loops. An improved experiment is now in progress that incorporates these modifications.

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ANISOTROPIC ULTRASONIC PROPERTIES OF A NEMATIC LIQUID CRYSTAL

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Ultrasonic measurements (2 to 6 MHz) on a room-temperature nematic liquid crystal have shown the attenuation to vary strongly with the angle θ between the sound-wave propagation direction and the direction of an aligning magnetic field. The velocity change is quite small, amounting to some 0.1% between the $\theta = 90°$ and the $\theta = 0°$ case. The orientation-dependent attenuation is of the hysteresis type.

Many of the physical properties of nematic liquid crystals display a pronounced anisotropy associated with the orientational ordering of the long molecular axes in this phase.[1-3] We have measured a dependence of ultrasonic attenuation and velocity on the angle between the sound-wave propagation direction and the direction of an aligning magnetic field acting on *N*-(*p*-methoxybenzylidene)-*p*-*n*-butylaniline (MBBA) which, to the best of our knowledge, represents the first observations of anisotropy in the ultrasonic properties of a nematic liquid crystal.

MBBA (Distillation Products Industries, Inc.) is nematic in the range 20°-40°.[4] Measurements were carried out primarily at room temperature at frequencies of 2, 3, 5, and 6 MHz using the commercially available MATEC[5] unit as the electric pulse generator for the input quartz crystals. Voltage picked up by the output quartz crystal was amplified by a Tektronix-121 wide-band preamplifier and then fed into either the receiver portion of the MATEC unit or a Tektronix-545 oscilloscope. The cell is a cylindrical cavity hollowed from an aluminum block. The cylinder is $\frac{5}{16}$ in. long and $\frac{5}{8}$ in. diam and was sealed at its ends with the sending and receiving quartz crystals of $\frac{3}{4}$ in. diam each, which were fine ground and plated with chromium and gold.

The attenuation versus orientation, at 6 MHz, for a field of 10 000 Oe is shown in Fig. 1, and the general shape of the curve is similar at the other frequencies. These changes followed the field almost instantaneously. Background attenuation varied from 2.18 dB/μsec at 6 MHz to 0.37 dB/μsec at 2 MHz. This observed anisotropy is consistent with reordering a large portion of the

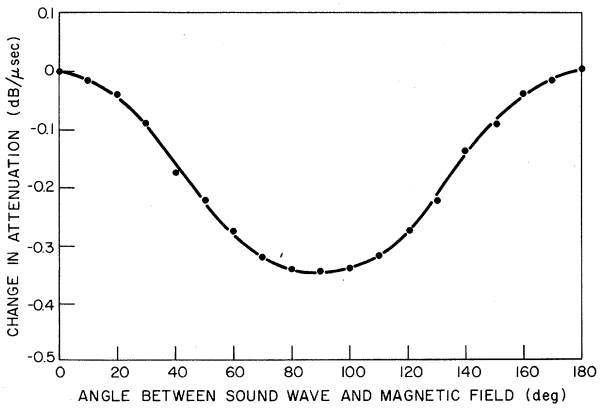

FIG. 1. Change in the ultrasonic attenuation as a function of the angle between the propagation direction of the sound wave and the direction of the aligning magnetic field.

molecules as the magnetic field rotates. The effect saturates at ~1000 Oe and the mirror symmetry across the $\theta = 90°$ line is indication that there is no favored polarity to the molecules, and is therefore consistent with observations on many other physical properties of nematics. In the freshly prepared sample with no field applied, there is a strong tendency for molecular alignment to occur parallel to the quartz transducers. Fields up to 12 000 Oe do not change the attenuation when applied parallel to this long molecular axis direction, and hence the natural alignment must be taking place over a distance of several mm. Carr[6] has interpreted certain dielectric loss data in nematics as also indicating that wall effects extend a few mm into the bulk sample. However, when the field is applied perpendicular to the long molecular axes, the changes given in Fig. 1 occur instantaneously. When the field is removed, the attenuation changes slowly to an intermediate value (about half the change shown in Fig. 1) in a few hours and stays at this intermediate value for days. Vigorous mechanical agitation of the sample will produce this same effect in ~30 sec. This can be interpreted as indicating that in the absence of any applied field or mechanical forces acting as a torque on molecular orientation, the thermal relaxation time of MBBA is very long.

A small, completely reproducible change in ultrasonic velocity of about 0.1% is also observed between the parallel and perpendicular molecular orientation, with the wave parallel to the long molecular axis traveling faster than the perpendicular wave. These measurements were performed by the technique of recording the change in arrival time of the undetected echoes on the scope at 3 and 5 MHz, with a time-base resolution of 0.05 μsec. The change in velocity was too small to be seen at 2 MHz, where the attenuation is low, and also too small to probe for any orientation dependence.

The frequency dependence of the difference in attenuation between the parallel and perpendicular cases is given in Fig. 2. In the limited frequency range examined a linear dependence is observed. We have also measured the "critical attenuation," i.e., the attenuation which is associated with the transition from the nematic phase to the isotropic phase,[7] and find it to be completely independent of the orientation of the molecules. Thus, the orientation-dependent attenuation observed arises from a cause other than that causing the "critical attenuation." Because this orientation-dependent attenuation varies linearly with frequency, we label it a hysteresis effect, in keeping with other workers.[8-10] It is interesting that a phenomenological treatment of hysteresis[11] predicts zero velocity change, consistent with the small velocity change we observe. The origin of the hysteresis loss is generally unknown. Attenuation measurements in which the ultrasonic pulse amplitude was varied by at least a factor of 10 failed to show any amplitude dependence in the orientation-dependent attenuation. This same type of hysteresis attenuation as we see here has been observed in very viscous liquids, glasses, and metals.[8-10] Thus, although the viscosity of most nematic liquid crystals (1-100 *cP*) is what is usually termed low viscosity, it appears here, as in dielectric relaxation studies[12,13] (and other measurements[2]), that the effective viscosity is much higher. Litovitz and Lyon[10] indicate that a hysteresis-type dielectric loss has also been observed in liquids at frequencies above the main relaxation frequencies of the liquid.

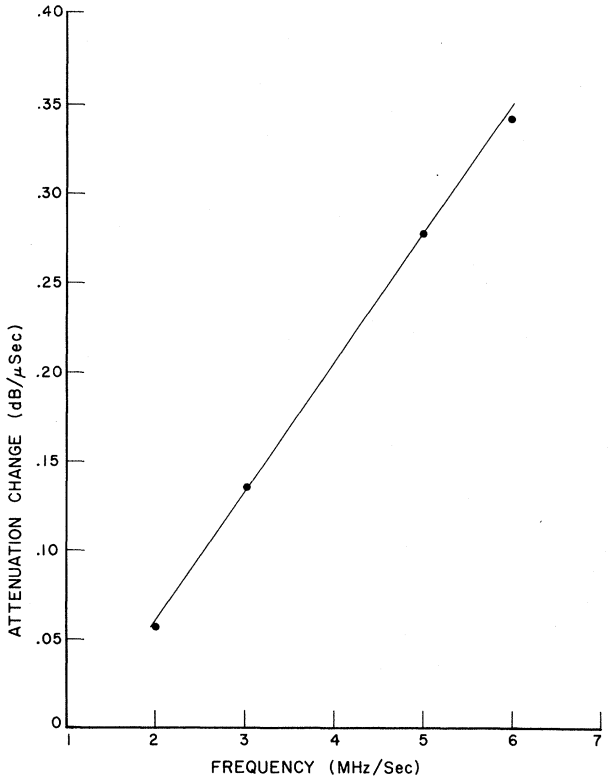

FIG. 2. Change in the ultrasonic attenuation between the parellel (θ = 0°) case and the perpendicular (θ = 90°) case as a function of the ultrasonic frequency.

It would be interesting to examine ultrasonic attenuation and velocity changes over a much

wider frequency range to attempt to observe the normal-liquid structural relaxations at frequencies below those used here.

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VORTICITY IN HELIUM FILM CREEP

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The viscous drag of the normal-fluid component on moving superfluid vortex-line cores is shown to have two effects: to push the vortex lines toward the film surface and to enhance the film-creep velocity. A class of experiments in the millidegree temperature range is proposed in order to test for the presence of vorticity in helium film creep.

A common facet of the variety of models[1-5] designed to explain the helium film-creep velocity is the assumed existence of quantized vorticity in the superfluid.[6,1] In spite of the quantitative and even conceptual[7] problems associated with these vortex models, alternatives such as intrinsic fluctuation effects[8] are lacking; and the initial ideas of Feynman[1] and Richards and Anderson[9] still hold as relevant for an explanation of the film-creep velocity.[4] In the present paper a new factor is introduced in a state-of-the-art vortex model, and predictions are given for a new class of experiments designed to test for the presence of vorticity in helium film creep.

The core region of a superfluid vortex line can scatter quasiparticles as it moves through the normal-fluid component of the film, the resulting viscous drag per unit length of vortex line being $2v(m/h)\alpha(T)$, where $\alpha(T)$ has been defined and measured by Rayfield and Reif,[10] m is the helium atom mass, h is Planck's constant, and v is the film-creep velocity. One effect of this viscous drag follows from the condition that it must be counteracted by a Magnus force associated with the motion of the vortex line outward with velocity u toward the film surface.[11] Equating the Magnus force, $\rho_s(h/m)u$,[10] with the magnitude of the viscous drag gives

$$u/v = Id/Z, \tag{1}$$

with I defined as

$$I = (2/\rho_s)(Z/d)(m/h)^2\alpha(T), \tag{2}$$

and d/Z as the ratio of the film thickness to the film height. If $I \ll 1$, $u/v \ll d/Z$, and the vorticity can exit into the bulk liquid at the base of the film before it is forced into the film surface.

Including this viscous loss in the energy conservation condition used by Donnelly[4] leads to the prediction of enhanced film-creep velocities by a factor of $(1-I)^{-1}$. Anderson's phase-slippage formula,[9,12]

$$\dot{n} = gzm/h, \tag{3}$$

for the average rate at which quantized vortex lines move across an orifice, is not obviously applicable to the case of helium film creep. However, the criterion for applying Eq. (3) is that the vortex-line motion be parallel to equipotential surfaces in the liquid. Hence, we assume that this equation gives the average rate at which horizontal[13] vortex lines are first created in the