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WAVE PROCESSES IN He II NEAR THE SURFACE OF A HEATER

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Mobile "sources" of radiation of (first) sound, which are not produced in He I, were observed near a heated surface in He II by Schlieren photography of the optical inhomogeneities excited in the liquid helium following a pulsed release of Joule heat from a thin flat heater; the propagation of these sources along the heater is also accompanied by excitation of second sound.

The investigated flat layer of liquid helium, 57 mm thick, was poured into the chamber between two plane-parallel glass discs. Figure 1 shows part of this layer in the form of a parallelepiped measuring 51 × 57 × 100 mm, bounded by the discs (not shown in the figure), and also by vertical (2, 3) and horizontal (4, 5) walls (laminated bakelite). The flat heater 1, parallel to the wall 3 and located 50 mm away from it, was made up of vertical sections of constantan ribbon 0.02 mm thick and 0.47 mm wide, spaced about 1 mm apart (the mass of the constantan was about 9 mg/cm^2). The surface area of the metal exposed to the liquid equalled the area of the section occupied by the heater, and the heat flux was calculated per unit of this area. On the left wall was placed heater 2, made of horizontal sections of ribbon. The temperature of the liquid was regulated and measured by determining the saturated vapor over it (T_{58} scale). The chamber with the liquid helium was installed in the beam of parallel light rays of the shadow instrument in such a way that the projection of the heater 1 represented a thin line (the dark vertical line in the centers of the photographs in Figs. 2 and 3). A single rectangular pulse of duration t_* and front rise time ≤ 0.05 μsec was passed through the heater ribbon. The pulse amplitude was measured with a digital voltmeter. The power N (in the pulse) is dissipated on both sides of the heater 1. After a time t_+, reckoned from the leading front of the pulse, a light flash ($\sim$1 μsec) is started and registers the instantaneous picture of the perturbations. The construction of the cryostat and the experimental procedure are described in [1]. The photographs in Figs. 2 and 3, obtained by the knife-edge and slit method (vertical slit 0.05 mm wide) give the horizontal projections of the density gradient of the liquid. The smallest distinguishable values are equal to $d\rho/dx \geq 1.5 \times 10^{-6}$ g/cm^4 and $d\rho/\rho dx \geq 10^{-5}$ cm^{-1}. Such a

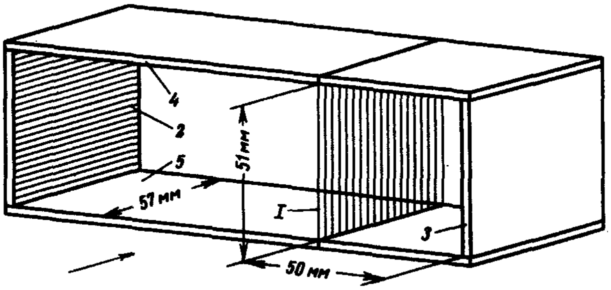

Fig. 1

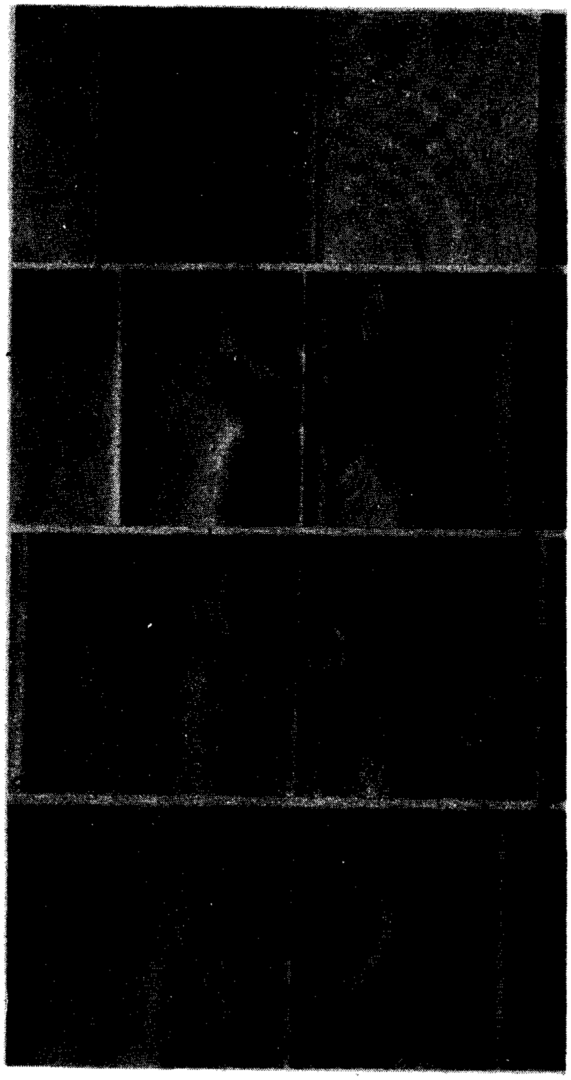

Fig. 2. a - T = 2.165°K, N = 14.2 W/cm², t_* = 100 μsec, t_+ = 201 μsec; b - T = 2.030°K, N = 14.3 W/cm², t_* = 100 μsec; t_+ = 173 μsec; c - T = 2.086°K, N = 8.8 W/cm², t_* = 500 μsec, t_+ = 267 μsec; d - T = 2.087°K, N = 8.8 W/cm², t_* = 500 μsec, t_+ = 288 μsec.

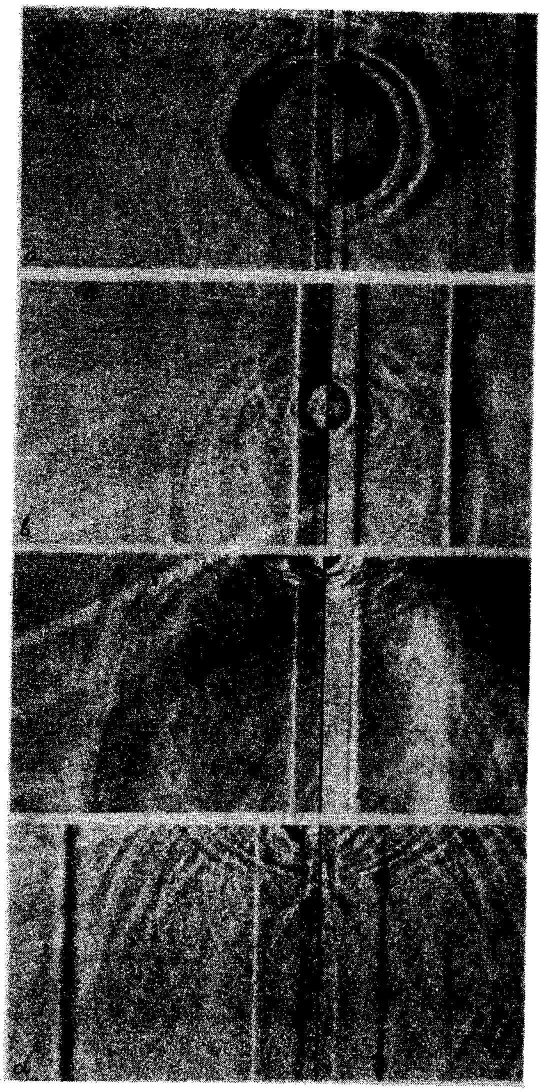

Fig. 3. a - T = 2.121°K, N = 7.7 W/cm², t_* = 300 μsec, t_+ = 300 μsec; b - T = 1.89°K, N = 17.2 W/cm², t_* = 200 μsec, t_+ = 337 μsec; c - T = 2.078°K, N = 8.0 W/cm², t_* = 300 μsec, t_+ = 425 μsec; d - T = 1.87°K, N = 11.0 W/cm², t_* = 500 μsec, t_+ = 665 μsec.

change of density in the acoustic wave is connected with the pressure gradient $dP/dx = u_1^2(d\rho/dx) \geq 10^3$ dynes/cm³ (u_1 = 220 - 230 m/sec).

The pulsed heat release in heater 1 excites packets of "plane" acoustic waves in the liquid helium surrounding the heater; these waves go off symmetrically to both sides (see Fig. 2a; a photo at N $\leq$ 3.2 W/cm² is given in [1]). The dark image of the heater 1 in Fig. 2a becomes thicker than the initial image, owing to the formation of a vapor layer. When the temperature T of the liquid in the chamber is increased above T_λ = 2.172°K, this picture remains unchanged. In He II ($T < T_\lambda$) the pulsed heating excites also packets of "plane" waves of second sound; the leading fronts of these packets, the illumination of which corresponds to the growth of the density of the liquid, are seen in all photographs of Figs. 2 and 3 (straight lines parallel to the projection of the heater and located 1 - 13 mm away from it). The brief appearance of an invisible layer of vapor in He II at $N \geq 1.5 - 2$ W/cm^2 was revealed by the change in the character of the interaction between heater 1 and the sound packets transmitted to heat from heater 2 before and after the pulse. When a vapor layer is produced, the sound is reflected from surface 1 just as from a free surface.

An unexpected phenomenon is observed in He II at $T < 2.15$°K and $N > 5$ W/cm^2. At a time t_ϕ after the start of the pulse (after the departure of the leading fronts of the plane packets), moving "sources" appear on the surface of the heater 1; they excite around themselves sound waves with well-distinguishable lengths, 1 - 3 mm. At an instant $t_+ > t_\phi$, the pattern of these waves has the form of circular bands with offset centers, and a region of condensed liquid of diameter 1 - 3 mm can be seen around the source (Fig. 2b). The number of the sources, the time and place of their appearance in plane 1, depend on T, N, t_*, and the time interval t between the photographs. When T drops from 2.14 to 1.7°K, the values of N needed to excite the sources increase from 6 to 19 W/cm^2, and the smallest necessary value of $(Nt_*)_0$ increases from 700 to 4000 J/cm^2 ($t_- \geq 60$ sec).

In the interval $1.7 < T < 2.15$°K it is possible to choose for each temperature a power value N_2 such that a pair of sources (or a pair of narrow groups of small sources) appears simultaneously on each side of the plane 1. In the course of time, these sound-radiating sources move along the heater at a velocity 120 - 160 m/sec (Fig. 2b). The encounter of the sources in the central part of the plane 1 produces a compression zone, surrounded on the sides by rarefaction regions. The initial pattern of such a zone (Fig. 2c) constitutes two distinct semicircles with illumination oppositely located on different sides of the vertical axis (indicating that the density increases toward the axis). The compression zone then expands in radial directions at the speed of sound (Fig. 2d), after which the sound waves excited upon collision of the sources acquire a higher intensity than the waves in the plane packets. The "opposing" sources are produced once (or twice) during the time of current flow through the heater, but their subsequent displacement and "collision" occurs also after the termination of the pulse. Figure 3a shows inside the compression zone a second pair of approaching sources. When $N > N_2$, the number of simultaneously produced sources increases, and at large values of N, soon after the start of the pulse, the entire plane 1 of the He II is suddenly covered with small pulsating sources. When $6 < N < N_2$, only one source is produced near the lower wall; it shifts along the heater until it meets the upper wall, as a result of which there is produced there a "half-round" compression zone (Fig. 3c), followed by an expansion. If T, N, t_*, and t_- are invariant, then the instant of appearance of the sources and the entire picture of the perturbations are consistently reproduced, with a time scatter not larger than 2%. Complete reproducibility of the source collision in the center indicates that the sources extend linearly along the thickness of the He II layer.

By limiting the energy released in the heater to the smallest values $(Nt_*)_0$, it can be noted that after the source passes along the heater in the liquid, it is possible to see (particularly clearly when $T < 2$°K) new straight-line fronts of the second sound, making an acute angle α to the plane 1 and converging in the direction of displacement of the sources (Figs. 3b, c, d). The quantity $u_2/\sin\alpha$ is the speed of source propagation and coincides with the speed calculated from the displacement of the center of the sound-wave patterns. Figure 3d shows clearly, besides the plane packets of first and second sound, which are parallel to the heater 1, also perturbations due to the upward propagation of one source at a value of $(Nt_*)_0$ lower than T. The inclined ("source") fronts of second sound in Fig. 3d cross the rear boundaries of the packets of second sound. The sources of sound waves are observed in He II also on the flat heater 2, which has a different construction. The visible bubbles of vapor in He II reach maximum dimensions (1 - 4 mm) within 2 - 10 msec, and their vanishing by the time the instant t_+ = 20 msec is reached is not accompanied by noticeable emission of sound.

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"QUENCHING" OF CROSS CORRELATION IN INHOMOGENEOUSLY BROADENED EPR LINES

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Spin-spin correlation has a significant influence on the processes of saturation and relaxation and multilevel systems [1], particularly in inhomogeneously broadened EPR lines. In measurements of the spin-lattice relaxation (SLR) times by the pulsed-saturation method, the cross relaxation can distort in a complicated manner the relaxation curves and lead to considerable errors in the determinations of the SLR times T_1. We have set up an experiment wherein the influence of the cross relaxation within the line can be completely eliminated (we call this the "quenching" of the cross relaxation), and have shown that the SLR time obtained in this case differs strongly from that obtained with the aid of the ordinary pulsed-saturation method. The "quenching" effect was obtained by rapidly sweeping the line during the saturation time. The entire line turned out to be then homogeneously saturated, and the restoration of any section of the line took place exponentially only as a result of the spin-lattice relaxation, without participation by the cross relaxation.

The gist of the effect can be easily understood by using two spin subsystems ("spin packets") as an example. If only one subsystem is saturated (the usual pulsed-saturation procedure), then the restoration of its population occurs in accordance with the doubly-exponential law [1]

$$A\exp[-(T_1^{-1} + T_{12}^{-1})t] + B\exp(-T_1^{-1}t).$$

Here T_1 are the SLR times of both subsystems and T_{12} is the characteristic cross relaxation time. The first term describes the cross relaxation to the second subsystem. It decreases with increasing duration τ of the saturation, but does not vanish even when $\tau \gg T_{12}$.

However, if both subsystems are saturated, then, using the equations of [1] we can show that the restoration of the population of the levels of both subsystems will proceed exponentially, with a time T_1, and the cross relaxation is completely eliminated ($A = 0$).

In a many-level system, such as an inhomogeneously broadened EPR line, there should obviously exist an entire spectrum of cross-relaxation times T_{12}^{i} and, since one may encounter in such a system values of T_{12}^{i} close to T_1, it is impossible to separate in the relaxation curves the spin-lattice exponential, i.e., it is impossible to determine T_1.

The results of the analysis for two spin subsystems can obviously be extended to the case of an inhomogeneously broadened EPR line. If the entire EPR is homogeneously saturated, say by rapidly scanning it during the time of action of the saturating pulse, then, provided all the spectral parts of the line have identical SLR times T_1, each part of the line (each "spin packet") will relax