Thermomechanical effect in liquid helium I

G. A. Gamtsemlidze, Sh. A. Dzhaparidze, and D. I. Tsaava

Tbilisi State University
(Submitted July 11, 1975)
Pis'ma Zh. Eksp. Teor. Fiz. **22**, No. 5, 278–281 (5 September 1975)

A thermomechanical effect, due to the presence of weakly-damped phonons, has been observed in normal liquid helium I. The phonon part of the entropy is calculated and found to coincide with the theoretical value.

PACS numbers: 67.40.D, 67.20.S

1. A two-liquid model was proposed in[1] for He I and was experimentally confirmed in[2]. In this paper we report results describing a thermomechanical effect in a normal classical liquid, namely helium I.

It was shown in[1] that the presence of weakly-damped phonons in a normal liquid introduces a term proportional to the temperature gradient ΔT into the expression for the liquid-mass flux through a gap (see Eq. (13) of[1]). When the condition $c\alpha/aT^2 \to \infty$ is satisfied (c is the speed of sound in the liquid, α is the sound absorption coefficient, a is the dimension of the gap, and T is the temperature), as is indeed the case in our experiment, it is found that

$$\Delta p / \Delta T = S_{ph} \qquad (1)$$

where Δp is the pressure corresponding to the temperature difference ΔT, and S_{ph} is the phonon part of the entropy per unit volume of the liquid, i.e.,

$$S_{ph} \approx (2\pi^2/45)(T/\hbar c)^3 = 1.2 \cdot 10^{21}\ \text{cm}^{-3}. \qquad (2)$$

2. Figure 1 shows the diagram of the instrument. A cylindrical reservoir (diameter 30 mm, height $H_p = 28$ mm), made of organic glass, is joined to a glass capillary of length $L = 120$ cm and inside diameter 0.9 mm. A constantan heating coil, of resistance $R = 160\ \Omega$ is wound around part of the capillary. The heater is insulated from the surrounding medium by a vacuum jacket. To exclude the heat of evaporation, the reservoir is covered with a cap having a tube immersed in the helium-I bath.

A constant temperature was established and maintained during the time of the experiment. The instrument was immersed with the aid of a lifting mechanism into the liquid helium in such a way that the bottom of the reservoir coincided with the level of the liquid in the bath. When current was made to flow through the heater, helium flowed into the reservoir at a constant speed $v = 0.014$ cm/sec. The larger the current through the heater, i.e., the larger the temperature difference ΔT between the ends of the capillary, the larger the rise of the helium height in the reservoir. It should be noted that the inflow of helium occurred both with the reservoir cover on and with the cover off. The height H of the helium level in the reservoir was read with a cathetometer accurate to ± 0.1 mm.

3. The temperature difference produced on the ends of the capillary, i.e., between the helium in the bath and the helium in the reservoir, was estimated from the current in the heater. In the stationary regime, the entire thermal power released in the heater goes to maintain a constant temperature difference between the liquids in the reservoir and in the bath. Owing to the

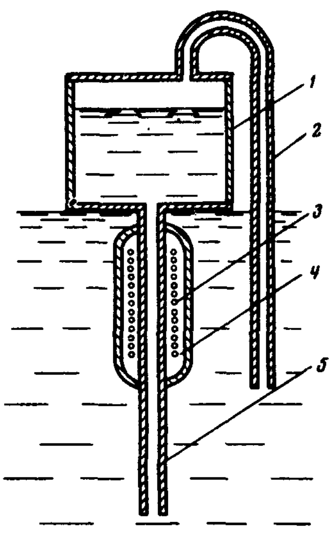

FIG. 1. Diagram of the instrument: 1—cylindrical reservoir, 2—tube joining the reservoir and the bath, 3—heater, 4—vacuum jacket, 5—capillary.

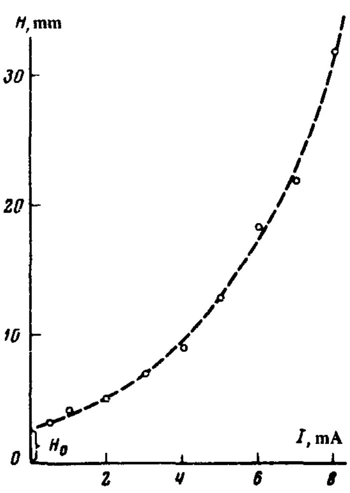

FIG. 2. Dependence of the rise H of the helium in the reservoir on the current I in the heater.

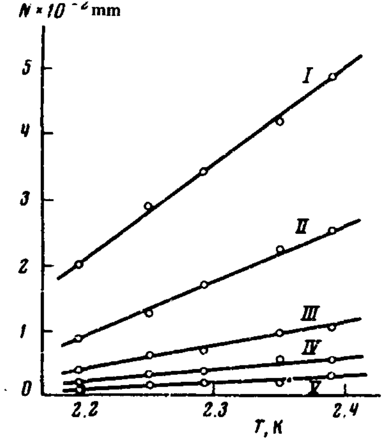

FIG. 3. Amplitude N of the oscillation of the pointer on the scale vs the temperature T for various values of the distance Z between the generator disk and the receiver disk. Lines I to V correspond to the values $Z = 5$, 7, 10, 15, and 20 mm.

high thermal conductivity of the helium, we assume that the power released by the heater is carried away by the liquid helium through the capillary. Thus

$$\Delta T = I^2 R / \varkappa (S / L) \approx 20 I^2, \quad (3)$$

where $\varkappa$ is the coefficient of thermal conducitvity of the helium and S is the capillary cross section area. Substitution of this value of ΔT in (1) yields for the phonon part of the entropy the expression

$$S_{ph} = \rho g \Delta H / 20 I^2 k, \quad (4)$$

where k is Boltzmann's constant, $\Delta H = H - H_0$ is the height of the level measured from the lower end surface of the bottom, and H_0 is the rise of the helium due to the capillary forces.

Fig. 2. shows a plot of $H = f(I)$. From the parabolic relation we get

$$\Delta H / I^2 = 4 \cdot 10^4 \text{ cm/A}^2$$

and substitution of this value in (4) yields $S_{ph} \approx 2.1 \times 10^{21}$ cm^{-3}. This agrees, within the limits of errors, with the value of S_{ph} obtained from the theoretical formula (1). The presented experimental results prove the existence of a thermomechanical effect in a classical normal liquid (helium I), in the entire temperature interval.

4. The two-liquid model of a normal liquid was confirmed in[2] by establishing the power-law character of the damping of the shear oscillations. Figure 3 shows by way of a supplement to the cited paper the temperature dependence of the velocity of the shear oscillations. The dependence is linear, in full accord with the theoretical expression of[1].

We note in conclusion that the study reported in[2] and the present study have fully confirmed experimentally A. F. Andreev's theory of a two-component normal liquid.

The authors are grateful to A. F. Andreev for many valuable suggestions.

[1]A. F. Andreev, Zh. Eksp. Teor. Fiz. **59**, 1819 (1970) [Sov. Phys.-JETP **32**, 987 (1971)].
[2]G. A. Gamtsemlidze, Sh. A. Dzhaparidze, and D. N. Tsaava, ZhETF Pis. Red. **20**, 45 (1974) [JETP Lett. **20**, 19 (1974)].