In Memoriam

IGOR' VASIL'EVICH KURCHATOV

(Biographical Sketch)

Usp. Fiz. Nauk **73**, 593-604 (April, 1961)

IGOR' Vasil'evich Kurchatov was born on January 12, 1903 in the village of Sim, Ufa Province. His father, Vasilii Alekseevich Kurchatov, was at that time an assistant forest ranger and later worked as a surveyor and land manager. His mother, Mariya Vasil'evna Kurchatova, née Ostroumova, was a teacher at a parish school before she married.

In order to provide secondary education for his children, Vasilii Alekseevich Kurchatov moved his family in 1908 to Simbirsk (now Ul'yanovsk), where in 1911 Igor' Vasil'evich entered the public secondary school. In 1912, because of the illness of his daughter, V. A. Kurchatov moved his family to Simferopol' in the Crimea. Here Igor' Vasil'evich received his secondary education and was graduated in 1920 from the Simferopol' public secondary school with a gold medal. In this same year he entered the Crimean University, in the mathematics division of the physico-mathematical faculty.

Difficult living conditions compelled him to combine his work in the university with employment in various establishments. He was a tutor in a children's home, a foreman in an automobile garage, a watchman in a state farm garden, and sawed fire wood in a canning factory. Only in 1922 did I. V. Kurchatov find work which proved to be useful for his future. He received the post of demonstrator in the physics laboratory of the Crimean University, while continuing to study at the same time. Included in the duties of a demonstrator were the preparation and demonstration of lecture experiments, looking after and adjusting apparatus, and other jobs of similar nature that to a marked degree belong to the functions of an assistant.

His superior capabilities as a student attracted the attention of a number of university professors (S. N. Usatoĭ, N. S. Koshlyakov, and others).

In the spring of 1923 Kurchatov took his third-course exams and during the summer period he worked independently on the program of the fourth faculty course. Completing during the same year his thesis on the theory of the gravitational element, he finished the university ahead of schedule.

In the autumn of 1923 he left for Leningrad. Here he realized his cherished dream — he entered the naval-architecture school of the Polytechnic Institute and at the same time began working in the Magneto-Meteorological Observatory at Pavlovsk as an observer in the electrical pavilion. He did not finish at the Polytechnical Institute; his interest in science took possession of him more and more strongly, and by the summer of 1924, he was already devoting himself completely to scientific activities.

In Pavlovsk Igor' Vasil'evich completed his first experimental scientific work, concerning the α radioactivity of snow. This investigation was carried out at a high level for that time, with a thorough mathematical treatment of the results. In this work the α radioactivity of snow at the moment of its fall was determined reliably for the first time, and he devised calculation methods that took into account the radioactive equilibrium of the decay products of the radium emanation and the absorption of α particles in water.

In the summer of 1924 Kurchatov worked in the Hydro-Meteorological Center in Feodosiya. The most important work of this period was the investigation of seiches (slow oscillations in the mean water level) in the Black Sea and the Sea of Azov. In this work he made an exhaustive mathematical analysis of the data accumulated by stations on the periodic variations in the levels of both seas. He modified the existing theory of the oscillations of inland basins (Darwin's theory), taking into account the free vibrations of the system. The formula he obtained turned out to be in good agreement with the observed data.

In the autumn of 1924, on the invitation of his university teacher Professor S. N. Usatoĭ, he moved to Baku. There he worked one year as an assistant to the physics faculty of Azerbaĭdzhan Polytechnic Institute, and completed his first investigation in the physics of dielectrics. At that time there were practically no facilities for experimental scientific work at this institution, and in the autumn of 1925, he left for Leningrad.

At Leningrad, he spent one of the most important periods in his career. Here he knew intense work, solid creative research, great successes, joys of discovery, and now and then even inevitable disappointments. In Leningrad, in 1927, he married Marina Dmitrievna Sinel'nikova, who remained his true friend and companion the rest of his life.

Igor' Vasil'evich began working in the Leningrad Physico-Technical Institute, which was organized in the first year of Soviet rule under the leadership of academician A. F. Ioffe. This institution was one of the first large-scale scientific establishments of the new type founded by the Soviet government. Well equipped with modern physical apparatus, and staffed by the leading Soviet physicists of the day and by talented young people from all ends of the country, the Leningrad Physico-Technical Institute was then the basic research center of the Soviet Union.

The atmosphere of scientific enthusiasm, bold creative research, topics connected with timely problems in modern physics, and renewed contact with the world of science — all this provided the young scholar with the possibility of rapid growth.

The period of work at Leningrad Physico-Technical Institute was the turning point in Kurchatov's scientific life. His exceptional talent as an experimentalist in physics blossomed out luxuriously in the fertile soil of a large scientific institute. With his very first work in the Institute Kurchatov quickly acquired scientific authority, and before long became one of the leading scientists in an institute rich in talented scientific workers. Taken into the Institute as an assistant, he soon received first the title of "Scientist, First Class" (according to the nomenclature in use then) then "Senior Engineer-Physicist," and in 1930, at the age of 27, he became director of the big laboratory.

Kurchatov began his work in the Institute on the physics of dielectrics under the direct leadership of academician A. F. Ioffe. His first projects at Leningrad Physico-Technical Institute were devoted to the investigation of the electrical conductivity of solids, the formation of space charge by the passage of current through dielectric crystals, and the mechanism of breakdown of solid dielectrics. All these problems had been studied either little or not at all at that time, and his research contributed significantly to the study of the electrical properties of crystals, which was started by A. F. Ioffe.

Along with a great scientific interest in the physics of crystals, Kurchatov was also attracted by the technical prospects of developing a scientific basis for the technology of electric insulating materials. At that time, academician A. F. Ioffe and his closest associates, in particular Kurchatov, had great hopes of creating an insulator of a new type, the so-called "thin-film insulator." They did not succeed in realizing it; their experiments did not confirm the previously obtained results on the increased strength of thin dielectric films. Nonetheless the numerous papers produced in this field significantly enriched the technology of electrical insulating materials in that they led to the creation of a series of new technically important insulating materials (styrene, eskapon, etc.).

At the end of 1929 A. F. Ioffe set Kurchatov and P. P. Kobeko to the task of examining the phenomenon of the anomalously high dielectric constant of Rochelle salt. The youthful investigators initiated a series of conclusive experiments and quickly adopted a preliminary working hypothesis (the hypothesis of a high-voltage polarization with the formation of a thin electrode film of high capacity); they concluded that the phenomenon was of a new nature. Rochelle salt seemed to be an electrical analog of a ferromagnet, i.e., a crystal of this salt consists of regions of spontaneous electrification such that each region contains electrical dipoles oriented in a single direction. As a whole, the crystal is electrically neutral on account of the alternating directions of electrification of neighboring regions. Even in weak fields application of an electric field causes reorientation of the domains and the development of a large electric moment in the whole crystal.

In a number of subsequent investigations, Kurchatov studied the mechanism of the spontaneous polarization of Rochelle salt in detail. It was found that the polarizability is higher in thick crystals and the differential dielectric constant in small fields could attain values up to 190 000 units under conditions of good contacts and high crystal quality. He collected much data on the rate of establishment of polarization and depolarization, information essential for the model of the formation of spontaneously polarized domains in the crystal. The secondary origin of such a puzzling phenomenon as the asymmetry (unipolarity) of the polarizability of Rochelle salt was clarified.

Investigations on isomorphous mixtures of Rochelle salt and ammonium-sodium salts of acetic acid, completed under Kurchatov's direction, yielded much new information.

The fundamental analogy with ferromagnets was particularly complete and strong in this case. The range of crystal properties obtained, depending on the concentration of the components, signified the discovery of a new group of dielectrics, called ferroelectrics.

Kurchatov explained the vast accumulation of experimental data on the basis of a theory of the polarization of ferroelectrics. He arrived at the conclusion that for the internal field in ferroelectrics, $\mathbf{F} = \mathbf{E} + \gamma\mathbf{P}$, the coefficient γ is close to the value $4/3\,\pi$ given by Lorentz. Starting from the concept of rotating dipoles in the solid, Kurchatov analyzed the behavior of ferroelectrics above the Curie point. He showed that the experimental dependence of the dielectric constant on temperature and electric field intensity in ferroelectrics, outside of the region of spontaneous orientation, agreed with the classical formulas of Debye and Herweg-Debye, modified for a dipolar gas with allowance for the possibility of orienting the dipoles in one direction only. The end result was the foundation of a new field of science — the study of ferroelectrics.

Later the Soviet scientists Vul and Gol'dman discovered a new kind of ferroelectric — barium titanate. In their research and in the investigations of other scientists, the study of ferroelectrics found its further development and wide practical application.

For his investigations in the physics of dielectrics Kurchatov was awarded in 1934 the degree of Doctor of Physico-Mathematical Sciences without having to defend a dissertation.

During 1927-1929 he carried on pedagogical work along with his research. He taught a special course in the physics of dielectrics as a lecturer in the Engineering-Physics faculty of the Leningrad Physico-Technical Institute. A brilliant lecturer, he possessed in full degree the skill to impart the physical meaning of each question set forth, and he gained great love and respect amongst his young students. He would frequently speak with enthusiasm about new results of his research as they were obtained, awakening in the youths a serious interest in science.

In 1931-1932 he made a new contribution to the then incipient field of solid-state physics — the physics of semiconductors. He conducted (with K. D. Sinel'nikov) a fine, thorough investigation of barrier-layer photocells and established a connection between their properties and the internal photoeffect.

Under his leadership a classical investigation of semiconducting carborundum resistors was completed. In particular it was shown by these investigations that the true resistivity of carborundum was small, on the order of 0.5 ohm, and that the observed high resistance of polycrystalline samples was due to the contact resistance of carborundum granules. A complete explanation was given of the results obtained in the light of the theory of the tunnel effect for the passage of electrons through barriers.

Beginning in 1932, Kurchatov gradually changed over to research in the physics of the atomic nucleus. One of the most important problems of Soviet nuclear physics, which was just in its infancy at that time, was the construction of powerful sources of fast particles capable of causing nuclear reactions. Kurchatov did much to solve this problem.

His first step in this direction was the building of high-voltage apparatus and an accelerating tube to give a beam of protons with energy of 350 kev, which was assembled by him and his colleagues at the Leningrad Physico-Technical Institute in 1933. After that, he took direct part in the construction of high voltage apparatus at Khar'kov Physico-Technical Institute. Under his leadership the first cyclotron in the U.S.S.R. came into being (at the Radium Institute). The cyclotron at Leningrad Physico-Technical Institute was built with Kurchatov's active participation. This cyclotron, constructed just before World War II, was at that time the largest cyclotron in Europe. Even at that stage of growth of Soviet nuclear physics Kurchatov displayed his extraordinary abilities as an organizer and prime mover of the work of a large research group. Always cheerful, happy, optimistic, he was skillful in stimulating the group in its solution of the assigned task, showing by his personal efforts an example of self-effacing service to science and country.

Not everything went smoothly in this new and difficult field. The trial period of the cyclotron of the Radium Institute was delayed for several years. His arrival on the scene really animated the work. The earnest exertions of the scientists in the cyclotron group headed by Kurchatov, who spent day and night along with them at the machine, yielded the first fruits. A new operating mode of the cyclotron was found, providing a high neutron yield. The method employed had at that time definite advantages in a number of cases over the usual method of cyclotron operation.

The creative collaboration between Kurchatov and organized bodies of scientists of other institutes in this pre-war period was not, of course, limited to work on the technical implementation of Soviet nuclear physics. In parallel with this he also led investigations in the physics of the nucleus. This included research on the fission of lithium and boron by protons (nuclear reactions which were among the first to be accomplished in accelerators in the U.S.S.R.) and several later researches on neutron physics (with A. I. Leĭpunskii and others).

The flowering of Kurchatov's scientific career in the field of nuclear physics began in 1934, at the moment of Fermi's discovery of artificial radioactivity induced by neutrons. Ampoules of radium and beryllium — the first neutron sources — served for a long time as the main research tools in his laboratory.

The Radium Institute was of great help in supplying preparations of the radon-beryllium sources. However, the number of the sources which the Radium Institute could produce was very limited; the neutron flux was not high and investigations were carried out with extreme difficulty.

In his first papers on neutron physics, dating back to 1934, I. V. Kurchatov established the fundamental fact of the branching of nuclear reactions. Upon the irradiation of phosphorus (a single-isotope element) with fast neutrons, two half-lives were observed, which could be explained only by the independently proceeding reactions (n, α) and (n, p) with formation of the isotopes Al^{28} and Si^{31}. This result was soon confirmed by another single-isotope element — aluminum, for which the formation of Mg^{27} by the reaction (n, p) and Na^{24} by a (n, α) reaction was demonstrated by Kurchatov and his co-workers.

In the winter of 1935, Kurchatov and his colleagues (L. I. Rusinov and others) discovered, by irradiating bromine with neutrons, a third new radioactive isotope of bromine with a half-life of 36 hr, besides the two already known radioactive isotopes with half-lives of 18 min and 4.2 hr. This result did not fit into the reaction scheme of radiative capture of neutrons known at the time, since bromine has only two stable isotopes.

Of two hypotheses advanced, the first explanation of the formation of the third radioactive isotope as being due to the $(n, 2n)$ reaction was not confirmed by subsequent experiments, and in 1936 Kurchatov finally arrived at an explanation according to which two radioactive isotopes of bromine were nuclear isomers, i.e., they had different properties, but the same mass. This great discovery of isomerism of artificially radioactive nuclei was of universally recognized merit. Later, after the appearance of the theory of

Weizsäcker which attributed isomerism to the presence of metastable nuclear levels, Kurchatov developed this idea further. He first formulated the basic thesis that the most frequently occurring process by which a discharge of a metastable nuclear state takes place is an internal conversion. This fruitful idea of his received a thorough corroboration in the works of his colleagues on the spectra of the electronic conversion of Br^{80} and was universally accepted.

The study of nuclear isomers is at present one of the important methods of obtaining information about low-lying excited nuclear states.

This interest in this field was maintained throughout his life. Later, in his Moscow period, when he was absorbed in atomic energy problems, Kurchatov had a lively interest in the research of his colleagues on nuclear isomers, and he took measures for the maximum development of this research.

In the period 1935-1940, in addition to nuclear isomers, Kurchatov carried out extensive investigation in the field of neutron physics.

Besides research in his own laboratory, he worked on a number of projects in association with the laboratory of L. A. Artsimovich, with the physics laboratory of the Radium Institute, and with the Khar'kov Physico-Technical Institute. He organized the scientific work on neutron physics in the physics faculty of the Leningrad Pedagogical Institute. He continued to study nuclear reactions produced by fast and slow neutrons. To this period belong his papers on the reactions of nuclei of lithium, boron, gold, palladium, ruthenium, and rhodium with neutrons.

In 1935, in a paper with L. A. Artsimovich and others he first clearly demonstrated the capture of a neutron by a proton and obtained the first value of the capture cross-section. This work had essential significance for the theory of the nuclear structure of deuterium.

A large part of Kurchatov's effort was devoted to problems of the scattering and absorption of neutrons in various media. In 1935 problems associated with the investigation of scattering cross-sections occupied a great deal of the attention of physicists. The existing theory predicted that strong absorbers of neutrons should also be strong scatterers of slow neutrons. The investigations of Kurchatov, Artsimovich, and others on the scattering of thermal neutrons by silver, however, showed that the effective scattering cross-section of slow neutrons was at least 20 times less than the capture cross-section. Another fact fundamental for nuclear theory was discovered, concerning the measurement of the absorption coefficient of slow neutrons in any element. The coefficient turns out to be greatest when the measurement of the intensity of the neutron beam is carried out with the aid of an indicator of the same element as the absorber. This result, obtained independently here and abroad, laid the groundwork for the discovery of the phenomenon of the selective absorption of neutrons.

Kurchatov's work on neutron physics played an essential role in the development of a true picture of the course of nuclear reactions and of the structure of nuclear energy levels, finding its first consummation in Bohr's liquid-drop model of the nucleus.

In 1939, Kurchatov began working on a new problem — the fission of heavy nuclei. Research in this field, led by him, culminated in the discovery by his colleagues G. N. Flerov and K. A. Petrzhak of a new kind of radioactivity — the spontaneous fission of uranium.

The first projects directed toward the study of the problem of chain reactions involving fast neutrons were set up in Kurchatov's laboratory at the Leningrad Physico-Technical Institute. To this end the cross-section of inelastic scattering in various nuclei was studied and the value for U^{238} determined. In a report at the All-Union Conference on the Physics of Atomic Nuclei (November 1940) and in an article, "The Fission of Heavy Nuclei" (Usp. Fiz. Nauk **25**, 1941), Kurchatov discussed in an exceptionally clear manner the question of nuclear chain reactions. Summing up the experimental and theoretical work carried out in the U.S.S.R. and abroad, he arrived at an optimistic conclusion regarding the probability of chain reactions with slow neutrons and gave values of the critical mass for systems of uranium and moderators.

Kurchatov planned an extensive development of research in this new direction. The first plan of work on nuclear chain reactions that was presented to the presidium of the Academy of Sciences in 1940 was adopted. According to this plan, the work was divided among four physics institutes of the country. The plan included as one of its basic tasks the determination of the capture cross-section of slow neutrons by heavy hydrogen, helium, carbon, and oxygen. Because of the difficulty of these measurements, it was contemplated that these investigations would be carried out in parallel in three institutions in order to secure the most reliable results.

Investigations were also planned on the determination of the conditions of chain branching in a mass of metallic uranium, the clarification of the influence of neutrons arising from the splitting of U^{238} on the course of the chain reaction in a mixture of uranium and water, and the conditions under which the chain reaction could be realized in a mixture of uranium and heavy water.

At the time of the second world war Kurchatov, as a patriot, applied his strong and rich experience to the task of strengthening the defense of his homeland. He did much work on ship protection, taking a personal role in the installation and testing of suitable equipment on ships under battle conditions.

The successful solution of assigned tasks was rewarded by the Government in 1942 with the Stalin Prize of the First Degree.

Upon getting the chance to return to his work in the field of nuclear physics, Kurchatov renewed the most intricate and extraordinarily difficult projects on the realization of a nuclear chain reaction in uranium. Under his leadership, a special laboratory of the Academy of Sciences was founded, in which work on nuclear chain reactions was undertaken on a large scale and in different directions.

The laboratory quickly grew, collecting a diverse staff of physicists, and becoming a large scientific research center, called the Institute of Atomic Energy of the Academy of Sciences of the U.S.S.R.

In this tense and demanding period the best qualities of Kurchatov emerged brilliantly: deep scientific erudition, optimism, skill in uniting and heading a large scientific establishment of unusual urgency and purpose.

Kurchatov took a personal part in the solution of the basic problem in the way of mastering nuclear energy — the achievement of a chain reaction in the fission of uranium.

The solution of this problem demanded simultaneous scientific efforts in three fundamental directions — the measurement of nuclear constants of uranium and moderator, the development of reactor theory, and macroscopic experiments with uranium plus moderator lattices.

The very first measurements suggested a solution, which, while presenting greater difficulty, seemed technically to be the best prospect — the construction of a uranium-graphite breeder system. Exponential experiments with uranium-graphite lattices of increasing scale went on in parallel with production of increasing quantities of uranium and graphite of unsurpassed purity.

Kurchatov was not only the prime mover but also the direct leader of this cycle of work. Experiments were performed around the clock, and in these months it was hard to find a moment when he was not in the laboratory. Exponential experiments with a pure moderator allowed the determination of its most important constants, slowing-down length, length of neutron diffusion, and were utilized in the control of the purity of the material.

From experiments with uranium-graphite lattices, i.e., systems in which metallic uranium was distributed in the form of separate blocks in the moderator, the optimum parameters of the lattice were determined — the dimensions of the blocks and the distance between them. At the same time, Kurchatov's scientists made measurements of the microscopic nuclear constants that characterize fission: the number of neutrons created in an act of fission, the cross-section, and their variation with energy.

All these measurements were interwoven with the development of the theory of reactors. The theory of the multiplication coefficient for infinite lattices as well as the theory of heterogeneous reactors of finite dimensions were developed. Kurchatov's outstanding physical intuition and his understanding of neutron physics frequently allowed him to foresee the results of theoretical investigations and indicate the way to their refinement and development.

The selfless work of Soviet scientists, engineering-technical personnel, and workers soon was crowned by the first victory. I. V. Kurchatov and his colleagues started up the first uranium-graphite reactor in the U.S.S.R. and Europe in the presence of government representatives. The construction of this pile, the stages of its assembly and testing were set out in a report by V. S. Fursov at a session of the Academy of Sciences of the U.S.S.R. on the peaceful uses of atomic energy on July 1 — 5, 1955.

Kurchatov had a direct part in the design and operation of succeeding high-power atomic reactors. In the entire time from the operation of the first research reactor up to the last days of his life, he was the scientific leader of the effort to create an atomic industry and technology in our country.

The building of the first atomic reactors, which were powerful sources of neutron radiation, allowed the undertaking of a new step in neutron-physical investigations both of an applied and basic scientific character. On his initiative and through his never-weakening attention, research was developed in the basic trends of neutron physics and neutron spectroscopy, the study of gamma-ray capture, characteristics of the fission process, and properties of the neutron.

From the moment of the organization of the special laboratory in Moscow, Kurchatov conducted also a tireless activity in the development and organization of extensive investigations in the field of nuclear physics in the U.S.S.R. He showed thereby great persistence and a statesmanlike approach to duty.

Kurchatov educated numerous cadres of workers in nuclear physics and atomic techniques, boldly promoting talented young men to responsible positions.

During the Moscow period, he developed to its full capacity his huge organizational talent, which in conjuction with his brilliant capabilities as a scientist, vast erudition, and extraordinary capacity for work allowed him successfully to work in the honorable positions entrusted to him.

The name of Kurchatov is irrevocably associated with the history of the conversion of the U.S.S.R. into a potent atomic state, occupying a leading position in the field of investigation of the atomic nucleus and the utilization of atomic energy for peaceful aims.

In the early fifties extensive investigations were begun in the Institute led by Kurchatov in the area of controlled thermonuclear reactions. This field of physics became a subject of particular interest to him in the latest years.

In his report in England (in 1956) he first favored removal of the mantle of secrecy by which these researches were surrounded in many countries, thus opening up the possibility of widespread scientific intercourse between physicists of different countries working in this field.

Later, basic research in the U.S.S.R. on controlled thermonuclear reactions was conducted under his leadership. On his initiative, and with his daily attention one of the largest machines for obtaining and studying high-temperature plasmas — the Ogra — was assembled in a very short time. In the few days before his sudden death, he and his co-workers were engaged in investigations with this apparatus.

Later, Kurchatov took on a wide program of development and research in the field of controlled thermonuclear reactions. Death suddenly cut short his life while he was discussing one of these projects with his closest comrades.

While supervising huge scientific and scientific-administration projects, Kurchatov still found time for an active public life. He was a fighter for peace and friendship among nations, and an active supporter of an international scientific society. In a number of his speeches, I. V. Kurchatov appealed for a ban on nuclear weapons and the utilization of nuclear energy only for peaceful purposes.

Kurchatov was the permanent director of the Institute for Atomic Energy that he founded and which became in an unusually short time one of the largest physical institutes. Owing to his personal charm he was able to attract and kindle enthusiasm in a large group of scientific workers and deservedly enjoyed their love and respect.

The influence of his scientific talent, however, was not confined solely to his own large institute. A large number of scientific and industrial organization were constantly under the influence of his scientific and scientific-technical ideas.

Kurchatov enjoyed a huge popularity among the Soviet people. He was repeatedly selected as Deputy to the Supreme Soviet of the U.S.S.R. The Government valued his extraordinary merit, rewarding him with the highest awards. The Academy of Sciences of the U.S.S.R. recognized his outstanding scientific achievements by electing him a member (1943).

The last month of his career was particularly busy. Full of new ideas, he traveled to the Ukraine in order to become acquainted with the work of the Khar'kov Physico-Technical Institute and the Institute of Physics of the Ukrainian Academy of Sciences and planned new projects in nuclear physics and thermonuclear reactions. Returning to Moscow, he worked with great drive from morning to night, ignoring the restrictions and advice of his doctor. On February 7, 1960, his brilliant life was suddenly cut short, a life that was wholly dedicated to the service of science and the socialist fatherland.

The memory of I. V. Kurchatov, noted Russian scientist, patriot, communist, and public worker, will be forever preserved in the hearts of the Soviet people.

List of the Publications of Academician I. V. Kurchatov

1. The Application of Harmonic Analysis to the Investigation of the Ebb and Flow of the Black Sea, Декад. бюлл. погоды, изд. Гимецентром Черного и Азовского морей (Ten-Day Bulletin of Weather, publ. Hydrometeorological Center of the Black Sea and Sea of Azov), No. 28 (1924).

2. On the Question of the Radioactivity of Snow, Ж. геофиз. и метеор. (Journal of Geophysics and Meteorology) **2**, 17-32 (1925).

3. Seiches in the Black Sea and the Sea of Azov, Изв. Ц. гидромет. бюро Цумора (Bulletin of the Central Hydrometeorological Bureau, Centr. Admin. of Naval Forces), No. 4, 149-158 (1925).

4. On the Question of the Electrolysis of Solids. Some Remarks in Connection with the Work of Tubandt and Schmidt, Научн. изв. Азерб. политехн. ин-та (Scientific Bulletin of the Azerbaijan Polytechnic Institute), No. 2, 39-42 (1926).

5. On Electrolysis at an Aluminum Anode, Изв. Азерб. гос. университета, отд. ест.-мед. (Bulletin of the Azerbaijan State University Div. of Nat. Sci. and Med.) **4**, 121-133 (1926) (with Z. Lobanova).

6. On the Passage of Slow Electrons Through Thin Metallic Foils, Тр. Ленингр. физ.-тех. лаб. (Reports of Leningrad Physico-Technical Laboratory) **3**, 67-71 (1926) (with K. D. Sinel'nikov); also in Phys. Rev. **28**, 367-371 (1926).

7. On the Question of the Mobility of Ions in Crystals of Rock Salt, Ж. Русск. физ.-хим. об-ва, часть физ. (J. Russ. Phys.-Chem. Soc., Phys. Sec.) **59**, 421-422 (1927) (with A. K. Val'ter, P. P. Kobeko, and K. D. Sinel'nikov).

8. On the High-Voltage Polarization of Solid Dielectrics, ibid. **59**, 327-329 (1927).

9. The Electrical Strength of Dielectrics, Doklady Akad. Nauk SSSR, No. 4, 65-68 (1927) (with A. F. Ioffe and K. D. Sinel'nikov).

10. The Liberation of Oxygen at the Anode in the Electrolysis of Glass, ibid. No. 11, 187-192 (1928) (with P. P. Kobeko).

11. Ionic and Mixed Conductivity in Solids, Usp. Fiz. Nauk **8**, 361-393 (1928) (with P. P. Kobeko).

12. Investigation of the Breakdown of Some Resins, op. cit. ref. 7, **60**, 211-217 (1928) (with P. P. Kobeko and K. D. Sinel'nikov).

13. The Faraday Law in Impact Ionization, op. cit. ref. 7, **60**, 509-518 (1928) (with P. P. Kobeko).

14. The Breakdown of Solid Dielectrics, op. cit. ref. 6, No. 5, 5-19 (1928) (with P. P. Kobeko and K. D. Sinel'nikov).

15. Unipolar Conductivity of Some Salts, op. cit. ref. 7, **60**, 145-149 (1928) (with P. P. Kobeko).

16. The Similarity Principle in the Electrical Conductivity of Solid Dielectrics, op. cit. ref. 7, **61**, 321-332 (1929) (with B. Kurchatov).

17. Breakdown of Rock Salt, op. cit. ref. 7, **61**, 379-384 (1929) (with P. P. Kobeko).

18. The Mechanism of Rectification in Some Salts, op. cit. ref. 7, **61**, 459-475 (1929) (with P. P. Kobeko and K. D. Sinel'nikov).

19. Dielectric Properties of Rochelle Salt Crystals, op. cit. ref. 7, **62**, 251-265 (1930) (with P. P. Kobeko); also in Z. Physik **66**, 192-205 (1930).

20. Some Electrical Anomalies of Rochelle Salt Crystals, op. cit. ref. 7, **62**, 477-483 (1930) (with V. Bernashevskii).

21. Investigation of the Dielectric Constant of Rochelle Salt during Short Electrical Pulses, JETP **1**, 121-128 (1931) (with A. K. Val'ter and K. D. Sinel'nikov).

22. Investigation of the Dielectric Constant of Rochelle Salt in Different Crystallographic Directions, JETP **1**, 164-166 (1931) (with G. Shchepkin).

23. Solid Rectifiers, JETP **1**, 634-645 (1931).

24. Solid and Barrier Layer Photoelements, JETP **1**, 655-671 (1931) (with K. D. Sinel'nikov).

25. Barrier Layer Photocells, Usp. Fiz. Nauk **12**, 365-388 (1932).

26. The Dielectric Constant of Solid HCl, JETP **2**, 245-253 (1932) (with G. Shchepkin).

27. Electrical Properties of Rochelle Salt Crystals with additions of $NaRbC_4H_4O_6 \cdot 4H_2O$ and $NaTlC_4H_4O_6 \cdot 4H_2O$, JETP **2**, 102-107 (1932) (with M. A. Eremeev, P. P. Kobeko, and B. V. Kurchatov).

28. The Lower Curie Point in Ferroelectrics, JETP **2**, 319-328 (1932) (with B. V. Kurchatov); also in Physik. Z. Sowjetunion **3**, 321-324 (1933).

29. Untersuchung der Sperrschichtphotozellen. I, Physik. Z. Sowjetunion **1**, 23-42 (1932) (with K. D. Sinel'nikov).

30. Untersuchung der Sperrschichtphotozellen. II, Physik. Z. Sowjetunion **1**, 42-60 (1932) (with K. Sinel'nikov and M. Borisov).

31. Die Elektrolyse der Steinsalzkristalle und deren Durchlag, Physik. Z. Sowjetunion **1**, 337-352 (1932) (with K. D. Sinel'nikov, O. N. Trapeznikova, and A. K. Val'ter).

32. Untersuchung der Durchschlagerscheinungen des Steinsalzes. I, Physik. Z. Sowjetunion **1**, 353 (1932) (with K. D. Sinel'nikov and O. N. Trapeznikova).

33. Zur Frage nach dem Mechanismus des electrischen Durchschlages, Z. Physik **73**, 775-777 (1932) (with A. Ioffe, P. Kobeko, and A. Val'ter).

34. Ionic Polarization in Solids, JETP **3**, 153-155 (1933).

35. The Dependence of Polarization on Field Strength in Ferroelectrics Outside of the Spontaneous Orientation Region, JETP **3**, 181-188 (1933).

36. Rochelle Salt in the Region of Spontaneous Orientation, JETP **3**, 537-544 (1933); also in Physik. Z. Sowjetunion **5**, 200-212 (1935).

37. Investigation of Carborundum Self-Regulating Resistors, JETP **3**, 1163-1184 (1933) (with N. A. Kovalev, T. Z. Kostina, and L. I. Rusinov).

38. Einfluss der Temperatur auf die Roentgenisierung des Steinsalzes, Physik. Z. Sowjetunion **3**, 262-268 (1933) (with K. Sinel'nikov, A. Val'ter, and S. Litvinenko).

39. Unipolarität der Polarisation in Seignettesalzkristallen, Physik. Z. Sowjetunion **4**, 125-130 (1933).

40. Gamma-Rays in the Proton Bombardment of Boron, Doklady Akad. Nauk SSSR **1**, 486-487 (1934) (with G. Shchepkin et al.).

41. On the Disintegration of Li^6 by Protons, JETP **4**, 548-549 (1934) (with K. Sinel'nikov); also in Physik. Z. Sowjetunion **5**, 919-921 (1934).

42. On the Radioactivity of He^3, JETP **5**, 545-547 (1934) (with K. Sinel'nikov, G. Shchepkin, and A. Vibe); also in Physik. Z. Sowjetunion **5**, 922-926 (1934).

43. The Fermi Effect in Phosphorus, Doklady Akad. Nauk SSSR **3**, 221 (1934) (with L. Mysovskii, A. Vibe, and G. Shchepkin).

44. The Fermi Effect in Aluminum, I, ibid. **3**, 226-229 (1934) (with B. Kurchatov, G. Shchepkin, and A. Vibe).

45. The Possibility of the Fission of Nuclei by Neutrons with the Emission of Three Heavy Particles, ibid. **3**, 230-232 (1934) (with L. Mysovskii, N. Dobrotin, and I. Gurevich).

46. The Fermi Effect in Aluminum, II, ibid. **3**, 422-424 (1934) (with L. Mysovskii, B. Kurchatov, G. Shchepkin, and A. Vibe).

47. Fast Electrons from the Neutron Irradiation of Fluorine, ibid. **3**, 572-575 (1934) (with G. Shchepkin and A. Vibe).

48. Artificial Radioactivity and the Lande Scheme, ibid. **4**, 202-207 (1934).

49. Investigation of Artificial Radioactivity by Neutron Irradiation. Communication 1, Вестник рентгенологии и радиологии (Bulletin of Roentgenology and Radiology) **15**, 431-439 (1935) (with G. D. Latyshev, L. M. Nemenov, and I. P. Selinov).

50. Scattering of Slow Neutrons by Hydrogen, JETP **5**, 355-359 (1934) (with M. Eremeev, and G. Shchepkin); also in Physik. Z. Sowjetunion **7**, 267-274 (1935).

51. The Fission of Lithium by Slow Neutrons, JETP **5**, 360-367 (1935); The same in Physik. Z. Sowjetunion **7**, 474-483 (1935) (with D. Z. Budnitskii and G. D. Latyshev).

52. Some Wilson Chamber Observations on the Fermi Effect, JETP **5**, 367-370 (1935) (with G. D. Latyshev); also in Physik. Z. Sowjetunion **7**, 262-266 (1935).

53. The Energy of Neutrons and the Fermi Effect, JETP **5**, 371-375 (1935) (with L. Mysovskii, M. Eremeev, and G. Shchepkin); also in Physik. Z. Sowjetunion **7**, 257-274 (1935).

54. The Scattering of Neutrons by Water and Lead, JETP **5**, 459-466 (1935) (with M. Deĭzenrot-Mysovskaya, et al.); also in Physik Z. Sowjetunion **7**, 656-669 (1935).

55. Artificial Radioactivity in Neutron Irradiation of Gold, JETP **5**, 467-469 (1935) (with G. D. Latyshev); also in Physik. Z. Sowjetunion **7**, 652-655 (1935).

56. The Absorption of Slow Neutrons, Part I, JETP **5**, 659-670 (1935) (with L. Artsimovich, M. Mysovskii, and P. Palibin).

57. The Scattering of Slow Neutrons by Iron and Other Elements, JETP **5**, 671-676 (1935) (with D. Z. Budnitskii); also in Physik. Z. Sowjetunion **8**, 170-178 (1935).

58. Inversion Phenomena in the Polarization of Ferroelectrics, JETP **5**, 751-755 (1935) (with A. Shakirov); also in Physik. Z. Sowjetunion **7**, 631-639 (1935).

59. La désintégration du bore par des neutrons lents, Compt. rend. **200**, 1199-1201 (1935) (with B. Kurchatov and G. Latyshev).

60. Sur un cas de radioactivité artificielle provoquée par un bombardement de neutrons, sans capture du neutron, Compt. rend. **200**, 1201-1203 (1935) (with B. Kurchatov, L. Mysovskii, and L. Rusinov).

61. Au sujet de la capture de neutrons lents par un noyau, Compt. rend. **200**, 2159-2162 (1935) (with L. Artsimovich, L. Mysovskii, and P. Palibin).

62. La radioactivité artificielle du ruthenium bombardé par des neutrons, Compt. rend. **200**, 2162-2163 (1935) (with L. M. Nemenov and I. P. Selinov).

63. Kontakterscheinungen in Karborundwiderständen, Physik. Z. Sowjetunion **7**, 129-154 (1935) (with T. Kostina and L. Rusinov).

64. Über Absorption von Neutronen in Wasser, Paraffin, und Kohlenstoff, Physik. Z. Sowjetunion **8**, 472-486 (1935) (with L. A. Artsimovich, V. A. Khramov, and G. D. Latyshev).

65. Künstliche Radioaktivität bei Neutronbestrahlung, Physik. Z. Sowjetunion **8**, 589-594 (1935) (with G. D. Latyshev, L. M. Nemenov, and I. P. Selinov).

66. Investigation of Artificial Radioactivity under Neutron Irradiation. Communication II, op. cit. ref. 49, **16**, 3-9 (1936) (with G. D. Latyshev, L. M. Nemenov, and I. P. Selinov).

67. The Continuous Spectra of Beta Rays from Bromine of 36-hr Half-Life from Observations in the Wilson Chamber, Сб. к 50-летию научной деятельности акад. В. И. Вернадского (Anthology on the 50th Anniversary of the Scientific Activity of Academician V. I. Vernadskii) M., Acad. Sci. U.S.S.R., 547-551 (1936) (with L. V. Mysovskii, R. A. Éĭkhel'berger, and G. D. Latyshev).

68. On the Selective Absorption of Neutrons (in English), Physik. Z. Sowjetunion **9**, 102-105 (1936) (with G. Shchepkin).

69. Über die Absorption termischer Neutronen in Silber bei niedrigen Temperaturen, Physik. Z. Sowjetunion **10**, 103-105 (1936) (with V. Fomin, F. Houtermans, A. Leĭpunskii, L. Shubnikov, and G. Shchepkin).

70. The Interaction of Neutrons with Nuclei, Izv. Akad. Nauk SSSR, Ser. Fiz., No. 1-2, 157-171, 205-208 (1938).

71. Fission of Boron by Slow Neutrons, JETP **8**, 885-893 (1938) (with A. Morozov, G. Shchepkin, and P. Korotkevich).

72. The Diffuse Radiation of Neutrons in a Cyclotron, Doklady Akad. Nauk SSSR **24**, 31-32 (1939) (with D. G. Alkhazov, M. G. Meshcheryakov, and V. N. Rukavishnikov).

73. Academician Abram Fedorovich Ioffe. On his 60th Birthday, Электричество (Electricity) **10**, 34-36 (1940).

74. Metastable Level of the Gadolinium Nucleus, Izv. Nauk SSSR, Ser. Fiz. **4**, 327-329 (1940).

75. On the Work of the Cyclotron of the Radium Institute of the Academy of Sciences, USSR, Izv. Akad. Nauk SSSR, Ser. Fiz. **4**, 372-375 (1940).

76. Fission of Heavy Nuclei, Usp. Fiz. Nauk **25**, 159-170 (1941).

77. Isomerism of Atomic Nuclei, Юбилейный сб. к 30-летию Великой Октябрьской социалистической революции (Jubilee Anthology on the 30th Anniversary of the Great October Socialistic Revolution, Part I) M., Acad. Sci. U.S.S.R., 285-304 (1947).

78. Some Problems in the Development of Atomic Energy in the U.S.S.R., Атомная энергия (Atomic Energy) No. 3, 5-10 (1956).

79. On the Possibility of the Creation of Thermonuclear Reactions in a Gaseous Discharge, ibid. No. 3, 65-75 (1956).

80. On Some Researches of the Institute for Atomic Energy of the Academy of Sciences USSR on Controlled Thermonuclear Reactions, ibid. **5**, 105-110 (1958).

81. Ядерные излучения в науке и технике (Nuclear Radiation in Science and Technology) M., 1958, 53 pp.

Textbooks and Monographs

1. Сегнетоэлектрики (Ferroelectrics), L.-M. GTTI, 1933, 104 pp.

2. Электронные явления (Electronic Phenomena), L., ONTI, 1935, 388 pp. (with D. N. Nasledov, N. N. Semenov, and Yu. B. Khariton).

3. Курс фізики. Молекулярна фізика (A Course in Physics. Molecular Physics), in Ukrainian, Kiev, 1935, 323 pp. ill. (with N. N. Semenov and Yu. B. Khariton).

4. Расщепление атомного ядра (Nuclear Fission), M.-L., 1935, 212 pp.

5. Le champ moleculaire dans les dielectriques (Le sel de Seignette) Paris, Hermann, 1936, 46 p.

Translated by L. M. Matarrese