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Cherenkov radiation as a serendipitous phenomenon

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Abstract. A brief account is given of P A Cherenkov's Voronezh years, a period during which the future Nobel laureate in physics attended school (in the village of Novaya Chigla near Voronezh) and studied at Voronezh State University. The history of the serendipitous discovery of the radiation which was to be named after him is described and its importance for modern science is discussed. Possible modern approaches are considered to explain — without using the concept of 'cold nuclear synthesis' — some other unexpected experimental results on the nonthermonuclear fusion of light nuclei stimulated by electron beams and by laser and gamma radiations.

Keywords: Novaya Chigla, Voronezh State University, Cherenkov radiation, Nobel Prize, serendipitous discoveries, light nucleus fusion reactions, neutronium

1. Introduction

Voronezh State University, where P A Cherenkov (photo 1), the first Russian Nobel Prize laureate in Physics 1958, studied, is in the center of the city of Voronezh.

Not far from the University, one can find the Literary Museum, and close to it there is a monument to Ivan Alekseevich Bunin (photo 2), winner of the Nobel Prize in Literature 1933. And the secondary school named after Nikolai Gennadievich Basov (photo 3), Nobel Prize winner in Physics 1964 is situated a bit farther.

Thus, the Voronezh region is home to three Russian Nobel Prize winners. What is remarkable in this context is that, besides Moscow and Saint Petersburg, Voronezh is the only Russian city that became home for three Nobel laureates.

Photo 1. Pavel Alekseevich Cherenkov, the Nobel Prize laureate in Physics 1958.

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2. Voronezh period of P A Cherenkov's life

Pavel Alekseevich Cherenkov was born on 28 July 1904 into a quite upstanding peasant family in the village of Novaya Chigla, about 150 kilometers s.-w. from Voronezh. His father Aleksei Egorovich Cherenkov was among the most talented of the 150 million peasants [1], who succeeded by the end of the World War I in receiving officer's epaulets, although he had attended the orthodox parish school for only four years.

Photo 2. Ivan Alekseevich Bunin, the Nobel Prize laureate in Literature 1933.

Photo 3. Nikolai Gennadievich Basov, the Nobel Prize laureate in Physics 1964.

Photo 4. Graduates of the village school of Novaya Chigla (1924). Pavel Cherenkov is third from the right in the second row. Photo courtesy of E P Cherenkova, his daughter.

Photo 5. Physics laboratory of Voronezh State University. P A Cherenkov is the sixth from the left. Photo courtesy of E P Cherenkova.

The Civil War stretched out Pavel Cherenkov's school days until he was 20 years old, breaking it up into several stages: first, he graduated from the orthodox parish school, then was an unskilled worker and a clerk and, finally, attended the gymnasium, transferred from the city of Bobrov (photo 4).

In 1924, Academician V I Vernadsky wrote from Paris to his friend I I Petrunkevich [1]: "In the field of exact knowledge there is interesting evidence concerning the occurrence of young talents in the people's surrounding. This may be our main opportunity for a resurgence ... which depends on laws, unknown to us, of the appearance of great personalities." P A Cherenkov was doubtlessly one of these young talents.

Immediately upon graduating from school in 1924, Pavel Cherenkov enrolled as a student in the Department of Physics and Mathematics of the Pedagogical Faculty at Voronezh State University (VSU) (photo 5). This university was decreed in 1918 by Lenin to be the successor of one of the oldest Russian universities, namely, Derpt (Yuryev) University, established by Emperor Aleksander I in 1802, and evacuated to Voronezh (because of the risk of a German army offensive in the Baltic States territories). In the autumn of 1918, the staff of Voronezh State University consisted of 21 professors, 3 docents and more than 20 instructors and assistants, among which were such well-known scientists as doctors N N Burdenko and I V Georgievsky, mathematicians V G Alekseev and N P Sambikin, biologists K K Saint-Hilaire and M S Tsvet, geologists V E Tarasenko and N N Bogolyubov, and others.

Student P A Cherenkov was notable for his exceptional capacity for work and enormous desire to acquire new knowledge. It is known that he showed great abilities in mathematics, which permitted him to become a close friend of professor N P Sambikin, one of the leading VSU mathematicians. P A Cherenkov also did volunteer work in the university (photos 6, 7).

3. History of the discovery of Vavilov–Cherenkov radiation

Upon graduating from university, P A Cherenkov worked as a teacher in the city of Kozlov (now Michurinsk) (photos 8, 9). In 1930, he passed an interview for postgraduate study (after reading about it in a newspaper announcement) at the Leningrad Physico-Mathematical Institute of the USSR Academy of Sciences, and was enrolled in a postgraduate study programme there. In 1931, P A Cherenkov married Maria Putintseva, the daughter of Aleksei Mikhailovich Putintsev, VSU professor of philology, well-known literary critic, and founder of the poet I S Nikitin Museum in Voronezh.

In 1932, S I Vavilov started working at the Leningrad Physico-Mathematical Institute of USSR AS, and became supervisor of P A Cherenkov; of the research topics S I Vavilov proposed to his postgraduate students, P A Cherenkov got a subject related to the investigation of luminescence origination under the influence of gamma-rays from radium in solutions of uranyl salts.

In the course of his work, P A Cherenkov found out that the gamma-rays excited a strange glow in the solution studied. And here P A Cherenkov's remarkable merits as a researcher were manifested. He did not set the phenomenon mentioned aside as a false effect, but methodically continued his studies and demonstrated that such a glow arose both in sulphuric acid and in other pure liquids, for example, in water. S I Vavilov wrote in the review concerning his postgraduate student that P A Cherenkov actually completed two interesting projects during his studies. The first, defended in 1935 as a thesis for his degree of Candidate of Sciences, provided the key to understanding luminescence caused by hard radiation. The second one involved the unexpected discovery of a phenomenon [2, 3] which hitherto had not been predicted by existing theories.

Photo 6. The board of management of the trade-union mutual aid fund at Voronezh State University (2 April 1928). P A Cherenkov is second from the right in the upper row. Photo courtesy of E P Cherenkova.

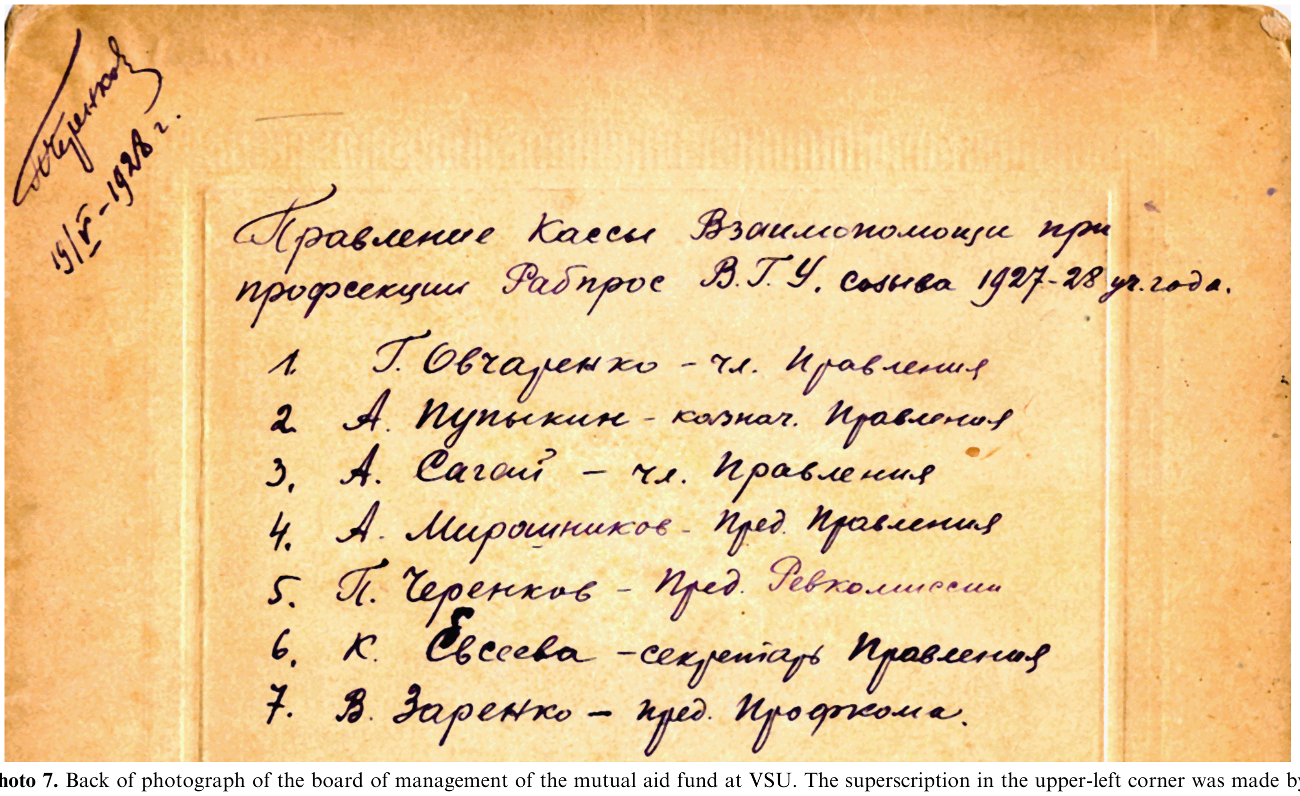

Photo 7. Back of photograph of the board of management of the mutual aid fund at VSU. The superscription in the upper-left corner was made by P A Cherenkov. Photo courtesy of E P Cherenkova.

Photo 8. Graduates of the Department of Physics and Mathematics of the Pedagogical Faculty of Voronezh State University in 1928. P A Cherenkov is in the middle of the third row. Photo courtesy of E P Cherenkova.

Photo 9. Michurinsk. Graduates of Voronezh State University: Tatiana, P A Cherenkov's sister, is on the extreme left in the first row; P A Cherenkov is beside her; Maria Alekseevna Putintseva (who married P A Cherenkov in 1931) is in the second row to the left, and to the right is Galina Aleksandrovna Zaitseva (who attended the same secondary school as P A Cherenkov), university student in the same year as M A Putintseva. Photo courtesy of E P Cherenkova.

In 1936, P A Cherenkov moved to Moscow and continued his research work at the Physical Institute of the USSR Academy of Sciences (PIAS). When he put liquids being studied into a magnetic field, he revealed the new radiation to exhibit spatial anisotropy [4], which was decisive for clarifying its true nature.

Photo 10. P A Cherenkov (1945). Photo courtesy of E P Cherenkova.

The theory of this phenomenon, developed in 1937 by the outstanding physical theorists I E Tamm and I M Frank [5] on the basis of classical electrodynamics, explained the luminescence discovered in P A Cherenkov's work by the radiation of electrons traveling in an optically transparent medium with a constant velocity superior to the phase velocity of light in the medium.

In 1937–1940, P A Cherenkov experimentally confirmed [6] all the regularities following from the Tamm–Frank theory. As G S Landsberg said, the studies, which have become classics, carried out by P A Cherenkov (photo 10) are "an ornament to Soviet physics."

In 1958, P A Cherenkov, jointly with I E Tamm and I M Frank, was awarded the Nobel Prize in Physics for "the discovery and the interpretation of the Cherenkov effect" [6–8]. At one of the seminars at PI of USSR AS, S I Vavilov proposed that this phenomenon be called the 'Cherenkov effect'. But, taking into account the role played by S I Vavilov himself in the process of revelation and physical interpretation of the phenomenon, in our country this effect is often called the Vavilov–Cherenkov effect.

In 1937, P A Cherenkov was the first to put forward the truly revolutionary idea concerning the possibility of applying the discovered radiation to measure the velocities of relativistic charged particles [9]. This idea was implemented [10] by the creation of various types of Cherenkov counters and spectrometers, including RICH (Ring Image Cherenkov) detectors developed by the European physicists J Séguinot and T Ypsilantis, which played a very important part in the discovery of antiprotons in 1955, and of $W^{\pm}$-bosons in 1983. At present, Cherenkov counters are applied in Switzerland at the Large Hadron Collider (LHC) to register various relativistic particles produced in collisions of counterpropagating proton beams with energies up to 14 TeV. The same kind of counters serve as the basis for creating the largest cosmic ray telescope in the world in the Tunka Valley (Buryatia) to realize the project Gamma Astronomy of Multi-TeV Energies.

4. Role of unexpected discoveries in science

An important part in forming new lines of scientific cognition is played by unexpected discoveries that were not predicted previously, among which the discovery of Vavilov–Cherenkov radiation holds a firm place.

A wonderful example, reflected in textbooks, of such a discovery is the one made in 1896 by the French physicist A Becquerel of radioactivity, which stimulated the origination of nuclear physics.

Modern physicists were staggered at the end of the 20th century by the experimental proof in astrophysics of the existence in our Universe of dark matter and dark energy, which confirmed the essential incompleteness of modern fundamental physical theories, which doubtless is a stimulus for the development of new physical ideas.

5. Problems in describing low-energy fusion reactions involving light hydrogen isotopes

Result, that hitherto have not been predicted and have not been explained within the framework of existing conceptions apparently include the experimental results obtained by quite illustrious physicists, presented in a noticeable number of publications in serious scientific periodicals and revealing the existence of low-energy nuclear reactions involving light hydrogen isotopes. We shall present examples of several such studies.

On 25 April 1956, in a lecture [11] to the epochal conference at the British nuclear center in Harwell, I V Kurchatov presented data on the appearance of hard X-ray radiation and of neutrons when high currents pass through gases containing hydrogen, deuterium, and helium at low pressures. The short pulses caused by neutrons and X-ray quanta could be precisely phased on oscillograms. They turn out to have originated at the same time. The energy of X-ray quanta appearing in the case of pulsed electrical processes in hydrogen and deuterium amounts to 300–400 keV. It must be noted that at the instant of time when quanta of such high energies originate, the voltage applied to the discharge tube only amounts to 10 kV. The thermal characteristics of the plasma produced during electric discharges in gases show that the observed nuclear reactions cannot be considered thermonuclear.

A G Lipson et al. [12] reported that, in the case of deuterium desorption from the palladium heterostructure $Pd/PdO:D_x$ stimulated by an electron beam, the nuclear reactions registered by track detectors result in the production of protons and alpha particles of energies 2.5–2.75 MeV and 11–16 MeV, respectively. In the opinion of the authors of Ref. [12], if the kinetic energy of the deuterons were determined by its equilibrium value at the temperature arising in the vicinity of the surface indicated, then the deuterium–deuterium (DD) reaction rate would be five orders of magnitude inferior to the one observed experimentally.

N A Kirichenko, A V Simakin, and G A Shafeev [13] have presented the results of an experimental investigation of the influence of laser radiation on the activity of radionuclides ^{234}Th, ^{234m}Pa, and ^{235}U in a heavy-water solution of uranium chloride containing gold nanoparticles, as well. The activity of radionuclides in the irradiated solutions differed significantly from the equilibrium values. The authors of Ref. [13] interpreted their results as evidence that laser radiation is capable of accelerating the α-decay processes involving a number of radionuclides. Here, the processes observed were organically linked to the presence in the solution of heavy-water molecules comprising deuterium nuclei as constituents.

The list of experiments that yielded similar results could be extended.

An analysis of experimental data permits drawing three conclusions. First, in no case does doubt arise concerning the participation of light hydrogen isotopes in nuclear reactions. Second, the fusion reactions of the indicated charged isotopes, usually named 'cold nuclear fusion', cannot in principle be a source of the observed nuclear reactions, since the kinetic energies of these light isotopes turn out to be much lower than the heights of the Coulomb barriers they must surmount to undergo fusion with their partners-nuclei. And third, taking advantage of the mechanism of thermonuclear fusion of the aforementioned hydrogen isotopes to explain the nuclear reactions considered is not possible either, owing to the temperatures arising in the media under investigation being substantially lower than characteristic thermonuclear temperatures.

There are still no conventional explanations for the experiments indicated.

Quite recently, one of my students, Yu L Ratis, put forward an interesting hypothesis (see, for example, his work "Neutrino catalysis of nuclear fusion in cold hydrogen" [14] and "Experimental confirmation of the existence of a neutronlike exoatom 'neutronium'" [15]) which apparently provides a qualitative explanation for the aforementioned experimental results.

This hypothesis is based on the idea of new quasibound neutral particles being produced in the reactions investigated, the production and existence of which is due to electroweak interactions peculiar to the beta-decay of nuclei. Like neutrons, being neutral, these particles merge readily with atomic nuclei, thus causing various nuclear reactions to occur.

Yu L Ratis considers such particles to include exoatom 'neutronium' that represents a quasibound state, due to weak interaction, of a neutron–neutrino pair with a lifetime on the order of 4×10^{-5} s and a negative binding energy. Neutronium constitutes an extremely narrow low-lying resonance in the elastic electron–proton scattering cross section at electron kinetic energies in the region of 10–200 eV. Owing to its small width and amplitude, this resonance cannot be revealed in direct electron–proton scattering experiments. The presence of a third particle upon the collision of the electron and the hydrogen atom leads to the width of the resonance in the neutronium production cross section in this collision being 14 orders of magnitude larger than the width of the analogous resonance in elastic ep scattering, so its properties can be studied experimentally.

Neutronium can form bound states with normal nuclei. For example, a dineutronium exoatom is produced with a negative binding energy and a lifetime on the order of 10^{-4} s in the case of its interaction with a neutron.

On the basis of his hypothesis, Yu L Ratis qualitatively explained the results of the aforementioned experiments and made a number of predictions permitting us to make use of the new particles in obtaining a whole number of interesting applied results.

Photo 11. P A Cherenkov (1980s). Photo courtesy of E P Cherenkova.

The ideas dealt with above can be perceived differently. However, no doubts arise concerning the necessity of continuing serious experimental and theoretical studies in order to achieve an ultimate explanation of the nature of the unexpected findings presented above.

6. Conclusion

It can be considered a good tradition to name Russian scientific research institutions after outstanding scientists, which is reflected, for example, in the names of such institutions as the P N Lebedev Physical Institute, RAS, the I V Kurchatov Institute of Atomic Energy, the M V Keldysh Institute of Applied Mathematics, RAS, the P L Kapitza Institute for Physical Problems, RAS, the L D Landau Institute of Theoretical Physics, RAS, the A M Prokhorov Institute of General Physics, RAS, and the G I Budker Institute of Nuclear Physics.

In Russia, there are also institutions of higher education named after outstanding scientists, for example, M V Lomonosov Moscow State University, N I Lobachevsky State University of Nizhny Novgorod, S P Korolev Samara State Aerospace University, and others.

It would be appropriate if, among the leading institutions of higher education, there finally appeared institutes named after Russian scientists who were Nobel laureates. The staff of Voronezh State University would be happy, if VSU were named after its graduate, one of the first Russian physicists awarded the Nobel Prize, Pavel Alekseevich Cherenkov (photo 11). Note that quite serious reasons for this exist.

VSU comprises 18 faculties with more than 20 thousand students and 800 Russian and foreign postgraduate students.

University graduates work in 141 countries in the world, while 308 professors with a Doctor of Sciences degree and 970 docents who are Candidates of Sciences teach at the university. Renowned scientific schools in the fields of physics, chemistry, mathematics, biology, geology, philology, and other sciences exist at Voronezh State University. In different years, VSU academic staff has included such outstanding scientists as N N Burdenko, N P Dubinin, K K Saint-Hilaire, I I Schmalhausen, M S Tsvet, B E Regel, M A Levitskaya, B M Kozo-Polyansky, A K Sushkevich, M A Krasnoselsky, I Ya Krein, A V Dumansky, and L P Rapoport, who are highly esteemed both at home and abroad.

Voronezh State University is among the ten best Russian universities.

Therefore, on behalf of the staff of Voronezh State University, I appeal to the administrations of the RAS Presidium, of the RAS Physical Sciences Division, and of LPI of RAS to support naming VSU after the VSU graduate and Nobel laureate in Physics 1958 P A Cherenkov.

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