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Relationship between the Linear Ringing Frequencies in ${}^3\text{He-A}$ and ${}^3\text{He-B}$ near the Polycritical Point*

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New measurements of parallel ringing in a quasi-ideal geometry for ${}^3\text{He-B}$ near the temperature and pressure of the polycritical point suggest $f_B^2/f_A^2 \sim \frac{5}{2}$, where f_B and f_A are the linear parallel-ringing frequencies at a given temperature near T_c . This result approaches the prediction of theory using the Anderson-Brinkman-Morel and Balian-Werthamer states to describe ${}^3\text{He-A}$ and ${}^3\text{He-B}$, respectively, and hence the results of Osheroff at melting pressure, but disagrees with earlier observations at pressures near the polycritical point.

In our first work^{1,2} on parallel-ringing phenomena in ${}^3\text{He-A}$ and ${}^3\text{He-B}$, the A -phase ringing was readily observable over a wide range of temperature and pressure while the B -phase ringing could be observed only in a very narrow "window" a few tenths of a percent below T_c . The observations were made on a ${}^3\text{He}$ sample contained in a 3-mm-diam tube with both steady and turn-off fields parallel to the tube axis. By taking advantage of the supercooling and superheating of the A - B transition² we were able to observe the "linear" ringing frequencies f_A and f_B in the A and B phases at what we believed to be the same temperature. (Linear ringing corresponds to $\gamma\Delta H \ll 2\pi f$ where the ringing frequency f is independent of ΔH .) For a variety of pressures from 12.1 to 21.4 bar and a variety of average magnetic fields from 3 to 300 G, but consistent always with the requirement that T be close to T_c as indicated above, we found that $f_B/f_A = 1.9 \pm 0.1$. This result has been an impediment to the currently widely held belief that ${}^3\text{He-A}$ reflects the axial p state of Anderson, Brinkman, and Morel (ABM) and ${}^3\text{He-B}$ the "quasi-isotropic" p state of Balian and Werthamer (BW) since the theory³ predicts unambiguously that if these state assignments are correct, the B -to- A frequency ratio should be $(\frac{5}{2})^{1/2} = 1.58$ near the polycritical point where both the susceptibility and the average square of the gap are the same. In the meantime, Osheroff⁴ showed that his NMR results for the A and B phases at melting pressure could be accounted for by theory with the above state assignments and the concomitant $(\frac{5}{2})^{1/2}$ factor. More recently Ahonen *et al.*⁵ deduced from NMR measurements a value of 1.93 ± 0.05 for the B -to- A frequency ratio at 18.7 bar and near T_c .

In this Comment we present new measurements of f_B and f_A in a geometry favorable to the B phase^{3,6}: a stack of parallel plates 5 mm in diam-

eter with a 0.46-mm separation between plates and a 1.3-mm-diam hole down through the center for thermal contact and with the steady field \vec{H}_0 and the turn-off field $\Delta\vec{H}$ perpendicular to the plates. For this geometry the B -phase ringing is no longer confined to a small window near T_c . Although the geometry is not ideal for A -phase ringing, in the 20-G steady field used for the measurements the ratio of f_A^2 to $1 - T/T_c$ near T_c is essentially the same as that observed in a more suitable geometry with \vec{H}_0 parallel to the texture-aligning plates. Cooling of the ${}^3\text{He}$ is by powdered cerium magnesium nitrate and temperature measurement is achieved with use of a small cerium-magnesium-nitrate thermometer separated from the ringing-measurement region but coupled to it thermally as tightly as possible. Reduction of magnetic temperatures to provisional absolute temperatures is discussed in Ref. 2.

Some measurements obtained at a pressure of 22.0 bar are shown in Fig. 1. This pressure is chosen to be close to the polycritical point (at ca. 21.2 bar²) but far enough away to allow, via supercooling, a substantial penetration into the A phase. The B -phase measurements were made after a deep cooling into the B phase and continued until a superheated $B \rightarrow A$ transition occurred. As for our earlier measurements¹ the A -phase measurements were made after the ${}^3\text{He}$ was slowly cooled from above T_c to just above the supercooling $A \rightarrow B$ transitions. The data shown were taken during one day in the sequence B (\circ), A (\triangle), B (\square), A ($+$). The irreproducibility of the two successive B -phase runs reflects some difficulty of the thermometer in "tracking" the temperature of the ${}^3\text{He}$ in the ringing part of the cell. This failure to track could represent a fluctuating heat leak, but whatever its cause it indicates a fundamental problem in achieving precise thermal equilibrium. The A -phase data were

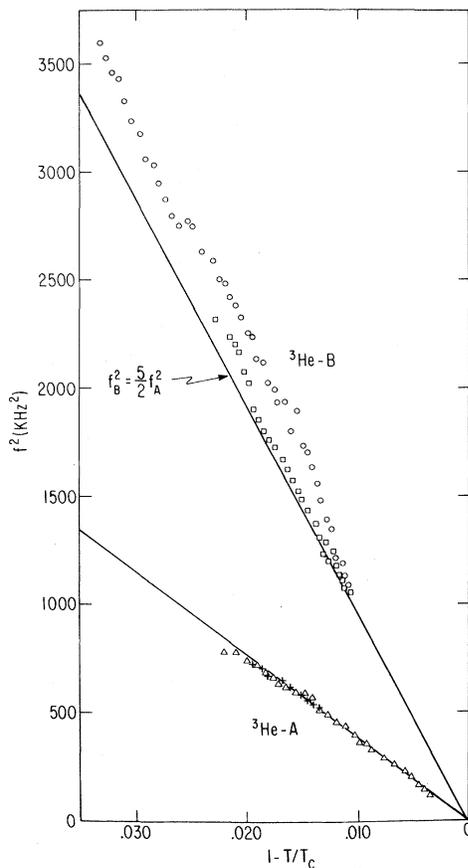


FIG. 1. Dependence of the square of the linear ringing frequencies for ${}^3\text{He-B}$ and ${}^3\text{He-A}$ on $1 - T/T_c$ at 22.0 bar in a parallel-plate geometry with both $H_0 \approx 20$ G and ΔH normal to the plates. The data were obtained on one day in the sequence B (\circ), A (Δ), B (\square), A ($+$).

very reproducible. For the data in Fig. 1, f_B^2 is not far from $\frac{5}{2}f_A^2$ near T_c . If the theoretical curve is modified to take into account the reduced susceptibility of the B phase with respect to the A phase,^{2,3} then experiment and theory compare more favorably than suggested in Fig. 1, but we have not made this modification in view of the discrepancies between static and resonant susceptibilities.² We do not regard these results as a "proof" of the $\frac{5}{2}$ factor, at least because of the possible problem of thermal equilibrium. However, they definitely do not support the 3.6 factor (1.9^2) that might have been expected from our earlier work and that of Ahonen *et al.* Although it might have been tempting to ascribe our initial result¹ to a problem with thermal equilibrium, particularly because of the different heat-flow properties of the A and B phases²; this

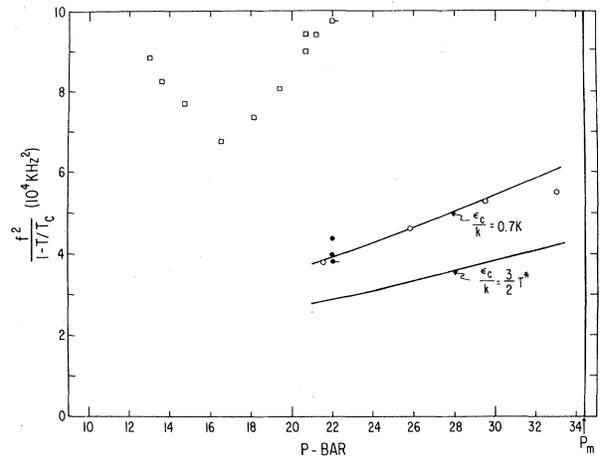


FIG. 2. Observations of the pressure dependence of the quantity $f^2/(1 - T/T_c)$ for both A and B phases both from Ref. 1 (A , \circ) and present work [A , \bullet ; B , \square ; data of Fig. 1 (A , \bullet —; B , \square —)]. The smooth curve labeled $\epsilon_c/k = 0.7\text{K}$ is derived from Leggett's theory (Ref. 3) with use of experimental data (Ref. 2) with $\langle R^2 \rangle = 1$ and with a pressure-independent cutoff as given. The curve labeled $\epsilon_c/k = \frac{3}{2}T^*$ uses the same theory but a pressure-dependent cutoff, where T^* is the magnetic temperature of the ${}^3\text{He}$ (Ref. 2).

at the time was considered unlikely because of the consistent behavior over a wide range of conditions, including large changes of pressure and magnetic field. Furthermore, our earlier B -phase measurements¹ were made much closer to T_c than the present ones.

We also have additional data, Fig. 2, which are useful in examining the result of Ref. 5. These show the limiting behavior near T_c of $f^2/(1 - T/T_c)$ versus pressure for the A and B phases. These results depend on the accuracy of our provisional absolute scale, for which comparison with the melting-pressure scale has shown reasonable agreement.² What Ahonen *et al.*⁵ find is that, near T_c , $f_B^2/(1 - T/T_c) = (11.38 \pm 0.10) \times 10^4$ kHz^2 for a pressure of 18.7 bar. Referring to Fig. 2 we interpolate for this pressure 7.7×10^4 kHz^2 from present data. The ratio of these numbers is 1.48 while the current discrepancy with theory is a factor $1.9^2/2.5 = 1.44$. Or one could extrapolate the A -phase frequencies in Fig. 2 to 18.7 bar, in which case $f_B/f_A \approx 1.9$, taking f_B from the data of Ref. 5, in agreement with the conclusions of Ahonen *et al.*⁵ This suggests that the problem in the ratio f_B/f_A is in f_B and not in f_A , as expected.² The apparent contradictions amongst the various measurements suggests that one should look more closely before making final

conclusions regarding the dynamic magnetic properties of superfluid ^3He .

In Fig. 2 $f_B^2/(1-T/T_c)$ starts to rise at lower pressures. This effect is reflected in other measurements at our laboratory on fourth sound⁷ and ultrasonic attenuation,⁸ but it may well indicate an inaccuracy of the provisional absolute temperature scale in this region. As a general matter it is important to recognize that this scale has not been given a rigorous check using other methods, and that quantitative matters which depend crucially on the accuracy of the scale must be regarded with appropriate caution. For further discussion of temperature scales, see Ref. 2.

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velopment Administration under Contract No. E(04-3)-34, P.A. 143.

¹R. A. Webb, R. L. Kleinberg, and J. C. Wheatley, *Phys. Rev. Lett.* **35**, 145 (1974).

²J. C. Wheatley, *Rev. Mod. Phys.* **47**, 415 (1975).

³A. J. Leggett, *Rev. Mod. Phys.* **47**, 331 (1975).

⁴D. D. Osheroff, *Phys. Rev. Lett.* **33**, 1009 (1974).

See also, for further supporting frequency measurements on the *B* phase at melting pressure, D. D. Osheroff, S. Engelsberg, W. F. Brinkman, and L. R. Corruccini, *Phys. Rev. Lett.* **34**, 190 (1975).

⁵A. I. Ahonen, T. A. Alvesalo, M. T. Haikala, M. Krusius, and M. A. Paalanen, *Phys. Lett.* **51A**, 279 (1975).

⁶W. F. Brinkman, H. Smith, D. D. Osheroff, and E. I. Blount, *Phys. Rev. Lett.* **33**, 624 (1974).

⁷H. Kojima, D. N. Paulson, and J. C. Wheatley, *J. Low Temp. Phys.* **21**, 283 (1975).

⁸D. N. Paulson, R. L. Kleinberg, and J. C. Wheatley, unpublished.

Film-Asymmetry Effects in Resonant Photoexcitation of Plasmons*

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The spacings and strengths of plasmon resonances in the optical properties of thin films depend on film symmetry, i.e., on whether the film surfaces are identical or not. Taking account of film asymmetry, the reinterpretation of photoyield data of Anderegg, Feuerbacher, and Fitton explains the fairly systematic alternation of their plasmon-associated resonance strengths and implies that their best-fit values of film thicknesses were about twice too large.

Because the conversion of transverse to longitudinal electromagnetic waves is a phenomenon which can only occur by virtue of dielectric inhomogeneities, the interpretation of peak shapes in the observation of resonant bulk-plasmon photoexcitation (RBPPE)¹ may yield new surface-electronic-structure information, and is therefore of great interest.² The object of this note is to point out an apparent error in the published interpretations^{3,4} of the RBPPE data of Anderegg, Feuerbacher, and Fitton (AFF),³ obtained in measurements of photoyield versus frequency from thin potassium films. By reinterpreting AFF's data one can explain the fairly systematic alternation in the strengths of their resonances and one finds that, according to this reinterpretation, the best-fit values of AFF's film thicknesses⁵ given in Refs. 3 and 4 are about twice too large.

The essential element missed in the previous interpretations of AFF's data^{3,4} is that one cannot describe resonant plasmon excitation in an asym-

metric film, i.e., a film with electronically or optically inequivalent surfaces (and AFF's films were grown on silica while having nominally clean upper surfaces), in terms of a model which assumes film symmetry—because film symmetry imposes a selection rule which suppresses every other resonance.

To understand this point, consider a free-electron-metal film whose surfaces lie just (microscopically) to the left of the plane $z=0$ and just to the right of $z=d$.⁶ The excitation of plasmons in the film will be mediated by four complex parameters²: p , which governs the probability that a transverse wave striking the $z=0$ surface (from either side) will be converted to a plasmon traveling toward $z=d$; \bar{p} , the analogous quantity for the $z=d$ surface; s , which governs the probability that a plasmon striking the $z=0$ surface will be reflected as a plasmon and not disappear with the creation of an electron-hole pair; and \bar{s} , the analogous quantity for the $z=d$ surface. In terms