I. V. KURCHATOV — INVESTIGATOR OF DIELECTRICS

A. F. IOFFE*

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AT the age of twenty-three young Igor' Vasil'evich Kurchatov went to the Leningrad Physico-Technical Institute from the Crimean State University. The institute had been in existence for only seven years, its workers were young, and people spoke teasingly of it as a "kindergarten." The institute was a perfect environment for Kurchatov, not only because of his youth, but because of his enthusiasm, drive, and ability to work as a member of an organization and to be stimulated by its interests, which at that time were dielectrics, the mechanism of electric breakdown, and the still puzzling phenomenon of high-voltage polarization.

While participating in the common efforts, Kurchatov carefully studied the literature of his own problems and everything connected with solid-state physics. He gave careful attention to effects conflicting with his concepts, and was puzzled by the results of experiments on electron passage through thin layers of metal. Not confining himself to critical comments, he suspected that errors had resulted from the destruction of layer continuity, and proved this experimentally. Thus his first published work in the dielectrics laboratory was an investigation of the passage of slow electrons through thin metallic films. The previously observed anomalous results had been eliminated and the problem had been cleared up. This work, like some of his later work, was done in collaboration with Kiril Dmitrievich Sinel'nikov, to whom Kurchatov was bound to the end of his life by friendship, and in time became related by marriage.

This first problem revealed one of Kurchatov's principal characteristics, that of noticing contradictions and anomalies, which he clarified by direct experiments. This trait appeared throughout his long career as an investigator, and led to the discovery of ferroelectricity, to research on the mechanism of current rectification, to investigations of current nonlinearity in carborundum fuses, prebreakdown currents in glasses and resins, and current unipolarity in salts, and later to discoveries in nuclear physics.

The basic problem of the laboratory that Kurchatov had joined was the behavior of dielectrics in strong electric fields leading to breakdown. Up to a certain point Ohm's law was observed as in weak fields, although superficially complicated by high-voltage polarization; but electrical conductivity began to increase rapidly after a certain field strength was reached. The current mechanism obeying Ohm's law was explained satisfactorily as electrolysis in a solid medium. But could these concepts be extended to currents rising exponentially with increasing voltage? Are the mobility and concentration of ions enhanced or do new current carriers (electrons) appear?

Kurchatov undertook to answer these questions, collaborating with another enthusiastic worker, his friend Pavel Pavlovich Kobeko, who had been educated as a chemist. Kurchatov was responsible for the fact that Kobeko had become a chemist. The latter had come as an attendant who boiled varnish and cleaned the laboratory rooms. Kurchatov quickly observed that Kobeko was an unusual attendant, who understood everything and confessed that he had been graduated from a higher agricultural school.

Are ions the only current carriers involved in the nonobservance of Ohm's law? A positive answer was supplied by the exact correspondence with Faraday's law established by Kurchatov and Kobeko. The problem was difficult; glass is almost an insulator and products of electrolysis can hardly be detected. Small quantities had to be measured very accurately. They accurately determined the liberation of matter at the cathodes and measured the amount of oxygen liberated at the anodes. It was subsequently found that in some crystals such as mica departures from Ohm's law in strong fields are due to electrons. However, electrons were not found in glasses, and this fact for a long time influenced the ideas developed in the laboratory.

Kurchatov took a large part together with Sinel'nikov in the investigation of high-voltage polarization, the accumulation of space charge around electrodes resulting from the passage of electric currents. Careful measurements determined the space charge distribution through the thickness of charged layers less than one micron thick.

In addition to his work with glasses, Kurchatov carefully studied the current mechanism and electric breakdown in resins and especially in varnish, which was considered a promising material as a new high-quality insulator. These expectations were based on the fact that, after eliminating certain shortcomings of breakdown voltage measurements at that time, Kurchatov far surpassed earlier results; he reached a few million volts per centimeter instead of a few hundred thousand volts. To be sure, A. P. Aleksandrov later showed that the measurements of that period concealed a source of error that increased as layer thickness decreased. However, the investigations published by Kurchatov, Kobeko, and Sinel'nikov in 1928 on the breakdown mechanism of solid dielectrics contain much data that are still valuable.

*Deceased.

The mechanism of thermal breakdown has been completely elucidated by the experiments of N. N. Semenov and the theory of V. A. Fock.

On his own initiative, Kurchatov studied in 1928 and 1929 current anomalies in certain salts, especially unipolar conductivity. He carefully investigated the geometry of point electrodes opposite plates, as well as secondary electrolytic processes. Collaborating closely with his friends Kobeko and Sinel'nikov, Kurchatov completely accounted for many observed facts. An attempt was made to extend these results to certain cases of current rectification as in cuprous oxide, for which the existence of electrolysis had not been established.

For both electric breakdown and rectification there was a steady development of ideas based on the hypothesis regarding the electric nature of the currents involved. These ideas have not been confirmed for electronic semiconductors but remain valid for solid electrolytes. At the time of Kurchatov's investigations the prerequisites for developing the investigation of electronic processes in solids were unknown, there was no quantum theory of electronic currents, band structure, and holes. Therefore studies of semiconductors could only accumulate experimental facts, and analogies with ions were prevented by the quantum nature of electronic processes.

Kurchatov's talents were fully revealed in his discovery and study of ferroelectrics. Certain anomalies in the dielectric properties of Seignette (Rochelle) salt had previously been described. Kurchatov intuitively suspected new aspects of dielectric behavior. He and Kobeko quickly established far-reaching analogies with the magnetic properties of ferromagnets in what they called "Seignette-electrics". This term is still used by Soviet authors; workers in other countries speak of ferroelectrics by analogy with ferromagnetics.

I myself had occasion to report on Kurchatov's investigations at an international electrotechnical congress in Paris and at Rutherford's laboratory in Cambridge. His experiments were performed with extreme care, and his curves representing the dependences of an effect on field strength and on temperature demonstrated his discovery so convincingly that almost no comments were required. I was able to make my report using the international language of diagrams.

Kurchatov investigated the dependence of ferroelectricity on crystallographic direction, duration of the electric field, and previous history. He determined the Curie point and discovered the lower Curie point, spontaneous crystal orientation and the properties of Rochelle salt beyond the Curie point.

From pure Rochelle salt Kurchatov and his coworkers passed to solid solutions and complex compounds with ferroelectric properties. In these investigations Kurchatov was assisted by his brother, Boris Vasil'evich Kurchatov, as well as by Kobeko.

After only ten years B. M. Vul made the next important step forward by discovering ferroelectric properties in barium titanate. After ten more years G. A. Smolenskii broadened the field of ferroelectrics still further.

With regard to the theoretical explanations of his discoveries, Kurchatov immediately recognized the significance of the ideas advanced by Lev Davidovich Landau, basing all his concepts on the latter's theory and using it to develop his experimental work.

In 1933 Kurchatov wrote a monograph of more than 100 pages on ferroelectrics.

At low temperatures hydrogen chloride crystals exhibit peculiar dielectric properties, although for other reasons than in ferroelectrics. Kurchatov and Shchepkin investigated and gave a clear physical explanation of the observed facts.

Kurchatov and his pupils began to investigate the puzzling electrical properties exhibited by carborundum fuses used in high-voltage technology. An extensive experimental investigation led to a definite hypothesis regarding the mechanism of contact between carborundum grains, which successfully accounted for all data. The appropriate theory was developed by Ya. I. Frenkel'. This was Kurchatov's last contribution to the field of dielectrics and the overlapping field of electronic semiconductors. His interest and inexhaustible energy were transferred to the field of nuclear physics, which owes much to him.

Although from our present-day point of view Kurchatov made a relatively modest contribution to the study of dielectrics, it must not be forgotten that the ferroelectrics discovered by Kurchatov and Kobeko represent the most outstanding result in this field.

Kurchatov was devoted to science without stint; he lived science. It was almost always necessary for others to induce him to leave his laboratory at midnight. Every young physicist was enthralled by the prospect of being sent to the best foreign laboratories, where he could become acquainted with new people and with new scientific methods. Twenty workers at the Physico-Technical Institute had been sent abroad for periods from six months to two years. In the course of several years Kurchatov also had such opportunities, but he always postponed acceptance. Whenever the time for departure arrived, he always was engaged in an interesting experiment, which he preferred to the trip abroad. He went to England only many years later, as a member of a delegation accompanying Nikita Sergevich Khrushchev.

When we remember Kurchatov's work prior to his nuclear physics period, we cannot forget his constant effort to link physics and technology, his search for practical means of utilizing ferroelectrics (with the assistance of V. P. Vologdin), carborundum, and new insulators.

This tendency manifested itself very strikingly at the very beginning of the Second World War. Both the cyclotron and neutrons, where were then Kurchatov's life, were instantly applied to the defense of the navy, for which purpose he assisted A. P. Aleksandrov. By

his unselfish work at Sebastopol he earned the unlimited confidence of our sailors. Admiral Galler stated that the sailors went to sea without fear when instructed by Kurchatov, and entrusted their lives only to him.

At the death of Vladimir Lavrent'evich Kuprienko, director of the tank armor laboratory, Kurchatov became its head and changed its field of investigation. Ships and armor were short interludes between dielectrics, to which Kurchatov devoted the first eight years of his scientific life, and the nucleus, to which he devoted eight prewar years and the rest of his life, fifteen years, following the war period.

However different the physical problems and experimental conditions may be in the fields of dielectrics and the atomic nucleus, in both fields of study he was the same peerless scientist, completely devoted to his work, a talented investigator of nature, a supreme patriot who gave himself entirely to his country. Although uncompromising in his demands on himself, Igor' Vasil'evich Kurchatov was a true friend who showed touching concern for his colleagues and assistants. The vicissitudes of life were more easily endured by many because of his constant kindness and friendly humor. The peoples of the Soviet Union will never forget Kurchatov. For those who knew him personally his memory is surrounded by an aura of personal veneration.

Translated by I. Emin