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Laszlo Tisza (1907–2009): An Appreciation

Allan Griffin

Laszlo Tisza at age 31, taken in 1938 at the Collège de France in Paris (photo courtesy of Magda Tisza)

Laszlo Tisza, Professor Emeritus of Physics at MIT and a founding father of the theory of quantum liquids, died on April 15, 2009. He was 101. Tisza was famous

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A. Griffin (✉)
Department of Physics, University of Toronto, Toronto, M5S 1A7 Canada
e-mail: griffin@physics.utoronto.ca

for his fundamental work in 1938–1940 introducing a two-fluid model to explain the strange properties of superfluid ^{4}He which had just been discovered. Starting with the idea of Fritz London that the superfluid phase was related to the appearance of a Bose-Einstein condensate (BEC), Tisza quickly took a giant step further than London. He argued that the hydrodynamics of superfluid ^{4}He involved the motion of two fluids, a superfluid based on a BEC in which all the atoms move coherently with the same velocity $\mathbf{v}_s$ and a normal fluid composed of atoms which move around incoherently as in ordinary liquids. With London, Tisza was the first theorist to argue that superfluid ^{4}He was a quantum liquid, showing macroscopic quantum effects visible to the eye.

Laszlo Tisza was born in Budapest, Hungary on July 7, 1907. In the late 1920s, he learned the new quantum theory from people such as Born, Heisenberg and his mentor, Edward Teller. Tisza's life and research is the subject of two long articles that have just been published, based on interviews with Tisza by Andor Frenkel over the period 2004–2006 [1, 2]. In these memoirs, Tisza gives an honest assessment of his research: what he achieved and what he did not. In addition, close colleagues at MIT have written an obituary of Tisza [3] emphasizing his warm generous personality and the wide-ranging intellectual interests he had over his long career. I also call attention to the extensive interviews with Tisza which form an important part of the scientific biography of Fritz London written by Gavroglu [4].

Since it is his signature work, the present article concentrates on an assessment of Tisza's work on superfluid ^{4}He carried out in the period 1938–1940, and its huge impact on our modern understanding of quantum fluids. This cannot be done without discussing the related work of Fritz London and Lev Landau. The contrasting approaches of London and Tisza based on BEC, and that of Landau based on quasiparticles, make the early history of superfluid ^{4}He both confusing and confrontational.

Tisza's greatest scientific work was done in the golden period immediately after superfluidity in liquid ^{4}He was discovered in January, 1938 by Kapitza in Moscow and, independently, by Allen and Misener in Cambridge. The unexpected discovery of zero viscosity in small channels and many subsequent papers on other strange behavior (such as the fountain effect) thrust liquid ^{4}He to center stage. It was the beginning of a new field of research on quantum fluids, which continues today. Tisza and London, who both had temporary research positions in Paris in 1938, were quite excited about the newly discovered bizarre behavior of superfluid ^{4}He. The "quantum fluid" aspect started with the suggestion by London that, since ^{4}He atoms were bosons, the new phase was related to the formation of a Bose-Einstein condensate (BEC), a phenomenon first predicted by Einstein in 1925 to occur in an ideal gas but largely ignored as being incorrect. London concentrated on the thermodynamic aspects related to the presence of BEC, such as the peak in the specific heat at the superfluid transition of 2.18 K.

After London told him about his new idea that a BEC might be involved, Tisza (after a sleepless night) made a major generalization. He argued that superfluidity in liquid ^{4}He was related to the undamped coherent motion of a Bose condensate involving a macroscopic number of atoms all in the same single particle quantum state of momentum $m\mathbf{v}_s$. This new quantum degree of freedom was in addition to the dynamics of the atoms outside the condensate, which would behave like an ordinary fluid. Tisza developed this two-fluid scenario in several papers in the period 1938–1940, concentrating on the new hydrodynamics of such a model [5–9]. Tisza's papers were the first to discuss the dynamics of a Bose condensate, with two separate velocity fields for the superfluid and the normal fluid. That this extension was not trivial is indicated by the fact that, initially, London did not accept Tisza's ideas. London only changed his opinion about Tisza's two-fluid model when second sound was found in Moscow by Peshkov in 1944.

With London, Tisza was well aware that BEC in a non-interacting Bose gas could only be the starting point of a theory of superfluid ^{4}He. His work attracted great attention, much of which was criticism by fellow theorists for being too naive. With courage and ingenuity, Tisza persisted in trying to develop a new set of hydrodynamic equations for his two-fluid model. The superfluid was described by a mass density ρ_s and velocity field $\mathbf{v}_s$ and the normal fluid was described by a mass density ρ_n and a velocity field $\mathbf{v}_n$, the total mass density and mass current being $\rho = \rho_s + \rho_n$ and $\mathbf{j} = \rho_s \mathbf{v}_s + \rho_n \mathbf{v}_n$ respectively. Many striking features of superfluid ^{4}He were immediately explained by this kind of model. For example, one could have zero net current ($\mathbf{j} = 0$) but still have counter flows of the superfluid and normal fluid ($\rho_s \mathbf{v}_s = -\rho_n \mathbf{v}_n$). Tisza predicted how such a counterflow of the superfluid could produce a temperature gradient. Moreover while the superfluid component could flow without any viscosity, the normal fluid flow was viscous. This explained contradictory results obtained in different experiments. One of Tisza's greatest triumphs was the prediction of temperature waves [6, 7] (later christened second sound by Landau [10, 11]) which involved time-dependent out-of-phase oscillations of the two components. Before WWII started, Tisza actively encouraged experimentalists to look for such temperature waves as a central test of his ideas.

Apart from the basic idea of two fluids rooted in the existence of a macroscopic number of atoms in a Bose condensate, Tisza never was able to develop a systematic approach or deep insight that would guide the extension of these ideas to a strongly interacting Bose liquid like superfluid ^{4}He. Important later developments include the seminal work of Bogoliubov in 1947 on a weakly-interacting Bose-condensed gas and that of Feynman in 1953–1954, who first showed how Bose statistics constrained the many-particle wavefunctions of liquid ^{4}He. A complete understanding was only achieved in the period 1957–1963 with the application of new field theoretic techniques to many particle systems with a Bose condensate order parameter [12]. As he describes in his memoirs [1, 2], Tisza was well aware that his theory was a “patchwork” of different ideas. Reading over his longer papers [8, 9, 13] from a modern perspective, one sees that he was too much influenced by ideas in the late 1930s about how to characterize the difference between classical gases and liquids, ideas that completely missed the unique features which appear in superfluids. The extremely subtle relation between the superfluid density and the condensate fraction, for example, would only be resolved in the late 1950s. In 1956, calculations by Penrose and Onsager [14] showed that in liquid ^{4}He, only about 10% of the atoms are in the condensate at $T = 0$, even though the whole liquid is superfluid ($\rho_s = \rho$) [12].

As mentioned earlier, in discussing the legacy of Laszlo Tisza, one has to deal with the rival theory Landau developed. Tisza was a research student in Landau's theoretical group at the Ukranian Physical Technical Institute (UFTI) during the period 1935–1937. In fact, Tisza was student number 5 in the famous list of those who successfully passed Landau's “Theoretical Minimum”. In his memoirs [1, 2], Tisza describes these exciting years and pays homage to Landau and his effect on his own approach to physics, especially deepening his understanding of statistical physics and the creative use of thermodynamics in dealing with quantum systems. Indeed, Tisza states that this was the inspiration of his later work on superfluid ^{4}He when he went to Paris in 1937.

In his work Landau introduced a whole new approach [10, 11] to deal with the excited states of condensed matter in terms of elementary excitations, and brilliantly applied these concepts to superfluid ^{4}He. That a new phase of matter could be defined by its characteristic excitation spectrum was a novel idea at the time. Landau obtained the correct form of the two-fluid hydrodynamic equations and, at the same time, the meaning of all parameters in the theory. For example, central to Landau's theory is that the superfluid velocity field $\mathbf{v}_s$ is irrotational. He also derived a precise formula to calculate the normal fluid density ρ_n in terms of the thermal excitations, with the phonons (sound waves) playing the crucial role below 1 K. Both aspects are missing in Tisza's formulation. Tisza's curious omission of sound wave excitations in determining the normal fluid density was a serious error, since it led to the prediction that the second sound velocity would decrease at low temperatures, rather than increase as Landau correctly predicted. However, Landau initially missed the fact that second sound was a temperature wave, as predicted by Tisza [6, 7]. There seems little question that Tisza had priority in introducing the basic concepts of the two-fluid model, although Landau later claimed that in 1941, he had only seen Tisza's brief note published in 1938 [5] and not the later papers [6–9] (see, however, Balibar [15]).

The signature of Landau's approach was that it was a consistent and complete description. Once one had determined the phonon-roton excitation dispersion relation, all thermodynamic functions as well as the velocities of first and second sound could be calculated in a quantitative fashion, with excellent agreement with experimental data. One might say that Tisza was too ambitious in trying to develop a truly microscopic theory, a theory that would only begin to appear a decade later. Landau, in contrast, is silent about a microscopic basis for his theory related to the quantum behavior of atoms. This was probably a "minimalist" strategy, since Landau realized that many body theory had not yet developed enough to grapple with strongly interacting many body systems. As Tisza correctly emphasized [13], Landau's repeated claim that his own theory followed from the "basic principles of quantum mechanics" had little justification. Indeed, Landau's paper makes no reference to the fact that ^{4}He atoms are bosons or to the importance of Bose statistics. Landau thus missed the fundamental insight of Tisza and London: namely that superfluid ^{4}He was a quantum liquid because a Bose condensate played a central (if somewhat hidden) role. In his 1947 paper [13], just before experiments were performed, Tisza predicted that liquid ^{3}He would not be a superfluid at temperatures of order 1 K and, moreover, that liquid ^{3}He would have quite different properties from liquid ^{4}He above the transition.

With hindsight, we might say that Tisza was unlucky that a Bose superfluid liquid was discovered well before a Bose superfluid gas. BEC in dilute weakly interacting Bose-condensed gases produces a superfluid where the Bose order parameter plays an obvious role [16]. In such atomic gases, one can derive the Landau two-fluid equations at finite temperatures in an explicit fashion starting from a Bose order parameter, with the superfluid density being very close to the Bose condensate density. Tisza's two longer papers [8, 9] published in 1940 (but apparently largely unknown until after 1945) can be assessed more fairly today in the context of a dilute Bose gas, where the condensate and a thermal cloud of atoms play the roles of the superfluid and normal fluid, respectively. His treatment of the thermal cloud hydrodynamics is essentially correct. However, Tisza had no equivalent of a generalized Gross-Pitaevskii time-dependent equation for the macroscopic wave function describing the condensate [16]. As a result, he had to proceed with "educated guesses" for the condensate dynamics.

For years, the low temperature community generally viewed the work of Tisza and Landau as being alternative theories, with the Landau theory being the correct one. Modern theories developed since 1960 give a more balanced view, with Tisza and London being given credit for insisting that the Bose condensation of atoms must be the underlying microscopic order parameter [17]. Direct experimental evidence for this condensate fraction (using high momentum neutron scattering to measure the momentum distribution of atoms) only started to appear in the 1970s [12]. While he stopped his active research on superfluid ^{4}He by 1950, Tisza must have been excited to hear about these experiments. He was also fortunate to see the creation of a BEC in trapped ultracold atomic gases in 1995. In contrast to superfluid ^{4}He, where superfluidity is easily measured but the underlying BEC is elusive, in ultracold gases the BEC condensate was the first property that was measured. The new ultracold atom research community generously acknowledged Tisza as a pioneer in BEC studies.

Laszlo Tisza has a permanent place of honor in the history of physics for introducing a time-dependent Bose condensate as a microscopic basis for understanding superfluidity, an idea which has had a huge effect.

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