CREATION OF SUPERFLUID HELIUM ROTONS BY A SOLID'S PHONONS INCIDENT NORMAL TO THE INTERFACE

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We solve the one-dimensional problem of quasiparticles' transfer through the interface between a solid and superfluid helium. Superfluid helium is treated as a continuous medium with correlations. When a solid's phonon is incident on the interface, phonons, R^- and R^+rotons are created in helium, and their creation probabilities are obtained. When a quasiparticle of superfluid helium is incident, it can be reflected as any one of the three quasiparticles, and the corresponding probabilities are derived. The R^- rotons creation and detection probability are both shown to be small, and this explains why they could not be detected experimentally for a long time.

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1. INTRODUCTION

The dispersion curve of superfluid helium $\Omega(k)$ was first sketched by L. D. Landau, and later it was measured in various experiments, particularly on neutron scattering in helium. The curve has a specific form: it is almost linear at small wave vectors k, then reaches the maximum called the "maxnon maximum", goes down to the "roton minimum", then goes up again, and finally becomes unstable. The quasiparticles that populate the mostly linear part of the curve are called phonons, R^- rotons are on the downward section left from the minimum, and R^+rotons are to the right from the minimum. The R^-rotons are quasiparticles with negative dispersion $d\Omega/dk < 0$, i.e. they propagate in the direction opposite to the one of the momentum they carry. However, for a long time they could not be detected in direct experiments, such as the experiments on creating beams of quasiparticles in superfluid helium by a solid heater [1]. The first time they were registered was in 1999, when the experimental group of A.F.G. Wyatt used a special cunningly constructed source to create them and detection was achieved by means of quantum evaporation [2]. This event made relevant some questions regarding R^-rotons, in particular the explanation of the failures to detect them earlier became necessary.

In order to describe rotons and phonons in a unified way, a model of quantum fluid was proposed [3], in which it is treated as a continuous medium with correlations. This theory is based on the fact that the thermal de Broglie wavelength of a particle of a quantum fluid exceeds the average interatomic separation. Then the variables of the continuous medium can be assigned values in each mathematical point of space in the probabilistic sense, but the relations between them become nonlocal. This nonlocality allows one to describe a continuous medium with an arbitrary dispersion relation. The quasiparticles are described then as wave packets propagating in the medium.

In a series of papers [4-6] the theory built in [3] was applied to solve the problem of waves' transmission through the interface between a solid and a quantum fluid, for the case when the dispersion relation of the latter is nonlinear. The considered dispersion relation was the one of BEC in the approximation of point-like interaction [7], which is essentially nonlinear, though monotonic. The problem was solved in full, and the reflection and transmission coefficients were derived as functions of the incidence angle and frequency.

In the present work we consider the same problem with the dispersion relation of the form that approximates well the specific dispersion curve of superfluid helium with its phonons and rotons. We solve the problem of any quasiparticle incident on the interface from either side in the one-dimensional case. This includes creation and reflection of rotons on the interace.

Section 1 contains derivation of the solutions of the equations describing the quantum fluid with the taken dispersion relation in the half-space. The problem of a solid's phonon incident on the interface is solved in section 2. The probabilities of creation of either the reflected phonon or the phonon or R^-roton or R^+roton in superfluid helium are obtained as the corresponding reflection and transmission coefficients for wave packets. The second part of this problem, when one of the quasiparticles of superfluid helium is incident on the interface, is solved in section 3. The probabilities of each quasiparticle creation are obtained. It is shown that the total reflection probability of an R^-roton is close to unity, while its creation probability on the interface is very small compared to the other quasiparticles' of superfluid helium. This makes the detection by a solid detector of R^-rotons created by a solid heater almost impossible, and explains why they were not detected until 1999.

The results are also important for classical acoustics, as an example of solution of the problem of creating multiple waves lying on the same non-monotonic dispersion curve.

2. QUANTUM FLUID WITH ROTON-LIKE DISPERSION RELATION

In the model of quantum fluid built in [3] it is described by the linearized equations of ideal liquid with nonlocal relation between pressure and density. In the one-dimensional case, when the fluid fills the half-line

$x>0$, the problem in terms of pressure P can be brought to the form

$$\frac{\partial^2 P(x,t)}{\partial x^2}=\int_0^\infty dx' h(x-x')\frac{\partial^2 P(x',t)}{\partial t^2},\qquad (1)$$
$$x\in(0,\infty),\ t\in(-\infty,\infty).$$

The Fourier transform of the kernel $h(x)$ is related with the dispersion relation of the quantum fluid [3]

$$h(k)=\frac{\Omega^2(k)}{k^2}.\qquad (2)$$

In this work we consider the dispersion relation of the form

$$\Omega^2(k)=s^2k^2\left\{1+\frac{k^2}{k_g^2}\left(2\lambda+\frac{k^2}{k_g^2}\right)\right\}.\qquad (3)$$

Here s is the sound velocity at zero frequency; k_g is the quantity that defines the scale of wave vectors on which $\Omega(k)$ becomes essentially nonlinear; parameter λ determines the form of the dispersion curve. The values $\lambda<-1$ give negative $\Omega^2(k)$ for a range of wave vectors and therefore are not physically relevant; $\lambda>-\sqrt{3}/2$ provide monotonic function $\Omega^2(k)$ that does not differ in principle from the relation already considered in [6]. In the interval $\lambda\in\left(-1,-\sqrt{3}/2\right)$ the dispersion curve is non-monotonic, with the "maxnon" maximum $\omega_{\max}$ and the "roton" minimum ω_{rot}, and the value of $\lambda=-0{,}98$ gives good approximation of the dispersion relation of superfluid helium (see Fig.1).

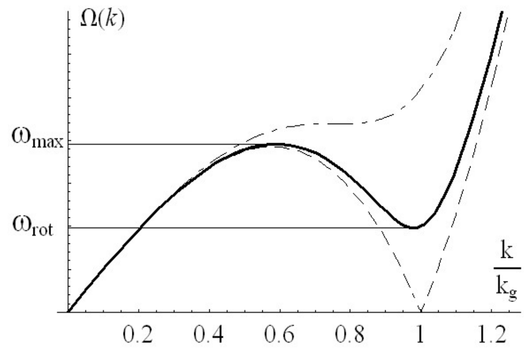

Fig. 1. *The curves $\Omega(k)$ for $\lambda=-1$ (dashed), $\lambda=-0.98$ (thick solid) and $\lambda=-\sqrt{3}/2$ (dash-dotted). The roton minimum ω_{rot} and maxnon maximum $\omega_{\max}$ are shown for $\lambda=-0.98$*

In this paper we restrict our consideration to the last case, that is most interesting, and to frequencies $\omega\in(\omega_{rot},\omega_{\max})$. In this interval all the six roots $\pm k_{1,2,3}$ of dispersion equation

$$\Omega^2(k_i)=\omega^2,\qquad (4)$$

are real and can be put in the order $0<k_1^2<k_2^2<k_3^2$. Then k_1 corresponds to a superfluid helium's phonon, k_2 to R$^-$roton and k_3 to R$^+$roton.

The kernel $h(x)$ that corresponds to the dispersion relation (3) is obtained from (2) and (3):

$$h(x)=h_+\exp\left(ik_+|x|\right)+h_-\exp\left(-ik_-|x|\right).\qquad (5)$$

Here

$$h_\pm=\frac{ik_\mp}{2s^2}\frac{k_g^2}{k_+^2-k_-^2}\qquad (6)$$

and $k_\pm$ are the poles of $h(k)$, that in the considered case $\lambda\in\left(-1,-\sqrt{3}/2\right)$ can be written as

$$k_\pm=k_g\left(\sqrt{1-\lambda}\pm i\sqrt{1+\lambda}\right)/\sqrt{2}.\qquad (7)$$

The problem (1) was solved by Wiener-Hopf method in [5] for $\Omega^2(k^2)$ of polynomial form, and the solutions were shown to be sums of waves that correspond to all the roots of dispersion equation (4) in the complex k plane. Therefore we can search for solutions of (1) with the kernel $h(x)$ from (5) in the form

$$P(x.t)=\sum_i\alpha_i\exp(ik_ix-i\omega t).\qquad (8)$$

Substituting (7) and (5) into (1), we obtain that all the k_i of (8) really have to be the roots of equation (4), and the amplitudes of the waves α_i satisfy the two equalities

$$\sum_i\frac{\alpha_i}{k_i-k_+}=0,\quad \sum_i\frac{\alpha_i}{k_i+k_-}=0.\qquad (9)$$

The number of waves in the solution (8) can be up to six. However, when we solve a definite problem of waves' transmission through the interface, the given asymptotes of the solution at infinity force some of the amplitudes to be equal to zero. Then the boundary conditions stated on the interface, together with equations (9), provide enough equations for the problem to be solved in full.

3. CREATION OF PHONONS AND ROTONS OF SUPERFLUID HELIUM BY A SOLID'S PHONONS

Let there be an interface $x=0$ between a solid and the quantum fluid dispersion relation (3) and let a phonon of the solid be incident on the interface. The solid with density ρ_{sol} and sound velocity s_{sol} occupies the half-space $x<0$, and is described as an ordinary continuous medium. The quantum fluid with density ρ_0 and dispersion relation (3) fills the region $x>0$, and is treated as a continuous medium with correlations (1). Quasiparticles of energy $\hbar\omega$ are wave packets propagating in corresponding media with the carrier frequency ω. It can be shown (see for example [5]), that the wave packet's interaction with the interface can be described in the first approximation as that of a plane wave with the carrier frequency. All the transmission and reflection coefficients are obtained then as those quantities for plane waves.

In the problem formulated for plane waves, the solution in the solid is known to consist of the incident and reflected waves. The solution in the quantum fluid can consist only of waves that are constitutuents of wave packets traveling away from the interface, i.e. with $d\Omega/dk > 0$, so there is only one of each pair $\pm k_1, \pm k_2, \pm k_3$. We define the signs of roots $k_{1,2,3}$ of (4) for them to be the wave vectors of this solution. As R⁻ rotons have negative dispersion, the R⁻roton wave of the out-solution has negative wave vector $k_2 < 0$, and the roots are put in order as

$$0 < k_1 < -k_2 < k_3 . \tag{10}$$

With the help of relations (9) we can put down this "out-solution" in the form with a single "amplitude"

$$\widetilde{P}_{out}(x,t) = \widetilde{P}_{out}(0)\sum_{i=1}^{3}\frac{(k_i - k_+)(k_i + k_-)}{\prod_{j\neq i}(k_i - k_j)}\exp(ik_i x - i\omega t) . \tag{11}$$

The hydrodynamic velocity is found from (11) and the linearized equations of ideal liquid

$$\widetilde{V}_{out}(x,t) = \frac{\widetilde{P}_{out}(0)}{\rho_0\omega}\sum_{i=1}^{3}k_i\frac{(k_i - k_+)(k_i + k_-)}{\prod_{j\neq i}(k_i - k_j)}\exp(ik_i x - i\omega t) . \tag{12}$$

The three plane waves in (11) and (12) correspond to the phonon, R⁻roton and R⁺roton wave packets that travel away from the solid, R⁻roton having momentum $\hbar k_2$ directed towards the interface.

The two boundary conditions, that demand continuity of pressure and velocity on the interface, sew together the solutions in the quantum fluid (11), (12) and in the solid. Then the amplitudes of the reflected and transmitted waves are expressed in terms of the amplitude of the incident wave. The reflection coefficient, defined as the ratio of pressures in the reflected and incident waves, is obtained

$$r_{\rightarrow} = \frac{Z_0\chi - \widetilde{f} + i\Delta}{Z_0\chi + \widetilde{f} - i\Delta} . \tag{13}$$

Here Z_0 is the impedance of the interface at zero frequency, χ is dimensionless frequency, Δ is a constant, $\widetilde{f}$ is a construction of wave vectors $k_{1,2,3}$, that can be shown to be the function of only χ and λ:

$$Z_0 = \frac{\rho_0}{\rho_{sol}}\frac{s}{s_{sol}}; \quad \chi = \frac{\omega}{sk_g}; \quad \Delta = \sqrt{2(1+\lambda)};$$
$$\widetilde{f}(\lambda,\chi) = \frac{f_3}{k_g f_2}; \tag{14}$$
$$f_n = k_1^n(k_2 - k_3) + k_2^n(k_3 - k_1) + k_3^n(k_1 - k_2), \quad n = 2,3.$$

When the solid's phonon is incident on the interface, it is either reflected with certain probability, or one of the three possible quasiparticles is created in the superfluid helium. The probability of the phonon's reflection is equal to the reflected fraction of the incident wave's energy density $|r_{\rightarrow}|^2$ in the problem formulated in terms of plane waves. The energy transmission coefficient is the fraction of energy density that is transferred through the interface $D^{\rightarrow} = 1 - |r_{\rightarrow}|^2$, so from (13) we have

$$D^{\rightarrow} = \frac{4Z_0\chi\widetilde{f}}{(Z_0\chi + \widetilde{f})^2 + \Delta^2} . \tag{15}$$

It is the creation probability of either a phonon or an R⁺roton or an R⁻roton. The creation probability of each of them is the corresponding partial transmission coefficient – the fraction of the energy of the incident wave that is carried from the boundary by each of the three waves of superfluid helium.

The energy fractions are proportional to the energy density fluxes in each wave packet (not energy densities, as the packets differ in length due to difference in group velocities) when they all are far enough from the interface to be spatially separated. It was shown in [8] for the quantities averaged that over quick oscillations, the energy density flux in a wave packet Q_i is equal to $Q_i = u_i\varepsilon_i$, where ε_i is the energy density and u_i is the group velocity of the wave packet. The energy density in a wave packet can be brought to the form $\varepsilon_i = \rho_0 V_i^2/2$ [5], where V_i is the amplitude of hydrodynamic velocity. The relative amplitudes of velocities in the three wave packets, as well as in plane waves, are given by (12), and the group velocities are obtained from the dispersion relation (3), so the energy fluxes in the wave packets can be shown to be proportional to the coefficients

$$\xi_i = k_i(k_i^2 - k_j^2)(k_i^2 - k_k^2)(k_j - k_k)^2, \tag{16}$$

where $(i,j,k) = (1,2,3),(2,3,1),(3,1,2)$.

Then the partial transmission coefficients $D_i^{\rightarrow}$ for $i = 1,2,3$ are equal to

$$D_i^{\rightarrow} = \frac{\xi_i}{\xi_1 + \xi_2 + \xi_3}D^{\rightarrow} . \tag{17}$$

The structure of coefficients (16), together with inequalities (10), leads to the fact that $\xi_2 < \xi_{1,3}$ for all frequencies. Also we can see that near to the roton minimum $(k_2 + k_3) \sim \sqrt{\omega - \omega_{rot}}$ is a small parameter, so ξ_2 and ξ_3 also tend to zero as $\sqrt{\omega - \omega_{rot}}$. In the same way ξ_2 and ξ_1 tend to zero as $\sqrt{\omega_{\max} - \omega}$ in the neighborhood of maxnon maximum. So one can say that these two asymptotes of $\xi_2(\omega)$ at the ends of the interval of frequencies, in which R⁻rotons exist, pull the R⁻roton creation possibility curve to zero. The qualitatively described behavior of the partial transmission coefficients is well reflected by numerical evaluation of the curves $D_i^{\rightarrow}(\chi)$ for different parameters Z_0 and λ. Fig. 2 shows the partial and total transmission coefficients for $\lambda = -0.98$ and $Z_0 = 0.01$, which is common impedance for a boundary between superfluid helium and a solid.

The smallness of $D_2^{\rightarrow}(\chi)$ compared even to $D^{\rightarrow}(\chi)$, which is small by itself for the considered impedances, means that R⁻rotons are barely created in the experiments on creation of beams of quasiparticles of superfluid helium by a solid heater.

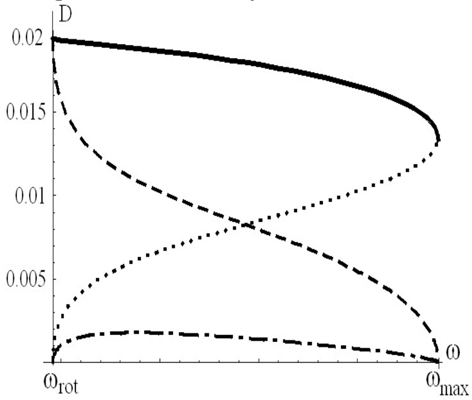

Fig. 2. *The total transmission coefficient* $D^{\rightarrow}$ *for a phonon incident on the interface from the solid (thick solid curve) and partial transmission coefficients* $D_i^{\rightarrow}$, *equal to creation probabilities of the phonon* $D_1^{\rightarrow}$ *(dashed),* R^-*roton* $D_2^{\rightarrow}$ *(dash-dotted) and* R^+*roton* $D_3^{\rightarrow}$ *(dotted), as functions of frequency. Here* $\lambda = -0.98$, $Z_0 = 0.01$

4. REFLECTION OF PHONONS AND ROTONS FROM THE INTERFACE

Now let us consider the problem when one of the quasiparticles of superfluid helium is incident on the interface with a solid. The solution in the solid is just one transferred wave. About the solution in the quantum fluid we know that there is only one wave that corresponds to the wave packet traveling towards the interface. Together with the wave packets traveling away from the interface there are four waves in the solution. Taking into account the two relations between the amplitudes (9), there are two free amplitudes. We take the already considered out-solution (11) as the first of the two linear-independent solutions, that constitute the full solution in the quantum fluid with the given asymptotes at infinity.

The second one is built this way: if, for example, a phonon (wave 1) is incident, we constitute the solution of waves with wave vectors $(-k_1)$, k_2 and k_3, with the amplitudes related through Eqs. (9). This way the linear combination of the in- and out-solutions gives the full solution in the quantum fluid when the incident quasiparticle is phonon, and consists of waves that give a phonon wave packet traveling towards the interface and three wave packets traveling away from it. The three sorts of in-solutions, corresponding to the type of the incident wave, can be written in the form

$$P_{in}^n(x,t) = P_{out}(x,t)\big|_{k_n \to -k_n}, \quad n = 1,2,3 \,. \tag{18}$$

The two boundary conditions provide two relations between the amplitudes of in- and out-solutions and the transmitted wave in the solid. Then the relative amplitudes of all the constituent waves are calculated with the use of (11) and (18). The energy fluxes are obtained in the same way as in the previous section.

When an i-th wave packet of superfluid helium is incident on the interface, all the three waves are reflected. We denote the fraction of the energy of the incident wave packet that is carried by the j-th reflected wave as R_{ij} for $i, j = 1,2,3$. It is shown that

$$R_{ii} = \frac{\left(k_g f_{-2}^{(i)} Z_0 \chi + f_{-3}^{(i)}\right)^2 + \Delta^2 k_g^2 f_{-2}^{(i)2}}{\left(k_g f_2 Z_0 \chi + f_3\right)^2 + \Delta^2 k_g^2 f_2^2} \,. \tag{19}$$

Here $f_{-n}^{(i)}$ are modified combinations of wave vectors $k_{1,2,3}$, that are equal to f_n from (14) in which one of the three wave vectors enters with the opposite sign: $f_{-n}^{(i)} = f_n[k_1, k_2, k_3]\big|_{k_i \to -k_i}$.

For $i \neq j$ $R_{ij} = R_{ji}$ and the expressions for them are obtained from the expression for R_{12} by cyclic permutation of subscripts in R_{12}, k_3 and u_3:

$$R_{12} = 4\chi^2 k_g^6 \frac{k_g^2}{k_3^2}\left|\frac{u_3}{s}\right| \frac{\left(Z_0\chi + k_3/k_g\right)^2 + \Delta^2}{\left(k_g f_2 Z_0 \chi + f_3\right)^2 + \Delta^2 k_g^2 f_2^2}. \tag{20}$$

In terms of quasiparticles the quantity R_{ij} gives the probability the quasiparticle of type i is reflected as type j, i.e. the probability that when a quasiparticle of type i is incident on the interface, the quasiparticle of type j is reflected, so R_{ij} can be called conversion coefficients. The probability that the quasiparticle i is reflected is $R_i = \sum_j R_{ij}$, the probability it is transmitted is its energy transmission coefficient $D_i^{\leftarrow} = 1 - R_i$. When all types of quasiparticles coexist in the quantum fluid in equilibrium, the fraction of the total energy flux incident on the interface, that is transmitted into the solid, can be shown to be equal to $D^{\leftarrow} = \sum_i^3 D_i^{\leftarrow}$, and thermodynamic equilibrium between the two media at equal temperatures demands that $D^{\rightarrow} = D^{\leftarrow}$. This equality can be checked in a straightforward way by simple, though a little cumbersome, calculations.

In the neighborhood of the roton minimum $\omega \approx \omega_{rot}$ the small parameters are $u_{2,3} \sim (k_2 + k_3) \sim \sqrt{\omega - \omega_{rot}}$, and the asymptotic behavior of conversion coefficients is obtained by direct substitution into $f_{\pm n}^{(i)}$ and then (19) and (20):

$$\begin{aligned} R_{11} &= O(1), \\ R_{22,33} &= O(\omega - \omega_{rot}), \\ R_{12,13} &= O\left(\sqrt{\omega - \omega_{rot}}\right), \\ R_{23} &= 1 - O\left(\sqrt{\omega - \omega_{rot}}\right). \end{aligned} \tag{21}$$

In the neighborhood of the maxnon maximum $u_{1,2} \sim (k_2 + k_1) \sim \sqrt{\omega_{\max} - \omega}$ and we obtain in the same way

$$\begin{aligned} R_{33} &= O(1), \\ R_{11,22} &= O(\omega_{\max} - \omega), \\ R_{31,32} &= O\left(\sqrt{\omega_{\max} - \omega}\right), \\ R_{12} &= 1 - O\left(\sqrt{\omega_{\max} - \omega}\right). \end{aligned} \tag{22}$$

The asymptotes (21) and (22) give us full qualitative description of R_{ij} behavior on frequency. In particular, the last equality of (21) means that when an R$^-$roton with frequency close to the roton minimum is incident, it is almost always reflected as R$^+$roton, and vice versa. The last equality of (22) means that when an R$^-$roton with frequency near to the maxnon maximum is incident, it is almost always reflected as phonon, and vice versa. The asymptotic behavior of the conversion coefficients R_{ij} is illustrated by Fig. 3, in which the curves $R_{ij}(\omega)$ are shown for the same parameters as in Fig. 2, $\lambda = -0.98$ and $Z_0 = 0.01$.

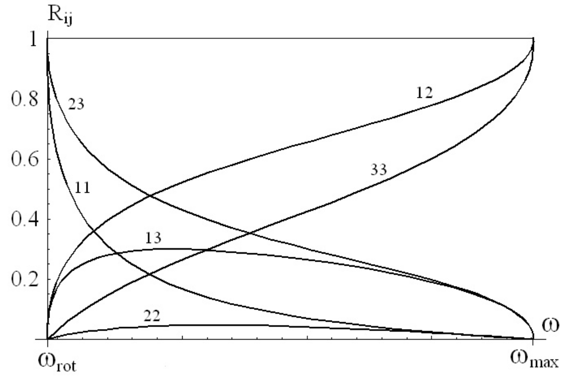

Fig. 3. *$R_{ij}(\omega)$ for $\lambda = -0.98$ and $Z_0 = 0.01$. The curves are denoted by the corresponding pairs of subscripts. R_{11} and R_{33} are cloze but not equal to unity at $\omega_{rot,\max}$ because of the small impedance, and the picture's scale just does not let us see the finite difference*

The total probability that R$^-$roton is reflected is $R_2 = R_{21} + R_{22} + R_{23}$, and so it tends to unity at both ends of the interval $\omega \in (\omega_{rot}, \omega_{\max})$. These two asymptotes pull to zero the curve of R$^-$roton detection probability $D_2^{\leftarrow}$, which is equal to $1 - R_2$, in the same way as $D_2^{\rightarrow}$ in the previous section. Moreover, the dependences $D_i^{\leftarrow}(\omega)$ are qualitatively the same as of $D_i^{\rightarrow}(\omega)$, so the transmission coefficient for R$^-$rotons $D_2^{\leftarrow}$ is much less than the ones for phonos $D_1^{\leftarrow}$ and R$^+$rotons $D_3^{\leftarrow}$ (see Fig. 2). This means that R$^-$rotons are very poorly detected by solid detectors, in comparison to phonons and R$^+$rotons. Put together with their small creation probability, it makes detection of R$^-$rotons in the experiments on creating beams of quasiparticles of superfluid helium by a solid heater almost impossible. This is the reason they could not be directly detected until 1999, when the experimental group of A.F.G. Wyatt used a special source and R$^-$ rotons were finally registered by means of quantum evaporation [2].

5. CONCLUSIONS

In this paper we considered the one-dimensional problem of quasiparticles' transfer through the interface between a solid and superfluid helium. This problem can be also formulated in terms of wave packets or plane waves. The dispersion relation of superfluid helium is non-monotonic, so there are multiple roots of dispersion equation $\Omega^2(k) = \omega^2$. The quasiparticles corresponding to these roots $0 < |k_1| < |k_2| < |k_3|$, in ascending order of wave vectors, are phonons, R$^-$rotons and R$^+$rotons. Creation probalilities of quasiparticles of each type $D_i^{\rightarrow}$ by a solid's phonon are obtained (17). The probabilities R_{ij} that a quasiparticle of type j is reflected when a quasiparticle of type i is incident on the interface are derived (18), (19). The R$^-$rotons creation $D_2^{\rightarrow}$ and detection $D_2^{\leftarrow}$ probability are both shown to be small, and this explains why they could not be detected until the experiments [2].

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REFERENCES

1. A.F.G. Wyatt, N.A. Lockberie, and R.A. Sherlock. Liquid ^{4}He: a tunable high-pass phonon filter //*Phys. Rev. Lett.* 1974, v. 33, p. 1425.
2. M.A.H. Tucker and A.F.G. Wyatt. Direct evidence for R$^-$ rotons having antiparallel momentum and velocity //*Science*. 1999, v. 283, p. 1150.
3. I.N. Adamenko, K.E. Nemchenko and I.V. Tanatarov. Application of the theory of continuous media to the description of thermal excitations in superfluid helium //*Phys.Rev. B*. 2003, v. 67, 104513.
4. I.N. Adamenko, K.E. Nemchenko and I.V. Tanatarov. Energy transfer through the interface into a quantum fluid with nonlinear dispersion relation //*J. of Low Temp. Phys*. 2005, v. 138, N 1/2, p. 397-403.
5. I.N. Adamenko, K.E. Nemchenko and I.V. Tanatarov. Normal transmission of phonons with anomalous dispersion through the interface of two continuous media //*Fiz. Nizk. Temp*. 2006, v. 32, N 3, p. 255-268 [*Low Temp. Phys.* 2006, v. 32, N 3, p. 187-197].
6. I.N. Adamenko, K.E. Nemchenko, and I.V. Tanatarov. Transmission of phonons with anomalous dispersion through the interface of two continuous media //Published online *J. of Low Temp. Phys*. 2006, v. 144, N 1/3, p. 13-34.
7. N.N. Bogoliubov. To the theory of superfluidity //*Izv. AN USSR, ser. fiz.* 1947, v. 11, # 1, p. 77-90.
8. I.N. Adamenko, K.E. Nemchenko and I.V. Tanatarov. The density of energy flow of quasiparticles with arbitrary energy-dispersion law //*The J. of Molecular Liquids*. 2005, v. 120, # 1-3, p. 167-169.

РОЖДЕНИЕ РОТОНОВ СВЕРХТЕКУЧЕГО ГЕЛИЯ ФОНОНАМИ ТВЕРДОГО ТЕЛА, ПАДАЮЩИМИ НОРМАЛЬНО НА ГРАНИЦУ

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Мы решаем одномерную задачу о прохождении квазичастиц через границу между твердым телом и сверхтекучим гелием. Сверхтекучий гелий описывается как сплошная среда с корреляциями. Получены вероятности того, что фонон твердого тела при падении на границу рождает фонон, R^- или R^+ротон сверхтекучего гелия. Также вычислены вероятности, с которыми отражается одна из трех возможных квазичастиц при падении на границу заданной квазичастицы сверхтекучего гелия. Показано, что вероятности рождения и регистрации R^-ротона малы, и, таким образом, дано объяснение тому, что в течение долгого времени они не были экспериментально зарегистрированы.

НАРОДЖЕННЯ РОТОНОВ НАДПЛИННОГО ГЕЛІЮ ФОНОНАМИ ТВЕРДОГО ТІЛА, ЩО ПАДАЮТЬ НОРМАЛЬНО НА ГРАНИЦЮ

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Ми розв'язали одновимірну задачу про проходження квазічастинок через границю між твердим тілом та надплинним гелієм. Надплинний гелій описується як суцільне середовище із кореляціями. Отримано ймовірності того, що фонон твердого тіла при падінні на границю народжує фонон, R^- або R^+ ротони надплинного гелію. Також обчислено ймовірності, з якими відбивається одна з трьох можливих квазічастинок при падінні на границю заданої квазічастинки надплинного гелію. Показано, що ймовірності народження й реєстрації R^- ротону малі, і, таким чином, дано пояснення тому, що протягом довгого часу вони не були експериментально зареєстровані.