Hundredth anniversary of the birth of A. F. Ioffe: Academician A. F. Ioffe and Soviet science[1)]

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Although there were some notable science schools in pre-revolutionary Russia, some of which were world leaders, the overall development of science was negligible. The training of scientific personnel was usually completed in the laboratories of foreign scientists, and the number of such trainees was very small. Instrumentation was at an exceedingly low level, most reagents were almost exclusively imported, and so on. The result was that only certain individual branches of science developed successfully in Russia, but even this development was largely limited by the extent to which the necessary instruments, reagents, and materials could be bought abroad or produced domestically with the very slender resources available.

Industry in pre-revolutionary Russia was largely dependent on foreign countries for technology, many types of raw material and essential components (for example, for instrumentation), machine tools, and electrical equipment. It was also frequently dependent on engineers brought in from abroad. The standard of education was exceedingly low and this, of course, had an important influence on the quality of technical personnel.

However, soon after the October Revolution, the young Soviet Government took, as one of its first tasks, the extensive development of education, culture, and science. It is now difficult to imagine that, during the period of famine, great economic depression, developing civil war, and foreign intervention, very energetic steps were taken all over Soviet territory to eliminate illiteracy, to establish new schools, to develop primary education, to open new and to extend existing higher educational institutions, and even to organize research institutes for various branches of science. These institutions were essentially a new type of scientific organization in Russia since, prior to the advent of the Soviet Government, all research was carried out in individual departments of higher educational institutions. The development of education all over the country, including some of the most backward areas, released new creative forces which, in turn, resulted in great advances in science and general standards.

V.I. Lenin showed surprising foresight when he approved, in April 1918, the suggestion made by the Academy of Sciences that the manufacturing capacity of the country be investigated with a view to establishing a scientific basis for the restoration and development of national economy in Soviet Russia. On April 12, 1918, the Sovnarkom (Council of People's Comissars) resolved that this should remain a permanent task for the Academy of Sciences. On V.I. Lenin's instructions, steps were taken to support the initiative taken by scientists in the organization of a number of scientific institutions. This period saw the creation of the Central Aerohydrodynamic Institute (CAGI), the State X-Ray and Radiological Institute in Petrograd, the Central Radio Laboratory in Nizhnii Novgorod, and many other institutes. This laid the foundations for the development of science in the country, and eventually spawned many other scientific-research organizations. The creation of scientific institutions by the Soviet Government was directed by major contemporary scientists such as N.E. Zhukovskii, V.I. Vernadskii, M.A. Bonch-Brue-

ABRAM FEDOROVICH IOFFE

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vich, and P.P. Lazarev. This famous team also included the relatively young Professor A.F. Ioffe.

During the first years of its life, the State X-Ray and Radiological Institute, which included the Physicotechnical Division directed by Ioffe, underwent many reorganizations which eventually resulted in both a change of name and a change of purpose. Thus, the Optical Division of the Institute almost immediately (in 1918) became the Optical Institute (GOI). In 1921, the medical laboratories became the X-Ray Institute and the Radium Division was reorganized into the Radium Institute. At the same time, the Physicotechnical Division became an independent institute as well. The creation of new fields of research, which subsequently resulted in the establishment of independent scientific institutes, was the characteristic feature of the activities of the Physicotechnical Institute that was responsible for its importance in the development of Soviet science. This creation process occurred not only in the field of traditional physics, but also in adjacent fields such as chemical physics, radiophysics, biophysics, agrophysics, semiconductor physics, nuclear physics, high-energy physics, and so on.

Soviet physics, many branches of which were initiated at the Physicotechnical Institute and of which we can justly be proud, is, in many ways, the result of the inspired scientific and organizational work of the creator of the Physicotechnical Institute, Academician Abram Fedorovich Ioffe.

Abram Fedorovich Ioffe was 38 years old when the Physicotechnical Institute was set up. He was a broadly educated scientist who received magnificent training under the direction of V.K. Roentgen, one of the most outstanding physicists of the time. In 1918 (the year in which the Physicotechnical Institute was established), A.F. Ioffe was elected Corresponding Member of the Academy of Sciences. While A.F. Ioffe was working in Germany in V.K. Roentgen's laboratory, he became familiar with all the latest ideas in physics. Personal contacts with major physicists of the time contributed to A.F. Ioffe's unusually extensive erudition and a deep commitment to the revolution in physics that coincided with the beginning of this century and seemed to change completely the then existing order in the fundamentals of science.

This was a very acute period in the development of physics: new physical ideas were given in a hostile reception both by our own and by foreign scientists of the old school, and also by some philosophers who tried to present them as philosophically unacceptable.

A.F. Ioffe's versatility was striking: partly in collaboration with his pupils and colleagues, and often personally, he carried out experimental work in very different fields, including quantum physics, physics of dielectrics, and the theory of mechanical strength. He also investigated the mechanism of elastic aftereffects in quartz, the internal photoelectric effect, and plastic deformation and twinning in semiconductors (through x-ray structure analysis). Abram Fedorovich carried out many extensive fundamental researches (usually with A. V. Ioffe) into the physics of semiconductors, including their photoelectric, thermoelectric, and numerous other properties associated with their band structure. At the same time, he continued to participate creatively in many theoretical and experimental researches in the different branches of physics that were being studied at the Institute, and constantly stimulated scientists at the Institute, especially young scientists, with his new and original ideas.

One of the characteristic traits of A.F. Ioffe was the breadth of his interests, rapid assimilation of new theoretical and experimental ideas, and a lively, comprehensive, and creative approach to all problems. He had a striking knack for finding a simple approach to complicated phenomena and played an enormous role in familiarizing our scientists with the ideas of the then new physics. Personal simplicity, interest in people, and complete absence of arrogance were characteristic of this charming man.

Ioffe clearly understood that it was essential for the new Russia to develop, without access to foreign capital or specialists, all kinds of industrial capability, its own science, and its own scientific and engineering personnel. With enormous energy, he devoted himself to this task. He was one of the few who believed that the development of physics was the basis for advance in many branches of technology. The name of his institute, the *Physicotechnical* Institute, reflected his personal views on this subject, which were not at all trivial at the time.

Whilst he was establishing the Physicotechnical Institute, which, by the middle 20's, was already the leading physics institute in the country, Ioffe devoted much energy to the education of new scientists. There were no ready-made procedures and Abram Fedorovich had to invent them and introduce them after much trial and error. In the end, he found what he wanted: even undergraduate students at the Institute had to take part in research performed in the laboratory of the Physicotechnical Institute. Abram Fedorovich believed that the aim of higher education was not so much to give the students some finite range of knowledge, but to give them experience in the use of scientific literature and to train them in the right skills and habits in their approach to the problems presented by developing science. A further important element of this program was the instillation of the understanding that a developing science is never complete. The main aim, in his view, was to stimulate creative activity. This was introduced by Ioffe into the higher educational institutions in the 1920's and is now a characteristic feature of our best institutions of this kind. Creative students, often those in their second year, found that they easily became "part of the scene" in the laboratory of the Physicotechnical Institute. This was a novel idea of this remarkable institute, which was often referred to as "Ioffe's nursery."

The breadth of Ioffe's interests and his personal charm contributed to the fact that the Physicotechnical Institute collected together a first-rate team of physicists belonging to the older generation, including V.R. Bursian, N.I. Dobronravov, V.K. Frederiks,

D.V. Skobel'tsyn, N.N. Davidenkov, A.A. Chernyshev, N.N. Andreev, S.A. Shchukarev, D.A. Rozhanskiĭ, and others. The younger of them included P.L. Kapitsa, P.I. Lukirskiĭ, N.N. Semenov, V.A. Fock, Ya.I. Frenkel', P.S. Tartakovskiĭ, and many others. I.E. Tamm, L.I. Mandel'shtam, N.D. Papaleksi, D.S. Rozhdestvenskii, Yu.A. Krutkov, A.A. Lebedev, P.P. Lazarev, S.A. Vekshinskiĭ, and other leading physicists working in different higher educational institutions and scientific institutes, and in different branches of developing industry, took part in the seminars held at the Physicotechnical Institute. One particularly recalls V.V. Skobel'tsyn, professor at the Polytechnical Institute, in whose department Abram Fedorovich began his teaching career in 1906. Many years later, in 1918–1923, V.V. Skobel'tsyn placed some of the facilities at the Department of General Physics at the disposal of the staff of the Physicotechnical Institute, who continued to work there until the Insitute transferred to its new premises.

During the seminars held at the Physicotechnical Insitute, anyone could ask a question or express a view, and this often developed into lively and interesting discussions. Complicated theoretical contributions were always followed by explanations from Abram Fedorovich, who had the knack of exposing their physical meaning. All this ensured that the seminars were an important training ground for younger scientists.

A.F. Ioffe's work in the administration of science was not confined to Leningrad and Moscow, to which the USSR Academy of Sciences was transferred in 1934. Ioffe was one of the organizers of national Russian conferences of physicists in which both students and numerous teachers of physics in higher and intermediate educational institutions took part. These conferences introduced a large public to the problems of modern physics, and were open to all. Major foreign scientists took part in them as well.

Abram Fedorovich kept careful track of the development of science, especially physics, in the different towns of our country, and always vigorously supported any new sign of scientific activity. For example, he heard that a group of young scientists was working on the physics of dielectrics under the direction of Professor V.K. Roshe at the Kiev X-Ray Institute. Having examined this work, he sent N.N. Semenov to Kiev and, some time later, Ya.I. Frenkel', who suggested to the Kiev workers that they attend the Conference of Physicists in Odessa in the fall of 1930. Ya.I. Frenkel' introduced us at that conference to Academician Ioffe, who questioned us closely on our research and invited the entire group, i.e., D.N. Nasledov, P.V. Sharavskiĭ, V.M. Tuchkevich, and myself, to come to Leningrad to the Physicotechnical Institute, for which we soon departed.

I was thus fortunate in coming into contact with A.F. Ioffe at the Physicotechnical Institute, and this determined my subsequent fate. I.V. Kurchatov, P.P. Kobeko, Yu.B. Khariton, S.N. Zhurkov, L.A. Artsimovich, the brothers Alikhanov, I.K. Kikoin, V.M. Tuchkevich, K.D. Sinel'nikov, G.V. Kurdyumov, A.N. Shchukin, Yu.B. Kobzarev, B.P. Konstantinov, and many of my contemporaries at the Physicotechnical Institute were in debt, as I was myself, to our supervisor, Academician Ioffe, and to the environment which he created in the Physicotechnical Institute. These names speak for themselves. Practically all of them are Academicians and directors of major scientific schools. A.F. Ioffe knew how to choose his intake!

Close personal contact among the younger scientists, frequent discussions of results and of ways of formulating experiments and of preparing resistors, capacitors and other elements of measuring circuits—all this led to rapid familiarization with the art of experimentation and a rapid expansion of horizons. Mutual help was readily given and, in fact, it would have been impossible to continue without it. Being novices, we did not know anyone at the Institute and bombarded all and sundry with requests. P.P. Kobeko and A.I. Shal'nikov taught me how to mount the filament of an electrometer and where and from whom to obtain the necessary instruments (there were only three capacitor banks in the entire Institute and everyone was using them). The remarkable master glassblower, Nikolaĭ Gavrilovich Mikhaĭlov, readily taught us all how to make T-joints and how to assemble vacuum apparatus (all made of glass at the time) until, at the end of the day, we acquired the skills of performing minor glassblowing tasks ourselves. Major mechanical work was carried out in the workshops of the Institute (where, for example, electrometers and other instruments were made), whereas lesser undertakings were dealt with in the tiny one-room workshop of N.M. Reĭnov. He had to be given a sketch and an explanation of what was required, because the sketch alone was often incomprehensible. He was very ready, especially in the evenings, when his assistant had gone home, to allow us to work with his tools so that, eventually, we became, to some extent, independent.

I spent most mornings in the library. Most of the tables of contents of the scientific journals carried A.F. Ioffe's annotations, such as I.V. P.P. A.P. and so on,[2] drawing the attention of the various persons in the Institute to the various papers. This environment of unusual attention, help, and serious though friendly criticism, helped each of us to progress at a rate consistent with our abilities and our capacity for hard work. Once a week, A.F. Ioffe visited each laboratory and asked many detailed questions about work in progress. He thus became familiar with the results of measurements, discussed them, and made suggestions for future work. One felt very ill at ease when a particular week's work was not very productive.

Although he was very busy, Abram Fedorovich never neglected his own experimental research. In the 1930's, after a considerable change in the aims of the Institute, he collaborated with Anna Vasil'evna Ioffe in experimental work on the physics of semiconductors so that he was able to direct research in this field not in a gen-

[2] I. V.—Igor' Vasil'evich Kurchatov; P. P.—Pavel Pavlovich Kobeko; A. P.—Anatoliĭ Petrovich Alexandrov. (Ed.)

eral way but on the basis of his own results and his own experiments.

Occasionally, Abram Fedorovich invited us to his laboratory to inspect some result of new device. He often invited the younger scientists to his home. Anna Vasil'evna received us very warmly, and the evenings were spent in telling jokes, playing games, and in serious discussions. Ioffe told us about his plans, and this frequently influenced the direction of our own work, although he never imposed his own views upon us. Regular discussions not only of physics problems but also of problems in engineering or construction, new directions in power engineering, and so on, gave us food for thought and led us to a more varied approach to current problems. This ensured that none of the new directions in physics (there were many "points of growth" in physics at the time) was ignored and that promising lines of enquiry were regularly taken up at the Institute. This mobility of effort can be illustrated by the example of Kurchatov, who changed his topic four times in the space of eight years. He studied breakdown in solid dielectrics, protection of high-voltage lines from overvoltage by solid-state diodes, ferroelectric materials (this was his doctoral topic), and, finally, nuclear physics. I also began with the physics of breakdown, but soon transferred to the physics of polymers, which was the topic of my doctoral thesis. P.P. Kobeko first worked on breakdown in dielectrics, but soon after transferred to ferroelectric phenomena and then, together with all his collaborators, switched to the physics of the amorphous state and laid the foundations for this branch of physics in our country. A.F. Ioffe and A.V. Ioffe became interested in the physics of semiconductors quite early on (1932–1933), and D.N. Nasledov, V.P. Zhuze, Yu.P. Maslakovets, V.M. Tuchkevich, and others also took up this subject. However, this did not mean at all that A.F. Ioffe lost interest in other researches in the Institute. For example, this period saw the beginning of his interest in the new and developing subject of biophysics which was taken up by G.M. Frank at the Institute. His laboratory eventually became the Institute of Biophysics of the USSR Academy of Sciences. A little later, A.F. Ioffe organized the Agrophysics Institute, since he was convinced that great benefit could be derived from applications of the results of physical researches in agriculture. During this period (1930–1940), the Physicotechnical Institute was the springboard for the establishment of the Leningrad Institute of Chemical Physics (now the Institute of Chemical Physics of the USSR Academy of Sciences), directed by N.N. Semenov, the Leningrad Electrophysical Institute, directed by A.A. Chernyshev, the Institute of Physics of Metals at Sverdlovsk, the nucleus of which consisted of Ya.G. Dorfman, I.K. Kikoin, and M.N. Mikheev, the Ukrainian Physicotechnical Institute in Kharkov, to which were sent A.K. Leĭpunskiĭ, L.D. Landau, I.V. Obreimov, K.D. Sinel'nikov, L.V. Shubnikov, and others, the Tomsk and Denpropetrovsk Physicotechnical Institutes, the Leningrad Institute of Musical Acoustics, directed by N.N. Andreev, which subsequently became the Acoustics Institute of the USSR Academy of Sciences, and so on. A.F. Ioffe was convinced that, once a particular branch of science matured, and a suitable person could be found to take charge of it, the best course to adopt was to set up conditions for an independent development of the particular subject. The realization of this idea was, in fact, exceedingly fruitful in our country. A solid research program was developed in the Soviet Union between 1935 and 1940, dealing with all branches of physics at the time and, in some of them, we became world leaders. This was, of course, the result of contributions from many institutes, including important contributions from the Physics Institute of the Academy of Sciences, the Optics Institute, the Radium Institute, and many others, but the contribution of the Physicotechnical Institute was the most important.

The Physicotechnical Institute was sometimes severely criticized for its alleged lack of contact with practicalities, for ignoring the needs of industry, or for engaging in such "impractical" researches as those concerned with nuclear physics. However, Ioffe was clear in his own mind what his responsibility to the country was. He was convinced that it was precisely fundamental scientific research that was, in the final analysis, to result in the development of new technologies and in changes in the direction of scientific and technological advance. This was the rationale for his insistence on the development of these new lines of research at the Institute. It is only now that one can clearly see the courage, the scientific morality, and the striking foresight of A.F. Ioffe, who made sure that the Physicotechnical Institute and its daughter institutes did, in fact, engage in an unusually broad range of scientific research. The great majority of the main lines of research at the Physicotechnical Institute have become major branches of science or important components of scientific and technical advance.

It is common knowledge that researches into nuclear physics, semiconductor physics, the physics of amorphous bodies and polymers, the mechanics of fracture of metals and of nonmetallic solids, and so on, which were begun at the Physicotechnical Institute, have had major impact in both science and technology. These researches are now being developed at many institutes and have led to the establishment of major branches of industry and numerous technological undertakings. They all provide a major contribution to the national economy and to the defense of our country. The I.V. Kurchatov Institute of Atomic Energy, the Institute of Theoretical and Experimental Physics (initially directed by A.I. Alikhanov) and the Institute of Chemical Physics (Academician N.N. Semenov) are all daughter institutes of the Physicotechnical Institute, they have spawned many second-generation institutions and have made a decisive contribution to the development of major branches of science and technology.

Many of the more specialist researches have also contributed in an important way to both the technology and the defense of our country. Thus, ferroelectric materials play an important role in hydrodynamics, and elsewhere, as transducers transforming mechanical into electrical oscillations. Work on radar, initially be-

gun at the Physicotechnical Institute, now covers an enormous span. Development work at the Physicotechnical Institute on the strength of armor plate and the mechanics of destroying it, on mine detection for ships, on the stability of ice along the wartime "lifeline" on Lake Ladoga, on electron-optical image converters, and so on, has been of major importance.

Many of the subsidiary results of physical investigations at the Physicotechnical Institute have now found unusually wide applications. For example, polystyrene, which was recommended in the 1930's as a dielectric for high frequencies, is now a common material; cold-resistant rubber, developed at the Physicotechnical Institute, has been used for many years. The "cracking" of polycrystalline bodies under plastic deformation, which was investigated by M.V. Klassen, has found increasing applications as a diagnostic method for testing the state of mechanical structures by making use of their "acoustic emission"; the "Elegaz," proposed by B. M. Gokberg, i.e., gaseous sulfur hexafluoride, which exhibits high dielectric strength, is now finding extensive applications in ultrahigh-voltage equipment. S.N. Zhurkov studied the strength of glass and quartz filaments. The method of protecting surfaces, discovered by Zhurkov, is now used in the development of fiber optics. These are only a few examples but they could be multiplied many times over.

In 1943, the majority of institutes with physics and chemistry departments, including the Physicotechnical Institute, began urgent work on the uranium problem. This necessitated considerable concentration of effort and an extensive reconstruction of all scientific research with emphasis on engineering aspects.

A number of major laboratories were taken out of the Physicotechnical Institute after 1943 and subsequently formed the nucleus for new institutes. The laboratories of I.V. Kurchatov, A.I. Alikhanov, L.A. Artsimovich, L.M. Nemenov, A.P. Aleksandrov, and M.I. Kornfel'd were transferred to Moscow. The Physicotechnical Institute increased its effort in new fields. It commissioned a cyclotron and designed a new accelerator at Gatchina. B.P. Konstaninov, B.A. Gaev, and others carried out a series of important researches that involved the participation of many of the most outstanding workers previously occupied with other problems. This improved the technological basis of the Institute. The most urgent task was to mobilize all effort toward the solution of the atomic problem. Semiconductor work took second place at this stage and A.F. Ioffe was removed from the direction of the Institute, which was assigned a different profile. As a communist and a man of principle, A.F. Ioffe survived this blow manfully. A change of directorship in a complex and productively working scientific organization is an exceedingly complicated process, especially if the new director is far removed from the traditions of the collective. The creative organism developed over decades can be easily damaged, and this process did, in fact, begin at the Physicotechnical Institute.

Some of the laboratories (P.P. Kobeko, M.M. Koton, and a number of others) transferred to other institutes, and a proportion of the laboratories engaged in research into the physics of semiconductors was reorganized into the Laboratory of Semiconductors of the Academy of Sciences with A.F. Ioffe as its Director. This laboratory eventually (by 1955) developed into the Institute of Semiconductors of the Academy of Sciences of the USSR and A.F. Ioffe, who again became the Director of the Institute, devoted all his resources to its establishment and development. The Institute began to succeed and produce first results but, unfortunately, Abram Fedorovich's strength was in decline.

By then, the situation at the Physicotechnical Institute had changed—B.P. Konstantinov, who was a pupil of A.F. Ioffe, became its Director (in 1957), and the situation at the Institute gradually returned to normal. New scientific teams were established and gradually became part of the creative effort of the Institute. The importance of the Physicotechnical Institute began to rise again.

The two institutes were subsequently combined into the A.F. Ioffe Physicotechnical Institute, but this occured only after the sudden death of A.F. Ioffe, who was full of plans and ideas right to the end. The reestablishment of the Physicotechnical Institute was of major importance in raising its scientific standards. It relied on younger staff and began to reassert its preeminence in science. Today, the Physicotechnical Institute is again creatively active, and is one of the major physics institutes in the country. It has again given birth to a new institute, namely, the B.P. Konstantinov Leningrad Institute of Nuclear Physics at Gatchina.

The outstanding service given by Academician Ioffe was frequently noted by both Party and Government. In 1955, he was awarded the title of Hero of Socialist Labor and was given the highest award in our country, namely, the third Order of Lenin and the Gold Medal. In 1942, he was awarded the State Prize and, in 1961, he was awarded, posthumously, the Lenin Prize.

Since the middle 1910's and right up to his death, A.F. Ioffe was one of the world figures in physics. He initiated the development of physicotechnical researches, and the institute created by him has now successfully combined—for over 60 years—development of fundamental research with realization of its technological potentialities. The Physicotechnical Institute is a remarkable legacy left to us by Academician A.F. Ioffe.

Those of us who were the pupils of Academician A.F. Ioffe are now few in number, but the enthusiasm for science and the sense of responsibility for Soviet physics have remained with us as has our gratitude to our Director. Abram Fedorovich Ioffe carried us all with him in his impassioned quest for advance in scientific and technological research and for the enrichment of technology with the achievements of science in our country.

The A.F. Ioffe Physicotechnical Institute is rightly regarded as the Alma Mater of Soviet Physics. The scientific and administrative work of A.F. Ioffe, and of his collaborators and pupils, led to the establishment of an extensive net of institutes in our country,

which have played a decisive role in the development of many branches of physics and adjacent fields. In all corners of our great country, there are now many pupils of pupils of Academician Abram Fedorovich Ioffe, who are working in different branches of physics and adjacent areas of technology, in biology and agriculture, in chemical physics and in physical chemistry. He was undoubtedly the creator of a major physics school in our country.

Translated by S. Chomet