Interaction between an oscillating solid wall and a ^{3}He-^{4}He solution

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Viscous interaction between quartz and a solution of ^{3}He in ^{4}He are measured in a dilution refrigerator in the 800 to 7 mK temperature range. The forces are found to be more than 10 times weaker than expected. This is explained by the fact that the accommodation coefficient for the ^{3}He atoms of the solution by the surface of the solid is much less than unity. This results in slipping of the solution relative to the surface of the solid. Moreover, a film of about a hundred angstroms thick, in which the ^{3}He concentration is close to that of the lower phase of the solution, is formed at the surface of solid bodies in the upper phase of the solution even for concentrations of ^{4}He in ^{3}He of the order of 10^{-28}.

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As already reported,[1] the damping of the shear oscillations of a quartz resonator placed in a saturated solution of ^{3}He in ^{4}He, at temperatures much lower than 1 °K, has an entirely different temperature dependence and magnitude than expected from available data and theoretical ideas concerning the viscosity η of ^{3}He and its solutions in ^{4}He.[2–11] The present article is devoted to a more detailed description of our experiment and treatment of the observed phenomena.

The experiment was carried out in the ^{3}He–^{4}He dilution refrigerator, the lower part of which is shown in Fig. 1. A separate chamber for ^{4}He, with temperature ~ 1.3 °K, was located in the vacuum jacket 1 of the cryostat. The tube carrying the concentrated ^{3}He first entered a dewar with ^{4}He at $T = 4.2$ °K, then a chamber with ^{4}He at $T = 1.3$ °K, and ultimately the ^{3}He evaporation chamber 2. The ^{3}He then flowed through a throttle 3 into a tubular heat exchanger, where it was cooled by the flow of the solution from the dilution chamber 10 and was fed through capillary 12 into the dilution chamber. The level of the ^{4}He in the chamber with the ^{4}He could be monitored with a capacitive pickup,[12] and it was possible to add liquid ^{4}He from an external container through a special small valve, without changing significantly the temperature in the chamber. This ensured stable operation of the cryostat. The coaxial line 5 feeding to the quartz resonator 7, made successive thermal contact with the ^{4}He chamber, with the evaporation chamber, and with heat exchanger 4. The evaporation chamber was assembled, without soldering, using bolts 6 with Mylar gaskets thus preventing the quartz surface from becoming heated, and therefore from being contaminated, during the assembly. The quartz was in a horizontal position at the very top of the dilution chamber. It comprised an optically polished flat plate on which gold electrodes were deposited. Inside the dilution chamber there were three thermometers (carbon thermometer 8 and cadmium resistance thermometers 9), with which it was convenient to observe the course of cooling of the cryostat, as well as a sphere 11 of cerium-magnesium nitrate (CMN), measurements of the susceptibility of which made it possible to determine the dilution chamber temperature at $T < 1$ °K. A system of ballistic coils 13 and a system of coils 14 producing a constant magnetic field were used for this purpose.

To establish a temperature scale from the measurements of the susceptibility of the CMN we used the following procedure: we calibrated the ballistic system against the magnetic moment of a superconducting tin

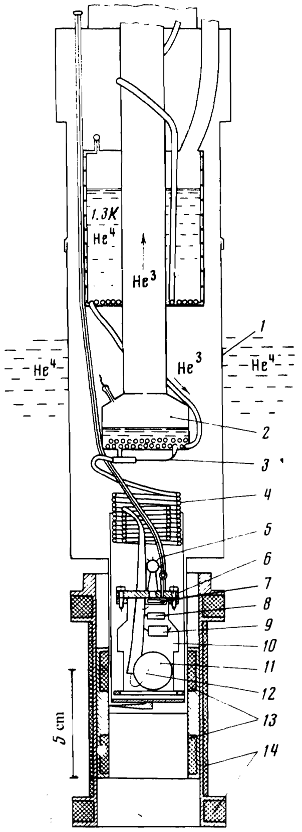

FIG. 1. Lower part of dilution refrigerator: 1—vacuum jacket, 2—evaporation chamber, 3—throttle, 4—tubular heat exchanger, 5—coaxial line leading to the quartz resonator, 6—clamping bolt, 7—quartz resonator, 8—carbon resistance thermometer, 9—cadmium resistance thermometer, 10—dilution chamber, 11—sphere of powdered CMN, 12—tube for direct flow of ^{3}He, 13—balistic coils, 14—coils for the production of a constant magnetic field.

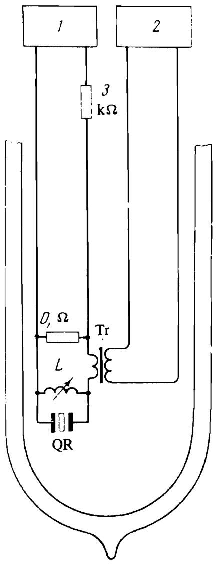

FIG. 2. Block diagram of the measurement of the resonance frequencies of quartz: 1—frequency standard Ch1-28 with voltage divider, 2—microvolt meter V6-1, L—inductance to cancel the static capacitance of the quartz and the capacitance of the coaxial line connected to it, Tr—transformer, QR—quartz resonator.

sphere, and in addition, we had a reference point on the temperature scale, namely the superconducting transition temperature T_{Cd} of cadmium. On the basis of[13] we assumed $T_{Cd}=0.472$ °K at $H=4.8$ Oe. To verify and refine the temperature scale, experiments were performed on the demagnetization of CMN from a temperature on the order 6–7 mK and a magnetic field ~1 kOe. The magnetic moment of the CMN after the end of the demagnetization was constant for 2–3 min and corresponded to a magnetic temperature $T^{(*)}_{\min}=2.3$ mK in accordance with the temperature scale adopted by us. Assuming that the Curie constant of the CMN powder is equal to $2.77\cdot 10^{-4}$ K/g,[14] at an average sphere density $\rho=1.90$ g/cm^3, the estimated minimal magnetic temperature $T^{(*)}_{\min}=2.2$ mK is close to the value of $T^{(*)}_{\min}$ obtained upon demagnetization.

In the experiment we measured two frequencies, f_1 and f_2, of the resonance curve of quartz, corresponding to $1/\sqrt{2}$ of the resonance amplitude. Their difference yielded the width Δf of the resonance curve, and their arithmetic mean yielded the resonance frequency of the quartz. A block diagram of the measurement of f_1 and f_2 is shown in Fig. 2. A voltage of frequency 15 or 25 MHz, corresponding to series resonance of the quartz at the third of fifth harmonic, was applied to the quartz from a Ch1-28 frequency standard (1), which had a calibrated voltage divider. The quartz was shunted with a 0.1 Ω resistor. The intrinsic resistance of the quartz at the series-resonance circuit was ~10 Ω. With the aid of transformer Tr and selective microvolt meter V6-1 (2) we were able to monitor the current in the quartz circuit. The quartz-resonator susceptance due to its static capacitance and the capacitance of the connected coaxial cable was balanced by an inductance L. As a result, when the Ch1-28 generator frequency was detuned by ~10 kHz from the resonance frequency of the quartz, the transformer primary-winding current due to the residual susceptance of the capacitance shunting the quartz induced a voltage $U_2 \lesssim 1$ μV at the input of the microvolt meter V6-1 connected to the secondary winding of the transformer. At the resonant frequency of the quartz, depending on its quality factor, U_2 ranged from 100 to 1000 μV. The power dissipated by the quartz was about 10^{-9} W.

The sequence of the experiments was the following: the ^{3}He–^{4}He mixture was condensed in the dilution refrigerator. The circulation was started in the refrigerator, and the frequencies f_1 and f_2 were measured simultaneously. Figure 3 shows the width of $\Delta f=f_1-f_2$ of the resonance curve of quartz for the frequencies 15 and 25 MHz during the course of cooling of the refrigerator. To reach a temperature of approximately 50 mK, the dilution refrigerator was changed from the circulation regime to the one-shot regime—point P on Fig. 3. The amount and concentration of the mixture were such that the quartz was at that instant 3 cm above the phase-separation level in the dilution chamber. At the end of the oneshot process, when the upper phase of the solution, in which the quartz was located, terminated, the quartz went over to a 6% solution of ^{3}He in ^{4}He. This

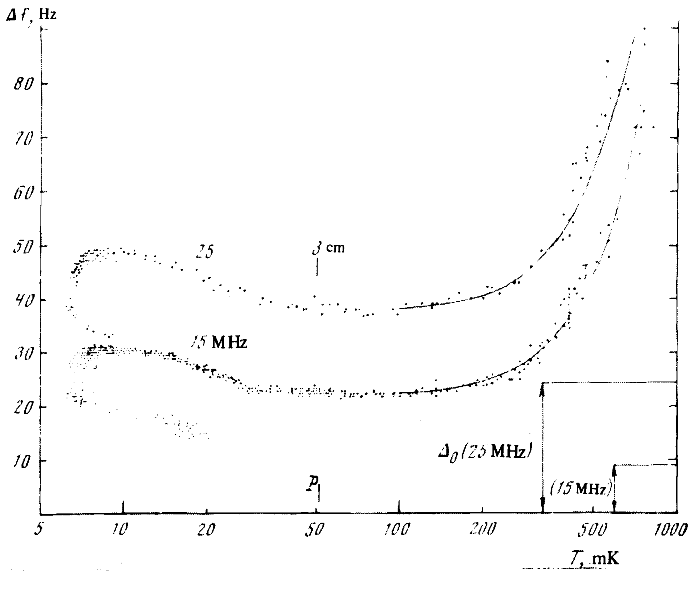

FIG. 3. Temperature dependence of the widths of the resonance curves of a quartz resonator at frequencies 15 and 25 MHz. The results of six experiments are given for 15 MHz and of three experiments for 25 MHz. Solid lines—calculation in accordance with the formula $\Delta f=\Delta_0+(2/\pi\rho_q l_q)\,\mathrm{Re}\,z$ at $\alpha=0.19$, $l\,[\mathrm{cm}]=10^{-7}(1.6\nu^{1/3}/T^2+1/\nu)$.

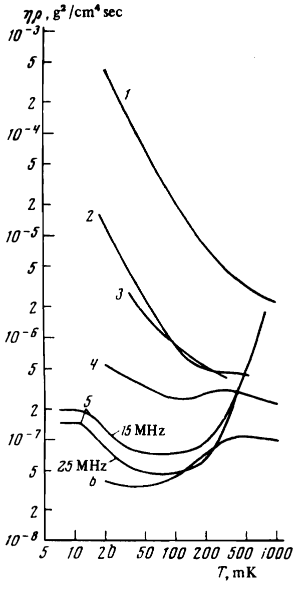

FIG. 4. Values of $\eta\rho$: curve 1—pure ^{3}He in accordance with the data on η_3 from[5] and on ρ_3 from[17]; curve 2—value of $\eta\rho_n$ for a 5% solution of ^{3}He in ^{4}He, obtained on the basis of the theoretical data on η of a 5% solution from[7] and on ρ_n from[21]; curves 3 and 4—data for 5% solution of ^{3}He in ^{4}He from[12] and[22], respectively; curves 5—our measurements of $\eta\rho_n$ in the upper phase of the laminated solution of ^{3}He in ^{4}He; curve 6—data of[21] for 2% solution of ^{3}He in ^{4}He.

occurred at $T \sim 7$–8 mK, and Δf remained practically unchanged. With further cooling due to depletion of the 6% solution of the ^{3}He, the value of Δf decreased. Then, when practically all the ^{3}He was drawn out of the solution, heating of the dilution chamber started, and in this case Δf was close to the width Δ_0 of the quartz resonance line in vacuum. The corresponding values of Δ_0 for 12 and 25 MHz are shown in Fig. 3 by arrows. A hydrodynamic analysis of the interaction between quartz that executes shear oscillations (only its central part oscillates) with a liquid leads to the following relation between the parameters characterizing the liquid and the quartz resonator[15]:

$$\eta\rho = \frac{\pi}{4}\frac{(\rho_q l_q)^2}{f}(\Delta f - \Delta_0)^2. \tag{1}$$

Here η is the coefficient of the first viscosity of the liquid, ρ is the density, ρ_q is the density of the quartz (2.65 g/cm³), l_q is the thickness of the quartz resonator, in our case $3.32 \cdot 10^{-2}$ cm, f is the resonance frequency of the quartz, and Δf and Δ_0 are the widths of the resonance curve of the quartz in the liquid and in vacuum, respectively.

At $T < 0.1$ °K, the upper phase in which the quartz was situated was practically pure ^{3}He. If we use the experimentally verified formula for the concentration of ^{4}He (ν_4) in a saturated solution of ^{4}He in ^{3}He[16]:

$$\nu_4 = 0.85 T^{1/2} e^{-0.56/T}, \tag{2}$$

then ν_4 ranges from 10^{-4} at $T = 0.1$ °K to $4 \cdot 10^{-28}$ at $T = 0.01$ °K. Thus, the values of $\eta\rho$ determined by us at $T < 0.1$ °K should be attributed to the pure ^{3}He. The viscosity of the liquid ^{3}He was measured by various methods.[2-6] All the measurement results differed from one another by not more than 1.5 times and show that the viscosity decreases like $1/T^2$ with decreasing temperature. Curve 1 of Fig. 4 shows a plot of $\eta\rho$ for pure ^{3}He. (The value of η_3 was taken from[5] and that of ρ_3 from[17].) This behavior of the viscosity of liquid ^{3}He should lead to a monotonic increase of the width of the resonance curve of the quartz with decreasing temperature. However, as follows from Fig. 3, Δf of quartz has a complicated temperature dependence. The effective value of $\eta\rho$ calculated from the results of measurements of Δf by formula (1) is shown in Fig. 4 (curves 5). As seen from curves 5 and 1 of Fig. 4 the discrepancy, at $T \leq 50$ mK, between the known value of $\eta\rho$ of ^{3}He and that which follows from our experiments was more than 10^3. We attribute this discrepancy to the existance of a number of phenomena which occur on the surface of a solid immersed in liquid helium.

First, that surface of the solid which is in the upper ^{3}He-rich phase of the solution is covered by a superfluid film which is rich in ^{4}He. This film separates the surface of the solid from the liquid ^{3}He. Second, in the film itself, owing to the difference between the atomic volumes of ^{3}He and ^{4}He, a concentration gradient is produced in the field of the Van der Waals forces, as has already been noted in the literature,[18-20] and the moving ^{3}He atoms do not reach the surface of the solid.

An estimate of the dependence of the ^{3}He concentration in the film on the distance x to the surface of the solid can be obtained[20] from the following considerations. The variation of the potential of the Van der Waals forces with changing distance is not known, but a dependence of the type Ax^{-3} in the calculation of the thickness of the ^{4}He films produced on the walls yields satisfactory results. Assume that the liquid ^{4}He expels the ^{3}He atoms floating in it with a force that is smaller by a factor $(n_4 - n_4)/n_4$ than the Van der Waals forces acting on the ^{4}He. Then the additional contribution from the Van der Waals forces to the chemical potential of the ^{3}He atoms in the film is determined by the term $Ax^{-3}(n_4 - n_3)/n_4$, that is,

$$\mu_3(x, \nu) = \varepsilon_0 + kT_F[1 - \pi^2 T^2/12 T_F^2] + Ax^{-3}(n_4 - n_3)/n_4, \tag{3}$$

where ε_0 is the zero-point energy, k is Boltzmann's constant, $T_F = \hbar^2(3\pi^2 n\nu)^{2/3}/2m^*k$ is the Fermi temperature, $\hbar$ is Planck's constant, n_1, n_3, and n_4 are the atomic densities of the solution in the film and of the liquid ^{3}He and ^{4}He, $m^* = 2.1 m_3$ [21] is the effective mass, m_3 is the mass of the ^{3}He atom, and $A \approx 10^{-36}$ erg-cm³ is a constant determined from the thickness of the film.[20] In this case we obtain for the concentration ν of the ^{3}He in the film the relation

$$\nu(x, T) = \nu_\infty(T)[1 - B(T)x^{-3}]^{3/2}, \tag{4}$$

where $B \approx 2 \cdot 10^{-21}$ cm³, $\nu_\infty = 0.23$ at $T = 0.5$ °K and $B \approx 4 \cdot 10^{-21}$ cm³, $\nu_\infty = 0.065$ at $T = 0.05$ °K. This formula shows that the concentration of the ^{3}He in the film remains practically constant, and only at $x \leq 20$ Å does it being to decrease rapidly, vanishing at $x \leq 15$ Å. This means that if we have a surface with roughness smaller than 15 Å, then the ^{3}He, which is responsible for the viscosity of the solution, will not be dragged at all by the tangential motion of the surface, that is, slipping of the surface of the solid relative to the liquid solution will be observed. If the surface has roughnesses much larger than 15 Å (for example, the usual matte surface) and moves tangentially, then the ^{3}He will be dragged by those sections of the rough surface which are normal to the motion.

Everything said above concerning the slipping phenomenon should be observed also in unsaturated solution of ^{3}He in ^{4}He. From this point of view, the fact that different values were obtained by different methods for $\eta\rho_n$ of a 5% solution of ^{3}He in ^{4}He is quite natural. In the experiments of Fisk and Hall[11] with a string viscosimeter, which agree also with the experiments of Kuenhold[10] with a capillary viscosimeter, the obtained viscosity values were apparently close to the hydrodynamic viscosity of the solution (the surfaces of the string and of the capillary were not polished). Curve 3 of Fig. 4 shows the value of $\eta\rho_n$ for a 5% solution of ^{3}He in ^{4}He from the experimental data obtained for η by Fisk and Hall,[11] with ρ_n of the solution taken from[21]. Curve 4, which differs considerably from it, represents the value of $\eta\rho_n$ obtained by Bertiant *et al.*[22] by measuring the damping of torsion oscillations of quartz in a 5% solution of ^{3}He and ^{4}He. The quartz had a polished surface, and this ensured partial slipping of the quartz relative to the liquid solution of ^{3}He in ^{4}He. Failure to take slipping into account leads to an appreciable underestimate of the value of $\eta\rho_n$ of the solution.

An examination of the film produced on the surface of a solid immersed in a liquid rich in ^{3}He from the point of view of the hydrodynamic characteristics of the liquid of the film, leads to the following picture. In the temperature range 0.8–0.1 °K, the mean free path of the ^{3}He atom in the solution of the film is smaller than the film thickness d (in our case $d \sim 5 \cdot 10^{-6}$ cm[20]), and furthermore l is less than the depth δ of the viscous wave, that is, the film can be regarded in this temperature interval as a viscous liquid. Since the viscous penetration depth δ in the film is $\delta \ll d$, we can disregard, in the calculation of the interaction of the quartz with the solution and the film, the backward viscous wave reflected from the boundary between the solution in the film and the solution rich in ^{3}He. In view of the low concentration of the ^{3}He in the film, we shall regard the solution of the atoms ^{3}He in ^{4}He as a degenerate Fermi gas. Since the solid wall is rough, a fraction α of the ^{3}He atoms is reflected diffusely when colliding with the wall, that is, on the average, this fraction acquires on the average the tangential velocity of the moving surface u_0, while the fraction $(1-\alpha)$ of the atoms is specularly reflected and retains the tangential velocity it had prior to the collision with the surface. Then, in analogy with a rarefied gas,[23,24] the tangential force τ experienced by a unit moving surface is equal to

$$\tau=\alpha[{}^1/_2\eta\partial u_1/\partial x+{}^1/_6\rho_n v_F(u_1-u_0)], \tag{5}$$

where η is the viscosity of the gas, which assume equal to $\rho_n v_F l/3$, ρ_n is the density of the gas, x is the coordinate perpendicular to the moving surface, v_F is the Fermi velocity of the ^{3}He atoms, u_1 is the average tangential velocity of the ^{3}He atoms at the surface itself, and l is the mean free path of the ^{3}He atoms. In this case

$$u_1={}^1/_2[(u_1+l\partial u_1/\partial x)+(1-\alpha)(u_1+l\partial u_1/\partial x)+\alpha u_0].$$

The first term pertains here to the gas atoms incident on the surface from the layer l, while the second and third terms pertain to the gas atoms that move away from the surface after specular or diffuse reflection, respectively.

Thus,

$$u_1-u_0=\frac{2-\alpha}{\alpha}\left(\frac{\partial u_1}{\partial x}\right)l. \tag{6}$$

For the viscous wave moving away from the surface we have

$$\partial u_1/\partial x=-(1+j)u_1/\delta. \tag{7}$$

From (5)–(7) we obtain

$$z=-\frac{\tau}{u_0}=\frac{\rho_n v_F}{3}\left[\left(\frac{2}{\alpha}-1\right)+\frac{\delta}{(1+j)l}\right]^{-1}. \tag{8}$$

The width Δf of the resonance curve of the quartz, due to the interaction with the external medium, is connected with the quantity z in the following manner[15]:

$$\Delta f=\frac{2\,\mathrm{Re}\,z}{\pi\rho_\kappa l_q}. \tag{9}$$

Taking the values of ρ_n on the lamination curve from[21,25]:

$$v_F\left[\frac{\text{cm}}{\text{sec}}\right]=8.7\cdot10^3\,\nu^{1/3}\left(\frac{1-0.44\nu}{1-0.25\nu}\right)^{1/3}$$

and writing down in the region of the degeneracy of the Fermi gas, in analogy with Baym and Ebner,[8] the mean free path in the form of a sum of two terms, we obtain at $\alpha = 0.19$ and l [cm] $= 10^{-7}(1.6\nu^{1/3}/T^2 + 1/\nu)$ fairly good agreement with experiment (Fig. 3, solid curves). (Here ν is the molar concentration of ^{3}He in the film, assumed equal to the concentration of the ^{3}He in the superfluid phase corresponding at the given temperature to the lamination curve.)

It should be noted that the value $\alpha = 0.19$ is more likely to be highly overestimated, owing to the roughness of the surface. As seen from the electron microscope photograph[1)] in Fig. 5, the surface of the gold layer deposited on the quartz was not smooth within 15 Å. To produce the photograph, the gold layer was separated from the quartz by etching in hydrofluoric acid. l becomes equal to the film thickness at $T \sim 0.1$ °K, and much larger at $T < 0.1$ °K. The concept of

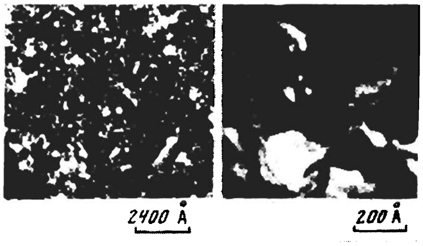

FIG. 5. Electron-microscope photograph of gold film.

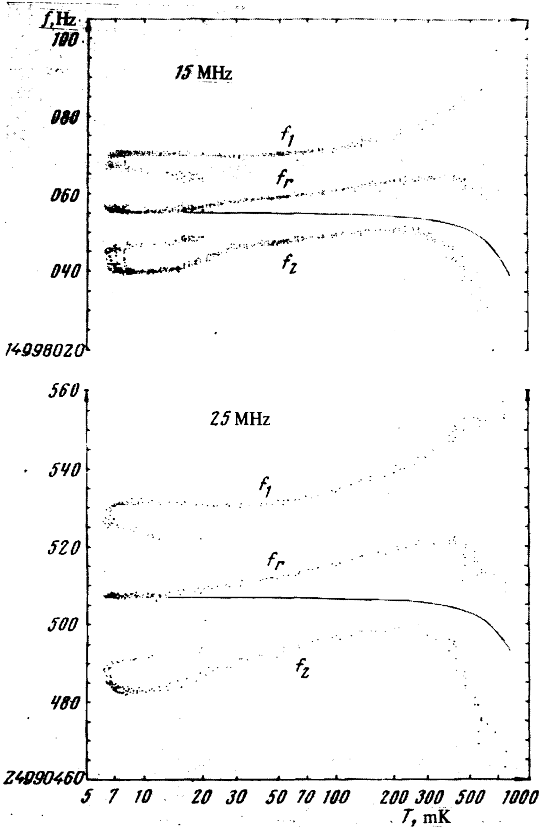

FIG. 6. Temperature dependence of f_1, f_2, and f_r at 15 and 25 MHz. The solid lines were calculated in accordance with Eq. (12).

hydrodynamic viscosity in a film becomes meaningless at $T<0.1$ °K. Curves 5 of Fig. 4, for $\eta\rho_n$ at $T<0.1$ °K, are arbitrary in character and are shown for comparison with the results of other experiments.

The question of the interaction of a quartz resonator in the temperature region where $l \gg d$ can be analyzed in the following manner: the ^{3}He atoms, after interacting with the quartz, transfer the momentum acquired from the moving quartz surface to the liquid ^{3}He. The time of flight of the ^{3}He atoms through the film is much less than the period of the oscillations of the quartz resonator, that is, the momentum carried by the ^{3}He atoms from the surface of the quartz through the film is transferred completely and in phase to the liquid ^{3}He, producing a viscous wave in the latter. We can therefore write

$$\tau={}^1/_6\alpha\rho_n v_F(u_0-u_3)=u_3(1+j)(\omega\rho_3\eta_3/2)^{1/2}, \tag{10}$$

where u_3 is the velocity of the liquid ^{3}He on the boundary with the film; η_3 and ρ_3 are the viscosity and density of the liquid ^{3}He. From (10) we can obtain for z the expression

$$z=-\frac{\tau}{u_0}=a\frac{\varphi+2\varphi^2}{1+2\varphi+2\varphi^2}+ja\frac{\varphi}{1+2\varphi+2\varphi^2};$$
$$a=\alpha\rho_n v_F/6, \qquad \varphi=(\omega\rho_3\eta_3/2)^{1/2}/a. \tag{11}$$

At $t=0.05$ °K, $\rho_n=0.015$ g/cm^3, $\eta_3=2/T^2$ [micropoise] we have $a=8.7\alpha$ and $\varphi\approx 7/\alpha$, and with good accuracy we have $\mathrm{Re}z=a$ is constant and independent of ω. Comparing with the experimental data for $\Delta f-\Delta_0=2(\mathrm{Re}z)/\pi\rho_q l_q$, we obtain for α the value 0.22, which is in good agreement with the value of α obtained from the hydrodynamic analysis at $T>0.1$ °K.

It follows also from (10) that

$$|u_3/u_0|=(1+2\varphi+2\varphi^2)^{-1/2}\sim T.$$

At $T=0.05$ °K we obtain $|u_3/u_0|=0.02$, that is, at these temperatures the liquid ^{3}He is practically not dragged, owing to its large viscosity, and behaves like a solid wall. It was therefore to be expected that with decreasing temperature the losses of the quartz should become constant. This was observed in experiment down to 0.04 °K (Fig. 3). However, starting with 0.04 °K and down to $T\approx 0.012$ °K, both at 15 and 25 MHz, the losses of the quartz resonator and the liquid almost double. With further lowering of the temperature, the quartz losses remain constant down to 7 mK. This increase of the quartz lost in the liquid remains unexplained so far.

In the course of the experiments we measured not only the width of the resonance curve but, accurate to 1 Hz, the absolute value of the frequencies. Figure 6 shows the dependence of the frequencies f_1, f_2, and $f_r=(f_1+f_2)/2$ on the temperature for the third and fifth harmonics of the quartz oscillations. f_1 and f_2 are the frequencies at which the amplitude of the oscillations of the quartz is smaller than the resonant value by a factor $\sqrt{2}$. The solid curves in the same figure correspond to the frequencies calculated from the formula

$$f=f_0-\frac{\mathrm{Im}\,z}{\pi\rho_q l_q}, \tag{12}$$

where f_0 was chosen such that the frequencies f and f_r coincide at 0.01 °K; Imz is the imaginary part calculated from formula (8) at $T>0.1$ °K and from formula (11) at $T<0.1$ °K. If the shift of the resonant frequency were to be determined only by the reaction of the liquid helium, then the values of f and f_r would coincide. As seen from the curves of Fig. 6, this is not the case. There is a noticeable difference between f and f_r, and this is due to the character of the gold layer deposited on the quartz. It is seen from the photograph of Fig. 5 that the gold layer consists of a large number of minute crystallites with dimensions 50–300 Å. The liquid helium has penetrated into the space between the crystallites, changing the resonant frequency but causing no additional losses. If we compare the relative shift $(f_r-f)/f_r$ of the resonant frequency from the calculated one, then in the temperature range from 0.01 to 0.6 °K it is the same for 15 and 25 MHz, and increases with increasing temperature. This means that the mass of the liquid helium contained in the pores of the gold layer varies with temperature. With increasing temperature, part of the ^{4}He atoms should be replaced by ^{3}He atoms as a result of the increase of the concentration of the ^{3}He in the film. This is precisely the dependence observed in our case. Of course, owing to the uncertainty in the structure of the gold layer, one cannot hope to obtain a sufficiently accurate quantitative description of the phenomenon. An estimate at $T = 0.4\ ^\circ\mathrm{K}$ by means of the formula

$$\Delta d = \frac{f_r - f_0}{2f_r}\frac{\rho_q l_q}{\Delta\rho}$$

yields $\Delta d \approx 3 \cdot 10^{-6}$ cm, where $\Delta\rho$ is the difference between the density of ^{4}He and the density of the solution of the lower phase at $T = 0.4\ ^\circ\mathrm{K}$, and Δd is the thickness of the liquid-helium layer penetrating into the pores of the gold film of approximate 1.5 μ thickness.

Thus, our experiments have shown that the presence of a film of a superfluid phase of approximate thickness 10^{-6}–10^{-5} cm on the surface of a solid changes radically the character of the interaction forces between the ^{3}He atoms and the solid surface, even in the most concentrated ^{3}He–^{4}He solutions. In addition, in the field of the Van der Waals forces the difference between the atomic volumes of ^{3}He and ^{4}He produces, on the solid wall a layer of approximate thickness 10–15 Å, consisting only of ^{4}He atoms, and if the surface is smooth enough this should cause the tangential forces of the interaction of the ^{3}He with the solid wall to vanish.

In our case, where a gold film was deposited on the polished quartz, slippage of the ^{3}He atoms was observed, described by an accommodation coefficient $\alpha \approx 0.2$. In the temperature range from 0.1 to 0.8 °K, in solutions with a concentration ν of ^{3}He in ^{4}He, the mean free path of the ^{3}He atoms, determined from measurements of the viscous losses, turned out to be

$$l[\mathrm{cm}] = 10^{-7}\left(1.6\frac{\nu^{1/3}}{T^2} + \frac{1}{\nu}\right).$$

It must be emphasized once more that the increase of the damping of the quartz oscillations observed at temperatures below 40 mK, while located in the region where phenomena analagous to zero sound should be expected in the shear oscillations of liquid ^{3}He, cannot be explained on the basis of the presented concepts.

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1) The authors are grateful to V. E. Zhokhov for obtaining the photographs.

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