Physics – Uspekhi **37** (12) 1159 – 1166 (1994)

CENTENARY OF P L KAPITZA'S BIRTH

PACS numbers: 01.60. + q

Life and scientific work of P L Kapitza

A S Borovik-Romanov

Petr Leonidovich Kapitza was a scientist with a very broad profile. He was a major experimental physicist and contributed significantly to the development of the physics of magnetic phenomena, physics and technology of low temperatures, quantum physics of the condensed state, electronics, and plasma physics.

Petr Leonidovich was born in Kronstadt on 9 July 1894 to the family of a military engineer. His scientific work started while he was still a student of A F Ioffe at the Electromechanical Department of the Petrograd Polytechnic Institute, from which he graduated in 1919. After graduation, Petr Leonidovich remained at the Polytechnic Institute as a lecturer. He was a member of a group of young, talented, and energetic people who gathered around Abram Fedorovich Ioffe and formed the first crop of the successful school of Leningrad physicists, who founded the Leningrad Physicotechnical Institute, closely linked to the Polytechnic Institute. All of them combined teaching with serious scientific research.

The first original scientific work of Petr Leonidovich was the development of a new method for the preparation of Wollaston filaments, which were thin (less than 1 μm) platinum or gold wires formed by drawing while covered by a silver cladding, which was then dissolved. P L Kapitza used an electrolytic method for the dissolution of silver and thus reduced the danger of breaking of these thin filaments. In his next work, Kapitza proposed an original model of an x-ray spectrometer in which the intensity of x-rays reflected from a crystal was enhanced by a large factor as a result of focusing by a bent cylindrical surface of the crystal.

The third original work of Petr Leonidovich was carried out in cooperation with N N Semenov. In this work he proposed a method for determination of the atomic magnetic moment based on the interaction of an atomic beam with an inhomogeneous magnetic field. This method was subsequently used in the familiar experiments of Stern and Gerlach.

The year 1920 was very tragic in the life of Petr Leonidovich. In one month he lost his father, wife, and two children. He was in a terribly depressed state. One of the reasons why A F Ioffe recommended that he should join a group of scientists posted for a time abroad was to shake Kapitza out of his bitter thoughts. In 1921 this group — consisting of Academician A F Ioffe, several other major scientists, and young P L Kapitza — went to Germany and England to establish contacts with leading laboratories and to buy equipment for the institutes being organised in Petrograd.

When they visited Cambridge University, Kapitza was accepted, on recommendation of Abram Fedorovich, for a temporary post at the Cavendish Laboratory headed by Ernest Rutherford. Rutherford's laboratory was at the time the centre of research on radioactivity and structure of the atomic nucleus. The initial period at this post was to be one year. In that year Petr Leonidovich revealed a great inventiveness and constructed an instrument for the measurement of the energy lost by an α particle at the end of its range, and then carried out such measurements. He achieved a considerable improvement in the sensitivity of these measurements. The results of this work made a great impression on Rutherford and he not only kept Petr Leonidovich for a longer time in Cambridge, but agreed to finance Kapitza's project for the generation of very high magnetic fields in which it should be possible to observe bending of the α-particle tracks. In tackling this task, Petr Leonidovich revealed a feature of his character typical of his whole life: he never went along a beaten path, but always sought new, original solutions. He demonstrated that it would be pointless to use iron-cored electromagnets in the generation of very high magnetic fields and that it is necessary to employ coils and pass a very high current through them. The main difficulty is then the heating of such coils. Kapitza proposed an original method for overcoming this difficulty. He suggested that magnetic fields be generated for a brief moment by passing a pulse of high current through the coil: during this time the coil would not have time to heat up. In his first experiments, Petr Leonidovich used an accumulator with a very small capacity and a low internal resistance. He charged this accumulator for a period of several minutes and then discharged it through a coil in a hundredth of a second. He thus generated fields of the order of 100 kOe and he even produced a record field of 500 kOe in a small volume (when the coil diameter was 1 mm). Petr Leonidovich was the first to place a Wilson chamber in a strong magnetic field and to observe bending of the α-particle tracks.

In the summer of 1923 Kapitza defended his thesis and in the same year he was awarded a Ph.D by Cambridge University. He then obtained a Maxwell Fellowship for three years.

Petr Leonidovich was not satisfied with fields of 100 kOe and put forward a new bold project for energy storage. He proposed to construct a motor – generator of special design. In this generator the energy needed to create a magnetic field would be stored in the form of the kinetic energy of the rotor. Rutherford supported this project and provided very solid, for the time in question, means and

Uspekhi Fizicheskikh Nauk **164** (12) 1251 – 1258 (1994)
Translated by A Tybulewicz

special accommodation for constructing this system. In 1924–1925 a unique generator with a rotor weighing 2.5 tonnes was made by Metropolitan-Vickers in Manchester. The rotor was set in motion by an electric motor and then short-circuited across a coil thus releasing a power of 220 MW. Petr Leonidovich travelled frequently to Manchester and participated in the design of this motor–generator and in its tests. In June 1925 the motor–generator was brought to Cambridge and mounted on a strong foundation. In December of that year, Petr Leonidovich carried out the first test of the motor–generator system. In this system he was able to create a magnetic field of 320 kOe intensity in a pulse of the order of 10 ms. The principle of generation of pulsed fields is now used widely in many laboratories. The technological developments have made it possible to employ capacitors as energy storage devices, but the magnetic energy produced in a coil by Kapitza still remains a record value. He also developed original methods for measuring various physical parameters in pulsed magnetic fields.

The work on observation of α-particle tracks in very high magnetic fields ended the cycle of research connected with the topics studied directly under Rutherford. In 1924, Petr Leonidovich began investigating the Zeeman effect and then the galvanomagnetic properties of metals in strong fields. Rutherford not only did not impede, but — just the opposite — supported this independent path of the scientific work of Petr Leonidovich. The mutual liking of Rutherford and Kapitza grew into a friendship and soon Kapitza became Rutherford's deputy for magnetic investigations in the Cavendish Laboratory. On 12 October 1925 Petr Leonidovich was elected Fellow of Trinity College.

One of the main results of Kapitza's studies of the physical properties of matter in strong magnetic fields was the discovery, in 1928, of the linear dependence of the electric resistance of a number of metals on a magnetic field when this field is very high. This experiment and discovery preceded by 30 years the development of theoretical ideas on the nature of motion of electrons in metals, which have accounted for this unexpected anomaly. The anomaly is a consequence of the complex topological structure of the Fermi surfaces of metals.

Petr Leonidovich investigated the magnetostriction of paramagnetic and diamagnetic materials in strong magnetic fields and discovered an anomalously high magnetostriction of bismuth single crystals. He also discovered a very strong anisotropy of this magnetostriction: the application of a magnetic field along the trigonal axis causes elongation of bismuth in the direction of the field and compression if the field is applied perpendicular to this axis. Kapitza investigated also the Zeeman effect in strong magnetic fields and observed the Paschen–Back effect. The progress made by Petr Leonidovich in his studies of properties in very high magnetic fields bore fruit in the establishment of a special magnetic laboratory within the overall structure of the Cavendish Laboratory. It was inaugurated officially in 1926. The apparatus used to generate very high magnetic fields struck all physicists at the time by its grand scale and engineering perfection.

Beginning from 1926, Petr Leonidovich began to visit the Soviet Union regularly. He came with lectures and papers, and frequently spent his holidays on the shores of the Black Sea. In 1929 Kapitza was elected Corresponding Member of the USSR Academy of Sciences. In the same year he was elected Fellow of the Royal Society of London.

Investigations of the properties of metals in strong magnetic fields led Kapitza logically to the need to extend his investigations to the lowest possible temperatures. This determined, for many years, the work of P L Kapitza in the field of low-temperature physics and technology. Once again, he began with a critical review of the existing methods for reaching low temperatures.

At the time, the lowest temperatures had been obtained with the aid of liquid helium. Helium is liquefied in apparatus based on the Joule–Thomson effect, which is cooling of the gas when it is 'choked', i.e. passed through a nozzle where a large pressure drop occurs. The Joule–Thomson effect is related to the nonideal nature of real gases and leads to cooling only below a certain temperature known as the inversion temperature. The inversion temperature of helium is of the order of 50 K. Therefore, a helium liquefier based on the Joule–Thomson effect must have a preliminary stage of cooling of helium with liquid hydrogen.

Kapitza constructed apparatus for liquefaction of helium in which gaseous helium is cooled by doing external work in the course of adiabatic expansion of the gas in a special expander which is a piston engine. This method is optimal from the thermodynamic point of view and, by a large factor, more effective than the method based on the Joule–Thomson effect; moreover, it does not require preliminary cooling with liquid hydrogen. However, to do this it seemed necessary to tackle an insoluble problem, i.e. to find a lubrication material operating at such low temperatures. Petr Leonidovich used gaseous helium itself as a 'lubricant' by leaving a 35 μm gap between the walls of a piston and of a cylinder. Skewing and wedging of the piston was avoided by forming several annular channels in the piston, where the gas pressure on the cylinder wall became equalised. Kapitza constructed the first such liquefier in 1934 and practically all the liquefiers are now working on the basis of this principle. Liquefiers of this kind are now produced by many commercial firms in various countries at a rate of several hundred per year.

Rutherford actively supported the work of P L Kapitza in this new direction and obtained large subsidies as well as a new building for this task. This led to the establishment of the Mond Laboratory of the Royal Society in Cambridge for research on properties in strong magnetic fields and at low temperatures. Kapitza was appointed Director of this Laboratory, where he constructed his first helium liquefier.

1934 was a dramatic year in the life of Kapitza. Following the custom of previous years, he came in September to the Soviet Union to see his friends and to present lectures. He was summoned to the Council of People's Commissars and told he could not return to England. This upset and the interruption, for a considerable time, of the successfully developing research was a serious blow for Petr Leonidovich. Right to the end of 1934 his fate hung in the balance. In these sad years his acquaintances avoided close contact with him. Petr Leonidovich was unhappy in his loneliness and inability to do his favourite work, which was scientific experimentation. At the time he frequently met the outstanding physiologist I P Pavlov and discussed with him the feasibility of turning to biophysics at Pavlov's institute. However, in December 1934 there was a significant break in the life of Petr Leonidovich: first the leaders of the Academy of Sciences and then Deputy Chairman of the Council of People's

Commissars, V I Mezhlauk, met Kapitza and discussed his plan to found a new institute in Moscow for which equipment in the Mond Laboratory of Kapitza would be bought in England. As a result, the Council of People's Commissars resolved on 23 December 1934 to found the Institute of Physical Problems in Moscow. Kapitza was appointed Director of this Institute. He learnt about it from newspapers.

Petr Leonidovich began to work on the organisation and construction of this Institute. However, even in 1935, Petr Leonidovich lived in very difficult circumstances. He was separated from his family, he had no laboratory where he could experiment, and in the design and building of the Institute he met with a bureaucracy to which he was not accustomed. (In a letter to his wife he then wrote: "... Without this bureaucracy everything would have been simple and easy, but three-quarters of Muscovites would have been unemployed ...".) However, because of the unusual persistency of Petr Leonidovich, the construction of the laboratory building was finished (in one year!) at the end of 1935 and the equipment began to arrive from England. The equipment at the Institute, including the apparatus constructed by Petr Leonidovich to generate strong magnetic fields and to liquefy helium, was bought by the Soviet Government in England with the help of Rutherford.

In his new Institute, Kapitza continued investigations in strong magnetic fields and on low-temperature physics and technology. He obtained many particularly outstanding results on low temperatures over a period of two – three years from the end of construction of the Institute and installation of the equipment (1936).

Let us first consider the major engineering achievement of Petr Leonidovich. It is related to intensification of a whole range of industrial processes, particularly in metallurgy, by the use of oxygen. This has required the production of oxygen in large amounts, which would have been difficult to achieve in the then-used cryogenic installations in which air was separated by a high-pressure cycle. Low-productivity piston compressors have been used in such installations. In many branches of technology the transition to higher powers has involved replacement of piston engines with turbines. Petr Leonidovich put forward the idea of using turbines also in the liquefaction of air and extraction of oxygen from it. He designed, constructed, and tested a special radial expansion turbine designed for work in air liquefiers. This expansion turbine was very unusual. Kapitza showed that since the density of air increases strongly on cooling, the correct type of expansion turbine would be a compromise between water and steam turbines. The first expansion turbine constructed by Kapitza therefore had a rotor 8 cm in diameter and weighed only 250 g. It rotated at 40 000 rpm and produced a flow of air at a rate of up to $1000\,\mathrm{m^3\,h^{-1}}$. As in the history of magnetic fields and helium liquefiers, this was a quite unexpected solution and there were many sceptics. The achievement of such very fast stable rotation of the turbine rotor was itself a difficult technical task, which Petr Leonidovich performed in a strikingly successful manner. At the beginning of 1938 the first prototype low-pressure expansion turbine for the liquefaction of air began to work at the Institute of Physical Problems. Instead of a pressure of 200 bar, used in all the installations where the last cooling stage was based on the Joule – Thomson effect, the pressure in Kapitza's system was 9 bar. The prototype was capable of producing liquid air at a rate of $30\,\mathrm{kg\,h^{-1}}$. This prototype had a very short start-up time: only 20 min.

The success in constructing the expansion turbine installation enabled Petr Leonidovich to put a proposal to the Government for large-scale construction of such installations for the production of oxygen and wide use of oxygen in various branches of industry. His success in this direction was recognised by the State Prize awarded in 1941 for the work on "An expansion turbine for the attainment of low temperatures and its application in liquefaction of air". In spite of the wartime evacuation of his Institute to Kazan, Kapitza continued his work actively even under these very difficult conditions. A mobile air-separation system was constructed for the needs of aviation and fleet. When the Institute returned to Moscow, a new more productive installation (TK-200) was constructed and commissioned in 1943. A special administration was established attached to the Council of People's Commissars: it was called Glavkislorod (Main Administration of the Oxygen Industry), which was headed by Kapitza. Mastering of the industrial construction of expansion turbines began, although with great difficulty. In May 1945 an industrial air-separation installation at the Balashikha Oxygen Factory was commissioned. This, the largest at the time, installation produced liquid oxygen at a rate of $1300\,\mathrm{kg\,h^{-1}}$. Petr Leonidovich was awarded the Lenin Order in 1943 and the title of Hero of the Socialist Labour in 1945 for his outstanding achievements in the development of new industrial methods.

The factory for the manufacture of liquefiers constructed under the leadership of Kapitza served as a nucleus of a modern progressive scientific and production enterprise called Kriogenmash. A highly efficient radial expansion turbine with an efficiency of 80% – 85% developed by Kapitza was the forerunner of modern major low-pressure air-separation installations used to produce oxygen, developed around the world. The use of an expansion turbine in the production of gaseous oxygen from air saved our country hundreds of millions of roubles.

Large low-pressure air-separation installations capable of delivering from 10 000 to $65\,000\,\mathrm{m^3\,h^{-1}}$ of oxygen are working or are being built in the countries of the former Soviet Union. In industrialised countries of the West over $150 \times 10^6\,\mathrm{m^3}$ of oxygen is produced annually in low-pressure air-separation installations in which expansion turbines proposed by Kapitza are used. About half of the oxygen currently produced is utilised in ferrous and nonferrous metallurgy. Apart from metallurgy, oxygen is used extensively in the chemical industry and in rocket technology.

The work of Kapitza on very high magnetic fields and liquefiers has demonstrated a rare combination of a major scientist and a major engineer in one man. Petr Leonidovich was one of the first to use large modern technological equipment in the laboratory. At the same time he put the latest physics achievements to practical use. This was the beginning of the process, which is now being developed fully and is a characteristic feature of the modern scientific and technological revolution.

In the field of low-temperature physics, Kapitza began a series of exceptionally elegant and fine experiments on the anomalous properties of liquid helium. The first stage of this work was completed by Kapitza's discovery, in 1937, of

superfluidity of liquid helium at temperatures below 2.19 K. Kapitza called liquid helium a superfluid because, as he demonstrated, its viscosity during flow through thin capillaries and gaps is so much lower than the viscosity of the least viscous liquid that it should be regarded as zero. The next important stage in the study of the anomalous properties of liquid helium was an investigation of the propagation of a heat flux from a heater placed inside a closed container with helium.

This experiment was conducted as follows. A small glass bulb filled with liquid helium and containing an electric heater was used. The bulb terminated in a fine capillary through which it was connected to a surrounding Dewar container, also filled with liquid helium. In front of the end of this capillary there was a little vane attached to a light rod suspended by a thin filament. Petr Leonidovich discovered that when the heater was switched on, the rod with the vane was deflected, as if liquid flowed out of the bulb, although there was no visible motion of helium and the bulb remained filled with liquid helium. This demonstrated that two types of macroscopic motion with different properties took place simultaneously in helium: one motion was viscous and influenced a body placed in the stream and the other was nonviscous.

Petr Leonidovich next proposed that the part of the liquid moving in a nonviscous manner has a lower value of the thermal function (enthalpy) i.e. that this part of the liquid does not carry heat. This assumption enabled Petr Leonidovich to explain the experiment with the bulb. Switching on of the heater sets in motion the anomalous 'cold' part of the liquid which travels in a nonviscous manner to the heater, absorbs heat, and is converted to the 'normal' liquid, which is expelled from the bulb and exerts pressure on the vane.

The surprising results of Petr Leonidovich could not be explained on the basis of the then accepted ideas. They served as the basis of a new branch of physics, which is the physics of quantum liquids. A quantum theory of superfluidity was developed by L D Landau, working in close cooperation with Petr Leonidovich. This theory accounted fully for the experiments of Petr Leonidovich and confirmed the validity of his hypothesis of the existence of two parts or components of liquid helium with different properties. Quantum mechanics predicted an even more surprising result than that suggested by P L Kapitza. He assumed that the two types of motion of helium are separated in space. It has been found that the normal and anomalous components are apparently mixed and they counterpropagate throughout the whole mass of a liquid.

The discovery of superfluidity by Kapitza threw light also on the yet unexplained phenomenon of superconductivity. Superconductivity became regarded as superfluidity of the electron gas, which had a fruitful influence on the development of the theory of superconductivity. In this way Kapitza's experiments determined the developments in experimental and theoretical low-temperature physics for many years.

Investigations of heat transfer in liquid helium led Petr Leonidovich to the discovery of the following important effect: the transfer of heat from liquid helium to a solid creates a temperature jump at the interface. This is now known as the Kapitza jump. The magnitude of this jump rises very rapidly as temperature is lowered. An explanation of this apparently very classical transport phenomenon has also required a quantum approach. The Kapitza jump plays an important role in the task of attainment of temperatures of the order of or less than a few millikelvins.

In 1939 Petr Leonidovich was elected full member of the USSR Academy of Sciences for his success in the work on low-temperature physics and technology. He was awarded the State Prize in 1943 for studies of liquid helium.

In 1978 he received the physics Nobel Prize for his fundamental discoveries and inventions in low-temperature physics.

As mentioned above, aware of his inability to overcome bureaucracy and to ensure that an industrial expansion turbine installation would be constructed for the production of oxygen, Petr Leonidovich decided to head Glavkislorod himself. Many conservative-minded engineers and scientists, dealing with this problem within the traditional framework of piston engines, began a bureaucratic war against Kapitza. This war became fiercer when in October 1945 it was decided to merge two administrations: Glavkislorod and Glavavtogen (Main Administration of the Gas-Welding Industry). The former head of Glavavtogen, M K Sukov, began to speak actively against Kapitza. However, the main conflict arose between Kapitza and L P Beria in the Special Committee and Technical Council on the atomic bomb. Different versions of the causes of this conflict have been put forward. However, as a result of this sharp conflict, Petr Leonidovich wrote two letters (in October and November 1945) to I V Stalin, in which he made critical comments about L P Beria in connection with the decision to make Sukov the deputy to Kapitza in Glavkislorod. However, in his letter Kapitza concentrated mainly on the incorrect strategy of Beria on tackling the problem of building an atomic bomb.

The resultant sharp confrontation between Kapitza and Beria in August 1946 under the spurious pretext of an alleged 'low efficiency of the expansion turbine proposed by Kapitza and the consequent lag of the oxygen industry' ended with Kapitza being removed as the head of Glavkislorod and an unjust assessment of his oxygen production method. Kapitza was also removed from the post of Director of the Institute of Physical Problems and prevented from working at his institute. In those difficult years Petr Leonidovich showed great courage, organised a tiny domestic laboratory in his dacha, and carried out active research there. He began with a series of elegant studies of mechanics and hydrodynamics and in the late forties returned to a different field of physics, which was the construction of high-power continuously operating microwave oscillators.

Petr Leonidovich was able to solve the difficult mathematical problem of the motion of electrons in magnetron-type microwave oscillators. He used these calculations to construct two new types of a microwave oscillator: planotron and nigotron. The output power of the nigotron was a record at the time: 175 kW delivered continuously. In the course of his studies of these high-power oscillators, Kapitza encountered an unexpected phenomenon: when a helium-filled bulb was placed in a beam of electromagnetic waves emitted from an oscillator, a bright luminous discharge appeared in helium and the walls of the silica bulb melted. This led Petr Leonidovich to the idea that high-power electromagnetic oscillations could be used to heat a plasma to very high temperatures.

P L Kapitza and L D Landau at Nikolina Gora, 1948. Landau was one of the few who dared visit Petr Leonidovich at Nikolina Gora during the years that Kapitza was 'in disgrace'.

In 1955 Kapitza returned to the post of Director of the Institute of Physical Problems. The unjust accusations against him were officially expunged. However, on return to the Institute he did not go back to the work on low temperatures, interrupted in 1946, but continued his studies of high-power electronics and plasma physics begun at his dacha at Nikolina Gora. A new building was constructed specifically for this work and new young scientists were recruited: they formed the Physics Laboratory. As a result, the Institute split into two parts: the Low-Temperature and Physics Laboratories. Petr Leonidovich was greatly interested in the work done in the 'first half' on low temperatures, but with few exceptions he did not interfere, did not participate, and was not the coauthor of the papers on low temperatures, apart from the few occasions dealing with the improvements in gas liquefiers.

In the Physics Laboratory he built apparatus to generate a continuous hf discharge. This was done by connecting a nigotron to a chamber acting as a resonator cavity for microwave oscillations. When this chamber was filled with gases (helium, hydrogen, or deuterium) under a pressure of the order of 20 bar, Petr Leonidovich discovered that a filamentary discharge appeared at the centre of the chamber where the density of the electric component of the microwave oscillations was maximal.

Kapitza devoted the last 20 years of his life to detailed studies of filamentary discharges. Elegant methods for plasma diagnostics in a filamentary discharge were developed under his leadership and comprehensive investigations were made of the physical properties of such a discharge. Petr Leonidovich was of the opinion that an increase in the gas pressure and dimensions of the plasma filament should make it possible to produce a plasma in which the ion temperature will be sufficiently high to ignite a thermonuclear reaction. In spite of his advanced age, Kapitza worked in this field with surprising enthusiasm. His death on 8 April 1984 terminated this research and left open the possibility of constructing a thermonuclear reactor based on this approach.

In summarising the creative path of P L Kapitza, it is necessary to stress the characteristic features of the Kapitza style in science and technology.

Above all, Petr Leonidovich was an innovator, a man who always sought new ways and new solutions. His nonstandard thinking was so advanced that the majority were unable to understand his ways.

An important characteristic of the scientific creativity of Petr Leonidovich was a rare combination of major scientific and engineering skills in one person. This enabled him to find unexpected engineering solutions in the course of fundamental scientific research. On the other hand, a deep scientific analysis of industrial installations helped to solve complex engineering problems.

The development of complex and original engineering structures by Petr Leonidovich was combined with the development of intricate laboratory instruments in which the smallest components he frequently made himself. One of his passions was the repair of old clocks. At home, in the study of Petr Leonidovich, there was a tiny lathe and a set of tools for fine work. Sometimes he made even larger items

With P A M Dirac, a close friend of Kapitza from 1923. The photograph was taken in 1973 after Dirac's lecture at a seminar at the Institute of Physical Problems.

at home: with the help of his sons, he constructed two boats at his dacha.

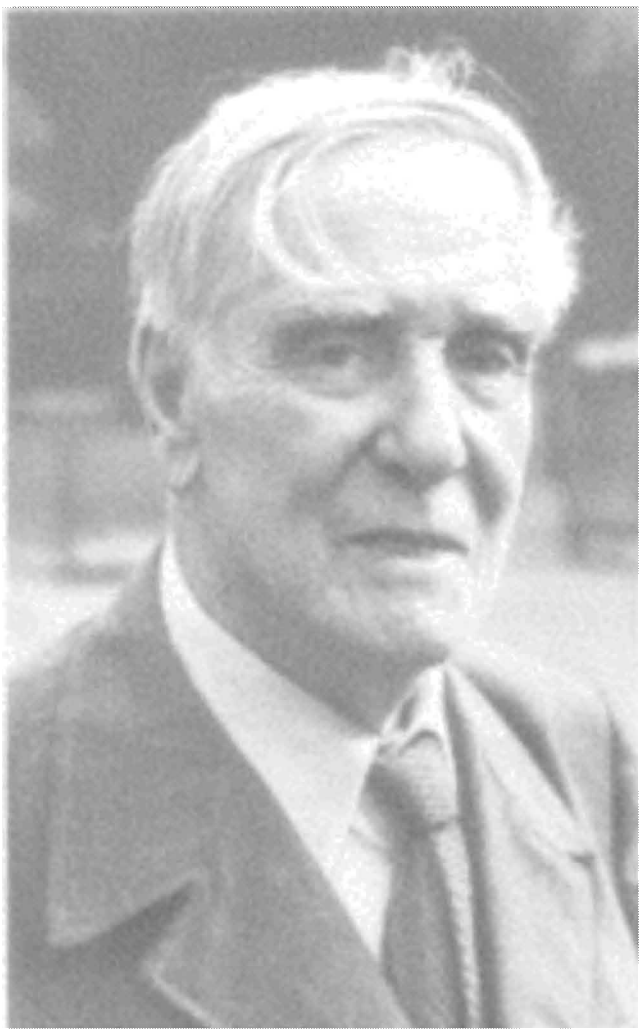
In his scientific research Petr Leonidovich stressed the importance of experiments. In comparing the role of theory and experiment he liked to repeat the words of a heroine of an American novel: "Love is beautiful, but a gold bracelet is forever". An experiment should always be designed in such a way as to lead to the discovery of new facts, which can be used to draw conclusions independent of the current theoretical ideas. The work which gives results contradicting current thinking is particularly valuable. Experimental work simply confirming the existing theoretical predictions was jokingly called 'battening down' by Petr Leonidovich. The foundation of a successful experiment is the development of original apparatus which can be used to observe physical phenomena under new conditions.

One of the criteria of the significance of scientific and technical discoveries is the period for which they remain useful. The main results of the 70 years of the scientific work of P L Kapitza are still alive. His pulsed method of creating very high magnetic fields, the expansion-type helium liquefier, and the expansion turbine installation for the production of oxygen have not become obsolete in the last 40–60 years, but — just the reverse — are with each passing year being used more extensively in science and technology. This is not a frequent phenomenon in our age of rapid growth of technology. This comment applies also to the scientific discoveries of P L Kapitza. It has been mentioned already that the linear dependence of the resistance of metals on the magnetic field has for 30 years determined the development of the theoretical ideas needed to account for it. A new branch of physics, quantum physics of the condensed state, which has appeared with the discovery of superfluidity, is continuing to develop rapidly even now 55 years after the first work of Petr Leonidovich.

Petr Leonidovich Kapitza was not only an outstanding scientist, but a major science organiser. He founded an excellent physics research institute, led this institute, and created there exceptionally favourable conditions for scientific creativity.

Petr Leonidovich took very seriously the task of organisation of scientific work at the Institute of Physical Problems. He devoted a special paper to this subject (which can be found in the collection of Kapitza's work entitled *Experiment, Theory, Practice*). Kapitza regarded as his main target the creation of a small team of people with great creative talents and approaching their work in a creative manner. He thought that this nucleus should be supplemented by collaborators on a temporary assignment (undergraduate and postgraduate students, those preparing for a doctorate, and scientists assigned from other laboratories), who would learn by experience at the Institute and spread their experience to other establishments.

Kapitza treated very seriously the selection of staff for the Institute, both scientific and technical, permanent and temporary. Petr Leonidovich had a firm rule to meet personally each new man and woman arriving to work at the Institute, irrespective of the function he or she were to perform. Kapitza selected good young people, good specialists, and good in the moral sense. The result was



P L Kapitza in 1982.

the assembly of a very good team of both scientific workers and technical personnel at the Institute.

In this connection it is worth mentioning the relationship between Petr Leonidovich and the Party Committee. At many institutes such committees carried out the general policy of encouragement of people for their law-abiding and strict following of the political line of the Party. With this in mind, rules were established according to which the Party Committee had to approve the defence of a doctoral thesis, signatures of the staff were collected under protest against A D Sakharov and other defenders of the law, and not all the staff were given an opportunity to travel abroad. All this was in conflict with the ideas of Petr Leonidovich about the rights of the people working at the Institute and, in view of his strong personality, he was able to put the Party Committee in its place and he forced them to judge everybody in accordance with their merit (scientific, industrial, or management, depending on their duties). He had been able to oppose also the Regional Party Committee, if this Committee tried to take some thoughtless measures. When conflict arose, P L Kapitza was not afraid to telephone the top people — Khrushchev, Brezhnev, Andropov — and convince them that he was right. For this reason the lower functionaries were afraid to come into conflict with Kapitza. As a result, morale at the Institute was much healthier than at many other establishments and this helped greatly in creative activity.

An important role in the life of the Institute was played by scientific seminars. These seminars were a continuation of the 'Kapitza Club' established by Petr Leonidovich back in 1922 in Cambridge (this Club was in turn a continuation of A F Ioffe's seminars). At these seminars it was permissible to interrupt the lecturer and all types of scientific discussion were encouraged. These seminars attracted scientists from the whole of Moscow, who were affectionately dubbed 'kapichniks'. The seminar room was frequently overflowing. Kapitza was able to select the lecturers very well, who could sometimes be of major calibre and on other occasions a young person. If the lecturer began to talk and it was obvious that the audience were not interested, Petr Leonidovich was capable of redirecting the lecturer by two or three questions. Naturally, everybody was keen to hear Kapitza's concluding remarks. This could be just one phrase, but it meant very much to the lecturer and the audience.

Petr Leonidovich was a member of the Presidium of the Academy of Sciences of the USSR and the editor of the leading physics journal of our country *Zhurnal Eksperimental'noi i Teoreticheskoi Fiziki*. As in scientific work, so in the actual scientific organisational activity, he was an innovator fighting against the bureaucratic methods of leadership and seeking the most progressive methods for the management of such a fine mechanism as a team of creative scientists. P L Kapitza frequently spoke at general meetings of the Academy of Sciences and at those of the Presidium about the problems relating to the organisation of research and always drew attention to the importance of leadership in science. He stressed the greater merit of the discoverers in fundamental sciences, compared with those for moving along existing grooves.

The problem of organisation of science is closely related to that of creative training of young scientists which Petr Leonidovich regarded as of very great importance. He was one of the founders of the Moscow Physicotechnical Institute. The students from this Institute spend a large part of their study at the leading physical and physicotechnical research laboratories of the country. The theses of the students working at the Institute of Physical Problems were defended at meetings always chaired by Petr Leonidovich. This was an examination not only of the student, but also of his supervisor. At the entry examinations for postgraduate studies at the Institute, which were always conducted by Petr Leonidovich, he thought up every year four new problems. A special feature of these problems was that they had no standard solutions. These problems always dealt with a specific physical experiment or phenomenon. In the course of the solution of the problem the examinee should analyse what interactions and effects are important in a given phenomenon and which can be ignored. The discussion of possible solutions of these problems would continue for several days after the examination with the participation not only of postgraduate students, but also of the leading members of the Institute. Petr Leonidovich often repeated that young disciples of a mature scientist were an essential condition for "ensuring continuation of boldness and interest in all that is new and leading in science".

Petr Leonidovich Kapitza was not only an outstanding scientist and science organiser, he was also a major activist

in social affairs. He was strongly moved by all aspects of the future of mankind. He was a member of the Soviet National Committee of the Pugwash Movement of the scientists supporting peace and disarmament, and he actively participated in this Movement. He frequently spoke on the future of mankind, particularly in relation to such urgent problems as disarmament, pollution of the environment, and energy crisis.

In his social activities P L Kapitza actively responded to all events in the life of the society and particularly in the life of scientists and artists. It is well known that the intervention of Petr Leonidovich caused the release of V A Fock and L D Landau from prison. At the time such interventions required major personal courage and equally a great skill in talking to the top levels of the Government. Petr Leonidovich also defended A D Sakharov, Yu F Orlov, and many others. Equally important in the life of our society were Kapitza's interventions on purely scientific subjects. The striking example in this respect was the active support of E K Zavoiskii by Petr Leonidovich when many authoritative physicists could not understand or recognise the work of Evgenii Konstantinovich who discovered electron paramagnetic resonance. Petr Leonidovich regarded it as his duty to support all the innovators in science, knowing from his own experience that very new ideas are very rarely supported by colleagues.

The Government had a high regard for the work of P L Kapitza: he received the order of the Red Labour Banner, six Lenin Orders, and was twice given the title of Hero of the Socialist Labour. His work was twice recognised by the State Prize.

Petr Leonidovich was held in high regard internationally. He was a Nobel laureate, a member of about thirty academies and scientific societies throughout the world. Over ten universities of different countries gave him an honorary doctorate. Many scientific societies and universities recognised his scientific achievements with their own awards.

This brief account of the life of P L Kapitza should be concluded by stressing once again the main features of his character. The most striking feature was the absolutely nonstandard way of thinking in approaching the solution of scientific, organisational, and ordinary life problems. The result has been that, during his lifetime, he became a legend and his thoughts were passed on by word of mouth. Petr Leonidovich regarded concrete experiments as his life's work. This attitude he retained right up to the last days of his life, spending a major part of his working hours in the laboratory.

The firmness and courage he displayed in life were very important. A strong will and purposefulness helped him to overcome many of life's obstacles. The high standard he set for himself and those around him were combined with an exceptional consideration and kindness. Petr Leonidovich helped energetically and boldly very many people at difficult moments in their life. Finally, he had a strong sense of humour.

The very interesting life of that remarkable man Kapitza still awaits its own biography.