PROPAGATION OF FIRST SOUND IN LIQUID ^{3}He

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The dispersion of first (hydrodynamic) sound in normalfluid and superfluid ^{3}He has been
measured in a cylindrical resonator at a pressure of 18.8 bar in the frequency range
between 85 kHz and 227 kHz and in the temperature range between 1.2 and 50 mK. The sound
velocity measured in the normalfluid regime confirms recent theories of the slip
effect in Fermi liquids; in superfluid ^{3}He-B we find qualitative agreement between
experiment and theoretical sound velocity.

INTRODUCTION

From estimates of the dispersion law of first
sound in liquid ^{3}He at low temperatures one ex-
pects a small decrease (<0,3%) of the sound velo-
city c_1 with decreasing temperature down to T_c
(the superfluid transition temperature). Our pulse
method of measuring both sound attenuation and
sound velocity c_1 yields a sufficient accuracy
for c_1 to allow for quantitative comparisons be-
tween theory /1,2/ and experiment.

Jensen et al. /2/ have predicted the slip effect
for Fermi liquids, an effect already known from
the description of rarefied gases. We present an
experimental confirmation of this effect in liquid
^{3}He.

EXPERIMENTAL

The experimental arrangement was similar as in
our earlier experiments /3/, but the data hand-
ling was improved and the pressure stability in
the experimental cell was about 1 part in 10^5.

Our experiments were performed at 5 different
frequencies, for which we choose the odd harmonics
from 85 kHz to 227 kHz (5th to 13th harmonic).
The frequencies were kept low in order to remain
in the hydrodynamic regime. The pressure in the
experimental chamber was 18.8 bar, the temperature
ranged from 1.2 mK to 50 mK.

Fig. 1 represents a typical sound velocity curve
(7th harmonic, 122 kHz). Note that the dip of the
sound velocity at T_c is less than 0.3 percent;
the other harmonics give similar results.

To evaluate our measurements of sound dispersion
we used a recently published theory /1/ where a
visco-elastic model description of the Fermi
liquid was employed and which is applicable in
the hydrodnamic and in the collisionless regime.
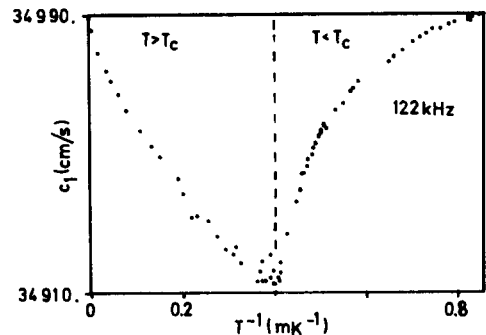There are two main contributions for the disper-

Fig. 1: Sound velocity at 18.8 bar and 122 kHz

sion relation in our case, one coming from sur-
face friction and a smaller one from the bulk
attenuation. The contribution from the bulk in-
cludes zero sound effects at higher frequencies;
the contribution from the wall includes the slip
effect. A slip of the quasiparticles at the walls
develops then when the quasiparticle mean free
path becomes comparable with the size of the
viscous mean free path, which leads to an increa-
sing contribution with decreasing temperature.

Fig. 2 shows the influence of the slip effect on
the sound velocity (227 kHz, 13th harmonic) in
the normalfluid phase.

At T_c the dip of the second velocity is reduced
to about 35 % when compared with the hydrodynamic
case $\omega\tau = 0$ (curve a), with τ being the quasipar-
ticle relaxation time. A correction from zero
sound (c) is included in the figure. As seen from
this figure we have good agreement between theory
and experiment for the sound velocity; the other
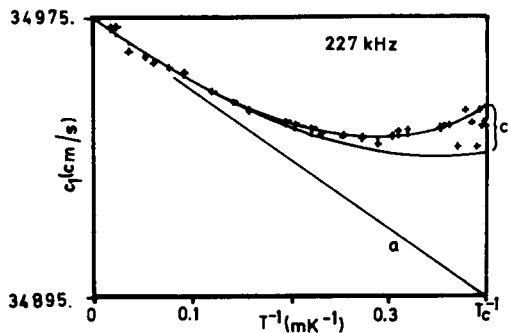harmonics show very good agreement with the theo-
retical description, too.

Fig. 2: Normalfluid sound velocity at 227 kHz

From the sound attenuation we derived the viscosity η. In the normalfluid phase η agrees nicely with recently published data /4/ and our results confirm the expected T^{-2} behaviour of the viscosity. In the superfluid phase our earlier measurements of η /3/ were confirmed.
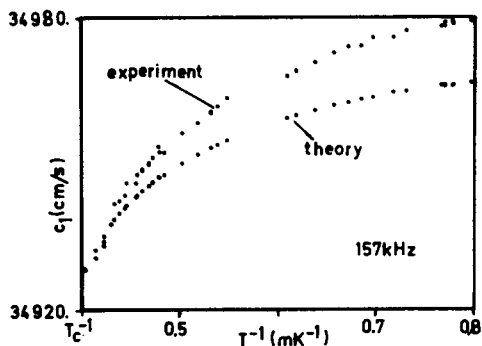

Fig. 3: Experimental and theoretical sound velocity

Fig. 3 shows the values determined experimentally for c_1 in the superfluid phase (upper curve) and c_1 as calculated after Ref. 2. The deviations at low temperatures are about 15 cm/s whereas the experimental scatter of the points is 1.5 cm/s.

Uncertainties of the Landau parameters or the normalfluid density (as cited in Ref. 3) as well as in our temperature determination cannot explain these deviations. At the moment possible systematical errors which may be induced by our resonator geometry are being examined, but we feel they are not responsible for the deviation because of the good agreement of our data with theory in the normalfluid phase.

In the theoretical description purely diffusive scattering of the quasiparticles at the walls was assumed. If one allows for partly specular scattering as mentioned in Ref. 2 it would raise the theoretical values of c_1. The authors of Ref. 2 define the diffusivity factor (1-s); s = O

corresponding to purely diffusive scattering and s = 1 to purely specular scattering, respectively. The specularity factor s which would be necessary to get consistency between theory and our experiment is shown in Fig. 4.
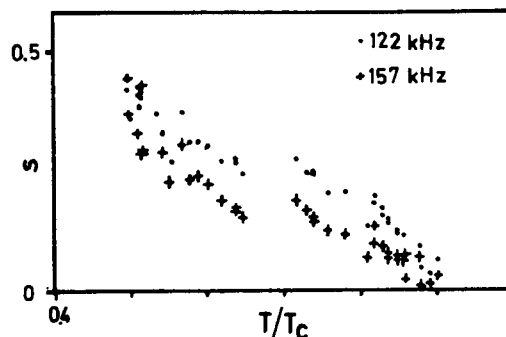

Fig. 4: Specular reflection factor

At our lowest temperatures the analysis yields a portion of specular scattering of about 45 %, here we have induced the data of two harmonics.

The parameter s as shown above can describe our data in the superfluid phase, but a theoretical description of this parameter, especially of its temperature dependence is still lacking.

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