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Who discovered cosmic rays, and when?

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Abstract. A brief essay on the history of the discovery of cosmic rays. Emphasis is on the strange circumstances as to why D V Skobeltsyn — who was the first to observe cosmic ray tracks — was not even mentioned in speeches by the winner (V Hess) of and nominator (A Compton) for the Nobel Prize awarded for the discovery of cosmic rays, although he was named first in a speech by C Anderson, who received the Nobel Prize for the discovery of the positron.

Keywords: cosmic rays, high-altitude radiation, Compton effect, positrons

1. Introduction

There is a standard answer to the question in the title. Austrian physicist Victor Franz Hess made the discovery in 1912 and was awarded the Nobel Prize for it in 1936. In 2012, the scientific community of cosmic ray researchers celebrated the centenary of this event. Incidentally, it was in connection with this anniversary that general attention was drawn to the history and background of this discovery, and many new facts were published. As a result, it turned out that Hess's work [1], so highly valued by the Nobel Committee, was not the first and not the most convincing. Although the wording of the award is very laconic and unambiguous, "For the discovery of cosmic radiation," the history of the discovery was very long and involved. It should be mentioned that the Nobel Committee apparently had some doubts, since Arthur Compton, in his nomination of Victor Hess, after the words, "The time has now arrived, it seems to me, when we can say that the so-called cosmic rays definitely have their origin at such remote distances from the Earth that they may properly be called cosmic, and that the use of the rays has by now led to results of such importance that they may be considered a discovery of the first magnitude," took the liberty of justifying the significant delay in awarding the prize. Namely, he stated: "Before it was appropriate to award the Nobel Prize for the discovery of these rays, it was necessary to await more positive evidence regarding their unique characteristics and importance in various fields of physics."

He then named several scientists on whose results, in his opinion, Hess's discovery was based. As is shown below, the most important names are missing from this list. And there were no references to the more positive evidence that was widely known at the time the prize was awarded.

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2. History of the issue

The main instrument in early studies of ionizing radiation was the electroscope. In 1785, Coulomb found that an electroscope spontaneously discharges under the influence of air (not due to poor insulation). In 1896, Becquerel discovered radioactivity, and, in 1898, Pierre and Marie Curie, when studying new radioactive elements, already used the electroscope discharge rate as a measure of the level of radioactivity. After the discovery of radioactivity and X-rays (1895), systematic studies of gas ionization began, and, in 1900, Julius Elster and Hans Geitel discovered that ionization was observed in closed and insulated vessels even in the absence of any sources. It was concluded that unexpected ionization was caused by radioactive substances in the walls of the detector or in the substance surrounding it. Charles Wilson, who studied the 'electric leakage' in tunnels in 1900 and 1901 [3], was the first to raise the question: could this penetrating radiation be of extraterrestrial origin? In 1908, the same Elster and Geitel discovered a 28% decrease in ionization when moving the detector from the surface to a salt mine and concluded that Earth is a source of penetrating radiation, and some substances (water, salt deposits) are largely free of ionizing substances and can be used as effective protection against them.

In the same year, the German Jesuit priest Theodor Wulf made an electrometer (an electroscope with a measuring

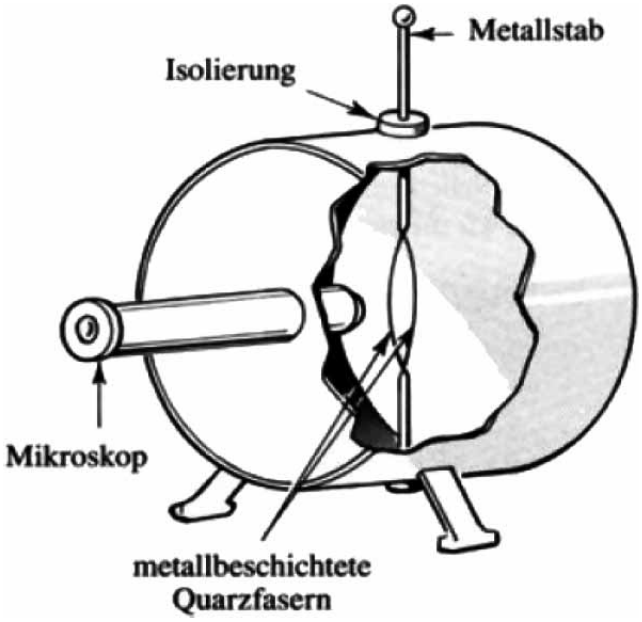

Figure 1. Wulf's electrometer.

scale) of his own design (Fig. 1) and, together with the Swiss Albert Gockel, moved the research on the ionization rate to mountain heights. These measurements in the Alps did not show a significant difference from those at sea level. The idea behind the high-altitude experiments was that, if Earth was the source of radioactivity, an exponential decrease in ionization would be expected with distance from it. Hoping to detect this effect, Wulf conducted a series of experiments on the Eiffel Tower (300 m high) in 1909 and 1910, but found nothing of the sort. Gockel, together with Karl Bergwitz, used Wulf's device to make the first measurements on a balloon that reached an altitude of 1,300 m. Then an altitude of almost 4 km was reached, but no decrease in ionization with height was detected. The idea of testing the radiation source by shielding the detector with a thick layer of water was implemented in 1911 by Domenico Pacini (Fig. 2) in experiments carried out at a depth of 3 m in the sea near Livorno and on Lake Bracciano (Italy). He concluded as a result that "a significant portion of the penetrating radiation in the air has a source independent of the direct action of active substances in the Earth's crust." After Hess published his results, Pacini reproached him for not citing his measurements. The correspondence between them began in March 1920, when Pacini sent Hess a reference to his priority work, which claimed that penetrating radiation did not come from Earth. Hess responded that he did not claim that his short work was complete. In April 1920, Pacini again reproached Hess for having "no references to the underwater measurements on Lake Bracciano, which led me to the conclusion that you later confirmed with your balloon flights." In May 1920, Hess replied: "I am ready to admit that you were the first to express the opinion in Nuovo Cimento, Feb.1912 that there is an ionization of 2 ions cm^{-3} s^{-1} at sea level, which is not connected with the earth. However, the existence of a new source of penetrating radiation coming from above was demonstrated in my ascent in a balloon to an altitude of 5000 m on August 7, 1912, when I discovered an enormous increase in radiation above 3000 m." This opinion of Hess's (we discuss its validity below) became generally accepted and brought him the Nobel Prize.

Figure 2. Domenico Pacini (1878–1934) in 1910.

However, the Italians have always believed and still believe that it was Pacini who discovered cosmic rays. An amusing testimony to this is contained in a letter from the famous physicist Edoardo Amaldi to Antonio Lo Surdo, the director of the Rome Institute of Physics dated July 14, 1941. Condemning an article in "Il Tevere," a newspaper which had great political influence during the Mussolini era, in which it was claimed that nuclear physics and cosmic ray physics were Jewish sciences, Amaldi wrote: "Such a statement is strange for anyone who knows that the Italian Domenico Pacini (not a Jew) discovered cosmic rays."

3. High-altitude radiation and Hess's experiment

Victor Hess (Fig. 3) made seven flights in total in 1912. Of these, six, from April 17 to June 28, were made on balloons of the Vienna Imperial Aeronautic Club at relatively low altitudes (maximum 2,750 m on the first flight). Measurements were made using two or three electrometers, but the results were not of particular interest. The seventh flight was made on August 7, 1912, using a hydrogen-filled balloon of the Bohemia-based German Aero Club. On this flight, Hess reached an altitude of 5,350 m, and all three detectors on board registered a strong increase in ionization (Fig. 4). Based on the results obtained, Hess made several important conclusions.

(1) At altitudes below 1000 m, the data did not disagree with previous measurements.

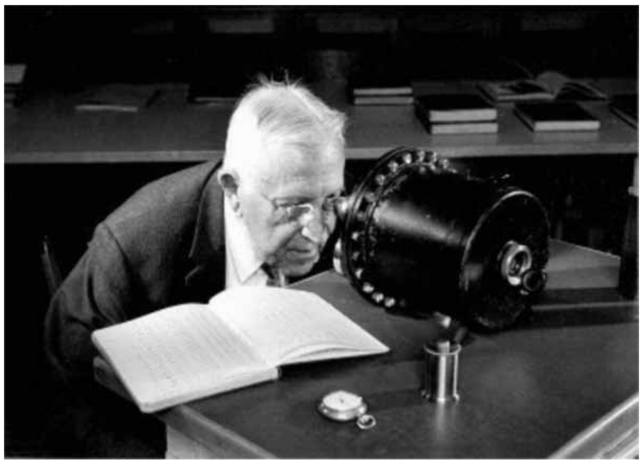

Figure 3. Victor Hess and his apparatus.

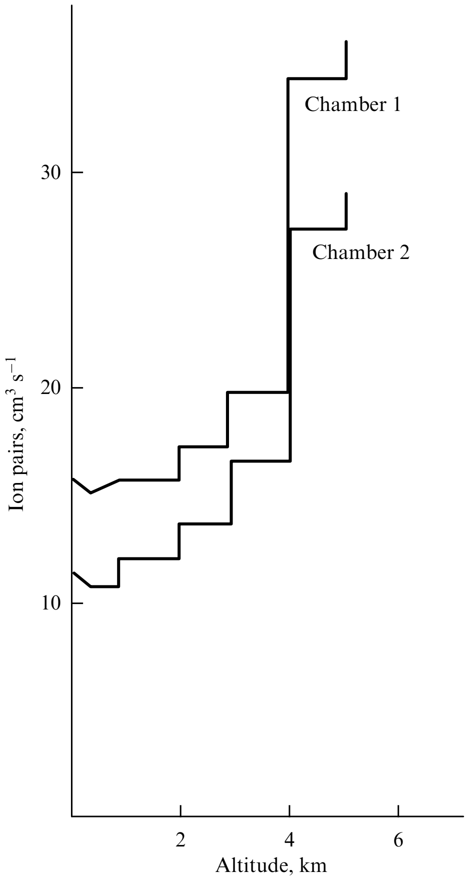

Figure 4. Measurements of altitude variation in ionization during Hess's seventh flight on August 7, 1912.

(2) Highly penetrating radiation comes from above and cannot be caused by radioactive emanations.

(3) This same radiation contributes to the ionization observed at lower altitudes.

(4) There is no difference between ionization measured during the day and at night.

(5) The Sun is not a source of extraterrestrial radiation (assuming that it is gamma radiation).

The new unknown radiation was called high-altitude radiation, and its nature triggered heated debates, in which the American Robert Millikan, a Nobel Prize winner in 1923 (for his work in the field of the photoelectric effect and the measurement of the electron charge), was particularly active. His publications in popular periodicals were so sensational that American journalists even tried (fortunately, unsuccessfully) to introduce the term "Millikan rays."

However, even earlier, Hess's results were confirmed with much greater accuracy in a series of balloon experiments by W Kolhörster (Fig. 5), who measured the high-altitude ionization profile up to an altitude of 9 km in 1913 and 1914. Kolhörster scheduled the last flight for June 28, 1914. It was on this day that the Austrian Archduke Franz Ferdinand was assassinated in Sarajevo: World War I began.

Many years later, historians of science discovered that an experiment similar to the one for which Hess was awarded the Nobel Prize had been conducted by the German meteorologist Franz Linke [2] more than ten years earlier than Hess. From September 1900 to August 1903, Linke conducted 12 launches of balloons with an Elster–Geitel electrometer. In his dissertation, "Messungen elektrischer Potentialdifferenzen vermittels Kollektoren im Ballon und auf der Erde,"[1] he wrote: "If we compare the obtained values with those measured on the ground, then at an altitude of 1000 m, where measurements usually begin, the ionization is less than on the ground, at altitudes from 1 to 3 km it is the same, and even higher it is greater than on the ground, with a value reaching a factor of 4 at an altitude of 5500 m." Thus, Linke (Fig. 6) obtained the same result as Hess, having conducted many more flights, with no less accuracy and much earlier. Still, Hess probably knew nothing about this result, and by 1936 it was forgotten. However, for some reason, another result that everyone should have known had been forgotten about.

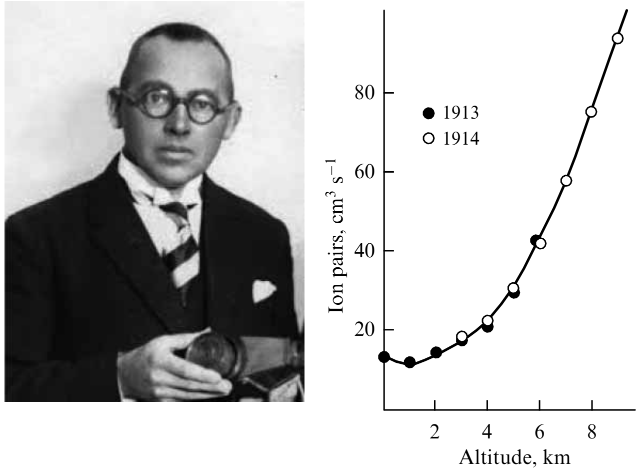

Figure 5. Werner Kolhörster and results of his measurements on balloons during flights of 1913 and 1914.

Figure 6. Franz Linke (1878–1944).

[1] Measurements of electric potential differences using collectors on a balloon and on the ground.

4. Skobeltsyn and his discoveries

The biography of D V Skobeltsyn and his scientific achievements are presented in publications fairly well. For example, various stages of his life are described in good detail in the proceedings of the scientific session dedicated to the 120th anniversary of Skobeltsyn's birth, published in *UFN* ("On the 120th anniversary of the birth of Academician D V Skobeltsyn" *Phys. Usp.* **56** 401–422 (2013); *Usp. Fiz. Nauk* **183** 423–444 (2013)). A good essay by G A Bazilevskaya, "Skobeltsyn and the early years of cosmic particle physics in the Soviet Union" (*Astropart. Phys.* **53** 61–66 (2014)) is also recommended. However, in the context of this article, it is necessary to recall some basic facts.

In 1924, first at the Polytechnic Institute in Leningrad and then at the Physicotechnical Institute, Dmitry Vladimirovich Skobeltsyn began studying the recently discovered Compton effect with a gamma-ray source (Compton's experiments used X-rays). Skobeltsyn placed a cloud chamber in a magnetic field to measure the momentum of Compton electrons from the curvature of their tracks. Among the trajectories he recorded, there were some with incredibly high momentum. Skobeltsyn called the particles he recorded "schneller β-Strahlen" (fast β-rays). He first mentioned them in his report [4]. He then presented his photographs at a conference held in Cambridge on July 23–27, 1928 chaired by Rutherford. Finally, in 1929, he devoted a special publication to these particles [5]. For example, one of the particles had a momentum of 7.3 MeV$/c$. It should be borne in mind that the upper limit of the energy spectrum of natural radioactivity is 2.62 MeV (the gamma line of ThC$''$). Figure 7, taken from [6], shows the trace of a particle whose momentum could not be estimated at all, since its deflection in the magnetic field is too small. Since none of these tracks was directed at the source with which he was working, and in general their direction was rather close to the vertical, the extraterrestrial nature of the radiation became obvious. Skobeltsyn showed that the ionization losses of these particles corresponded to the phenomenon of high-altitude radiation, which thus turned out to be consisting of high-energy particles. Therefore, several of Skobeltsyn's stereoscopic photographs, including the one displayed in Fig. 7, are included in monograph [6] with the caption, "The first recognizable cosmic-ray particles in cloud chamber photographs." It would seem that this is much more positive evidence that, according to Compton, should have been expected before the Nobel Prize was awarded. However, Compton preferred not to mention it. He could not have been unaware of it. The fact is that Carl David Anderson, who won the Nobel Prize in Physics in 1936 at the same time as Hess, began his Nobel lecture with the words: "After Skobeltsyn in 1927 had first shown photographs of tracks of cosmic ray particles... ."

In total, Skobeltsyn recorded 27 trajectories of high-energy particles (in 613 photographs). In three cases, double rays were observed, and in one image there were even three tracks. Skobeltsyn proved that double and triple trajectories originated from a common source, and concluded that these were showers of particles arising from the interaction of high-altitude radiation and air atoms. Thus, he not only proved the corpuscular nature of cosmic radiation, but also discovered cosmic ray showers. Moreover, he was the first to observe positron tracks. But before we proceed to this issue, it is worth summarizing what is known about the discovery of cosmic rays. Many years of intense work by many researchers led to the discovery of high-altitude radiation. Skobeltsyn completed it with direct experiments with photographs of particles that had long been called cosmic rays. In legal terms, instead of indirect evidence, direct proof was finally obtained. The whole picture of the discovery can ultimately be described as follows:

- 1901: C Wilson was the first to hypothesize the existence of extraterrestrial radiation.
- 1904: F Linke was the first to observe the manifestation of high-altitude radiation.
- 1908: A Gockel and T Wulf introduced the term "cosmic rays."
- 1910 and 1911: D Pacini was the first to show that penetrating radiation does not come from Earth.
- 1926: First nomination (unsuccessful) for the Nobel Prize for research in cosmic rays (W Kolhörster and E R A Regener) [7].
- 1927: D Skobeltsyn was the first to observe cosmic rays.

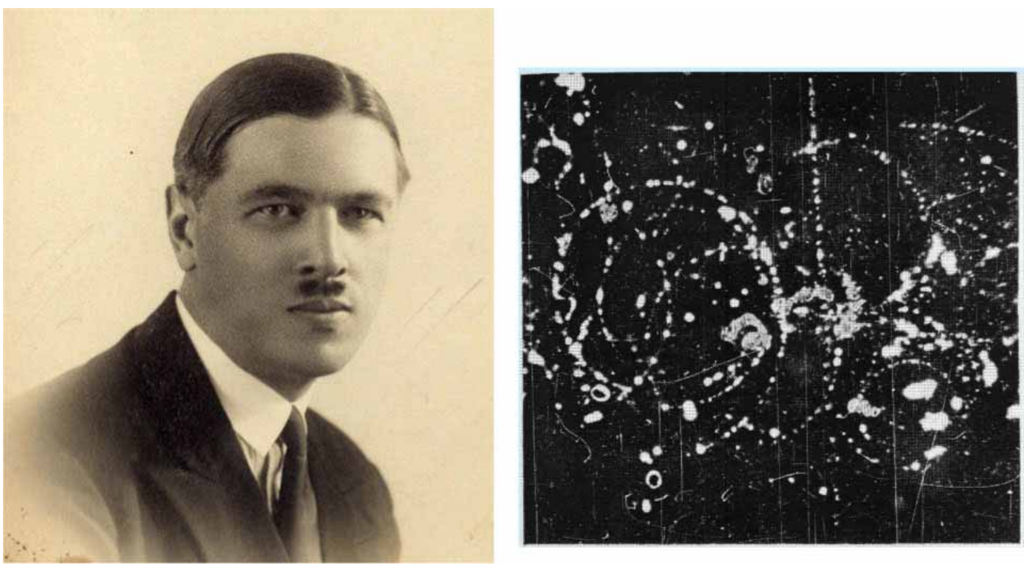

Figure 7. D V Skobeltsyn in his young days and the most energetic particle he registered in 1927.

• 1936: W Hess and K Anderson awarded the Nobel Prize for the discovery of cosmic rays and the positron.

5. Positron. Discovery and problem of its acceptance

It was already mentioned above that Skobeltsyn also observed positron tracks in his experiment. The history of the discovery of this particle is described in the brilliant monograph [8] by Norwood Russell Hanson, who personally interviewed many of the participants in this exciting drama of ideas and experimental facts. He also addressed Skobeltsyn, who, in response to his request, wrote: "In this connection I must quote my note in *Nature* **133** 23 (1934).

"In this case it is quite clear that already in 1931 I observed some cases of electron-positron pairs, but gave them an incorrect interpretation in the above-mentioned sense, as energy losses of particles in nuclear collisions... ."

It is not surprising that Skobeltsyn was reluctant to interpret the incorrect tracks as tracks of positive electrons. He was not alone. In fact, it was known that there are positive and negative charges and their carriers, positive and negative particles (protons and electrons). Why do we need another positive particle?

Hanson writes: "Anderson's predecessors and contemporaries were so resistant to the assumption of a positive electron. Theory was against it. Observations were against it. The giants of physics, Bohr and Rutherford, were against it." True, Dirac's theory appeared. And yet: "Even as early as 1933, W Pauli said that Dirac's equation was a remarkable contribution to microphysics; however, it implied the concept of positive electrons; therefore, this equation must be wrong." Dirac himself long resisted his own conclusions. Another quotation from Hanson: "It is precisely this deep conceptual resistance, built into the structure of classical electrodynamics and particle theory, that must be kept in mind to appreciate why physicists like Dirac, Blackett, Skobeltsyn, Pauli, Oppenheimer, Anderson, Bohr, and Rutherford were so determined to avoid this hypothesis.

...We must admire the conceptual courage of Anderson and Dirac, who, each in their own way, first latched onto the conclusion that the positive electron exists and then had the courage to publicly state their opinion and defend it before a potentially unreceiptive scientific audience."

Hanson recollects Dirac as saying about Skobeltsyn: "Professor P A M Dirac once told me about a lecture delivered by D Skobeltsyn at the Cavendish Laboratory 'somewhere in 1926 or 1927.' Dirac recalled that Skobeltsyn himself or someone in the audience described an experiment in which Skobeltsyn bombarded a metal target. One of the oddities mentioned by Skobeltsyn was the presence of several particles which, being undoubtedly electrons, seemed to 'fall back into the source,' while most of the electrons, as expected in this experiment, were moving away from the source. Professor Dirac believes that what Skobeltsyn described could only be positive electrons, and he thinks it may well be that this Russian made this discovery then."

6. Compton effect

We now return to Compton's nomination. Here is what he said exactly: "Hess's discovery was based on contributions of many scientists; the contributions by Pacini, Wulf, Gockel and Eve were correctly cited in the final report by the Nobel prize Committee to the Royal Academy of Sweden." As already mentioned, only Hess's predecessors are listed here. What was the more positive evidence obtained by the time of the nomination? It was a whole set of properties of high-altitude radiation obtained in various experiments. In 1926, L Mysovsky and L Tuwim discovered the barometric effect of cosmic rays in Leningrad. Their electrometer was immersed in the water of the Neva River to a depth of 1 m, and the decrease in intensity with increasing atmospheric pressure, discovered in this experiment, was correctly interpreted only much later, after the discovery of pions and muons in cosmic rays. In the same year, J Clay, traveling from Amsterdam to Indonesia, measured ionization using an electrometer to discover the latitude effect predicted by Kolhörster back in 1919. Compton himself organized measurements in various parts of the globe in the 1930s and confirmed this effect. Finally, in 1927, Skobeltsyn obtained photographs of charged particles and detected particle showers. In 1928, W Bothe and W Kolhörster carried out the famous experiment in which Geiger counters, connected for coincidence, were separated by a thick layer of gold, borrowed for a while from a bank. Incidentally, it was for the use of the coincidence method that Walther Bothe subsequently won the Nobel Prize (1954; Kolhörster had already died by that time). In 1928, Bothe and Kolhörster obtained additional (to Skobeltsyn's discovery) evidence that at least part of the secondary cosmic radiation consists of corpuscular particles. In 1931, C D Anderson discovered the positron, predicted two years earlier by P A M Dirac. Bruno Rossi, using triple coincidences of Geiger counters, confirmed the existence of showers, the number of which, contrary to expectations, increased with the thickness of the absorber layer, while P M S Blackett and D Occhialini obtained the same result

Figure 8. Carl D Anderson (1905–1991).

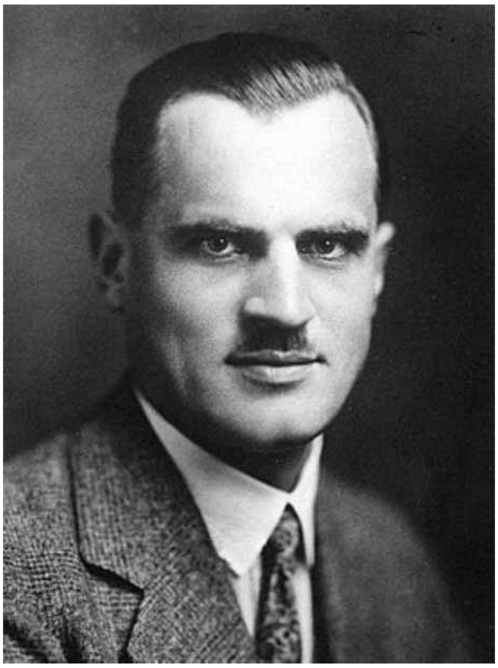

Figure 9. Arthur Holly Compton (1892–1962).

using a Wilson cloud chamber. In 1932, Compton himself, together with L Alvarez, in a high-altitude experiment in Mexico, confirmed the existence of the west-east asymmetry, previously predicted by Rossi on the basis of Stoermer's calculations for cosmic particles in Earth's magnetic field. Rossi confirmed their result in his experiment conducted in Eritrea in 1933.

This was the background against which Compton nominated Hess, and none of this was mentioned. Of all the results listed above, Skobeltsyn's is undoubtedly the most striking and important (indirect evidence and direct proof should be recalled once again), so much so that one cannot help but wonder why he did not share the prize with Hess. But Compton apparently did not want this, and to avoid questions about why this was not done, he did not even mention Skobeltsyn or anyone else.

Thus, Compton, apparently, deliberately ignored Skobeltsyn's results when nominating Hess. But why?

It is unlikely to be due to Russophobia or personal hostility. Perhaps it was related to the main topic of Skobeltsyn's research. It should be recalled that all the discoveries described above were made in an experiment aimed at studying the Compton effect. The late A A Pomansky, the first head of the Baksan Neutrino Observatory, the construction of which began at the Lebedev Physical Institute, often communicated with Skobeltsyn, the then director of the Lebedev Physical Institute. He said that he once asked Skobeltsyn which of his results he considered the most important in his life. To his great surprise, Skobeltsyn answered that it was the confirmation of the Compton effect. It should be noted here that the consequences of the discovery of this effect were no less revolutionary than the discovery of the positron. According to I S Veselovsky [9], the most important evidence on this matter is contained in the classic monograph [10]: "From this book by Rutherford et al. it follows that Skobeltsyn developed an original and powerful method for studying the interaction of gamma quanta with matter, the Wilson chamber in a magnetic field (pp. 472–476). It was Skobeltsyn's experiments that made it possible to show that the old theories of Compton (*Phys. Rev.* **21** 483 (1923)) and Dirac (*Proc. Roy. Soc.* **A121** 405 (1927)) do not agree with experiment, while the Klein–Nishina theory (*Zs. f. Phys.* **52** 853 (1928)) — the first rigorous result of quantum electrodynamics — agrees well with experiment (pp. 459–464 and 475–479)." Thus, Compton's formula for the Compton effect turned out to be incorrect.

Were any attempts made to nominate Skobeltsyn for the Nobel Prize? The Nobel Committee declassifies such data after 50 years, so now we can only learn about fairly old nominations. Currently, only one is available. It looks like this:

- Nominator: Czeslaw Bialobrzeski, Warsaw, Poland.
- Nominees: Physics 1947 for Max Born, Dmitrij Scobelzyn, Bruno Benedetto Rossi.

It must be said that Dmitry Vladimirovich's company here is very dignified. However, there was another attempt at nomination, the information on which is available in the archives of Moscow State University [11]. In my opinion, the justification for this nomination is ideal in meaning and form: "For his discovery of high-energy particles in cosmic rays and pioneering research on the experimental justification of quantum electrodynamics."

7. Why was all this written (addition and apology from author)?

Many publications in *Uspekhi Fizicheskikh Nauk* (*UFN*) journal have been devoted to cosmic rays. In particular, the protagonist of this essay, Dmitry Vladimirovich Skobeltsyn, published a detailed article, "The Nature of Cosmic Radiation" [12] in *Uspekhi Fizicheskikh Nauk* back in 1950, and an abridged translation of his fundamental article dated 1929 was reprinted by *Uspekhi Fizicheskikh Nauk* in 1967 [5]. Very important and detailed reviews [13] and [14] were published by the 2003 by Nobel Prize winner in physics, Vitaly Lazarevich Ginzburg (Editor-in-Chief of *Uspekhi Fizicheskikh Nauk* (*Physics–Uspekhi*) in 1998–2009), who devoted a significant part of his studies to cosmic rays.

Various aspects of cosmic ray physics were covered in reviews by V S Ptuskin [15], A D Filonenko [16], M I Panasyuk and M L Miroshnichenko [17], Yu V Stenkin [18], A D Panov, D M Podorozhnyi, A N Turundaevskii [19], and A M Bykov [20]. A biography of D V Skobeltsyn and his role in the formation and development of cosmic ray science in the Soviet Union were also presented in great detail in *Uspekhi Fizicheskikh Nauk* (*Physics Uspekhi*) publications [21–25]. Of course, the issues related to the history of Skobeltsyn's discoveries and their assessment by contemporaries and descendants were also touched upon. Why then another publication on this topic?

First, as was said in the Introduction, in connection with the centenary, new data appeared on the predecessors of the discovery of cosmic rays (for example, on F Linke's experiment), and the history of the discovery itself with accompanying circumstances was partly revised. In any case, considerable attention was attracted to it.

Second, the astonishing fact of Compton's ignoring Skobeltsyn's work when nominating Hess for the Nobel Prize, on the contrary, has, to a best of my knowledge, received no attention at all. And this fact itself is both important and instructive.

Finally, another circumstance seems quite significant. We live in the era of 'cancel culture,' when, for ideological or political reasons, zealots from overwhelmingly civilized countries seek to discredit and defame great manifestations of human genius in music, literature, and politics. This practice is especially popular in relation to Russia. Perhaps it will come to science; some tendencies certainly exist. In this regard, the issue of the priority of Russian scientists in the past and present is acquiring new relevance. This topic was once compromised by an unsuccessful campaign conducted by zealous government officials. It should be remembered, however, that it was initiated by P L Kapitsa and was based on quite apparent facts concerning the underestimation of Russian inventors and scientists by the Russian government and society. I believe that it is useful to recall all cases of this kind.

P.S. This article is based on the report delivered by the author at a conference dedicated to the 75th anniversary of the Skobeltsyn Institute of Nuclear Physics of Moscow State University. It should be considered a first step in preparing to celebrate the real centenary of the discovery of cosmic rays in 2027.

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