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Abstract. In the present work we propose the explanation of the recently observed at temperatures about 1.7 K anomalous ultrasound attenuation in high-porous aerogels filled in by liquid ^{4}He by means of 2D-3D roton transformations. The existence of so-called 2D rotons in the system "aerogel-liquid ^{4}He" has been found early in the experiments on inelastic neutron scattering $T < 1.5\ K$ where the spectrum of roton excitations is well-defined. The difference in energies of 3D-rotons and 2D-rotons at low temperatures exceeds the energy of acoustic phonons and the process of transformation of 2D-roton to 3D-roton is forbidden by energy conservation law. But with increasing temperature the 2D-roton and 3D-roton states begin to be broadened (the lifetime of excitations is decreasing) and possibility of the mutual transformation of rotons with the participation of a phonon appears. The further increasing of temperature leads to the essential decreasing of superfluid density and the efficiency of the proposed mechanism decreases too. Numerical simulations show the qualitative agreement of the proposed mechanism with the observed data.

1. Introduction

Last decades liquid ^{4}He confined into different nano-porous media, like aerogel, Vycor glass, Gelsil glass etc., attracts much attention. ^{4}He in nano-porous media is an ideal example of bose system with disorder and/or an excellent model of bosons in an external potential [1]. Experimental and theoretical studies have revealed a number of features such as a suppression of superfluidity by disorder [2] and the alteration of $P - T$ phase diagram of ^{4}He confined to pores [1]. The critical exponents of superfluid density and the heat capacity of confined helium also seem to be different from that of the bulk helium [3].

Recent inelastic neutron scattering measurements investigated excitations in liquid ^{4}He confined to aerogel [4], vycor [5] and gelsil [6]. There was found a new type of excitations in confined ^{4}He, so called 2D-rotons, which believe to propagate in several liquid layers adjacent to media walls. Except these 2D-rotons excitation spectrum of confined ^{4}He was almost the same as that of bulk ^{4}He. Another important finding of inelastic neutron scattering measurements was that in confined ^{4}He the roton excitations exist well above superfluid transition temperature, and disappear only above the transition temperature of bulk ^{4}He [5], [6]. This led to the idea of existence of local BEC in confined ^{4}He above critical temperature.

Recently some new results on ultrasound measurements in helium-4 in aerogel have appeared [7], [9]. Sound velocity and sound attenuation in ^{4}He confined to several aerogel samples with different porosity and structure were measured. The most striking result was that in some

samples of aerogel temperature dependence of sound attenuation showed a well distinguished peak just below the superfluid transition temperature, while in other samples there were no evidence of the peak. In the present paper we try to explain this unusual phenomena.

2. Ultrasound attenuation peak below T_λ

Aerogel samples of five different porosities were studied, in the first series of experiment 92,6%, 94%, 97% [7], [8] in the second series 85.2%, 87.2% [9]. The broad peak in the temperature dependence of sound attenuation below superfluid transition was observed in 97% sample (see Fig. 1 and [8]) and 85.2% sample [9] only, so finally it was clear that porosity does not play crucial role in this phenomena.
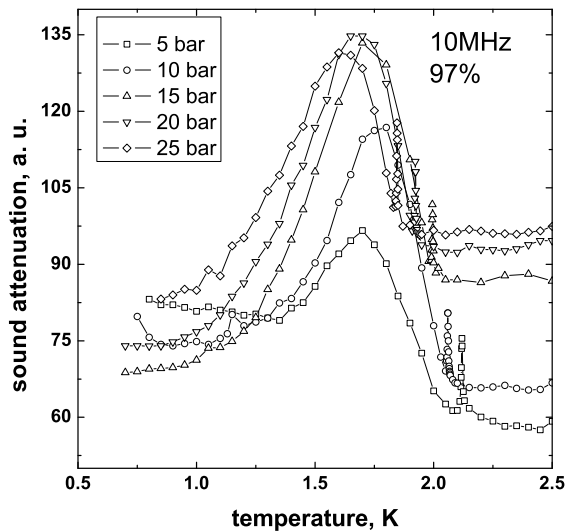

Figure 1. Temperature dependence of ultrasound attenuation in 97% aerogel filled in by liquid ⁴He at different pressures [7].

The 85.2% and 87.2% aerogels used in the second series of experiment were manufactured using some another method. Their pore size was homogeneous with very narrow pore distribution. They had two different types of structure, tangled strand structure for 85.2% aerogel and aggregated particles structure for 87.2% aerogel. 85.2% aerogel had much stronger mechanical strength due to structure difference. About aerogels from the first series of experiment we know, except porosity, that they had large pore size distribution, and nothing concerning structure. From this point of view it seems that it is the type of aerogels structure and its mechanical strength which is important to explain the presence or absence of the peak in sound attenuation.

3. Model

It is clear that sound attenuation is connected with some phonon scattering process. The main idea of this paper is to explain this attenuation, and especially the peak, as a result of the scattering process with the participation of phonon, ordinary roton (3D-roton) and the 2D-roton found in the experiments on inelastic neutron scattering. For this process to be possible, the energy conservation law should be satisfied. From neutron scattering experiments it is

known that the 2D-roton excitation spectrum looks like 3D one and can also be fitted by the same square function, but its minimum is shifted towards lower energies. Actually 3D-roton minimum is 0.74 meV, 2D one is 0.63 meV in aerogel accordingly to neutron scattering measurements[4]. The energies of phonons studied during ultrasound experiments are about five orders of magnitude smaller. Another important feature of excitation spectrum of confined ^{4}He is that at low temperatures the dynamic structure factor has a narrow peak and its width is determined by instrumental resolution. However, with increasing temperature the peak is broadened. In other words at low enough temperatures excitations have long (limited to infinity) lifetime, but with increasing temperature the lifetime decreases. The excitation spectrum line is transformed to the excitation spectrum band.

The qualitative explanation of the observed attenuation peak formation in [7], [9] is the following. At low enough temperatures the energy of phonon is much smaller than the difference of energies of 2D and 3D rotons. The energy conservation law is not satisfied and the process is impossible. With increasing temperature the 2D and 3D roton excitation spectrum lines are turned to the bands and start to overlap. The states, for which the energy conservation law is satisfied, appear, and their number grows with temperature. It leads to the increasing attenuation. But with further increase of temperature the intensity of roton peaks decreases and becomes zero at bulk transition temperature. This means that the number of roton excitations decreases, and consequently the number of proposed scattering processes decreases too.

The number of phonon scattering processes, and consequently the sound attenuation, is proportional to the product of numbers of 2D and 3D rotons with appropriate energies and the probability of the scattering process. At the moment we know nothing about the probability of the process, so lets assume that it does not change greatly with temperature. However, we can estimate the product of the 2D and 3D roton numbers. In the present experiment the energy of phonons is negligibly small, so 2D and 3D rotons involved in the scattering process should have almost the same energies. Accordingly to neutron scattering experiment [4] the 3D-roton line in the dynamic structure factor for ^{4}He in aerogel has a Lorenzian shape and its amplitude scales with temperature as superfluid density. The halfwidth of the line is also temperature dependent, so the line is broadened as temperature increases.

The data concerning 2D rotons is much more poor. In the neutron scattering experiments [4] 2D-rotons were found only at temperatures above 1.5 K. The 2D roton line was fitted by a Gaussian shape, but no data concerning temperature dependence of its parameters was given. It was only mentioned that 2D roton line is two or three times wider than 3D one, and with increasing temperature it also broadens and its intensity decreases. The simplified theoretical model for dynamic structure factor of ^{4}He on Si substrates [10] gives a good agreement with experimental data for porous media like Vycor glass but for aerogels the applicability of this model is under question because of complex web-like structure of them.

So to provide the numerical simulations for the proposed model of 2D-3D roton transformations it is necessary to make several assumptions. The first one is that 2D roton excitations exist in the whole temperature range below bulk critical temperature. Then one can assume that intensity and linewidth of 2D-roton line are proportional to that of 3D roton line and to fit the calculated temperature dependence of sound attenuation to the observed data one can vary the coefficient of proportionality. The result of simulations is shown in Fig. 3.

4. Conclusion

To explain the existence of the peak in the sound attenuation for aerogels filled in by liquid ^{4}He below T_λ the theoretical model of 2D-3D roton transformations was proposed. The calculated temperature dependence of sound attenuation shows a clear peak what supports the idea about roton transformations. However it does not fit experimental data very well because of absence the detailed information about 2D rotons in aerogel.
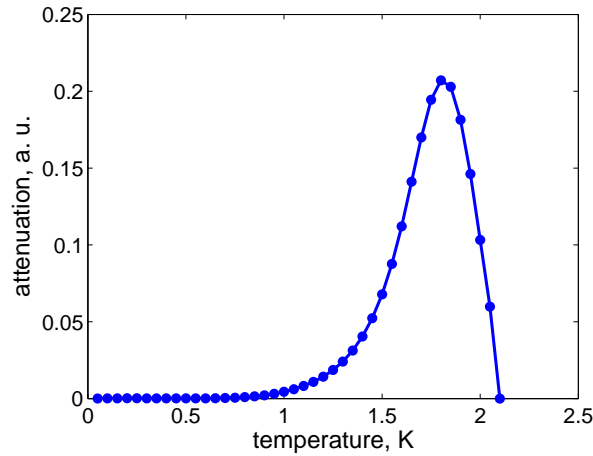
Figure 2. The simulated sound attenuation for aerogel filled in by liquid ^{4}He with taking into account the possible transformations between 2D and 3D rotons.

As it was mentioned above, five aerogel samples filled in by ^{4}He were investigated in ultrasound experiments [7], [9] and only two of them showed the peak in the temperature dependence of sound attenuation. The energy of 2D rotons depends on the strength of binding between helium atoms and wall surface, and the strength of binding should depend on structure. So it is possible that for aerogel with particle like structure the energy of 2D rotons lies well below the energy of 3D rotons and the overlap between 2D and 3D roton lines in the dynamic structure factor is negligibly small, so the proposed mechanism does not work and there is no peak in temperature dependence of sound attenuation.

Also it is possible that there are some other scattering mechanisms, which are not considered, in this system. Further work toward a clear interpretation of this interesting result is needed.

5. Acknowldegments

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