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SUPERFLUID DENSITY IN METASTABLE ^{3}He-^{4}He MIXTURES

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We have studied superfluid ^{3}He-^{4}He mixtures quenched into nonequilibrium states inside the miscibility gap by means of second sound . From the results for the second sound velocity we conclude that the superfluid density in the metastable state is well described by extrapolation from equilibrium values. The boundary of the metastable region, where nucleation processes set in rapidly, is reflected in a sharp increase of the second sound attenuation.

1. INTRODUCTION

The superfluid density ρ_s of ^{4}He and of ^{3}He-^{4}He mixtures, being one of the essential quantities of the superfluid state, has been studied in great detail. In particular, the behavior near the λ-line and along the coexistence curve near the tricritical point has been investigated with high accuracy (1). Little is known, however, about the superfluid density in the miscibility gap of ^{3}He-^{4}He, where the mixture is not thermodynamically stable, but where for some limited time homogeneous metastable states are accessible (2,3). In this work we address the question how ρ_s behaves in this non-equilibrium state as one approaches the so-called cloud line, where spontaneous nucleation of ^{3}He-rich droplets sets in.

2. EXPERIMENTAL

In order to prepare the mixture in a proper state inside the miscibility gap we used the pressure quench technique with an experimental set-up as described earlier (2). A schematic path in the phase diagram, plotted on a reduced temperature scale, is shown in the insert of Fig.1. The quench starts on the superfluid branch of the coexistence curve (A), and the system remains in a homogeneous, metastable state (B). Upon nucleation, which develops rapidly as the cloud point is reached, local decomposition into ^{3}He-rich droplets (C$^+$) in a superfluid ^{4}He-rich background phase (C$^-$) occurs within a few milliseconds. Subsequently the system "slides down" along the coexistence curve until the pressure quench is terminated at points D$^+$ and D$^-$. There the late stages of decomposition, coarsening and macroscopic phase separation by gravity, are also completed. The typical time scale for the whole decomposition process is a few seconds for ^{3}He-^{4}He.

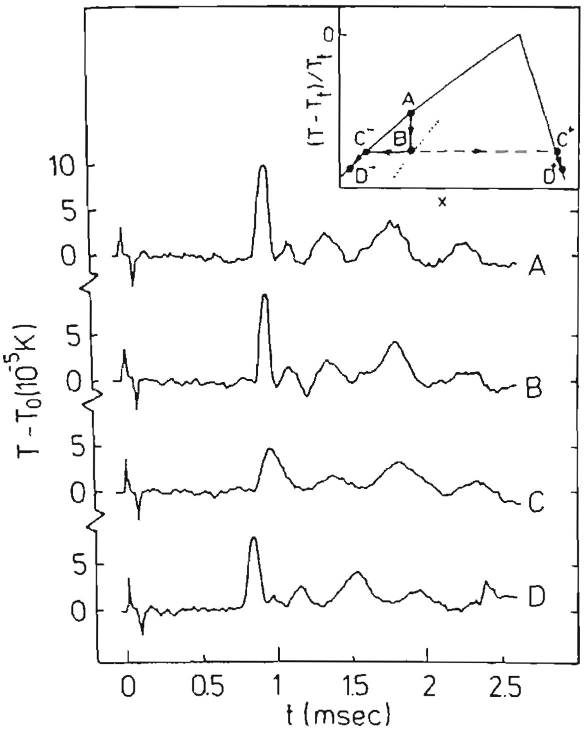

Fig. 1:Second sound signal in a superfluid ^{3}He-^{4}He mixture at various stages of the decomposition process. The traces, taken at subsequent identical quenches, refer to the following conditions, also marked in the schematic phase diagram shown in the insert (the dotted curve symbolizes the cloud line): A)In the homogeneous phase on the coexistence curve, 23 mK below the tricritical temperature T_t, at p=880 mbar; B)in the metastable regime just before reaching the cloud point;C)after nucleation, when the system has undergone decomposition on a local scale; D)at the end of the decomposition process, when the superfluid phase is homogeneous again(T_t-T=35mK,p=510mbar)

The qualitative behavior of the second sound signals is illustrated in Fig.1, which shows examples of the various conditions (A-D) described above. The pulses were generated by heating a thin metal film and detected with a

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carbon bolometer at a distance of 0.7 mm. The traces display a sharp rise about 1 msec after the application of the heat pulse, corresponding to the transit time of second sound. The structure after the leading pulse is due to multiple reflections. It is seen that well-defined second sound signals are obtained not only in the superfluid phase on the coexistence curve, but also in the metastable state (B) and in the heterogeneous mixture (C).

3. RESULTS AND DISCUSSION

Here we concentrate on the metastable regime and the onset of nucleation. Data for the velocity and the attenuation of second sound in this region are shown in Fig 2a and 2b. The time axis is related to the quench depth, although in a nonlinear way (2). In the metastable mixture, which here corresponds to the time interval $0<t<0.12$sec, the velocity remains unchanged within our accuracy of about 1%. This is to be compared with data in the vicinity, but outside the miscibility gap (4), which when extrapolated to the thermodynamic path of our quench also yield a constant value of v_{II} within 1%. Thus the superfluid density in a metastable mixture appears to follow a regular behavior up to a supersaturation $\delta x/\Delta x=0.15$, the largest value reached under the present conditions.(Here $\Delta x=x^{+}-x^{-}$ is the width of the miscibility gap and δx is the deviation from the equilibrium concentration on the superfluid branch of the coexistence curve.)

The arrow in Fig.2 indicates the onset of nucleation, as determined independently from the optical transmissivity of the sample (2). Although some structure in v_{II} might be present near that point, it is obviously not larger than 1%, so that the velocity in the heterogeneous mixture ($t>0.12$sec) is nearly the same as in the homogeneous case. By contrast, the attenuation of the second sound is strongly affected by the normalfluid droplets developing during the nucleation process, as seen from Fig.2b.

4. CONCLUSIONS

The measurements show that the superfluid density in the metastable state agrees with an extrapolation from the equilibrium values of ρ_s, indicating that this order parameter is insensitive to the miscibility gap. In addition, we have observed that the attenuation of the second sound increases drastically upon nucleation, which makes it an interesting tool to study this process.

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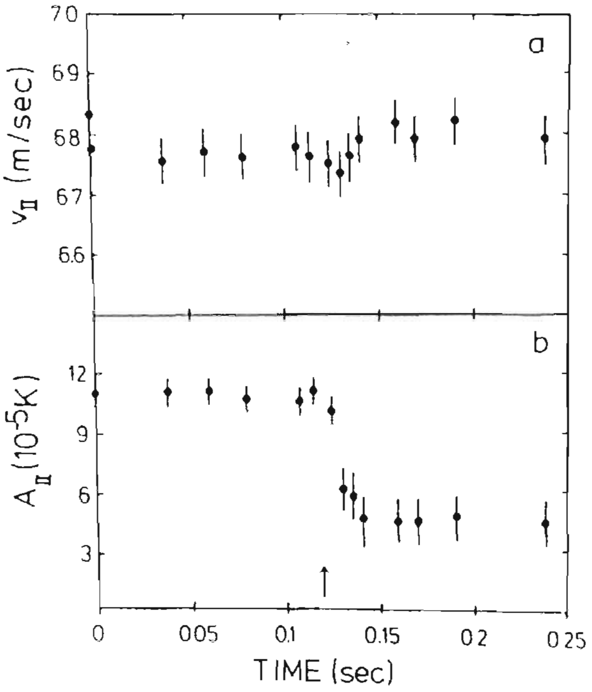

Fig.2 :a) velocity$_{II}$ and b)amplitude $A=T-T_o$ of a second sound pulse propagating through a ^{3}He-^{4}He mixture at various times after the start of the quench. T_o is the temperature before the application of the heat pulse. The quench parameters were the same as in Fig. 1, except for the initial and final temperature on the coexistence curve, which was $T_t-T=17$ and 29 mK, respectively. The onset of nucleation is marked by an arrow.

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