

Absorption of first sound in liquid He³

N. E. Dyumin, B. N. Esel'son, and É. Ya. Rudavskii

Physico-technical Institute of Low Temperatures, Ukrainian Academy of Sciences

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The absorption coefficient of first sound in liquid He³ is measured in the 0.45–2.5 °K temperature range at a frequency of 10 MHz. It is shown that first viscosity plays the main role among the dissipative processes that determine the damping of sound, whereas thermal conductivity is decisive at high temperatures. The contribution of second viscosity is negligible.

The absorption of first sound in liquid helium has been studied in detail only in pure He⁴ and in He³ – He⁴ solutions. Such data are practically non-existent for He³. The studies of sound oscillations in He³, carried out in^[1,2], refer only in small measure to first sound and are devoted primarily to the study of zero sound, and also the transition region between first and zero sound. The purpose of this research has been the measurement of the absorption coefficient of first sound in liquid He³ in the temperature range 0.45–2.5 °K.

METHOD OF EXPERIMENT

Absolute measurements of sound absorption were carried out in the high-temperature region ($T > 1.4^\circ\text{K}$) and relative measurements were made below 1.4°K with normalization in the high-temperature region.

The absolute measurements were made by means of a sound cell with a variable acoustic path (Fig. 1), which had been used previously.^[3] The sound source was an X-cut quartz crystal 5 with resonant frequency ~ 10 MHz, which generated ultrasonic pulses in the liquid and served as a receiver, during its quiescent periods, of the signals reflected from the polished surface of the reflector 8. The piezoelectric quartz was placed in a quartz container 2 which was connected electrically with one of the electrodes of the quartz plate. The other electrode was formed by the central part of the crystal, of diameter 10 mm, to which was connected a variable voltage by means of a light helical spring 4 (made of a thin copper wire). To suppress the undesired signals which are produced by the reverse side of the quartz, a fine rouge powder 3 was pressed against the bottom face of the quartz container.

The length of the acoustic path was varied by displacement of the reflector 8, which was connected with the movable piston 10 by means of the three adjusting screws 10 and the curly spring 9. The motion of the piston was produced by means of an electromagnet located over the crystal through the link rod 12 and the tube 13. The amount of the displacement of the entire moving system could be changed by change in the position of the coil of the electromagnet. The amount of displacement was determined by measurement of the time of flight of the pulse, with account of the known velocity of sound in liquid He³.^[4]

The parallelism of the plane of the reflector and the crystal was established in a special experiment with He⁴ at a temperature $\sim 1.95^\circ\text{L}$, when the sound absorption was minimal. The change in the position of the plane of the reflector was accomplished by means of the balancing screws 10, the location of which could be changed by means of a special screwdriver, inserted in the measurement cell through the cap of the cryostat. The criterion of parallelism was the presence of a

maximum amount of reflected signals, which also was accompanied by their maximum amplitude. After adjustment with a screwdriver was accomplished, the cell was sealed. In order that the parallelism not be altered in the displacement of the reflector, and also from experiment to experiment, the cell was made of a single piece of brass L-62, which had previously been annealed. It was also of extraordinary importance to prepare carefully the pair consisting of piston 11 and cylinder 7, the abutting surfaces of which lapped one another, which guaranteed excellent reproducibility of the data. For $T < 1.4^\circ\text{K}$, the measurements were made in the cell with a fixed distance (20.9 mm) between the quartz detector and the reflector. Adjustment of the reflector was accomplished in the same way as at high temperatures.

The absorption coefficient was measured by a pulse method, the circuit of which is shown in Fig. 2. Radio pulses the length and amplitude of which could be varied, were fed to the quartz transducer from the pulse transmitted PT. The reflected signal was picked up by the same quartz, amplified by the broadband amplifier BA and fed to the oscilloscope O for visual observation. To measure the amplitude of the signal, a single comparison pulse, having the same frequency and duration as the incident pulse, was passed through the calibrated attenuator CA to the common amplification channel and detector. The comparison pulse was, observed on the screen of the oscilloscope, together with the reflected pulses, and compared with the received signal. This made it possible to eliminate errors connected with nonlinear distortion and instability in the amplification coefficient.

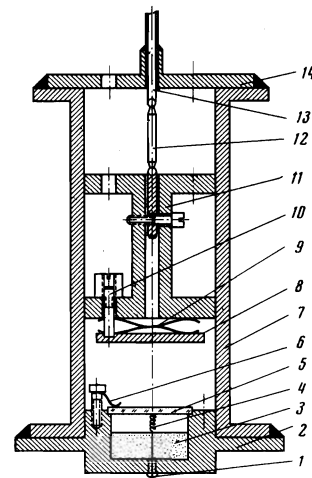


FIG. 1. Scheme of the test cell: 1—electrical contact; 2—quartz container; 3—compressed rouge; 4—contact spring; 5—piezoelectric quartz; 6—phosphor bronze spring; 7—cylinder; 8—reflector; 9—spring; 10—control screw; 11—piston; 12—link rod; 13—tube; 14—upper cap.

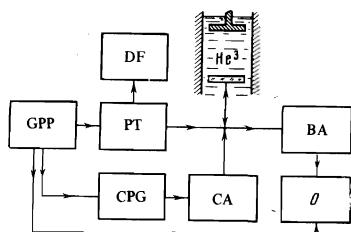


FIG. 2. Block diagram of sound absorption measurements in liquid He³: GPP—generator of pair pulses; PT—pulse transmitter; BA—broad-band amplifier; O—oscilloscope; DF—digital frequency meter; CPG—comparison pulse generator; CA—calibrated attenuator.

Low temperatures were obtained by pumping the gas over the liquid He³ by an adsorption pump, similar to the procedure in [5] and were determined by measuring the vapor pressure with a account of the thermomolecular correction. [6] All the measurements were made at constant temperature, which was stabilized by means of an electronic stabilizer. The isothermal interval amounted to ~60 min in most cases, and the amplitude was recorded only after the signal reached constant amplitude. The criterion here was the stability of the amplitude in time. In the cell with variable length, the time to achieve equilibrium could be significantly reduced by repeated motion of the reflector.

In order to avoid errors due to departure from equilibrium conditions, the measurements were carried out both with increasing temperature and decreasing temperature. The difference between such measurements, following corresponding isothermal exposures, lay within the limits of accuracy of the experiment. Moreover, the possible effect on the sound absorption by the gas bubbles which could exist in liquid He³ at the saturated-vapor pressure was also tested. [7] For this purpose, special measurements were made at somewhat elevated pressures, up to 0.3 atm. Here the sound absorption, with account of the small change in velocity of sound due to the pressure increase, [4] remained the same as at the saturated vapor pressure.

The measurements were made in liquid He³ of 99.83% purity.

The use of the pulse method of measurement is always accompanied by a lack of strict monochromaticity of the oscillations propagated in the liquid, inasmuch as the spectrum of the radio pulse contains in addition to the carrier frequency also a set of other frequencies. In the given case, the relative error in the determination of the absorption coefficient, produced by the lack of monochromaticity, amounted, by our estimates, to no more than 10%. Another possible systematic error associated with the divergence of the ultrasonic beam, was also negligible, inasmuch as the ratio of the radius of the source to the sound wavelength amounted to $\sim 3.5 \times 10^2$. Special attention was paid to the absence of nonlinear effects, produced by the large amplitude of the sound wave. Thus, it can be assumed that the error of measurement of the sound absorption coefficient was determined only by random errors in the measurement of the amplitude of the signal (0.2%) and of the distance (0.2–0.3%). The total error of determination of the absorption coefficient did not exceed 2.5%.

RESULTS AND THEIR DISCUSSION

The measured values of the absorption of first sound are shown in the table and in Fig. 3. As is seen from

Smoothed values of the first sound absorption coefficient in liquid He³ at the frequency of 10 MHz

T, °K	α , cm ⁻¹	T, °K	α_1 , cm ⁻¹	T, °K	α , cm ⁻¹
0.45	0.226	1.1	0.175	2.0	0.270
0.5	0.215	1.2	0.178	2.1	0.303
0.6	0.191	1.3	0.182	2.2	0.343
0.7	0.180	1.4	0.187	2.3	0.390
0.8	0.175	1.5	0.192	2.4	0.451
0.9	0.174	1.6	0.202	2.5	0.536
1.0	0.174	1.7	0.213		
		1.8	0.229		
		1.9	0.246		

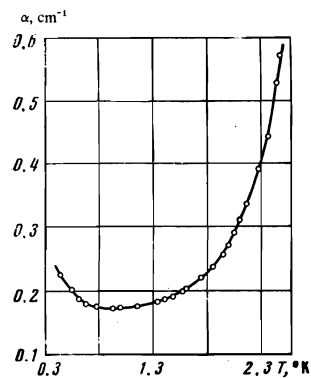


FIG. 3. Temperature dependence of the sound absorption coefficient in He³ (frequency 10 MHz).

the graph, the absorption curve is nonmonotonic and forms a shallow minimum at a temperature 0.9–1.0°K. Thereafter, the absorption increases with increase in temperature, the increase being particularly sharp for $T > 2.0^\circ\text{K}$, which is apparently connected with the effect of the liquid-vapor critical point. Because of the strong absorption, it was difficult to obtain reliable values at temperatures above 2.5°K.

The experimental data obtained can be used to determine the relative contributions to the sound absorption due to the various dissipative processes—first viscosity η , thermal conductivity κ , and second (bulk) viscosity ζ :

$$\alpha_1 = \frac{2\pi^2 f^2}{\rho u_1^3} \left[\frac{4}{3} \eta + \zeta + \kappa \left(\frac{1}{C_v} - \frac{1}{C_p} \right) \right];$$

here ρ is the density of the liquid, u_1 the velocity of first sound, and f the frequency of the oscillations. However, the existing values in the literature of first viscosity [8–13], which plays an important role in [1], are in poor agreement with one other. At low temperatures, the difference between the data of different authors reaches ~30%. This circumstance makes it difficult to use the formula (1). Nevertheless, if we determine the value of the second viscosity ζ from Eq. (1) for the existing scatter of values of η , by using the resultant experimental data on α_1 and the literature data on κ [14], C_p , C_v , u_1 [4] and ρ [15], then it turns out that the quantity ζ is close to zero (Fig. 4).

This result is confirmed by the following circumstance. According to the general theory of Mandel'shtam and Leontovich, which describes the relaxation processes in a sound wave (see [16]), the value of the second viscosity should be proportional to $u_\infty^2 - u_0^2$, where u_∞ and u_0 are the velocities of high-frequency and low-frequency sound, respectively, in He³. As measurements of u_∞ in liquid He³ (from the scatter of x-rays) show [17] the velocity of high-frequency sound for $T > 0.8^\circ\text{K}$ does not

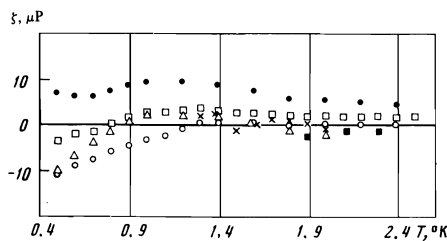


FIG. 4. Values of the second viscosity of liquid He^3 , determined from data on the absorption of first sound. The different experimental points correspond to different values of η used: \square —from [9]; \bullet —[10]; Δ —[11]; \square —[12]; \times —[13].

differ from the value of the velocity measured in^[4]; by the same token, the quantity ζ should be equal to zero.

Thus, in liquid He^3 as well as in He^4 above the λ point,^[18] the sound absorptions is excellently described by the ordinary classical Stokes-Kirchhoff theory, according to which only the contribution of first viscosity and the thermal conductivity enters into α_1 .

Calculations from Eq. (1) show that at low temperatures the first viscosity is the principal dissipative process making a contribution to the absorption of first sound. The role of heat conductivity begins to appear only for $T > 1^\circ\text{K}$. Upon further increase in the temperature, the contribution of the thermal conductivity to α_1 grows appreciably and, for $T \approx 2.4^\circ\text{K}$, becomes equal to the contribution of first viscosity. The growth of the effect of thermal conductivity with growth of temperatures is due not only to the increase in κ but also in significant measure to the difference between C_p and C_v .

In conclusion, we note that, as the given research has shown, the sound absorption in liquid He^3 , as also in He^4 , is so great in spite of the smallness of the viscosity, that He^3 belongs to the strongly absorbing liquids. This is explained by the low density of He^3 and to the sound velocity, which is lowest of all the liquids, and which,

in accord with (1) has a strong effect on the sound absorption.

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Translated by R. T. Beyer
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