Nobel Prize awarded to P. L. Kapitsa

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Academician Petr Leonidovich Kapitsa was awarded the 1978 Nobel Prize for physics in recognition of his fundamental inventions and discoveries in low-temperature physics.

The inventions and discoveries to which the citation by the Nobel Committee refers were made by P.L. Kapitsa largely in the 1930's.

Academician Kapitsa successfully combines the talents of a scientist with the ingenuity of an engineer. It was, in fact, his engineering work at low temperatures that led to the development of the gas-expansion machine for the liquefaction of helium and of low-pressure equipment for the industrial production of oxygen.

He developed a new helium liquifier in the early 1930's while working at the Cavendish Laboratory. The installations that had been used for helium liquefaction prior to this were based on the Joule-Thomson effect which was due to the departure of real gases from the properties of the perfect gas. In the case of helium, this produced cooling only at temperatures below 50 °K, so that preliminary cooling of the gas well below this temperature was necessary in the old liquefiers. Liquid helium was used for this purpose, which substantially complicated the design and reduced the efficiency of the liquefiers. Petr Leonidovich proposed the thermodynamically most advantageous method for cooling helium in which adiabatic expansion of the gas accompanied by external work was employed. It was essential to find a lubricant for the piston gas-expansion machine that would work at helium temperature. Petr Leonidovich suggested the use of the gaseous helium itself as the lubricant. Several grooves were used on the piston of the gas-expansion machine to equalize the pressure over the periphery of the piston and thus prevent its misalignment and wedging.

The first such liquefier was built by Kapitsa in 1934 and produced 2 liters per hour. For a long time, it was used only in his laboratory. It was not until the 1950's that initially one and then several other companies began manufacturing helium liquefiers using the gas-expansion machine. All helium liquefiers now being manufactured are based on the principle proposed by P. L. Kapitsa. Some of them are capable of producing several hundred liters of liquid helium per hour.

The second fundamental engineering achievement of Petr Leonidovich in the field of low temperatures was concerned with the industrial production of oxygen. The end of the 1930's saw the emergence of the problem of using oxygen for the intensification of many manufacturing processes, and it became necessary to develop equipment for the efficient separation of atmospheric components (as a way of producing oxygen). P. L. Kapitsa developed a new method for liquefying air, based on a low-pressure cycle. The use of low pressures made it possible to replace the relatively inefficient piston machines in the old equipment with turbocompressors and turbo-expansion machines.

His design of the turbo-expansion machine was based on an original idea in which he used the fact that, because of its high compressibility at low temperatures, the properties of air were closer to that of a liquid than of a gas. The highly efficient radial turbo-expansion machine which he developed was more similar to a hydroturbine than a gas turbine. This turbo-expansion machine was the starting point for the world-wide development of major installations for the extraction of oxygen from air. The introduction of the turbo-expansion machine in our country resulted in the saving of hundreds of millions of roubles.

We note in connection with our review of the engineering achievements of Petr Leonidovich that his views and ideas were always well ahead of time. Both the above liquefier designs, and his early ideas on the production of pulsed magnetic fields and the utilization of magnetic fields in combination with Wilson cloud chambers, found extensive application in laboratories and industry only 10–15 years later. A still more striking fact is that his solutions have survived for 30–40 years and are still being used.

The fundamental discovery of Academician Kapitsa in low-temperature physics is the discovery of the superfluidity of liquid helium. This was the culmination of research performed by Petr Leonidovich in the second half of the 1930's which were begun with the aim of elucidating the "superthermal conductivity" of helium II in the case of heat transfer through thin capillaries, which had been discovered earlier by the Dutch physicist Keesom and his daughter.[1)]

P.L. Kapitsa suggested that the "superthermal con-

[1)]Liquid helium exists under saturated vapor pressure in two states: above the lambda point ($T_\lambda = 2.19$ °K), the state is referred to as helium I and its properties are not very different from the properties of ordinary liquids. Below T_λ, helium is found in a state referred to as helium II, which exhibits many anomalous properties. From now on, we shall be exclusively concerned with helium II but, for the sake of brevity, we shall refer to it simply as helium.

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ductivity" was not true molecular thermal conductivity but the result of *convective* transfer of heat. This implied that the viscosity of helium had to be very low. Measurements of very low viscosities are very difficult to perform, since experimental uncertainties lead to results that are too high. Petr Leonidovich constructed an original viscometer in which helium was allowed to flow through a thin annular gap (of the order of half a micron). Experiments with this viscometer led to the discovery of the surprising fact that the viscosity of helium was, at any rate, much lower than the viscosity of the least viscous known materials. This was used by Petr Leonidovich as a basis for suggesting that the viscosity of liquid helium was, in fact, simply zero. He referred to this as superfluidity. This first stage of research into the anomalous properties of liquid helium was completed in 1937 [Dokl. Akad. Nauk SSR 18, 21 (1938) and Nature (1938)].

Further studies of heat transfer in thin capillaries led P.L. Kapitsa to the conclusion that, although helium had zero viscosity, its enormous thermal conductivity could not be explained simply in terms of convection, since this mechanism involved unjustifiably high rates of convective motion. Having performed a number of different exploratory experiments, Petr Leonidovich proposed the classic decisive experiment on the outflow of the "normal" component of helium from a closed bulb. The experiment was performed as follows. An electric heater was placed in a glass bulb completely filled with liquid helium. The bulb was connected through a thin horizontal capillary to a surrounding dewar which was also filled with liquid helium. A small lid was placed in front of the end of the capillary and was attached to a light beam hung on a thin suspension. Petr Leonidovich discovered that, when the heater was turned on, the beam carrying the lid was deflected as if a flow of fluid was issuing from the bulb although no motion was observed visually in the helium and the bulb remained completely filled with the liquid helium. This meant that two macroscopic motions with different properties occurred simultaneously in the liquid helium. One of them was subject of viscosity and affected the body suspended in the flow, and the other, the superfluid motion, had no effect on the body. Petr Leonidovich then suggested that the part of the liquid that moved without viscosity had lower enthalpy than the normal part (he established, as a result of a subsequent experiment, that the enthalpy of the superfluid part was zero). Having made this suggestion, P. L. Kapitsa explained the above experimental result as follows. When the heater was turned on, the superfluid "cold" part of the liquid tended to flow toward it without friction. As it absorbed heat, it was converted into the "normal" liquid and was expelled from the bulb, thus exerting pressure on the lid. In a subsequent experiment, Petr Leonidovich attached the bulb itself to the beam and demonstrated that the outflow of the "normal liquid produces a reactive force, whereas the inflow of the anomalous part does not produce this force." The result of this was that, when the heater was turned on, the beam carrying the bulb was deflected. This suprising behavior of liquid helium could not be explained within the framework of the existing classical ideas on the hydrodynamics of liquids. Quantum mechanics had to be used to provide the explanation. In fact, the quantum-mechanical theory of superfluidity was developed by L. D. Landau, who worked in close cooperation with Petr Leonidovich. This theory gave a complete explanation of the experiments of Petr Leonidovich and confirmed the validity of his assumption that liquid helium consisted of two parts (components) with different properties. In addition, quantum mechanics predicted a still more unexpected result than P.L. Kapitsa was able to put forward. He assumed that the two motions of helium were separated in space. In fact, it turned out that the normal and anomalous components coexisted within the same volume and their opposite motion occurred throughout the mass of the liquid.

P. L. Kapitsa thus not only made one of the surprising discoveries of our age, but also laid the foundations of a new branch of physics, namely, the physics of quantum-mechanical fluids. The experiments performed by P. L. Kapitsa determined the development of experimental low-temperature physics for many years. The volume of work performed as a result of his initial experiments is so great that it is difficult to estimate even approximately. Moreover, in order to explain the phenomena thus discovered, it was necessary to reexamine many of the existing theoretical ideas. This has led to the introduction of the idea of elementary excitations which are now used to describe the energy spectra of macroscopic bodies. P. L. Kapitsa's discovery also contributed to the elucidation of the phenomenon of superconductivity which could not be explained at the time but which was eventually interpreted as the superfluidity of the electron gas and this, in turn, had a very fruitful influence on the development of the theory of superconductivity.

In the ensuing years, it became clear that liquid helium was not the only superfluid material. Thus, the superfluidity of nuclear matter is important for nuclear physics and there are reasons to suppose that neutron stars are superfluid objects. The superfluidity of He^3 has recently been discovered.

P. L. Kapitsa does not like to spend too much time on a particular problem. He is currently interested in phenomena occurring in hot plasmas. All his friends and colleagues congratulate Petr Leonidovich on the award to him of the Nobel Prize and wish him further success in his new researches and all the best for the future.

Translated by S. Chomet