Personalia

ABRAM FEDOROVICH IOFFE

(on his eightieth birthday)

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Usp. Fiz. Nauk 72, 307-321 (October, 1960)

THE Soviet scientific community celebrates with special feeling the eightieth birthday of the senior Soviet physicist, Academician A. F. Ioffe, because of his exceptionally personal influence on the development of physical science in our country. The senior Academician, elected to the U.S.S.R. Academy of Sciences on May 8, 1920 has gained the deep respect of scientists of all countries; this found expression in his being elected as a member of numerous foreign scientific societies and academies, and in his being awarded many honorary scientific degrees.

A. F. Ioffe entered the field of science at the very beginning of our century, which became also the beginning of the new modern era in the development of physics. However, in Tsarist Russia the prevailing conditions did not allow Russian science to play an honorable role during these initial stages of the development of modern physics. If we do not count the laboratory established with difficulty by the distinguished Russian physicist P. N. Lebedev, there were in the old Russia actually no scientific schools engaged in the investigation of large-scale scientific problems. The individual scientists worked singly, without much communication among themselves, isolated from the problems of the country, and without government aid. No specialized scientific institutions existed in the country, and scientific investigations were conducted in poorly equipped laboratories. These were indeed the reasons why many Russian physicists of that era began their scientific path in the laboratories of foreign scientists.

The situation changed radically only after the great socialist October revolution. The Soviet government established and directed by V. I. Lenin began from the first days of its existence to attract scientists to the building of a new Soviet Russia.

A. F. Ioffe, who was one of the first representatives of progressive Russian intelligentsia began in those years the difficult task of organizing Soviet physics, clearly realizing the grandiose role which science was called upon to play in the building of a new Russia and the unprecedented possibilities which the building of socialism opened up for the development of science.

At that time Ioffe was already a scientist of world renown who worked productively on new assignments which he himself planned. The problem now arose of how he was to continue his scientific activity. He could have immersed himself in his personal scientific work, set up experiments which interested him, and, to the extent that this is possible for one man, he could have possibly obtained very interesting results. Ioffe, however, chose another path: giving up to a large extent his own work, he began to organize Soviet physics systematically. His work in this field was original and revolutionary, and of decisive significance in the development of all aspects of science.

His broad outlook, far-reaching foresight, and versatile talents made it possible to reform our physics both as regards its scope and organization and with regard to the training of new workers. The results of his tireless scientific-organizational work cannot be overestimated.

His invaluable achievement is that he was able to bring physical science in our country to a hitherto unprecedented standard. He was able to awaken in the large group of his pupils an interest in the physical sciences, and this enabled him to establish during a comparatively short period of time a group of physicists which continued to grow both qualitatively and quantitatively. To work in the Institute directed by Ioffe has always been, and is considered a great honor.

Perhaps an even larger achievement of his is the fact that he and his pupils were able to inspire workers of the national industry with an interest in physics. Now, after some years of work of physicists on large technical problems, industrial workers have recognized the possibilities which physics offers for the improvement and fundamental change of production processes, and we are already witnessing the joint fruitful work of physicists and industrial workers. This was to a considerable degree furthered by the work of Ioffe himself, and that of his closest pupils.

Today, just as some decades ago, Ioffe is full of strength and energy. He has many original and creative ideas, makes courageous plans, looks into the future with perspicacity, and possesses an inexhaustible supply of optimism.

He has everything a scientist can dream of: a noted scientific school, a first-class institute, great scientific merit recognized in the scientific world, many friends, and all the conditions necessary for his work. He lacks but one thing — a feeling of complete satisfaction with his activity, the feeling of confidence that all past work was conducted with the maximum efficiency. It is for this reason that Ioffe continues to work uninterruptedly with the ardor of a youth. "Nulla dies sine linea'' always was and remains his motto. With his enthusiasm, with the courageous flight of his healthy scientific imagination, and with his love of science he carries along his pupils and co-workers.

Much work still remains in store for Ioffe, many unrealized thoughts, ideas, plans, and they will, of course, be translated into reality. The guarantee for this is the enthusiastic assistance rendered by our people and by its leaders to the leading scientists of our country.

I

The name of A. F. Ioffe, the distinguished Soviet scientist, is very popular; the basic facts of his biography are too well known to need repetition.

It seems to us more important to attempt to give at least a short outline of his scientific stature, and to characterize the uncommon personality of this eminent scientist.

Ioffe began already in his youth, as a pupil of the Realgymnasium, to take an interest in physics problems connected with the nature of light. He was particularly excited by the ether hypothesis. ''The explanation that light is a wave propagating in a universal ether bothered me,'' Ioffe remembers from that period of his life.

. . .''I realized that the ether must fill the whole of space whence light comes, even at such unbounded distances where light does not even exist. . .''

''Such a purposeless wastefulness of nature seemed to me so unnatural and thoughtless that I began to doubt the hypothesis of the light ether . . .''

Another problem which interested Ioffe in his early youth was the problem of the nature of the spreading of odor. He tried to engage in scientific work in the St. Petersburg Technological Institute, which he entered after completing the Realgymnasium. At that time there were, however, no suitable conditions at the Technological Institute for scientific work in the field of physics.

Ioffe's engineering activity was limited to the erection of a railroad bridge on the Poltava-Rostov railroad and the construction of one of the workshops in a Izhor plant. Following the advice of his physics professor N. A. Gesehaus, Ioffe, after completing his studies at the Technological Institute, set out to Munich to the laboratory of one of the best experimental physicists of that time, the famous Roentgen.

Roentgen was the successor of the well known school of Kundt, where a brilliant group of physicists, among them P. N. Lebedev, were trained.

Before he could obtain permission to begin scientific work, A. F. Ioffe, as all students of the Munich University, had to complete a scientific laboratory program. Ioffe completed within one month a complete series of assignments consisting of some dozens of laboratory experiments.

One characteristic, in itself insignificant fact, referring to that period, made it possible for Roentgen to estimate the quality of the remarkable experimental gift of the young Russian engineer.

The scientific laboratory experiments included one on spectral analysis. The result which Ioffe obtained did not coincide with the tabulated data. Roentgen, naturally doubting the correctness of this result and putting the discrepancy to the inexperience of the beginning experimenter, decided to demonstrate to him the technique of precise spectral measurements. Roentgen himself did a part of the work, and obtained . . . the same result. An error had crept into the tabulated data. After this, Roentgen proposed to his pupil to check Pierre Curie's paper on the thermal energy liberated by radium, which had then appeared in print. At that time this fact was of very great significance, and Roentgen insisted on checking its soundness.

The method proposed by Ioffe for measuring the evolved heat made it possible to confirm Curie's data very convincingly (even for Roentgen). At the same time, Ioffe, checking a theory which he thought of to explain this phenomenon (it was incorrect), noted that the intensity of the glow on the fluorescent screen under the action of the beta rays of radium increased in the presence of a magnetic field.

Nowadays, when the methods of electron optics have become an every-day instrument of the physicist, it is naturally not difficult to attribute this phenomenon to magnetic focusing; and this was the reason A. F. Ioffe gave for it. At the beginning of this century such a completely correct analysis of an obtained experimental result indicated the remarkable ability of the originator of this explanation.

Roentgen liked this result so much that he told Ioffe, with an animation unusual for him in conversations with his co-workers, that he considers him a real physicist, and that it is time for him to begin his doctoral dissertation. At this early period of Ioffe's activity the fundamental features of his creative stature already became noticeable. These were, first of all, his experimental skill — the ability to obtain by simple means the necessary results. Furthermore, the unusual care in the setting-up of control experiments, the art of analyzing experimental data and finding an explanation for them. Finally, it was his uncommon ability to work, allowing him to obtain the required results within a short time.

The subject proposed by Roentgen for his doctoral dissertation was the investigation of the nature of the piezoelectric effect in quartz crystals by investigating the elastic aftereffect.

At that time Roentgen, as indeed many others, believed that the piezoelectric effect in crystals depends essentially on the elastic aftereffect.

In the course of his work, Ioffe soon exchanged the places of the proposed cause and effect. He succeeded in showing, initially from thermodynamic considerations and later by a series of experiments, that the piezoelectric effect does not depend on the elastic aftereffect, but that, on the contrary, the so-called elastic aftereffect is a manifestation of the piezoelectric effect, arising from the deformation of the crystal.

Ioffe gave a simple method for the proof of this statement. He illuminated a deformed crystal with ultraviolet light or with radium rays; as a result, the electric conductivity of the quartz increased sharply, the piezoelectric charges were conducted away, and the elastic aftereffect practically disappeared. It became so small that it could not be observed even by the most sensitive interference methods.

In this work Ioffe resolved the complex long-discussed problem on the elastic aftereffect in crystals (this problem occupied even Maxwell).

For this excellent investigation of the elastic aftereffect the physics faculty of the Munich University awarded Ioffe the degree of doctor summa cum laude. Such an appraisal of a work was very infrequent, and an event in the life of the faculty.

"An unusual incident occurred at the defense of my dissertation" — Ioffe recalls, "the dean made his speech of greeting in Latin which I did not understand. The only thing I had understood was the positive result, since the speech was concluded by a handshake. However, when I met Roentgen in the laboratory he was indignant by the cold manner in which I reacted to the dean's speech."

". . . I should have been moved, but I had not even known that there existed four types of degrees, and I had received the highest of these."

The phenomenon of the increase of conductivity of illuminated quartz, used to study the elastic aftereffect, suggested to Ioffe the investigation of photoconductivity in dielectrics.

At his own initiative, Ioffe had already engaged in the study of the electric conductivity of rock salt and its behavior in x rays. He succeeded in discovering in rock salt irradiated by x rays the internal photoeffect in the visible region. This discovery interested Roentgen so much that he expressed his desire to join his pupil in this work. This joint work continued for a long time, even after Ioffe's return home (1906), and developed into a broad investigation. Unfortunately, only a small part of the results of this large work has been published, and even this after some delay.

The Munich research produced in Ioffe a long-lasting interest in the study of the mechanical and electrical properties of dielectrics. This interest did not abate for more than a quarter of a century. Up to 1930 Ioffe personally engaged in and directed the work of a large group of his co-workers in these important fields of solid-state physics.

A characteristic feature of Ioffe's talent as an experimenter is his ability to set up simple and clear experiments, which give a direct answer to the problem raised, experiments in which secondary side effects are excluded. Such experiments, if they touch upon current burning questions of science technology, soon become classical.

Ioffe, again returned to the study of the mechanism of the deformation of crystals in his newly reorganized Physico-Technical X-ray Institute.

One of his first investigations conducted in this institute was indeed the study of plastic deformation of crystals with the aid of x rays. He observed the diffraction of x rays after passage through a single crystal of rock salt deformed by an external load. For small loads the Laue diagram remained unchanged. Starting with some value of the load, a sudden splitting of the Laue spots which received the name of asterism was observed. Ioffe gave an exhaustive explanation of this phenomenon. Asterism appears when the applied pressure reaches the elastic limit. Here the investigated sample ceases to be a true single crystal; it is divided into discrete single-crystal blocks turned relative to each other by small angles. Each such block produces on the screen its own Laue pattern, i.e., its own system of Laue spots which superimposed on each other give rise to the phenomenon of asterism. It has been observed that plastic deformation does not occur continuously but in jumps.

This mechanism of discontinuous deformation was later studied in detail by a number of co-workers of the Physico-Technical Institute.

Ioffe's work on the x-ray analysis of plastic deformation of crystals, and the explanation of its mechanism, received wide acknowledgement. This work initiated a separate research trend in the physics of metals, which is developing successfully to this day.

Ioffe's excellent experiments on the hardening of rock salt whose surface is dissolved with water in order to remove surface defects have already penetrated general physics courses under the name of the "Ioffe effect." Undoubtedly, Ioffe laid with these investigations the foundation of present-day study of strength of materials in which problems of crystal defects play a fundamental role.

It is possible that the following elegant experiment set up by Ioffe to prove the high true strength of crystals is less well known. A sphere cut from a crystal of rock salt is slowly cooled to the temperature of liquid air, and then quickly plunged into molten lead. Calculation shows that pressures up to 70 kg/mm^2 should occur at the center of the sphere. The sphere, however, does not break up. This experiment was a direct proof that the strength of the inner layers (the surface of the sphere remained unstressed) is considerably higher than the strength determined by the usual methods, and approaches the theoretical value (200 kg/mm^2).

In the course of investigating the mechanical properties of crystals, Ioffe made another great discovery of technical importance. He observed that the character of the breakdown of crystals at a given temperature (which can be brittle or plastic) is determined by the ratio between the temperature-dependent yield point and the ultimate strength, which depends weakly on temperature. This dependence was further investigated for a number of technical substances (in particular, for steels), and led to a number of practically important conclusions.

No less fundamental results were obtained by Ioffe in his studies of the electrical properties of dielectrics, the beginnings of which were laid down by his works in Munich. Here, too, Ioffe focused his attention on the solution of fundamental problems, endeavoring to create such experimental conditions under which the investigated phenomenon would appear in pure form, free from all interfering side effects.

Ioffe was the first who was able to explain the complex and involved question of the so-called "electrical anomalies" of quartz. He showed that these anomalies are connected with the production of space charges within the current-carrying crystal.

When the measurements are properly set up, these anomalies disappear, and the electric current flowing through the crystal obeys Ohm's law. The crystal, therefore, possesses a characteristic true electrical conductivity.

Ioffe demonstrated the extremely strong effect that an insignificant amount of impurity exerts on the electrical conductivity of dielectrics, and worked out methods for the complete purification of crystals.

In the twenties Ioffe, together with a large group of his pupils, occupied himself with the study of the phenomenon of high-voltage polarization. This is the phenomenon that causes the space charge appearing in the crystal with flow of current to be concentrated in a very thin layer at the electrode surface.

Ioffe's experiments showed that the electric field intensity in this layer can attain enormous values, on the order of 10^7 v/cm. The possibility that such fields exist in a thin layer of dielectric promised attractive technical possibilities.

Under Ioffe's direction certain investigations were undertaken of the electric strength of thin dielectric films, whose purpose it was to produce so-called thin-layer insulation of large electric strength.

In spite of the fact that Ioffe's hopes to produce such an insulation were not fulfilled, the enormous work carried out in this connection was very fruitful. New materials were produced in the course of this work which turned out to be technologically very important, and which found wide application; technical methods were developed for removing overvoltages, etc.

The investigations of Ioffe and his school in the field of electric phenomena in dielectrics influenced at the time the works of many scientists in this field of physics and technology both in the U.S.S.R. and abroad. The new direction in the research of dielectrics set up by Ioffe and his close pupils has proved its great vitality, and develops successfully.

II

Ioffe's scientific interests are unusually broad and versatile. In addition to solid-state physics he also takes an interest in general physics problems. Even at the very outset of his scientific activity he showed an interest in the then new quantum theory of light, and endeavored to verify its consequences experimentally.

A small article of his was published in 1907 in which it was shown that the results of the experiments on the external photoeffect fit well within the framework of Einstein's theory.

It must be noted that the author of these experiments himself, Ladenburg, reached on the basis of his results the contrary conclusion. Ioffe showed in his work that similar experiments could directly confirm the correctness of Einstein's theory of the photoeffect. (As is well known, the corresponding experiments were later conducted by Millikan.)

In 1910 Ioffe published a work on the photon theory of radiant energy.* In this work an attempt was made to construct a "gas-kinetic" photon theory of light.

Ioffe convinced himself that the usual statistics are unsuitable for photons. Following Ioffe's proposal, Yu. A. Krutkov assumed different statistics, and derived a relation for blackbody radiation which coincided with Planck's formula. Thus, Ioffe's ideas at that time were close to the Bose-Einstein statistics introduced in 1923.

These works were a kind of prelude to the subsequent excellent work "The Elementary Photoelectric Effect." Now this work in a somewhat altered form has been included in the program of the student practicum of many schools, and the corresponding model of Ioffe's experiments has become a lecture demonstration. This work of his planned and in the main conducted earlier than, and independently of, Millikan's known work on the determination of the electron charge (it was published later), was a striking event in contemporary physics (1912-1913).

In this research the full extent of the experimental ability of its author already became apparent. The method chosen made it possible to show unambiguously that the loss of electric charge by a metal particle occurs in discrete amounts, and that the charges of the discrete photoelectrons are always equal.

At the same time it was established that the time

***A. F. Ioffe, Contribution to the Theory of Radiant Energy, J. Russ. Phys.-Chem. Soc. 42, 409 (1910).**

intervals between the instants of emission of discrete photoelectrons at constant illumination have a statistical distribution. This circumstance can only be interpreted as a direct proof of the discrete structure of the radiation. The tiny particle loses an electron after the electron has absorbed a photon. Ioffe estimated quite correctly the value of the results which he obtained, in the following words: "If we combine these experimental facts, already established by previous investigations, then the experimental proof of the existence of the electron can be considered to have been completed.[11*] Ioffe returned again to the problem of the elementary interaction of radiation with electrons in 1925. This time the experiments were conducted with the aid of x rays.

An extremely convincing and graphic experiment to demonstrate that x rays are emitted in quanta was set up (with N. I. Dobronravov). A metallic (bismuth) particle suspended between capacitor plates was continuously irradiated by x rays from a miniature x-ray tube. On absorbing discrete quanta the particle should have lost electrons and its equilibrium should have been disturbed.

Observations indeed showed that after prolonged equilibrium (during several hours) the particle suddenly began to move as a result of the loss of an electron. After equilibrium was re-established, hours passed before the particle lost its equilibrium on account of the loss of another electron. This unusually graphic experiment convincingly proved the quantum nature of x rays.

Speaking about experiments which are notable for their clarity, their convincing results, and elegance of their method, one must mention the work Ioffe conducted in 1910 on the experimental proof of the existence of a magnetic field of cathode rays. However strange nowadays, at that time the problem of the existence of a magnetic field around a beam of cathode rays was still not clear. Moreover, a number of scientists denied this now obvious fact. Ioffe thought of an extremely sensitive magnetometric method for a direct measurement of the magnetic field around the beam of cathode rays of a discharge tube. These difficult measurements, due to the smallness of the magnetic field, Ioffe completed in record time — in the course of one month. As a result not only was the magnetic field of cathode rays observed, but the measurements showed that the intensity of this field coincides with the field intensity of an equivalent current passing through a conductor.

These experiments of A. F. Ioffe were of the same significance as at their time the classical experiments of Rowland and Eichenwald.

We have dwelt in some detail on the earlier works of Ioffe (in spite of the fact that they are well known), assuming that nowadays when the technique of the physical experiment has become uncommonly complex, the reader will find it pleasant to remember that at one time the talent of an experimental physicist allowed him to attain very important results by extremely simple means.

At the beginning of the thirties Ioffe began a new and wide scientific program — the study of the properties of semiconductors. This became one of the main deeds of his life.

To fulfil this program, including both a many-sided study of the physical processes in semiconductors and the solution of problems connected with their technical application, Ioffe formed a "semiconductor" group of co-workers.

Even at that time, thirty years ago, he clearly understood that semiconductors will play in the future an important role in technology. One of his articles of that time (1931) was entitled: "Semiconductors — The New Material of Electrical Technology."

Among the possibilities of a technical utilization of semiconductors Ioffe was particularly attracted by the possibility of applying semiconductor thermocouples and photocells as technical converters of heat and light into electrical energy.

By means of his numerous articles, lectures, and lessons, Ioffe assisted to a large extent in the development of works on the physics and technology of semiconductors in many scientific and technical institutes of our country. Both Ioffe himself and his co-workers were very successful in discovering a series of new fundamental facts in the physics of semiconductors, some of these of greatest significance for technology.

In the Thirties the physics of semiconductors was in its initial stages; the very concept "semiconductor physics" came into being much later. Ioffe, therefore, at that time gave much attention to the development of experimental methods for the determination of fundamental physical properties that characterize the semiconductor: the concentration of carriers, their charge, mobility, etc.

The success of this essential stage of work was assisted by his long and great experience in the investigation of the electrical properties of dielectrics.

The most important result of the investigation of a whole series of various semiconductors was the observation of the great effect of impurities on their electrical properties. This now generally known fact became the property of physics as a result of extensive and difficult work on the group directed by A. F. Ioffe. It was ascertained that the impurities change the conductivity of the sample within wide limits; moreover, the signs of the carriers in the given sample change under the influence of the impurities. It was proved by direct experiments that not only strange atoms introduced into the given semiconductor can serve as impurities. If the semiconductor is some chemical compound (for instance, lead sulphide), then an even negligible deviation of its composition from stoichio-

*A. F. Ioffe, The Elementary Photoelectric Effect, St. Petersburg, 1913, p. 49.

metric changes its electrical conductivity many fold. An excess or a deficiency of one of the components of the compound is an "impurity," which mainly determines the electrical properties of the semiconductors. The same lead sulphide containing an excess (relative to the stoichiometric composition) of lead atoms is an electron semiconductor, while an excess of sulphur transforms it into a hole semiconductor. By the way, the now widely used terms "hole" and "electron" semiconductors were apparently first coined in Ioffe's laboratory. The explanation of these facts given at the time by Ioffe, consisted of the fact that the atoms of the impurity produce either additional sources of electrons, or centers of attraction for electrons which lead to the production of holes. This explanation fully coincides with the concepts of present-day semiconductor theory. A thorough understanding of the structure of semiconductors, and in particular of the role of the impurities, and the mechanism of their conductivity led Ioffe to the formulation of a completely new idea on the nature of the semiconductor properties of a large group of intermetallic alloys, the so-called "daltonides." It is well known that the properties of such alloys as ZnSb, Mg_3Sb_2, Mg_2Sn, etc, differ sharply from the properties of metals in their small electrical conductivity, their anomalous optical properties (the absence of metallic luster), their small thermal conductivity, etc.

Ioffe's idea was that such alloys are typical chemical compounds with a valence bond. Compounds of the ZnSb type form a heteropolar lattice consisting of positive Zn^{++} ions, and negative Sb^{--} ions. Such compounds, according to Ioffe, should in the ideal case be dielectrics at absolute zero, and typical semiconductors at elevated temperatures. The comparatively large electrical conductivity observed for daltonides Ioffe explained by the inexact stoichiometric composition of these alloys, unavoidable in the usual method of their preparation.

These ideas of Ioffe's were brilliantly confirmed by irrefutibly convincing experiments, conducted by a group of his co-workers. In one such experiment a Zn-Sb alloy with a continuously varying concentration of components was prepared by evaporation in vacuum according to the method of S. A. Vekshinskiĭ. At a concentration corresponding to the compound ZnSb (50% by atomic weight), the electrical conductivity of the alloy turned out to be three orders of magnitude smaller than in an alloy of the same nominal concentration obtained by the usual methods.

In Ioffe's laboratory a whole series of daltonides with characteristic semiconductor properties was studied. Thus, a new direction of research appeared in the physics of semiconductors, which opened up the way to the production of new semiconducting materials whose properties can be changed within a wide range. A series of new semiconductors with important technological applications was prepared in precisely this way.

Among many other problems of the physics of semiconductors which Ioffe occupied himself with, special mention should be made of the problem of rectification. The mechanism of rectification (the appearance of a barrier layer at the boundary between two semiconductors, or a semiconductor and a metal) remained for a long time a puzzle. Numerous theories on the contact phenomena of semiconductors followed one another, unable to stand up to experimental verification.

One of these theories was developed in 1932 by A. F. Ioffe in conjunction with Ya. I. Frenkel'; according to this theory the barrier layer is a gap at the boundary of the semiconductor and the metal with a thickness of several atomic layers. Electrons pass through such a gap as a result of the tunnel effect. The experiments did not confirm this theory. Another conception, according to which the rectifying layer is simply a thin layer of matter with a large specific resistance was also not confirmed. Only at the end of the thirties, on the basis of an enormous experimental material, A. F. Ioffe in conjunction with A. V. Ioffe formulated an idea of the rectification mechanism which is, in its main features, now generally accepted. The quantitative theory based on this conception was developed by D. I. Blokhintsev, B. I. Davydov, et al. According to this idea the barrier layer is formed at the point of contact of two semiconductors with various conductivity mechanisms, electron and hole conductivity (according to present day terminology a "p-n junction"). Here the passage of electric current in the "forward" direction corresponds to a motion of electrons and holes towards each other in the direction of the contact. At the point of contact the electrons and holes recombine. On changing the direction of the current the electrons and holes move away from the contact in opposite directions, producing in the vicinity of the contact a charge-deficient layer, thereby increasing its resistance. The charge-deficient layer in the vicinity of the contact is in fact the barrier layer.

The work of Ioffe on the explanation of the rectification mechanism influenced greatly the development of this problem not only in our country, but also the world over, and contributed considerably to the successes achieved by industry in the important field of development of semiconductor rectifiers (diodes).

We have already mentioned that of the numerous possibilities for the practical application of semiconductors Ioffe was especially attracted by the utilization of the thermoelectric and photoelectric properties of semiconductors as a technical means for the conversion of thermal or light energy into electrical energy. To this problem was added in recent years the problems of utilizing thermoelectricity (the

Peltier effect) for cooling. Ioffe's interest in these problems, which appeared already at the end of the twenties, has not been weakened to this day.

"In connection with the problems of the industrialization of the Soviet Union at the beginning of the first five-year plan in 1929, I indicated the problem of the production of a thermoelectric generator from semiconductors, having calculated that the efficiency may reach 2.5 — 4%, and that a further considerable increase is quite probable," — writes Ioffe in his book "Semiconductor Physics."*

The following are excerpts from Ioffe's speech at the plenary session of the central committee of the communist party of the Soviet Union in July 1960:

"An economically feasible extraction of electrical energy from the rays of the sun by means of semiconductor thermoelements is imminent and will change the entire scope of power engineering.

"An efficiency of 8 to 15% is already in itself of great interest, in particular for the obtaining of electrical energy from the sun and for agriculture. However, directly before us, already within the period of this seven-year plan there arise even greater real possibilities."

Ioffe understands clearly that the solution of such an enormous technical problem should be preceded by serious and systematic scientific work on the detailed theoretical and experimental investigation of numerous problems connected with thermoelectric and photoelectric properties of semiconductors.

Even before the war a thulium sulphide photoelement with an efficiency above 1% was produced under Ioffe's guidance; even this was a large step in the direction of the realization of his earlier goal. As is well known, physicists now succeeded, by employing new materials, in producing photoelements whose efficiency reaches 12 — 15%.

Later Ioffe gathered a scientific group for the study of the problems of thermoelectricity. The theory of thermoelectric generators and thermoelectric cooler (the utilization of the Peltier effect) worked out by Ioffe has given a clear perspective for physicists and engineers working in this field. The fundamental results of his work in this field Ioffe presented in his monographs: "The Energetic Bases of Thermoelectric Batteries of Semiconductors" (1950), "Semiconductor Thermoelements" (1956), and a book published in English "Semiconductor Thermoelements and Thermoelectric Cooling" (1957).

The precise analysis of physical properties of semiconductors carried out by Ioffe with his habitual conviction made it possible to establish the expediency of replacing the conventional refrigerating devices by thermoelectric devices. At present, thermoelectric refrigerators more economical than absorption refrigerators are being constructed after Ioffe's idea.

*A. F. Ioffe, Semiconductor Physics, M., Acad. Sci. Press, 1957, p. 261.

Very recently the Peltier effect found a completely unexpected original application in the hands of Ioffe and his co-workers in the form of semiconductor microcoolers. These microcoolers are at present employed in the most diverse fields of science and technology. Vacuum traps, microcoolers for photoresistors, microthermostats, microsection tables, and other biological coolers; more than thirty similar devices have been developed at the Semiconductor Institute directed by Ioffe. Some of these play an indispensible role in the solution of a series of technological problems.

At present we are witnessing the intense development in many countries of the so-called plasma thermoelectricity, the idea of which was advanced in its time by Ioffe. And when he states that it will not be long before thermoelectric generators will find wide application in industrial power, then this statement is based on a thorough scientific analysis of the aggregate of theoretical and experimental data which have been and are being obtained until this very day to a large extent by himself and his numerous co-workers.

III

A. F. Ioffe is rightly considered the father and teacher of an enormous family of Soviet physicists. Even in 1929, "pupils of pupils of his first pupils" attended the tenth anniversary of Ioffe's Physico-Technical Institute. Up to 1960 the family of "Ioffites" (as the pupils of Ioffe are humorously called) grew enormously, and now he is greeted at least by the fourth, if not by the fifth, generation of his pupils who have filled numerous institutes over the whole of the Soviet Union.

From Ioffe's school came such great scientists as the academicians A. P. Aleksandrov, A. I. Alikhanov, L. A. Artsimovich, P. L. Kapitza, V. N. Kondrat'ev, B. P. Konstantinov, G. V. Kurdyumov, I. V. Kurchatov, L. D. Landau, P. I. Lukirskiĭ, I. V. Obreimov, N. N. Semenov, Yu. B. Khariton, corresponding members of the U.S.S.R. Academy of Sciences A. I. Alikhanyan, B. M. Vul, P. P. Kobeko, Yu. B. Kobzarev, Ya. I. Frenkel', A. I. Shal'nikov, and full members of the Ukrainian S.S.R. Academy of Sciences A. K. Val'ter, N. N. Davidenkov, A. I. Leĭpunskiĭ, and K. D. Sinel'nikov.

Many of them have themselves created schools and are directors of large scientific institutes. Few physicists can be found in the world who succeeded in creating such a school. Ioffe succeeded because of his personal charm, his rare gift for attracting youth by means of tempting scientific prospects, and naturally, thanks to his unquestionable scientific authority. However, the main reason for such "success" is his deep understanding of his scientific duty before his country and before his people. Ioffe understood already during the first years after the great socialist October revolution that for the development of future Soviet industry, a scientific physical basis has to be created which must be assured within a short time of scientific cadres. For this purpose Ioffe took several measures. Above all, he decided to attract courageously youth to scientific work. Such great scientists as P. L. Kapitza, N. N. Semenov, Ya. G. Dorfman, P. I. Lukirskiĭ, Ya. I. Frenkel' began their scientific work under Ioffe while still students.

In 1920 a physico-mechanical faculty was organized through the efforts of A. F. Ioffe within the Leningrad Polytechnic Institute. This was a faculty of a new type, where following Ioffe's idea instruction was organized in such a manner that the students, together with knowledge in the field of physico-mathematical sciences, also obtained a basic acquaintance with the engineering disciplines.

Ioffe was not afraid to attract the most gifted of the second- or even first-year students of this faculty to active scientific work within the Physico-Technical institute which he directed, entrusting them with independent serious investigations. As a result, the majority of scientific co-workers of the Physico-Technical Institute during the first years of its existence consisted of students (the Physico-Technical Institute was in this connection often referred to, for the most part good naturedly but sometimes also with a touch of malice, as Ioffe's kindergarten).

This experiment in the selection of scientific workers was brilliantly justified. True, not all the students attracted to scientific work stood the "test." Some of them were eliminated already during the first period. The remaining students, however, were on the day of their graduation already authors of published scientific works, and had made a name for themselves in science. Many of the pupils from Ioffe's "kindergarten" now occupy leading positions in Soviet physics, and are filled with the feeling of deepest gratitude toward their teacher, not only for having taught them, but also for the manner in which he had taught.

Ioffe possesses the art of teaching to a full extent. Even at an early period in the organization of the Physico-Technical Institute Ioffe had worked out forms of scientific guidance which have been adopted by his numerous pupils, and which became traditional in Soviet physics. These were the methods of collective scientific work with a broad discussion of scientific problems and scientific results, in which both mature and also young scientists took part. One can readily grasp what effect such methods of guidance had on the young who had just entered their scientific path. It is no wonder therefore that the youths tried to improve their scientific qualifications in order to justify the trust put in them. After all, they, the "green ones" were on par with their older colleagues charged with the responsibility of the correct choice of scientific themes, and their treatment. This explains the uncommonly rapid growth of the scientific skill of the young scientific workers, the pupils of A. F. Ioffe.

When scientific degrees and titles were introduced in the U.S.S.R. at the beginning of the Thirties, many of Ioffe's co-workers defended their doctoral dissertations before they had reached the age of thirty.

Ioffe knows the secret of producing a special scientific atmosphere among the group under his guidance. This is an atmosphere in which it is impossible to work without enthusiasm. In the Leningrad Physico-Technical Institute scientific work continued around the clock. Many a scientific worker attracted by an experiment, particularly of course the youth, could not tear himself away even at night, and this was considered normal.

Among the means which Ioffe employs for the scientific education of the workers, the scientific seminars which he directs always were and are of special significance. Many great Soviet physicists who have taken part in these seminars agree that they acquired there both their basic physical education and the correct method of physical thinking. Ioffe possesses an exceptional gift which enables him to penetrate deeply into the essence of physical phenomena, and a special ability to uncover their mechanism. Many physicists know how after an often long discussion of this or that paper at the seminar the discussed problem becomes completely clear as a result of Ioffe's presentation, facts that have not been understood are explained, and errors committed are corrected. Ioffe's seminars are a real school for physicists of all generations. Not in vain do great physicists who work outside Leningrad consider it essential to present their work in the field of semiconductors at Ioffe's seminar, being sure that there their work will be correctly judged on its merits. Ioffe's seminars became an example for many scientific institutions of our country.

Ioffe's enormous merits lie in the creating of a school of physicists. It is impossible to imagine what difficulties we would have experienced if there had not appeared at the right time a large group of scientists-physicists who were able to solve and did independently solve important scientific problems. These merits of Ioffe's have geen generally recognized, and are held in high esteem by the Soviet government, and Soviet society.

IV

Ioffe never considered his scientific activity as a purely private matter. He is deeply convinced that it is the holy duty of a scientist to work for the good of the people, and this conviction he has never ceased to inspire in his pupils. All aspects of Ioffe's activity are a practical realization of this conviction.

A feeling of special admiration fills everybody who becomes acquainted with Ioffe's scientific organizational activity.

Ioffe is rightly considered one of the greatest organizers of Soviet physics. His talent for organizing appeared in its full extent immediately after the great socialist October revolution. He took part enthusiastically in the creation of one of the first scientific institutes established by the Soviet government — The State X-Ray and Radiological Institute. The physico-technical department of this institute, which he directed, soon became an independent institute. This is the same Physico-Technical Institute (initially it was called State Physico-Technical X-Ray Institute) which played such an eminent role in the history of Soviet physics. Ioffe was the director of this institute for more than thirty years. The history of this institute and the different aspects of its activities have often been described, and are well known.

Ioffe has never limited his activity to the institute which he directs, but shows continuous concern for the development of physics in the country as a whole. He also indicated the vital necessity for the creation of a complete chain of physico-technical institutes, and plant laboratories which would be the scientific basis for the developing industry.

Ioffe has received extensive and many-sided assistance from the Soviet government through the great directors of Soviet industry. In the course of a few years new physico-technical institutes were organized in a series of large industrial cities of the Soviet Union. The first of these was the Ukrainian Physico-Technical Institute in Khar'kov; it was followed by Physico-Technical Institutes at Dnepropetrovsk, Tomsk, and the Ural'. For each of these Ioffe selected from the staff of the Leningrad Physico-Technical Institute a group of qualified scientific workers which became the scientific nucleus of the new institutes.

Simultaneously, the following independent Leningrad institutes separated from the Leningrad Physico-Technical Institute: The Institute for Chemical Physics (headed by N. N. Semenov), and the Electrophysical Institute (headed by A. A. Chernyshev).

In 1932 Ioffe proposed the organizing of a new type of institute under the name of Physico-Agronomical Institute. The basic task confronting this institute was the application of present-day physics for the improvement of agricultural production methods. His proposal was accepted, and the Leningrad Agrophysical Institute (as it is now called) has already been working successfully for almost thirty years under Ioffe's permanent direction. The character of this institute is unique throughout the world. Experience has shown what an important role physical methods can play in the solution of such problems as the improvement of the structure of soils, the regulation of heat conditions of the atmospheric layer near the surface of the earth, crop improvement of some fruit cultures, etc. The Agrophysical Institute pays particular attention to the construction of special measuring apparatus for the needs of agriculture. Various types of thermometers for the determination of temperature of the soil, simple hygrometers for the measurement of atmospheric humidity, anemometers for the determination of wind velocities, etc were developed at the institute. All this work was dictated by the aspiration to raise considerably the scientific-technical level of agriculture, and thereby to make possible a quantitative account of external factors affecting it. Ioffe is rightly considered the creator of Soviet agrophysical science which has already done much, and which looks forward to a bright future.

It has been calculated that sixteen scientific institutes were created with the direct participation of Ioffe and under his direction. The Semiconductor Institute of the U.S.S.R. Academy of Sciences in Leningrad which he directs now and which was established by government decision at the end of 1954 is the sixteenth institute according to this count (but not according to its significance).

Ioffe's extraordinary energy and his enormous experience allowed him, with the assistance of guiding organizations, to shorten the organizational period of the establishment of the institute to the absolute minimum, to gather within a short period of time an amicable scientific group, and thus to assure normal conditions for scientific work. In the course of the comparatively short time of its existence the new institute attained deserved fame not only in our country, but also far beyond its borders. From this institute came out the well-known aforementioned works on thermoelectricity, and its technical application. In this institute Ioffe, directing his seventeen laboratories, also carries out his personal scientific work which he has at no time and under no circumstances given up. As always, the direct work at the laboratory was and remains for Ioffe his primary concern.

V

Ioffe's literary work is broad and versatile in its subject matter. He has written more than 600 articles, monographs, textbooks, etc. He has published about 150 original scientific works. The first of these devoted to the investigation of the elastic aftereffect in quartz crystals was published in 1906.

Currently in 1960 Ioffe has sent into print several papers on the thermal-conductivity mechanism of complex semiconductor systems.

Ioffe's monographs are widely known. Each reflects the corresponding stage of scientific activity of its author. His monograph "The Elastic and Electric Properties of Quartz" appeared during the initial period of the investigations of the mechanical and electrical properties of crystals (1915).

In 1928 his work of many years in the field of physics was crowned by a widely known monograph "Crystal Physics" (it was compiled from the lectures of a course with the same name which he gave in the United States).

This initial period of his work in the physics of semiconductors was marked by a small book "Electrical Semiconductors" which appeared in 1933 (it was also published almost simultaneously in France). In 1957 there appeared an excellent monograph devoted to the same subject entitled "The Physics of Semiconductors," which became a reference book for all those who work in the field of semiconductor physics and technology. (This book is a revised edition of Ioffe's "Semiconductors in Contemporary Physics.")

Ioffe's period of intensive work on the physical and technical aspects of thermoelectricity was accompanied by the publication of the already mentioned three monographs on thermoelectricity.

In 1955 there appeared his monograph "Physics and Agriculture."

Each monograph summarizes past stages of a given field of science, and notes problems and the outlook for future investigations. It is, therefore, no wonder that his monographs are widely known all over the world; many of them have been translated into foreign languages.

A. F. Ioffe regarded teaching with special attention and affection. All whose luck it was to hear his lectures on physics know their brilliant presentation, the superb demonstrations which accompanied them, and the attention and interest with which they were listened to.

Ioffe introduced a new lively stream into the teaching of physics, and broke with the rooted traditions according to which a general physics course customarily began with a detailed description of the most diverse methods of measuring lengths, angles, weights, etc. In his first lectures he immediately introduces his listeners to the attractive field of the structure of matter, sketches the tempting prospectives which science uncovers, and only then passes on to a presentation of the classical foundations of science. The principles for the planning of a general physics course which he worked out have now become generally accepted.

The teaching activity of A. F. Ioffe has been reflected in the form of a series of textbooks which he has published at various times. Many generations of engineers and physicists received their first acquaintance with the structure of matter from his excellent book "Lectures in Molecular Physics."

Together with his co-workers, Ioffe undertook the publication of the well-known four-volume course of physics, intended for the physico-mechanical faculty.

Much of his energy is devoted to the popularization of physics. His numerous popular science articles and books are always written in clear understandable language accessible to the widest circle of readers. At the same time the popular presentation is not accompanied by any vulgarization of the presented problem.

The art of popular and simultaneously scientific presentation of special problems is a gift possessed by only the greatest of scientists who have a deep and precise understanding of the presented subject. Ioffe possesses this art in its full extent. Many lively arguments and useful discussions were roused by Ioffe's book "Fundamental Concepts of Modern Physics" in which he attempted to consider the development of physics during the last decades from the point of view of Marxist philosophy. This book has also been published in a number of peoples' democracies.

Ioffe also wrote a number of memoirs. Of these one should mention the brilliantly written biographical outline of his teacher W. Roentgen, whom Ioffe regards with special respect.

In 1933 there appeared the autobiography "My Life and Work."

"Encounters with Physicists," a book which will no doubt arouse great interest in a broad circle of readers, has been published this year.

VI

A. F. Ioffe's scientific achievements have found wide and general recognition all over the world. This found its expression in the many scientific degrees and titles which have been awarded to him. The following is a list of scientific titles which he received at various times: professor in ordinary of the Leningrad Polytechnical Institute (1915), corresponding member of the U.S.S.R. Academy of Sciences (1920), corresponding member of the Goettingen Academy of Sciences (1924), honorary doctor of the California University (1927), corresponding member of the Berlin Academy of Sciences (1928), honorary member of the American Academy of Arts and Sciences (1929), Honored Worker of Science of the U.S.S.R. (1933), honorary member of the Physical Society (Gt. Britain) (1944),* honorary doctor of the Sorbonne (1946), honorary doctor of the Bucharest University (1947), honorary doctor of metallurgy of the Polytechnikum in Graz (1949), hon-

*On the occasion of his election the Chairman of the Society wrote: "Honored and dear Abram Fedorovich, I have read with great satisfaction your agreement that your name be included in the limited list of (eleven) Honorary Members of our Physical Society. There are several reasons for this satisfaction. First, your reputation as a scientist gives us reason to be proud of the fact that you will be among our Members. I have had occasion to study a part of your works in detail, and I am deeply struck by their elegance and originality. Furthermore, your high position in the general structure of scientific research organizations of your great country emphasizes to us your importance. Finally, in addition to satisfying our desire to give your personal merits as a scientist and organizer of scientific research work their due, your election to the Honorary Membership of our Society is a sign of the intimate closeness between British and Russian science for which we British scientists feel deep respect and admiration.

Please accept, dear Abram Fedorovich, a hearty welcome and our very best wishes both from me personally, and also from the Physical Society which I, as its chairman, have the honor of representing.

Yours sincerely,
Andrade.

orary doctor of philosophy of the Munich University (1955), honorary member of the All-Union V. I. Lenin Academy of Agricultural Sciences (1956), honorary member of the French Physical Society (1957), honorary member of the Leopoldine Academy (German Democratic Republic, 1958), honorary member of the Indian Academy of Sciences (1958), and foreign member of the Italian Academy of Sciences (Academia dei Lincei, 1959).

These are the tokens of recognition with which Soviet and foreign scientific societies have celebrated the remarkable activity of A. F. Ioffe.

VII

Ioffe combines harmoniously his versatile scientific and organizing work with widely recognized and distinguished public activity.

Ioffe is the vice president of the Russian Physico-Chemical Society, chairman of the All-Union Association of Physicists, academician, secretary of the Physico-Mathematical Section of the U.S.S.R. Academy of Sciences, vice president of the U.S.S.R. Academy of Sciences, and editor of numerous journals. During the war he was the chairman of the Commission on War Technology at the Leningrad city committee of the communist party of the Soviet Union, chairman of the War Naval Commission, deputy to the Leningrad municipal soviet of workers' deputies. This is a far from complete list of the elective offices which Ioffe has at various times held.

At present he is the chairman of the Commission on Semiconductors of the Presidium of the U.S.S.R. Academy of Sciences, the chief editor of the journal "Solid-State Physics," vice president of the International Union of Pure and Applied Science and chairman of its commission on semiconductors. Ioffe's distinguished scientific and organizing activity is highly regarded by the government. He has been accorded the distinguished title of Hero of Socialist Work and has been rewarded with two Lenin orders and medals. He has been awarded a Stalin prize of the first order.

* * *

All aspects of Ioffe's activity, be it large-scale scientific work, the solution of a technical problem, a popular science lecture, the writing of a book, or the solution of a large organizational problem, are stamped with the mark of his original and peculiar talent.

Ioffe is distinguished by his exceptional ability to formulate clearly the most difficult problems, and to find the most direct ways to solve them. Being a remarkable teacher, he is able to attract to himself gifted youths, passing on to them the wealth of his experience and knowledge, and firing them with his enthusiasm.

His eightieth birthday finds Ioffe working strenuously, surrounded by numerous pupils with whom he shares his new scientific ideas, and plans new and greater deeds.

As the last page was being printed we received the painful news of A. F. Ioffe's sudden death which occurred on October 14, 1960.

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