λ-POINT ANOMALY IN ROTATING HELIUM*

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Recently Tsakadze and Shanshiashvili[1] have performed a variant to an earlier experiment by the author, but with decidedly different results. Intended for exploring the nature of rotating liquid-helium II by means of a Rayleigh disk probe, the author's original experiment[2] revealed a marked temperature anomaly. Although performing as expected at both higher and lower temperatures, the otherwise well-behaved disk response was observed to disappear entirely in the region just below the λ point. Next Tsakadze and Shanshiashvili[1] attributed this anomaly to thermal effects introduced by the optical system employed by the author for observing the disk behavior. Now the results reported herein are believed to eliminate that explanation.

Figure 1 shows side by side (a) the equipment developed by those workers for identifying optical effects, and (b) the approach taken by the author to reaffirm the nonoptical nature of the anomaly. Tsakadze and Shanshiashvili attached two separate disks rigidly to the upper and lower ends of a long vertical rod [as shown, Fig. 1(a)], and then suspended the composite structure by a fiber as a torsion-pendulum element. By observing disk-system deflections under conditions of the light beam striking either the lower disk immersed in rotating liquid or the upper disk in vapor only, any optico-thermal effects should become manifest. An effect of such nature was reported by those investigators.

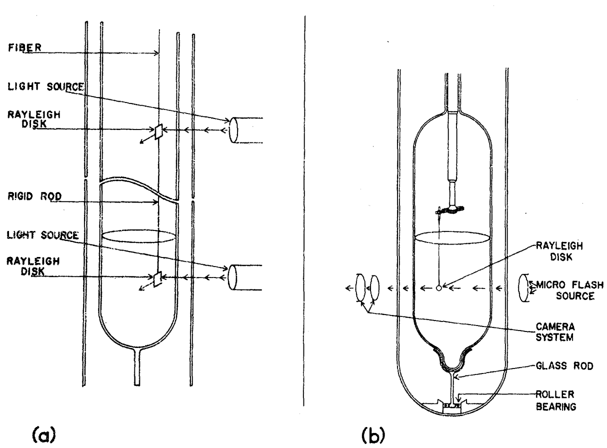

FIG. 1. Comparative equipment for the two experimental approaches: (a) "two-disk" equipment of Tsakadze and Shanshiashvili, and (b) "photo-flash" equipment of present method. (Note that probe "disk" of Tsakadze and Shanshiashvili had a rectangular shape.)

Comparative experimental results for the various methods are shown in Fig. 2, where the relative angular deflection of the disk from equilibrium orientation is plotted versus temperature (T) for each. The solid line of Fig. 2 represents the author's early results employing an immersed disk in the dual role of both test probe and optical reflector. The temperature anomaly in disk response appears as the sharp descent of the curve to zero just below the λ point. That this anomaly could be duplicated, or eliminated, at will was asserted by Tsakadze and Shanshiashvili on the basis of their modified experiment. When the illumination was directed upon the lower (immersed) disk, the same anomaly in temperature dependence as before was observed, as shown by the open circles for their data. But when illumination was limited to the upper disk only, the response of the disk system became nearly independent of temperature. Such results are indicated by the closed circles of Fig. 2.

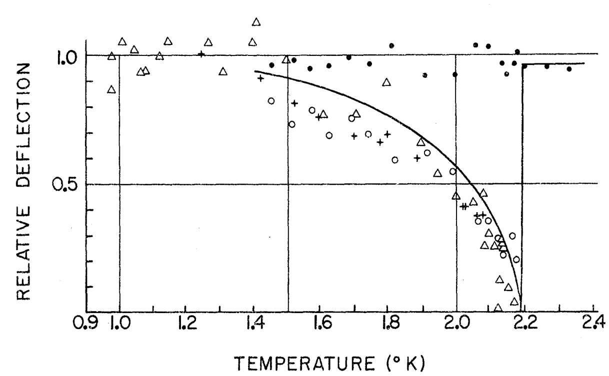

FIG. 2. Relative (normalized) deflections of the Rayleigh disk in rotating liquid helium plotted versus temperature for various methods. Triangles represent data from the author's present experiment, obtained by analyzing photo-flash image widths (10-μsec silhouette images, as illustrated in Fig. 3). Crosses indicate data also from the present investigation, obtained by the deflected flash-beam method (4-msec duration beam flashes). Circles represent observations by Tsakadze and Shanshiashvili (Ref. 1) using the two-disk method: Open circles indicate results for illumination applied to lower, immersed disk; closed circles indicate results for illumination applied only to upper disk above liquid. Solid curve represents the author's (Ref. 2) original beam deflection results.

These findings stand at even greater variance with the earlier work in view of the care originally taken to avoid just such effects. The author had employed a variable light source adjusted to the minimum limit of visibility. Since disk deflections showed no dependence whatsoever upon illumination level, any associated influence was dismissed as irrelevant. Clearly the situation required an unambiguous resolution, and for this purpose the present method was developed.

The author decided upon an independent check under conditions retaining the dual role of the disk as both detection and beam-deflection device, but insuring separation of these two functions. By achieving rotational equilibrium of the system under conditions of total darkness and then recording the associated disk deflections by means of flash photographs, the "predisturbance" orientation was ascertained. The roughly one-second vibrational period of the disk prevented any optico-thermal effects from influencing the "instantaneous" observations. The method offers the obvious additional advantage of permitting use of the original disk system.

The experimental arrangement used for this present approach is indicated in Fig. 1(b). Single photoflashes of 10-μsec duration (generated by a General Electric "Strobelume" source, not shown) were collimated to traverse the liquid-helium sample as parallel rays. A camera was clamped in a single fixed position facing this beam and was aligned to give an exact "edge-on" view of the suspended disk for equilibrium orientation. Since the light source was located directly opposite the disk system from the camera, the disk images were obtained in silhouette. Angular deflections from equilibrium orientation became observable as a widening of the silhouette disk images in the photographs. A separate photoflash was employed for each exposure and results were recorded on high-speed film (ASA 3000, Polaroid). The approximately one-second torsional oscillation period for the disk thus appears to guarantee against any discrepancy of optico-thermal origin occurring during the 10-μsec exposure interval.

Results are shown in Fig. 3, where the photographs speak for themselves. Two "calibration" exposures illustrate the equilibrium orientation for the nonrotating state. Thus the first photograph (a) represents zero deflection under zero rotation at a temperature of 1.01°K, and the last photograph (j) corresponds to zero rotation at 2.18°K, just above the λ point. The intervening sequence of photographs (b)-(i) illustrates the equilibrium behavior under conditions of uniform rotation rate 2 rpm (and fixed disk location at 1.84 cm from the rotation axis) for a series of relevant temperatures.

As clearly observable from this photographic series for rotational equilibrium, a near-maximum deflection occurs at the same low-temperature limit (1.01°K) and large deflections persist through at least the 1.5°K range. But for somewhat higher temperatures, the disk images may be observed to narrow progressively, in unmistakable evidence of reduced deflection upon approach to the λ point. Already at 1.8°K the change is perceptible, and by 2.0°K the deflection has reduced to about half its maximum value (after correction for disk thickness). Note that at temperature 2.167°K, immediately below the λ point, the disk system shows no deflection whatever under conditions of full rotational equilibrium [photograph (i)]. The qualitative substan-

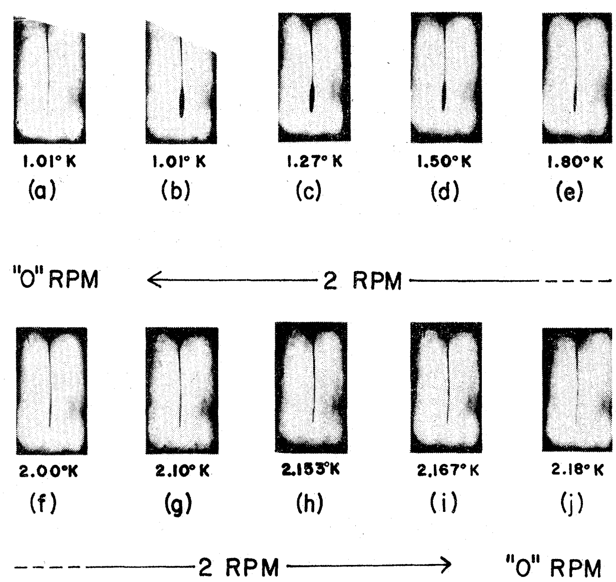

FIG. 3. Disk silhouette images as recorded by fixed-position Polaroid camera. Edge-on views, pictures (a) and (j), indicate equilibrium orientation of disk for state of zero rotation at 1.01 and 2.18°K, respectively. Behavior under steady-state rotation is illustrated in the intervening photo sequence (b)-(i), where disk response appears as widening of images. For uniform rotation rate of 2 rpm, the systematic decrease of deflection from maximum value (b) at 1.01°K to near-equilibrium orientation (i) just below the λ point is clearly evident.

tiation of the author's earlier results appears clear.

Although intended primarily for resolving the gross dependence of disk deflection on temperature, the disk-silhouette photographs do provide some quantitative information as well. Relative disk deflection data obtained from analysis of such disk images are plotted as triangles in Fig. 2, superposed on the graph of Tsakadze and Shanshiashvili.[1] As already evident from direct observation of the disk photographs, no doubt exists that results obtained by the present flash illumination method agree substantially with the author's original findings.

As earlier stated, the disk-silhouette measurements were made under conditions of minimum illumination. For each observation the state of complete darkness was broken only by a single low-intensity Strobelume flash of 10-μsec duration and the result recorded on high-speed film (ASA 3000, Polaroid). As a final precaution against any optical problems introduced by the method, however, a procedure was added which combined the original beam-deflection method with the present photoflash method. By inserting a high-speed (1/250 sec) camera shutter in the optical path between the (continuous) light source and the disk, the deflection of the disk —and therefore the outgoing beam—was recorded by photographing the calibrated scale upon which the reflected beam then falls. Although involving relatively greater flash durations (1/250 sec), the method still qualifies as "instantaneous" compared with the 2-sec vibration period of the disk. Results obtained by this "combined process" are represented as crosses in Fig. 2.

These results were reported[3] briefly earlier. But some publications, already in press at that time and treating the "temperature anomaly" as erroneous on the basis of the Tsakadze-Shanskiashvili work, have meanwhile appeared. Examples include a review article by Andronikashvili and Mamaladze[4] and a theoretical paper by Van Atta.[5] Naturally the present results substantiating the author's original findings clearly tend to negate those views.

The author is much indebted to Mr. R. Lynch and Mr. R. Horton for their excellent help and cooperation. Special credit goes to R. Lynch for valuable help in the development of the photographic techniques employed and, in particular, for suggesting the combined beam-flash method comprising the final "last-check" phase of the above experiments.

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SPIN-LATTICE RELAXATION FROM NEGATIVE TEMPERATURES IN SOLID ^{3}He †

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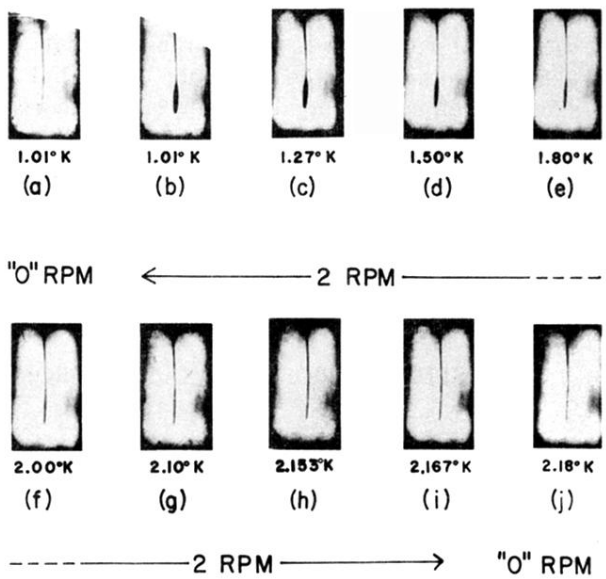
Recently Senghaphan and Zimmerman[1] (SZ) have reported spin-lattice relaxation measurements in solid ^{3}He with the method of applying a sequence of 180° and 90° pulses and looking at the time τ_0 for zero absorption. Thus τ_0 is the time for the Zeeman system to reach infinite temperature after its temperature has been made negative. Usually the spin-lattice relaxation time T_1 is related to τ_0 by $\tau_0 = T_1 \ln 2$.[2] If one uses this relationship in the τ_0 measurements of SZ one finds T_1 obtained for $T \gtrsim 0.5$°K is the same as that obtained by others,[3,4] whereas for $T \lesssim 0.3$°K, it is one to two orders of magnitude smaller depending on the Zeeman frequency. SZ have suggested that τ_0 measures the Zeeman-exchange relaxation time. We show that this is not true, and explain the above mentioned experimental results on the basis of the theory of spin-lattice relaxation in a three-bath model.[3,5] On the same basis, we suggest a new method of deducing the exchange frequency which should be experimentally simpler and yield highly accurate results. Further we explain qualitatively the sharp reduction (resonance) in τ_0 observed by SZ when an ultrasonic wave of frequency ω_a nearly equal to the Zeeman frequency ω_0 is ap-



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