# Fiftieth anniversary of a fundamental discovery in cosmic-ray physics

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The fiftieth anniversary of the publication of the celebrated paper by D. V. Skobel'tsyn[1] "Die Intensitätsverteilung in dem Spektrum der $\gamma$-Strahlen von RaC," occurred in 1977. This paper reported the discovery of charged cosmic-ray particles and elucidated their properties. It played a fundamental role in a number of branches of physics. Before its appearance, cosmic rays were regarded as a geophysical phenomenon. Hess and, especially, Kolchörster and Millikan investigated in detail the absorption of cosmic rays in the earth's atmosphere, in water, and in other absorbers. The existence of a new source of ionization of air was reliably established. It was clear that the primary cause of this was radiation arriving on the earth from outer space. But no one among the physicists of the time was able to answer what appeared to be the basic question, namely—precisely what was responsible for the ionization of air.

The Wilson cloud chamber, one of the most remarkable instruments in physics, had already been developed by that time and produced the first visualization of the paths of individual elementary particles. The Wilson cloud chamber was very erratic in its operation and there were only a few physicists that could cope with the difficulties associated with experiments performed with this device. It was only after the work of D. V. Skobel'tsyn that the cloud chamber became widely used.

In 1923, D. V. Skobel'tsyn, working in his father's laboratory at the Leningrad Polytechnical Institute and at the Physicotechnical Institute, began to investigate one of the elementary events in the microworld, namely, the Compton effect. He used the Wilson cloud placed in a magnetic field. By modern standards, the magnetic field was very low (~1000 Oe). However, this was quite sufficient for the investigation of the Compton effect, i.e., for studying the properties of electrons ejected by gamma rays from radioactive materials, because the maximum energy of the electrons did not exceed a few MeV.

The aim of the celebrated work of D. V. Skobel'tsyn,[1] begun in 1923, was to investigate recoil electrons produced by these gamma rays. By using the Wilson cloud chamber in a magnetic field, he was the first to succeed in indirectly observing and photographing the electron recoil tracks resulting from collisions between gamma rays and electrons in the gas atoms filling the chamber. This work provided not only direct confirmation of the hypothesis of the quantum-mechanical nature of the Compton effect, but also resulted in a very effective application of this phenomenon to the spectroscopy of gamma rays.

The most important point is that this work led to the discovery of a particle track (initially only one) which could in no way be ascribed to radioactive materials. The particle was not deflected by the magnetic field, which led to the conclusion that its energy must have been about 20 MeV, an unprecedented value at the time. It was subsequently established that such particles were not at all infrequent and, most important, they appeared in groups (this was reported in the paper, "Uber eine neue Air sehr schneller $\beta$-Strahlen"[2]). Of course, these groups consisted of a small number of particles. However, D. V. Skobel'tsyn knew how to draw quantitative conclusions from his work, even though these conclusions were based on few (but reliable) experimental data. By analyzing his data, he clearly showed that the number of groups of particles that he found greatly exceeded anything that could be expected on statistical grounds, especially when their direction of motion was taken into account.

D. V. Skobel'tsyn was also able to show that the total number of tracks due to particles with energies in excess of 20 MeV was just right to explain the ionization produced by cosmic rays. This then was the first explanation of ionization in the earth's atmosphere by cosmic rays. Fifteen years had elapsed between the discovery of ionization by cosmic rays by Hess and Kolchörster and the establishment of the reason for it by D. V. Skobel'tsyn.

D. V. Skobel'tsyn was thus the discoverer of charged cosmic-ray particles and of their appearance in groups (showers).

Considerable experimental skill was required to detect this rare phenomenon against the background of many others. Precise (for that time) measurements of the particle momenta resulted in a reliable segregation of the cosmic-ray particle tracks from recoil electron tracks.

On reading Skobel'tsyn's papers fifty years after their publication, one is struck by the boldness of his ideas, his skill and intuition, and the depth of his analysis.

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We are now fully justified in saying that high-energy physics has its beginnings in the work of D. V. Skobel'tsyn.

The fundamental principle of the Skobel'tsyn school is that each experimenter must carry out a detailed study of the theory. Skobel'tsyn himself and his numerous pupils, whose number after four generations amounts to many hundreds, believe that the experimenter has no right to take theoretical predictions on trust. Before theory can be verified, it must be well appreciated and understood. This is a very difficult proposition as we have frequently experieneed ourselves. Indeed, the understanding of many theories necessarily involves a greater knowledge of mathematics than experimenters are usually found to have. But this is not always the case. Quite frequently, and D. V. Skobel'tsyn has given many examples, theory can be simplified so that its essence can be explained by "hand-waving" arguments.

The work of D. V. Skobel'tsyn and his school was based precisely on the proposition that one should never ignore discrepancies between theory and experiment. This, in turn, requires that the experimental errors must be reliably estimated and, secondly, one must be aware of the consequences of errors in interpretation and uncertainties in the theory.

It seems to us that a clear example of this approach to the relationship between theory and experiment is the analysis of the accuracy of the electron-photon cascade theory. The various variants of the cascade theory have predicted the shape of the cascade curve, but have suggested that the height of its maximum could be found only with the so-called logarithmic precision. D. V. Skobel' tsyn showed that, by applying the law of conservation of energy, one could increase in a simple way the precision of the theory by an order of magnitude.

In our view, this kind of interpenetration of theory and experiment is exceedingly important. To an extent, it has been generally excepted throughout the world. Experimenters spend much time and effort trying to understand the essence of the theory. At the same time, many theoreticians have learned to appreciate the basic problems and even the possibilities of experimental physics. Indeed, many theoreticians are currently directing major scientific centers researching into high-energy physics in the USSR and abroad.

The work of D. V. Skobel'tsyn produced a very considerable response in the world of science of the time. It will be sufficient to mention that one of the founders of quantum mechanics, W. Heisenberg, discussed in detail the results of D. V. Skobel'tsyn in a review paper, and developed new hypotheses on the basis of these results.[3]

The importance of these researches is also clearly demonstrated if we consider the experiments of Anderson and Neddermeyer and of Blackett and Occhialini,[4] which resulted in the discovery of the positron, the first antiparticle. These authors have themselves acknowledged their debt to the work of D. V. Skobel'tsyn.

It is particularly interesting to note reviews of Skobel'tsyn's pioneering work published many years later. For example, in 1948, in a paper entitled, "Millikan as a Physicist and Teacher,"[5] Einstein wrote that, with his characteristic intuition, Millikan saw that D. V. Skobel'tsyn's experiments revealed a new research field, and assigned to Anderson the study of cosmic-ray particles in the Wilson cloud chamber placed in a much stronger magnetic field. This led to the discovery of the positron.

The discovery of the positron, the first anti-particle, was accompanied by a number of interesting details. In the fall of 1931, Anderson's teacher, Millikan, went on a lecture tour of the scientific centers of Europe, including Paris. In the course of his lectures, he showed photographs of cosmic-ray particle tracks recorded in his laboratory in California with the aid of the Wilson cloud chamber in a strong magnetic field. The sign of the curvature of these tracks showed that they were due to particles of positive charge. Millikan therefore interpreted Anderson's observations as the discovery protons in cosmic rays.[1)]

The existence of the positron was predicted by Dirac in a theory published in 1930,[6] but this theoretical prediction was treated by physicists with skepticism (apparently shared by the author of the theory himself). It is clear that the authors of the California paper had to overcome a definite barrier of doubt before they were able to report their discovery of the positron. The first brief note about this appeared only in the summer of 1932 in the periodical "Science."

Cylindrical counters played a major role in the study of high-energy particles including, in particular, cosmic-ray particles. Counter systems are always ready to receive such particles and can reliably operate for long periods of time. But they are "blind" devices and the correct interpretation of the results obtained with such systems of counters requires a "cross fertilization" with techniques that remove this impediment. It is precisely for this reason that extensive applications of counters in cosmic rays work began after the publication of the above papers of D. V. Skobel'tsyn.

Bothe and Kolchörster were the first to show in a famous paper[7] that cosmic-ray particles were capable of penetrating considerable amounts of material (4.1 cm of gold, in this particular case). Their paper starts with a detailed description of D. V. Skobel'tsyn's photographs, and it is quite clear that it was precisely these photographs that suggested to them their own experiment. The researches of Bothe and Kolchörster were subsequently developed further by Rossi, who used up to 1 m lead between the counters in his telescope. On

[1)]D. V. Skobel'tsyn received reports on Millikan's lectures from F. Joliot-Curie and M. Curie in France, and from L. H. Gray in England (these letters have survived). In his letters to F. Joliot-Curie, D. V. Skobel'tsyn drew attention to the fact that the reported $H\rho$ values for the tracks demonstrated by Millikan were inconsistent with their identification as protons.

the other hand, Rossi arranged his counters in a triangle and studied the particle groups discovered by D. V. Skobek'tsyn or, as we now call them, cosmic-ray showers.

In his widely known monograph, "Cosmic Rays," published in 1936, D. V. Skobel'tsyn not only analyzed all the data then available in high-energy and cosmic-ray physics, but also noted the difficulties and apparent contradictions, and made suggestions for further studies.

After the above fundamental discovery, D. V. Skobel'tsyn and his school carried out a very detailed study of the production of showers consisting of many millions of particles (the so-called extensive air showers). This work resulted in the discovery of nuclear cascades.

By that time (late nineteen forties), it was commonly considered that extensive air showers were produced in the same way as electron-photon showers, namely through the multiple cascade repetition of bremsstrahlung emission followed by the formation of electron-positron pairs. D. V. Skobel'tsyn and his pupils, on the other hand, proposed a completely different process, namely, the nuclear cascade. This consisted of the cascade repetition of the generation of the so-called nuclear-active particles (mainly pions).

The group of physicists directed by D. V. Skobel'tsyn pieced together the overall picture of the penetration of the atmosphere by cosmic rays, and of the accompanying processes. This was subsequently generally accepted. In 1950, D. V. Skobel'tsyn summarized his work up to that point in his address to the annual meeting of the USSR Academy of Sciences.

He pointed out in this address that, when a primary cosmic-ray particle of sufficiently high energy enters the atmosphere, it produces a very restricted number of secondary particles (mainly pions) in the first interaction event, and the inelasticity coefficient at this stage is 0.5 or even less. It was clear even then that the interaction probability (cross section) must have been a relatively slowly-varying function of the primary energy.

A system has now been build near Yukutsk, in the USSR, with an overall area of 20 $km^2$. It is designed for studies of ultrahigh energy particles with energies of $10^{19}$–$10^{20}$ eV. The results of studies of extensive air showers on Tyan'Shan, at Moscow State University, and in Yukutsk, have led to the very important conclusion that new regularities appear when energies of $10^{14}$–$10^{15}$ eV are reached.

The fiftieth anniversity of D. V. Skobel'tsyn's paper coincides with the eighty-fifth birthday of this patriarch of high-energy physics. We are very glad that our teacher is facing his eighty-fifth birthday in excellent shape. It will be sufficient to recall that the present journal published in 1977 his latest paper (without co-authors) on fundamental theoretical questions.

D. V. Skobel'tsyn's contributions to the development of Soviet science range well outside the framework of cosmic-ray physics. The major research school developed by D. V. Skobel'tsyn is concerned with many branches of nuclear physics. It will be sufficient to recall the discovery of the principle of phase stability by V. I. Veksler (the basic principle underlying the operation of all modern accelerators). V. I. Veksler, who originally trained as an electrical engineer, became D. V. Skobel'tsyn's doctoral student and was taught by him not to fear theory and how to develop it creatively. He gave much help to V. I. Veksler in the development of accelerators and in his researches generally. The principle of phase stability as published by V. I. Veksler is rightly considered a triumph of the Skobel'tsyn research school.

When Soviet science lost the great patriot and scientist, S. I. Vavilov, it was D. V. Skobel'tsyn who was able to take on the mantle of the Director of the Physics Institute of the Academy of Sciences of the USSR. Indeed he was its Director for 22 years (between 1951 and 1973) and, retaining the Vavilov traditions, he creatively developed them under the new conditions. His reward was the development of quantum electronics in the USSR. Although he has not published a single paper on quantum electronics, this great achievement of Soviet science is, in many respects, due to D. V. Skobel'tsyn in his role as director of the major physics institute. In the first experiments of A. M. Prokhorov and, later, in the celebrated work of N. G. Basov and A. M. Prokhorov, D. V. Skobel'tsyn was the first to see the beginning of an important new branch of science and technology. His view was not widely shared at the time, but he was proved right.

In conclusion, we could not fail to mention that D. V. Skobel'tsyn was responsible for setting up the Scientific Research Institute of Nuclear Physics of Moscow State University, which, apart, from carrying out important research work, has since 1946 trained more than 3,000 specialists in nuclear physics.

We greet D. V. Skobel'tsyn on the occasion of the fiftieth anniversary of his discovery and his eighty-fifth birthday and wish him new creative successes and, on behalf of his school, we promise to be guided in our own work by his principles and methods.

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