Aleksandr Evgen'evich Chudakov (on his sixtieth birthday)

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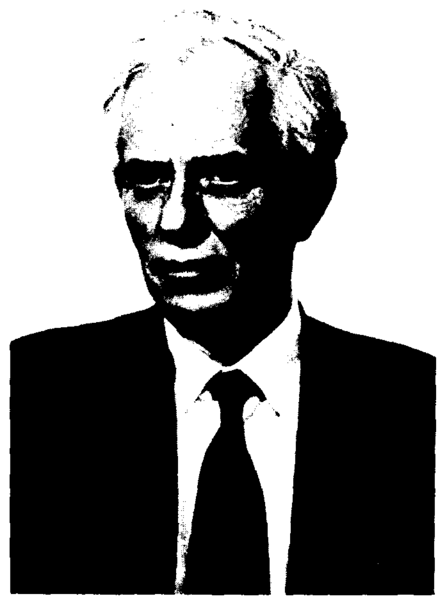
Aleksandr Evgen'evich Chudakov is a well-known scientist, Corresponding Member of the Academy of Sciences of the USSR, and specialist in the area of cosmic ray and elementary particle physics.

A. E. Chudakov is an experimental physicist with equal emphasis on both words. A very broad education, the ability to see the very essence of a physical phenomenon, and amazing clarity of thought, together with a brilliant engineering talent, determined A. E. Chudakov's role in the development of research on the physics of cosmic rays and elementary particles.

He was born on June 16, 1921, in Moscow, to the family of a well-known engineer and scientist, and founder of the automobile industry in the USSR, Academician E. A. Chudakov. Having obtained in his youth a broad and multifaceted education, Aleksandr Evgen'evich became aware of his range of interests at an early age and in 1939, after completing secondary school, he entered the Physics Department at Moscow State University. Very quickly thereafter he was called to active military duty and, after demobilization, began working as a radio engineer in the Oscillations Laboratory in the P. N. Lebedev Institute of Physics of the Academy of Sciences of the USSR. In 1944, taking up once again his studies at the Moscow State University, Aleksandr Evgen'evich returned to his second year in the Physics Department and completed it with honors in 1948.

A. E. Chudakov finally chose his specialty in 1946, when he, while still a student at the Moscow State University, was included at the Physical Institute of the Academy of Sciences in the work of a group that was given the problem of studying cosmic rays with the help of rockets. It is here that A. E. Chudakov, who all his life would be interested not only in the final result, but also in the method used in the investigation and who would be attracted by technical obstacles along the path to the main goal and not frightened away by them, first revealed his character.

In order to carry out the rocket investigations, A. E. Chudakov had to develop not only the instrumentation for recording cosmic rays, placed onboard the rocket, but also methods for transmitting information by radio to Earth, including original methods for coding, receiving and transmitting antennas, ground-based photographic recording, and so on. Many methods, such as, for example, amplitude–time–code transformation, now widely used, were first developed by A. E. Chudakov especially for these experiments. This was very intense work, if one takes into account the fact that the period of time set aside for preparing the first experiments was not much more than one year.



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In the course of this work, the intensity of cosmic rays outside the atmosphere was measured and the first bounds on the flux of γ quanta with energies ~1 MeV and ~100 MeV were obtained. The formation of the electron–photon component by primary particles (protons) in dense matter was discovered by measuring the so-called transition effect in thin layers of lead. From here, two years before the discovery of the π^0 meson in accelerators, it was concluded that the meson, which is responsible for the formation of photons and electrons, has a lifetime less than 10^{-9} s. The final rocket experiment was carried out in 1951 and, using the results of this work, A. E. Chudakov defended his Candidate's Dissertation in 1953.

In 1949, Aleksandr Evgen'evich turned his attention to the fact that at high energies a weakening of the ionization caused by e^+-e^- pairs, due to mutual screening of the electron and positron fields, should be observed. This effect, known as the Chudakov effect, was used in its time for measuring the energy of electron–positron pairs in studying nuclear interactions using the photoemulsion method.

Remaining true to his principle of choosing the most direct path to studying physical phenomenon (which, as a rule, also turns out to be technically the most complicated), Aleksandr Evgen'evich began in 1953 studying Cherenkov emission of extensive air showers. This required developing the technology of high-speed oscil-

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lography using simultaneously eight independent channels and creating a method for studying photomultipliers in the nanosecond range (for this purpose, a low intensity spark was used for the first time as a short light signal). In this experiment, he realized the idea of calorimetrically measuring the energy of a cascade by detecting the Cherenkov radiation and he experimentally measured for the first time the relationship between the cascade energy and the observed number of particles. This permitted, in particular, determining the slope of the energy spectrum of primary particles over a wide energy range near 10^{15} eV. The results of this experiment remained unsurpassed over the course of almost twenty years which is quite rarely encountered in present-day nuclear physics.

As a side-line, in the course of preparation of this experiment, in 1953, ionization luminescence (luminescence of air under the action of ionizing radiation) was investigated. This effect was studied at different pressures and it was unexpectedly discovered that weak luminescence is observed even with total evacuation of the vessel. To investigate its nature, A. E. Chudakov placed additional metallic foils along the path of the electrons and arrived at the conclusion that the phenomenon that he discovered is transition radiation, arising when an electric charge traverses the boundary separating two media. This was the first experimental confirmation of the existence of transition radiation, predicted in 1945 by V. L. Ginzburg and I. M. Frank. Somewhat later, in 1958–1960, Aleksandr Evgen'evich again returned to this problem and carried out a detailed investigation of transition radiation in the optical range. At the present time, transition radiation is widely used for identifying fast charged particles, as well as for studying optical properties of surfaces. The ionization luminescence of air itself turned out to be quite weak and in practice does not interfere with the Cherenkov experiments, although its isotropy permits, in principle, recording very large extensive air showers at very large (of the order of tens of kilometers) distances. At the present time, this proposal made by A. E. Chudakov is realized, in somewhat modified form, in a number of laboratories in the world.

The first water Cherenkov calorimeter appeared as a continuation of the Cherenkov theme in A. E. Chudakov's works in 1957–1960. Containing 100 tones of water, this was also the largest detector of its time. In 1960–1963, a search was carried out for local sources of hard γ quanta by recording Cherenkov radiation in the atmosphere. The telescope constructed in Crimea under the direction of A. E. Chudakov, had a large aperture and permitted recording over a small solid angle ($\sim 10^{-3}$ sr) extensive air showers caused by particles with energies $\geq 2.5 \cdot 10^{12}$ eV. No effect was observed. The flux of γ quanta in a direction toward the sources being studied (including the Crab Nebula) did not exceed the level of the isotropic background and constituted less than 10^{-9} photons $\cdot$ cm$^{-2} \cdot$ s^{-1}. This limit remained as the upper limit over the course of ten years and served as an indisputable argument against the hypothesis of a secondary origin of relativistic electrons in the Crab Nebula. The technique developed by A. E. Chudakov for studying fluxes of high-energy quanta was later widely used in the work of Soviet and foreign physicists.

In 1957, when the first artificial earth satellites were put into orbit, new possibilities were opened up for studying cosmic rays with the help of rockets and Aleksandr Evgen'evich again was actively included in this work. The instruments that he developed over a very short period of time were placed on the third Soviet artificial satellite and recorded the presence of two zones with high charged particle density trapped by the Earth's magnetic field. In this and a number of subsequent experiments, the spatial structure of radiation belts and their dynamics were studied, the composition of particles was studied, the energy spectrum of electrons was measured, and so on. For this series of investigations, A. E. Chudakov was awarded, in 1959, the degree of Doctor of Physical-Mathematical Sciences and he was awarded the Lenin Prize "for discovering and studying the outer radiation belt of the Earth" (1960).

In the history of the development of twentieth century physics, the frontier of the 1950's to the 1960's is marked by the realization of the possibility of directly studying high-energy neutrinos experimentally in cosmic rays and with accelerators. The study of natural neutrino fluxes required creating detectors, placed deep underground, with unheard of dimensions and with a complex control system that would ensure reliable identification of rare (several tens per year) neutrino events in the presence of high cosmic-ray muon intensity.

This problem, which was at the frontier of the technical possibilities of that time, could not help but attract Aleksandr Evgen'evich, and he plunged into this work. In 1963, in connection with the decision to create a neutrino station for the Physical Institute of the Academy of Sciences in the northern Caucasus (now the Baksansk Neutrino Observatory of the Institute of Nuclear Studies of the Academy of Sciences of the USSR), he began designing an underground scintillation telescope for studying muons and neutrinos as components of cosmic rays. The main difficulty consisted of the fact that the dimensions of the detector, which up to now has no equal in world practice, required technical solutions that would not only be economically feasible but, which is much more complicated, could be realized under conditions of mass production and with commercial methods for equipping the installation. Thus, in spite of the fact that neutrino events must be separated out by measuring the time of flight of the muon between the layers of the detector, Aleksandr Evgen'evich found that it is possible to make use of counters that do not have a very high resolution time, that are quite simple to make, and that are convenient to use. In his laboratory and under his direction, a unique electronic system was developed and constructed which permitted solving for the first time the problem of collecting information from more than 3000 photomultipliers simultaneously. Under his direction, the technology was successfully developed and mass production of an inexpensive liquid scintillator was organized, which permitted meeting the requirements of not only the given experiment (the apparatus used 330 tons of scintillator), but of other physical laboratories in the country as well.

The scintillation telescope was put into operation in 1978. At the present time fifteen years, separating the initial planning and its execution, is a very long period. It is all the more long, when we are talking about experimental nuclear physics. For this reason, we can only be surprised at the flexibility and perfection of the initial design of the detector that A. E. Chudakov developed, when having just been put into use, it not only changed the level of the results in its own areas of cosmic ray physics, but also turned out to be the most suitable device in the world for studying problems that generally did not concern the experimental nuclear physics at the beginning of the 1960's when the scintillation telescope was being designed. Thus, in recent years, many laboratories in the world, in experiments involving reactors, accelerators, and cosmic rays, are checking the hypothesis put forth by B. M. Pontecorvo concerning the existence of oscillations between different types of neutrinos. The measurements of the intensity of the flux of muon neutrinos, formed by the interaction of primary cosmic rays with the Earth's atmosphere in passing through the entire thickness of the Earth, carried out on the scintillation telescope, have led to the conclusion that the intensity of the flux of these neutrinos is not noticeably changed over a distance of ten thousand kilometers. This permitted establishing (for the case of maximum mixing of the two types of neutrinos) the highest limit to this day on the difference in the squares of the masses $(m_1^2-m_2^2) \leq 6 \cdot 10^{-3}$ eV^2.

In the mid-1970's, the problem of the stability of the proton was at the center of attention of the physics of elementary particles. Proton decay with violation of baryon conservation turned out to be the only prediction of the unified mode of weak, electromagnetic, and strong interactions that is presently accessible to direct experimental verification. The data, obtained over the last four months of operation of the scintillation telescope, show that the lifetime of nucleons relative to neutrino-free decay channels exceeds 10^{30} years, which is already much greater than the most probable prediction of the presently widely discussed minimum standard unified model.

Work on the underground scintillation telescope is beginning to pick up and many programs are being carried out simultaneously. These include: first, and foremost the very interesting and fascinating problem of searching for local extraterrestrial sources of high energy neutrinos (super nova remnants, pulsars, galactic center, and so on); investigation of variations in cosmic radiation with energies of 10^{13} eV, of primary significance for constructing a picture of the origin of cosmics rays; a search for bursts of neutrino radiation from gravitational collapse of stars; investigation of cascades, caused by muons, and of parallel groups of muons, caused by primary cosmic rays with very high energies up to 10^{16} eV, when more than 100 muons are incident on the telescope. There is reason to believe that the study of muon groups will permit establishing the chemical composition of cosmic rays in this energy range. This simple list of programs indicates the universality of the instrument created and shows the enormous possibilities for studying cosmic rays with proper organization of the experiment.

During the time the scintillation telescope was being developed and constructed, Aleksandr Evgen'evich completely concentrated his efforts on solving the methodological and organizational problems, and for this reason, at this time, he did not actively participate in the physical research. Nevertheless, in order to gain experience in working with the apparatus created for the telescope and, mainly, in order to teach his young coworkers, he proposed at this time a number of interesting experiments. Thus, many people surely remember the lively discussions surrounding the indications (at the beginning of the 1970's) of a sharp increase in the cross section for interaction of muons with matter in the 300 to 400 GeV energy range. Measurements of the ratio of the number of muons stopped to the number of muons passing through matter, carried out by A. E. Chudakov in 1972 in underground enclosures of the Bakansk Neutrino Observatory of the Institute of Nuclear Studies of the Academy of Sciences of the USSR then under construction, did not confirm the existence of this effect. In the same location, some years later, he created an installation on the Earth's surface for studying the structure of extensive air showers consisting of 400 scintillation detectors, placed right next to one another, with an overall surface area of 14×14 m^2 and representing an exact copy of of a single layer of the scintillation telescope. Supplemented by outlying detectors, placed along a circle of 35 m radius, this installation is a unique instrument for studying the spatial structure of the stems of extensive air showers. The multistemmed events, detected in this experiment, show that at energies of 10^{14} eV, the cross section for interactions involving high momentum transfer increases sharply. This confirms the predictions of quantum chromodynamics in an energy range that is not yet accessible to accelerators.

Working on the creation of the telescope, Aleksandr Evgen'evich also searched for new directions for further developing investigations of muons and neutrinos in cosmic rays. In the mid-1960's, he proposed a project for a large, deep-water installation for studying muons in Lake Baikal. This idea is currently being realized within the framework of the general development of work on deep water detection of muons and neutrinos.

The works of A. E. Chudakov are widely known. Research along the paths that he delineated is being carried out in many physical laboratories in the world. He is a recognized authority in the area of cosmic rays and experimental nuclear physics, he is a member of many problems and qualification scientific committees, and he is a member of the Commission on Cosmic Rays of the International Union of Pure and Applied Physics. As a professor at Moscow State University he was been training specialists for about twenty-five years in the area of experimental nuclear physics. But this is not all that determines the role of A. E. Chudakov in the developments of cosmic ray physics. As a man who does not tolerate even the smallest traces of falsehood in any of its manifestations and who is always absolutely sincere in his estimates, and very demanding of himself and of his work, he was, through all his work, an enormous influence on the thinking, scientific world outlook, and work style of many generations of physicists, working in the area of cosmic rays.

As a scientist whose name is known throughout the world, directing large groups of people, and overloaded with a mass of necessary and unnecessary work, he as always can completely marshal his wonderful talents, when an especially interesting and especially difficult experimental problem appears on the horizon, and only from the solution of such problems does he gain true satisfaction. All his friends, colleagues, and students wish that Aleksandr Evgen'evich should retain this priceless quality and will have further successes.

Translated by M. E. Alferieff