LEV DAVYDOVICH LANDAU

WINNER OF THE SECOND FRITZ LONDON AWARD

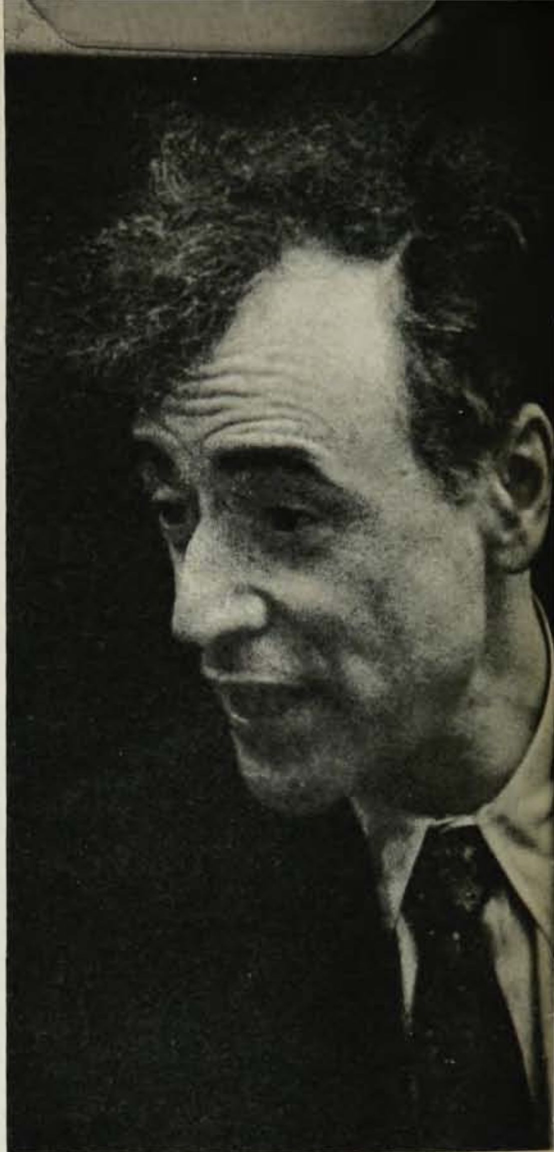


Photo by L. Alvarez

An address presented at the 7th International Conference on Low Temperature Physics (Toronto, Aug. 29 to Sept. 3, 1960) on the occasion of the 2nd Fritz London Award ceremony. Dr. Landau was unable to attend.

By *J. R. Pellam*

I HAVE been asked by the Committee for the Second Fritz London Award to give an account of the life and work of this eminent recipient of the Award, Lev Davydovich Landau. I was very honored that I had been asked to undertake this task but felt rather overwhelmed by the responsibility it entailed. Because Landau has contributed to so many fields of physics, an award could have been made to him at any one of several conferences in any one of several fields. The main problem, I found, was to limit myself primarily to Landau's work in the field of low-temperature physics for which this Award is made. My own work in this field has been so strongly influenced by these significant contributions that I, like so many of us similarly influenced, feel that I do know him, although I have never met him personally.

A considerable wealth of material is available describing Landau's work in the many fields of physics to which he has contributed. The following outline of Landau's career is drawn from two articles [1, 2] published in Soviet scientific journals commemorating his fiftieth birthday, which he kindly arranged to have fall two years before winning the Fritz London Award.

Lev Davydovich Landau was born on January 22, 1908, in Baku, the capital of Azerbaijan on the Caspian Sea. His father was an engineer; his mother a doctor. His mathematical talents were apparent at a very early age and he can scarcely remember not being able to differentiate and integrate. At the age of fourteen he entered Baku University, from which he transferred two years later to the University of Leningrad, where he completed his studies in 1927 at the age of nineteen. Scientific writing did not await the completion of his studies, however, for he published twice during each of his last two school years. He developed an active interest in the new science of quantum mechanics, and at the age of nineteen introduced the concept of the density matrix for energy which is now so widely used in

John R. Pellam is professor of physics at the California Institute of Technology, Pasadena, Calif.

[1] Soviet Physics—JETP **7**, 1 (1958).
[2] Uspekhi Fizicheskikh Nauk **64**, 616 (1958).

quantum mechanics. His active scientific research career began in the Leningrad Physicotechnical Institute where he stayed from 1927 to 1929, working on the theory of the magnetic electron and on quantum electrodynamics. In 1929 he was sent abroad and spent a year and a half as guest of the Danes, the Germans, the Swiss, the Dutch, and the English. Of particular importance to Landau's development was his work at the Institute in Copenhagen during this period, and he considers himself a student of Niels Bohr. (At Bohr's invitation, Landau was in Copenhagen again in 1933 and in 1934, participating in theoretical conferences.)

SOME measure of his personality can be gained by the following quotations from letters which I have received from two physicists associated with Landau during this period. The first is from Professor Niels Bohr, his teacher:

> It is a great pleasure indeed to learn that the Fritz London Award will be presented to Landau. Of course we all here share in the appreciation of Landau's great work and have vivid remembrances from the time about thirty years ago when he joined our group in Copenhagen. From the very beginning we got a deep impression of his power to penetrate into the root of physical problems and his strong views on all aspects of human life, which gave rise to many discussions. In the booklet which was published at my seventieth birthday, Rosenfeld has given a vivid picture of the stir at the Institute caused by the paper of Landau and Peierls on the measurability of field quantities, which eventually gave rise to a long treatise by Rosenfeld and myself. Also from our visits to Russia before the war my wife and I have many treasured remembrances of Landau's personal attachment and his striving for promoting mathematical physical research in Russia, in which he since has had so great success. In the years after the war we have constantly hoped to see Landau here again, but so far he has not been able to come. However, my son Aage and several of the other members of the Institute have, on visits to Russia, met and spoken with Landau and not only learned about the admiration in which he naturally is held by his colleagues, but in him found the same warm and enthusiastic personality, which we all here hold in so deep affection.

The other letter is from Professor Edward Teller, a contemporary of Landau:

> I met Landau in Leipzig in 1930 and later I spent some time with him in Copenhagen in 1934. My most vivid visual memory of him is the red coat he wore in Copenhagen. Mrs. Bohr teased him that he was wearing precisely the correct outfit for a postman. You will understand the somewhat strange circumstances that I would have forgotten about the red coats of the Copenhagen postmen except for this incident. I liked Landau very much and learned from him a great deal of physics. He enjoyed making statements calculated to shock members of the bourgeois society. While we were both in Copenhagen I married. He approved of my choice (and played tennis with my wife). He also asked both of us how long we intended to stay married. When we told him that our plans were definitely for a rather long duration and, in fact, we had given no thought to terminating the marriage, he expressed most strong disapproval and argued that only a capitalistic society could induce its members to spoil a basically good thing by exaggerating it to this extent. In Copenhagen Landau had many arguments with James Franck about religion. He considered his religious belief incredibly outmoded for a scientist and expressed himself in immoderate terms both in the presence and absence of Franck. Franck always laughed at him. It was very nice that when Landau left Copenhagen he made a very special point to say good-bye to Franck. It was quite clear that if he meant what he said about Franck, he did mean it in rather a peculiar way and, in fact, he meant perhaps the opposite of what he said.
>
> I continue to have a great deal of affection for Landau and I am glad that he is getting the Fritz London Award; he fully deserves it.

One should remember that Landau was very young at this time; he may have mellowed some since.

During this period abroad there occurred the first step which represented a transition of his interests and was destined to confront him with the major problems of low-temperature physics. The interesting pattern which had dominated his previous work provided the ammunition for tackling new problems. This became a cumulative process. At the age of 22 he developed the theory of "Landau diamagnetism" of metals, showing that a degenerate ideal electron gas possessed a diamagnetic susceptibility equal to $\frac{1}{3}$ the paramagnetic susceptibility. Some years later (1937–38) this led to the explanation of the de Haas-van Alphen effect. In this very case of diamagnetism, the proficiency which in his early years Landau had developed in manipulating Fermi systems has been basic to his latest theory predicting "zero sound" in liquid helium-3, involving distortions of the Fermi surface. Landau's ease of handling this situation is quite understandable considering the mastery of Fermi systems which he gained thirty years earlier.

HIS return to Leningrad was of short duration, for at the age of 24 he went to Kharkov to head the theoretical section of the Physicotechnical Institute (1932–37), where versatility both in achievement and outlook began to appear. His publications during the first year at Kharkov range from a paper "On the Theory of Stars" to a paper "On the Theory of Energy Transfer in Collisions". The latter characterizes a Landau specialty: the solution of difficult theoretical problems by brilliant mathematical flank attacks. The same methods have held him in good stead—his mastery of collision problems reached a peak in 1949 when he considered roton-roton and roton-phonon collisions (with Khalatnikov) to predict (correctly) the attenuation of second-sound waves.

Landau's convictions that independent creative work in any field of theoretical physics must begin with a sufficiently deep mastery of all its branches took root at Kharkov, where he developed the special program widely known among his physics students as the "theoretical minimum". Here also he began to accumulate a following among students, of whom the best known in low-temperature physics include Lifshitz and Pomeranchuk. His versatility is illustrated by quoting the titles of the papers which he wrote during his last two years at Kharkov:

> Theory of Photo-emf in Semiconductors, Theory of Monomolecular Reactions, Theory of Sound Dispersion (with E. Teller), Kinetic Equation of the Coulomb Effect, Properties of Metals at Very Low Temperatures, Scattering of Light by Light, Theory of Phase Transitions.

All these were published in 1935. In 1936 he published:

> The Kinetic Equation for the Case of Coulomb Interaction, Absorption of Sound in Solids, Theory of Phase Transitions, Theory of Superconductivity, Statistical Model of Nuclei, Scattering of X-Rays by Crystals Near the Curie Point, Scattering of X-Rays by Crystals with Variable Structure, Origin of Stellar Energy.

Of deeper consequence to the field of low-temperature physics, however, was a direction of interest which he developed at Kharkov and continued after moving to Moscow, during the organization of the P. L. Kapitza Institute for Physical Problems. Landau's attention to diamagnetism proved transitional between quantum mechanics and the theory of metals. Besides explaining the de Haas-van Alphen effect, Landau's applications of thermodynamics to electronic systems at low temperatures included the following:

1. He introduced the concept of antiferromagnetic ordering as a new thermodynamic phase;
2. He developed the thermodynamic theory of magnetic domains (with Lifshitz), providing a foundation for theories of magnetic permeability and resonance of ferromagnetics;
3. He studied phase transitions and determined the profound relation between transitions of the second order and variation of symmetry of the system. He gave a detailed thermodynamic theory of the behavior of systems near the transition point;
4. He studied the intermediate state of superconductors and proposed a theory of laminar structure of superconductors.

Also during this Kharkov period, Landau started the series of now well-known monographs on theoretical physics.

It was only natural upon his arrival at Moscow in 1937, where he was appointed head of the theoretical section of the Institute for Physical Problems, that his interests turned to the subject of superfluidity which was then being investigated experimentally by Kapitza himself. This marks an all-out assault by Landau on pure low-temperature physics, and under his attack the major problem of the nature of the helium II phase of liquid helium-4 soon withered. This work was close to the well-known interests of Fritz London, who solved the problem using another approach. The crux of Landau's cracking the helium problem (published in 1941) was his ability to deduce semiempirically the energy spectrum[3] of the Bose excitations in this liquid. The shape of the now well-known curve of energy versus momentum for such quasi-particles included a valley occurring at an energy height (equivalent kT) of $8-10$ °K. Such a spectrum permitted these quasi-particles to exist in equilibrium at this level, and these, following a suggestion by I. Tamm, Landau named "rotons". The energy gap, Δ, inherent to these rotons, permits the existence of superfluidity.

As a consequence of Landau's interpretation of superfluidity, he was able to predict independently the existence of the "second-sound" mode of wave propagation in liquid helium II (independently, because Tisza somewhat earlier had predicted second sound on the basis of Fritz London's approach).

Two aspects of Landau's manner of handling the second-sound problem are particularly noteworthy, in that they may also bear on his most recent predictions of "zero sound" in liquid helium-3:

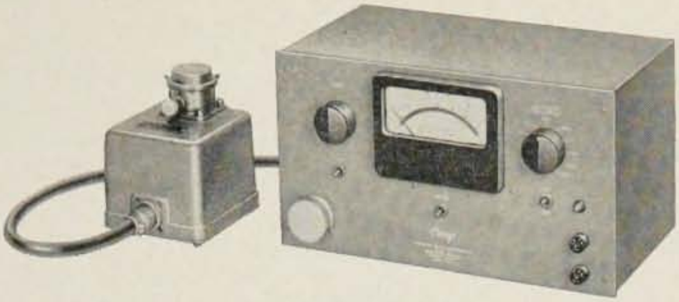
1. Landau's presentation shows certain detachment from the problems of experimental generation and detection of second sound. Early efforts by Shalnikov and Sokolov before the war were unrewarding because they attempted to detect second sound using standard acoustical methods. In fact, the problem was clarified by a subsequent publication by Lifshitz, who pointed out the essential thermal nature of second sound. On the basis of this prescription, Peshkov observed second sound experimentally in 1944.

2. In the same 1941 paper, Landau correctly predicted the magnitude of the velocity of second sound in the vicinity of absolute zero as $c_1/\sqrt{3}$, where c_1 is velocity of ordinary sound. He produced this result only after complicated mathematical acrobatics, and one wonders how much faith could possibly be placed in such a conclusion. Landau's own faith in his result was eloquently expressed, in a 1949 Letter to the Editor of *The Physical Review* defending his theory:

> . . . I have no doubt whatever that at temperatures of $1.0-1.1$ °K the second-sound velocity will have a minimum and will increase with the further decrease in temperature. This follows from the thermodynamic quantities in helium II calculated by me.

Who could be so certain? This clearly demonstrates Landau's extraordinary physical intuition. Despite the intricate mathematics he recognized the situation at absolute zero, not as an extrapolation, but as an end position for buttressing the results. Thermodynamic complications dissolved as $T \rightarrow 0$ °K. With only phonons of first sound present, the root-mean-square velocity component along any particular propagation direction of any more subtle propagation could occur only $1/\sqrt{3}$ as fast. This was perhaps Landau's ace-in-the-hole and private little joke besides. We will later

[3] A purely quantum-mechanical derivation of this spectrum has been achieved recently by Feynman.



MODEL 31

Detects currents to 10^{-17} ampere. Provided with ten ranges, separate input-preamplifier unit.

Cary®

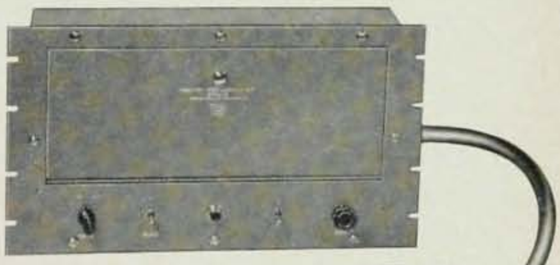
VIBRATING REED
ELECTROMETERS

MODEL 32

Designed specially for radioisotope studies. Single-unit design, provided with four ranges.

Outstanding instruments for precise, reliable measurement of extremely small charges, currents and voltages.

Several models are available to serve a variety of applications including radioisotope assays, ion current measurements, pH determinations, and solid-state studies.



MODEL 36

Offers exceptional response, DC to 10 cps, sensitivity and stability for small currents to 10^{-15} ampere originating in a high impedance source.

Cary® INSTRUMENTS

APPLIED PHYSICS CORPORATION
2724 South Peck Road, Monrovia, California

recall these two facets in connection with the theory of "zero sound" in liquid helium-3, and how they may bear on this subject.

IT is quite out of the question to consider all aspects of Landau's accomplishments. Typical of his versatility is a series of five papers published in 1945 concerning shock waves at large distances from their place of origin, and related subjects. (This work was carried out under the Engineering Committee of the Red Army.) Then, in 1946, papers appeared on oscillations of plasmas, which, it is stated, "received specially large notice recently in connection with the study of the properties of plasmas". A large amount of work in this field has been carried out recently by a group under A. E. Akhasier in Kharkov.

During the late 1940's Landau devoted his efforts to a whole gamut of activities. Efforts in the field of low-temperature physics consisted primarily of further applications of his spectrum of excitations in liquid helium to examining various kinetic processes. This included viscosity, thermal conductivity, and attenuation of second-sound waves (with Khalatnikov). In recent years his efforts have included a series of papers (with A. A. Abrikosov and M. I. Khalatnikov) on quantum electrodynamics. During the period when nonconservation of parity in weak interactions had been proposed by Lee and Yang, but before experimental verification, Landau proposed the hypothesis of the *conservation of combined parity*. He transferred his attention to the fact that nonconservation of parity does not, without fail, require violation of the properties of symmetry of space, if it is assumed that also <charge conjugation> is not conserved simultaneously but the product of these quantities, named by him "combined parity", is conserved. This puts definite restrictions on the general hypothesis of conservation of parity. He predicted the polarization of the neutrino, as did Lee and Yang, who did not however connect it with the principle of combined parity. He also discussed the polarization of β particles.

The theory of "zero sound" in liquid helium-3 may quite possibly develop into Landau's greatest contribution to low-temperature physics. This combines Landau's talents in the fields of diamagnetism and of the properties of quantum liquids. Essentially it is a treatment of oscillations of the surface of the Fermi sea, and Landau is quite at home navigating waves on the Fermi sea.

As in his successful approach to the helium-4 problem, Landau considers not the individual particle motion, but instead the collective motion of particles, i.e., the "elementary excitations" or quasi-particles. Also, as in the case of his second-sound predictions, the precise nature of "zero sound" in the sense of the experimental techniques for generation or detection is not discussed; at least, this is the case for the experimentalist who is speaking! The ubiquitous $\sqrt{3}$ shows itself again, and, as before, I feel sure that it carries more physical significance than the limiting form of a complicated formula. But here the velocity of "zero sound" equals the velocity (c_1) *times* $\sqrt{3}$, rather than (c_1) *divided by* $\sqrt{3}$. Probably this is the key to the reason Landau has named this mode of propagation "zero sound" rather than "third sound", for example. It evidently represents [4] a turning back of the crank to arrive at an even more elementary excitation than first sound!

The scientific accomplishments of Lev Davydovich Landau have received due recognition within his own country. In 1946 he was elected an active member of the Academy of Sciences of the USSR. He has been awarded the Stalin prize three times (once in 1941 for his theory of liquid helium and work on phase transitions). Outside his own country, Landau has been elected to membership in the Danish and the Dutch Academies of Sciences; he has recently been elected a foreign member of the Royal Society of London and of the US National Academy of Sciences. He has published well over a hundred papers in more than a dozen scientific journals, and is the author or coauthor of a total of ten books. I will conclude with two excerpts from the *JETP* article [1] written on the occasion of his fiftieth birthday, which to me appear particularly appropriate:

> It is not without significance that at the weekly seminar which Lev Davydovich conducts at the Institute for Physical Problems, reports are presented not only on theoretical researches but also on the results of experimental work on the most varied problems in physics. Participants in the seminar are repeatedly amazed to see Lev Davydovich show equal enthusiasm and thorough knowledge in discussing, for example, the energy spectrum of the electrons in silicon, directly after dealing with the properties of the so-called "strange" particles. . . .
>
> The breadth of Lev Davydovich's grasp of contemporary physics is even more convincingly shown by the course of theoretical physics which he has written together with E. M. Lifshitz.
>
> Taken together, these books are a fundamental treatise on theoretical physics. In originality of exposition and broad grasp of the material they are unprecedented in the whole world-wide literature of physics, and so have attained wide popularity not only in this country but also abroad.
>
> The contribution for which theoretical physics is indebted to Lev Davydovich is not exhausted by his own scientific writings. We have already spoken of another side of his activity—his founding of a broad school of Soviet theorists. His inextinguishable enthusiasm for science, his acute criticism, his talent and clarity of thought attract many young people to Lev Davydovich. The number of those, both young and mature scientists, who turn to Dau (as his pupils and associates have come to call him) is very large. Lev Davydovich's criticism is hot and merciless, but behind this outer sharpness is hidden devotion to high scientific principles and a great human heart and human kindness. Equally sincere is his wish to aid the success of others with his criticism, and equally warm is his expression of approval.

[4] Zero sound appears distinguished from first sound primarily as a distortion, rather than a displacement, of the Fermi surface.