anomalous vertical profile, anomalous width, presence of penetrating and "nuclear-active" particles), but also, and more importantly, to tie together experimental data from the entire enormous range of primary cosmic ray energies from 10^{10} to 10^{15}–10^{16} eV and treat them from a consistent standpoint. The basic conclusions from this analysis, which were formulated in the mid-1950's, were as follows: 1) At all observed energies, the primary particles are protons, with an admixture of nuclei of heavy atoms. 2) The cross section of interaction of the protons with the nuclei of air atoms is approximately constant or, in any event, does not decrease with increasing energy.

3) When a high-energy nucleon interacts with a nucleus, the primary nucleon retains 50% of its initial energy after the collision, i.e., the coefficient of inelasticity is 0.5. 4) On the average, the most energetic of the pions produced in the interaction carries out 15% of the total initial energy. 5) The muons observed deep in the atmosphere appear for the most part as a result of the decay of charged pions, and the energy spectrum of the solitary muons is similar to the power-law spectrum of the primary particles as long as the pion decay probability is near 1. 6) The observed electron–photon component is formed by the practically instantaneous decay of neutral pions. In the extensive air shower, in which the energies of the charged pions are very large and their decay probability is low, the greater part of the nuclear cascade is converted irreversibly to the electron-photon component.

It is interesting to note that the idea of constancy of the effective interaction cross section, of the average value of the inelasticity coefficient in nucleon–nucleon and nucleon–nucleus collisions, and of the probability of production of pions with energies composing an appreciable fraction of the total energy, which has also been used by other authors in the field of cosmic rays in the more than 20 years since Zatsepin's work appeared—this idea is in fact fully consistent with the so-called model of "scaling" in strong interactions that was formulated by R. Feynmann in 1969 on the basis of much more accurate and detailed data from accelerator experiments. Needless to say, the establishment of the phenomenological characteristics of multiple particle production in cosmic rays ten years before the appearance of the accelerator data was an incomparably more complex matter and a focus of lively dispute. Zatsepin took the lead in discussions of this subject at a cosmic ray seminar at the FIAN and at All-Union and International Conferences. He demonstrated the disagreement between the experimental data and the then popular Fermi–Landau hydrodynamic model and, to explain the observed inelasticity coefficient, advanced the hypothesis that the transferred momentum was limited in nucleon–nucleon interactions. Zatsepin was attracted by the fireball model proposed by Mensovich, but he stressed that nucleons and leading pions should be considered apart from fireballs and that the excited-nucleon (isobar) model is suitable for their kinematic description. Now, when all characteristics of multiple production can be measured with high accuracy on accelerators at energies up to 10^{12} eV, one can only wonder that the basic ideas embodied in the description of this process have undergone only comparatively minor modifications.

In the early 1960's, Zatsepin's scientific interests shifted to electromagnetic and weak interactions and study of muons and neutrinos in cosmic rays. A special laboratory was organized at the FIAN in 1963 to develop work in these areas (since 1971, it has been part of the Nuclear Research Institute). In the physics of cosmic-ray muons, Zatsepin calculated the energy and angular distributions of the muons on the basis of a "scaling" model and was the first to solve the problem of absorption of high-energy muons in deep soil layers with consideration of the fluctuations of their energy losses. Analysis of the absorption curve on this basis led him to the conclusion that the experimental and calculated data agree up to a muon energy of 10^{13} eV. At the same time, data indicating significant anomalies in the angular distribution, energy spectrum, and interaction of muons at energies $\sim 10^{12}$ eV were being accumulated in the late 1960's in a number of laboratories, both in the USSR and abroad. Zatsepin designed two experiments to establish the truth. The cross section for generation of a nuclear cascade by a muon was measured in the first. This process was identified by an original method first developed in the laboratory for this purpose, which used large scintillation-type neutron detectors. The experiment indicated constancy of the cross section and the absence of any anomaly.

The second large-scale experiment was set up with Zatsepin's participation at the MGU to verify the muon angular distribution and energy spectrum with x-ray emulsion cameras. The result: there are no anomalies in either the angular distribution or the spectrum of the muons up to an energy of 10^{13} eV. The admissible fraction of "direct-production" muons is less than 0.5%. Thus, Zatsepin clarified this disputed question and showed that up to 10^{13} eV the "scaling" model gives a good description of pion and kaon production by cosmic rays in the atmosphere.

Zatsepin was greatly interested in the idea of studying neutrinos formed concurrently with muons in pion and kaon decay in the atmosphere. His detailed calculations of neutrino energy spectra formed the basis for the design of experimental studies and analysis of results obtained in deep shafts in India and South Africa. There was special interest in the questions as to whether the cross section of interaction of a muonic neutrino with a nucleon increases in proportion to the energy of the neutrino, and, if the cross-section increase stops, then at what energy? Some experimentors were inclined to interpret their own data as favoring the existence of a light intermediate boson that limits the cross-section increase at energies of 30–50 GeV. However, Zatsepin's detailed comparison of the experimental results with calculations led him to the conclusion that the neutrino–nucleon interaction cross section increases with increasing energy: $\sigma \sim (0.55 \pm 0.2) \cdot 10^{-38} E$ (where E is in GeV and σ is in cm^2), at least up to 100 GeV. These cosmic-ray data do not differ greatly from the results of recent direct measurements on the Batavia accelerator: $\sigma \sim (0.83 \pm 0.11) \cdot 10^{-38} E$ up to an energy of 200 GeV.

In addition to the study of cosmic-ray muons and neutrinos, Zatsepin acquired a new interest even as the laboratory was being built; it was eventually to become his basic theme. We refer here to the development of methods for registration of neutrinos of extraterrestrial origin in order to extract astrophysical information. The small neutrino interaction cross section causes enormous difficulties in detection, but on the other hand it makes it possible to obtain unique information that is inaccessible to other methods. This applies primarily to registration of the neutrino emission of the sun. Zatsepin showed that by using neutrino detectors with different energy thresholds, it is possible in principle not only to verify the main hypothesis of synthesis of helium nuclei from hydrogen as the source of solar energy, but also to determine several important elements of the structure of the sun's central region, e. g., temperature. Under Zatsepin's direction, the laboratory developed a technique for registration of solar neutrinos, analyzed the backgrounds of the various detectors, built working models of some of them, worked on methods for shielding them from extraneous radiation, etc. It was found that the problem was a very difficult one technically but that it can be solved if a radiochemical method is used, the experiment is conducted at a great depth underground (for shielding from the cosmic-ray muon background), and the detector is shielded from the radioactivity of the rocks by sufficiently pure materials. In view of the importance of this trend, the USSR Academy of Sciences undertook to build a special underground laboratory in the Northern Caucasus, which is now being equipped by its Institute of Nuclear Research. Implementation of this project will offer unique possibilities for large-scale underground physical experimentation under low-background conditions. The results of the first solar neutrino detection experiment, which was performed in the USA by R. Davis by the chlorine-argon method proposed B. Pontecorvo, showed that the effect is much smaller than would be expected from theory and that it is necessary to increase the sensitivity of the neutrino detector substantially. Precisely this experiment had been planned in Zatsepin's laboratory even before the appearance of Davis' enigmatic results, which posed with special urgency the problem of a more fundamental approach to detection of neutrinos from the sun. Zatsepin plans to conduct a broader chlorine-argon experiment in the future underground laboratory and to initiate the use of a new method—the gallium-germanium method—which was first proposed in his laboratory. The result of the gallium-germanium experiment will depend weakly on detail of the solar model, but it will answer the question as to whether thermonuclear reactions are now a source of solar energy at all.

Registration of solar neutrinos is a fundamental but not the only possible way to "look" into the interior of a star.

In 1965, Zatsepin drew attention to the possibility of registering the neutrino-emission burst that occurs on gravitation collapse of a star if the collapse occurs within our Galaxy. As was first shown by Guseĭnov and Zel'dovich, emission of neutrinos in the collapse of a star is not merely a concomitant process, but in fact determines the dynamics of collapse. Zatsepin emerged as the initiator of international collaboration in the organization of a neutrino-burst observing service. Correlated observations will begin in 1977, making use of a 100-ton scintillation detector built in Zatsepin's laboratory and several other underground detectors in Italy and the United States.

The basic possibilities of the "observational neutrino astrophysics" that Zatsepin is developing relate to moderate-energy neutrinos generated in the interiors of stars. In recent years, however, he has drawn attention to the fact that the possibility of obtaining new astrophysical information from high-energy neutrinos cannot be excluded either, because neutrinos are not absorbed when they interact with relict radiation even over cosmological times. A paper on the same subject is being published in this issue. It is interesting to note Zatsepin's observation of more than twenty years ago that cosmic space ceases to be fully transparent to particles of sufficiently high energy in the presence of electromagnetic radiation. In 1955, he wrote a paper on the splitting of ultrarelativistic cosmic-ray nuclei on collisions with photons of sunlight. When the relict (3 °K) radiation was discovered, Zatsepin immediately pointed out that the interaction with this radiation should, over the time of existence of the Universe, result in cutoff of the cosmic-ray energy spectrum at a proton energy above $5 \cdot 10^{19}$ eV. Accordingly, giant installations have been built in Australia, Great Britain, the USSR, and the United States to study the "upper limit" of the cosmic-ray energy spectrum.

Zatsepin's 33 years of work in the field of cosmic rays have been highly productive. His ideas in a number of areas have determined the development of this field of physics for many years and have won international recognition. He has also made a major contribution to the training of specialists in cosmic rays in our country. His teaching work is not limited to his duties as a Professor in the Cosmic Ray Department at Moscow State University and his work with students and graduates, but covers a much broader range, including both junior collaborators in his laboratory and staff members of related laboratories, many of whom consider themselves Zatsepin's students.

Now, as Georgiĭ Timofeevich addresses himself to the complex task of developing a new field of neutrino astrophysics, the problem of designing a unique complex of underground laboratories and neutrino detectors of unprecedented size, we wish him health and great success in this major undertaking.

Translated by R. W. Bowers