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THE 50TH ANNIVERSARY OF THE DISCOVERY OF PHASE STABILITY PRINCIPLE

The investigations carried out by means of charged particle accelerators, based on the phase stability principle discovered by **V.I.Veksler** and **E.M.McMillan**, have resulted in radical changes in our picture of the microcosm: new laws of nature and physical principles have been discovered.

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THE 50th ANNIVERSARY OF THE DISCOVERY OF PHASE STABILITY PRINCIPLE

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Vladimir Iosifovich Veksler discovered the phase stability principle while working at the D.V.Skobeltsyn Laboratory of the P.N.Lebedev Physics Institute of the USSR Academy of Sciences (FIAN).

What role FIAN played in Veksler's destiny he said best himself at the ceremony where the Atoms for Peace Award was presented to him and E.McMillan in the USA in 1963: "I should consider myself especially lucky. Despite the ordeals of the Second World War, our Soviet state gave support to fundamental science during all these hard years. Physics in the Soviet Union began developing much faster than usual after the war. That was a lucky circumstance for me, since in 1936 I, as quite a young specialist, was invited to work at the P.N.Lebedev Physics Institute of the USSR Academy of Sciences where such outstanding Soviet scientists as Academicians S.Vavilov, L.Mandelstam, I.Tamm and many others were then working, as well as Academician D.Skobeltsyn, the person I consider to be my teacher and to whom I am indebted for many things".

Veksler continues, "There was a wonderful atmosphere of boundless devotion to science that reigned at the Institute, as well as opportunity for continuous personal contact with these outstanding scientists and with my friends and colleagues of the same age - I.Frank and P.Cherenkov, subsequent Nobel-prize winners, - and with Professors S.Vernov and N.Dobrotin. One had the attention and help of theorists, first of all E.Feinberg and M.Markov, and also the participation of a large group of gifted physicists from the younger generation - this is an incomplete list of people I have been connected with in team-work for scores of years and who have every reason to consider our success a common one".

It should be noted, however, that the pre-FIAN period of Veksler's life also played a significant role in forming him as a leader of world science in the field of accelerator physics.

Vladimir I.Veksler was born on March 4, 1907 in Zhitomir. Because of unfavourable domestic reasons, from the age of 14 to 18 he was educated at a children's home in Moscow. After leaving school, in the spirit of that time and together with the entire Komsomol cell, he refused an offer to enter any institution of higher education and became an electrician at a printing factory. In 1927, he joined the G.V.Plekhanov Institute of the National Economy. In 1930, this Institute was reorganized, and for this reason he went to work as a laboratory assistant at the All-Union Electrical Engineering Institute. In 1931, he received his diploma in electrical engineering after finishing correspondence courses at the Moscow Power Engineering Institute. His experience in production work, his ability to communicate with large groups of people, and the necessity of making responsible decisions very quickly made him a brilliant organizer. It would have been simply impossible to construct the accelerator centres at the Academy of Sciences without possessing such excellent qualities.

V.I.Veksler(1934-1935)

The construction of the accelerator centres seemed to be something extremely bold, unbelievable, and a worthless expenditure to physicists of previous generations. In this connection, one can read the opinions of N.Bohr, W.Heisenberg, P.Kapitza. One should remember the conditions in which Vavilov, Skobeltsyn and Veksler had to make responsible decisions and how things could have turned out for them in the 1940s and in the beginning of the 1950s. Let me quote another part of the above-mentioned speech of Veksler: "Due to the great help of the USSR Academy of Sciences and the State Committee for the Utilization of Atomic Energy, an experimental realization of the phase stability principle had already begun in 1945 when we started constructing the new type accelerators.

During this period, I had the luck to take advantage of the work, experience and support of many outstanding engineers of our country who had made large contributions to the construction of accelerators and to the experimental base of high energy physics. First of all, I should name here the scientists and engineers of the Efremov Institute of Electrophysical Apparatus in Leningrad, and the Moscow Radio Engineering Institute".

D.I.Blokhintsev, V.I.Veksler, M.A.Markov (left to right) at the seminar LHE JINR.

These words reflect the great respect Veksler held for the creative work of engineers and highly skilled workers. Veksler's ability to work with people and to select personnel, helpers and like-minded people, played a large role in creating the accelerator technique.

Large public activities, which Veksler always spared a lot of time for, left their indelible mark on his character. He was a convinced collectivist and communicated easily with people of widely diverse levels of culture and status.

In contrast to his academic colleagues, he was able to aim at getting the decisions from the administrative and government institutions, up to the highest rank, than were necessary for creatingthe accelerator centres. In these cases, his picturesque, emotional speech was accompanied by "terminology" borrowed from his Komsomol past that was especially intelligible to the bureaucracy formed in the same stormy and, alas, culture-poor, post-revolutionary environment as he was.

Veksler took his Party and administrative duties very seriously and with a great responsibility. The combination of his capacity for work, self-discipline, great creative potential and rich imagination seemed to be paradoxical. I think he paid dearly for the balance of his creative and organizational abilities.

Work at the Academy of Sciences and Moscow University, as well as constant self-education, made him one of the leaders in academic surroundings, as well. On holiday, at home every evening, and in the car, he studied abstracts he had made of articles from the scientific literature. Veksler was a great admirer of the fine arts, collected albums of art, and never missed an opportunity to visit museums and exhibitions or to talk with artists and writers.

It was a great surprise to many people that Veksler, who had been engaged in electrical engineering and X-rays previously, chose nuclear physics when coming to work at FIAN. In the middle of the 1930s, nuclear physics was thought to hold little promise, and Vavilov was criticized for his initiative to develop research in this field at FIAN.

V.Veksler's choice was not accidental. He came to FIAN already having the developed proportional counters.

At that time, the development of the methods for proportional counters was such a complex problem that it was the basis for Veksler's thesis for his Doctor's degree. The main problem was to have a stable voltage for the counter supply. The counters were used in the experiments devoted to cosmic rays, which had been the main subject of Veksler's research for 10 years (1937-1947). The leader of the experiments was D.V.Skobeltsyn, a recognized founder of high energy physics. He directed his followers' and colleagues' attention to research into processes occurring at the extreme of attainable energies. The classic monograph by E.Rutherford, J.Chadwick and C.D.Ellis ("Radiation from Radioactive Substances", Cambridge, 1930) very likely contains the most authoritative appreciations of D.V.Skobeltsyn's work:

1. Skobeltsyn has created an original and powerful method of studying the interaction of gamma-quanta with a substance - the Wilson chamber in a magnetic field.
2. A direct and authentic test of the existence of the photon momentum has been carried out by Skobeltsyn.
3. The first strict result of quantum electrodynamics agrees well with Skobeltsyn's experimental data obtained earlier.

The first observations of recoil electrons marked the beginning of a new area of physics, namely experimental elementary particle physics, and it belongs, by right, to D.V.Skobeltsyn. D.V.Skobeltsyn's correspondence with U.Nishina, one of the authors of the first quantitative regularity of Maxwell-Dirac electrodynamics, is evidence of this fact. It should also be noted that Skobeltsyn had turned the Wilson chamber from a demonstrational device into a device for quantitative measurements.

The most outstanding discovery of D.V.Skobeltsyn, however, was the first observation of particles of energies much higher than that of particles from radioactive sources. He attributed these particles to cosmic radiation and quantitatively explained the distribution of the geophysical effect in the ionized atmosphere observed by V.Hess. It is no accident that Skobeltsyn's discovery of the nature of cosmic rays is regarded as the beginning of high energy physics.

Veksler's first investigations of cosmic rays were made in the Elbrus expeditions of 1937-1940 and in expeditions to the Pamirs. The main equipment preparation, assembly and adjustment were performed at FIAN in Moscow. The transportation and installation of the equipment in the mountains and its operation required very large efforts. Veksler's talent for organization showed itself very quickly here and he became head of the expeditions. The successful combination of creative work with a great talent for organization is one of the characteristic traits of Veksler that allowed him afterwards to head the construction of gigantic research facilities based on accelerators. From the beginning of his studies of cosmic rays, he understood that quantitative results on particle properties would cost much effort in this area. The solution of the problems of obtaining intensive beams of relativistic particles under laboratory conditions became his main life's work.

At the end of the thirties, work on the design of a large cyclotron was being done at FIAN by the group of V.I.Veksler, S.N.Vernov, L.V.Grosheva, P.A.Cherenkov and E.L.Feinberg. By June of 1940, the room of a cyclotron laboratory was equipped and industrial orders were placed. The start up of the experimental cyclotron was scheduled in the second half of 1941.

The research programs using cyclotrons were directed to nonrelativistic nuclear physics that was of no interest to Veksler. His main purpose was to study the phenomena that had been observed only in cosmic rays, at that time. Cyclotrons were capable of accelerating particles only to the limited energies where relativistic effects, violating the resonance of particle motion in the accelerator, begin showing themselves. Five years, on the whole, of futile search to overcome this barrier were crowned with success only at the beginning of 1944. He suggested the accelerator that became known as the microtron. It is characteristic that its initial name was an electron cyclotron. Analysing the operation of his microtron, Veksler understood that the question was not the improvement of the cyclotron but the discovery of a fundamental principle - the phase stability principle - due to which the limit of achievable energies of particles increased by many orders of magnitude under laboratory conditions. Veksler proposed all four methods of synchronization of particle motion, and the appropriate terminology was suggested.

The history of particle acceleration is mainly the invention of methods of particle motion synchronization with an alternating acceleration field. In a resonance accelerator, permanent acceleration exists because a charged particle reaches the acceleration electrodes every time the electric field is directed in the direction of particle motion. An ideal equilibrium particle reaches the same equilibrium phase every time. The phase stability mechanism provides a correlation between increasing energy and the changing period of particle rotation in the orbit. The energy increment of the equilibrium particle is defined by the resonance condition $T = qT_a$, where T_a is the period of rotation and q is the multiplicity of the accelerating field frequency $\omega_a = 2\pi / T_a$. For a cyclic accelerator, the energy of the equilibrium particle is

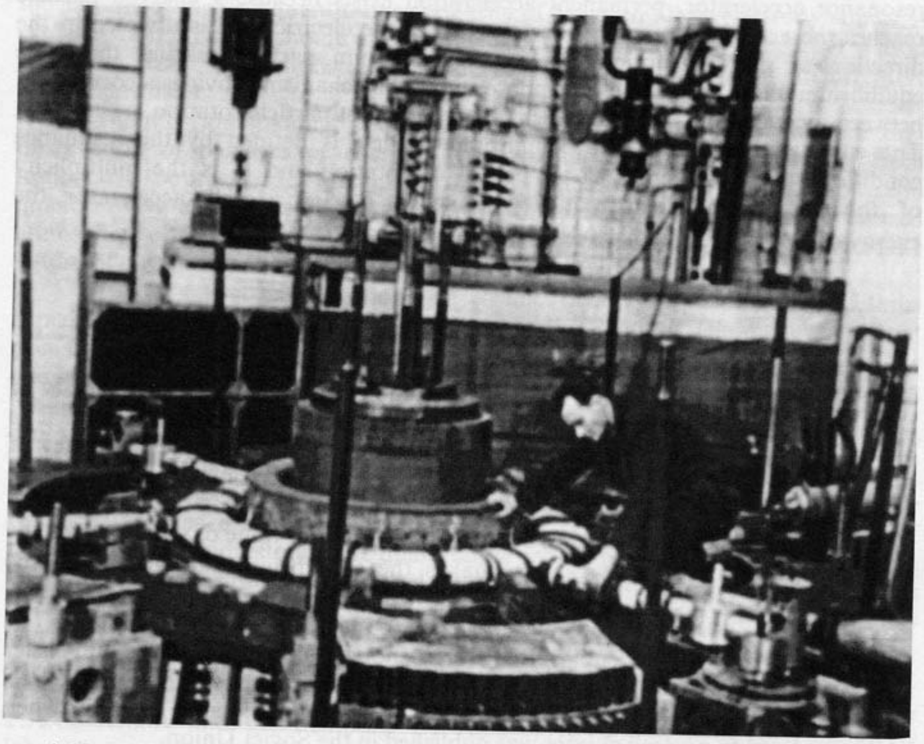
$$E = \frac{ce\langle B\rangle q}{\omega_a}.$$

Here $<B>$ is the mean value of magnetic field induction, c the velocity of light and e the charge of the particle. To increase the quilibrium energy, it is necessary to increase the magnetic field (synchrotron), decrease the frequency of the accelerating field (phasotron), change the combination of both (synchrophasotron), or, finally, change the multiplicity of the acceleration (microtron). The law for changing B, ω_q and q defines the value of the phase for the equilibrium particle. Phase stability makes the equilibrium particle choose the energy which is defined by the formula presented above.

Being a man of business, Veksler began to realize his ideas immediately. The results of this activity have not been covered enough. Two basic works of Veksler devoted to phase stability had managed to present the possibilities. Veksler's priority had been recognized. However, a little later, there came the time when nothing related to nuclear physics was published in the Soviet Union.

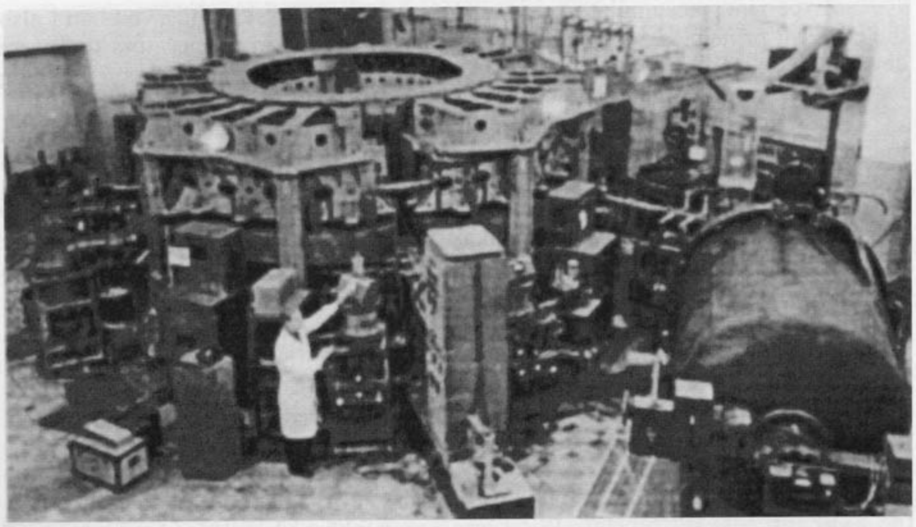
Under the quidance of Veksler, four accelerators operating even now were constructed. In 1947, the first relativistic accelerator, a 30 MeV electron synchrotron, was started up at FIAN. A large series of research projects was carried out at this accelerator. In 1949, V.I.Veksler, A.P.Komar, P.A.Cherenkov, M.S.Rabinovich succeeded in starting up a 250 MeV electron synchroton on which meson photoproduction was discovered. This gave rise to the physics of electromagnetic hadron interactions. Among the physical results obtained at this accelerator are rightfully the near-threshold photoproduction of charged and neutral pions on hydrogen and deuterium. These experiments which demonstrated the possibility of describing the phenomena of meson physics on the basis of quantum field theory were awarded the State prize of the USSR. The well-known studies of photodisintegration of few-nucleon systems were also awarded this prize.

Experiments on the detection of the electromagnetic polarizability of nucleons, showing that the proton is not only an extended but also a deformed system having an internal structure should be particularly noted. These difficult experiments have remained unique for a long time, and the data on proton polarizability available in the tables of elementary particles differ only slightly from the original values.



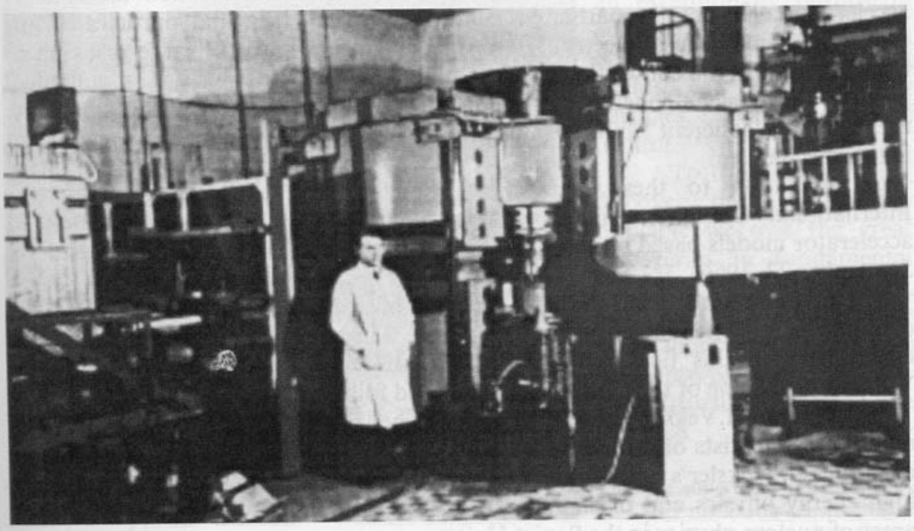
A 250 MeV electron synchrotron C-25 to be put into operation in 1949 under construction.

In addition to Veksler's laboratory, the laboratory of A.L.Mints was organized at FIAN in 1946. The latter was doing work on the synchrocyclotron (phasotron) project for a proton energy of 680 MeV. This synchrocyclotron was used as the basis of the new accelerator centre in Dubna. In 1947, I.V.Kurchatov, Director of Laboratory N 2, organized an accelerator department led by M.G.Meshcheryakov. In 1948, it was reorganized as the laboratory called the Hydrotechnical laboratory, for secrecy reasons (Director M.G.Meshcheryakov). Afterwards, this laboratory was named the Laboratory of Nuclear Problems (Director V.P.Dzhelepov) and became the first laboratory of Dubna. The synchrocyclotron was put into operation in December, 1949. At this accelerator, deuterons and α - particles were accelerated up to energies of 280 and 560 MeV, respectively, and then, in 1953, protons up to an energy of 680 MeV. A large 30-year research program on the physics of intermediate energies, in which institutions of many countries participated, was implemented.



A 180 MeV proton synchrotron MKM - model of the synchrophasotron under tests.

In Veksler's plans, supported by Vavilov, Skobeltsyn, Markov and other physicists from FIAN, was the construction of electron accelerators for high energies. However, these plans met with the resistance of physicists, specialists in nuclear physics, who said that electromagnetism had been studied and was of no interest. The second viewpoint was victorious, and the government decision was made to build a proton accelerator.



The model (C-60) of a 10 GeV synchrophasotron after completion of construction.

Experience accumulated at the laboratories of Veksler and Mints and also the physical principles and the theory of particle motion in accelerators that were developed at the end of the 1940s opened up the possibilities of building accelerators for still higher energies.

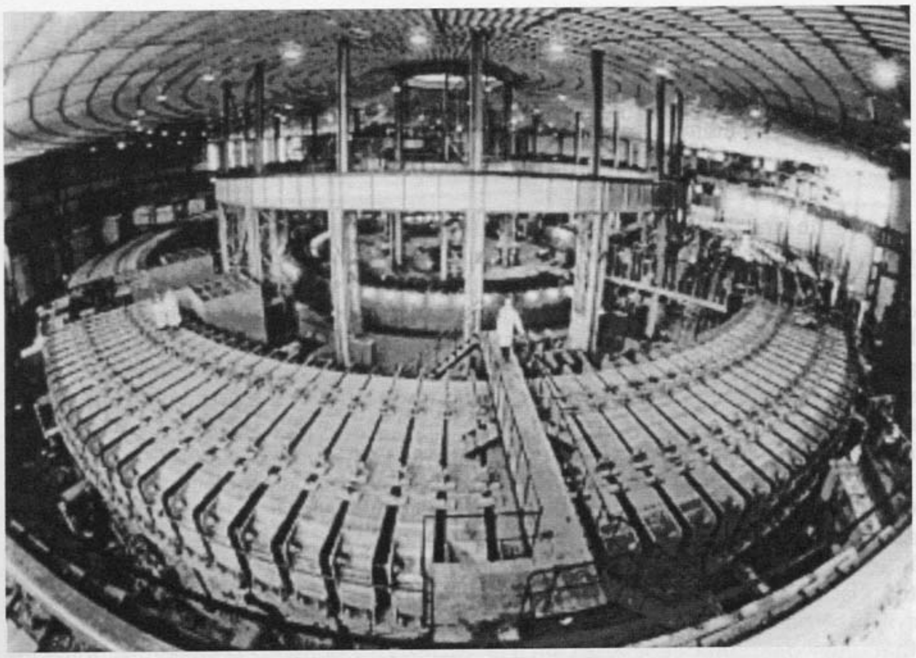
In 1949, work on the Dubna 10 GeV synchrophasotron project began. Veksler was appointed the leader of this work. The scale of this synchrophasotron demanded a preliminary study of the technical approaches and some fundamental questions. In was resolved to construct an operating model accelerator capable of accelerating protons to energies of 180 MeV. Later, it was modified to a 680 MeV electron synchrton that continues to operate at FIAN. Using this model accelerator, the basic ideas were verified and the specialists were trained who then formed the main body of accelerator specialists in Dubna. Some of them took a leading part in building and commissioning the Serpukhov and Yerevan accelerators.

The development and construction of accelerators are an invaluable contribution to the scientific-technical potential of our country. However, large accelerators turned out to be too expensive and there arose a demand for international co-operation. The intergovernmental organization of socialist states, the Joint Institute for Nuclear Research, was established in 1956 on the basis of two accelerating complexes: the 10 GeV synchrophasotron and the 680 MeV phasotron belonging to the USSR Academy of Sciences. Veksler became one of the founders of this large Institute. To his complicated organizational activities related to the construction of an accelerator with record parameters in Dubna were added international responsibilities. Moreover, he headed the newly-organized department of nuclear physics at the USSR Academy of Sciences in Moscow. There remained practically no time for scientific work, and he continually had new ideas. As early as 1952, Veksler began seeking fundamentally new methods of acceleration. He became particularly interested in the idea that particles of low energy and small mass (electrons) could accelerate particles of large mass up to high energies. In the conventional method of acceleration, we observe an individual particle. In Veksler's coherent method, buches of particles interact as a whole, i.e. they must be "coherent" and the interaction of individual particles is not significant in this mechanism.

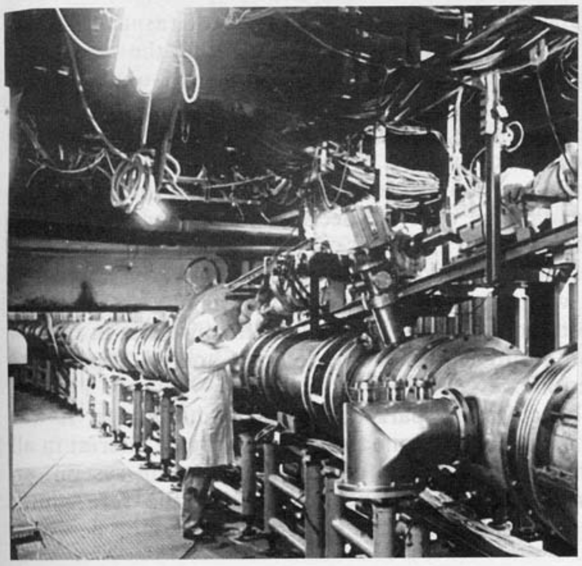
Attention to these ideas was attracted by Veksler's report at the International Conference in Geneva in 1956. However, the construction of accelerator models based on the new principles began only after Veksler's death on September 22, 1966.

Investigations using the new methods of acceleration invented by Veksler continue at many laboratories of the world. The most successful and intensive experiments in this field were carried out in Dubna under the leadership of V.P.Sarantsev, one of the closest colleagues and followers of Veksler.

Vladimir I.Veksler died not having reached 60 and left a rich legacy. A large number of scientists of different specialities are still working at the accelerators he constructed. Veksler's activity has left a deep impression on cosmic ray physics, high energy physics and plasma physics. He furthered the development of many areas of nuclear physics in the Soviet Union.



A 10 GeV proton synchrotron - the synchrophasotron is under operation since 1957.



However, his main life-work, an exceptionally purposeful activity on the development of the methods of obtaining beams of high energy particles, was especially fruitful.

To the epoch-making discovery of phase stability principle we owe the great discoveries in fundamental science of the XXth century; new laws of nature, new invariance principles, and new interpretations of the microstructure of the universe.

The first superferric synchrotron - 6A · GeV nuclotron constructed at the LHE JINR during 1987-92.