A NEUTRON SCATTERING INVESTIGATION OF BOSE-EINSTEIN CONDENSATION IN SUPERFLUID ^{4}He

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London[1] suggested in 1938 that many of the strange properties of superfluid ^{4}He result from the fact that below the λ point some of the ^{4}He atoms undergo Bose-Einstein condensation to a zero momentum state. It was suggested by Hohenberg and Platzman[2] that this proposal of a zero mementum state could be checked by high energy neutron inelastic scattering from ^{4}He. The scattering law $S(\vec{Q},\omega)$ for such an experiment is given by

$$S(\vec{Q},\omega) = \sum n(\vec{p})\ \delta\left(h\omega - \left(\frac{h^2}{2M}\right)\left(Q^2 + 2\vec{Q}\cdot\vec{p}\right)\right)$$

where $n(\vec{p})$ is the ^{4}He momentum distribution, $\vec{Q}$ is the neutron momentum transfer and M is the ^{4}He mass.

The result of the measurement would then be a distribution centered at $\frac{h^2}{2M} Q^2$ whose shape reflects the momentum of the ^{4}He atoms. If some fraction of the atoms are in a zero momentum state, they will manifest themselves in the scattering experiment as a sharper peak on top of the main distribution that reflects the momentum of the normal ^{4}He atoms.

The two-component distribution has been searched for by Cowley and Woods,[3] and by Harling.[4] Neither experiment employed sufficient statistical accuracy or resolution to see the condensate directly and thus could give no reliable estimate of the condensate fraction.

Our measurements were made at the HFIR on a triple-axis spectrometer at a consistent scattering angle of 135° and a momentum transfer of 14.33 $\mathring{A}^{-1}$. The results of the measurements are shown in Fig. 1 (DWG. 72-6085) for ^{4}He at 1.2^{o}K and 4.2^{o}K. All the data have been normalized to one run which represents about 20 minutes counting time per point. Of course, many runs were performed, especially in the area near the peak tip where evidence for a condensate is expected. The resolution energy width for the constant angle scan used in the experiment was about 2.1 MeV.

The measurements were alternated between ^{4}He at 1.2^{o}K and 4.2^{o}K so that the 4.2^{o}K data could serve as a check on the experiment. The two-component distribution indicative of a condensate is visible at 1.2^{o}K although the effect is quite subtle. The absolute value of the slopes of the two peaks plotted from the point on the sides of the peaks where the slope is greatest is shown in Fig. 2 (DWG. 72-4889). It is quite clear that the 1.2^{o}K distribution undergoes a change in slope representative of a condensate. Since the change in the slope marks the positions on the peak where the condensate begins, it is easy to draw curves representing the normal and condensate distributions and thus estimate condensate fraction. This type of estimate gives a condensate fraction of about 2%. Least squares analysis of the data gives a more accurate estimate for the condensate fraction, and a value of 2.4 ± 1% is obtained. This is considerably smaller than the theoretical estimates of the condensate fraction which range from 6% to 25%.

REFERENCES

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2. P. C. Hohenberg and P. M. Platzman, Phys. Rev. 152, 198 (1966).
3. R. A. Cowley and A. D. B. Woods, Phys. Rev. Lett. 21, 787 (1968).
4. O. K. Harling, Phys. Rev. Lett. 24, 1046 (1970).

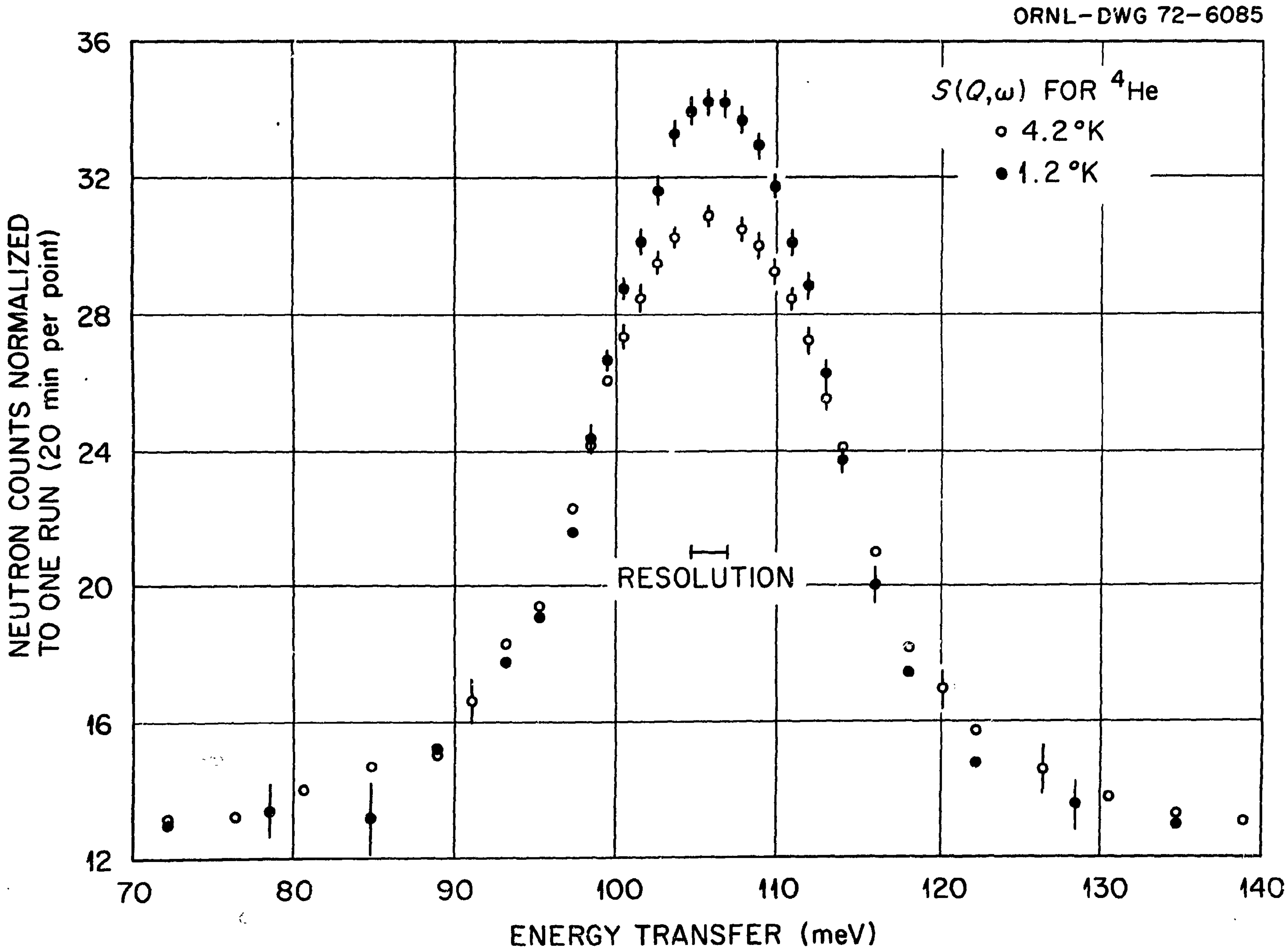
ORNL-DWG 72-6085
$S(Q,\omega)$ FOR ^{4}He
4.2°K
1.2°K
RESOLUTION
NEUTRON COUNTS NORMALIZED TO ONE RUN (20 min per point)
ENERGY TRANSFER (meV)
36
32
28
24
20
16
12
70
80
90
100
110
120
130
140

Figure 1

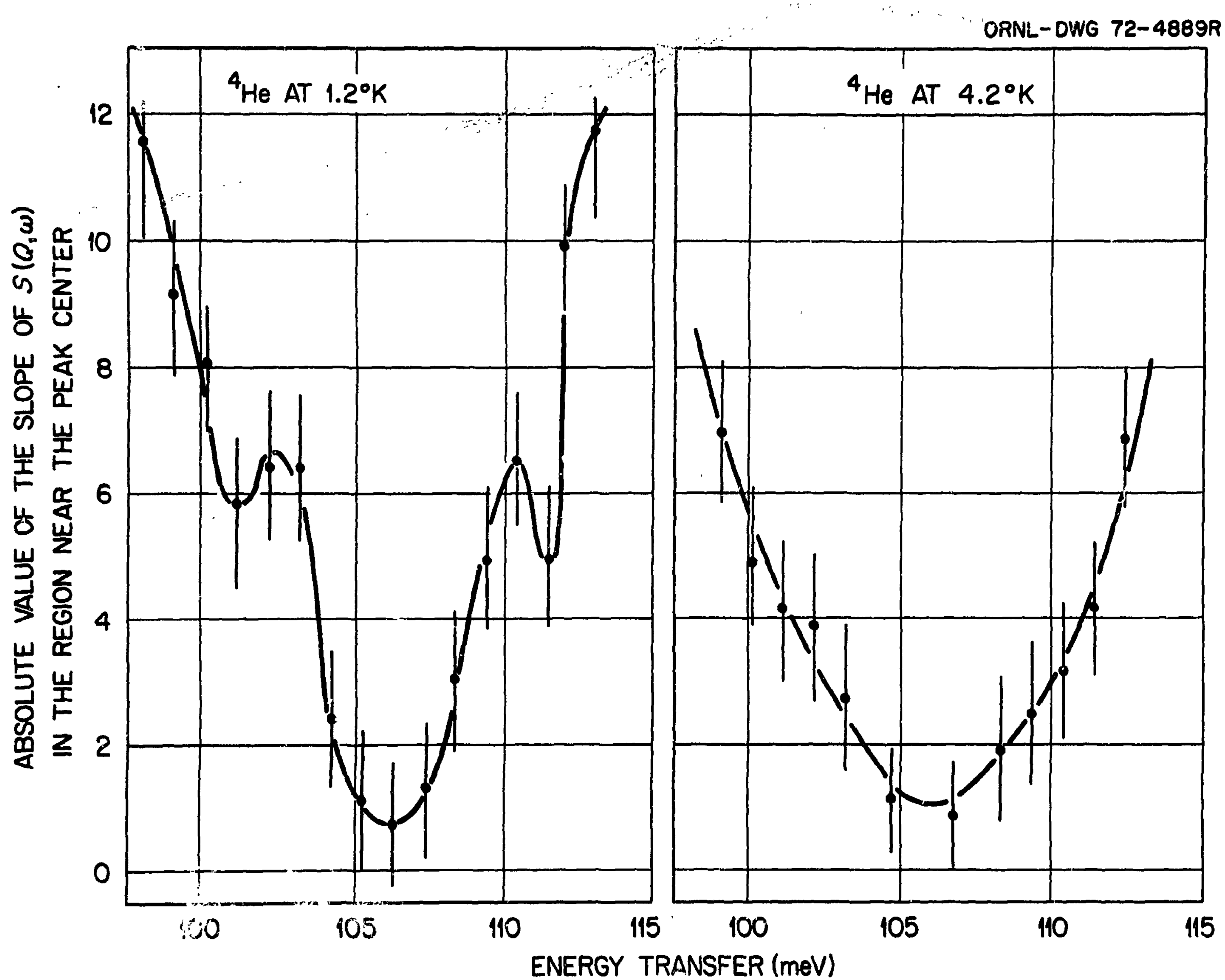
ORNL-DWG 72-4889R
ABSOLUTE VALUE OF THE SLOPE OF S(Q,ω)
IN THE REGION NEAR THE PEAK CENTER
4He AT 1.2°K
4He AT 4.2°K
0
2
4
6
8
10
12
100
105
110
115
ENERGY TRANSFER (meV)

Figure 2