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RECENT EXPERIMENTS IN SUPERFLUID $^{3}$He

D.D. Osheroff

Bell Laboratories, Murray Hill, New Jersey, U.S.A.

INTRODUCTION.- In this article I will discuss recent experiments in just three areas of study, trying to relate them to each other and to the fuller understanding of $^{3}$He we hope to obtain. These areas are magnetic resonance, electronic effects involving the magnetic phenomena have centered around three major areas: 1) Attempting to resolve the disagreements which existed when the B phase susceptibility was measured statically and then dynamically. 2) Studies of spin dynamics of spatially non-uniform samples, and 3) Studies of longitudinal spin recovery using the powerful SQUID-NMR techniques. In addition to these three major areas of interest, efforts have continued to measure longitudinal resonance frequencies as a function of pressure and linewidths as a function of temperature; and I refer the reader to the very beautiful work by Avenel et al. /7/ although I will not cover it here.

A) Nuclear Magnetism.-

i) Introduction.- The unusual behavior of the nuclear magnetic moments in superfluid $^{3}$He was one of the earliest and most useful probes of the nature of the ordered phases /1/. Interpreted through the theoretical work of A.J. Leggett /2/, the shifts in the magnetic resonance frequencies of quasi-uniform samples, as well as the longitudinal resonance modes first predicted by Leggett /3/, and combined with measurements of the nuclear magnetic susceptibilities /4/, have allowed us to fingerprint the microscopic identities of the new states within the broad manifold of $\xi = 1$ superfluids considered. The observation of a transverse resonance frequency shift in the $\Lambda_{1}$ phase /5/, combined with the theoretical work by N.D. Mermin /6/ further enhanced the likelihood that the A and B phases are $\xi = 1$ superfluids by eliminating as a possible contender for the $\Lambda_{1}$ phase the most likely $\xi = 3$ candidate.

By the time of LT14 a considerable amount was known both about the superfluid spin dynamics, even in the non-linear regime, and the implications that these observations had regarding the superfluids themselves. Since that time, studies of nuclear magnetic phenomena have centered around three major areas: 1) Attempts to resolve the disagreements which existed when the B phase susceptibility was measured statically and then dynamically. 2) Studies of spin dynamics of spatially non-uniform samples, and 3) Studies of longitudinal spin recovery using the powerful SQUID-NMR techniques. In addition to these three major areas of interest, efforts have continued to measure longitudinal resonance frequencies as a function of pressure and linewidths as a function of temperature; and I refer the reader to the very beautiful work by Avenel et al. /7/ although I will not cover it here.

ii) Static Susceptibilities in $^{3}$He.- One of the most unsettling controversies in the field of superfluidity in $^{3}$He has been the disagreement of static measurements of the B phase susceptibility, $\chi_{B}^{D}$, with values, $\chi_{B}^{D}$, made using NMR techniques. Generally, static measurements actually record $\chi_{B}^{S}$, whereas NMR measurements record only the nuclear susceptibility directly. Although one does not expect a change in the non-nuclear magnetic susceptibility contributions in the B phase, previous experiments have consistently found $\chi_{B}^{S} = 1.5 (\chi_{B}^{D} - \chi_{B}^{D}) /8$. One possible source of the above disagreement was long believed to be the manner in which the static SQUID magnetometers were calibrated. To eliminate this possible failure of the SQUID technique, two separate experiments have been performed /9,10/ in which the SQUID system was calibrated by using a resonant radio frequency (rf) pulse to tip the nuclear...
magnetization by a known angle, usually 180°, and observing the change in the static magnetization in the process. This calibration was generally performed just above $T_c$. Once calibrated, the SQUID systems were able to measure the changes in susceptibility at the $A \mp B$ transitions and as a function of temperature by noting the changes in magnetization as they had measured them before. In work by Webb at Argonne /9/, however, the recovery of the $B$ phase magnetization could be observed fully following an rf pulse while in the superfluid phase, so that Webb was able to use his SQUID system to actually measure the dynamic susceptibilities as well as the static changes in susceptibility. This eliminated the need to adjust thermometry scales in order to compare his results to the dynamic measurements.

The results of these experiments are still a mystery however: the static susceptibility differences Webb measures are still nearly 1.5 times as large as the differences, $\Delta \chi = \chi_{A} - \chi_{B}$, which he measures dynamically.

In work at La Jolla by Sager et al. /10/ measurements were made in three different geometries, although no significant dependence on geometry was noted. In the La Jolla work $\chi_A - \chi_B$ was recorded at the thermodynamic $B \rightarrow A$ transition as a function of pressure. Their results show that the static susceptibility differences are still consistently larger than the dynamic differences, but that the ratio of the two values approaches unity as the pressure approaches the melting pressure. This feature was not clear in the Argonne results, although those results were obtained only at 26.5 bar and 18 bar pressures. Because the La Jolla group must compare their static values with dynamic measurements made elsewhere, there is still a question concerning thermometry scales, and hence some room for further adjustment. It seems highly unlikely, however, that any such manipulation will eliminate the still substantial discrepancy between the results of the two different types of measurements at lower pressures, and the nature of the disagreement is still a fundamental question we do not understand.

iii) Spin Dynamics of Non-Uniform Samples.- Efforts to understand superfluid $^3$He spin dynamics in the presence of non-uniform textures have represented a major new thrust since LT14, and one which may well be expected to continue for years to come.

The first careful effort to understand standing spin waves in a known geometry was made at Bell Labs. /11,12/. In that work NMR spectra of a sample of $^3$HeB between parallel plates was studied when the static field was in the plane of the plates. In such a geometry the anisotropy axis in $^3$HeB, $\hat{\delta}$, is fixed almost rigidly at the walls to lie nearly perpendicular to $\hat{H}_0$, but bends upward between the plates to line nearly along $\hat{H}_0$. Since the transverse frequency shift in $^3$HeB is proportional to $n_2^2$, the square of the component of $\hat{\delta}$ perpendicular to $\hat{H}_0$, a large variation in the local transverse NMR frequency shift resulted. However, rather than observing a broad NMR line, the Bell group instead observed up to four nearly equally spaced resonance peaks.

To understand the above result, consider the equation governing the spin dynamics in such a geometry:

$$ E_S = - (R_S^2 f(\bar{\delta}) \frac{d^2}{dz^2} - n_2^2(z)) S $$

(1)

Here $E$ is the transverse frequency shift normalized to its value when $n_2^2 = 1$, $S$ is the precessing magnetization, $R_S$ is the dipolar healing length, and $f(\bar{\delta})$ is a scalar of order unity. This equation resembles a Schrödinger equation with $E$ the eigenvalue and $n_2^2$ a potential energy term. It is assumed that the variation of $\bar{\delta}$ is along $z$.

In the geometry of the Bell Labs experiment, $n_2^2$ varies approximately quadratically over the $^3$He filled region. Once this variation of $n_2^2$ is substituted into equation 1, one obtains the equation of a harmonic oscillator, in which the spin wave modes are trapped in the quadratic potential well created by the texture.

By determining the $\bar{\delta}$ texture numerically on a computer and using that texture in solving equation 1, the Bell group arrived at resonances which closely matched their data. These results have given us confidence in dealing with textural induced distortions in NMR spectra.

At the time of LT14, Avenel et al. /13/ observed "satellite" resonances in longitudinal NMR spectra in $^3$HeA. We now believe these satellites are associated with spin waves trapped in a dipolar potential well associated with a planar singularity in $^3$HeA which has been studied extensively theoretically by Maki and Kumar /14,15/. These singularities, topological solitons, result when two regions of $^3$HeA are joined together in which $\bar{\delta}$ is parallel to $\hat{k}$ in one of the regions and antiparallel to $\hat{k}$ in the other. Maki and Kumar determine the textures for such singularities in several experimental si-
tations by minimizing the total free energy associated with them. Then using an equation similar to equation 1, they determine the bound spin waves associated with the solitons. In general, their calculations fit recent data quite closely. In fact, recently Maki /15/ has fit the temperature dependence of the ratio of the longitudinal satellite resonant frequency to the main longitudinal resonant frequency as determined by Gould and Lee /16/ to estimate that the Landau Fermi liquid parameter $F_L^1 = -1.2$.

A very similar value of $F_L^1$ has also been arrived at by Osheroff et al. /12/ who needed to invoke a value of $F_L^1$ to fit their spin wave data to theory, and by Pethick, Smith and Bhattacharyya /17/ who needed it to fit normal state viscosity data to their theory. Perhaps we are again learning something about the normal Fermi liquid by studying the superfluid phases.

There is no universal agreement that the satellite resonances, seen in both longitudinal and transverse NMR experiments, can be completely explained by the soliton picture, although I personally am very optimistic: In work by Gould and Lee /16/ it was observed that rapid heat flow could create the satellite resonances, as if $\hat{\lambda}$ were being pulled out of the plane in which $\hat{\delta}$ must reside during turbulent counterflow, thereby allowing a soliton to be formed. Giannetta, Smith and Lee /18/ showed that satellites of nearly total line intensity (no main peak) could be formed in pulsed experiments by tipping the magnetization, $M_2^z$, well away from $H_0$. In later sections of this manuscript it will be shown how such a process can be expected to create solitons. Bozler and Bartolac /19/ have shown that in pulsed experiments, satellite resonances are created within a very short time (~20 ms) following a tipping pulse. Finally, Kokko et al. /20/ have demonstrated that the satellites originate from quite localized regions of the fluid, and that they require a static field to stabilize them, at least in their parallel plate geometry. All these characteristics are consistent with the soliton model.

Our apparent ability to identify textural singularities in $^3$HeA by their NMR signatures is very heartening, and may eventually prove important in understanding the effects of flow in $^3$HeA, such as the very complex result obtained by Adams and coworkers at the University of Florida, /21/ in which apparent decreases in the A phase susceptibility and a complex time dependent NMR spectra were observed during flow conditions.

In an area related to the soliton problem, groups at Sussex /22/ and Cornell /23/ have been studying NMR spectra of $^3$HeA contained in 2 μm diameter cylindrical channels in order to understand the equilibrium textures in restricted geometries. In such tight spaces $\hat{\lambda}$ cannot remain everywhere parallel to $\hat{\delta}$, and hence the NMR resonant frequency is depressed relative to the bulk. There is, as well, the possibility that the equilibrium texture will be dominated by a line singularity which can be determined from its NMR signature. It now appears that both groups have seen two separate textures stable in different temperature regions, which transform into each other on warming or cooling very slowly. These observations will undoubtedly produce a great deal of further experimental and theoretical work.

iv) Longitudinal Spin Recovery.- When the equilibrium magnetization, $M_z^2$, of the nuclear spin system along the static field is destroyed in a pulsed NMR experiment by tipping $M_2$ well away from $H_0$, spin nonconserving processes must eventually return $M_2$ to its equilibrium value. The characteristic time for this process to occur is usually termed $T_1$. In 1975 Corruccini and Osheroff /24/ showed that very unusual recovery mechanisms exist in both superfluid phases of $^3$He, sufficiently strange that even today we have no explanation for those observations, although recent experiments at La Jolla /25/ and at Argonne /26/ have given us further clues as to what may be happening in these inherently nonlinear and spatially nonuniform processes.

Shortly following the publication by Corruccini and Osheroff /24/ (C-O) of their results showing that $M_2$ recovered nearly linearly with time in the A phase, Leggett and Takagi /27,28/ (L-T) produced a theory predicting a new magnetization recovery mechanism in which the dipolar torque represented the spin nonconserving process. This theory suggested that the excess energy in the spin system should obey the relationship:

$$\frac{d}{dt} \left[ \frac{(x^H - M_z^2)^2}{2x} + E_D \right] = \frac{1}{\tau_T} \frac{x^2}{x_0} \left( \frac{(1-\lambda)}{\lambda} \right) \frac{\mu_B^2}{T}$$

Here the left hand side of the equation is the time rate of change of the energy in the spin system, with $E_D$ the dipolar energy, which we shall ignore as being negligible. $(x/x_0)$ is the susceptibility enhancement $(x/x_0 = (1 + z_0)^{-1}, \lambda = \frac{T}{15} \left( \Delta_0^{k_BT} \right)$ where $\Delta_0$ is the maximum of the gap function, $\Omega_L$ is the longitudinal resonant frequency, $\gamma$ is the gyromagne-
tic ratio, and $T$ is the normal quasiparticle scattering time at the Fermi surface.

The L-T equation suggests a relaxation time $T_1$ proportional to $(1-T/T_c)^{3/2}$ near to $T_c$, in which $M^2$ recovers linearly with time. Because the times for full spin recovery are proportional to $H^2_0$ in this theory, one needs to study this phenomenon in very low fields where more rapid processes will not dominate the recovery.

Sager et al. [25]/ at La Jolla, and Webb [26] at Argonne have employed SQUID NMR to study these relaxation processes. As in the static magnetization studies, they have tipped the magnetization with a resonant rf pulse, and then followed the recovery of $M_Z$ directly using SQUID magnetometers. This technique has many virtues over conventional NMR in this particular application, including good sensitivity at very low fields, and the ability to recore the entire $M_Z$ recovery after a single rf pulse. Both groups have been able to observe L-T recovery in both superfluid phases, although in the La Jolla study only in a narrow temperature range very near to $T_c$, and in fields of 30 Oe or less. In the Argonne work, L-T relaxation was observed in $^3$He in fields as high as 180 Oe for $(1-T/T_c)$ as large as 0.07, but never in a field as low as 31 Oe. In general, the measured relaxation rates appear to be somewhat too high in $^3$HeA, and in $^3$HeB Sager et al. measure a $(1-T/T_c)$ temperature dependence instead of $(1-T/T_c)^{3/2}$. It is clear, however, that in at least certain limits the L-T relaxation does dominate all other processes.

The differences between Webb's results and those of Sager et al. may lie in the differences in geometry, and perhaps in the gradients in $H_0$. The La Jolla group studied spin recovery in an open geometry, and in geometries containing parallel plates both parallel and perpendicular to the static field. The results showed strong dependences of the character of the recovery processes on geometry. L-T relaxation was only observed in $^3$HeA in the open and parallel (to $H_0$) plate array. In $^3$HeB, L-T relaxation was only observed in the open geometry.

Under other conditions than those described above, both groups observed a variety of different relaxation behaviors, including linear recovery of $M_Z$ with time very similar to the C-O results, and exponential recovery in the B phase which may be in good agreement with the behavior C-O observed in the B phase. (Because in the B phase C-O observed a strong dependence of $T_1$ on gradients in $H_0$, and such gradients could not be varied in either of the new experiments, this agreement is still in question.)

Two of many new features Sager et al. [25] observed were that in the perpendicular (to $H_0$) plate array, relaxation in $^3$HeA was much slower than either of the other two geometries; and that the magnetization in the A phase did not always recover monotonically. Frequently a reversal in the recovery would be observed in which the magnetization would drop for a while before continuing to recover. Sager et al. found the maximum of this reversal to be comparable to the susceptibility anisotropy in $^3$HeA, and its duration to be comparable to the orbital relaxation time.

Undoubtedly the most interesting new result in the Argonne work is the existence of a temperature and field dependent critical tipping angle for both superfluid phases beyond which nonexponential relaxation is observed, and below which exponential relaxation is observed. Webb feels his results explain the very different character of the A and B phase recovery mechanisms reported by C-O, but the dependence of his critical tipping angles on geometry and static field gradient are as of yet unknown. Significantly, these critical tipping angles extrapolate to zero at $T_c$ for both phases, suggesting that they are not related to the characteristic magnetic angles (such as $\cos^{-1}(-1/4)$) in either phase.

It has long been believed that the linear recovery of $M_Z$ with time may be due to counterflowing magnetization supercurrents caused by the differences in local chemical potential of the spin system following an rf pulse. If so, we would expect the $\mathbf{A}$ vector to twist up in space, since it is related to the relative phases of the up and down spin systems, and magnetization superflow is related to spatial gradients in that relative phase. Such a twisting would result in the (at least) temporary formation of $\mathbf{A}$ solitons in $^3$HeA and $\theta$ solitons in $^3$HeB, provided the gradients were sufficiently large. We therefore cannot discuss magnetization supercurrents without considering solitons as well. How these ideas must be modified by the results of Bozler and Bartolac [9] is unclear at this time, but certainly such studies which probe the nature of the disequilibrium state following an rf pulse will provide important new information in our efforts to understand $T_1$ processes in superfluid $^3$He.
B) Electronic Effects.-

i) Introduction.- We normally think of superfluid $^3$He as being composed of chargeless particles with spin $1/2$. Recently, however, Leggett has suggested /29/ that we should be aware of possible effects on the superfluids caused by a redistribution of electronic charge by atoms forming a Cooper pair. This redistribution might result if the atoms were to form an unbound dimer in response to conventional chemical energy considerations. Two possible consequences of such a charge redistribution might be the existence of a magnetic moment associated with the $\hat{z}$ vector in $^3$HeA, and a perhaps substantial alteration of the orientational effects an electric field /30/ might have on the angular momentum of the Cooper pairs.

ii) Orientation in an Electric Field.- Delrieu /30/ showed if an electric field $\hat{E}$ is applied across a sample of $^3$HeA, the $\hat{z}$ vector should feel a torque tending to align it normal to $\hat{E}$. This is due to the electric dipole energy of the polarized $^3$He atoms in direct analogy with the magnetic dipole energy. However, previous experiments /31,32/ have failed to observe such an effect. In an experiment at Cornell /31/ there appeared to even be a slight tendency for $\hat{z}$ to align parallel to $\hat{E}$. Although it was believed the absence of this effect might be a Fermi liquid like effect, it could perhaps be due to a redistribution of electric charge for small separations of the atoms of the Cooper pairs due to dimer effects just where the largest contribution to the electric dipole energy should occur.

Two groups have recently tried to measure the elusive electric field effect. At La Jolla, Paulson and Wheatley /33/ have used the anisotropy in the attenuation of zero sound as a probe /35/ to monitor the orientation of $\hat{z}$ in $^3$HeA. While observing the attenuation, $a$, the two applied a field of $\sim1$kV/cm across their zero sound cell and looked for a change in the attenuation due to a reorientation of their $\hat{z}$ texture. They calibrated their system to small torques on $\hat{z}$ by applying and then rotating a small (300-600 mG) magnetic field. Except for a transient, and a static effect which occurred even in the normal phase, Paulson and Wheatley observed no orienting effects of the electric field what so ever. They estimate that if it exists, the electric field orientational energy must be at least 1000 times smaller than Delrieu estimated.

At Bell Labs., Paalanen et al. /34/ looked for an orienting effect of the $\hat{z}$ vector in $^3$HeB. By looking for an effect in $^3$HeB, the Bell group could work at much lower sample pressures, where Fermi liquid effects should be smallest. In their experiment, changes in the orientation of the $\hat{z}$ texture upon the application of an electric field as high as 35 kV/cm were monitored by measuring the spin-wave spectra in a parallel plate array. The experimental geometry was nearly identical to that used previously in the B phase spinwave studies /12/. Again, no effect was observed which could be interpreted as evidence of an electric field orienting effect. At 32 bar, the Bell group estimate the orientational energy to be at least 3000 times less than simple theory predicted, and at 0 bar at least 700 times less.

Except for the 0 bar result by the Bell group, none of these renormalization factors is larger than those expected from a new theory /36/ which estimates Fermi liquid renormalizing effects. This is not to say that chemical effects do not exist in the orientational electric field energy, but that if they are indeed present, we will have to work much, much harder to measure them.

iii) Electronic Orbital Ferromagnetism in $^3$HeA.- $^3$HeA has been termed an "orbital ferromagnet" /37/ because the orbital angular momenta of all the Cooper pairs point in the same direction. If the sort of chemical effects Leggett has considered were to change the electronic charge distribution of the Cooper pairs, they could possess orbital magnetic moments, and hence the entire fluid could possess a spontaneous magnetization along the direction of $\hat{z}$. Leggett has estimated that this magnetization at 9Tc could be as large as the nuclear magnetization in an applied field of 1 mG.

Such a minute magnetization as the above might be observable in the zero sound experiments /33/ of Paulson and Wheatley. In similar experiments /39/, they have found that when they just reversed the sign of their applied 300 mG field, they measured a change in $a$, indicating a reorientation of $\hat{z}$. Such a reorientation could be expected if $\hat{z}$ had associated with it a magnetic moment. It also could result, however, if the field they reversed were not the total field across their sample. To limit this second possibility, Paulson and Wheatley carefully shielded their sound chamber from stray magnetic fields. Still, they estimate that perhaps a residual field of ~ 2 mG remained. This is the magnitude of the trapped field necessary to produce
the average shift in $\hat{z}$ observed.

The orienting effect due to a spontaneous magnetization along $\hat{z}$ would depend upon which direction $\hat{z}$ pointed relative to the applied field. If upon warming above $T_c$ and cooling back the $\hat{z}$ texture were to exactly reverse its sense, then the change in $\hat{z}$ caused by the magnetization would also reverse. In fact, Paulson and Wheatley did observe scatter in their changes in a upon repeated cycling above and below $T_c$, and an apparent clustering about two distinct sets of values; an encouraging sign.

Unfortunately, the $\hat{z}$ textures in the sound cell are not well known, and probably change with temperature. In any event, the changes in $\hat{z}$ above and below the value attributed to the residual field showed considerable scatter, and not the temperature dependence which is associated with the effects of the spontaneous magnetization. On the other hand, the magnitude of the scatter was far larger than the two could attribute to any known experimental artifact, and indeed very nearly equal to the magnitude of the change in orientation expected from the spontaneous magnetization.

It appears quite likely that the La Jolla pair have indeed detected spontaneous magnetization along $\hat{z}$, although as they are quick to point out, their experiment is only qualitative and from it no value of the moment can be extracted. If we are indeed to understand Leggett's chemical effects, more careful experiments will be needed. In particular, it will be necessary to reduce the magnitude of the residual field so that its effects are no longer comparable to the scatter which represent the effects of the spontaneous magnetization on the orientation of $\hat{z}$.

C) Torsional Pendulum Experiments Plus.- Of particular usefulness in the past and with even more promise for the future has been the technique of using the Andronikashvili oscillating-pendulum, or torsional pendulum, to measure superfluid properties of $^3$He such as $\rho_s/\rho$, the relative superfluid density, and $\eta$, the viscosity. Main et al. /40/ were the first to use the technique to show conclusively the anisotropy of $\rho_s/\rho$ in $^3$HeA, while Berthold et al. /41/ have gotten credit for the first accurate measurements of that anisotropy. Recently, Parpia et al. /42/ have again used such a technique to measure the normal and superfluid viscosities of $^3$He at a number of pressures, with particular emphasis being given to the region very near to $T_c$.

In their new results, Parpia et al. find that $\Delta\mu/\eta_c$ varies as $(1-T/T_c)^{1/2}$ only within about $5 \times 10^{-5}$ of $T_c$. This is significant because it was originally believed $\Delta\mu/\eta_c$ should be proportional to the energy gap only near $T_c$, but presumably over a substantial temperature interval. The new Cornell result supports a theoretical prediction by Ono et al. /43/. In addition, Parpia et al. find a substantial $\Delta\mu/\eta_c$ drop over a 5 $\mu$K temperature interval above $T_c$, and indicate that over this same temperature interval an anomalous rise in the period of their pendulum was observed. The authors suggest that these effects may be due to a fluctuation precursor such as Emery /44/ has predicted. Recently Paulson and Wheatley /45/ have reported what they believe to be precursory behavior over a much broader temperature interval above $T_c$ in the attenuation of zero sound.

In still unpublished work at Cornell /46/, high resolution studies of $\rho_s/\rho$ in $^3$HeB have been made at a large number of different sample pressures using platinum NMR thermometry. The data has been analyzed to extract the "weak coupling" $\rho_s/\rho$ the Yoshida function. In this analysis, values of $m^3/m$ published by Wheatley /47/ have been used to eliminate the Fermi liquid effects. Once complete, this analysis shows the Yoshida function in $^3$HeB to be a single function of $T/T_c$, independent of pressure. From the initial slope of $\rho_s/\rho$ near $T_c$, the Cornell group can estimate $\Delta c/\Delta c_{BCS} = 1.39$ at all pressures. This is in good agreement with the measurements by Halperin /48/ at melting pressure, but the failure of the strong coupling effects to decrease with decreasing pressure is not expected. Yet it seems unlikely that the platinum thermometry could be wrong by more than ten percent at most, and one would expect that that error should be a constant multiplicative factor at all temperatures.

Using their new Lanthinum diluted CMN thermometry scale, Wheatley and coworkers /49/ have recently reanalyzed previous zero sound data of Paulson et al. /50/ to estimate $\Delta c/\Delta c_{BCS}$. They note that the zero sound absorption peak in $^3$HeB is related to the energy gap, and use the position of the peak as a function of temperature to obtain their results. In strong contrast to the Cornell result, the La Jolla result shows $\Delta c/\Delta c_{BCS}$ almost equal to unity from 12 bar to 20 bar sample pressure. Although the lack of a temperature dependence
agrees with the Cornell result, the value of $\Delta C/\Delta C_{BCS}$ is nearly 40% lower than the Cornell result. This strong disagreement is well outside the errors in thermometry, and, according to Serene [51], appears beyond the range which "non-trivial" strong coupling effects could produce, at least those which influence $\rho_0$. It goes without saying that new, highly reliable measurements of the heat capacity jump are desperately needed.

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